Final Technical Report
Sacramento Municipal Utility District

DOE Assistance Agreement DE-EE0005414
Iowa Hill Pumped Storage – Project Investigations
July 2016

Principal Investigator: **David Hanson**

Team Members:

Electric Power Research Institute
Energy Exemplar
McMillen Jacobs Associates

Powering forward. Together.

SMUD®

Table of Contents

1 INTRODUCTION 1
1.1 SMUD AND THE UARP 1
1.2 THE BALANCING AUTHORITY OF NORTHERN CALIFORNIA 2
1.3 INITIAL RATIONALE FOR IOWA HILL PUMPED-STORAGE PROJECT 3
2 WORK PERFORMED UNDER THE ASSISTANCE AGREEMENT 4
2.1 TASK 1 – GEOTECHNICAL INVESTIGATION 4
2.1.1 SUBTASK 1.1 – ENVIRONMENTAL PERMITTING 5
2.1.2 SUBTASK 1.2 – FIELD MAPPING, ACCESS, AND SPOILS PILE STABILIZATION 7
2.1.3 SUBTASK 1.3 – ROCK CORING – TUNNEL ALIGNMENTS 8
2.1.4 SUBTASK 1.4 – ROCK CORING – PRESSURE SHAFT/TUNNEL AT IOWA HILL 9
2.1.5 SUBTASK 1.5 – RISK WORKSHOP 9
2.1.6 SUBTASK 1.6 – GEOTECHNICAL TEST DRIFT 9
2.1.7 SUBTASK 1.7 – ROCK CORING – POWERHOUSE CAVERN 9
2.1.8 SUBTASK 1.8 – ROCK CORING – VERTICAL SHAFT 10
2.1.9 SUBTASK 1.9 – LABORATORY AND FIELD TESTING 10
2.1.10 GEOTECHNICAL INVESTIGATION FINDINGS 11
2.2 TASK 2 – VALUE STREAM MODEL ANALYSIS 12
2.2.1 SUBTASK 2.1 – RESOURCE MIX SCENARIO DEVELOPMENT 14
2.2.2 SUBTASK 2.2 – DETERMINATION OF ANCILLARY SERVICES REQUIREMENTS 15
2.2.3 SUBTASK 2.3 – MODEL EXPANSIONS AND VERIFICATION 16
2.2.4 SUBTASK 2.4 – PRODUCTION COST SIMULATIONS 17
2.2.5 SUBTASK 2.5 – PUMPED STORAGE VALUE ANALYSIS 18

3 PRELIMINARY FUNCTION DESIGN 20

4 COST AND FINANCIAL RISK 24

Acknowledgement *– This material is based upon work supported by the Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Water Power Technology Office under Award Number DE-EE0005414.*

List of Acronyms

AFUDC	Allowance for Funds Used During Construction
AGC	Automatic Generation Control
AS	Ancillary Services
BANC	Balancing Authority of Northern California
BGS	Below Ground Surface
CAISO	California Independent System Operator
CFS	Cubic Feet Per Second
CH	Corehole
CVP	Central Valley Project
DOE	Department of Energy
ENF	Eldorado National Forest
EPRi	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
kV	Kilovolt
LiDAR	Light Detection and Ranging
SMUD	Sacramento Municipal Utility District
OPCC	Opinion of Probable Construction Cost
MW	Megawatt
NERC	North American Electric Reliability Corporation
NREL	National Renewable Energy Laboratory
RFP	Request for Proposal
RUC	Reliability Unit Commitment
SCUC	Security Constrained Unit Commitment
SMUD	Sacramento Municipal Utility District
SOPO	Statement of Project Objectives
SUA	Special Use Authorization
SUP	Special Use Permit
SWRCB	State Water Resources Control Board
TEPPC	Transmission Expansion Planning Policy Committee
UC/ED	Unit Commitment/Economic Dispatch
UARP	Upper American River Project
USFS	United States Forest Service
WECC	Western Electricity Coordinating Council
WI	Western Interconnection
WWSIS	Western Wind and Solar Integration Study

Executive Summary

This Final Technical Report is a summary of the activities and outcome of the Department of Energy (DOE) Assistance Agreement DE-EE0005414 with the Sacramento Municipal Utility District (SMUD). The Assistance Agreement was created in 2012 to support investigations into the Iowa Hill Pumped-storage Project (Project), a new development that would add an additional 400 MW of capacity to SMUD's existing 688MW Upper American River Hydroelectric Project (UARP) in the Sierra Nevada mountains east of Sacramento, California.

SMUD is a community-owned electric utility governed by a seven-member Board of Directors that stands among the nation's leaders in promoting a sustainable electric power supply. It was within this context that SMUD applied to FERC in 2005 for a new UARP license that would authorize the addition of an underground pumped-storage plant moving water between an existing lower reservoir and a planned new upper reservoir atop Iowa Hill. In 2005, the Project was seen as a key investment that would facilitate the inclusion of the expected high penetrations of solar and wind energy in the SMUD resource portfolio. At that time, the growth in power demand in SMUD's service territory was roughly two percent per year. It was expected that utilities across the United States would soon be importing significant quantities of natural gas, with prices and volatility expected to increase over time. High gas prices typically drive electricity prices higher, and higher prices make pumped-storage more profitable and provide a shield from price volatility.

The Project was also expected to provide several different value streams to SMUD, including operating flexibility, reliable capacity and support and integration of intermittent renewable generation assets such as wind and solar projects. The DOE Assistance Agreement commenced in February 2012. The overarching objectives of the investigation supported by DOE funding were to: (1) reduce uncertainty associated with underground geotechnical conditions at the Project site, and (2) model value streams that could be expected from operation of the Project.

On February 3, 2016, roughly four years into the Agreement, SMUD informed the DOE that the SMUD Board of Directors had determined it was in the best interests of SMUD to cancel plans to construct the Project. This decision ended a 15-year investigation into the opportunities and constraints associated with the construction and operation of

the Project. In this document, SMUD reports on the work performed under the Assistance Agreement, significant findings, and the rationale underlying the decision to cancel the Project.

Geotechnical Investigations

The Assistance Agreement Statement of Project Objectives (SOPO) consisted of two primary tasks focused on the above objectives: Task 1 (Geotechnical Investigation) and Task 2 (Value Stream Model Analysis). The primary thrust of Task 1 was a series of rock coring and tunneling studies focused on the underground conditions along the proposed water conveyance alignments as well as in the area of the powerhouse cavern. Each of five subtasks was completed prior to SMUD's canceling the Project except Subtask 1.6 (Geotechnical Test Drift) and Subtask 1.7 (Rock Coring – Powerhouse Cavern). The work performed under the three completed subtasks consisted of the following:

- Drilling, logging, and sampling two subhorizontal and two vertical rock-core borings totaling about 6,500 feet in length.
- Installing vibrating wire piezometers to measure water levels at three different depths in each of the two vertical coreholes.
- Performing in situ testing and geophysical exploration in all boreholes.
- In situ testing and geophysical exploration in selected boreholes, including packer permeability testing, hydrojack testing, and optical televiewer and acoustic logging.
- Performing laboratory tests of the core extractions to assess rock quality and strength.

The results of all geotechnical surveys clearly reveal the underlying rock at the Project site to be competent – capable of supporting the underground construction of water conveyance systems and pumping/generation equipment. SMUD also performed other geotechnical studies outside of the scope of the Assistance Agreement, including an extensive groundwater monitoring program at eight monitoring wells and a seismic refraction survey of the proposed upper reservoir site.

Subtask 1.1 of the Assistance Agreement focused on the environmental permitting necessary to perform the geotechnical investigations. Due in part to the complexity of the Project, securing the appropriate permits to perform the geotechnical investigation became a very challenging process. The permitting process was an outgrowth of an already complicated, multiyear regulatory process that began in 2001 with the release of the Initial Information Package for the UARP relicensing program. This initial action marked the beginning of a complicated process of applying for and receiving a series of regulatory licenses, permits, and authorizations necessary to evaluate, construct and operate the Project. One of the complicating permitting issues associated with the Project was the 5-year delay (from 2008 to 2013) in receiving the Clean Water Act Section 401 Water Quality Certification for the issuance of the UARP license. This delay pushed back the release of the new UARP license authorizing SMUD to construct the Project, with issuance eventually occurring in 2014, a full two years after the 2012 award of the Assistance Agreement.

During the wait for water quality certification, the SMUD Board made the decision in March 2013 to move forward with evaluating the feasibility of the Project. The first step was to secure a Special Use Permit (SUP) from the USFS to perform the geotechnical studies on National Forest System Lands. This allowed SMUD to perform initial geotechnical investigations under the Assistance Agreement. However, once the UARP license was issued in July 2014, the USFS insisted on a blanket Special Use Authorization (separate and distinct from the SUP) to continue performing geotechnical investigations. At this point, Project progress was slowed by the fact that SMUD was obligated to submit yearly work plans for review and approval under the Special Use Authorization (SUA) prior to performing the Assistance Agreement subtasks. Approval under the SUA to perform the Geotechnical Test Drift (Subtask 1.6) was further slowed by unexpectedly robust requirements of the USFS and SWRCB for development of a groundwater monitoring plan for the area underlying Iowa Hill, which ultimately involved installing eight groundwater wells near the upper reservoir, and the need to complete baseline monitoring (potentially for years) prior to starting to excavate the drift. Based on the plain language in the FERC license, SMUD had anticipated and planned for all groundwater monitoring activities to commence only after construction of the Project.

Despite delays in receiving the 401 Water Quality Certification, and despite the challenges working with the USFS and SWRCB, SMUD was successful in securing several additional required permits from other Federal and California agencies, El Dorado County, and working with the public to develop plans in the resource areas of transportation management, fire prevention, noise, and visual resources.

Value Stream Model Analysis

The work performed on the Value Stream Model Analysis task consisted of a detailed mathematical modeling study investigating Project value in meeting energy and ancillary services requirements under a number of possible future energy scenarios and cases. Because the value of pumped-storage depends on the level of penetration of variable generation (20, 33 or 50%) within the Balancing Authority of Northern California (BANC), of which SMUD is the largest Member, as well as within the much larger Western Interconnection (WI) area, the modeling exercise examined a discrete set of combinations of level of penetration and geographic scope. These combinations, or modeling scenarios, borrowed heavily from scenarios developed by the National Renewable Energy Laboratory (NREL). Value streams were modeled for each scenario using the Plexos® model under a set of cases prescribed by the Task 2 subtasks. The examined cases included with and without the Project, with and without an alternative technology for meeting peak load (e.g., reciprocating engines), with and without trading of Ancillary Services (AS) between balancing authorities within the WI, and with variable-speed turbines vs. fixed-speed turbines.

The primary value streams included: (1) Ancillary Service (AS) value, (2) production cost savings, and (3) avoided generation and transmission capacity investments. The value of production cost savings and AS provision for BANC and sales to AS markets from the Project varied significantly under the different renewable penetration scenarios. In general, as variable renewable resource penetration increases the need for AS increases which increases AS value. Value of the Project was greatest in cases with high renewable penetrations of 50%.

Modeling results demonstrated that avoided capacity investments, primarily supply capacity, had an inverse relationship with renewable penetration levels. In the 50% penetration scenarios, avoided capacity investments represented roughly 30% of the Project value, while under 33% penetration it represented 60% to 70% of the Project value. This level reflects the fact that much of the existing installed conventional power plants, such as gas-fired plants, were expected to be repurposed for balancing reserve rather than retired, as in the 50% penetration scenarios. Although the plant output is repurposed, it also serves as supply reserve, and hence the higher renewable penetration cases are also characterized by local and regional supply capacity surpluses.

What was clear from the model simulations was that increasing penetration of renewable energy sources increases the value of Iowa Hill to the BANC. This was true even more so as the levels of penetration increase within the entire Western Interconnection. The analysis also shows that increasing levels of wind penetration result in significantly more value from the Project than increasing levels of solar due to higher AS requirements for wind.

From the work performed under the Assistance Agreement, SMUD gained significant insight into the feasibility of constructing and operating the Project. Fieldwork and modeling studies advanced SMUD’s understanding of the geologic conditions in the area of the underground facilities proposed for the Project, as well as a better understanding of the potential energy management benefits provided by the Project.

Project Cost and Financial Risk

The primary drivers behind SMUD's decision to cancel the Project are cost and financial risks. Despite the results of the value stream modeling and the extensive environmental and geotechnical studies, construction impact assessments, and permitting work, SMUD concluded that the project would be too risky from a financial standpoint. This decision was based to a large degree on the estimated cost to construct the Project.

Throughout the years of Project planning, and at different stages of Project design, SMUD has developed estimates of the cost to construct the Project. The cost to SMUD of building the Project is the sum of a variety of individual costs, including direct and indirect construction cost, construction management, SMUD staff time, and the cost of financing. The estimated cost to construct the Project was estimated at between $1.37B and $1.45B in 2015 dollars.

Estimated Cost to SMUD to Construct the Iowa Hill Pumped-storage Project

Cost Estimate Components	**2015 Cost (millions)**
Direct Costs	743
Indirect Costs	206
Construction Management	28
SMUD Labor	32
Contingency (21.5%)	201
Financing Costs, i.e., Allowance for Funds Used During Construction (AFUDC)	162 – 243
Total	1,372-1,453

In addition to the high construction costs, a number of changes in the energy marketplace and customer behavior influenced the decision to cancel the Project. Primary among these is the change in the price of natural gas. As stated above, in 2005, SMUD expected natural gas prices to increase going forward, but more recent price projections are lower than the 2005 projections. As a result, the anticipated value from peak-power energy production and other energy services from a pumped-storage system were less.

Another change from 2005 has occurred in customer demand within the SMUD service territory. The 2% per year growth that existed for the ten years prior to applying for the UARP license, which argued in favor of the Project, has reversed to the point where peak loads have actually diminished over the past ten years. Energy efficiency and rooftop solar have reduced customer usage, and peak demand is expected to be further reduced when SMUD imposes residential time-of-use rates in 2018. These trends have greatly reduced near-term capacity and storage needs, stretching the timeline by over a decade before SMUD would realize the full potential of the planned facility.

On top of these trends, competing technologies such as battery storage have come down in cost much faster than expected. Battery storage, while higher in cost, can be scaled to exactly what is needed, so it is less costly and poses a reduced financial risk compared to a 400 MW pumped-storage facility.

Finally, the rate of technological change has quickened for the electric utility business. SMUD currently has ambitious plans to invest in new customer technologies such as battery storage systems, upgrade the grid and enable the system to integrate more distributed technologies. That will require a lot of new capital, which would not likely be available if SMUD took on significant debt service associated with the construction of the Project.

1 Introduction

This Final Technical Report is a summary of the activities and outcome of the Department of Energy (DOE) Assistance Agreement DE-EE0005414 with the Sacramento Municipal Utility District (SMUD). The Assistance Agreement, which commenced on February 2012, was created to support investigations into the Iowa Hill Pumped-storage Project (Project), a new facility that would enhance operational flexibility and add 400 MW of capacity to SMUD's existing 688MW Upper American River Hydroelectric Project in the Sierra Nevada mountains east of Sacramento, California.

On February 3, 2016, the SMUD informed the DOE that the Board of Directors had determined it was in the best interests of SMUD to cancel plans to construct the Project. This decision ended a 16-year investigation of the opportunities and constraints associated with the construction and operation of the Project. In the following sections, SMUD presents the initial rationale behind the project, the extensive and time-consuming permitting efforts, work performed under the Assistance Agreement prior to the Project cancellation, and the eventual assessment of financial risks that led to the decision to cancel the Project.

1.1 SMUD and the UARP

Formed in 1923, SMUD is a political subdivision of the state of California formed pursuant to the Municipal Utility District Act. SMUD is a customer-owned electric utility, overseen by a seven-member, publically-elected Board of Directors. The utility generates and purchases electric power that it distributes to its customers within Sacramento County and portions of nearby Placer County. SMUD is the sixth largest publicly-owned electric utility in the United States in terms of customers served, which currently totals about 1.5 million residents in a 900 square mile service area. As a not-for-profit utility with no shareholders, SMUD transfers all benefits to the customers in the form of lower rates and value to the community.

On August 28, 1957, the Federal Power Commission issued a license to SMUD for construction of the multi-development UARP. The UARP is a hydroelectric project owned and operated by SMUD. It is the only hydroelectric project owned by SMUD. SMUD began construction in 1957 and completed construction in 1985. For more than 45 years, the UARP has played a major role for SMUD in meeting the growing electrical demand of its customers. The UARP is located in the Silver Creek, Rubicon River, and South Fork American River basins, on the west slope of the Sierra Nevada Mountain Range, in El Dorado and Sacramento counties. The project comprises seven developments (Loon Lake, Robbs Peak, Jones Fork, Union Valley, Jaybird, Camino,

and Slab Creek/White Rock). Together, the existing developments include 11 reservoirs that can store up to 425,000 acre-feet of water, eight powerhouses that have generated an average of 1,730 gigawatt hours of power annually since 1990, 11 transmission lines with a combined length of about 177.2 miles, about 28 miles of power tunnels/penstocks, and one canal 1.9-miles long. Nearly all of the land surrounding the project reservoirs within the FERC Project Boundary is owned by the United States and administered by the Forest Service as part of the Eldorado National Forest (ENF).
A key feature of the Project was its integration into the existing UARP facilities. Perceived benefits of integration included minimization of environmental impacts, reduction in costs, and a shortened construction period. The existing 13,100 acre-foot Slab Creek Reservoir was selected to serve as the lower reservoir. A new 6,300 acre-foot, rock-filled embankment reservoir constructed on top of the mountain adjacent to Slab Creek Reservoir would serve as the upper reservoir. The Project was also located within 2.5 miles of the existing UARP 230 kV transmission line. A summary of the major engineering components of the Project, as developed independently by SMUD outside the Assistance Agreement, and accompanying map, are provided in Section 3.0.

The UARP generates enough electricity, on average, to meet about 18 percent of the customer load. To meet the customers' overall power requirement, SMUD has developed an integrated generation portfolio that includes renewable energy sources such as hydro, photovoltaic, and wind, as well as natural gas-fired cogeneration. In a typical year, this portfolio provides about one-half of the power demand of SMUD's customers. Other power is provided for through long- and short-term power contracts.

1.2 The Balancing Authority of Northern California

SMUD is a member of the Balancing Authority of Northern California (BANC). BANC is a Joint Powers Authority consisting of SMUD, Modesto Irrigation District, Roseville Electric, Redding Electric Utility, Trinity Public Utility District, and the City of Shasta Lake. BANC is the third largest Balancing Authority in California and the 16th largest Balancing Authority within the WECC area. The Central Valley Project (CVP), owned by the Bureau of Reclamation, and Western Area Power Administration's transmission facilities along with the 500 kV California Oregon Transmission Project, are included among other resources within the BANC footprint. BANC assumed the Balancing Authority responsibilities in 2011 from SMUD, which include the matching of generation to load and coordinating system operations with neighboring Balancing Authorities.

Creation of BANC as a partnership between public and government entities provides for an alternative platform to other Balancing Authorities like the California Independent System Operator (CAISO). BANC provides reliable grid operation consistent with standards developed and enforced by the Federal Energy Regulatory Commission (FERC), the North American Electric Reliability Corporation (NERC) and the Western

Electricity Coordinating Council (WECC). The BANC contracts with SMUD for operations of the balancing authority.

BANC also provides its members an ownership voice in all balancing authority decisions consistent with the principle of maximizing consumer value. It also provides members a unified voice and representation in topics pertaining to balancing area matters. The structure provides flexibility to expand, offers potential cost-saving opportunities by sharing future facility costs, and clarifies roles and responsibilities of the members regarding reliability standard compliance.

1.3 Initial Rationale for Iowa Hill Pumped-Storage Project

The decision to investigate a pumped-storage facility is a natural product of SMUD's role among the nation's leaders in promoting a sustainable electric power supply. In 2008, for example, the SMUD Board adopted the most aggressive long-term carbon reduction goal of any utility in California, committing to reduce greenhouse gas emissions levels to 10 percent of levels experienced in 1990 by the year 2050. In this vein, SMUD has aggressively pursued renewable energy projects since the 1980s, with a current goal of attaining a renewable portfolio standard of 50 percent by 2030. As stated in Section 1.2 SMUD also manages BANC, and as such is responsible for ensuring real-time system operations and engineering that support the reliable, safe, and cost-effective operation of the bulk electric system generation and transmission assets consistent with reliability standards established and administered by the WECC, NERC, and FERC. It was within this context that SMUD applied to FERC in 2005 for a new Upper American River Project (FERC No. 2101) license that would authorize the addition of a 400 MW pumped-storage facility.

In 2005, the Project was seen as a key investment that would facilitate the inclusion of the expected high penetrations of solar and wind energy in the SMUD resource portfolio. At that time, the growth in power demand in SMUD's service territory was roughly 2% per year. It was expected that the United States would soon be importing natural gas, with prices and volatility expected to increase over time. High gas prices typically drive electricity prices higher, and higher prices make pumped-storage more profitable and provide a shield from price volatility. The Project was also expected to provide several other important value streams to SMUD, including operating flexibility, reliable capacity and support and integration of variable renewable generation assets such as wind and solar. Nevertheless, as stated in the SMUD 2011 assistance application, the overall economic feasibility of the Project was uncertain, but known to be highly dependent on two key factors – construction cost and value streams. Hence, the overarching objective of the investigation was to reduce uncertainty associated with: (1) geotechnical conditions at the Project, which influence construction costs; and (2) value streams that can be expected from operation of the Project. More specifically, sub-objectives, as written in the Assistance Agreement application, included:

Geotechnical Investigations

- Identify geotechnical defects in the subsurface that could result in costly remedial measures.
- Determine depth of the weathered zone, landslides, and toppled rock in construction area.
- Develop detailed information through the powerhouse gallery, tunnels, and shafts on minimum in situ stresses to inform the degree of steel lining needed.
- Develop detailed information through the powerhouse gallery, tunnels, and shafts on geologic structures, contacts, and shears.
- Evaluate extent and impact of water-bearing geologic structures.

Value Stream Modeling Investigations

- Determine ancillary service requirements to balance increased variable renewable generation.
- Examine value from pumped storage relative to conventional gas generation for providing on-peak energy and ancillary services in the Balancing Authority of Northern California, as part of the greater California region.
- Define and quantify the value streams of Iowa Hill relative to conventional gas units with future anticipated higher levels of variable renewable generation.
- Analyze the net benefits of variable speed versus fixed speed for pumped-storage technology.

2 Work Performed Under the Assistance Agreement

All technical work performed under the Assistance Agreement fell within two primary tasks: Task 1 – Geotechnical Investigations and Task 2 – Value Stream Model Analysis. Each task was divided into several subtasks, as outlined in the Statement of Project Objectives (SOPO) provided in Appendix A. The following sections describe the work that was performed under each of the technical tasks and subtasks of the SOPO.

2.1 Task 1 – Geotechnical Investigation

All subtasks under this under Task 1 were accomplished prior to SMUD's decision to cancel the Project, except Subtask 1.6 (Geotechnical Test Drift) and Subtask 1.7 (Rock Coring – Powerhouse Cavern). The geotechnical field and laboratory exploration program was designed to generate data and information that would allow SMUD to assess the geological and groundwater conditions, and engineering properties of subsurface materials in the vicinity of the powerhouse cavern and water conveyance alignments. The boring locations, orientations, and lengths were selected to explore the geologic units in the vicinity of the underground structures. The actual boring locations were strongly influenced by accessibility, permitting, and safety issues.

The results of all geotechnical surveys are summarized in the technical report entitled Interim Iowa Hill Geologic/Geotechnical Data Report (Appendix B). The geotechnical information played an important role in the design and location of underground facilities, which was instrumental in generating the Opinion of Probable Construction Cost (OPCC), discussed in Section 4.

SMUD also performed other geotechnical studies outside of the scope of the Assistance Agreement, including an extensive groundwater monitoring program and a seismic refraction survey at the proposed Upper Reservoir site.

2.1.1 Subtask 1.1 – Environmental Permitting

The purpose of this subtask was to secure necessary environmental permits to perform the geotechnical investigations. While the subtask focused on the geotechnical investigation phase of the project development, the permitting and licensing work was part of a larger regulatory process leading up to the construction of the Project. This process extended over approximately 15 years, beginning with the 2001 release of the Initial Information Package within SMUD's UARP relicensing program. This preliminary action marked the beginning of a complicated process of applying for and receiving a series of regulatory licenses, permits, and authorizations necessary to evaluate, construct and operate the Project. After conducting an initial series of engineering and environmental studies in 2002-2004, SMUD submitted a UARP relicensing application in 2005 that included a request of FERC to authorize SMUD to construct and operate the Project as a new component of the UARP. This was followed by the FERC environmental review process under the National Environmental Protection Act and the SMUD environmental review process under the California Environmental Quality Act, both of which concluded in 2008.

From 2008 through 2014, FERC's release of the Order Issuing a New UARP License was delayed by the length of time it took the California State Water Resources Control Board (SWRCB) to issue a Section 401 Water Quality Certification under the Clean Water Act. Within this waiting period, and in anticipation of a pending new license, SMUD applied for and received the DOE Assistance Agreement, which initially spanned the period February 2012 through March 2014.

In March 2013, the SMUD Board made the decision to move forward with the geotechnical investigation despite the fact that neither the Section 401 Water Quality Certification document nor the new UARP license had been issued. This decision was made to ensure SMUD remained on the project schedule defined in Modification 3 of the Assistance Agreement. As a result, SMUD released a Request-for-Proposal (RFP) for Owner's Engineer services in April of 2013. The Owner's Engineer was hired to oversee the geotechnical investigation defined under Task 1 of the SOPO. When the Section 401 Water Quality Certification was issued in October 2013, the UARP license was still pending. Nevertheless, work on the geotechnical investigation commenced in December 2013, under a Special Use Permit (SUP) issued by the U.S. Forest Service (USFS). This included SOPO Subtasks 1.3 (Rock Coring – Tunnel Alignments) and 1.4 (Rock Coring – Pressure shaft/Tunnel). Value stream model development and analysis (Task 2, discussed in Section 2.2), performed by subcontractors Electric Power Research Institute (EPRI) and Energy Exemplar, commenced in late 2013.

A major milestone of the Project permitting process occurred in July 2014, when FERC issued a new 50-year license for the UARP. This event served as the catalyst for the USFS to begin work on reviewing SMUD's request for a blanket, multiyear Special Use Authorization (SUA). The SUA was viewed by the USFS as a separate and distinct authorization from the SUP. It wasn't until March 2015 that SMUD was successful in securing the 10-year SUA from the USFS for pre-construction and construction activities associated with the Project, subject to USFS approval of a series of annual Work Plans. In April 2015, the USFS approved SMUD's first Work Plan under the SUA to perform geotechnical investigations under Subtask 1.8 (Rock Coring – Vertical Shaft).

Project progress was set back when the USFS, backed by the SWRCB, informed SMUD they would not approve a work plan for Subtasks 1.6 and 1.7 until after SMUD developed a groundwater monitoring plan, install eight groundwater wells near the upper reservoir, and complete one or more years of baseline monitoring of groundwater conditions under different water year types prior to excavating the test drift. This decision required that SMUD prepare, and the USFS approve, a separate Work Plan to install six of the eight groundwater monitoring wells on National Forest System Lands to examine the effect of excavating the drift on groundwater resources. The effect of this decision essentially pushed back implementation of the two uncompleted SOPO subtasks until late 2016 at the earliest. Based on the plain language in the FERC license, SMUD had anticipated and planned for all groundwater monitoring activities to commence only after construction of the Project.

Despite the slowdowns associated with delayed certification and Work Plan approvals under the SUA, SMUD was successful in acquiring all other necessary permits and plans to perform Subtasks 1.6 through 1.9 by the end of 2014, including the following:

- Limited Threat Wastewater Discharge Permit from the Central Valley Regional Water Quality Control Board
- Low Threat Wastewater Discharge Permit from the Central Valley Regional Water Quality Control Board
- Storm Water Pollution Prevention Plan
- Drill and Blast Permit El Dorado County Sheriff's Office
- Grading Permit from El Dorado County for Spoils Pile
- Well Permit from El Dorado County
- Groundwater Monitoring and Mitigation Plan
- Geotechnical Surveys Noise Management Plan
- Geotechnical Surveys Transportation Management Plan
- Geotechnical Surveys Fire Prevention Plan
- Geotechnical Surveys Visual Resources Protection Plan

It was while SMUD was developing the baseline groundwater database required of the resource agencies that SMUD management announced in July 2015 a decision to delay all geotechnical investigations at the Project one year to thoroughly re-evaluate the costs, benefits, and risk associated with the Project before committing to the next phase of work.

2.1.2 Subtask 1.2 – Field Mapping, Access, and Spoils Pile Stabilization

The primary purpose of this subtask was to investigate qualitative and quantitative information of the surface morphology and geology at the Project site, including such features as weathering, landslide material, toppled rock, and geologic contacts and shears. The geologic field mapping was focused on existing cuts along prominent roads and other natural exposures within the project area. During the reconnaissance, loose rock and orientations of surface rock orientations were mapped. Light Detection and Ranging (LiDAR) methods were used to generate a morphological map of the Project site (Figure 1).

Geologic field reconnaissance was performed on various dates in spring of 2014. The reconnaissance focused on existing cuts along Chute Camp Road and the "Boat Ramp Road," and other natural exposures within the Project limits. During the reconnaissance, bedding/foliation and joint orientations were mapped and measured using a Brunton compass.

Bedrock discontinuities at the Project site were found to consist predominantly of bedding planes, foliation, and joints. Bedding was observed in the rock core typically as thin (1- to 4-inch-thick) interbeds between alternating rock units throughout the borings. Bedding was generally found to be planar, but in some cases was wavy and convoluted, possibly due to soft-sediment deformation or disturbance when the beds were originally deposited. Foliation is sheet-like planar units of rock resulting from regional shearing during metamorphism and the associated segregation and reorientation of minerals.

Access planning for drilling rigs along existing roads was also performed under this subtask as well as site preparation and spoils pile stabilization (i.e., Best Management Practices under the Grading Permit) for the expected 15,000 cubic yards of material that would have been generated during construction of the test drift (Subtask 1.6).

2.1.3 Subtask 1.3 – Rock Coring – Tunnel Alignments

Two horizontal rock coring operations were performed from an existing road near the shoreline of Slab Creek Reservoir. The coring operations were successful in crossing all major geological lineaments through which underground project features would exist between the existing Slab Creek Reservoir and the proposed underground generation and pumping facilities.

The first boring (CH-1) was drilled and sampled from December 2013 through January 2014. The boring was inclined slightly downward, at an angle of approximately 9° from horizontal. The borehole was advanced through variably weathered and fractured metamorphic bedrock to a depth of 2,010 feet from the ground surface. Groundwater was encountered at a depth of approximately 240 feet. Packer and hydrojacking tests were conducted at numerous locations along the coring alignment. Throughout the drilling operations groundwater inflows into the corehole ranged from 5-15 gallons per minute and water pressures ranged from 10 to 15 pounds per square inch.

The second boring (CH-2) was drilled and sampled from February through March 2014. Similar to CH-1, the boring direction was slightly downward, inclined at an angle of approximately 8° from horizontal. The borehole was advanced through variably weathered and fractured metamorphic bedrock to a depth of 1,473 ft. below from the ground surface. Packer and hydrojacking tests were conducted at numerous locations along the coring alignment. Groundwater was first encountered at a depth of approximately 140 ft. and was packered and measured throughout the drilling operations with flows ranging from 5 to 33 gpm and pressures ranging from 10 to 25 psi. In situ testing and geophysical exploration in the borehole also included optical televiewer and acoustic logging.

Core samples generated from Subtask 1.3 were transmitted to a laboratory for further analysis under Subtask 1.9.

2.1.4 Subtask 1.4 – Rock Coring – Pressure Shaft/Tunnel at Iowa Hill

The purpose for rock coring along the pressure shaft and tunnel was to improve the understanding of the rock structure and groundwater along the line of the vertical power shaft between which water would transit from the upper reservoir to the underground generating/pumping facilities. Accordingly, Corehole 3 (CH-3) was drilled and sampled from December 2013 into February 2014, and three vibrating-wire piezometers were installed (Figure 2). The boring was inclined 90° downward from horizontal or essentially vertical. The borehole was advanced through variably weathered and fractured metamorphic bedrock to a depth of 1,487 feet below ground surface. Groundwater was measured in the hole throughout the drilling operations at depths ranging from 90 to 110 feet below ground surface. Packer tests were performed at depths throughout the coring, and hydrojacking tests were performed at four separate locations. In situ testing and geophysical exploration in the borehole, also included optical televiewer and acoustic logging. The core samples were transmitted to a laboratory for further analysis under Subtask 1.9.

2.1.5 Subtask 1.5 – Risk Workshop

A Risk Workshop and Go/No-Go Meeting was convened in March 2014, during which SMUD and DOE reviewed draft geotechnical and value stream modeling reports and jointly determined the Assistance Agreement work should proceed with subtasks 1.6 through 1.8.

2.1.6 Subtask 1.6 – Geotechnical Test Drift

Work on this subtask had not commenced by the time SMUD canceled the Project. This subtask would have included excavation by drill and shoot methods of a single, horizontal test drift, 10 foot by 10 foot horseshoe shaped tunnel approximately 1,000 feet into the mountain in the area of the powerhouse cavern. This test drift was designed to allow for direct observations of geologic features and groundwater inflow rates that are difficult to interpret or measure from core borings and in situ testing alone.

2.1.7 Subtask 1.7 – Rock Coring – Powerhouse Cavern

Work on this subtask had not commenced by the time SMUD canceled the Project. The geotechnical test drift (Subtask 1.6) was planned to be sized to accommodate a small portable rock coring machine, which would allow for coring to the end of the drift tunnel. The work was to consist of drilling up to six coreholes into and through the proposed powerhouse cavern, which would generate information on rock structure, contacts, and shears in the area of the powerhouse cavern.

2.1.8 Subtask 1.8 – Rock Coring – Vertical Shaft

The purpose of the rock coring along the vertical, or utility, shaft was to generate information related to the depth of the weathered and toppled zones as well as geologic contacts and shear zones along this alignment. The vertical shaft would provide passage for the high voltage cables from the generating facilities to the earth surface, as well as ventilation and stairs for emergency egress and inspection. Communications (voice/data), auxiliary power cables, and lighting would also be provided in the utility shaft.

Accordingly, a single rock core boring (CH-4) was drilled and sampled from April 21, 2015 to May 11, 2015, and three VW piezometers were installed in the borehole on May 15 and 16, 2015. The boring was inclined - 90° (downward from horizontal). The borehole was advanced through variably weathered and fractured metamorphic bedrock to a depth of 1,458 feet below ground surface. Groundwater was first encountered in the hole at a depth of approximately 188 feet below ground surface. The three vibrating-wire piezometers were installed at depths of 811 feet, 1,101 feet, and 1,341 feet below the ground surface. Packer tests were performed at depths throughout the coring, and hydrojacking tests were performed at four separate locations. In situ testing and geophysical exploration in the borehole also included optical televiewer and acoustic logging. The core samples were transmitted to a laboratory for further analysis under Subtask 1.9.

2.1.9 Subtask 1.9 – Laboratory and Field Testing

Borehole packer injection tests were conducted in all borings to assess the hydraulic conductivity of the rock mass. These tests involved isolating a section of the borehole with a single packer and injecting water into the test interval either under falling head, constant pressure, or constant flow rate conditions. The tests generally were performed on 10-ft-long test intervals as the boreholes were being advanced. Test intervals were selected based on the rock conditions encountered in the borings. Multiple (stepped) pressure tests were performed in all boreholes, where each pressure step was held constant for 5 minutes and water intake is recorded in 60 second intervals.

Hydrojacking tests were performed in borings CH-1, CH-3, and CH-4 to assess the minimum in situ stress in the rock. Hydrojacking tests measure the pressure required to open existing fractures by increasing the pressure in the test section in a series of constant-pressure steps, until either hydraulic jacking occurs or the pressure reaches the limits of the equipment.

Laboratory tests were performed on selected core samples obtained from the boreholes. The laboratory tests measured index properties (such as density) and engineering properties (such as unconfined compressive strength, point load index, and elastic modulus).

In addition to these tests, some samples were selected for petrographic (thin section) analysis. Core samples from each of the sites boring sites were tested for the following characteristics:

- Unit weight
- Unconfined compressive strength
- Direct shear strength
- Brazilian indirect tension
- Cerchar abrasivity
- Point load index

Additional details of the laboratory testing program are provided in the Interim Geologic/Geotechnical Data Report, provided in Appendix B.

2.1.10 Geotechnical Investigation Findings

Bedrock at the Project site was mapped as Paleozoic-age Shoo Fly Complex, which typically consists of variably metamorphosed marine sedimentary rocks with minor volcanic rocks. Previous explorations at the site identified the primary bedrock lithologies as phyllite and metasandstone (greywacke) or quartzite. Based on the rock core encountered in the corehole borings and the results of petrographic analyses on selected core samples, bedrock at the site can be subdivided into five major rock units as shown in Figure 3. A summary of findings is presented below:

- In general, the rocks are not highly fractured, with the vast majority of the core samples exhibiting a fracture frequency of less than 1 fracture per foot. In all four borings, less than 10% of the core had more than 2 fractures per foot.
- Based on the results of the unconfined compression strength tests and point load index tests the rocks encountered in the exploratory borings generally can be classified as medium strong to very strong.
- The results of packer and hydrojacking tests indicate the rocks exhibit low hydraulic conductivity, ranging from about 10-6 to 10-7 centimeters per second.
- During drilling, boreholes CH-1 and CH-2 encountered localized fracture zones of sufficient conductivity that artesian groundwater backpressure and flow

developed. Based on observations of the core, the high conductivity zones appear to contain high angle, open fractures.

- There are no faults mapped in the Project area
- Field mapping results derived from the LiDAR data revealed numerous landslides on the canyon slopes in the vicinity of the Project. The slides are as much as 600 feet wide (across the slope) and 900 feet long (parallel to the slope), with several extending from the canyon rim down to Chute Camp Road along the shoreline of Slab Creek Reservoir.
- Overall, the underlying rock was found to be competent – capable of supporting the underground construction of water conveyance systems and pumping/generation equipment contemplated for the Project.

2.2 Task 2 – Value Stream Model Analysis

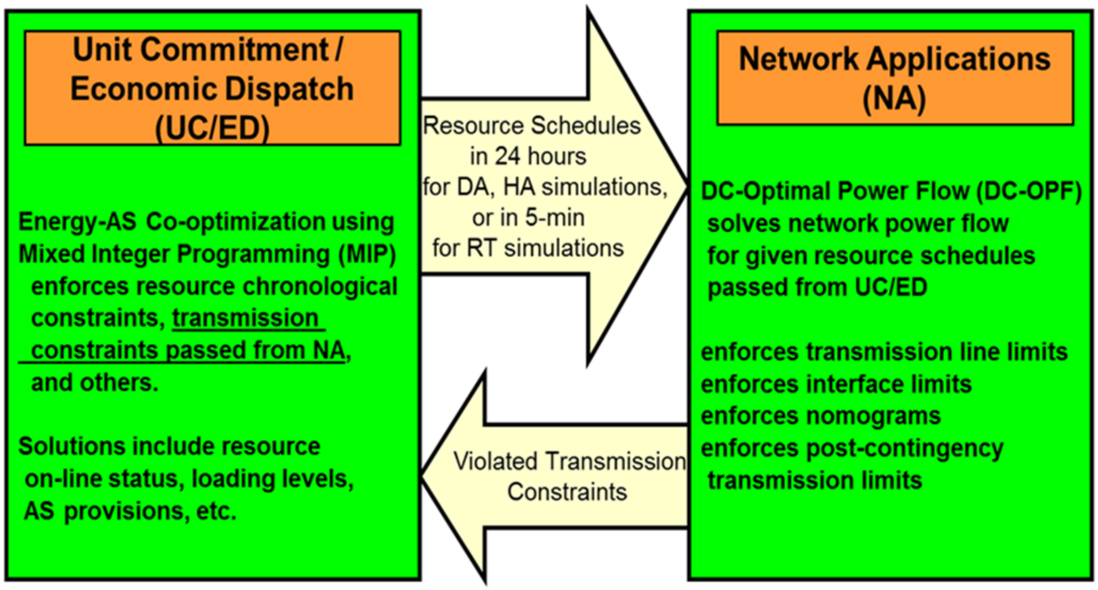
All subtasks of the SOPO Task 2 (Value Stream Model Analysis) were completed in 2014. A formal report describing the results of the modeling effort is provided in Appendix C. For the Iowa Hill Pumped-storage Project analysis, SMUD used Energy Exemplar's Plexos® simulation software, version 6.301 R03. Work performed under Task 2 was performed by SMUD staff in partnership with the Electric Power Research Institute (EPRI) and Energy Exemplar.

The performance criteria required of the Plexos® computer simulation model stemmed from the need of the overall analysis to evaluate the economic benefits of the Project by co-optimizing the energy and ancillary service benefits of all power generation resources in the SMUD system, including pumped-storage, while simultaneously ensuring full compliance of all requirements of the UARP license. The model incorporates the pumped-storage operation logic into its mixed integer programming problem formulation, which allows it to co-optimize the value of pumped-storage with cost variables including energy, ancillary services, and power flow. The Plexos® model also has the capability of modeling complex cascaded hydroelectric systems such as the UARP, where water passes in a linear fashion through a series of reservoirs from high to low elevation.

The model is widely used for a number of energy-related simulations. Electric utilities, transmission system operators, electricity market operators, and energy regulators use the Plexos® model to evaluate various aspects of electricity systems, including bulk power system studies, power resource valuations, integrated resource planning, regulatory studies, and market design studies.

Prior to the Project-specific study, SMUD had used the Plexos® model for integrated resource planning and had performed benchmark tests to ensure reasonable resource commitment and dispatch results. For the Project-specific application, SMUD inserted the pumped-storage facility into this earlier version of the Plexos® model. Benchmark tests of the Iowa Hill unit commitment and dispatch in the revised model consisted of matching model results with historic operating data for the UARP, checking model results with the results of other simulation models, and checking model results with separately-developed unit commitment and dispatch spreadsheet models.

The Plexos® model Security Constrained Unit Commitment algorithm consists of two main parts, including unit commitment using mixed integer programming and network applications, as depicted below.



The unit commitment and economic dispatch (UC/ED) logic performs the energy-ancillary service co-optimization using mixed integer programming enforcing all resource and operation constraints. The UC/ED logic commits and dispatches resources to balance the system energy demand and meet the system reserve requirements. Plexos® then passes the resource schedules from the UC/ED to the network applications logic. The network applications logic solves the direct current-optimal power flow (DC-OPF) to enforce the power flow limits and nomograms. Should the network applications logic find any transmission violations, Plexos® passes the violations back to the UC/ED logic for re-analysis. Plexos® continues the iterative UCD/ED and DC-OPF processes until Plexos® resolves all transmission violations. Many ISOs use this same UCD/ED algorithm in their market scheduling software but use the alternating current OPF (instead of DC-OPF) in the network applications logic.

2.2.1 Subtask 2.1 – Resource Mix Scenario Development

The resource mix evaluated in this task was based on the expectation that pumped-storage value is dependent to a large degree on the penetration variable renewable generation resources, such as wind and solar, on the interconnected grids of the western United States. As such, different scenarios were examined with different renewable penetrations in the BANC and in the much larger Western Interconnection (WI). The resource mix scenarios developed under this subtask were adaptations of scenarios used in the National Renewable Energy Laboratory (NREL) Western Wind and Solar Integration Study (WWSIS) phase 2 study. Those scenarios used high penetrations of wind and solar to achieve 33% total variable generation penetration in the main study scenarios.

The initial scenarios were developed using NREL's Regional Energy Deployment System capacity planning tool. This tool was used to site wind and solar energy requirements within the WI based on constraints supplied by the study team. Those requirements were then used to manually site wind from the NREL WWSIS-1 wind dataset and to locate solar resources based on a number of criteria. Three types of solar resources were considered:

- Distributed PV – Primarily modeled as rooftop PV in population centers. Siting was done based on population density.
- Utility Scale PV – Larger PV installations 33% of which were located near population centers and the other 67% located based on best available resources.
- Concentrated Solar Power with storage – Located based on best available solar resources.

Six resource mix scenarios were eventually developed, which included a combination of varying levels of wind and solar penetration within different regions. Three different renewable mixes were based on WECC TEPPC and from the NREL WWSIS Phase 2 study. Two other renewable mixes included a mix with 33% based on a high wind but relatively low solar, and a mix with high solar but less wind. The last mix of 50% was based on combining the two. The six resource mix scenarios created were:

- **TEPPC:** This case was close to the WECC TEPPC 2022 case, with some movement of variable generation plants. This was viewed as a bookend for low variable generation penetration in the California (CA) and WI.

- **High Wind:** This case was similar to the NREL WWSIS-2 study case with some changes as to ensuring 33% penetration in the BANC. This was to examine the case where the entire US portion of the Western Interconnection realized significant amounts of wind.
- **High Solar:** This case was similar to the WWSIS-2 high solar case which had a 33% total variable generation target for the WI with a 25% solar target and 8% wind target. Some adjustments were made in the original WWSIS-2 scenario to achieve approximately 33% penetration in the BANC.
- **CA High Wind, WI TEPPC:** This case examined the case where California, with more aggressive renewable targets, had a high wind penetration, but the rest of the WI did not.
- **CA High Mix, WI TEPPC:** This case assumed California had as much wind as in the previous two cases. Solar was added so that the RPS was closer to 50%, while the rest of WI still had lower renewables close to the TEPPC case.
- **CA High Mix, WI High Wind**: This case examined a situation where the entire WI had 33% of energy from renewables, much of it wind, with additional solar added for 50% RPS in California.

More detail on the development of the scenarios is provided in the value stream model analysis technical report provided in Appendix C (see section 2 of the report).

2.2.2 Subtask 2.2 – Determination of Ancillary Services Requirements

The purpose of this subtask was to ensure that the model met the functional requirements to calculate the value streams of a pumped-storage system. Model functional requirements included the ability to capture energy arbitrage and AS value streams through co-optimization of AS and energy, and enforcement of FERC license constraints on overall UARP operations and SMUD's energy requirements. Energy arbitrage optimization included the ability of the pumped storage system to generate during high-priced hours and pump during low-priced hours to maximize net energy value. AS value optimization included the ability to provide AS services when the most economic choice.

Prior to the Project-specific study, SMUD had used Plexos® Version 6.2 for its integrated resource planning and had performed benchmark tests on Plexos® to ensure reasonable resource commitment/dispatch and ancillary service provision results. Benchmark tests included matching model results with historic operating data, checking the results with other simulation model results, and further checking results with unit commitment and dispatch spreadsheet models. Thus, for the Project-specific study, SMUD began with the version 6.2 of the model, expanded it to include pumped-storage, additional constraints, and new Flex reserve ancillary services requirements thereby creating a new model – Version 6.3 This new version was subjected to the same validation process as the Version 6.2 before it.   Accordingly, SMUD checked resource portfolio, Iowa Hill unit commitment and dispatch, and AS provision results with results generated by predictive spreadsheet models developed by SMUD staff. SMUD also checked the enforcement of UARP water and generation constraints with and without Iowa Hill as predicted by Version 6.3 with spreadsheet models.

2.2.3 Subtask 2.3 – Model Expansions and Verification

A major focus of the model analysis expansion was energy reserves. The procedures used to calculate reserves were based on methods developed by the NREL. These methods examined the historical behavior of the variability wind and solar resources generation statistical information used to predict reserve needs at various timeframes. For the Project-specific study, the time frames of interest were day-ahead, four hour-ahead, and real-time. Each of these time frames had an associated planning or operations function associated with it. The definition of the time frames were:

- Day-ahead – Day-ahead unit commitment that used best forecasts of load and variable generation to create a schedule for the next day.
- Four hour-ahead – A second, faster unit commitment cycle that can recommit fast starting resources. The day-ahead commitment for longer starting resources was honored in this stage.
- Real-time – This was the operational timeframe where economic dispatch of the committed system was performed to meet load on a second-to-second basis. Adjustments to generation in this timeframe were made automatically.

Reserves requirements were calculated for each timeframe, where the reserve requirements were specific to a given set of variable generation resources. Factors that influence the magnitude of the reserves beyond the capacity are geographic diversity, mix of variable generation technologies, and size of the region that reserves were aggregated over. The types of calculated reserves included:

- Regulation Reserve – Resources that are spinning, synchronized capacity available for deployment in seconds to minutes timeframe, up to the re-dispatch interval of the system. These resources must be on Automatic Generation Control (AGC) since it is assumed that there is no other mechanism to command generation changes in this timeframe.

- Flex Reserves – Resources that are held to cover larger unpredicted changes in net load outside the regulation timeframe. These movements are primarily due to uncertainty in forecasts of wind and solar. Load uncertainty may be included in flex reserves. The time frame for these reserves is from the system re-dispatch interval to when replacement reserves can be activated and on-line. A portion of these reserves may be made up from spinning and synchronized units if the reserve amounts necessary require starting up longer-start units (units with two to 6 hour start times).
- Reliability Unit Commitment (RUC) Capacity – Resources capacity that is offline or has a longer-start in planning timeframe. RUC is needed to ensure that the system has sufficient capacity to handle a prescribed portion of possible forecast errors. For instance, day-ahead RUC capacity is dependent upon the day-ahead forecast errors that one can expect based on experience.

In addition to these reserves, the system must maintain all contingency reserves that are available to mitigate an unexpected system change like the sudden, unexpected loss of generation, load or transmission. These reserves are not affected in any way by the calculation of regulation, flex and RUC capacity reserves and are completely independent.

2.2.4 Subtask 2.4 – Production Cost Simulations

SMUD performed multiple simulations of the BANC and WI with different resource mixes, ancillary service requirements, and different balancing alternatives using Iowa Hill and gas power plants. Forecasts of energy and ancillary service values for storage resources were developed for these different alternatives. Results also included cases with ancillary service trading allowed between the BANC and the rest of study area, and cases where this is not possible.

Range of system values from the proposed Iowa Hill project included:

- Reduction of production costs in both the BANC and the study area (the BANC sees approximately 75% of total cost reduction).
- Improvement of ability to meet reserves (fewer shortages)
- Improved ability to trade ancillary services with the rest of the study region
- Reduction of wind and solar curtailment, especially at high penetrations, by up to 50%
- Reduction of cycling by more than 50% (costs and number of starts).

From these production cost simulations, it was clear that results varied significantly across scenarios, and so care should be given to ensuring that the scenarios are well understood and the most realistic are paid most attention. For example, Iowa Hill does not seem to provide as much value with high solar cases. In addition, the value of deferring generation and transmission investments are another value of the Project. For more details see Section 6 and 7 of the DOE report.

2.2.5 Subtask 2.5 – Pumped Storage Value Analysis

The primary value streams evaluated in the analysis included: (1) ancillary services value; (2) production cost savings; and (3) avoided generation and transmission capacity investments. The following table highlights the primary results of the analysis for each of the five modeled scenarios.

Simulated Value of Iowa Hill Pumped-storage Project ($-Millions).

Scenarios	**Wholesale Revenue**				
	Net Production Cost Savings[1]	**Ancillary Services**	**Energy**	**Resource Adequacy Capacity Value[2]**	**UARP Efficiency[3]**
TEPPC	12	7	14	20-64	0.1-0.35
CA High Wind, WI TEPPC	12	9	-2	20-64	0.1-2.7
CA High Mix, WI TEPPC	19	10	-4	20-64	0.1-2.3
CA & WI High Wind	43	5	-6	20-64	0.1-2.0
CA High Mix, WI High Wind	52	10	-12	20-64	0.1-1.9
High Solar	14	2	-2	20-64	0.1-2.2

1. Total production plus import cost minus wholesale revenues from ancillary services and energy

2. Resource adequacy (RA) is based on range depending on whether avoiding new peaking capacity or allowing for forward looking fixed cost recovery of existing plant.
3. UARP efficiency is based on average production costs and water savings for a range of water years (wet to medium to dry).

As seen in the table, many of the value stream values are a function of the modeled scenarios. The values shown for the net production cost savings are for cases where AS trading is allowed, which was deemed the most likely situation in the long term. For Resource Adequacy costs, the range varies depending on whether the Project would avoid the construction of new generation plants (high value) or whether it would support forward-looking fixed costs for other surplus generation to stay available (low value). The range of values predicted for UARP efficiency reflects the difference in water year types with the boundaries of the range representing low water years and high water years – normal years would fall somewhere in between values shown in the table. The values are deduced by multiplying the gigawatt-hours increase in UARP output by average production cost.

The production cost savings and AS value are interrelated and increase with higher AS requirements to balance variable renewable resources such as wind and solar energy. Hence, the value of production cost savings and AS provisioned from the Project varies significantly under different energy resource development scenarios (e.g., high wind with 50% renewable portfolio standard and is driven primarily by penetration levels of variable renewable resources in BANC and surrounding balancing authorities.

The value of production cost savings and AS is roughly 70% of the Project value in the 50% RPS cases represented by high levels of wind and solar energy. In the nearer-term, represented by a 33% renewable energy, the value of AS and production cost savings was in the 30% to 40% range.

Avoided capacity investments, primarily supply capacity, had an inverse relationship with renewable penetration levels. In the 50% RPS cases, avoided capacity investments represented roughly 30% of the project value, while the 33% RPS cases it represented 60% to 70% of the project value. This level reflects the fact that many of the existing installed conventional power plants are repurposed as balancing reserve rather than retired in the higher RPS cases. Although the plant output is repurposed, it also services as supply reserve, and hence the higher renewable penetration cases are also characterized by local and regional supply capacity surpluses.

What is clear is that increasing penetration of renewables increases the value of Iowa Hill to the BANC. This is true even more so as the entire WI starts to see high penetration levels, showing how important the remainder of the system is to value of the Project.

It was also found that avoided curtailment of renewable resources increases as penetration increases, as does avoided reserve shortfalls. It should be noted that reserve shortfalls are all for flexibility down reserve, which are reserves carried to cover unexpected increases in wind and/or solar output or unexpected decreases in load.

The analysis also shows that increasing levels of wind penetration result in significantly more value than increasing levels of solar, likely due to the shape of the solar energy providing more energy at or close to peak demand. This result demonstrates that the Project is less valuable in the high solar scenario than a scenario of high mixed resources or high wind penetration. Across most scenarios, energy revenue from the rest of California actually decreases for SMUD under Project operation, but this is offset by an increase in ancillary services value and a reduction in production costs within BANC, thus always ensuring a reduction in net production costs.

Based on other scenarios examined, other factors driving Project value include whether the pumped-storage turbines are fixed or variable speed. In general, variable speed turbines demonstrated at least one third additional value, but could be as much as double.

3 Preliminary Function Design

As discussed in Section 1.1, the Project was to be located adjacent to and directly east of Slab Creek Reservoir, on the South Fork American River (SFAR). The proposed Project area encompasses part of Slab Creek Reservoir and the adjacent canyon wall and rim of the SFAR. The topography of the upper Project area, where the upper reservoir was to be located, consists of numerous dissected and gently rounded peaks and ridges, with elevations ranging from about 3,100 to 2,800 feet. From the top of the canyon rim, the steep canyon wall of the SFAR descends for over 1,000 feet down to the waters of Slab Creek Reservoir.

At this location, the Project was conceived as a 400 MW development that incorporated a number of advanced concepts and new technologies, including:

- Use of existing facilities, such as Slab Creek Reservoir to minimize environmental impacts, reduce overall costs, and shorten construction times.
- A new 6,300 acre-foot upper reservoir created by an embankment with advanced lining technology to minimize leakage and improve efficiency, built on top of the mountain adjacent to Slab Creek Reservoir.
- Three 133 MW variable-speed pump-generators, housed in an underground complex approximately 1,200 feet below the upper reservoir.

- An underwater inlet/outlet structure in Slab Creek Reservoir designed and operated to reduce fish entrainment, minimize turbidity, and preserve recreational opportunities in the reservoir.

The design features of the Project were informed by the results of the geotechnical investigations under the Assistance Agreement, though preliminary functional design work was not included in the Agreement. Using these results, SMUD's Owner's Engineer, Jacobs Associates, developed a Preliminary Functional Design Report, highlighting major project components. This report is provided in Appendix D. The project design features contained in this report served as input to the Opinion of Probable Construction Cost (OPCC), discussed in Section 4.0.

As originally planned, within the preliminary function design, the Iowa Hill plant consisted of three 133 MW variable speed generator/motor units with a design capacity of 400 MW. The maximum design flow of the plant in the generation mode was 4,789 cfs while the design flow in the pumping model was 4,549 cfs. In operation, the maximum gross head would be 1,258, and the minimum gross head would be 1,095 feet.

The major project components developed in the preliminary functional design are outlined below. The locations of many of the project components described below are shown in the Project General Arrangement diagram (Figure 4).

Summary of major components of the Iowa Hill Pumped-storage Project, as developed in the preliminary Function Design.

Component	Description
Slab Creek (Lower) Reservoir Inlet/Outlet Structure	Reinforced concrete structure equipped with trash racks, isolation gates, a tunnel fill system, a tunnel drain vent, and equipment access into the tailrace tunnel.
Upper Dam and Reservoir	Embankment dam consisting of impermeable lining, emergency spillway, leakage monitoring system, and emergency low-level outlet with trash rack and water control gate. Also includes a power inlet/outlet (below), and access road along dam crest. Total reservoir capacity: Approximately 6,700 acre-feet. Active reservoir capacity: Approximately 6,300 acre-feet. Maximum depth: 142 feet.

	Surface area: 71 acres at maximum normal operation water surface elevation. Instrumentation: Water level indication, geotechnical, and leak detection. Security: Vinyl coated chain linked fence with barbed wire, public safety signage, and video cameras.
Upper Reservoir Inlet/Outlet Structure	A vertical, reinforced concrete hooded structure equipped with a trash rack. This inlet/outlet is not gated.
Power Shaft	Concrete lined shaft, 19 feet nominal internal diameter, approximately 1,200 feet deep.
Headrace (High Pressure) Tunnel	Concrete lined tunnel, approximately 900 feet long, 19 feet nominal internal diameter with a 19-foot-diameter manifold transition.
Headrace Tunnel Manifold	Concrete lined tunnel, approximately 200 feet long, 14 feet nominal diameter.
Penstock Manifold	Three penstocks, approximately 470 to 520 feet long, 9 feet nominal internal diameter. Approximately 250 feet of steel lining in each penstock extending from grout curtain to the isolation valves to prevent hydro jacking and water exfiltration. Concrete lined outside of steel lined section.
Draft Tube Extensions and Draft Tube Manifold	Three Draft Tube Tunnels approximately 260 to 300 feet long, 12 feet nominal diameter. Partially steel lined to prevent hydrojacking and water exfiltration.
Tailrace (Low Pressure) Tunnel	Concrete lined tunnel, approximately 1,700 feet long, 26 foot nominal internal diameter with a 19-foot-diameter manifold transition.
Powerhouse Access Tunnel (PHAT) & Portal	Lined tunnel, approximately 2,950 feet long, 25 feet wide nominal internal width and 25 feet tall, horseshoe shaped. Serves as the primary vehicular access route for operations and maintenance.
Underground Powerhouse	Approximately 66 feet wide by 370 feet long by 135 feet tall, located approximately 1,300 feet below the ground surface. Permanent support for crown and walls will be rock reinforcement with shotcrete-lining. Equipped with three fast-responding variable-speed pump-turbine generator/motors, power electronics, electrical and mechanical auxiliary equipment, switch-gear, protection, control equipment, and an overhead crane.
Pump-Turbine	Three single-stage Francis-type units; each unit's nameplate capacity rated at approximately 133.3 MW nominal.
Motor-Generator	Three direct-coupled 16.5 (or 18) kV fast responding variable speed motor-generators, each rated at approximately 150 MVA.

Bus Tunnels	Three tunnels, approximately 26 feet wide by 100 feet long by 50 feet tall, located at the main deck elevation. Same support and groundwater control strategy as used for the underground powerhouse.
Draft Tube/Transformer Cavern:	Approximately 47 feet wide by 345 feet long by 45 feet tall, located approximately 1,300 feet below the ground surface. Same support and groundwater control strategy as used for the underground powerhouse. Equipped with 16.5 (or 18 kV) / 230 kV step-up transformers rated at 175 MVA, overhead raceway, and high voltage cables. Includes independent smoke control system and blast panels.
Utility Shaft	Vertical shaft with rock reinforcement, approximately 19 feet nominal diameter by 1,400 feet deep. Lined or unlined, to be developed based on infiltration limits that will be determined with the groundwater monitoring program and USFS agreement. Provides passage for the high voltage cables to the surface, and ventilation and stairs for emergency egress and inspection. Communications (voice/data), auxiliary power cables, and lighting will also be provided in the utility shaft.
Utility Shaft Building	Building on top of the utility shaft to secure the utility shaft and house the ventilation fans, communication equipment, and backup battery banks, and also provide emergency egress from the underground powerhouse. A stationary backup generator will be located outside the utility shaft building.
Switchyard	Switchyard will be a breaker-and-half configuration and located on the surface adjacent to the Upper Reservoir to accommodate 230 kV and Station Service equipment. There will be three 230 kV circuits connecting the switchyard to the Powerhouse, one circuit for each motor-generator
Generation-Tie	There will be three 230 kV circuits connecting the switchyard to SMUD's existing transmission lines. The generation-tie (gen-tie) transmission line will connect the switchyard and the existing transmission lines. The gen-tie will be approximately 1.8 miles long, crossing through private property, U.S. Forest Service lands, and connected with existing SMUD 230 kV circuits. The gen-tie transmission towers will be brown-tinted galvanized steel mono-pole type.
Telecommunications	Communications, voice, and radio communications will be provided by digital microwave and fiber optic cables. A microwave tower will be constructed near the switchyard and

	switchyard control module and integrated with SMUD's telecommunication system. A new microwave tower will be constructed at Slate Mountain. Fiber optic cables will be carried on the 230 kV transmission towers via OPGW and integrated with SMUD's telecommunication system.
Access Roads	The following access roads will be constructed or improved: (1) Slab Creek Reservoir Road will be improved and maintained to provide project access to the site. (2) Boat Ramp Road will be improved to an 18-foot travel width over a length of 5,000 feet with an all-weather surface consisting of 8 inches of compacted Class 2 Aggregate Base Rock. Boat Ramp Road includes 3,600 feet along Chute Camp Road and an additional 1,400 feet from Chute Camp Road to Slab Creek Reservoir. The improvements are per agreement with the USFS and are to support the Design-Build Contractor's approved construction work plan and to improve recreation access to the Slab Creek boat ramp. (3) Long Canyon Access Road will be constructed as a 14-foot travel width over a length of 8,800 feet with an all-weather surface consisting of 8 inches of compacted Class 2 Aggregate Base Rock. Long Canyon Access Road will be constructed from Boat Ramp Road (Chute Camp Road) up to the existing Cable Point Road. The new road will provide construction and O&M access to the Upper Reservoir from Slab Creek Reservoir Road.

4 Cost and Financial Risk

The primary drivers behind SMUD's decision to cancel the Project are cost and financial risk. Despite the results of the value stream modeling analysis and the extensive environmental and geotechnical studies, construction impact assessments, and permitting work, SMUD concluded that the project would be too risky from a financial standpoint. This decision was based to a large degree on the estimated cost to construct the Project.

Throughout the years of Project planning, and at different stages of Project design, SMUD has developed estimates of the cost to construct the Project. The cost to SMUD of building the Project is the sum of a variety of individual costs, including direct and indirect construction cost, construction management, SMUD staff time, and the cost of financing the Project. As shown in the following table, the estimated cost to construct the Project was estimated at between $1.37B and $1.45B in 2015 dollars.

.

Estimated Cost to SMUD to Construct the Iowa Hill Pumped-storage Project.	
Cost Estimate Components	**2015 Cost (millions)**
Direct Costs	743
Indirect Costs	206
Construction Management	28
SMUD Labor	32
Contingency (21.5%)	201
Financing Costs, i.e., Allowance for Funds Used During Construction (AFUDC)	162 - 243
Total	1,372-1,453

The estimated overall construction cost contingency of 21.5% reflects a blending of component-specific cost contingencies, each individually determined on the basis of uncertainty. Contingency values ranged from 10% for access roads and SF-6 transformers to 25% for underground civil construction, and as high as 35% for construction of the lower reservoir inlet/outlet structure. Allowance for funds used during construction (AFUDC) is a standard component of utility capital projects and represents the estimated costs of debt and equity financings required by SMUD to finance the construction of a regulated asset such as the Iowa Hill Pumped-storage Project.

In 2010, one year prior to applying for the DOE Assistance Agreement, SMUD developed an Opinion of Probable Construction Cost (OPCC) that included direct and indirect costs. With limited data on the underground geological conditions and based on a conceptual design, the 2010 OPCC was $611M. Using the geotechnical information generated from the Assistance Agreement, coupled with preliminary discussions with FERC staff and the California Department of Water Resources, Division of Safety of Dams, SMUD developed a more refined functional design and new OPCC in 2015.

The 2015 direct and indirect OPCC was $949M. This value was $253M higher than the 2010 OPCC, after it was escalated from 2010 to 2015 dollars, essentially to a value of $696M. The difference between the two OPCC values is explained by increases in direct costs for certain components of the Project, as well as the addition of direct costs for components that were not included in the 2010 OPCC, as described in this table:

Summary of increases in direct costs between the 2010 and 2015 OPCC estimates.	
Direct Cost Increases from 2010 OPCC	**2015 Cost (millions)**
Upper Reservoir Civil	41
Upper and Lower Reservoirs Inlet/Outlet	2
Underground Civil	28
Powerhouse Mechanical/Electrical	32
Variable Speed Motor/Generator	8
Direct Costs not Included in 2010 OPCC	
SF-6 Transformers	15
Transmission and Switchyard Upgrades	88
Access Roads	20
Total	240

In addition to the high construction costs, a number of changes in the energy marketplace and customer behavior influenced the decision to cancel the Project. Primary among these is the change in the price of natural gas. As stated Section 1.3, in 2005, SMUD expected natural gas prices to increase going forward. Since then, "fracking" technologies have unlocked abundant natural gas resources. Natural gas prices have dropped, and nationally focus on natural gas has shifted from imports to exports. As a result, the likelihood of high and volatile energy prices over the next 30 years has gone down significantly, which means the peak-power energy production and other energy services from a pumped-storage system would be less valuable.

Another change from 2005 has occurred in customer demand within the SMUD service territory. The 2% per year growth that existed for the ten years prior to applying for the UARP license, which argued in favor of the Project, has reversed to the point where peak loads have actually diminished over the past ten years. Energy efficiency and rooftop solar have reduced customer usage, and peak demand is expected to be further reduced when SMUD imposes residential time-of-use rates in 2018. Lower and slower growth means SMUD needs fewer new resources to manage intermittency and balance system needs.

On top of these trends, competing technologies such as battery storage have come down in cost much faster than expected. Although the cost of batteries is not fully competitive with pumped-storage, battery systems can be a less risky investment for SMUD even if they are at a higher cost per kilowatt of capacity. The reason is scalability. The Project is a full 400 MW commitment, while SMUD's current studies indicate that only need 50 MW of its capacity is needed in the near term. The other 350 MW would have to be sold into the market. This scenario creates a risk, however, because if SMUD cannot cover the Project's debt service due to insufficient market revenues, the shortfall would add to the cost of the 50 MW SMUD uses, and ultimately SMUD customers would be required to make up the market shortfall in the form of increased rates. By comparison, battery storage, while higher in cost, can be scaled to exactly what is needed, so it is less costly and poses a reduced financial risk.

Finally, the rate of technological change has quickened for the electric utility business. SMUD currently has ambitious plans to invest in new customer technologies, upgrade the grid and enable the system to integrate more distributed technologies. That will require a lot of new capital, which would not likely be available if SMUD took on significant debt service associated with the construction of the Project.

These concerns were echoed in a Credit Outlook from Moody's Investor Service, which in response to SMUD's decision to cancel the Project stated, "The decision is credit positive for SMUD because the debt issuance to construct Iowa Hill would have significantly increased SMUD's financial risks and debt leverage. Advancements in storage technology over the next decade look promising in resolving power balancing issues. For example, California's Imperial Irrigation District recently began work on a 30-megawatt, 20-megawatt-hour battery storage system that we expect will provide for better utility management of renewable energy sources."

As discussed above, the decision by SMUD not to construct the Iowa Hill Pumped-storage Project was driven largely by cost and financial risk considerations that emerged within the 10-year period from 2005 and 2015. Nevertheless, certain aspects of the proposed Project had a direct effect on the overall success of the process. These aspects, while project-specific, can nevertheless serve to inform future developmental plans of similar projects. One feature of the Project was the integration of existing facilities into the design, such as the UARP Slab Creek Reservoir and transmission line. The effect of using existing facilities was to lower costs of both construction and environmental mitigation. The geotechnical investigations performed under the Assistance Agreement also provided valuable information that substantially improved SMUD's understanding of the underground conditions. This informed the evolving Project conceptual design, which in turn, contributed to increases as well as decreases in construction cost. Compared to 2010 estimates, costs associated with constructing the water conveyance tunnels decreased as a result while the powerhouse construction costs increased. Overall, the geotechnical investigations played a significant role in reducing the construction cost contingency from 35% in 2010 to a blended value of 21.5% in 2015.

Other factors influenced Project schedule, particularly in the area of permitting and licensing delays. Primary among these factors was ownership of the land upon which the geotechnical studies were performed. The schedule delays discussed in Section 2.1.1 would have been lessened if SMUD, rather than the USFS, had owned the land. Another important factor that had the potential to delay the project was opposition from the local community. While the preferred circumstance is to locate a project some distance from populated areas, the Iowa Hill Project was located near a rural area dominated by agricultural interests such as vineyards and apple orchards. Anticipating the concerns of the local community, SMUD proactively engaged the local community early and often to lessen the potential impact on project cost and schedule. A third factor that affected project progress centered around the level of specificity in regulatory requirements prepared by resource agencies. Based on the plain language in the USFS 4(e) Conditions, which were ultimately included in the FERC UARP license, SMUD had anticipated and planned for all groundwater monitoring activities to commence only after construction of the Project. However, the USFS required SMUD to prepare a groundwater monitoring plan, install groundwater monitoring wells, and monitoring groundwater dynamics two or more years prior to implementing Subtasks 1.6 and 1.7 of the Assistance Agreement SOPO. Had SMUD worked more closely with the USFS at the time they were preparing the condition to require a groundwater monitoring plan, the delay in implementing these subtasks would have been lessened or eliminated.

Figures

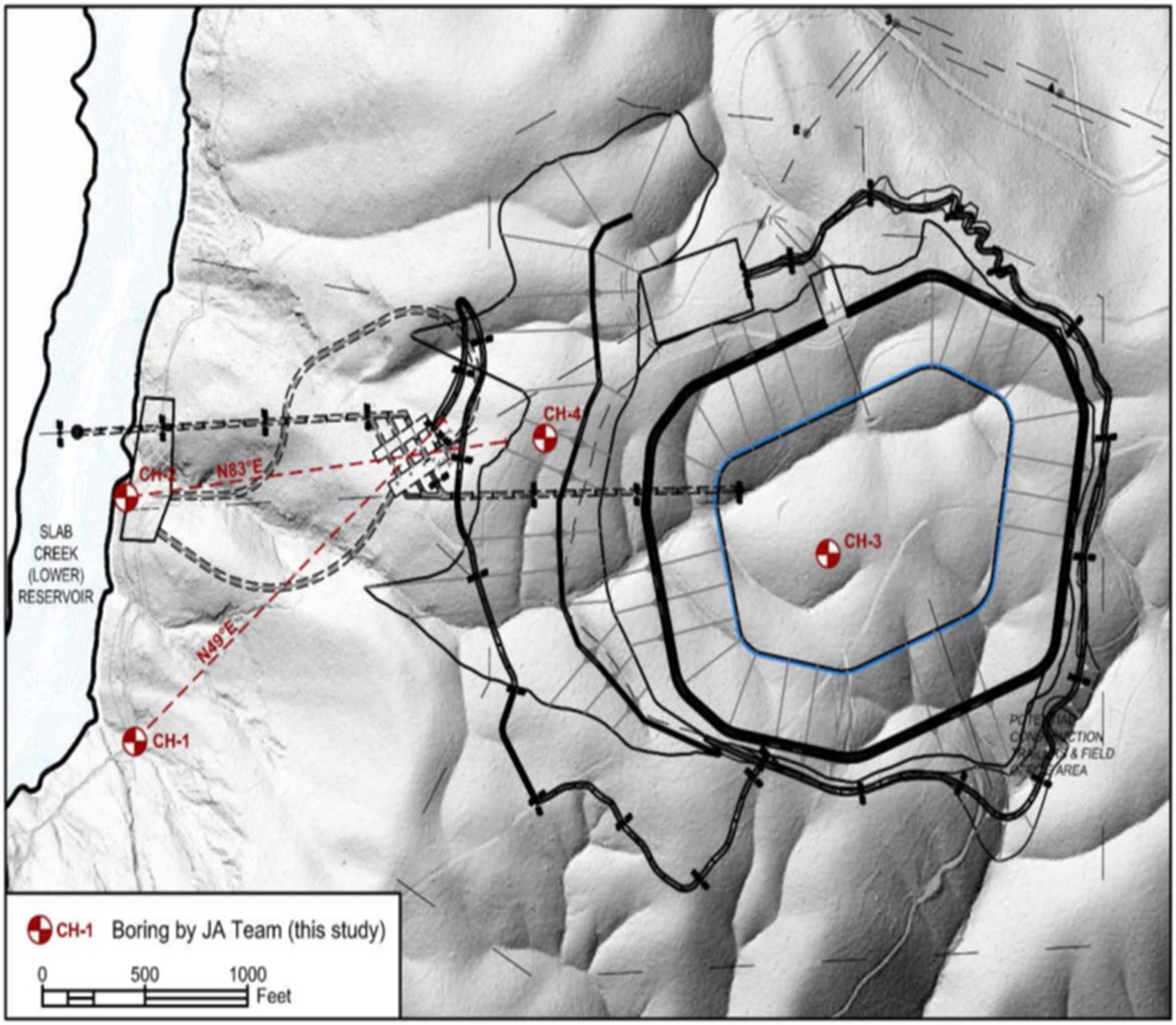


Figure 1. Morphological map of Iowa Hill Pumped-storage Project area, showing surface and underground project features relative to core drilling locations.

Figure 2. Core Hole Drilling at CH-3 within the proposed upper reservoir footprint of the Iowa Hill Pumped-storage Project.

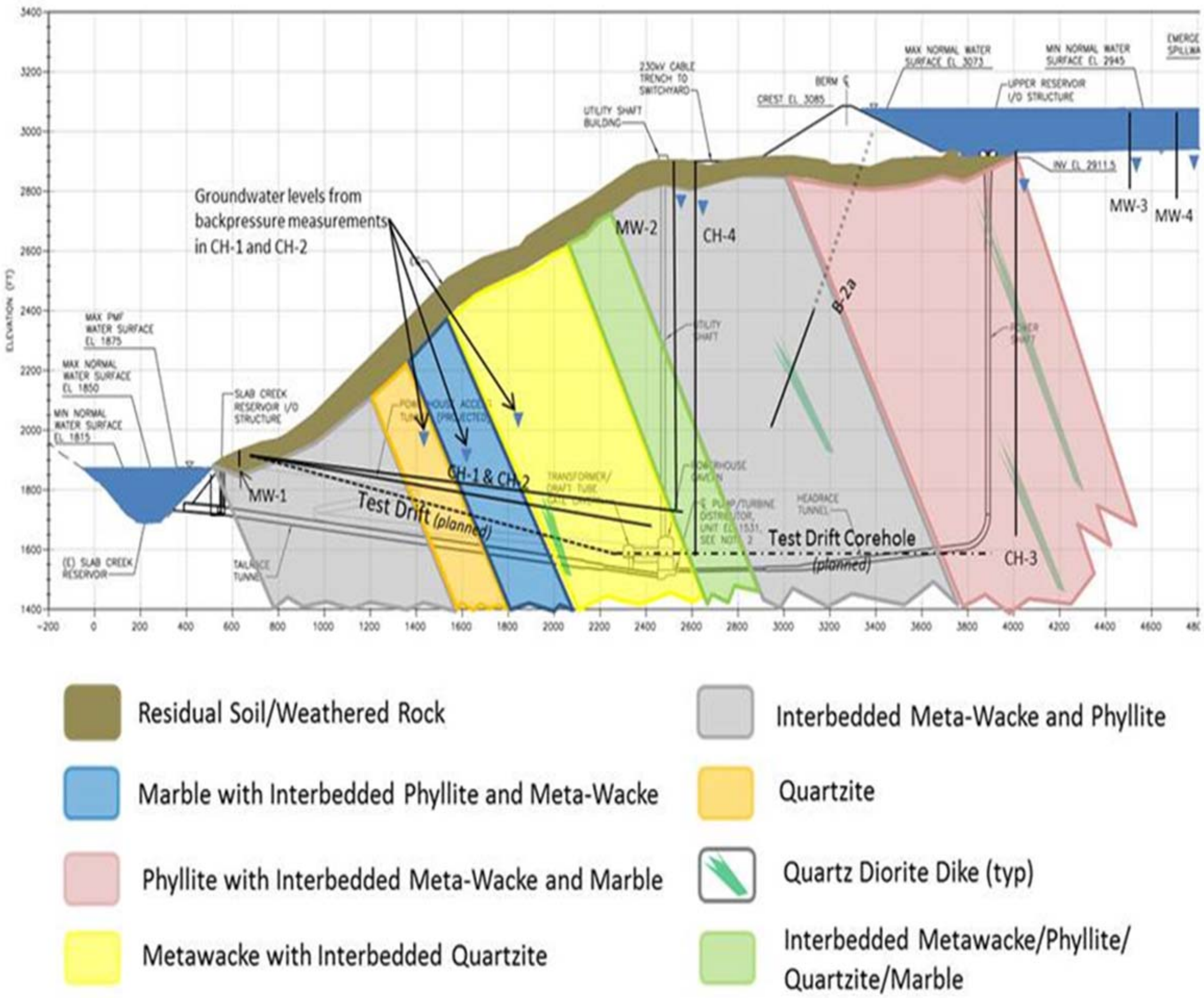


Figure 3. Geological conditions of the Iowa Hill Pumped-storage Project area.

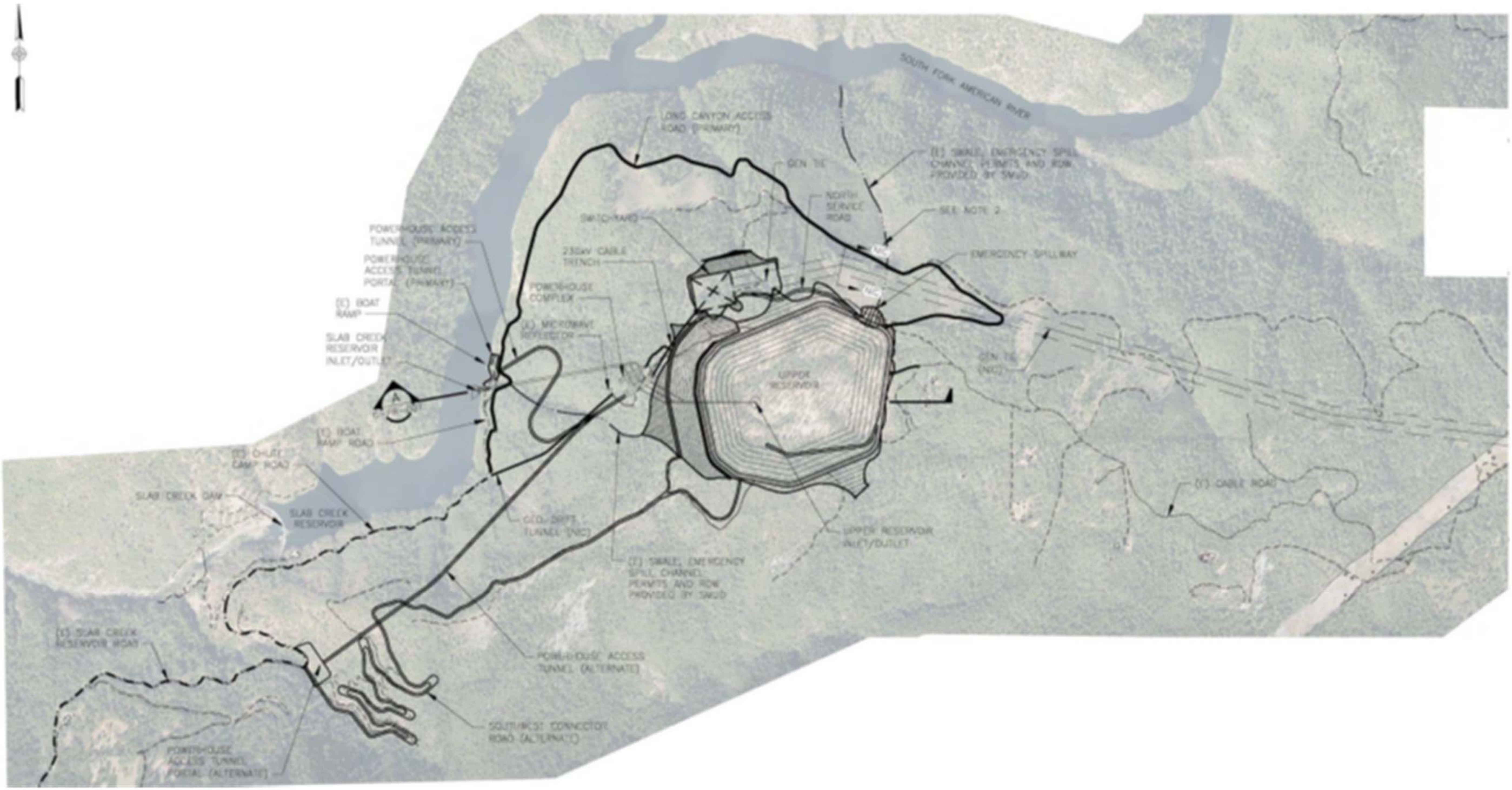


Figure 4. Iowa Hill Pumped-storage Project Arrangement Diagram.

Appendices

Appendix A

DE-EE0005414 Assistance Agreement

Statement of Project Objectives

A. PROJECT OBJECTIVES

The objectives of the Iowa Hill Pumped-storage Project (Iowa Hill) investigations are twofold: (1) reduce geotechnical uncertainty and (2) model energy and services value streams under a variety of energy scenarios.

Technical uncertainty of the subsurface geotechnical conditions in the locale of the underground facilities planned for Iowa Hill presents challenges for securing project financing and partners that would enable Iowa Hill to move into the final design, procurement and construction phases. The investigation has the following objectives:

- Identify geotechnical defects in subsurface that may result in delays and costly remedial measures.
- Determine depth of weathered zone, landslides, and toppled rock in project area.
- Develop detailed information through the powerhouse cavern, tunnels, and shafts on minimum in-situ stresses to inform the degree of steel lining needed that will result.
- Develop detailed information through the powerhouse cavern, tunnels, and shafts on geologic structures, contacts, and shears that will ultimately help in the design of underground openings.
- Evaluate extent and impact of water bearing geologic structures.

Iowa Hill is expected to provide several different value streams to its beneficiaries. These include operating flexibility, reliable capacity and environmental advantages. The overall purpose of the value stream modeling is to highlight the potential value of pumped storage to meet ancillary service requirements and address variability for increasing renewable generation.

The value stream modeling will determine the value of pumped storage flexibility with the overall generation resource portfolio. Also, the contribution to load-serving capacity during severe summer heat storms and peak demands will be considered. Environmental benefits are considered based on deferring transmission projects and lowering the carbon footprint by replacing fossil-based peaking generation with lower emission off-peak generation. The objectives of this part of the project investigations are:

- Determine ancillary service requirements to balance variable renewable generation.
- Examine value of pumped-storage relative to conventional gas generation in providing on-peak energy and ancillary services in the SMUD BA and California.
- Define and quantify value streams of Iowa Hill relative to conventional gas units with future anticipated higher levels of variable renewable generation.
- Analyze net benefits of variable speed versus fixed speed turbines.

B. PROJECT SCOPE

The 400-MW Iowa Hill Pumped-storage Project investigations will be funded under Department of Energy's Wind and Water Power Program, Topic Area 2 (Sustainable Pumped Storage Hydropower, Sub-topic 2.1 (Pumped Storage Hydropower Project Development Support). Pumped-storage is re-emerging from decades of quiescence in the U.S. in response to a new set of energy needs, including load following, regulation, renewable resource integration, capacity services, system reliability, grid stability, and voltage control. This requires current pumped-storage projects to embody innovations that advance the technology and design components while simultaneously satisfying the more stringent environmental protection needs of today. Examples from the Iowa Hill include:

- Variable-speed pump generators for use in regulating and efficiently integrating variable renewable energy, providing ancillary services to the grid and supporting Smart Grid technologies.
- Fully lined reservoir technology to minimize leakage.
- Mid-reservoir, underwater, multi-port intake structures to reduce fish entrainment, minimize turbidity in existing reservoirs, and preserve recreational opportunities.
- Use of existing facilities to minimize environmental impacts, reduce overall costs, and shorten construction times.
- Demonstrate advanced underground tunneling methods including improved drill and blast techniques and the use of road headers in hard rock.
- Use of electricity in construction to reduce noise of fossil fuel generators, increase use of electric vehicles and equipment and provide for other construction needs.
- Advanced plant control system to provide ancillary services to the grid to allow high penetration levels of renewable generation on to the grid and to provide support for the range of Smart Grid improvements including metering, peak shaving, and potential reductions of fossil fueled generation for peaking.
- Advanced technology for high capacity – high temperature ceramic core transmission line conductors to get more power to customers on existing transmission structures.

C. TASKS TO BE PERFORMED

TASK 1.0 Geotechnical Investigation

Subtask 1.1 Environmental Permitting: Secure necessary environmental permits to perform the geotechnical investigations.

Subtask 1.2 Field Mapping, Access, and Spoil Pile Stabilization: Collect qualitative information at the project site related to weathering, landslide material, toppled rock, and geologic contacts and shears. Access planning for drilling rigs along existing roads will be performed as well as site preparation for and spoils pile stabilization/BMPs will be performed for the expected 15,000 cubic yards of material that will be generated during the test drift task.

Subtask 1.3 Rock Coring – Tunnel Alignments: Two horizontal cores will be performed at existing roads near Slab Creek Reservoir with an estimated maximum total drilling length of 2,500 feet, with core hole orientations crossing all major lineaments potentially intersecting project features. This coring will provide basic information on rock structure and groundwater that will confirm the location of access tunnel and cavern locations.

Subtask 1.4 Rock Coring – Pressure Shaft/Tunnel at Iowa Hill: A single vertical core will be performed from the location of the upper reservoir, with an estimated maximum total length of 1,300 feet. This coring will provide information on rock structure and groundwater that will confirm the location of the proposed shaft site.

Subtask 1.5 Risk Workshop: This will constitute the beginning of the second phase of the investigations. The meeting will focus on the design of the test drift to further infill information at the proposed locations of the Main Access Tunnel, Concrete-lined Low-pressure Tunnel, Emergency Tunnel, Powerhouse, and Intake/Outlet Structure.

Subtask 1.6 Geotechnical Test Drift: A single test drift will be constructed that is approximately 1,000 feet long through the tunnel area and into the powerhouse cavern. Information derived from the surface rock coring program would be used to confirm the cavern location and test drift alignment. Approximately 2,000 feet of horizontal and vertical coring would commence from the end wall of the drift and extend through the cavern area to confirm rock quality, and for rock and hydraulic jacking/fracture testing.

Subtask 1.7 Rock Coring – Powerhouse Cavern: The geotechnical test drift will be sized to accommodate a small portable rock coring machine, currently assumed to be a 8 foot by 8 foot tunnel. Using the 1000 foot long geotechnical test drift as point of access, perform an inclined and vertical core drilling of the rock into and through the proposed powerhouse cavern location to verify rock quality and strength needed to accommodate the large cavern required for the proposed equipment. A minimum of six core holes will be performed from the end of the drift with approximately 3,000 feet of core drilling total. This will generate information through the powerhouse cavern on structure, contacts, and shears. It will also provide information in the cavern on minimum in-situ stresses to evaluate steel lining requirments.

Subtask 1.8 Rock Coring – Vertical Shaft: A vertical core will be performed through the area of the powerhouse vent shaft to generate information related to the depth of the weathered and toppled zones as well as geologic contacts and shear zones. Information on in-situ stress along the core will provide an indication of the length of steel lining required in the shaft.

Subtask 1.9 Laboratory and Field Testing: The testing program may include: Packer Tests; Determination of Rock Hardness by Rebound Hammer Method; Rock anchor Proof Tests; Cerchar Abrasiveness Test; Unconfined Compressive Strength of Intact Rock Core Specimens; Splitting Tensile Strength of Intact Rock Core Specimens; (7) Point Load Strength Index of Rock; and (8) Direct Shear Strength Tests of Rock Specimens Under Constant Normal Force.

TASK 2: Value Stream Model Analysis

Subtask 2.1 Resource Mix Scenario Development: Identify various resource mix scenarios including various renewable generation mixes to meet state goals and other unit additions as needed to maintain required reserve margins for reliability to be simulated in subsequent tasks for future generation plant mix in both 2020 and 2025. Different scenarios will be based on different build-out plans for wind and solar to meet the 33% renewables target in California. Include total penetration, share between technologies and location of resources. As an input to the production cost modeling, various hydro run-off assumptions will be examined based on SMUD's hydro system modeling.

Subtask 2.2 Determination of Ancillary Services Requirements: Gather and analyze data to develop day ahead and real-time variability in loads, renewable production and other key data. Based on this, compute ancillary service (A/S) requirements for SMUD, the Balancing Authority Northern California (BANC) and the major neighboring BAs including CAISO, PacifiCorp and BPA, ensuring in each case the BA maintains CPS2 reliability requirements as mandated by NERC. With increased variability and uncertainty, the need for dynamic response time A/S will increase, as this is crucial to variable generation which can be managed by pumped-storage. Thus, the determination of A/S (regulation and spinning reserve in particular) requirements will significantly impact the value of storage.

Subtask 2.3 Model Expansions and Verification: The purpose of this task is to ensure the model represents what is needed to calculate the value streams and make any adoptions necessary. The production model to be used must be able to capture arbitrage and A/S value streams through co-optimization of A/S and energy. The balancing of variable generation and load forecast errors as performed by the model will be verified to build confidence in the modeling approach. The model will capture different scenarios of Iowa Hill providing balancing for BANC only or selling balancing for BANC and selling surplus balancing services to outside regions. This task results in a model that accurately represents the effect of variable generation on A/S, volatility in energy prices and captures the operation of storage accurately.

Subtask 2.4 Production Cost Simulations: Develop a forecast of A/S and energy value for storage and use it to analyze the value of storage for multiple scenarios for resource mix, in 2020 and 2025. The system will be simulated with Iowa Hill, and a gas plant alternative, providing balancing services to examine the added value Iowa Hill provides related to A/S provision and energy arbitrage. In this task, two different analyses will take place for identifying the value streams of Iowa Hill for each of the resource mix scenarios:

A. Simulate the value of Iowa Hill and SMUD's portfolio providing A/S in the region (i.e. neighboring BAs). This will run the production cost simulation with BANC being able to trade A/S needs and resources to meet the neighboring BAs as well as SMUD's and BANCs needs. WECC will also be modeled to ensure flows to and from other WECC regions are well represented.

B. Here, the production cost simulations will be run where Iowa Hill and other A/S resources in the BANC would be available to provide A/S in SMUD/WAPA only, and no opportunity to sell A/S or purchase A/S needs from neighboring BAs. This will show the value of pumped-storage to the SMUD/WAPA region.

C. Rapid dynamic response capacity and time requirements identified in section 2.2 will be specified and modeled in the production cost simulations as a requirement to be maintained in daily operations to assess the value of pumped storage for provisioning these requirements. In addition, modeling production 5 minute interval time steps for selected time periods will demonstrate the value of higher pumped storage response rates in volatile 5 minute balancing markets.

Analysis performed in A and B above will evaluate unit commitment costs needed to meet forecasted load and A/S requirements followed by dispatching against realized values.

Subtask 2.5 Pumped-storage Value Analysis: Based on model results used to establish the A/S, (including load following) values for each scenario, establish value streams to Iowa Hill as contributing to A/S, either in SMUD/WAPA alone or in the entire CAISO region. Model results over the broad range of scenarios will provide a good picture of the value of storage at Iowa Hill. The values will be identified in terms of production cost changes, price impacts, revenue or value streams for Iowa Hill, performance of SMUD's generation fleet, and other metrics

TASK 3: Project Management And Reporting

Subtask 3.1 Kick-off Meeting: SMUD will meet with DOE representatives to establish lines of communication and procedures for performing the scope of work.

Subtask 3.2 Quarterly Progress Reports: All reports and other deliverables will be provided in accordance with the Federal Assistance Reporting Checklist following the instructions included therein. Each quarterly report will summarize activities performed during the reporting period, identify activities for the next reporting period, identify issues that may affect project performance, and form the basis for determining whether invoices are consistent with work performed.

Subtask 3.3 Final Report(s): SMUD will produce a draft report, detailing results of the geotechnical investigation and the value stream analysis. The report will also describe the value these two investigations contributed to the progress of Iowa Hill. Upon review and comment by the DOE, SMUD will produce a final report for submittal to DOE. In concert with production of the final report, the SMUD will discuss with DOE potential avenues of technology transfer, i.e., sharing the results from the work with the industry at large. This may include presentations at conferences, workshops, or other public venues.

Appendix B

DE-EE0005414 Assistance Agreement

Interim Iowa Hill Geologic/Geotechnical Data Report

SMUD™

DPG 16-061

March 11, 2016

Mr. Bradley Ring
Mr. Eric Mauer
U.S. Department of Energy
15013 Denver West Parkway, MS RSF/C250-3
Golden, CO 80401

IOWA HILL PUMPED STORAGE GEOTECHNICAL REPORT

Dear Eric and Brad,

As the Principal Investigator for Assistance Agreement DE-EE-00005414, I am submitting SMUD's final geotechnical report for the Iowa Hill Pumped-storage Project. This report includes all information completed under the Assistance Agreement identified as Subtasks 1.1 through Subtask 1.4 and Subtask 1.8-Subtask 1.9. As previously reported to you in my email of February 3, 2016, the SMUD Board of Directors has determined it is in the best interests of SMUD to cancel plans to construct the Iowa Hill Pumped-storage Development. Given this decision, SMUD will not implement two subtasks in the Statement of Project Objectives of the Agreement (Subtask 1.6 - Geotechnical Test Drift and Subtask 1.7 - Rock Coring Powerhouse Cavern), which is reflected in their omission from this final geotechnical submission.

The report is an update of the initial Interim Geologic/Geotechnical Data Report, submitted by SMUD in April 2014 in support of the Subtask 1.5 – Risk Workshop. This update has been prepared to SMUD by our engineering subcontractor, and contains the results of geotechnical studies performed to date under their contract with SMUD, which includes work described in the DOE SOPO as well as additional geotechnical work we requested of them. It is an interim report, prepared in September 2015 following the completion of coring and laboratory testing at Corehole 4 (CH-4).

To ease DOE review of the report, I provide a table below of cross references between subsections of the report and SOPO Subtasks. Also, references in the report to Tasks 1A and 1B correspond to tasks contained in the contract between SMUD and the engineering contractor, where Task 1A included SOPO Subtasks 1.2, 1.3, and 1.4, while Task 1B included SOPO Subtask 1.8. As stated above, while Subtasks 1.6 and 1.7 were included in the contractor Task 1B, they do not appear in the report as these elements of the SOPO will not proceed given the SMUD Board of Directors decision.

Subsection of 2.0 Field Investigation and Laboratory Testing	Corresponding DOE SOPO Subtask
2.2 Field Investigations	1.2 Field Mapping, Access, Spoil Pile Stabilization
2.3 Rock-Core Borings	1.3 Rock Coring Tunnel Alignments (CH-1, CH-2) 1.4 Rock Coring Pressure Shaft (CH-3) 1.8 Rock Coring Vertical Shaft (CH-4)
2.4 Geologic Field Reconnaissance	1.2 Field Mapping, Access, Spoil Pile Stabilization
2.5 Downhole In Situ Testing & Geophysics	1.9 Laboratory and Field Testing
2.6 Groundwater Sampling and Monitoring	Not part of SOPO
2.7 Laboratory Testing	1.9 Laboratory and Field Testing
2.8 Surface Geophysical Surveys	Not part of SOPO

If you have any questions, please don't hesitate to contact me at (916) 732-6174.

Respectfully,

Scott Flake
Principal Investigator
Senior Director, Project Development

Iowa Hill Pumped-Storage Development Project

Updated Interim Geologic/Geotechnical Data Report

September 2015

SMUD™

Prepared by:

amec

AMEC
180 Grand Avenue, 11th Floor
Oakland, CA 94612

GEI Consultants

GEI Consultants
180 Grand Avenue, 14th Floor
Oakland, CA 94612

JACOBS ASSOCIATES
Engineers/Consultants

Jacobs Associates
1350 Treat Boulevard, Suite 100
Walnut Creek, CA 94597

Distribution

To:	Scott Flake, P.E. Project Director Sacramento Municipal Utility District Clint Schelbert, P.E. Superintendent of Engineering Sacramento Municipal Utility District
From:	Blake Rothfuss, P.E., D.WRE Jacobs Associates
Prepared By:	Todd Crampton, C.E.G. GEI Consultants Christopher Slack, P.G AMEC
Reviewed By:	Mark Havekost, P.E. Jacobs Associates

Revision Log

Revision No.	Date	Revision Description
0-A	April 11, 2014	Internal Draft for Review and Comment
0-B	April 21, 2014	Interim Draft for Review and Comment
0-C	July 3, 2014	Interim Task 1A GDR
0-D	September 30, 2015	Updated Interim GDR
0 (future)		Task 1A DOE Milestone Deliverable

Table of Contents

1 Introduction 1
1.1 Project Description 1
1.2 Purpose and Scope 1
1.3 Project Authorization 2
2 Field Investigation and Laboratory Testing 4
2.1 Previous Studies 4
2.2 Field Investigations 4
2.3 Rock-Core Borings 5
2.3.1 Drilling Equipment 6
2.3.2 Borehole Sampling and Logging 6
2.3.3 Rock Quality Designation 7
2.3.4 Borehole Deviation Surveys 7
2.3.5 Drill Fluid Loss/Gain and Borehole Seepage 8
2.4 Geologic Field Reconnaissance 8
2.5 Downhole In Situ Testing and Geophysical Surveys 9
2.5.1 Packer Testing 9
2.5.2 Hydrojacking Measurements 9
2.5.3 Optical and Acoustic Logging 9
2.6 Groundwater Sampling and Monitoring 10
2.7 Laboratory Testing 10
2.7.1 Rock Core 10
2.7.2 Groundwater 12
2.8 Surface Geophysical Surveys 13
3 Site Conditions 14
3.1 Regional Geology 14
3.2 Geologic Units 16
3.2.1 Lithology 16
3.2.2 Bedrock Discontinuities 17
3.2.3 Discontinuity Characteristics 18
3.2.4 Fracture Frequency and RQD 18
3.2.5 Strength and Weathering 19
3.2.6 Hydraulic Conductivity 20
3.3 Geologic Structures 20
3.3.1 Lineaments 20
3.3.2 Faults 21
3.4 Groundwater 21

3.5 Landslides and Rock Toppling 22
4 Limitations 24
5 References 25

List of Tables

Table 2-1. Summary of Rock Core Borings 6
Table 3-1. Summary of Major Rock Units 16
Table 3-2. Summary of UCS Results 19

List of Figures

Figure 1-1. Project Location Map 28
Figure 1-2. Plan and Profile of Conceptual Project Layout 29
Figure 2-1. Location of Task 1A Borings 30
Figure 3-1. Regional Geologic Map 31
Figure 3-2. Stereonet of Bedding/Foliation Data from Previous Studies 32
Figure 3-3. Stereonet ofJoint Data from Previous Studies 33
Figure 3-4. Stereonet of COBL Discontinuity Data from CH-1 34
Figure 3-5. Stereonet of COBL Discontinuity Data from CH-2 35
Figure 3-6. Stereonet of COBL Discontinuity Data from CH-3 36
Figure 3-7. Stereonet of COBL Discontinuity Data from CH-4 37
Figure 3-8. Stereonet of Bedding/Foliation Data Obtained during Geologic Field Reconnaissance 38
Figure 3-9. Stereonet of Joint Data Obtained during Geologic Field Reconnaissance 39
Figure 3-10. Summary of Fracture Frequency by Boring 40
Figure 3-11. Summary of Fracture Frequency by Rock Unit 41
Figure 3-12. Summary of RQD by Rock Unit for CH-1 42
Figure 3-13. Summary of RQD by Rock Unit for CH-2 43
Figure 3-14. Summary of RQD by Rock Unit for CH-3 44
Figure 3-15. Summary of RQD by Rock Unit for CH-4 45
Figure 3-16. Summary of UCS by Rock Unit 46
Figure 3-17. Summary of Point Load Index Values from GTU 47
Figure 3-18. Summary of Point Load Index Values from Carlton 48
Figure 3-19. Summary of Hydraulic conductivities from Packer Test Results 49

List of Appendices

Appendix A. Drilling Details and Rock Core Logs
Appendix B. Photographs of Rock Core
Appendix C. Packer Test Results
Appendix D. Hydrojacking Data and Results
Appendix E. Optical and Accoustic Televiewer Logs (Prepared by Crux)
Appendix F. Groundwater Analytical Results

List of Appendices (cont'd)

Appendix G. Laboratory Test Data and Results
Appendix H. Summary of Rock Testing Performed by Geo Test Unlimited (Prepared by GTU)
Appendix I. Results of Thin Section Petrographic Analyses (Prepared by Colorado School of Mines)
Appendix J. Upper Reservoir Seismic Refraction Survey (Prepared by NORCAL Geophysical Consultants)
Appendix K. Groundwater Monitoring Reports

THIS PAGE DELIBERATELY LEFT BLANK

1 Introduction

This Updated Geologic/Geotechnical Data Report (GDR) presents data and information obtained from the Task 1A, Task 1B, and Task 1C geotechnical investigations conducted by the Jacobs Associates (JA) Owner's Engineer (OE) Team for the Sacramento Municipal Utility District's (SMUD) Iowa Hill Pumped-Storage Development Project (Project). The geologic and geotechnical data and information presented in this report will be used to support the assessment of the geologic risks of the Project, including conceptual layouts and associated construction approaches, and the overall Project feasibility. Upon the Project moving forward, this GDR will be updated with data and information obtained from subsequent geotechnical investigations and may ultimately serve as a contract document to provide information on the studies performed for the Project.

1.1 Project Description

The Project is adjacent to and directly south of Slab Creek Reservoir, on the South Fork American River, about 6 miles (mi) northeast of Placerville (Figure 1-1). This area is referred to as Iowa Hill, named for a small peak on a ridge top overlooking Iowa Canyon and the South Fork American River canyon, as depicted on the USGS Slate Mountain 7.5-minute quadrangle (see Figure 1). The Project area encompasses part of Slab Creek Reservoir and the adjacent canyon wall and rim of the South Fork American River. The higher topography of the Project area consists of numerous dissected and gently rounded peaks and ridges, with elevations ranging from about 3,040 feet (ft) to 2,800 ft (NGVD 29). From the top of the canyon rim, the steep canyon wall of the South Fork American River descends for over 1,000 ft down to Slab Creek Reservoir. A small, intermittent, west-flowing drainage flows through the Project area and down the canyon wall to the South Fork American River. Numerous other gullies occur on the steep canyon slopes.

As currently proposed, the major elements of the Project include a new dam-impounded Upper Reservoir with a morning glory-type inlet/outlet structure, a concrete-lined vertical shaft extending approximately 1,200 ft down from the bottom of the Upper Reservoir, a high-pressure concrete-lined headrace tunnel about 1,700 ft long, a powerhouse cavern with three variable-speed generating units, and a low-pressure concrete-lined tailrace tunnel about 1,000 ft long, and an inlet/outlet structure within Slab Creek Reservoir (the Lower Reservoir). Appurtenant facilities include a powerhouse access tunnel, a vertical cable and ventilation shaft, a 230kV switchyard proximal to the upper reservoir, a double-circuit 230kV transmission line, and access road improvements. The current Project layout is shown on Figure 1-2.

1.2 Purpose and Scope

The Task 1A field and laboratory exploration programs were carried out to assess the geological and groundwater conditions and engineering properties of subsurface materials in the vicinity of the powerhouse cavern and water conveyance alignments. These exploration programs were done between December 2013 and April 2014. The scope of work for the Task 1A investigations consisted of the following general tasks:

- Reviewing and compiling existing geologic and geotechnical information,
- Drilling, logging, and sampling three exploratory rock-core borings and sampling groundwater,
- Performing in situ testing and geophysical exploration in all boreholes,
- Installation of vibrating wire piezometers in one borehole,
- Developing and coordinating a laboratory testing program, and
- Reporting field exploration and laboratory test results.

The Task 1B field and laboratory exploration programs were carried out to assess the subsurface conditions in the vicinity of the cable shaft and in the Upper Reservoir area. These exploration programs were done between April 2015 and June 2015 and consisted of the following general tasks:

- Drilling, logging, and sampling one exploratory rock-core boring,
- Performing in situ testing and geophysical exploration in the borehole,
- Installation of vibrating wire piezometers,
- Developing and coordinating a laboratory testing program, and
- Reporting field exploration and laboratory test results.

The Task 1C investigations included a seismic refraction survey at the Upper Reservoir site. This work was performed by NORCAL Geophysical Consultants, Inc. (NORCAL) between May 13, 2015 and June 2, 2015.

1.3 Project Authorization

The work described in this GDR was authorized through Task Order 1A and Task Order 1B issued to JA in accordance with their September 29, 2004 Consulting Agreement with SMUD.

1.4 Acknowledgments

The Task 1A, 1B, and 1C studies performed by the OE Team were coordinated with the following key individuals:

<u>SMUD</u>
Mr. Scott Flake, P.E., Project Director
Mr. Clint Schelbert, P.E., Superintendent of Engineering

<u>Jacobs Associates</u>
Dr. Michael McRae, P.E., OE Project Director
Mr. Blake Rothfuss, P.E., OE Project Manager
Mr. Mark Havekost, P.E., Principal
Ms. Rachel Martin, P.E., Associate
Ms. Susan Bednarz, C.E.G., Senior Associate
Mr. John Waggoner, C.E.G., Senior Associate

Carlton Engineering
Mr. David Jermstad, C.E.G., Vice President
Mr. Alan Carlton, P.E., President
Mr. Christopher Trumbull, P.E., Senior Engineer
Mr. Kyle Jermstad, Staff E.I.T II

GEI Consultants
Mr. Alberto Pujol, P.E., Vice President
Mr. Todd Crampton, C.E.G., Senior Geologist

AMEC Environment & Infrastructure
Mr. Christopher Slack, P.G., Project Geologist
Mr. Shaun Cordes, Staff Geologist

2 Field Investigation and Laboratory Testing

Field investigation and laboratory testing programs were developed by SMUD and the OE Team. The completed Task 1A and Task 1B exploration program included a review of available geologic and geotechnical information, geologic field reconnaissance, drilling four (4) rock-core borings, performing in situ testing and downhole geophysical surveys in the boreholes, performing a variety of laboratory tests on materials recovered from rock-core borings, and performing a seismic refraction survey at the site of the Upper Reservoir. The activities completed are discussed below and in the various appendices to this GDR.

2.1 Previous Studies

A review and compilation of existing information was conducted to supplement the field investigations carried out for the Project. The review of available information included a variety of published and unpublished documents. The most relevant information was obtained from the following two reports:

- MWH, 2004, Sacramento Municipal Utility District Upper American River Project (FERC No. 2101), Iowa Hill Pumped Storage Development, Phase II Subsurface Exploration, Geotechnical Investigation Technical Report, August 2004
- Bechtel, 1972, Sacramento Municipal Utility District, Iowa Hill Pumped Storage Project, Preliminary Study, February, 1972

2.2 Field Investigations

The Task 1A field exploration and laboratory testing programs were conducted between December 2013 and June 2014. The field exploration program included the following:

- Drilling, logging, and sampling two (2) subhorizontal rock-core borings totaling about 3,500 ft;
- Drilling, logging, and sampling one (1) vertical rock-core boring totaling about 1,500 ft;
- Installation of 3 vibrating wire piezometers in the vertical borehole;
- In situ testing and geophysical exploration in selected boreholes, including packer permeability testing, hydrojacking testing, and optical televiewer (OPTV) and acoustic (BHTV) logging; and
- Geologic field reconnaissance.

The Task 1B field exploration and laboratory testing programs were conducted between April 2015 and June 2015. The field exploration program included the following:

- Drilling, logging, and sampling one (1) vertical rock-core boring totaling about 1,500 ft;
- Installation of 3 vibrating wire piezometers in the borehole; and
- In situ testing and geophysical exploration in the borehole, including packer permeability testing, hydrojacking testing, and optical televiewer (OPTV) and acoustic (BHTV) logging.

The Task 1C investigations included a surface geophysical survey at the Upper Reservoir site, carried out between May 13, 2015 and June 2, 2015.

An overview of the field exploration and in situ testing programs is described below.

2.3 Rock-Core Borings

The rock core borings were drilled at the locations shown on Figure 2-1. The borings and their lengths included:

- One subhorizontal boring (CH-1) drilled for about 2,000 ft from Chute Camp Road, oriented N49°E to intersect the powerhouse cavern and the strike of the regional rock structure;
- One subhorizontal boring (CH-2) oriented N83°E and drilled for about 1,500 ft along the approximate alignment of the tailrace tunnel from the vicinity of the existing boat ramp for Slab Creek Reservoir;
- One vertical boring (CH-3) drilled for about 1,500 ft from the Upper Reservoir area in the vicinity of the intake shaft, and
- One vertical boring (CH-4) drilled for about 1,500 ft from the downstream toe of the western embankment section of the Upper Reservoir area in the vicinity of the cable shaft.

The boring locations, orientations, and lengths were selected to explore the geologic units in the vicinity of the underground structures. The boring locations were strongly influenced by accessibility, permitting, and safety issues. Some road improvements were required to access the CH-3 drill site.
All boring locations and elevations were surveyed by Carlton upon completion of the drilling. The horizontal coordinates are based on the California State Plane, Zone 2 projection (North American Datum, 1927) and the elevations are based on the North American Vertical Datum (NAVD) of 1929. Table 2-1 summarizes key details of the exploratory borings, including the surveyed coordinates (eastings and northings) and elevations. Additional details of the field exploration and logs of the borings are included in Appendix A of this report. Photographs of the recovered rock core are included in Appendix B.

Table 2-1 – Summary of Rock Core Borings

Designation	Collar Elevation (ft)	Coordinates	Inclination	Azimuth	Length/ Depth (ft)	Date Started	Date Finished
CH-1	1962.80	Northing: 406334.30 Easting: 2373722.57	~10°	N 49°E	2010	12/5/2013	1/30/2014
CH-2	1864.09	Northing: 407329.46 Easting: 2373680.32	~9°	N 83°E	1473	2/12/2014	3/16/2014
CH-3	3056.57	Northing: 407098.12 Easting: 2377099.99	~80°-90°	N/A	1487	12/31/2013	2/16/2014
CH-4	2945.09	Northing: 407570.20 Easting: 2375720.85	~80°-90°	N/A	1458	4/21/2015	5/11/2015

2.3.1 Drilling Equipment

All borings were drilled by Crux Subsurface, Inc. (Crux), of Spokane Valley, Washington. The vertical borings (CH-3 and CH-4) were drilled using a Burly 6500 drill rig equipped with rotary wash and wireline core retrieval systems. Drilling of Ch-3 and CH-4 was initiated using a 31.5 inch (in) tri-cone bit through colluvium and weathered rock to depths of about 20 ft below ground surface (bgs) and 25 ft bgs, respectively. Below these depths, a triple-barrel HQ (2.4 in) core barrel was used. Boring CH-3 was cased to a depth of about 110 ft bgs to prevent severely weathered and fractured rock in the upper part of the hole from collapsing into the borehole and impeding drill circulation.

The subhorizontal borings (CH-1 and CH-2) were drilled using a Burly HTD 10K stationary geotechnical drill rig equipped with rotary wash and wireline core retrieval systems. Drilling was performed using triple-barrel HQ equipment. CH-1 was inclined -9° (downward from horizontal) and CH-2 was inclined -8°. These boreholes were not cased.

2.3.2 Borehole Sampling and Logging

With the exception of the upper 20 ft of CH-3 and the upper 25 ft of CH-4, all of the borings were continuously cored using triple-barrel HQ equipment. The rotating outer HQ barrel with diamond-impregnated bits at its end produces a borehole size of about 3.8 in and a core diameter of about 2.4 in. With the wireline retrieval system, a retriever is lowered by wireline (or pushed with water pressure) through the drill rod to release a locking mechanism in the inner barrel head. The inner barrel containing the core is then lifted with the wireline to the surface, the core is removed, and inner barrel returned to the bottom. Drilling fluid was used to cool the drill bit, to flush the cuttings from the hole, and to provide lateral support to the borehole wall. Core runs of 5 ft or 10 ft were generally made, but the actual length of core runs varied as a function of rock characteristics such as fracturing and weathering. Standard Penetration Test (SPT) drive samples were obtained in CH-3 at depths of about 8.5 ft and 18.5 ft bgs.

Rock logging generally conformed to the Project-specific Subsurface Investigation Manual. In general, the recovered core was logged (i.e., recovery, RQD, weathering, fracturing, strength, hardness, lithologic description, and discontinuity description were recorded on field logs), and stored in sturdy wooden core boxes. The rock core was later photographed (in the core boxes) in Carlton's laboratory. For additional details of the field procedures, refer to the Subsurface Investigation Manual.

2.3.3 Rock Quality Designation

The rock quality designation (RQD) of the recovered core is evaluated by determining the percentage of intact, "competent" core pieces within a run that have lengths greater than 4 inches. This determination can be somewhat subjective, because the "competency" of the recovered core is often based on experience and judgment. Severely weathered and/or intensely fractured rock is not considered in the determination of RQD. In general, rock core that does not easily break apart during handling by the geologist in the field is considered competent. Mechanical breaks are not considered in the determination of intact core pieces. In other words, a 2-ft-long piece of core that is broken into numerous smaller pieces by mechanical breaks would be treated as an intact, 2-ft long piece of core. RQD is summarized as a percentage on the boring logs in Appendix A.

2.3.4 Borehole Deviation Surveys

Downhole (deviation) surveys were performed approximately every 250 ft in boring CH-1. The results indicated the borehole inclination oscillated between upward (flattening) and downward (steepening), with relatively little movement side to side. Inclinations ranged from approximately -6° to -11° (downward from horizontal), with the planned and starting inclination being about -10°. No attempts were made to correct the oscillating inclinations in CH-1.

Downhole surveys also were performed in boring CH-2 at approximately 250-foot intervals. All surveys indicated the borehole trending upward (flattening) until reaching a positive angle (above horizontal) ending at +1.5° at a depth of approximately 1,478 ft bgs. Additionally the borehole trended to the left (north) continuously, ending leftward of start by 17° by the end of the hole. No correction attempts were made in borehole CH-1 based on schedule and performance of corrections in CH-3 (described below). Numerous short core runs were required in CH-1 due to continual plugging of the sampler with rock fragments. This reduced the average recovery rate (feet per day) substantially, especially towards to the bottom of the hole.

During the first downhole survey of boring CH-3 at a depth of about 1,017 ft bgs, the borehole was discovered to have decreased in inclination from 90° (downward from horizontal) to 77°. Crux devised a correction plan using a mud motor to bring the borehole back to vertical (90°), but first had to ream out the entire borehole using the mud motor, which was slightly larger in diameter than the HQ-3 bit used. Upon completion of reaming the borehole, Crux advanced the mud motor with a preset inclination determined by their engineering department for 30 ft before attempting to core again. After coring for 20 ft, the borehole was resurveyed to see if the correction was successful. The survey at 1,067 ft indicated that the boring had become slightly shallower, with an inclination of 76.5° after the correction. Crux preformed a second 30 ft mud motor correction starting at 1,067 ft, which was followed by 20 ft of rock coring and an additional survey. The third survey indicated the borehole inclination had returned to 77°. The overall time required to ream the borehole and perform the two correction attempts was approximately two and a half weeks. Due to schedule constraints, it was decided after the second correction attempt to continue rock coring to the target depth of 1,500 ft without additional correction attempts.

In CH-4, deviation surveys were performed at 100-ft intervals beginning at a depth of about 197 ft bgs. The surveys indicate a decreased inclination down the borehole from 90° to about 67° at the bottom of the hole. The deflection of the borehole was oriented about S40W over a lateral distance (between the top and bottom of the borehole) of about 250 ft. No corrections were attempted in the borehole.

2.3.5 Drill Fluid Loss/Gain and Borehole Seepage

A steady flow of water emanating from the collar of borehole CH-1 was encountered at a depth (along the borehole) of about 218 ft. The max flow during coring was about 20 gallons per minute (gpm), requiring extensive water management onsite. A series of snap tanks (3,000 gallons each) were used to temporarily contain and pre-treat water before spray disposal overland in accordance with the approved RWQCB permit. Loss of drilling fluid circulation never occurred.

In borehole CH-2, drilling fluid loss was observed exiting the slope up to a 3-foot-radius from the borehole collar until a depth (along the borehole) of approximately 37 ft. Drilling fluid return was lost at a depth of 40 feet and not picked up again until 509 ft. Water return was sporadic between this range. Staining in the recovered core indicated groundwater at depths as shallow as approximately 140 ft; however due to small flows and the porous nature of the near surface materials, this along with drilling fluid, was lost. Approximately 1.5 gpm artesian conditions were encountered at a depth of 509 ft, increasing to 8 gpm by 1,030 ft, to 12 gpm by 1,368 ft, and 35 gpm by 1,414 ft. A series of snap tanks (3,000 gallons each) were used to temporarily contain and pre-treat water before spray disposal overland in accordance with the approved RWQCB permit.

2.4 Geologic Field Reconnaissance

Geologic field reconnaissance was performed on various dates by AMEC between April 2014 and June 2014. The reconnaissance was focused on existing cuts along Chute Camp Road and the “Boat Ramp Road”, and other natural exposures within the Project limits. During the reconnaissance, bedding/foliation and joint orientations were mapped and measured using a Brunton compass. Those data are presented on stereonets in Section 3.2.2 of this report.

2.5 Downhole in Situ Testing and Geophysical Surveys

Downhole in situ testing and geophysical exploration was performed in all 3 boreholes. The in situ testing and geophysical exploration included:

- Packer permeability testing;
- Hydrojacking measurements; and
- Digital optical and acoustic imaging of borehole walls.

Packer testing and hydrojacking measurements were performed by field staff from AMEC and Carlton, with assistance from Crux field staff. Optical and acoustic imaging of the boreholes was performed by Crux. Summary descriptions of the procedures are provided below.

2.5.1 Packer Testing

Borehole packer injection tests were conducted in all borings to assess the hydraulic conductivity of the rock mass. These tests involved isolating a section of the borehole with a single packer and injecting water into the test interval either under falling head, constant pressure, or constant flow rate conditions. The tests generally were performed on 10-ft-long test intervals as the boreholes were being advanced. Test intervals were selected based on the rock conditions encountered in the borings. Multiple (stepped) pressure tests were performed in all boreholes, where each pressure step is held constant for 5 minutes and water intake is recorded in 60 second intervals. The pressure steps are: ½ max, ¾ max, max, ¾ max, ½ max.

The packer tests were performed using the procedure outlined in the U.S. Department of the Interior, Bureau of Reclamation Test Designation USBR 7310-89. It should be noted that the test pressures in the subhorizontal/angled borings were estimated without knowing the precise position of the groundwater table above (or below) the testing interval at the time the tests were performed. Limited groundwater elevation data and observations were available to estimate the position of the water table. The data and results of the packer tests are included in Appendix C.

2.5.2 Hydrojacking Measurements

Hydrojacking tests were performed in borings CH-1, CH-3, and CH-4 to assess the minimum in situ stress in the rock. Hydrojacking tests measure the pressure required to open existing fractures by increasing the pressure in the test section in a series of constant-pressure steps, until either hydraulic jacking occurs or the pressure reaches the limits of the equipment. Hydraulic jacking test intervals were selected based on the review from the borehole surveying to insure a fracture was present within the interval. The data and results of the hydrojacking tests are described in Appendix D.

2.5.3 Optical and Acoustic Logging

Digital optical televiewer (OPTV) and/or acoustic televiewer (ATV) logging was performed in all borings to provide information on the orientation, spacing, and aperture of discontinuities in the rock. The logging was performed by Crux, using their Crux Oriented Borehole Logging (COBL) system. Crux post-processed the COBL data to evaluate true orientations of discontinuities in the borehole walls. The results of the OPTV and ATV surveys, including interpreted discontinuities, are presented in Appendix E of this report.

2.6 Groundwater Sampling and Monitoring

Groundwater grab samples were collected from borings CH-1 and CH-2 for water chemistry testing. The groundwater analytical data is provided in Appendix F.

Vibrating wire (VW) piezometers were installed in boreholes CH-3 and CH-4 to monitor groundwater levels. The piezometers were taped to a PVC tremie pipe and grouted in place during the grouting of the borehole. In CH-3, VW piezometers were installed at the following depths bgs: 1,070 ft, 1,280 ft, and 1,480 ft. In CH-4, VW piezometers were installed at depths of 811 ft, 1,101 ft, and 1,341 ft bgs. At the surface, the VW cables are attached to a single data logger to obtain continuous measurements.

In May 2015, a Groundwater Monitoring and Mitigation Plan was implemented for the Project, which includes monthly reporting of groundwater data and observations at and around the Project site. The groundwater measurements include data from the VW piezometers installed in CH-3 and CH-4, and from several additional groundwater monitoring wells that were installed for the Project. The groundwater monitoring reports through July 2015 are included as Appendix K of this GDR.

2.7 Laboratory Testing

Laboratory tests were performed on selected core samples obtained from the boreholes. The laboratory tests measured index properties (such as density) and engineering properties (such as unconfined compressive strength, point load index, and elastic modulus). In addition to these tests, some samples were selected for petrographic (thin section) analysis. Additional details of the laboratory testing program are provided below.

2.7.1 Rock Core

Laboratory tests were performed on selected rock core samples from borings to evaluate their physical characteristics and engineering properties. Rock samples from the Task 1A borings (CH-1, CH-2, and CH-3) were tested by Geo Test Unlimited (GTU) of Swans Islands, ME, for the following characteristics:

- Unit weight
- Unconfined compressive strength (with and without modulus determination)
- Direct shear strength (undrained)
- Brazilian indirect tension
- Cerchar abrasivity
- Point load index (also performed by Carlton)

Rock samples from the Task 1B boring (CH-4) were tested by the Colorado School of Mines (CSM) for the following characteristics:

- Unconfined compressive strength (with and without modulus determination)
- Direct shear strength (undrained)
- Brazilian indirect tension
- Cerchar abrasivity

Additionally, point load index testing of selected samples from CH-4 was performed by Carlton.

Procedures for the tests are briefly described below. The laboratory test results are summarized in Tables G-1 through G-3 in Appendix G of this report; the test locations (and type) are shown on the boring logs in Appendix A. The laboratory test data and results also are presented boring-by-boring in tabular and/or graphic form in Appendix G of this report. Appendix H includes a report prepared by GTU that summarizes the results of the rock testing performed by GTU.

In addition to the laboratory tests listed above, thin section petrographic analyses were performed by CSM on selected core samples from all borings. The summary reports prepared by CSM are included as Appendix I of this report.

Unit Weight

Unit weight (density) was determined for selected core samples recovered from the borings. These determinations were conducted on samples that were designated and prepared for UCS and Brazilian Indirect Tension testing. The results of these determinations are summarized in Table G-1.

Unconfined Compressive Strength

Unconfined compressive strength (UCS) is a basic parameter of rock strength. UCS tests were performed on selected core samples in accordance with ASTM Test Method D 2938. UCS tests in which the elastic modulus was measured were performed in general accordance with ASTM Method D 3148. The results of these tests are summarized in Table G-1.

Direct Shear

Direct shear tests were performed to assess the shear strength of selected core sample discontinuities. The tests were performed according to ASTM Method D 5607. Results of the direct shear tests are summarized in Table G-1.

Brazilian Indirect Tension

Indirect (Brazilian) tension tests provide a measure of rock toughness, as well as strength. These tests were performed on selected rock samples in accordance with ASTM Test Method 3967. Test results are summarized in Table G-1 of this report.

Cerchar Abrasivity

Cerchar abrasivity index (CAI) tests were performed on selected rock core samples to measure rock abrasivity. The test involves a series of sharp pins of heat-treated alloy steel that are pulled across a freshly broken and prepared surface of the rock specimen. Results of the CAI tests are summarized in Table G-1.

Point Load Testing

Point load tests were performed on selected bedrock samples from all borings in accordance with ASTM Test Method 5731. The point load test involves placing a piece of rock core between two conical platens, measuring the diameter of the test sample, and applying pressure with a hydraulic jack until the sample fails (i.e., breaks). Both diametral and axial tests were performed. Typically, a diametral test was first performed with any observed bedding or foliation parallel to the plane passing through the tip of the platens. This test typically produced a disc of rock that was then used for the axial test, which was done approximately perpendicular to the foliation/bedding. Tests are considered invalid if the rock failure surfaces only passed through one of the loading points, as described in ASTM D 5731. The calculated Point Load Strength Index for each test sample was size-corrected, and the compressive strength was estimated, following the procedures described in ASTM D 5731. The results of the point load tests are summarized in Tables G-2 and G-3.

2.7.2 Groundwater

Laboratory tests were performed on groundwater samples collected by Carlton on March 16, 2014 from boreholes CH-1 and CH-2. The samples were collected in laboratory-supplied containers and transported under chain-of-custody procedures to California Laboratory Services (CLS) in Rancho Cordova, California, a California Environmental Laboratory Accreditation Program (ELAP) certified analytical laboratory. CLS analyzed the groundwater samples for selected inorganic constituents according to the following U.S. Environmental Protection Agency (EPA) methods or equivalent methods:

- Chloride, fluoride, nitrate as nitrate, and sulfate by EPA Method 300.0;
- Alkalinity (bicarbonate, carbonate, hydroxide, and total as calcium carbonate (CaCO3)) by Standard Method (SM) 2320B;
- Color by SM2120B
- Specific conductance by EPA Method 120.1;
- Methylene Blue Active Substances (MBAS) as Linear Alkylbenzene Sulphonates (LAS) by SM5540 C;
- Calcium, iron, magnesium, potassium, sodium, and hardness as CaCo3 by EPA Method 200.7;
- Odor by EPA Method 140.1
- pH by EPA Method SM4500-H B;
- Total dissolved solids by SM2540C;
- Turbidity by EPA Method 180.1; and
- Drinking water metals by EPA Methods 200.7/200.8/245.1

Analyses were performed as requested on the chain-of-custody forms. The full report from CLS is included in Appendix F. Results of the groundwater analytical program are summarized in Tables F-1 and F-2 in Appendix F.

2.8 Surface Geophysical Surveys

A geophysical survey at the Upper Reservoir was performed by NORCAL Geophysical Consultants (NORCAL) between May 13 and June 2, 2015. The survey included both seismic refraction and multichannel analysis of surface waves (MASW) surveys. This program included 14 traverses in a gridded pattern across the footprint of the Upper Reservoir, totaling over 26,000 lineal ft. The MASW surveys were performed along portions of two traverses, with each MASW line totaling about 1,200 ft. The complete report by NORCAL is included as Appendix J of this GDR.

3 Site Conditions

This section summarizes the regional and site geology of the Project area, based on the results of the Task 1A and 1B field and laboratory exploration programs and our review of existing relevant geologic and geotechnical information.

3.1 Regional Geology

The Project is in the western foothills of the north-central Sierra Nevada, a broad north-northwest-trending range that extends for over 400 miles in eastern California. The range is cored by a westward-tilted block of granitic and metamorphic rock that forms a gentle western slope and a steep eastern slope with several prominent escarpments. The geology of the north-central Sierra Nevada is complex, reflecting a long and diverse geologic history. Much of the western flank is composed of Paleozoic and Mesozoic metamorphic rocks that extend westward beneath the sediments of the Great Valley and represent the vestiges of island arc terranes that were accreted to the North American continent along ancient subduction zones. The higher parts of the Sierra Nevada are predominantly composed of Mesozoic granitic rocks that intruded the older Mesozoic and Paleozoic rocks during the late Jurassic to Late Cretaceous Nevadan orogeny. Tertiary volcanic flows and volcaniclastic rocks overlie the granitic and metamorphic rocks throughout the central and northern parts of the range, forming broad, concordant divides between the major west flowing rivers.

The oldest rocks in the region are the Paleozoic and Mesozoic accreted terranes exposed in the central and northern Sierra Nevada. These rocks, which are collectively referred to as the western metamorphic belt (e.g., Bateman and Wahrhaftig, 1966), form relatively continuous, northwest-trending bands of metamorphic rock units that typically are bounded by ancient, east-dipping faults. Primary bedding and foliation within the metamorphic rocks generally strikes north-northwest, parallel to the trend of the belt, and dips steeply to the east. Isolated masses of Sierran granitic rocks are exposed within the western metamorphic belt throughout the region, particularly in the northern part of the range (Jennings, 1977; Wagner and others, 1981). The local intrusive rocks are sometimes considered to be rooted in the magma chambers for the ancient Sierran volcanic arcs, whereas others are outliers of the larger Sierran batholith. Numerous igneous dikes from these intrusive bodies also are injected into the western metamorphic belt, particularly near its eastern margin.

The Paleozoic terranes in the region include metasedimentary and metavolcanic rocks of the Upper Paleozoic Calaveras Complex and the Lower Paleozoic Shoo Fly Complex. These rocks are strongly metamorphosed in places. The Calaveras Complex typically consists of dark gray phyllite and schist and interbedded chert, with subordinate interbedded mafic and intermediate volcanic rocks and sparse lenses of carbonate rock (Clark, 1976). The Shoo Fly Complex consists of a lower member that consists largely of slate and phyllite, and an upper member consisting largely of quartz-rich graywacke, slate, and quartzite (Clark, 1976). Subordinate rocks in the Shoo Fly Complex include thin-bedded chert, mafic volcanic rocks, and calcarenite, with local occurrences of dolomitic limestone (Clark, 1976). The Paleozoic terranes are separated by the east-dipping Calaveras-Shoo Fly Thrust fault, which juxtaposes the older Shoo Fly Complex on the east over and against the younger Calaveras Complex on the west. The Calaveras-Shoo Fly Thrust fault locally is marked by slivers of Jurassic-age gabbroic and ultramafic rock. The Paleozoic terranes were initially deposited in an island arc setting near what was then the western margin of the North American continent (Harden, 1998). They were accreted to the North American continent during various phases of subduction beginning in the early Devonian and culminating with the early Triassic Sonoma orogeny (Harden, 1998). In the Project area, the Shoo Fly Complex is bordered on the east by granitic rocks of the Sierra batholith; the western boundary of the adjacent Calaveras Complex generally is marked by the Melones fault zone and younger Mesozoic terranes to the west (Jennings, 1977; Wagner and others, 1981).

West of the Melones fault zone, a series of younger Mesozoic terranes represent island arc deposits that were subducted beneath the North American continent during the Mesozoic era. This period of subduction produced an arc of active Andean-type volcanoes located in the approximate position of the present-day Sierra Nevada (Harden, 1998). The accreted Mesozoic terranes are collectively referred to as the Foothills Terrane (Harden, 1998). The Foothills Terrane consists of several fault-bounded, northwest-trending bands and slivers of metasedimentary and metavolcanic rocks, including slices of the older Paleozoic metamorphic rocks. Many faults in the Foothills Terrane are accentuated by large slices of ultramafic rock that were emplaced during Mesozoic subduction. The faults within the Foothills Terrane are collectively referred to as the Foothills Fault System and include the Melones fault zone to the east, and the Bear Mountains fault zone to the west. Parts of these fault zones are considered to be potentially-active by the California Geological Survey (Jennings and Bryant, 2010).

The Project area is located within the Lower Paleozoic Shoo Fly Complex (Clark, 1976; mapped as “Paleozoic (?) Metasedimentary Rocks Undifferentiated” by Wagner and others, 1981), about 7 miles east of the Melones fault zone (Figure 3-1). Wagner and others (1981) indicate these rocks consist predominantly of quartzite and schist, with minor limestone and dolomite, and augen gneiss of uncertain age. Less than 1 mile to the west of the Project area and directly downstream of Slab Creek Dam, a small (about 5 miles in maximum dimension), Mesozoic granitic pluton is mapped within the older Paleozoic terrane. MWH (2004) reported that small granitic outcrops occur along Chute Camp Road and the access road to Slab Creek Dam. The western margin of the pluton is about 5 miles west of the Project and roughly coincident with the projection of the Calaveras-Shoo Fly Thrust fault, based on the mapped location of the fault directly north and south of the pluton. A thin sliver of the Calaveras Complex is mapped between the pluton and the Melones fault zone.

In addition to the Melones fault zone and the Foothills Fault System, there are numerous other active and potentially-active faults mapped in the region. The closest known active fault to the Project is the West Tahoe fault, about 34 miles to the east. Several other active faults occur in this area of the eastern Sierras, including the Genoa fault to the south and the Polaris fault to the north. The closest known potentially-active fault is the Rescue fault in the Bear Mountains fault zone, about 14 miles to the west. For reference, the historically-active San Andreas fault, which is the most active fault in the region, lies 124 miles to the west.

3.2 Geologic Units

This section describes the physical characteristics of various rock units encountered in the Project area, based on existing information and on field explorations performed during the Task 1A and Task 1B studies.

3.2.1 Lithology

Bedrock at the Project site is mapped as Paleozoic-age Shoo Fly Complex, which typically consists of variably metamorphosed marine sedimentary rocks with minor volcanic rocks. Previous explorations at the site by Bechtel (1972) and MWH (2004) identified the primary bedrock lithologies as phyllite and metasandstone (greywacke) or quartzite. Based on the rock core encountered in the Task 1A and Task 1B borings and the results of petrographic analyses on selected core samples, bedrock at the site can be subdivided into five major rock units as summarized below in Table 3.1.

Table 3-1. Summary of Major Rock Units

Rock Unit	Rock Description
Meta-wacke	A metamorphosed, indurated greywacke (sandstone) with partial recrystallization and linear realignment of grains displaying weak foliation.
Phyllite	A foliated rock that is intermediate in metamorphic grade between slate and schist and exhibits a dull metallic luster along foliation/bedding caused by the recrystallization and secondary growth of microcrystalline micas from the pelitic protolith. The phyllite occasionally contains graphite metamorphosed from organic material that appears as darker interbeds and readily leave a streak. The phyllite exhibits low tensile strength perpendicular to bedding/foliation surfaces. May appear more “slatey” or “schistose” locally.
Quartzite	Very hard, nonfoliated, metamorphosed quartz-rich sandstone. Rock matrix is typically granoblastic and has the appearance of secondary cementation.
Marble (and Dolomitic Marble)	A metamorphosed limestone that contains a microcrystalline to crystalline calcium carbonate matrix and occasional partial to full calcite rhombohedral porphyroblasts. The marble effervesces readily with hydrochloric acid, whereas the dolomitic marble does not.
Dike Rock	Composed of quartz, plagioclase feldspar, altered hornblende (?) laths, and (biotite) mica. Generally cuts other units obliquely to regional foliation/bedding and has been subsequently altered by hot fluids. Texturally similar to intrusive granitic rocks.

Quartz and calcite veins were common throughout all borings and within all rock units. Quartz veins contain occasional pyrite and trace amounts of calcite. In some cases, veins were greater than 3- inches thick and contained both pyrite and calcite. Such veins are easily distinguishable in the optical COBL data for CH-1 and CH-2 (See Appendix E). Other minor rock units include local occurrences of slate, schist, and hornfels.

3.2.2 Bedrock Discontinuities

Bedrock discontinuities at the site predominantly include bedding planes, foliation, and joints. Bedding was observed in the rock core typically as thin (1- to 4-inch-thick) interbeds between alternating rock units throughout the borings. Bedding was generally planar, but in some cases was wavy and convoluted, possibly due to soft-sediment deformation or disturbance when the beds were originally deposited.

Foliation is sheet-like planar fabric in rock resulting from regional shearing during metamorphism and the associated segregation and reorientation of minerals. Foliation also can be described as a “preferred orientation” in the rock, and typically it behaves as a plane of weakness. Foliation was observed in phyllite, meta-wacke, and in some instances slight foliation occurred within dikes as mafic (dark colored) mineral alignments, which typically appeared with approximately the same dip angle as foliation within the phyllite. The foliation generally is subparallel to bedding, often making it difficult to differentiate between the two.

As part of this study, available discontinuity data (bedding/foliation and joints) from the previous studies (i.e., Bechtel, 1972 and MWH, 2004) was compiled and plotted on the stereonets presented in Figures 3-2 and 3-3. The bedding/foliation data plotted on Figure 3-2 show a dense cluster of poles in the west-southwest quadrant, indicating the dominant bedding/foliation orientation strikes northwest and dips steeply to the northeast. These data also show a relatively weaker cluster of poles in the southwest quadrant that indicate a second, less dominant orientation, striking northwest and dipping moderately to the northeast. The joint data shown in Figure 3-3 generally are scattered and show no well-defined joint sets. A weakly developed set may be interpreted from the data, striking northeast and dipping moderately to steeply to the northwest. Other random joints are evident from these data, including both steeply- and gently-dipping joints with variable strikes.

During the field investigations, discontinuities were identified and measured during the field reconnaissance and while logging rock core, with the use of supplemental COBL data upon completion of the boreholes. While logging, only the dip angle of a discontinuity was measured in the rock core; the COBL data obtained oriented discontinuities from optical and acoustic images of the borehole walls. These data were tabulated for each boring and plotted on the stereonets shown in Figures 3-4 through 3-7.

Based on the stereonets from the COBL data, foliation/bedding is the dominant discontinuity encountered in each boring. The stereonets all show a dense cluster of poles in the southwest quadrant, reflecting the predominance of northwest-striking planes with steep dips to the northeast. The average foliation/bedding orientation from each boring is as follows:

- CH-1: N36°W, 78° NE (Figure 3-4)

- CH-2: N21°W, 78° NE (Figure 3-5)
- CH-3: N24°W, 66° NE (Figure 3-6)
- CH-4: N28°W, 76° NE (Figure 3-7)

The average bedding/foliation orientations from the COBL data are in good agreement with the data from the previous studies shown in Figure 3-2.

The stereonets for CH-2, CH-3, and CH-4 (Figures 3-5, 3-6, and 3-7) also shows a weak cluster of poles in the southeast quadrant, reflecting a less prominent set of discontinuities (likely joints) striking northeast and dipping moderately to gently to the northwest. Other, apparently randomly oriented discontinuities can be seen in all of the stereonets. These “random” joints have gentle to steep dips in variable directions.

Bedding/foliation and joint data obtained during the field reconnaissance are presented on Figures 3-8 and 3-9, respectively. The bedding/foliation data are in good agreement with the COBL data and the bedding/foliation data from the previous studies. The joint data shows a cluster of poles in the southeast quadrant, reflecting a northeast-striking, moderately- to steeply-dipping joint set. This joint set also appears to be reflected in the COBL data for CH-2, CH-3, and CH-4 (Figures 3-5, 3-6, and 3-7) and in the joint data from the previous studies (Figure 3-3).

3.2.3 Discontinuity Characteristics

As shown on the borehole logs, the characteristics of the joints and shears encountered in the boreholes were described according to the following attributes: dip of feature, feature type, aperture, infilling type, infilling amount, and surface roughness. Where similarly oriented joints were present, the joint spacing was also noted.

Discontinuities logged in the field generally include joints and shears. Foliation/bedding was generally pervasive throughout the rock core and frequent mechanical breaks of the core typically formed along these planes. In most instances, foliation and bedding did not form open partings in the rock, thus the vast majority of discontinuities logged in the field were joints and shears.

Based on the descriptions shown on the logs in Appendix A, most discontinuities were narrow to moderately wide, planar, and smooth to slightly rough with no infilling. In many places the discontinuities were tight, healed, undulating, or irregular. Few joints/shears were slickenside, stained or infilled with iron oxide. Many joints are healed or infilled with quartz or calcite.

3.2.4 Fracture Frequency and RQD

Fracture frequency was compiled from the rock core logs and is summarized by boring and rock unit on Figures 3-10 and 3-11, respectively. In general, the rocks are not highly fractured, with the vast majority of the core exhibiting a fracture frequency of less than 1 fracture per foot. The percentage of core with greater than 1 fracture per foot is as follows:

- CH-1 = 37%

- CH-2 = 41%
- CH-3 = 14%
- CH-4 = 19%

In all four borings, less than 10% of the core had more than 2 fractures per foot.

RQD also was compiled from the core logs and is summarized by lithology for each boring in Figures 3-12 through 3-15. The majority of the rock has an RQD value of 80 to 100, which is considered good to excellent.

3.2.5 Strength and Weathering

Based on the results of UCS and point load index tests (see Appendix G), the rocks encountered in the exploratory borings generally can be classified as medium strong to very strong. Of 91 total samples submitted for UCS testing, only two samples had a strength of less than 3,800 psi. The other 89 samples ranged from 3,872 psi to 34,748 psi, and averaged 16,266 psi. Table 3-2 summarizes the UCS results by boring and rock unit. Figure 3-16 presents a histogram of average UCS values by rock unit.

Table 3-2. Summary of UCS Results

CH-1	**Range (psi)**	**Average (psi)**
Phyllite (n=7)	3,872-17,212	11,641
Metawacke (n=18)	6,213-32,595	20,409
Quartzite (n=7)	9,781-34,748	23,932
Marble (n=3)	5,597-22,837	13,002
CH-2	**Range (psi)**	**Average (psi)**
Phyllite (n=2)	10,658-13,001	11,830
Metawacke (n=15)	7,026-33,530	19,756
Marble (n=5)	12,224-32,655	19,939
Quartzite (n=1)	3,216	3,216
CH-3	**Range (psi)**	**Average (psi)**
Phyllite (n=1)	2,612	2,612
Metawacke (n=16)	5,067-17,808	10,906
Marble (n=2)	7,890-12,267	10,079
CH-4	**Range (psi)**	**Average (psi)**
Phyllite (n=3)	4,608-9,444	6,553
Metawacke (n=7)	4,437-21,873	11,153
Marble (n=2)	10,482-10,510	10,496
Quartzite (n=2)	28,469-30,751	29,610

Carlton performed 223 point load tests and GTU performed an additional 103 tests. There were 12 outlier values in the Carlton data set, with point load index values greater than 2,000 psi. The average point load strength index (Is50) values are shown by rock unit on Figure 3-17 (GTU data) and Figure 3-18 (Carlton data, excluding the outlier values). Uniaxial compressive strengths (UCS) also were estimated from the point load index values, using an average correlation factor of 22.5. The estimated UCS values generally spanned a larger range than those derived from the UCS tests. Excluding the outlier values, the UCS values estimated from the point load index values are generally in good agreement with the laboratory-derived UCS values for each boring. The point load test data and estimated UCS values are summarized boring-by-boring in Tables G-2 and G-3 in Appendix G.

The results of the seismic refraction survey and the available boring data (both Project borings and existing borings) indicate a deep weathering profile in the Upper Reservoir area. The borings indicate severe to very severe weathering, with locally decomposed rock conditions, extends to depths (bgs) of about 70 ft to 100 ft. Moderate to slight weathering generally extends to depths of about 170 ft to190 ft. Below 190 ft, the rock is generally unweathered, except for isolated zones of more intensely fractured rock. The seismic refraction survey yielded P-wave (Vp) velocities ranging from about 1,000 ft/s to 9,000 ft/s. These velocities generally increase with depth and correlate well with observations of weathering in the borings. The seismic refraction profiles indicate deeper weathering across ridge tops, and shallower weathering in drainages, likely owing to erosion of the more weathered materials.

3.2.6 Hydraulic Conductivity

The results of packer and hydrojacking tests indicate the rocks exhibit low hydraulic conductivity, ranging from about 10^{-6} to 10^{-7} centimeters per second. Figure 3-19 shows a summary of the hydraulic conductivities estimated from packer test results.

During drilling, boreholes CH-1 and CH-2 encountered localized fracture zones of sufficient conductivity that artesian groundwater backpressure and flow developed. Based on observations of the core, the high conductivity zones appear to contain high angle, open fractures.

3.3 Geologic Structures

This section describes additional available data and evidence for regional geologic structures in the Project area, including potential shear zones and faults.

3.3.1 Lineaments

Lineament mapping was performed by MWH (2004) using stereo pairs of historical black and white aerial photographs. In addition to NW-trending lineaments controlled by the regional foliation/bedding, two sets of lineaments were observed by MWH (2004). One “set” of lineaments was trending about N70°W and the other about N60°E to N70°E. These features were reported to correspond to “principal regional joint orientations”; however, no orientations (i.e., strike and dip) were reported. No obvious shears or faults were identified by MWH (2004).

Carlton (2012) also mapped “linears” and “topographic linears” using a LiDAR-generated topographic map. A “prominent topographic linear” was mapped along the axis of the drainage that flows through the Project site. This feature cuts across the regional structural trend the metamorphic bedrock, with one section of the drainage in the upper reservoir area trending east-northeast (about N65°E) and the other section of the drainage on the canyon wall trending west-northwest (about N65°W). Carlton’s map also showed numerous short, discontinuous linears in multiple orientations on the steep canyon slopes. The prominent topographic linear mapped by Carlton has similar trends to the two sets of lineaments reported by MWH (2004), which are thought to correspond to regional joint orientations.

AMEC (JA and AMEC, 2014) performed analysis of Project LiDAR data and noted various lineaments across the Project site. AMEC noted that in most cases, the lineaments were controlled by regional bedding/foliation or systematic joints. In a few cases, lineaments were associated with debris-flow margins.

3.3.2 Faults

There are no faults mapped in the Project area; however, Bechtel (1966) mapped several shear zones in the foundation for Slab Creek Dam. One prominent, steeply-dipping shear zone was mapped near the axis of the river channel. This feature was marked by about 2 inches of talcose gouge and 6 inches of broken schist and quartz in the foundation excavation. The attitude of the shear zone was recorded as N40°E, 85°E and it was mapped over a distance of about 100 ft. According to MWH (2004), this shear zone was reported by Bechtel (1968) to be “relatively impermeable and strong below foundation grade”. We note that this shear zone, if projected to the north along strike, would not intersect the Project.

MWH (2004) reported a 4-inch-wide gouge zone in Boring B-2A at a depth of about 1,148 ft. The gouge marked the beginning of what MWH termed “an interval of ancient faulting” that extended down to a depth of 1,165 ft. Minor offsets of the bedrock were noted in this interval, but, with the exception of the gouge zone, all were rewelded and overall the rock was hard and strong. No other shear zones or faults have been noted in the existing Project reports.

In borings CH-1 and CH-2, mylonitic textures and zones of brecciated rock were encountered in multiple intervals. Some of the mylonitic zones exceeded 10 feet in thickness and were accompanied by large quantities of graphite, quartz and calcite veins, and quartz porphyroblasts up to 1 inch in size. These zones often were interbedded with phyllite. In CH-4, a 1½-ft-thick shear zone was identified at a depth of about 890 ft bgs. This zone was characterized by slickensided fractures within a thick bed of metawacke.

3.4 Groundwater

Prior to the Task 1B investigations, there were sparse available data regarding the groundwater conditions at the Project site. MWH (2004) reported groundwater in Boring B-1, at the level of Slab Creek Reservoir, and boring B-2A encountered local wet zones, suggestive of seasonally perched groundwater.

No mention of groundwater was made by Bechtel (1972), but they did map a small spring near the top of the canyon wall in the drainage that flows through the Upper Reservoir site. Flow from the spring was estimated at 2-3 gpm. Bechtel (1972) reported that water take generally was high in their borings, ranging from about 0.6 to 1.3 gpm per foot of borehole tested at 30 psi. Drill hole DH-1 reportedly was tight from 49 to 60 feet at 60 psi, but the rock was intensely weathered and clayey. Bechtel (1972) noted that their downhole testing and estimated water takes may not be representative of less weathered rock at greater depths.

Key observations of groundwater made during the Task 1A and 1B field investigations include the following:

- Stabilized groundwater levels between 90 and 110 ft bgs were measured in CH-3 at the beginning of each day as coring and testing progressed.
- Back pressure at the collar of CH-1 was measured after the encountering artesian flow from a fracture at a depth (along the borehole) of about 240 ft. Artesian flow was packered off between drilling shifts and measured at the collar throughout the drilling operations with pressures ranging from 10 to 15 psi. The back pressure indicates an equivalent groundwater head of approximately 20 to 30 feet at the collar elevation 1,963 ft.
- Groundwater pressure for the completed borehole CH-1 generally stabilized at 25 psi (~60 ft) at the collar.
- Back pressure at the collar of CH-2 was measured after the encountering artesian flow from a fracture at a depth (along the borehole) of about 580 ft. Artesian flow was packered off between drilling shifts and measured at the collar throughout the drilling operations with pressures ranging from 10 to 25 psi. This back pressure indicates an equivalent groundwater head of approximately 20 to 50 feet at the collar elevation 1,864 ft.
- Groundwater pressures for the completed borehole CH-2 generally stabilized at 30 psi (70 ft).
- A groundwater spring was observed on the boat ramp road, approximately mid-way between CH-1 and CH-2. The spring is located on the east side of the boat ramp road and is largely captured and conveyed through a CMP under the road; however, a portion of the flow continues down the road bypassing the CMP. Flows out of the CMP were estimated to be about 1 to 5 gpm.
- Another groundwater spring was observed at the end of the boat ramp road, below CH-1 in an ephemeral drainage. This spring fluctuated in flow from less than 1 gpm to approximately 2 gpm.
- Stabilized groundwater levels between 164 and 195 ft bgs were measured in CH-4 throughout the drilling.

As previously mentioned, a Groundwater Monitoring program was implemented at the site in May 2015. Data from this program indicates groundwater levels in CH-3 have steadily decreased between April 2014 and July 2015, with the shallowest VW sensor (which measures water pressure) indicating a drop from about 187 ft bgs to about 199 ft bgs. In CH-4 a similar decreasing trend was measured between June 2015 and July 2015, with groundwater levels decreasing from about 235 ft bgs to about 257 ft bgs. Other monitoring wells across the site indicate groundwater levels ranging from as shallow as about 25 ft to 85 ft bgs. Additional groundwater observations can be found in the Groundwater Monitoring Reports in Appendix K of this GDR.

3.5 Landslides and Rock Toppling

Bechtel (1972) and MWH (2004) both mapped relatively small, shallow bedrock landslides on the steep slopes directly above Slab Creek Reservoir in an area to the north of the proposed inlet/outlet structure. Bechtel (1972) mapped these slides as separate features; however, MWH (2004) mapped them as part of a single, nested complex. Based on the geometry of the slides and their apparent movement oblique to the overall canyon slope, MWH speculated that the slides may originate within a “specific package of geologic strata”. MWH (2004) noted planar joints within and parallel to the headscarp, in quartzite bedrock. Rock toppling was postulated as a possible cause of the landsliding.

Carlton (2012) mapped numerous landslides on the canyon slopes in the vicinity of the Project using a detailed topographic map derived from bare earth LiDAR data. The slides are as much as 600 ft wide (across the slope) and 900 ft long (parallel to the slope), with several extending from the canyon rim down to Chute Camp Road. One landslide area in the northern part of the Project area is labeled as “Toppled PZCC”, which indicates toppled Paleozoic bedrock. That label also appears at one other location on the map, at the top of the canyon slope where foliation exhibits a 15° northeasterly dip. Geologic mapping by the previous workers indicates that bedding and foliation of the metamorphic bedrock is not everywhere dipping steeply to the northeast. In some places, flatter northeast dips occur and in other places southwest dips are observed. These variations in dip are generally attributed to toppling, a gravitational phenomenon that affects bedrock with steeply-dipping strata or discontinuities near the ground surface, typically on steep slopes. Toppling occurs when steeply-dipping rock columns or strata rotate out of slope, usually under their own weight, and either slowly or rapidly become detached from the underlying or adjacent rock mass and move downslope. MWH (2004) reported that on steeper slopes in the Project area, significantly toppled bedrock extends to a depth of about 20 to 30 ft bgs and “somewhat” toppled rock extends to depths of 50 to 60 ft bgs. In the upper reservoir area, MWH (2004) reported “possibly toppled” rock to a depth of about 30 to 40 ft bgs, with “some toppling effects” extending to depths of 50 to 60 ft bgs.

The stereonet data presented in Section 3.2.2 of this report indicates that both plane sliding and wedge sliding also are kinematically feasible in the Project area. The systematic nature of the bedding/foliation and joints creates blocks and wedges that locally dip out of the slope, making it kinematically possible for such failures to occur. During the geologic field reconnaissance, numerous block and wedge failures of varying sizes were observed in the bedrock cuts and natural slopes along Chute Camp Road and in the road leading down to the boat ramp. These observations suggest that the larger failures (landslides) identified on the slopes above Slab Creek Reservoir may also be, at least in part, controlled by plane or wedge sliding along the bedrock discontinuities.

AMEC (JA and AMEC, 2014) performed a preliminary bedrock structural analysis for the Project based on field mapping data and analysis of LiDAR images. Refer to that document for additional discussions and interpretations of bedrock structure and slope failure mechanisms in the Project area.

4 Limitations

In the performance of its professional services, the OE Team, its employees, and its agents comply with the standards of care and skill ordinarily exercised by members of our profession practicing in the same or similar localities. The information presented in this report was collected to support the conceptual design of the Project. This report may not provide all of the information needed to construct the Project. No warranty, either express or implied, is made or intended in connection with the work performed by us, or by the proposal for consulting or other services, or by the furnishing of oral or written reports or findings. In the event conclusions or recommendations based on these data are made by others, such conclusions and recommendations are not our responsibility unless we have been given an opportunity to review and concur with such conclusions or recommendations in writing.

5 References

Bateman, P.C. and Wahrhaftig, C., 1966, Geology of the Sierra Nevada, California: in Bailey, E.H., *ed*., Geology of Northern California, California Division of Mines and Geology Bulletin 190, p. 107-172.

Bechtel, 1972, Sacramento Municipal Utility District, Iowa Hill Pumped Storage Project, Preliminary Study, February, 1972.

Bechtel, 1966, Slab Creek Dam Geology, miscellaneous drawings: Sacramento Municipal Utility District. Upper American River Project, drawings dated February, 1966 and Issued for Record Drawings in February, 1972.

Carlton Engineering, Inc., 2012, Upper American River Project, FERC Project No. 2101, Sacramento Municipal Utility District, Iowa Hill Pumped Storage Hydroelectric Project, Geotechnical Investigation Plan, April 2012.

Clark, L.D., 1976, Stratigraphy of the North Half of the Western Sierra Nevada Metamorphic Belt, California: US Geological Survey Professional Paper 923.

Harden, D.H., 1998, *California Geology*: Prentice Hall, Inc., 479 p.

Jacobs Associates and AMEC, 2014, Geologic Mapping and Bedrock Structural Analysis, Iowa Hill Pumped-Storage Development Project: prepared for Sacramento Municipal Utility District, August 2014.

Jennings, C.W., 1977, Geologic Map of California: California Division of Mines and Geology, California Geologic Data Map Series Map No. 2, scale 1:750,000.

Jennings, C.W., and Bryant, W.A., 2010 Fault Activity Map of California: California Geological Survey, Geologic Data Map No. 6, online version available at: http://www.quake.ca.gov/gmaps/FAM/faultactivitymap.html

MWH, 2004, Sacramento Municipal Utility District Upper American River Project (FERC No. 2101), Iowa Hill Pumped Storage Development, Phase II Subsurface Exploration, Geotechnical Investigation Technical Report, August 2004.

Wagner, D.L., Jennings, C.W., Bedrossian, T.L., and Bortugno, E.J., 1981, Geologic Map of the Sacramento Quadrangle: California Division of Mines and Geology, Regional Geologic Map Series Map No. 1A (Geology), scale 1:250,000.

Figures

THIS PAGE DELIBERATELY LEFT BLANK

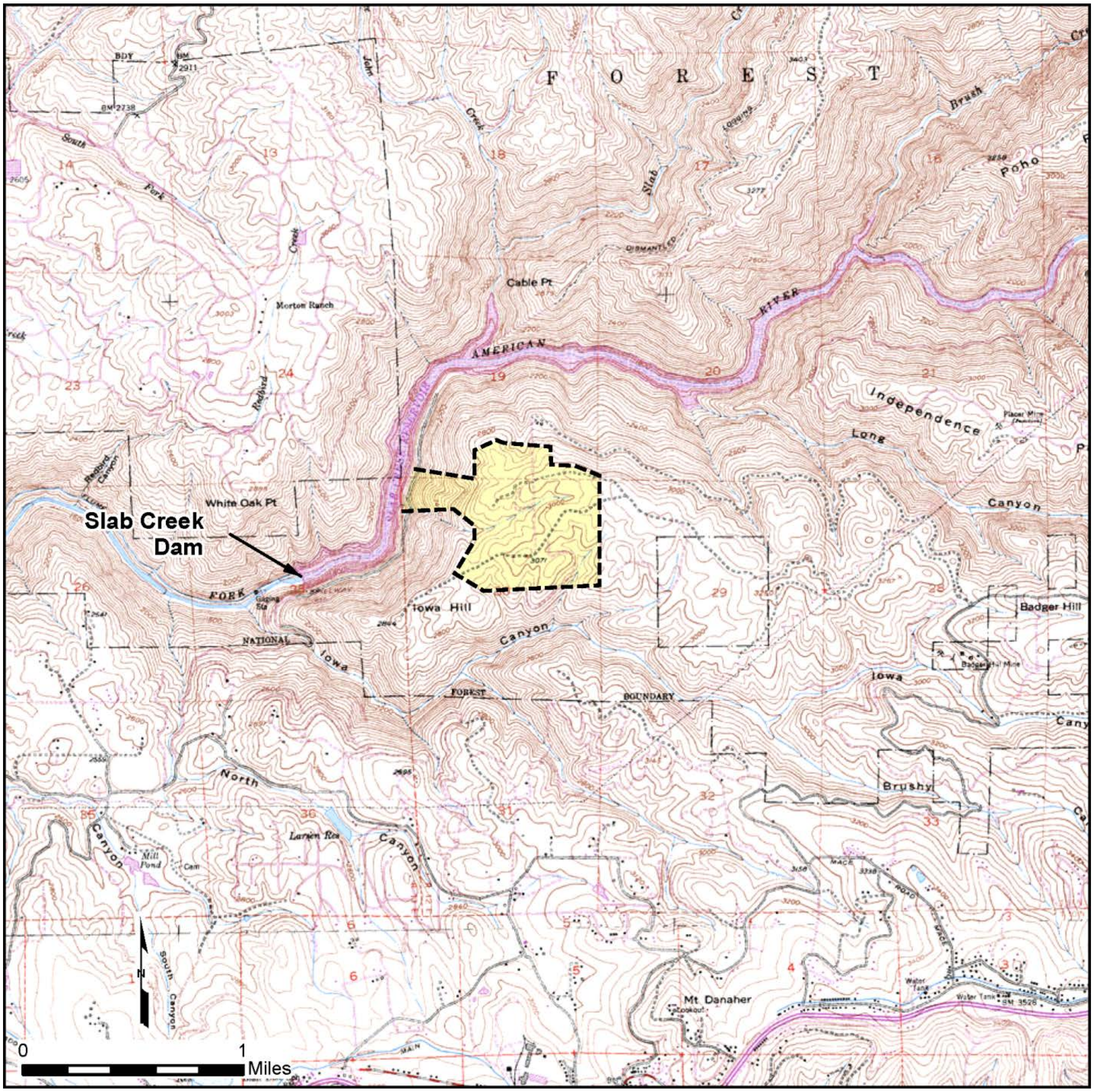
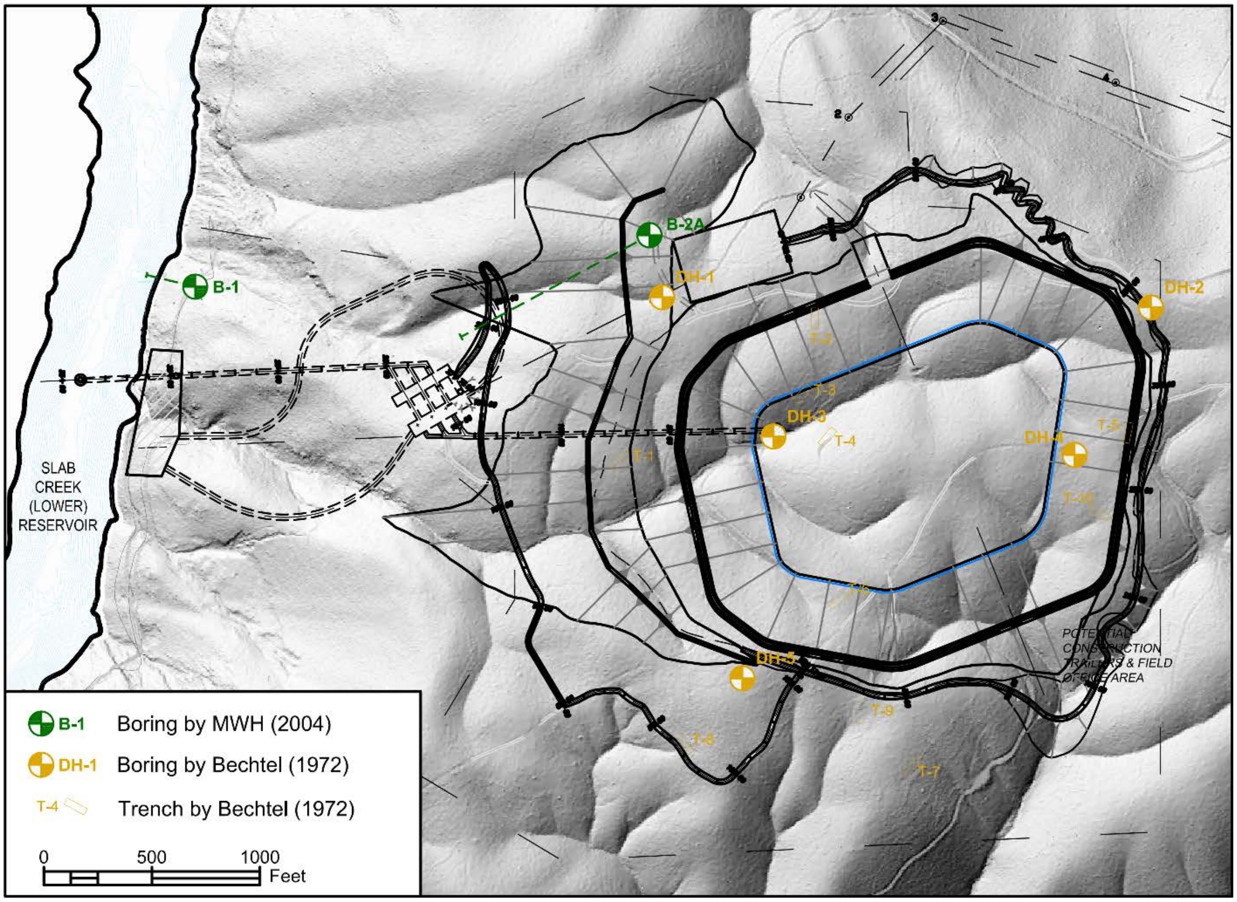


Figure 1-1. Project Location Map



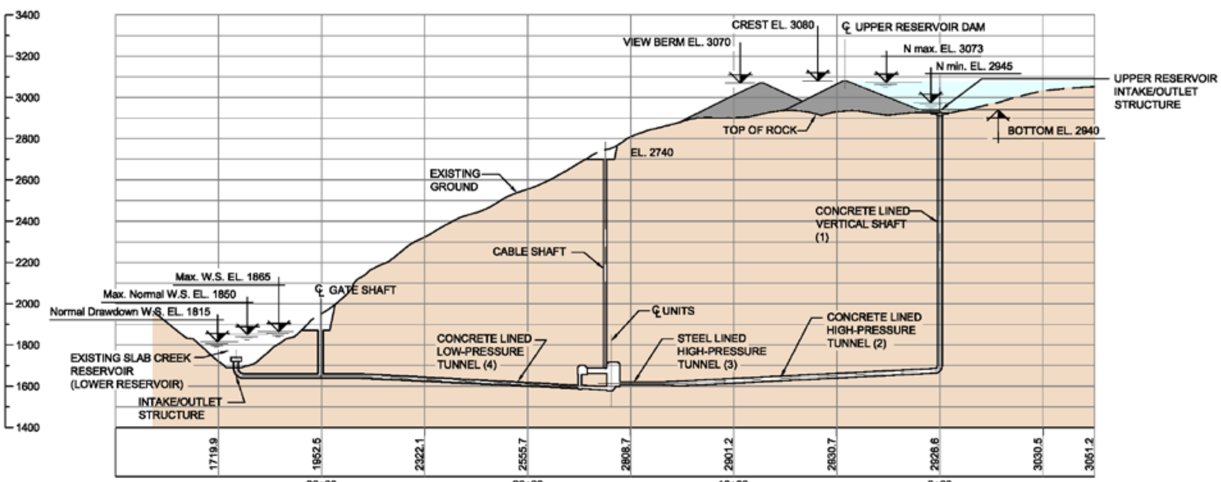


Figure 1-2. Plan and Profile of Conceptual Project Layout

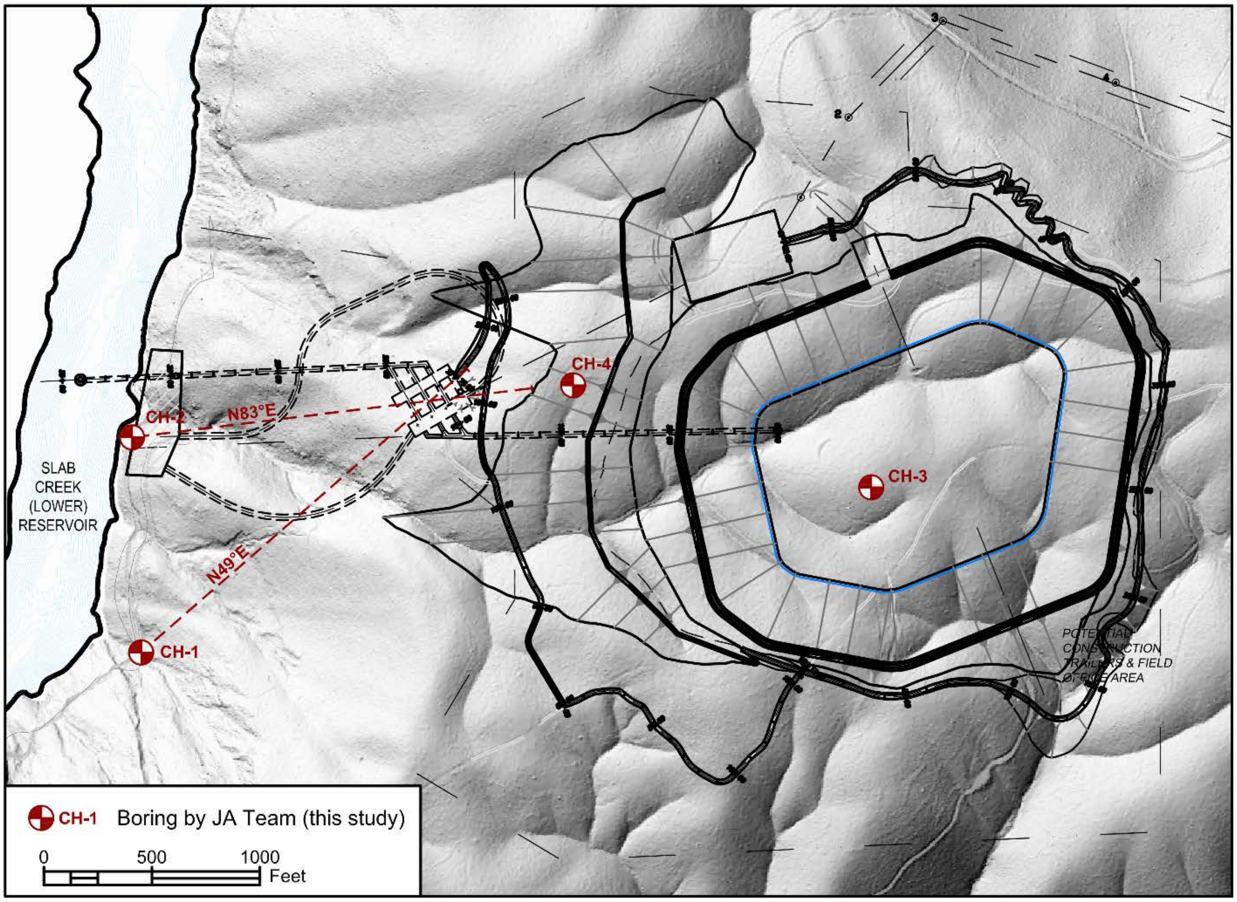


Figure 2-1. Location of Task 1A Borings

Document Path: S:\OD13\165410\165410.01\task_a\14_0224_gi\001_regional_geology.mxd

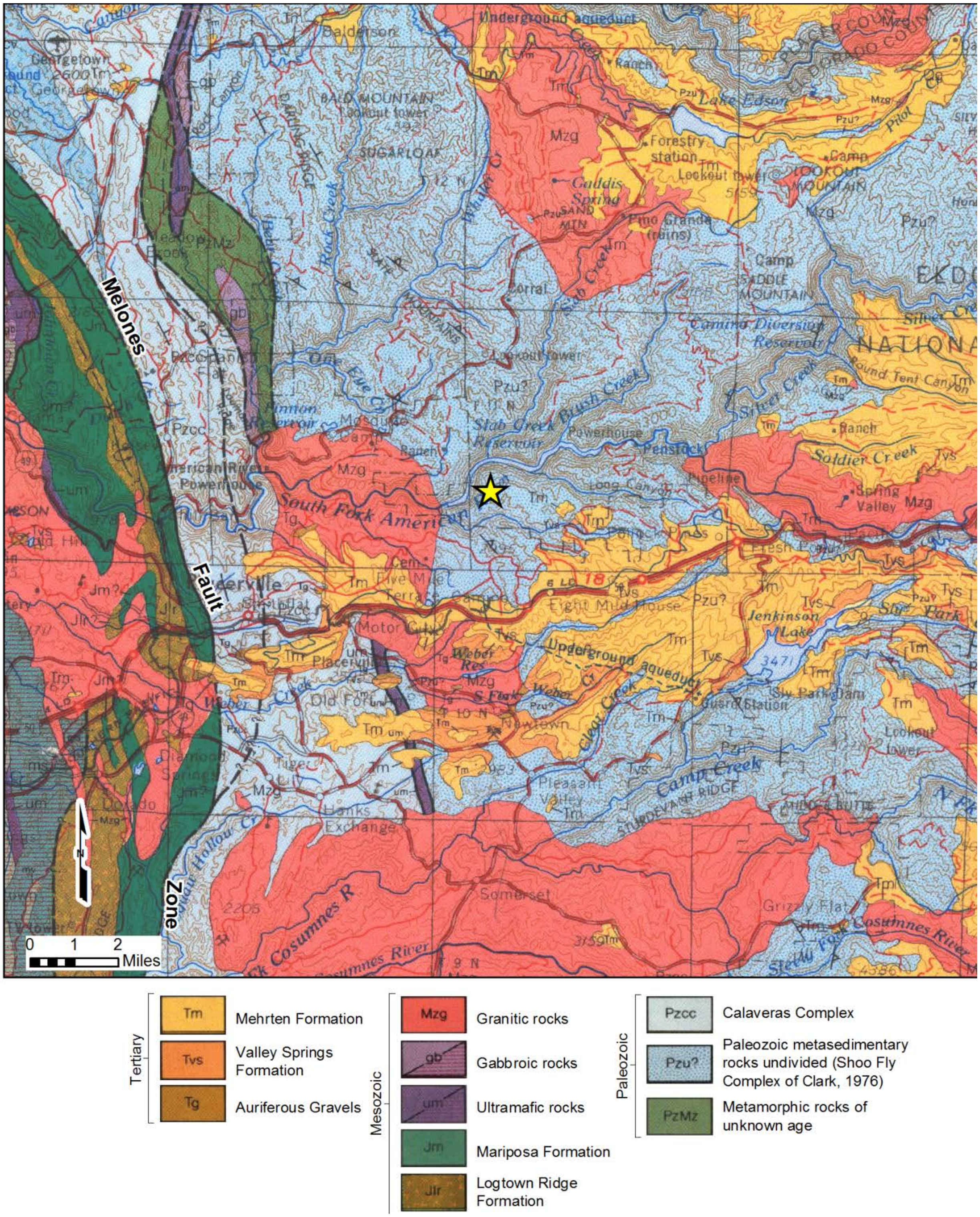


Figure 3-1. Regional Geologic Map

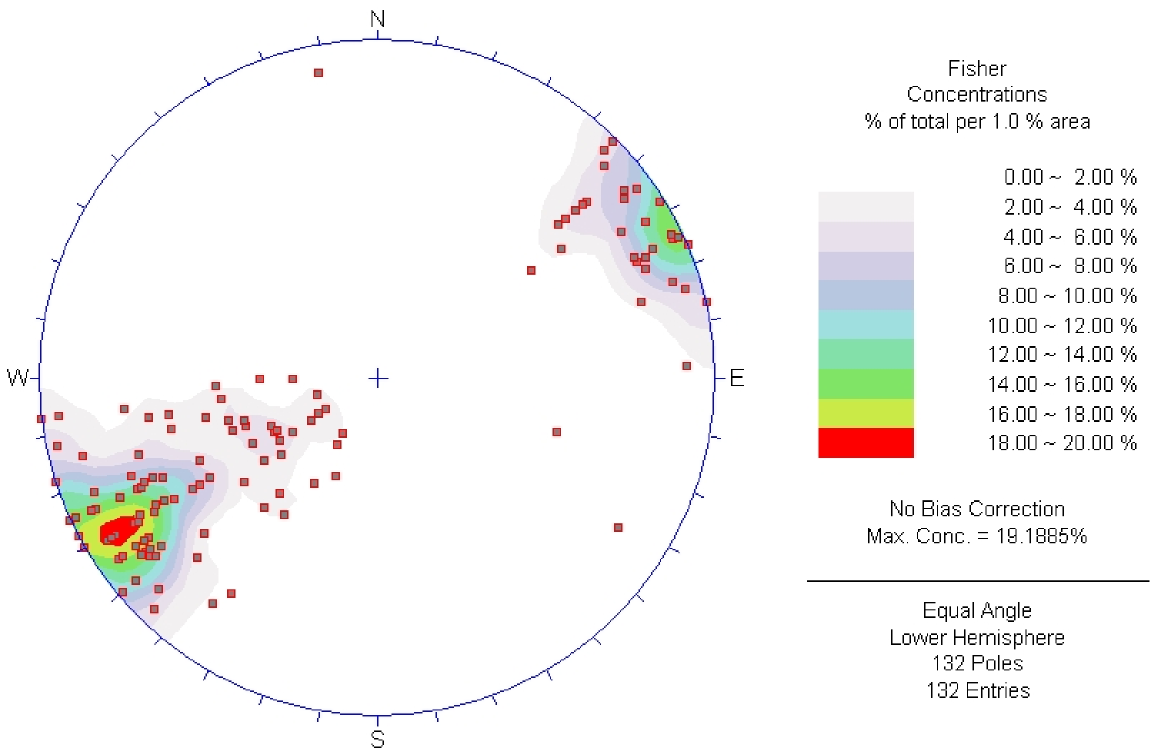


Figure 3-2. Stereonet of Bedding/Foliation Data from Previous Studies

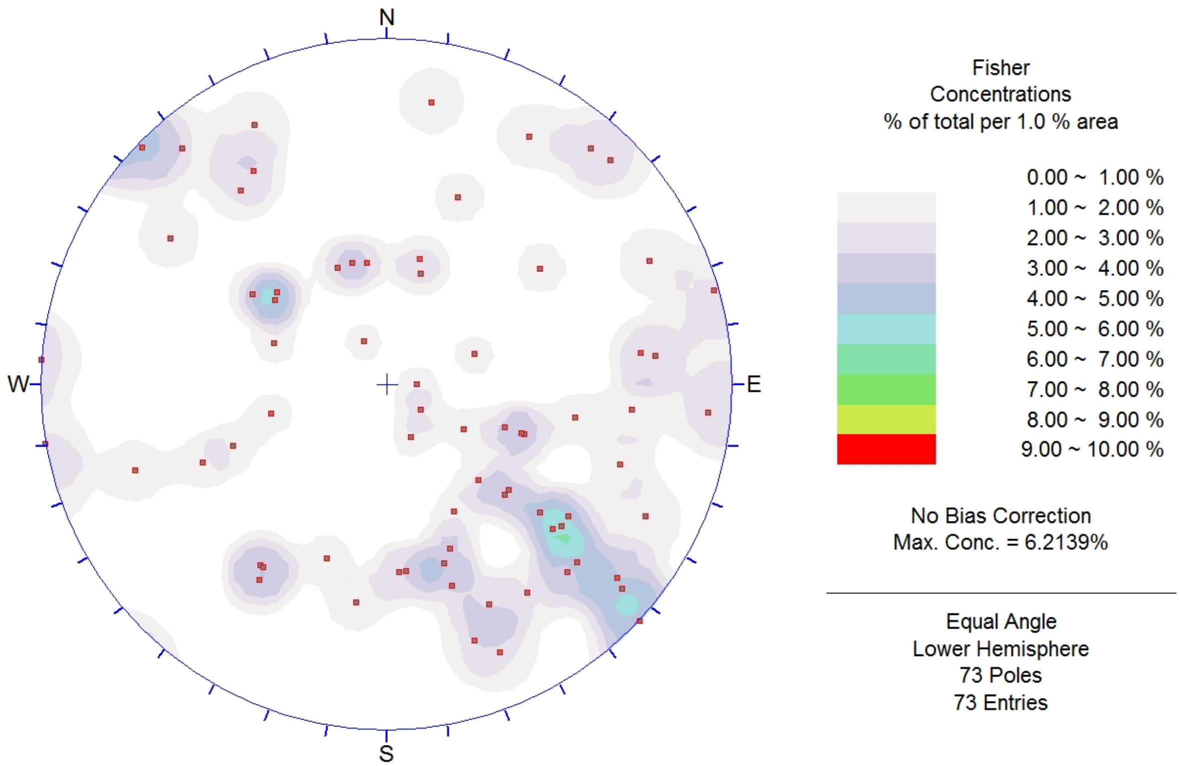
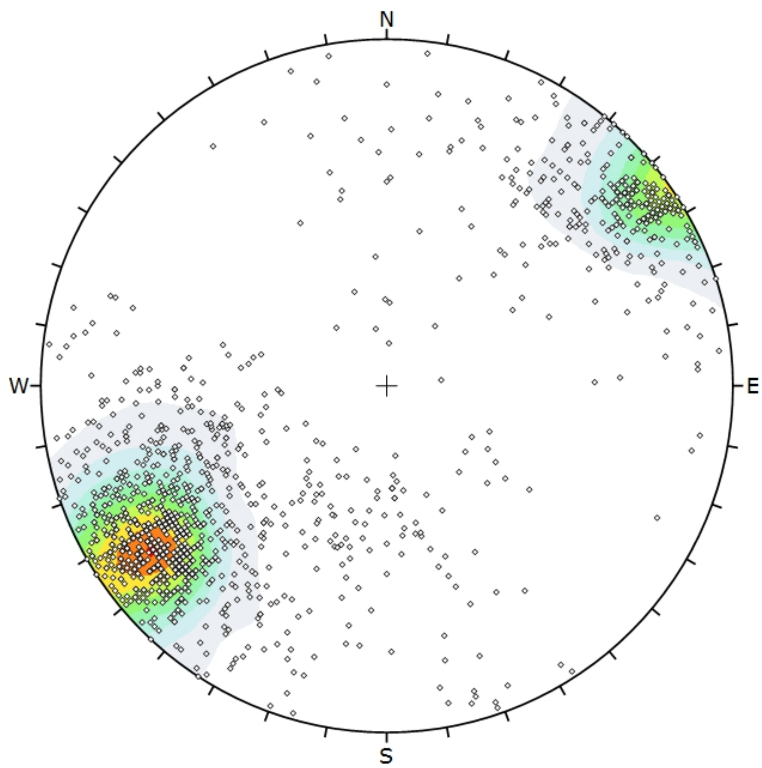


Figure 3-3. Stereonet of Joint Data from Previous Studies



Color	Density Concentrations
	0.00 - 2.00
	2.00 - 4.00
	4.00 - 6.00
	6.00 - 8.00
	8.00 - 10.00
	10.00 - 12.00
	12.00 - 14.00
	14.00 - 16.00
	16.00 - 18.00
	18.00 <
Maximum Density	18.40%
Contour Data	Pole Vectors
Contour Distribution	Fisher
Counting Circle Size	1.0%
Plot Mode	Pole Vectors
Vector Count	1171 (1171 Entries)
Hemisphere	Lower
Projection	Equal Angle

Figure 3-4. Stereonet of COBL Discontinuity Data from CH-1

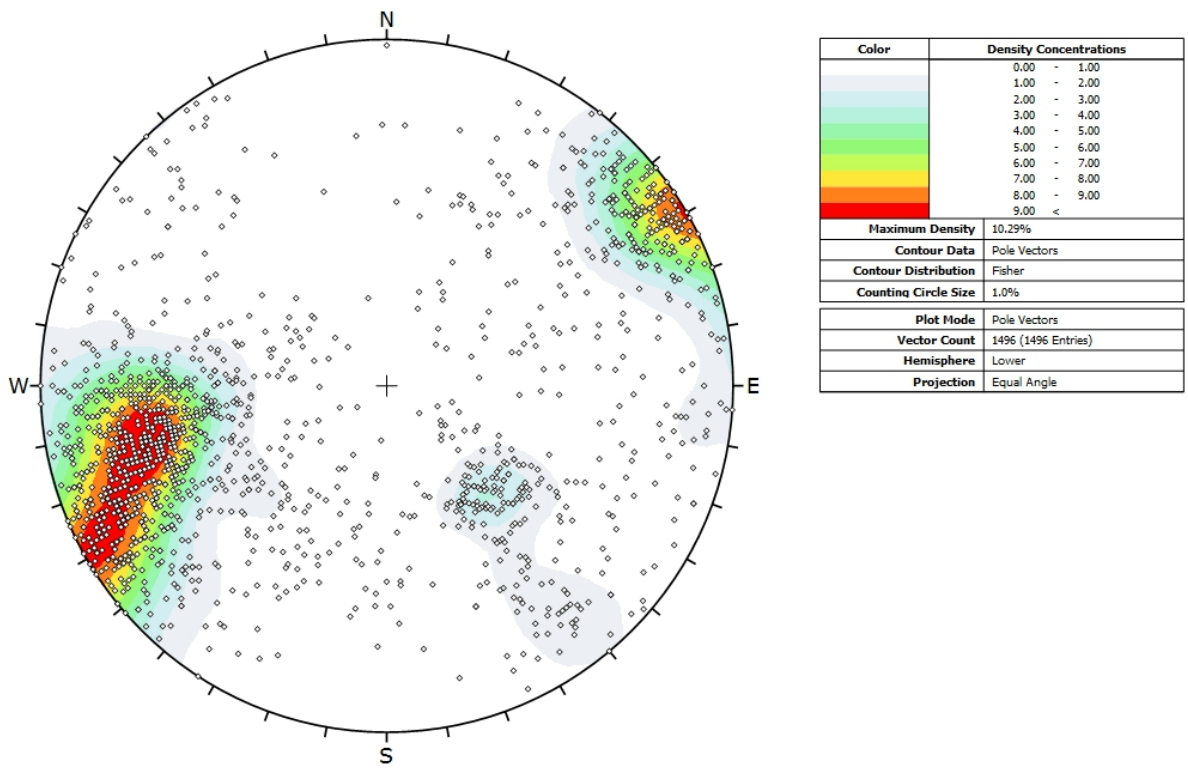


Figure 3-5. Stereonet of COBL Discontinuity Data from CH-2

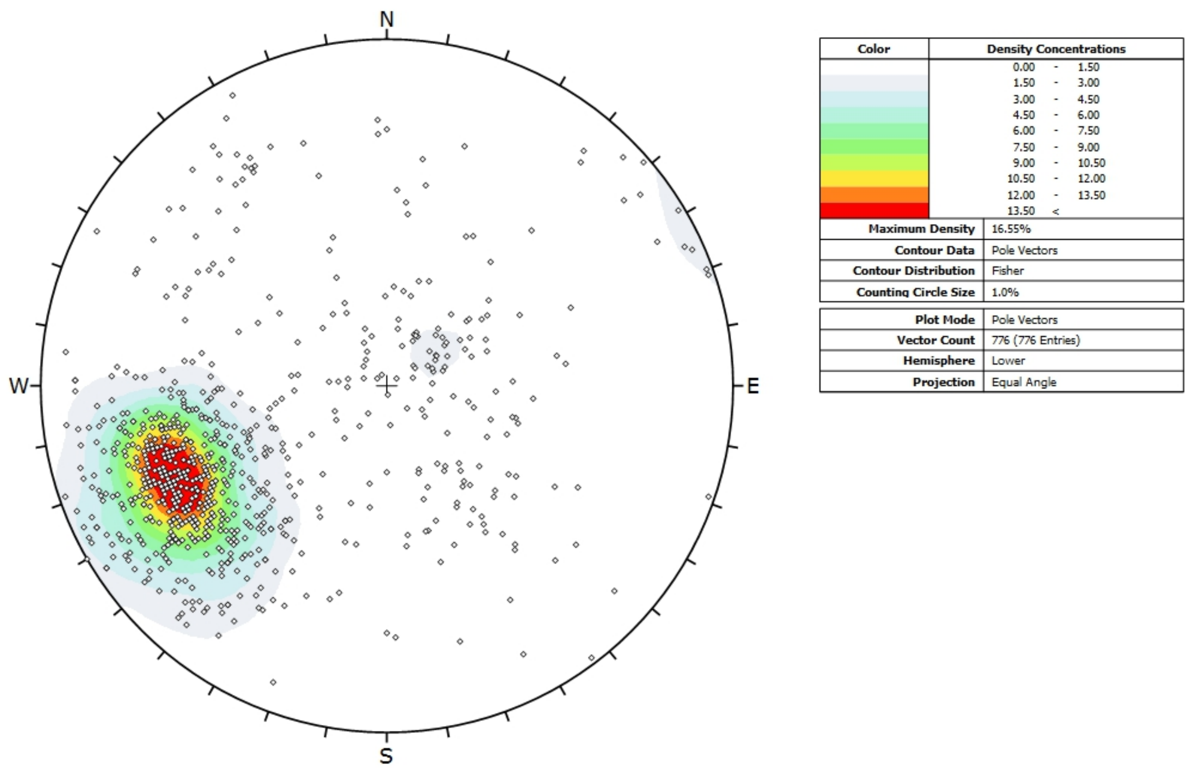


Figure 3-6. Stereonet of COBL Discontinuity Data from CH-3

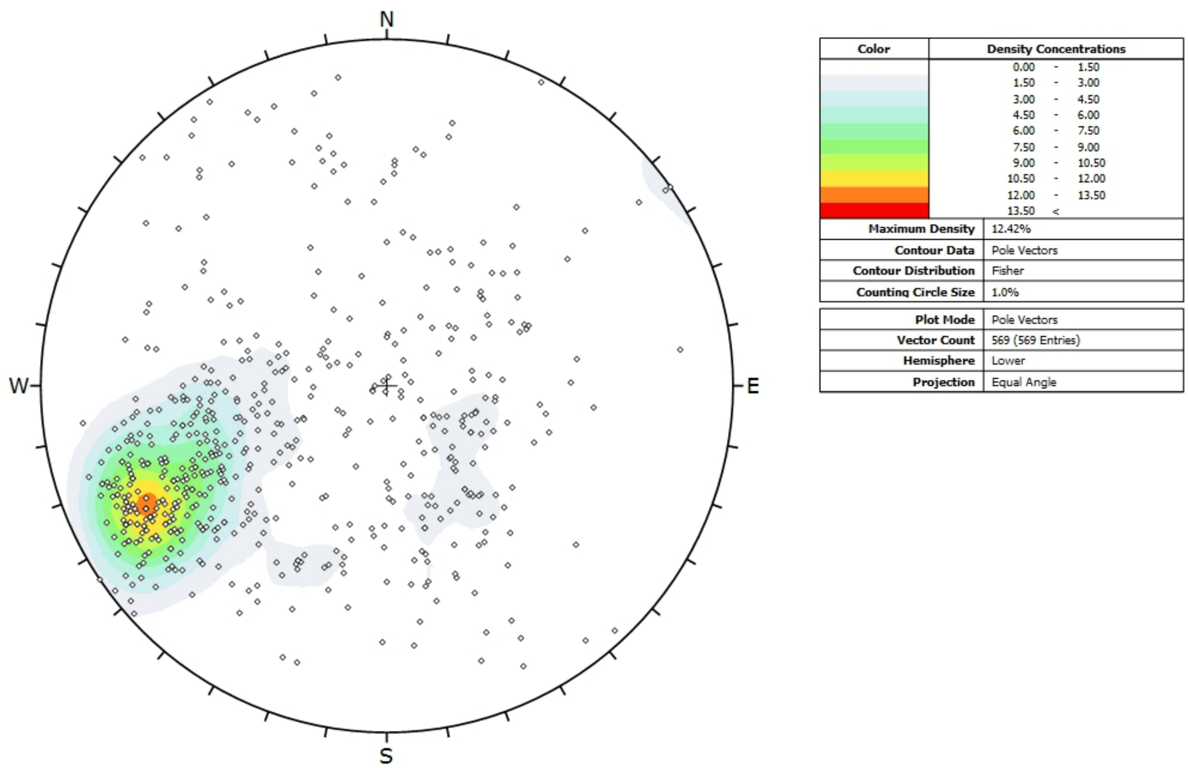


Figure 3-7. Stereonet of COBL Discontinuity Data from CH-4

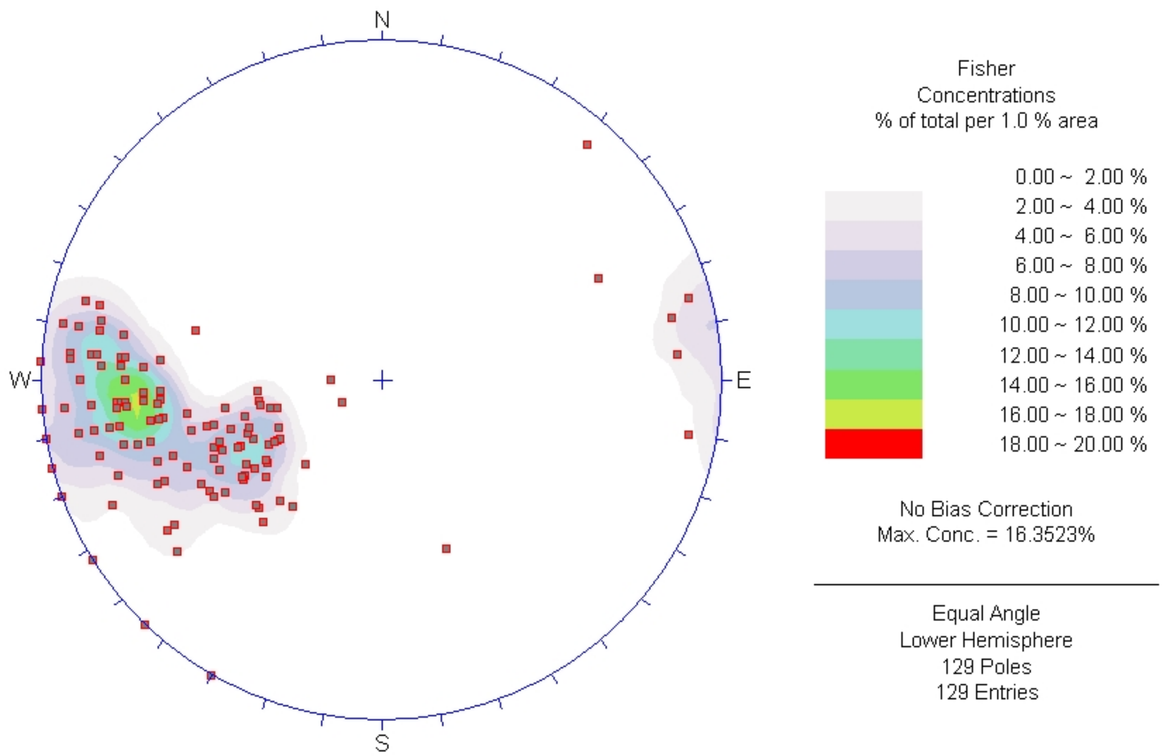


Figure 3-8. Stereonet of Bedding/Foliation Data obtained during Geologic Field Reconnaissance

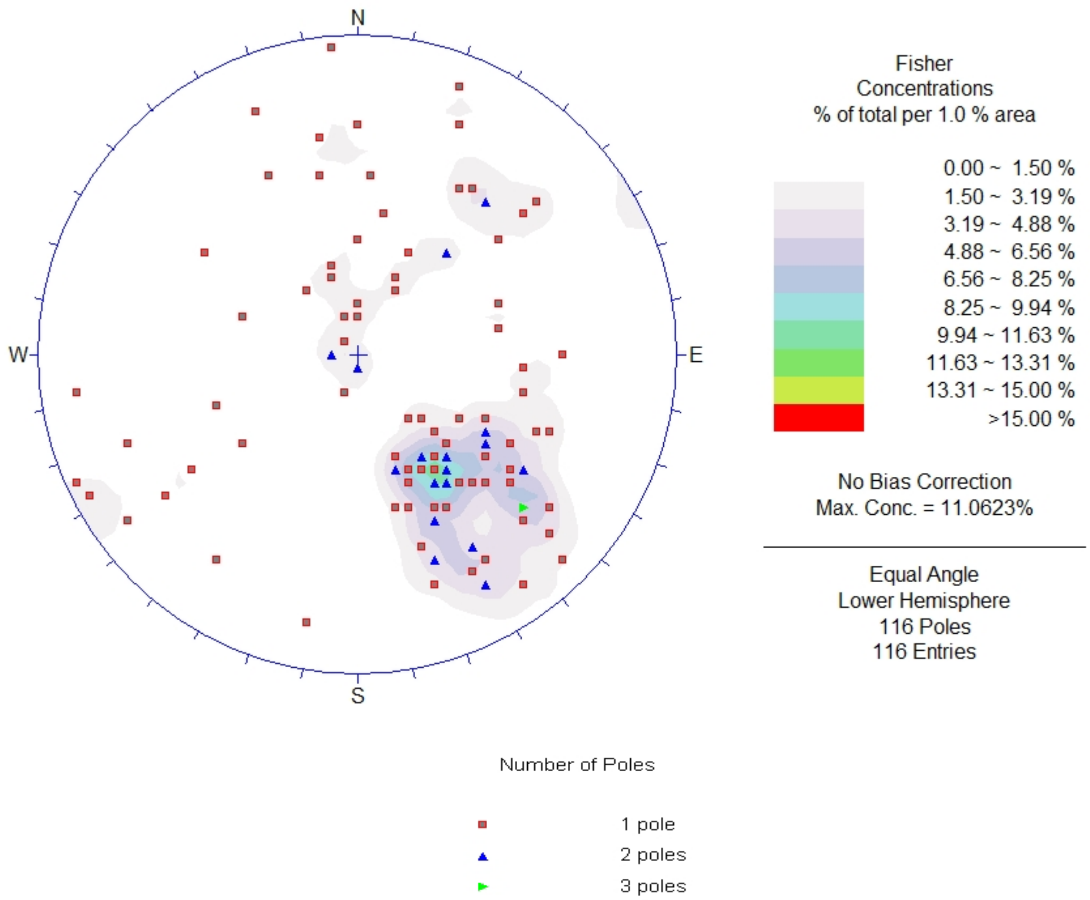


Figure 3-9. Stereonet of Joint Data Obtained during Geologic Field Reconnaissance

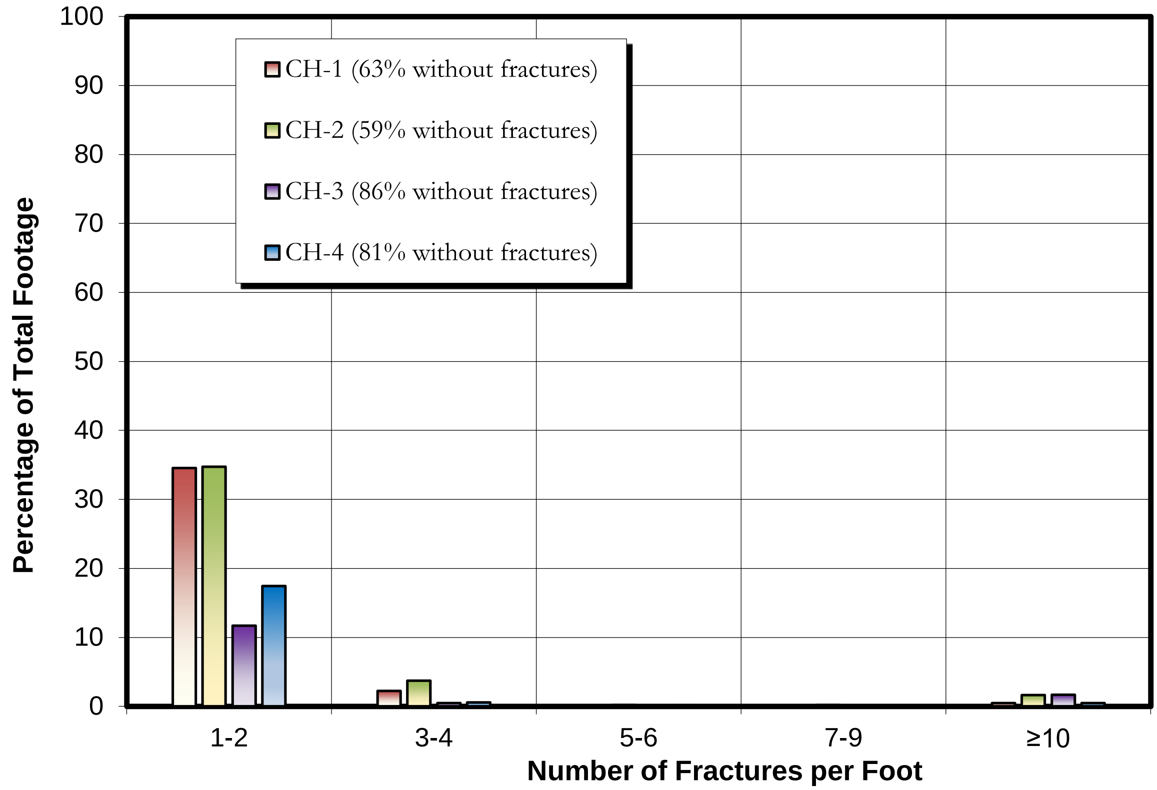


Figure 3-10. Summary of Fracture Frequency by Boring

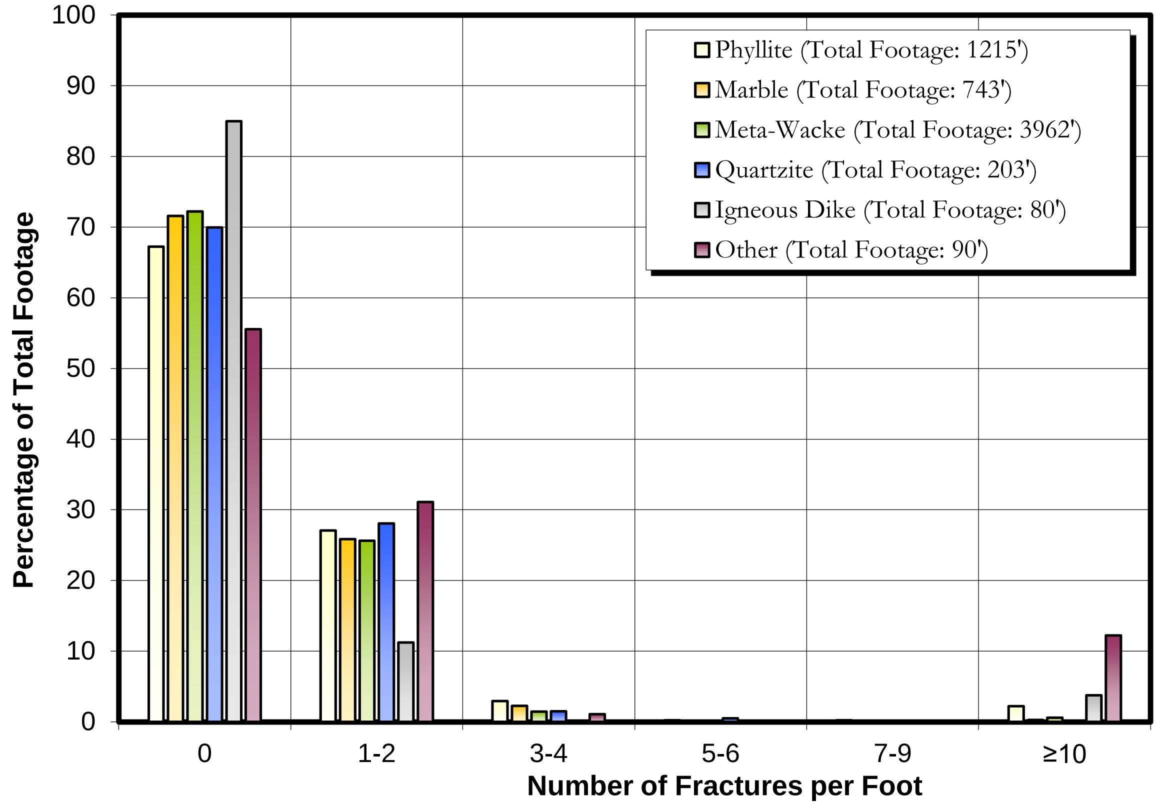


Figure 3-11. Summary of Fracture Frequency by Rock Unit

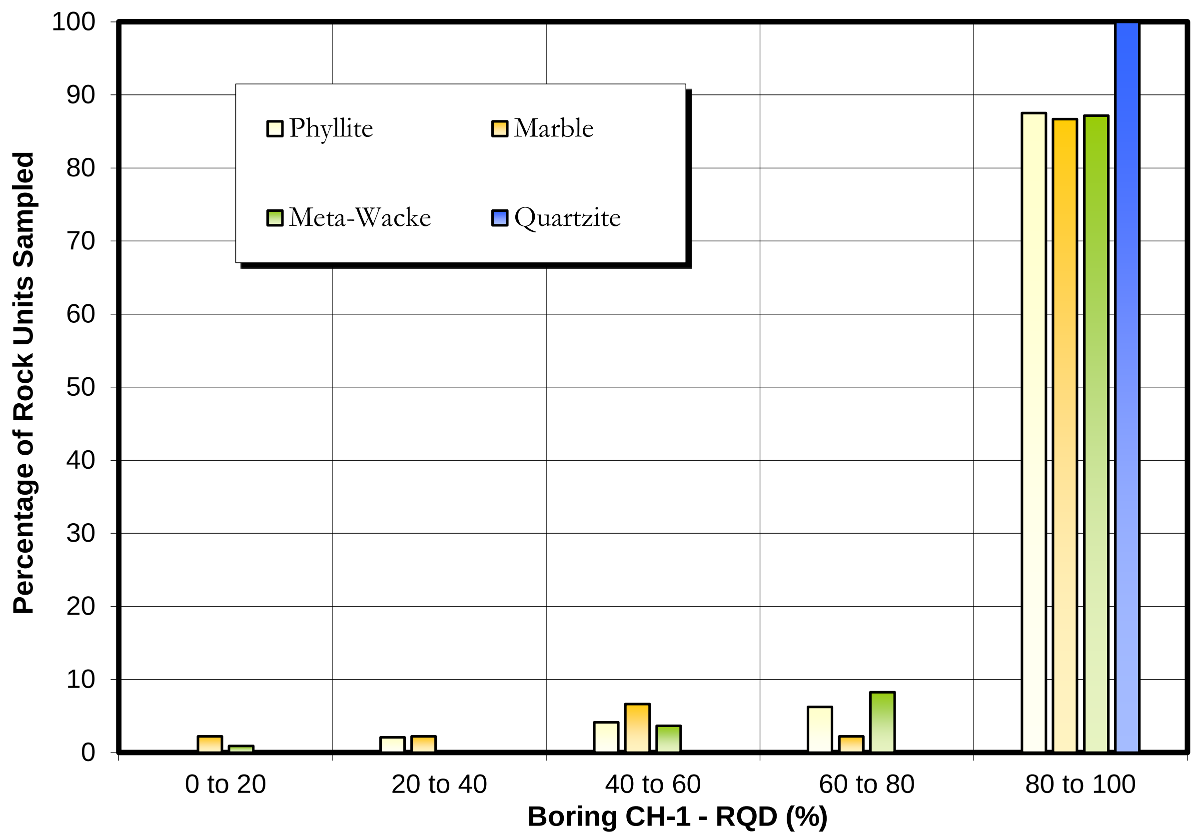


Figure 3-12. Summary of RQD by Rock Unit for CH-1

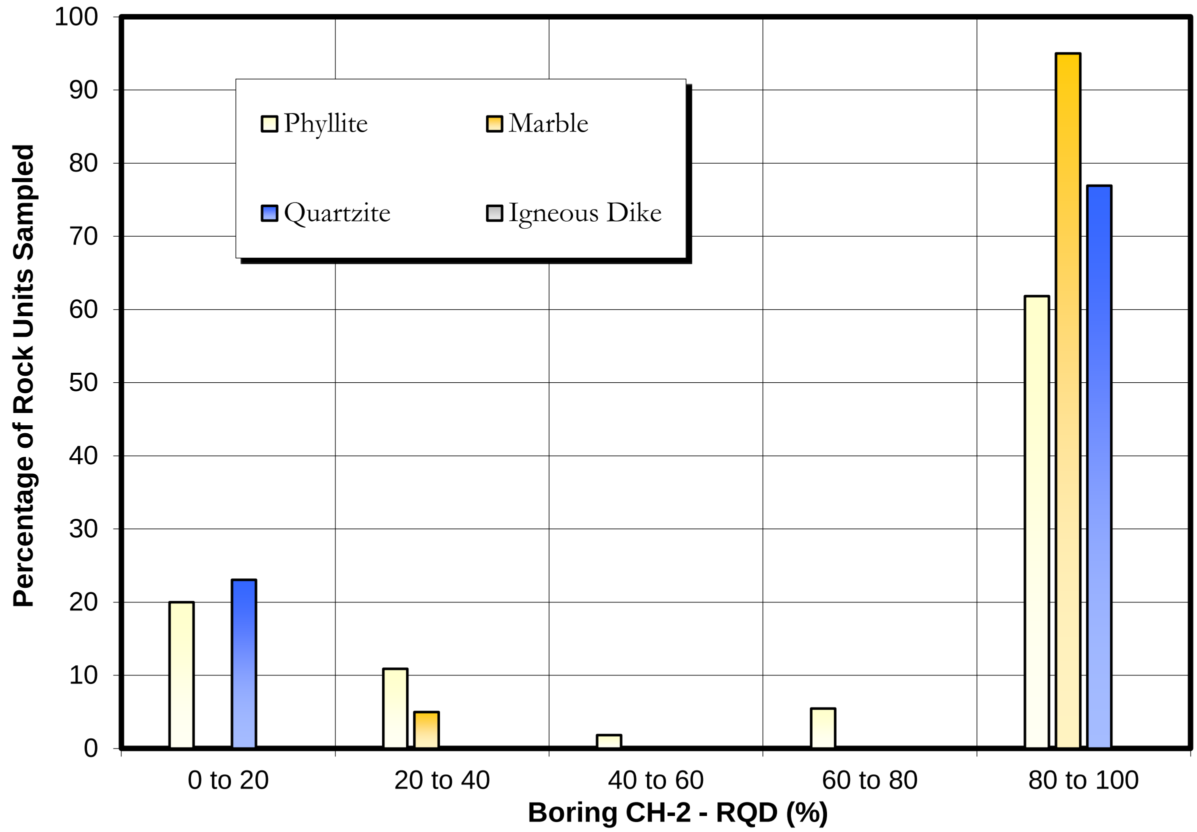


Figure 3-13. Summary of RQD by Rock Unit for CH-2

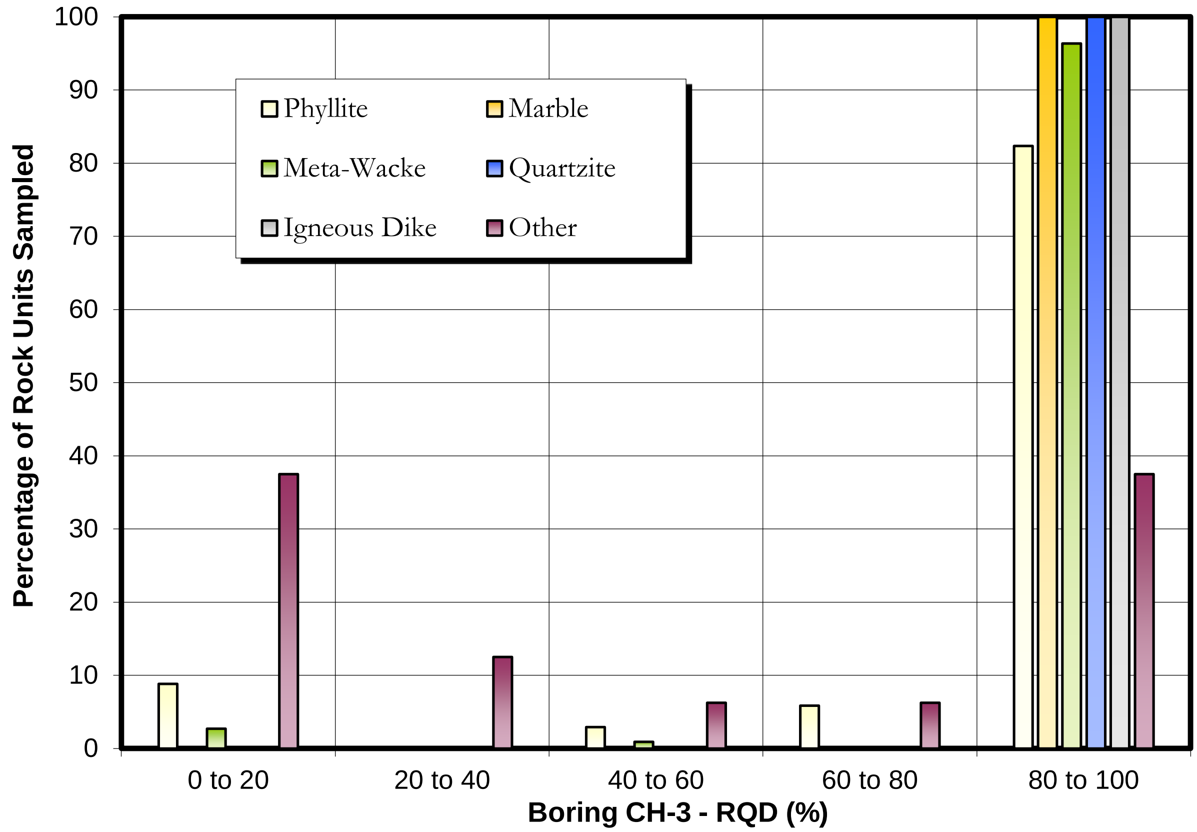


Figure 3-14. Summary of RQD by Rock Unit for CH-3

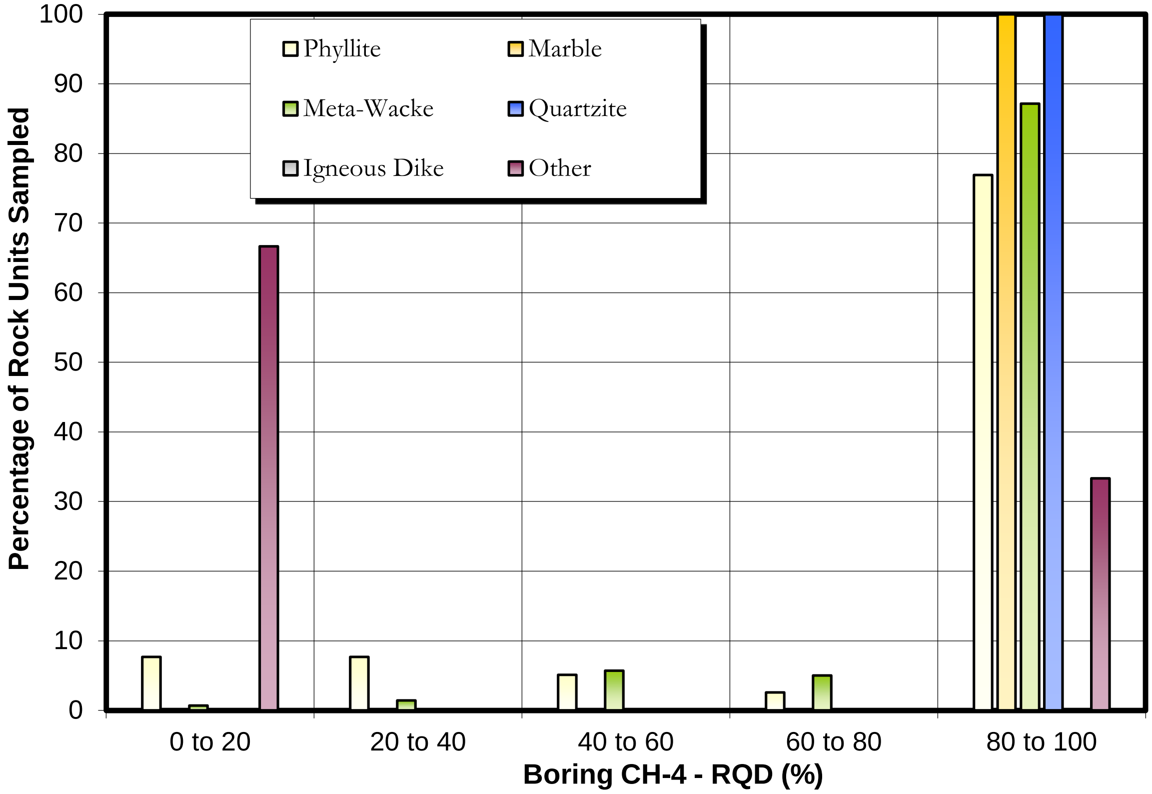


Figure 3-15. Summary of RQD by Rock Unit for CH-4

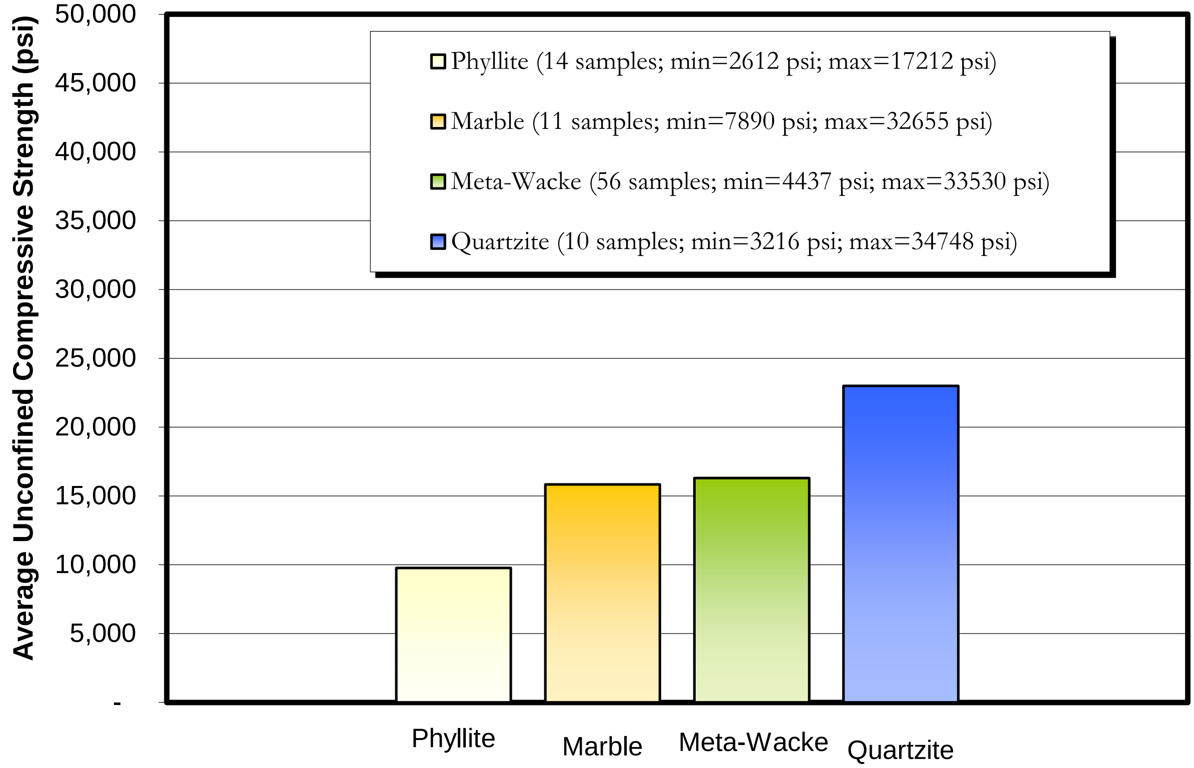


Figure 3-16. Summary of UCS by Rock Unit

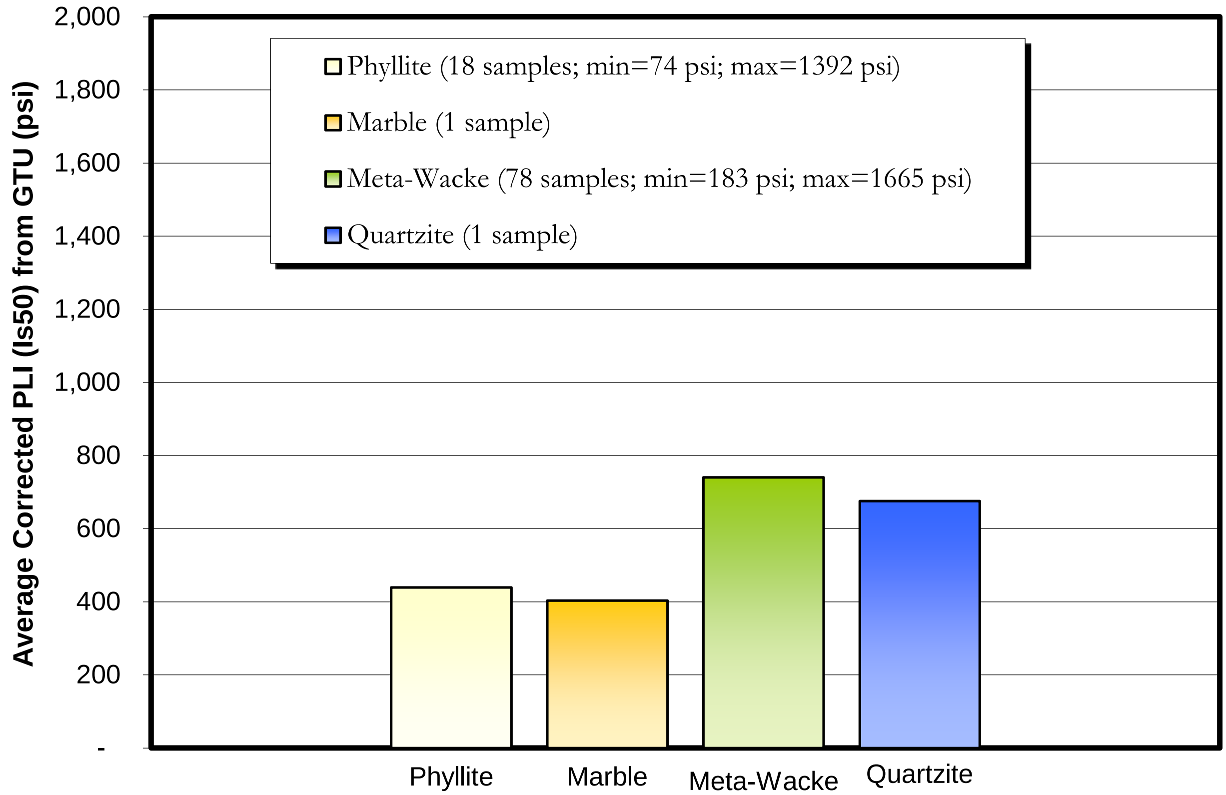


Figure 3-17. Summary of Point Load Index Values from GTU

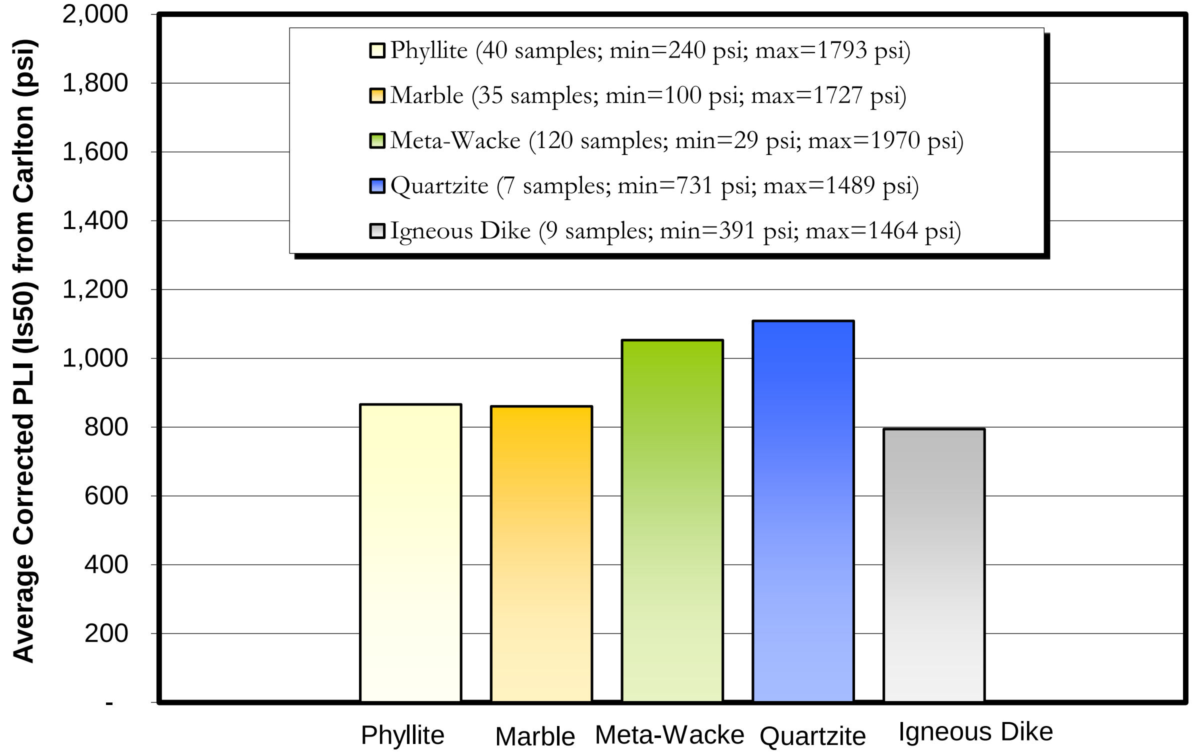


Figure 3-18. Summary of Point Load Index Values from Carlton

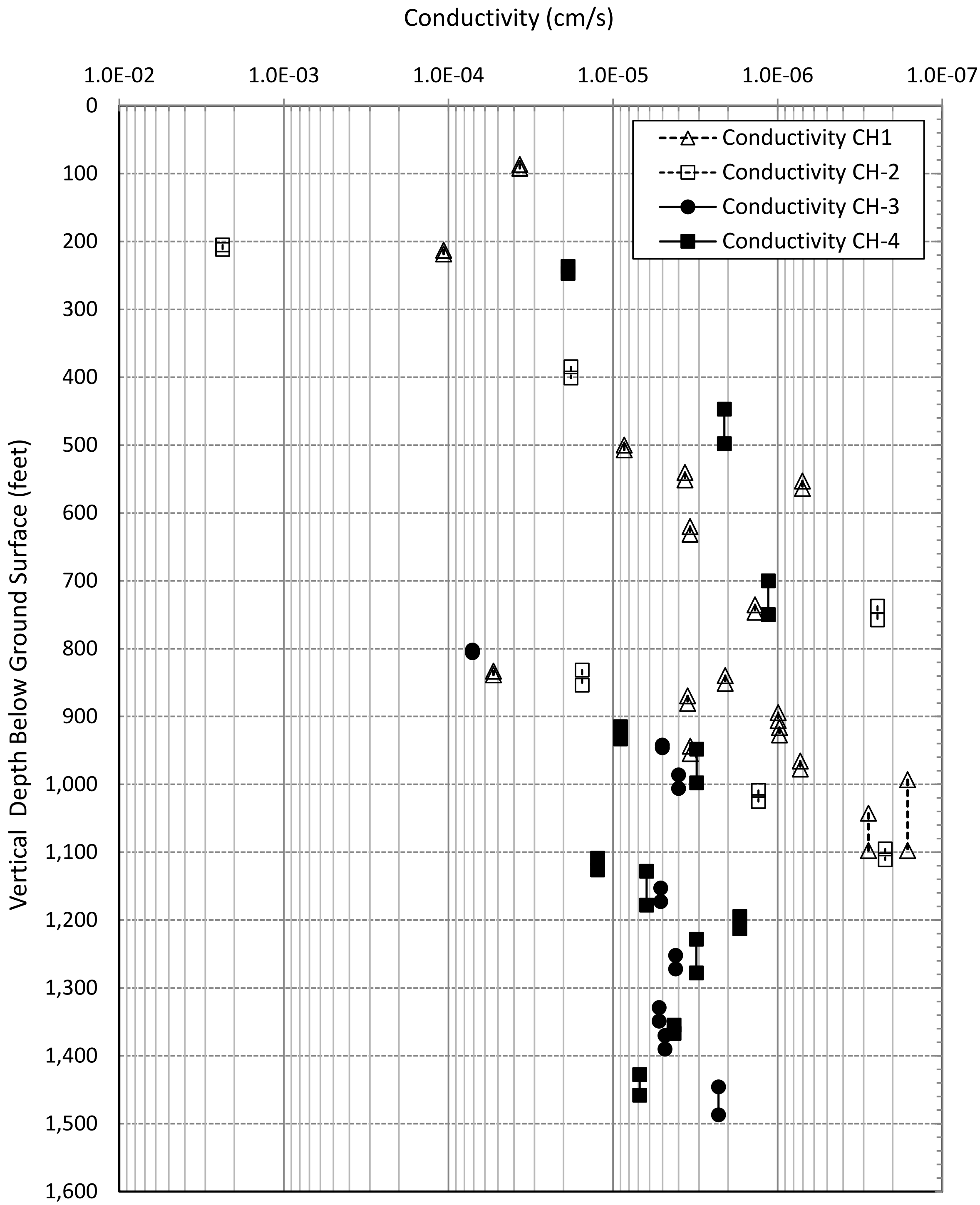


Figure 3-19. Hydraulic Conductivities vs. Depth from Packer Test Results

Appendix C

DE-EE0005414 Assistance Agreement

Modeling and Evaluation of Iowa Hill Pumped-Hydro Storage Plant: Value in SMUD and in larger region

Modeling and Evaluation of Iowa Hill Pumped-Storage Hydro Plant: Value in SMUD and in larger region

Gregory Brownell, Yongxin Cai, David Yomogida, Sacramento Municipal Utility District
Tao Guo, Guangjuan Liu, Lily Yu, Energy Exemplar
Aidan Tuohy, Ben Kaun, Stella Chan, Eamonn Lannoye, EPRI
Jack King, RePPAE

Powering forward. Together.

SMUD®

CONTENTS

EXECUTIVE SUMMARY **11**
Modeling Approaches 11
Study Results 14
Follow On Work 15
1 **INTRODUCTION** **17**
Background 17
Project Aims and overall approach 17
Innovative Features of approach 17
Report Layout 18
2 **WIND AND SOLAR PROFILE DEVELOPMENT** **20**
Introduction 20
Sources and Description 20
Variable Generation Scenarios and Mixes Used 21
Statistical Analysis 32
3 **RESERVE CALCULATIONS** **45**
NREL Method for Estimating Reserve Requirements with Variable Generation 45
Reserve Rules 46
Reserve Calculations 52
Reserve Results 53
4 **MODELING VALUE OF IOWA HILL: WESTERN INTERCONNECTION DATABASE** **60**
Introduction of Western Interconnection Database 60
Data readiness for the simulations 61
Adjustable Speed PSH Representation 65
Reciprocating Engine Representation 66
Data Assumption Revisions 66
Maintenance and Forced Outage Modeling 69
Analysis of fossil generation cycling costs included in model 70
5 **MODELING METHODOLOGY FOR STUDYING PUMPED HYDRO STORAGE** **73**
PLEXOS SCUC/ED algorithm 73
Reliability Unit Commitment 76
Scope of Simulations 82
CA-SMUD-NW Bid-base Market Simulation Approach 84
Transmission Expansion for the High-wind Renewable Scenario 87
6 **OVERVIEW OF PLEXOS SIMULATION RESULTS** **89**
Operation of Iowa Hill 89
Financial and Cost Impacts 91
Variable Generation Curtailment Reduction by Iowa Hill 93

Reliability and Reserve Impacts 94
Cycling and Emissions Impacts 94
Fixed Speed vs Variable Speed. 95
Summary 95
7 DETAILED SIMULATION RESULTS 97
Scenarios and Cases examined 98
Production Cost Savings due to Iowa Hill 99
System Reserve Shortage and Provision by Iowa Hill and Existing pumped storage 112
Impact of Iowa Hill on Emissions 125
Impact on Curtailment of Renewable Resources 134
Impact on Start Up Times, Start Up Cost and Ramping 135
Impact on Regional LMP 146
Potential Revenue if Iowa Hill was merchant plant 154
8 FUTURE WORK: THREE STAGE MODELING APPROACH 156
Wind and Solar Variability and Uncertainty – the case for three stage modeling 156
3-Stage DA-HA-RT Sequential Simulations 158
PSH Storage Modeling in 3-stage Sequential Simulations 160
9 EPRI ENERGY STORAGE VALUATION TOOL (ESVT) PRELIMINARY ANALYSIS 161
How the Energy Storage Valuation Tool Works 162
Recent Applications of the Energy Storage Valuation Tool 163
Potential Value of ESVT to This Study 163
ESVT Historical Price Benchmarking Analysis for the SMUD BA Iowa Hill 164
Next steps 169
10 SMUD HYDRO PORTFOLIO MODELING OF EFFECTS OF IOWA HILL TO THE UPPER AMERICAN RIVER PROJECT 170
SMUD Portfolio and Modeling Assumptions 170
Results 174
11 CAPACITY VALUE ANALYSIS OF WIND AND SOLAR AND RETIREMENT OF GENERATION 177
Capacity value calculation 177
Capacity adequacy study results 187
12 CONCLUSIONS AND FURTHER WORK 194

TABLE OF FIGURES

Figure 2-1 - Resource map for 33% mix 24
Figure 2-2 - Resource map for 50% mix 26
Figure 2-3 - Resource map for reference mix 28
Figure 2-4 - Resource map for high-solar scenario 30
Figure 2-5 - Monthly variable resources energy for the SMUD BA 33
Figure 2-6 - Monthly variable resource energy for all of California 34
Figure 2-7 - VG penetration (GWh) for northwestern zone 37
Figure 2-8 - Monthly variable resources energy for the entire US Western Interconnect 39
Figure 2-9 - Wind forecasts MAE for the SMUD BA for 33% and 50% mixes, 1915 MW wind nameplate 40
Figure 2-10 – Wind forecast MAE for California for 33% and 50% mixes, 11475 MW wind nameplate 41
Figure 2-11 - Solar forecast MAE for the SMUD BA for 33% mix, 580 MW PV nameplate 41
Figure 2-12 - Solar forecast MAE for the SMUD BA for 50% mix, 1126 MW PV nameplate 42
Figure 2-13 - Solar forecast MAE for California for 33% mix, 10397 MW PV nameplate 42
Figure 2-14 - Solar forecast MAE for California for 50% mix, 23488 MW PV capacity 43
Figure 3-1 – Short-term forecast error 47
Figure 3-2 – Hour forecast error used for flex reserves 47
Figure 3-3 – Example regulation requirements for 3675MW of wind 48
Figure 3-4 - Example flex reserve calculations 49
Figure 3-5 - Effect of various confidence intervals on regulation requirements 49
Figure 3-6 - Short-term forecast error for solar using SPI and clear sky power 50
Figure 3-7 – Example up regulation requirements for 5500MW solar PV data at 95% confidence interval 51
Figure 3-8 – Combining regulation reserve components to make the total regulation 53
Figure 3-9 - Illustration of distribution points 55
Figure 3-10- Duration curves for the SMUD BA reserve components 58
Figure 3-11 - Duration curves for aggregated California zone reserve components 58
Figure 3-12 – Reserve component duration curves for Northwest zone aggregated with the SMUD BA 58
Figure 3-13 - Regulation reserve components duration curves for the SMUD BA 59
Figure 4-1 The Average Heat Rates for Coal, CC, CT and Gas Steam Generators. 69
Figure 4-2: Start costs assumed based on APTECH report 71
Figure 4-3: Comparison of total costs between existing numbers and APTECH numbers, based on gas being used as start fuel for coal plants. The final database used the blue bars for the gas plants and purple bars for coal generation 72
Figure 5-1 PLEXOS Security Constrained Unit Commitment and Economic Dispatch Algorithm 73
Figure 5-2: Illustration of forecast error level 77
Figure 5-3: Load Forecast Error evolution over day 78
Figure 5-4 CAISO Energy Price-cost mark-up (2009-2012) 85
Figure 5-5 Logic flow for the Transmission Expansion Using Congestion Shadow Price Approach 88
Figure 6-1: Capacity Factor of Iowa Hill for different scenarios, with AS trading allowed 90
Figure 6-2: Regulation provision in the SMUD BA for different scenarios and cases (note high solar only examined for cases with trading 90
Figure 6-3: Percentage of each reserve category provided by Iowa Hill for different scenarios and cases (High Solar Case did not examine trading of AS from Iowa Hill) 91
Figure 6-4: Reduction in Renewable Curtailment when Iowa Hill is added to system 94

Figure 6-5: Change in number of starts in the SMUD BA and study region 95
Figure 7-1: Production Costs for the SMUD BA footprint for different cases...........................101
Figure 7-2: Savings due to presence of Iowa Hill for the SMUD BA and study area at different penetrations of wind and solar..103
Figure 7-3: SMUD BA net import costs with and without Iowa Hill, with AS trading 112
Figure 7-4: Regulation provision in the SMUD BA for different scenarios and cases..............114
Figure 7-5: Percentage of each reserve category provided by Iowa Hill for different scenarios and cases 115
Figure 7-6: CO2 emissions for the SMUD BA for AS trading base case for each scenario......125
Figure 7-7: Change in CO2 due to Iowa Hill for different scenarios and cases in study area...126
Figure 7-8: Change in NOx emissions due to Iowa Hill...127
Figure 7-9: % reduction in CO2 and NOx emissions in the SMUD BA...................................127
Figure 7-10: Impact on Renewable Curtailment when Iowa Hill is added to system 135
Figure 7-11: Change in number of starts in the SMUD BA and study region 136
Figure 7-12: Average Load-Weighted LMP in the SMUD BA for different scenarios and cases 146
Figure 7-13: Peak/off peak average difference for different scenarios, with and without Iowa Hill in AS trading case...149
Figure 7-14 SCE LMP in Week of July 17, 2022, in Three Cases for the High-wind Renewable Scenario...150
Figure 8-1 5-minute Actual Solar Generation and Hourly DA / HA Forecasts in Southern California in a Typical Winter Week of Year 2022 156
Figure 8-2 5-minute Actual Wind Generation and Hourly DA / HA Forecasts in Southern California in a Typical Winter Week of year 2022..157
Figure 8-3 5-minute Actual Solar Generation and Hourly DA / HA Forecasts in Southern California in a Typical Summer Week of year 2022..157
Figure 8-4 5-minute Actual Wind Generation and Hourly DA / HA Forecasts in Southern California in a Typical Summer Week of Year 2022 158
Figure 8-5 Wind and Solar generation forecasted error from DA to HA and HA to RT in Southern California in a typical winter week of year 2022. ....**Error! Bookmark not defined.**
Figure 8-6 Wind and Solar generation forecasted error from DA to HA and HA to RT in Southern California in a typical winter week of year 2 ....**Error! Bookmark not defined.**
Figure 8-7 DA-HA-RT 3-stage Sequential Simulations 159
Figure 9-1: SMUD BA PHS Output...165
Figure 9-2: SMUD PHS Output 166
Figure 9-3: No value for provision of regulation 166
Figure 9-4: Low Capacity Value of storage...167
Figure 9-5: Transmission benefits included 168
Figure 10-1: SMUD Portfolio Modeling Footprint...171
Figure 10-2: Detailed UARP Representation (Upper UARP Section) 172
Figure 10-3: Detailed UARP Representation (Lower UARP Section) 173
Figure 11-1: Available generation capacity distribution..178
Figure 11-2: Loss of Load Expectation as a function of peak load level 182
Figure 11-3: New LOLE-Peak Load curve with new generator addition..................................184
Figure 11-4: New LOLE-Peak Load curve with the addition of variable generation 186
Figure 11-5: Average capacity value of each VG resource type in each scenario 189
Figure 11-6: Production and Demand for Solar Resources 190
Figure 11-7: Capacity value of CSP resources with time shifting..191
Figure 11-8: Additional VG capacity additions between scenarios\..192
Figure 11-9: Incremental capacity values of VG in reach region...192

Table 2-1: Scenarios Used in Study 22
Table 2-2 - 33% mix (high wind) variable generation by reserve zone.....................................25
Table 2-3 - 50% mix variable generation by reserve zone...27
Table 2-4 - Reference mix variable generation by reserve zone..29
Table 2-5 – High solar mix variable generation by reserve zone 31
Table 2-6 - VG penetration (GWh) for the SMUD BA 32
Table 2-7 - VG penetration (GWh) for all of California 35
Table 2-8 - VG penetration (GWh) for northwestern zone 35
Table 2-9 - VG penetration (GWh) for US Western Interconnect...38
Table 3-1 - Reserve summary for 33% high wind mix 54
Table 3-2 – Reserve summary for 50% mix 55
Table 3-3 - Detailed SMUD BA reserves for 33% high wind mix 56
Table 3-4 - Detailed SMUD BA reserves for 50% mix 57
Table 4-1 Mapping of the load regions and the contingency reserve sharing groups 62
Table 4-2: Mapping of the load regions and the regulation / flexibility reserve sharing groups...64
Table 4-3 Characteristics of three proposed adjustable speed PSHs.......................................65
Table 4-4 Locations and Installed Capacity of the Existing FS PHS and Proposed AS PSHs in WI 66
Table 4-5 Assumptions revisions in the database 67
Table 4-6: Generator Characteristic Revisions and Eligibility for the Reserve Provisions 68
Table 5-1: Forecast distribution example...79
Table 5-2: Start time and generator capacity..79
Table 5-3: Generation and reserve requirements example..80
Table 5-4 Combinations of Renewable Penetration Levels in Different Regions 82
Table 5-5 List of Basic Simulation Cases 83
Table 5-6 Statistics of CAISO Historical NP15 LMP and AS Clearing Prices in Year 2012........85
Table 5-7 Correlation of CAISO Historical NP15 LMP and AS Clearing Prices in Year 2012.....86
Table 5-8 CA-SMUD-NW AS Bidding Price Scalar by Generator Type 87
Table 6-1: Summary of AS revenue and production savings impacts due to Iowa Hill for different scenarios, case with AS trading..92
Table 6-2 Summary of Production and AS Cost Reduction ($m) due to Iowa Hill or Reciprocating Engines for each Renewable Scenarios for a number of cases (note high solar did not examine cases without trading or with recips)...93
Table 7-1 Results of WI Simulations for a Variety of Renewable Scenarios 97
Table 7-2: Summary of Load, Renewable Generation and Outside Import (GWh) for a Variety of Renewable Scenarios from the WI Simulations...98
Table 7-3 Summary of Production Cost Reduction ($m) due to Iowa Hill or Reciprocating Engines for each Renewable Scenarios for a number of cases..100
Table 7-4: Value to different regions for different scenarios, in the case with AS trading and 0% of AS cost to load..102
Table 7-5 Comparison of Production Cost ($m) for different cases for the TEPPC Scenario...105
Table 7-6 Comparison of Production Cost ($m) for different cases for the CA High-Wind and WI TEPPC Renewable Scenario...106
Table 7-7 Comparison of Production Cost ($m) for different cases for the CA High-Mix and WI TEPPC Renewable Scenario...107
Table 7-8 Comparison of Production Cost ($m) for different cases for the High-Wind (everywhere) Renewable Scenario 108
Table 7-9 Comparison of Production Cost ($m) for different cases for the CA High-Mix and WI High-Wind Renewable Scenario 109
Table 7-10: Comparison of Production Cost ($m) for different cases for the High-Solar Renewable Scenario..110

Table 7-11: Flexible Down Shortages for the different scenarios (GWh change) 113
Table 7-12: Flexible Down Shortages for the different scenarios (% change) 113
Table 7-13: Comparison of Reserve Requirement and Provision of reserves by Iowa Hill and Recip for different cases and scenarios 116
Table 7-14: Comparison of Reserve Requirement and Provision by pumped hydro storage and Reciprocating Engines for the TEPPC Scenario 116
Table 7-15: Comparison of Reserve Requirement and Provision by pumped hydro storage and Reciprocating Engines for the CA High-Wind and WI TEPPC Renewable Scenario 117
Table 7-16: Comparison of Reserve Requirement and Provision by pumped hydro storage and Reciprocating Engines for the CA High-Mix and WI TEPPC Renewable Scenario 119
Table 7-17: Comparison of Reserve Requirement and Provision by pumped hydro storage and Reciprocating Engines for the High-wind (everywhere) Renewable Scenario 120
Table 7-18: Comparison of Reserve Requirement and Provision by pumped hydro storage and Reciprocating Engines for the CA High-Mix and WI High-Wind Renewable Scenario 121
Table 7-19: Comparison of Reserve Requirement and Provision by IH for the High-solar Renewable Scenario 122
Table 7-20: Comparison of Reserve Requirement and Provision by Iowa Hill and Recip for different scenarios and cases (high solar not shown here due to small number of cases run for that scenario) 123
Table 7-21: Summary of Emission Production Differences for a Variety of Renewable Scenario (GWh) 128
Table 7-22: Comparison of Emission Production for the TEPPC Scenario 129
Table 7-23: Comparison of Emission Production for the CA High-Wind and WI TEPPC Renewable Scenario 130
Table 7-24: Comparison of Emission Production for the CA High-Mix and WI TEPPC Renewable Scenario 131
Table 7-25: Comparison of Emission Production for the High-wind (everywhere) Renewable Scenario 132
Table 7-26: Comparison of Emission Production for the CA High-Mix and WI High-Wind Scenario 133
Table 7-27: Comparison of Renewable Energy Curtailment for different scenarios 134
Table 7-28: Summary of change in unit starts over the year for different scenarios and cases 137
Table 7-29: Summary of change in start costs for different scenarios and cases 138
Table 7-30: Summary of Impact of Iowa Hill or recips on ramping Reductions for a Variety of Renewable for different scenarios and cases 139
Table 7-31: Comparison of Thermal Cycling and Start Costs for the TEPPC Scenario 140
Table 7-32: Comparison of Thermal Cycling and Start Costs for the CA High-Wind and WI TEPPC Renewable Scenario 141
Table 7-33: Comparison of Thermal Cycling and Start Costs for the CA High-Mix and WI TEPPC Renewable Scenario 142
Table 7-34: Comparison of Thermal Cycling and Start Costs for the High-wind Renewable Scenario 143
Table 7-35: Comparison of Thermal Cycling and Start Costs for the High Solar Scenario....... 144
Table 7-36: Comparison of Thermal Cycling and Start Costs for the CA High-Mix and WI High-Wind Renewable Scenario 145
Table 7-37: Summary of Annual Average Regional LMP for a Variety of Renewable Scenarios ($/MWh) 147
Table 7-38: Annual Average Regional LMP ($/MWh) for the TEPPC Scenario 151
Table 7-39: Annual Average Regional LMP ($/MWh) for the CA High-Wind and WI TEPPC Renewable Scenario 151

Table 7-40: Annual Average Regional LMP ($/MWh) for the CA High-Mix and WI TEPPC Renewable Scenario....152
Table 7-41: Annual Average Regional LMP($/MWh) for the High-Wind Renewable Scenario....152
Table 7-42: Annual Average Regional LMP ($/MWh) for the High-Solar Scenario....153
Table 7-43: Annual Average Regional LMP ($/MWh) for the CA High-Mix and WI High-Wind Scenario....153
Table 7-44: Summary of Potential Revenue if Iowa Hill was merchant plant....154
Table 7-45: Projected revenue of Iowa Hill operating in a hypothetical market for fixed speed and adjustable speed in high wind case....155
Table 8-1 Max and Min Wind and Solar Forecast Errors in Southern California in a Typical Winter Week of year 2022....**Error! Bookmark not defined.**
Table 8-2 Max and Min Wind and Solar Forecast Error in Southern California in a Typical Summer Week of Year 2022....**Error! Bookmark not defined.**
Table 9-1: PHS Input Comparison....164
Table 9-2: Summary of Iowa Hill values for different cases as determined in ESVT, with generic assumptions for most values. All values in $m....169
Table 10-1: Annual Water Runoff Scenarios for UARP (AF)....172
Table 10-2: SMUD Renewable Portfolio in 2022 for Reference and High Wind Cases....175
Table 10-3: Reference Case, UARP Spillage, Generation and Reserve Provision with and without Iowa Hill....175
Table 10-4: High Wind Case, UARP Generation and Reserve Provision with and without Iowa Hill....176
Table 11-1: Study regions and constituent utilities....187
Table 11-2: Regional demand, capacity and LOLE....188
Table 11-3: Conventional generation removal targets in 33% and 50% scenarios....193
Table 12-1 Transmission line expansion for high-wind renewable scenario....A-3

List of Acronyms

ADI – Ace Diversity Interchange

AGC – Automatic generation control

ANL – Argonne National Laboratory

AS PSH – Adjustable Speed Pumped-storage Hydro Generator

AS – Ancillary Services

BA – Balancing Area

BAA – Balancing Area Authority

BAU – Business as Usual

BPA – Bonneville Power Administration

CAISO – California Independent System Operator

CPS – Control Performance Standards

DA – Day-ahead

DCS – Disturbance Control Standard

DOE – U.S. Department of Energy

DSM – Demand-side management

DSS – Dynamic Scheduling System

ECC – Enhanced Curtailment Calculator

EDT – Efficient Dispatch Toolkit

EIM – Energy Imbalance Market

ERCOT – Electric Reliability Council of Texas

EWITS – Eastern Wind Integration and Transmission Study

FERC – Federal Energy Regulatory Commission

FS PSH – Fixed Speed Pumped-storage Hydro Generator

GW – Gigawatts

HA – Hour-ahead

ISO-NE – ISO New England

ITAP – Intra-hour Transaction Accelerator Platform

MISO – Midwest Independent Transmission System Operator

NERC – North American Electric Reliability Corporation

NREL – National Renewable Energy Laboratory

NTTG – Northern Tier Transmission Group

NWP – numerical weather prediction

NYISO – New York Independent System Operator

ORNL – Oak Ridge National Laboratory

PNNL – Pacific Northwest National Laboratory

RPS – renewable portfolio standards

RT – Real Time

RTO – Regional Transmission Organization

SCED –Security Constrained Economic Dispatch

SCUC –Security Constrained Unit Commitment

SMUD – Sacramento Municipal Utility District

SPP – Southwest Power Pool

TEPPC – Transmission Expansion Planning and Policy Committee of the Western Electricity Coordinating Council

VG – Variable Generation

WAPA – Western Area Power Administration

WI – Western Interconnection

WECC – Western Electricity Coordinating Council

WWSIS – Western Wind and Solar Integration Study

EXECUTIVE SUMMARY

This report summarizes work performed through the Funding Opportunity Announcement DE-FOA 486, which was issued by U.S. Department of Energy (DOE). Sacramento Municipal Utility District (SMUD) has teamed up with Energy Exemplar and EPRI to examine the value of the proposed Iowa Hill Pumped Hydro Storage (PHS) project. The Iowa Hill project is expected to provide several different value streams to its beneficiaries. These include operating flexibility, reliable capacity and environmental advantages. While many of these have already been assessed to a greater or lesser extent in previous work, the purpose of the work carried out under this DOE grant is to refine the existing analysis, with a particular focus on the value to of pumped storage with increasing renewable generation. This value is expected to be found in the SMUD BA generation portfolio as well as the larger state and western region.

Modeling Approaches

As PHS can provide a wide range of values multiple modeling approaches were used. These modeled different value streams and how Iowa Hill could provide value to the SMUD BA for each. The following subsections summarize each of the modeling stages.

Wind and Solar Data and Reserve Requirements

As PHS value is likely to depend to a large degree on variable renewables (wind and solar) penetration. Different scenarios were examined with different renewable penetrations in the SMUD BA and in the entire Western Interconnection. To complete the data requirement, variable generation data synchronous with the load is required. The data needs to be synchronized to capture correlation that may exist between all the sources of variability - load and variable generation resources. This study borrows heavily from National Renewable Energy Lab efforts in modeling systems with high penetrations of variable generation resources. Five different penetration levels were studied, based on the following scenarios:

- **TEPPC:** This is close to the WECC Transmission Expansion Planning Committee Policy Committee 2022 case, with some movement of VG plants. This was done as a bookend for low VG penetration. In this scenario California includes 20% renewable generation and the Western Interconnection (WI) includes 14% renewable generation.
- **High Wind:** This is similar to the NREL Western Wind and Solar Integration Study phase 2 high wind study case with 33% renewable penetration across the WI, most of it wind; there are some changes to the NREL case to ensure 33% penetration in the SMUD BA. This is to examine the case where the entire US portion of the Western Interconnection utilizes significant amounts of wind.
- **High Solar:** This is similar to the NREL Western Wind and Solar Integration Study phase 2 high solar study case with 33% renewable penetration across the WI, most of it solar; there are some changes to the NREL case to ensure 33% penetration in the SMUD BA. This is to examine the case where the entire US portion of the Western Interconnection utilizes significant amounts of solar.
- **CA High Wind, WI TEPPC** examines the case where California, with more aggressive renewable targets, has a high wind penetration the same as that seen in previous case, but the rest of the WI remains at the TEPPC level.

- **CA High Mix, WI TEPPC** assumes California has as much wind as in the previous two cases, but also adds solar such that its renewable penetration is closer to 50%, while the rest of WI still has lower penetrations close to the TEPPC case.
- **CA High Mix, WI High Wind**: This case looks at a situation where the entire WI has 33% of energy from renewables, much of it wind, with additional renewables added to have 50% of energy in California from renewables – the additional energy added is assumed to be solar.

For each of these scenarios, a dataset comprising wind and solar output for every hour of the study year, synchronized to each other and to load, was developed. Then, for each scenario, a time series of reserve requirements was developed. These reserve requirements were determined such that an appropriate amount would be carried to cover variability and uncertainty of wind, solar and load over three different reserve categories: regulating reserve based on managing variability within each dispatch interval, flexible reserve to manage variability prior to the system re-scheduling intervals to balance variability a few hours before the active hour, and 'reliability unit commitment' reserves (developed for this study) which ensures sufficient flexibility to balance the day ahead load and renewable production forecast errors. These reserves were then used in the production simulations.

PLEXOS Modeling and Western Interconnection Database

The main focus of this modeling was in the value Iowa Hill could provide in meeting energy and ancillary services requirements. For this, the PLEXOS tool was utilized. This included a model of the entire Western Interconnection for the 5 scenarios listed above. Based on initial results from this model, the flows between interconnected portions of the WECC and a carved out study region -- the SMUD BA, the rest of California and the Northwest -- were fixed. This smaller footprint was then used to study a range of scenarios, including cases with and without Iowa Hill or reciprocating engines, with and without trading of Ancillary Services (AS) between BAs in the study region , with a sensitivity on using fixed speed versus variable speed PHS, and with fixed and variable speed PHS operating as merchant plants.

The PLEXOS model used the WECC TEPPC case as a starting case, and then added wind and solar as appropriate (note no generation expansion planning was carried out). The data was adjusted as deemed appropriate by the project team (e.g. flexibility characteristics of fossil generation were altered to be more realistic). For the PHS model, advanced capability based on a variable speed drive was modeled in PLEXOS. Both maintenance and forced outages were modeled, while cycling costs were represented based on the best available public information.

The PLEXOS Unit Commitment and Economic Dispatch algorithm provides a detailed co-optimization of energy and ancillary services across the entire study area footprint, including respecting constraints on all generation such as up and down time, ramp rates, minimum stable level etc. Limits on transfers between the different regions in the model are considered, while reserves are carried based on reserve groups for contingency and regulating/flexibility reserves. For the higher renewables scenarios, some additional transmission expansion was included to ensure deliverability of the renewables. PHS is included directly in the co-optimization, which is an important advantage of the PLEXOS tool for evaluating Iowa Hill. The reliability unit commitment in this study included additional consideration of forecast error, which has not previously been done in these types of studies. Finally, the model also included representation of bidding behavior for AS in the model based on historical CA behavior.

Energy Storage Valuation Tool (ESVT)

The Energy Storage Valuation Tool is an EPRI-developed tool which can perform detailed financial analysis of a wide range of value streams for different storage technologies. Unlike PLEXOS it takes prices as inputs (i.e. assumes price taker) but it can also calculate the value of different aspects of the system such as resource adequacy, transmission deferral, etc. Each of these uses assumptions provide by the user, and for this effort, many of the assumptions came either from SMUD or the California Public Utility Commission, which has recently used the tool to study storage value in CA. ESVT is used here mainly to examine the value for resource adequacy, as well as examine the financial performance based on assumptions on prices in future years. It will be extended in future work to also consider transmission deferral in more detail, as well as utilize results from PLEXOS runs to perform additional sensitivities on potential value for energy and AS.

Modeling value to Upper American River Project

The final value stream examined was the improvement in operation of the Upper American River Project due to the Iowa Hill project. For this, SMUD employed a tool which could model the reservoir system in detail, and examined how much spillage reduction (due to being able to pump at times of high water) and efficiency improvement (due to better usage of reservoirs and hydro generation plants) could be attributed to Iowa Hill. This was done for two scenarios, a TEPPC renewables scenario and a high wind scenario.

Study Results

The following table highlights the most important results from the study:

Summary of potential values of Iowa Hill under various scenarios

	Value of Iowa Hill ($000,000 per year and $/kW-yr)							Other Benefits	
Scenario	Net Prod Cost Save [1] $M	Wholesale Revenue AS $M	Wholesale Revenue Energy $M	RA Cap-acity Value [2] $M	UARP Efficiency [3] $M	Min Total $/kW-yr	Max Total $/kW-yr	Curtailed Renewable GWH	Reserve Shortages GWH
TEPPC	12	7	14	20-64	0.1-0.35	80	191	-	-0.5
CA High Wind, WI TEPPC	12	9	-2	20-64	0.1-2.7	80	197	-	-1.2
CA High Mix, WI TEPPC	19	10	-4	20-64	0.1-2.3	97	213	-2	-14.8
CA & WI High Wind	43	5	-6	20-64	0.1-2.0	157	272	-23	-78.5
CA High Mix, WI High Wind	52	10	-12	20-64	0.1-1.9	180	294	-29	-94
High Solar	14	2	-2	20-64	0.1-2.2	85	200	-	-31

Notes:

1. Total production plus import cost minus wholesale revenues from AS and energy
2. Resource Adequacy (RA) is based on range depending on whether avoiding new peaking capacity or allowing for forward looking fixed cost recovery of existing plant
3. UARP efficiency is based on average production costs and water savings for a range of hydro years (wet to medium to dry)

As can be seen, there are a range of values shown. The values shown for the net production cost savings are for cases where AS trading is allowed, which was deemed the most likely situation in the long term. For Resource Adequacy costs, the range varies depending on whether Iowa Hill would avoid new generation plant (high value) or whether it would support forward looking fixed costs for other surplus generation to stay available (low value). The UARP efficiency range is due to the range of high versus low hydro year – normal years would fall somewhere in between values shown here. The values are deduced by multiplying the GWh increase in UARP output by average production cost. Min and Max values are based on combining the other values; the actual value would therefore likely lie somewhere in between.

What is clear is that increasing penetration of renewables increases the value of Iowa Hill to the SMUD BA; this is true even more so as the entire WI starts to see high penetrations, showing how important the remainder of the system is to value of Iowa Hill. It can also be seen that avoided curtailment increases as penetration increases, as does avoided reserve shortfalls. Note that reserve shortfalls are all for flexibility down reserve, which are reserves carried to cover unexpected increases in wind and/or solar output or unexpected decreases in load. Note that increasing levels of wind penetration see significantly more value than increasing levels of solar, likely due to the shape of the solar energy providing more energy at or close to peak demand. Iowa Hill is less valuable in the case of high solar than a high mix or high wind case. This may also be due to the fact that solar requires less reserves to manage forecast error and unexpected variations when looked at on aggregate. In most cases, energy revenue from the rest of California actually decreases for SMUD with Iowa Hill, but this is more than offset by an increase in ancillary services value and a reduction in production costs within the SMUD region, thus always ensuring a reduction in net production costs.

Based on other scenarios examined, other factors driving Iowa Hill value include whether the PHS is fixed or variable speed; in general variable speed seems to show at least one third additional value, but could be as much as double. Another result of interest was when examining the case where the Pumped Hydro Storage has a hydraulic short circuit bypass. In this case, the value of Iowa Hill would be increased by two to four million dollars per year. More details on all costs are given in Chapter 7. In the high mix cases it should be noted that there is significant over capacity as no capacity was assumed to retire with wind and solar added; therefore storage may help contribute to capacity more in those cases in reality; however the regional plant mix in a high wind and solar case (over 50% energy penetration) would likely be so different it is difficult to conclude much.

In addition to examining impact of Iowa Hill on production costs in the SMUD BA, additional simulations were carried out to examine a hypothetical case of Iowa Hill operating as a merchant plant in California, where it would earn marginal costs of energy and ancillary services, and pay marginal costs of energy for pumping. This was examined for both fixed and adjustable speed technology for the high wind case. Adjustable speed technology resulted in a slightly higher capacity factor. The energy revenue and ancillary services revenue would be increased if adjustable speed technology were used. Total revenue from ancillary services and energy would be $24m/year ($60/kW-yr) with adjustable speed, whereas it would be $20.7m/year ($52/kW-yr) with a fixed speed. Of this, ancillary services revenue accounts for $12.4m in the adjustable speed case and $8.7m in the fixed speed case. This potential market revenue can be compared to the above cost savings for SMUD, which showed a potential production cost savings of $43m/year, showing that the value is not just for marginal cost reduction but also system wide production savings.

Other results to note include the fact that cycling of generation was seen to decrease by as much as 50% in SMUD depending on wind/solar scenario, while wind and PV curtailment is reduced by 50%. Emissions savings depend on the scenario, with some scenarios showing significant savings, others not showing much difference in emissions with and without Iowa Hill. The final result to note from the PLEXOS simulations was that the value of reciprocating engines production savings were 20%-25% as much as Iowa Hill.

Follow On Work

As can be seen, a significant variety of scenarios have already been examined. However, future work to understand the impacts better can be divided into future PLEXOS simulations and future work in other areas.

Additional Plexos Modeling

Further work in PLEXOS simulations will include a three –stage approach to the PLEXOS model to capture additional variability and uncertainty of wind and solar, and the contribution storage can make to manage that in daily and real-time operations. Additionally, the following may also be examined:

- The SMUD and neighboring BAs may share balancing and reserve resources under future market designs enabled by advances in information and control technologies.
  - This could mean combining reserve and balancing requirement and resources,
  - This would be modeled for a high wind and high solar scenario
- Develop a plausible plant retirement scenario for the high mix case. In this scenario, the value of both storage and conventional flexible capacity are likely to be higher.
- Look at different hydro conditions (e.g. a dry year)
- Examine Compressed Air Energy Storage – reciprocating engines were not shown to be as good as Iowa Hill (though may be cheaper) – CAES can charge and discharge at the same time and may have greater energy storage amounts
- Utilize a 3 stage modeling approach to more accurately represent the interaction between day ahead, hour ahead and real time scheduling and dispatch. This is explained in more detail in Chapter 8.

Additional Value Analysis in Other Areas

Future work in the ESVT may utilize the prices produced in PLEXOS in the financial analysis, provide more accuracy on transmission and capacity benefits, which are not captured in PLEXOS, and repeat the financial analysis for a variety of assumptions. Further analysis of resource adequacy value in different wind/solar scenarios can also be examined, and other values such as transmission deferral and voltage support can also be assessed.

Finally, the team examined the issues of resource adequacy and examined how increased levels of wind and solar can improve resource adequacy. Therefore, we examined how much capacity credit could be assumed for different wind and solar build outs, and thus how much additional plant may retire. This showed that in increasing from 33% RPS to 50% RPS, the capacity credit of the wind/ solar resource mix is very low, but varies significantly depending on the region examined and the relative amounts of wind and solar. By the time 50% penetration by energy scenarios are examined, the incremental capacity credit is very low. This study can be used in the future to determine how the plant mix may change in the higher penetration scenarios; the PLEXOS results here do not examine significant plant retirements which could be done using results from this study.

1 INTRODUCTION

Background

The work to be performed under this project is in response to the Funding Opportunity Announcement DE-FOA 486, which was issued by U.S. Department of Energy (DOE). Sacramento Municipal Utility District (SMUD) has teamed up with Energy Exemplar and EPRI to perform an analysis of both the geotechnical challenges and the value streams to the SMUD BA for the proposed Iowa Hills Pumped Hydro Storage project. This report outlines the results for the grid value analysis portion of the project.

Project Aims and overall approach

The Iowa Hill project is expected to provide several different value streams to its beneficiaries. These include operating flexibility, reliable capacity and environmental advantages. These have already been assessed in previous work. The purpose of the work proposed in this DOE grant application is to refine the existing analysis, with a particular focus on the value to of pumped storage to meet ancillary service requirements and address variability for increasing renewable generation. This value is expected to be found in the SMUD BA generation portfolio as well as the larger state and western region.

Analysis will determine the value of pumped storage flexibility with the overall generation resource portfolio. This includes contribution to reserves (spinning and regulation) and resource adequacy. Environmental benefits are considered based on deferring transmission projects and lowering the carbon footprint by replacing fossil-based peaking generation with lower emission off-peak generation. With higher penetration of wind and solar envisioned, both in the SMUD BA footprint and in the California in general, there is expected to be increased value related to flexibility offered by pumped hydro storage; this includes the ability to store wind or solar output for use during peak demand periods (energy arbitrage), contribution to reserve requirements which are increased due to wind and/or solar PV, reduction in fossil generation cycling and more optimal usage of the remainder of the SMUD hydro fleet.

The objectives of this part of the study are:

- Determine ancillary service requirements to balance increased variable renewable generation.
- Examine value from pumped storage relative to conventional gas generation for providing on peak energy and ancillary services in the SMUD BA and as part of the entire California region.
- Define and quantify the value streams of Iowa Hill relative to conventional gas units with future anticipated higher levels of variable renewable generation.
- Analyze the net benefits of variable speed versus fixed speed for pumped storage technology.

Innovative Features of approach

To study, in more detail than previously done, the value of Iowa Hill, a number of new approaches were used. Some of these are based on recent innovations in wind and solar integration studies, such as the treatment of forecast error and cycling cost. Other aspects include fully utilizing advanced features of the PLEXOS production simulation tool, while additional tools were also used to value the impact on the Upper American River project (UARP). Finally, the EPRI Energy Storage Valuation Tool (ESVT) was used to analyze a range of multiple value streams. The PLEXOS production simulation tool has been utilized extensively over the past few years to study wind and solar integration impacts, value of new resources, resource expansion, etc. This project utilizes some of the innovative features of the PLEXOS platform as well as the other tools. In the view of the project team, the following points summarize some of the most relevant features of the project: More detail is given in later chapters, particularly Chapter 5

- The forecast error is explicitly treated in the simulation, both for load and wind/PV – this allows for a greater understanding of how flexible resources, particularly pumped hydro storage such as Iowa Hill, can be utilized to mitigate uncertainty
- There is a consideration of the costs related to cycling of conventional plant, which can often be increased due to variable generation; the mitigation of this due to Iowa Hill can be thus be included in the analysis
- Innovative storage simulation in the Hour Ahead and Real Time as described in Chapter 5
- Simulating known forced outage in Day Ahead (that happens in Real Time but becomes known in the subsequent Day Ahead process) to allow for more realistic treatment of outages
- Soft requirement on flex down reserve allows it to be relaxed if otherwise it would require significant wind or solar curtailment.
- Reserves now include load forecast error as well as wind and solar
- In the Day Ahead optimization, there is consideration of the weekly load pattern so that the contribution storage can make in managing day to day changes in wind and solar output can be investigated
- Use of the EPRI Energy Storage Valuation Tool
- Reliability Unit Commitment in the Day Ahead and 4 hour ahead parts of the multi stage modeling, as described in Chapter 5.

Some of these features have been used in previous studies, notably the second phase of the Western Wind and Solar Study led by the National Renewable Laboratory, which developed a number of these new methods.

Report Layout

The report is laid out in the following fashion:

- Chapter 2 outlines the wind and solar profiles developed for production analysis, including description of different scenarios of variable generation build-out developed to analyze how the value of pumped hydro storage changes based on the penetration of variable generation
- Chapter 3 describes the methods used to calculate increased reserve requirements (regulation and spin/non-spin) due to the presence of high wind and solar PV penetrations, as well as presenting summaries of the derived reserve requirements.
- Chapter 4 describes the databases used in the modeling.
- Chapter 5 describes methodology employed thus far for the production simulations carried out in the PLEXOS tool. This includes scenarios examined in this report, the multi-stage

modeling (day ahead, four hour ahead and real time), analysis of cycling costs of conventional fleet, and description of the PLEXOS modeling tool.

- Chapter 6 gives an overview of the most important results from the PLEXOS runs thus far.
- Chapter 7 gives detailed results from the model (note more results for new scenarios and a deeper look at certain aspects are expected in the final report). Results examined include value of storage for the system under different scenarios.
- Chapter 8 introduces the EPRI Energy Storage Valuation Tool, and presents initial findings based on a first set of runs of this tool.
- Chapter 9 presents analysis carried out by SMUD to understand the impacts on UARP operation due to the presence of Iowa Hill in the hydro system.
- Chapter 10 describes results from a capacity value analysis of the increased levels of wind and solar on the SMUD system, which will likely be used in future work examining resource adequacy issues.
- Chapter 11 concludes with the main insights thus far from the study as well as outlining remaining work to complete this part of the analysis of the value of Iowa Hill.

2 WIND AND SOLAR PROFILE DEVELOPMENT

Introduction

This study uses production cost simulation techniques based on sequential modeling of load and resources. To complete the data requirement, variable generation data synchronous with the load is required. The data need to be synchronized to capture correlation that may exist between load and variable generation. This section describes the sources of the data used in this study; the scenarios analyzed and statistical description of the data.

This study borrows heavily from National Renewable Energy Lab efforts in modeling systems with high penetrations of variable generation resources. The wind and solar data, scenarios and various reserve calculation methods are used from the Western Wind and Solar Integration Study (WWSIS) phases one and two and from the Eastern Wind Integration and Transmission Study as well as other supporting efforts.

Sources and Description

Relatively little historical variable generation data has been recorded and when that data does exist it is rarely at the location, resolution and size appropriate for studying future systems. Because of this, we turn to simulated data that can meet the needs of the overall study.

Wind Data

The wind data used in this study was produced for NREL by 3Tier for phase 1 of the Western Wind and Solar Integration Study (WWSIS 1). 3Tier applied a numerical weather prediction (NWP) model to synthesize wind speeds in a 2-km grid at 10 minutes temporal resolution. These simulations were run as “back-casts” where the 3 dimensional atmospheric conditions at every grid point were calculated as known atmospheric data from the time were feed into the model on a continuous basis to keep the model ‘true’. This resulted in a large number of locations of which more than 30,000 grid points were retained. This provided nearly 1 TW of hypothetical wind plant output across the western interconnect. The simulations were run for the years 2004 through 2006 resulting in 10 minute time series of wind plant output for these 3 years.

The initial dataset was found to have an anomaly caused by periodic restarts of the model. This caused an increase in variability every 3rd day at midnight UTC that was only seen when plants were aggregated together. This increase in variability led to skewing of variability statistics and unrealistic ramps at this boundary. This problem has been well documented. As part of the WWSIS phase 2 project, these anomalies were corrected using statistical techniques yielding a new dataset without the artificial increase in variability[1]. This modified dataset was used for this study.

---

[1] Hummon, M.; Ibanez, E.; Brinkman, G.; Lew, D. (2012). “Sub-Hour Solar Data for Power System Modeling From Static Spatial Variability Analysis: Preprint.” Prepared for the 2nd International Workshop on Integration of Solar Power in Power Systems, Nov. 12–13, 2012, Lisbon, Portugal.

This data set included forecast information at several time horizons. The original 3Tier study developed day-ahead forecasts using the NWP model that were found to have significant bias towards over-forecasting. Additional corrections were applied at NREL to correct the statistics of these forecasts with state-of-the-art forecast for actual operating power plants.

A four-hour-ahead wind forecast for each site was also synthesized. Since there was not a NWP forecast made as part of the original data, a new approach was required. Through experiment, it was found that the statistical characteristics of a four-hour-ahead skill forecast are similar to a two hour persistence forecast where the forecast for two hours from a particular time is the same as the current value of production.

Also, a one-hour-ahead forecast was developed as a simple one hour persistence forecast. While not used in the simulations directly, the one-hour-ahead forecasts are used in developing reserve requirements as will be seen in a coming section.

Solar Data

The solar data used in this study was developed at NREL for the WWSIS phase 2 study. This data was based on satellite based solar irradiance observations for the year 2006 which covered the majority of the western interconnect. The measurements are hourly at .1 degree resolution. Sub-hourly data was synthesized by observing behavior in surrounding grid cells to estimate intra-hour production. Filters based on the size of the plant were used to control the variability seen. Larger plants covering large geographic areas naturally see less variability than smaller plants.

Variable Generation Scenarios and Mixes Used

The variable generation scenarios used in this study are adaptations of scenarios used in the NREL WWSIS phase 2 study. Those scenarios used high penetrations of wind and solar to achieve 33% total VG penetration in the main study scenarios. The penetration is based on energy and referenced to the United States western interconnection load and variable generation resources only. A reference scenario was also used that was based on WECC TEPPC 2020 reference case.

The initial scenarios were developed using NREL's ReEDS (Regional Energy Deployment System) capacity planning tool. ReEDS sited wind and solar energy requirements to the western interconnect based 34 regions based on constraints supplied by the study team. Those requirements were then used to manually site wind from the NREL WWSIS-1 wind dataset and to locate solar resources based on a number of criteria. Three types of solar resources were considered:

- Distributed PV – Primarily modeled as rooftop PV in population centers. Siting was done based on population density.
- Utility Scale PV – Larger PV installations 33% of which were located near population centers and the other 67% located based on best available resources.
- Concentrated Solar Power with storage – Located based on best available solar resources.

Regardless of the penetration, the targets for the overall solar were 40% CSP and 60% PV of which 40% was distributed and 60% was utility scale.

Six scenarios were eventually examined which will be presented in this report. These are made up by combining a number of different wind and solar mixes, as shown in Table 2-1.

Table 2-1: Scenarios Used in Study

Renewable Scenario	Renewable Penetration levels			
	CA	**SMUD BA**	**NW**	**Rest of WI**
TEPPC	**Base TEPPC from WWSIS 2 Study**			
High Wind	**High-Wind (33% mix from WWSIS 2 Study)**			
High Solar	**High-Solar (33% mix from WWSIS 2 Study)**			
CA High Wind, WI TEPPC	**High-Wind (33%)**		**TEPPC**	
CA High Mix, WI TEPPC	**High-Mix (50%)**		**TEPPC**	
CA High Mix, WI High Wind	**High-Mix (50%)**		**High Wind (33%)**	

As can be seen, there are essentially three different VG mixes which are chosen from here, a mix based on WECC TEPPC and from the NREL WWSIS 2 study, and then two more penetrations, a mix with 33% based on a high wind but relatively low solar, a mix with high solar but less wind; a 50% mix is then used based on combining the two. By choosing which areas of the simulation were assumed to have these different penetrations, the 6 final scenarios could be chosen. For example, the 2nd scenario used the full 33% mix described below, whereas the 3rd uses the SMUD BA and rest of California data from the 33% mix, but then uses the wind and solar data from the base reference mix described later. In this way a number of relevant scenarios could be chosen. The rationale for each scenario is as follows:

- **TEPPC:** This is close to the WECC Transmission Expansion Planning Committee Policy Committee 2022 case, with some movement of VG plants. This was done as a bookend for low VG penetration
- **High Wind:** This is similar to the NREL WWSIS-2 study case with some changes as to ensuring 33% penetration in the SMUD BA. This is to examine the case where the entire US portion of the Western Interconnection sees significant amounts of wind.
- **High Solar:** This case is similar to the WWSIS-2 high solar case which has a 33% total VG target for the western interconnect with a 25% solar target and 8% wind target. Some adjustments were made in the original WWSIS-2 scenario to force approximately 33% penetration in the SMUD BA.

- **CA High Wind, WI TEPPC:** examines the case where California, with more aggressive renewable targets, has a high wind penetration, but the rest of the WI does not.
- **CA High Mix, WI TEPPC** assumes California has as much wind as in the previous two cases, but also adds solar such that its renewable penetration is closer to 50%, while the rest of WI still has lower penetrations close to the TEPPC case.
- **CA High Mix, WI High Wind**: This case looks at a situation where the entire WI has 33% of energy from renewables, much of it wind, with additional renewables added to have 50% of energy in California from renewables – the additional energy added is assumed to be solar.

These 6 scenarios allow for a good mix of examining how the value increases with increasing VG, how the penetration levels of other parts of the west impact the value, and how wind and solar impact differently. The next few sections describe the individual component scenarios

33% Penetration Mix – High Wind

The 33% penetration mix is substantially the same as the WWSIS-2 high-wind scenario which has wind penetration of 25% and solar penetration of 8%. Note that the 33% penetration target applies to the western interconnect as a whole but not to each BAA within it. This mix tends to have higher penetrations in the wind rich areas in the eastern parts of the interconnection.

Changes were made to the mix to force 33% penetration in the SMUD BA to meet a 33% RPS mandate. To accomplish this, four 52 MW PV plants in Southern California Edison were changed to SMUD and their output moved to the SMUD BA for zonal runs. Ownership implies the requirement that the owning BAA is responsible for balancing the variability of the resource and must carry reserves for the plant. In addition, some changes to the wind plant assignments were made to improve the diversity of the fleet. Plants were swapped with PG&E and SPP territories to accomplish this goal.

Figure 2-1 shows the locations of the resources for the entire western interconnect and Table 2-2 summarizes these resources by reserve zone (20 reserve zones were used for the WI). The total for the interconnection is approximately 93 GW of variable generation producing 258 TWh for the study year. Within the SMUD BA, there is a total 2.5 GW variable generation capacity and 2.3 TWh of annual energy. Once this 33% penetration level mix was determined, the relevant pieces of it could then be picked to match the scenarios determined above.

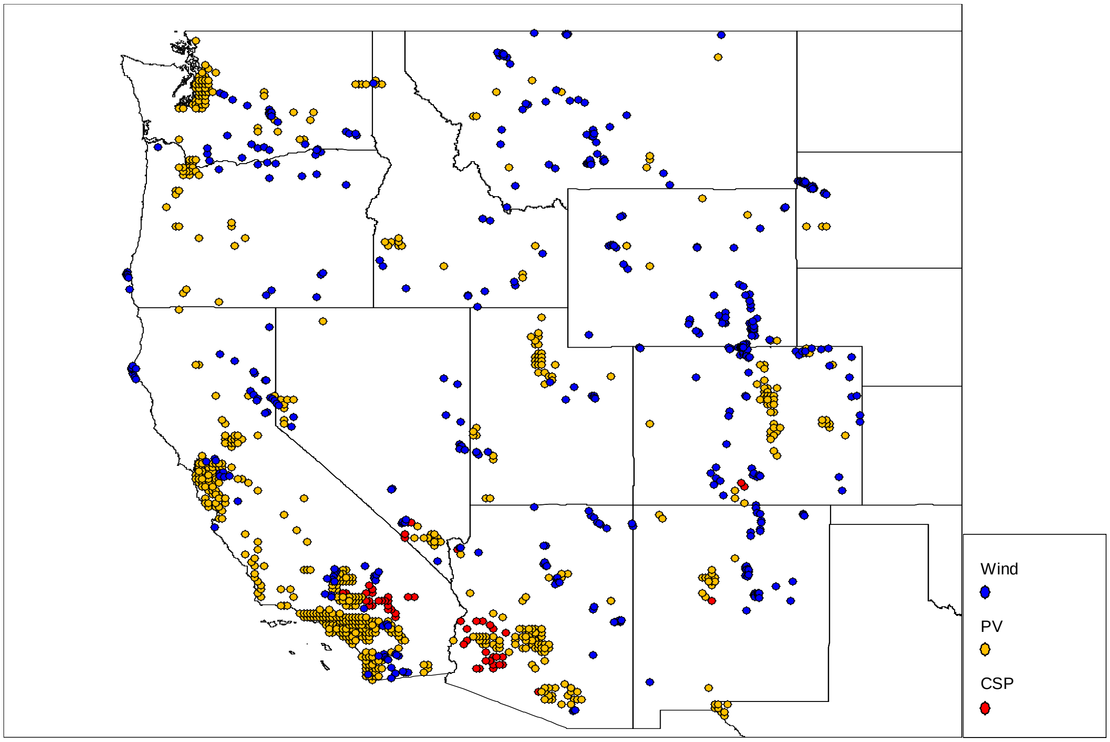


Figure 2-1 - Resource map for 33% mix

Table 2-2 - 33% mix (high wind) variable generation by reserve zone

	Load		Wind			Rooftop PV			Utility PV			CSP			Total		
Area	Peak (MW)	Energy (TWh)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)
Alberta	15843	114	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Arizona	21801	98	4941	13072	13%	1991	3357	3%	2330	5065	5%	2853	10741	11%	12114	32235	33%
British Columbia	11981	66	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
California North	12489	58	2014	5058	9%	393	595	1%	865	1649	3%	0	0	0%	3272	7303	13%
California South	21824	98	5671	17806	18%	2397	3722	4%	2571	5878	6%	2068	8017	8%	12707	35424	36%
Colorado	12564	73	14656	49740	69%	1072	1705	2%	1109	2137	3%	169	541	1%	17005	54124	75%
Idaho	5376	27	1348	3407	13%	0	1	0%	0	1	0%	0	0	0%	1349	3408	13%
IID	1202	5	1606	3358	74%	41	68	1%	422	932	21%	0	0	0%	2069	4358	96%
LDWP	8188	39	0	0	0%	984	1526	4%	665	1544	4%	851	3293	8%	2500	6363	16%
Mexico (CFE)	3443	18	294	602	3%	14	21	0%	0	0	0%	0	0	0%	308	624	3%
Montana	1982	12	6148	19322	160%	18	24	0%	28	42	0%	0	0	0%	6194	19388	160%
Nevada North	2155	13	2366	6053	47%	91	147	1%	270	486	4%	0	0	0%	2727	6687	52%
Nevada South	6725	29	1410	3987	14%	307	520	2%	289	553	2%	439	1623	6%	2445	6684	23%
New Mexico	5120	28	4784	16094	57%	233	404	1%	361	852	3%	156	526	2%	5533	17877	64%
Northwest	30589	172	12694	31863	19%	503	575	0%	611	1069	1%	0	0	0%	13808	33507	19%
San Diego	4816	24	88	111	0%	318	488	2%	225	443	2%	0	0	0%	632	1041	4%
San Francisco	8933	47	0	0	0%	687	1012	2%	250	435	1%	0	0	0%	937	1447	3%
SMUD BA	4230	16	1915	4198	26%	224	333	2%	356	805	5%	0	0	0%	2495	5335	33%
Utah	8479	39	1583	4486	11%	294	439	1%	281	542	1%	0	0	0%	2158	5467	14%
Wyoming	1849	14	4544	16573	121%	66	101	1%	13	22	0%	0	0	0%	4623	16696	122%
Total (US Only)	161763	810	66060	195729	24%	9635	15039	2%	10647	22458	3%	6536	24742	3%	92877	257968	32%

50% Penetration Mix

The 50% penetration mix used the 33% mix but merged the WWSIS-2 high-solar scenario solar resources into the model. This yielded a mix with 25% wind and 25% solar resources. In addition to the changes made for the SMUD BA in the 33% mix, 4 additional PV plants (524 MW) and 3 CSP plants (446 MW) were transferred to the SMUD BA ownership from Southern California Edison to bring the penetration in the SMUD BAA to 50%.

Figure 2-2 shows the location of the variable generation resources in the 50% mix and Table 2-3 provides a summary of the resources located in the 20 zones. The actual total penetration of this case is approximately 48%. The departure from the target is due to the fact that energy was sited based on the average of three year values and 2006, the source year, was the lowest of the years in average. The overall total variable generation capacity is 150 GW with a total energy of 391 TWh. The SMUD BA has 3.5 GW of VG capacity with a total of 8.2 TWh of energy.

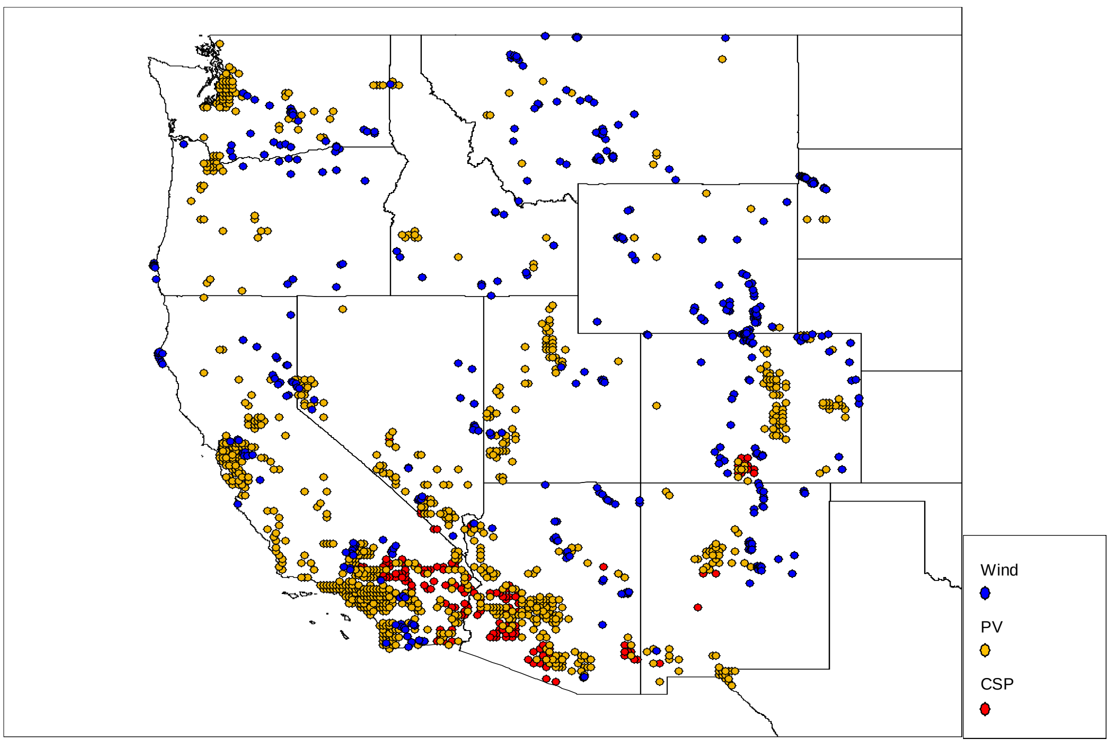


Figure 2-2 - Resource map for 50% mix

Table 2-3 - 50% mix variable generation by reserve zone

	Load		Wind			Rooftop PV			Utility PV			CSP			Total		
Area	Peak (MW)	Energy (TWh)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)
Alberta	15843	114	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Arizona	21801	98	4941	13072	13%	4585	7729	8%	10020	20524	21%	9644	35340	36%	29190	76666	78%
British Columbia	11981	66	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
California North	12489	58	2014	5058	9%	484	735	1%	1490	2695	5%	0	0	0%	3988	8488	15%
California South	21824	98	5671	17806	18%	5150	7998	8%	8683	17396	18%	6635	24918	25%	26140	68119	70%
Colorado	12564	73	14656	49740	69%	1141	1816	3%	4417	8492	12%	1440	4463	6%	21654	64511	89%
Idaho	5376	27	1348	3407	13%	0	1	0%	0	1	0%	0	0	0%	1349	3408	13%
IID	1202	5	1606	3358	74%	76	128	3%	1361	2626	58%	950	3559	78%	3994	9670	213%
LDWP	8188	39	0	0	0%	2132	3306	8%	1263	2554	6%	1043	4019	10%	4438	9879	25%
Mexico (CFE)	3443	18	294	602	3%	15	24	0%	50	121	1%	0	0	0%	359	747	4%
Montana	1982	12	6148	19322	160%	21	27	0%	28	42	0%	0	0	0%	6196	19391	160%
Nevada North	2155	13	2366	6053	47%	432	697	5%	3331	6585	51%	110	395	3%	6239	13731	107%
Nevada South	6725	29	1410	3987	14%	341	577	2%	3311	7021	24%	686	2395	8%	5748	13981	48%
New Mexico	5120	28	4784	16094	57%	1088	1892	7%	3239	6837	24%	574	1923	7%	9685	26745	95%
Northwest	30589	172	12694	31863	19%	552	631	0%	903	1507	1%	0	0	0%	14148	34001	20%
San Diego	4816	24	88	111	0%	394	601	3%	275	551	2%	0	0	0%	757	1263	5%
San Francisco	8933	47	0	0	0%	753	1110	2%	300	509	1%	0	0	0%	1053	1619	3%
SMUD BA	4230	16	1915	4198	26%	246	365	2%	880	2027	12%	446	1606	10%	3487	8196	50%
Utah	8479	39	1583	4486	11%	1740	2593	7%	2463	4623	12%	0	0	0%	5786	11702	30%
Wyoming	1849	14	4544	16573	121%	392	597	4%	739	1323	10%	0	0	0%	5675	18493	135%
Total (US Only)	161763	810	66060	195729	24%	19543	30827	4%	42755	85434	11%	21526	78618	10%	149885	390609	48%

Reference Mix

The reference mix was adapted from the WECC TEPPC reference case for the year 2020. Figure 2-3 shows the location of the variable resources in this mix. Table 2-4 shows a summary of the variable generation resources for each of the 20 zones. There is a total of 39 GW of variable generation capacity in this mix with energy of 103 TWh for a penetration of 13%. In SMUD, the VG capacity is 1.7 GW with energy of 2.1 TWh.

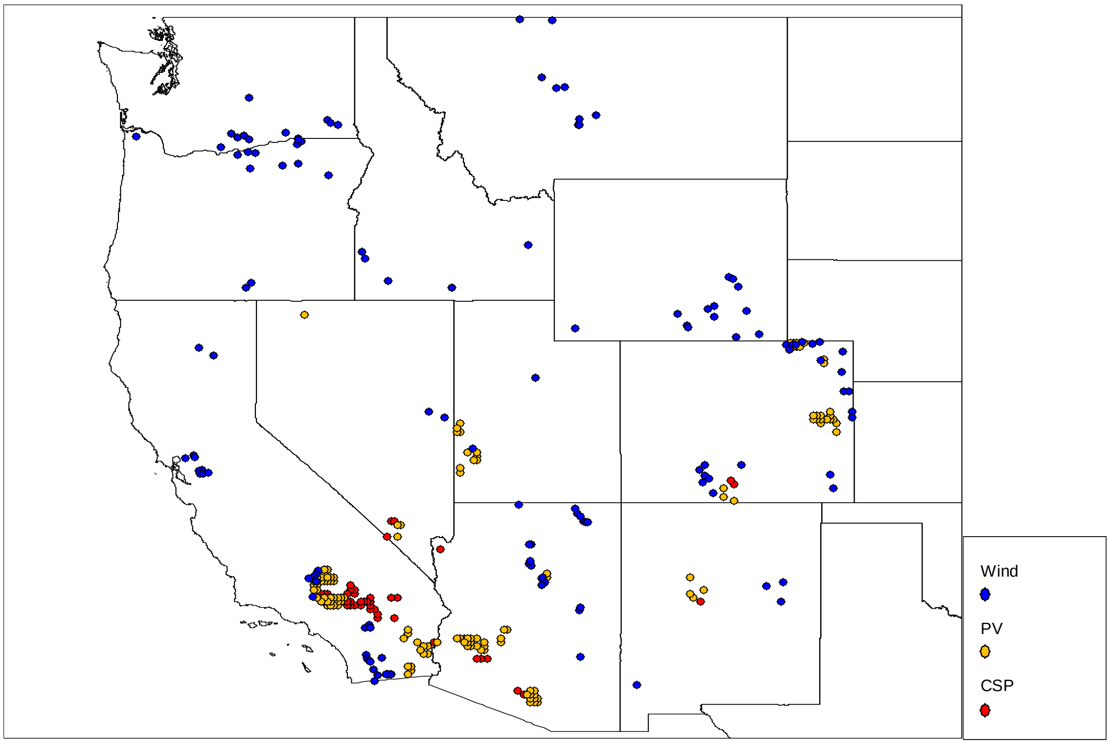


Figure 2-3 - Resource map for reference mix

Table 2-4 - Reference mix variable generation by reserve zone

	Load		Wind			Rooftop PV			Utility PV			CSP			Total		
Area	Peak (MW)	Energy (TWh)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)
Alberta	15843	114	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Arizona	21801	98	3681	9689	10%	0	0	0%	1171	2284	2%	472	1790	2%	5324	13763	14%
British Columbia	11981	66	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
California North	12489	58	724	1297	2%	0	0	0%	0	0	0%	0	0	0%	724	1297	2%
California South	21824	98	3991	12631	13%	0	0	0%	2542	5381	5%	2083	8095	8%	8617	26107	27%
Colorado	12564	73	3916	10904	15%	0	0	0%	1312	2333	3%	169	541	1%	5397	13779	19%
Idaho	5376	27	568	1341	5%	0	0	0%	0	0	0%	0	0	0%	568	1341	5%
IID	1202	5	1306	2935	65%	0	0	0%	234	506	11%	0	0	0%	1540	3441	76%
LDWP	8188	39	0	0	0%	0	0	0%	513	1202	3%	1043	4019	10%	1556	5220	13%
Mexico (CFE)	3443	18	294	602	3%	0	0	0%	0	0	0%	0	0	0%	294	602	3%
Montana	1982	12	838	2465	20%	0	0	0%	228	396	3%	0	0	0%	1066	2861	24%
Nevada North	2155	13	206	468	4%	0	0	0%	284	551	4%	334	1238	10%	824	2257	18%
Nevada South	6725	29	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
New Mexico	5120	28	494	1217	4%	0	0	0%	170	397	1%	156	526	2%	820	2140	8%
Northwest	30589	172	9454	21748	13%	0	0	0%	0	0	0%	0	0	0%	9454	21748	13%
San Diego	4816	24	58	106	0%	0	0	0%	0	0	0%	0	0	0%	58	106	0%
San Francisco	8933	47	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
SMUD BA	4230	16	823	1117	7%	0	0	0%	255	583	4%	96	364	2%	1174	2064	13%
Utah	8479	39	383	1087	3%	0	0	0%	260	450	1%	0	0	0%	642	1538	4%
Wyoming	1849	14	1064	3884	28%	0	0	0%	104	176	1%	0	0	0%	1168	4060	30%
Total (US Only)	161763	810	27798	71493	9%	0	0	0%	7074	14259	2%	4352	16574	2%	39224	102325	13%

33% Penetration High Solar Scenario

A final scenario was added to the project that had a high penetration of solar resources throughout the western interconnection. This scenario is modeled after the WWSIS-2 high solar scenario which has roughly 25% solar and 8% wind penetration. Again, the 33% penetration applies to the western interconnection as a whole and no targets are set for individual BAAs or states. This scenario tends to have significantly higher penetrations in the southern areas of the interconnection.

This scenario was built to provide a roughly 33% VG penetration in the SMUD BA. This was done by using the solar resources developed for the 50% scenario which totaled approximately 25% penetration in SMUD. This included all of the resources assigned to SMUD in the WWSIS-2 high solar scenario with 4 additional PV plants (524 MW) and 3 CSP plants (446 MW) transferred from Southern California Edison to make up the 25% solar target. The wind resources in the scenario are approximately the same as the wind resources in WWSIS-2 high solar scenario with several plants added to the SMUD BA to bring its wind penetration up to the 8% target.

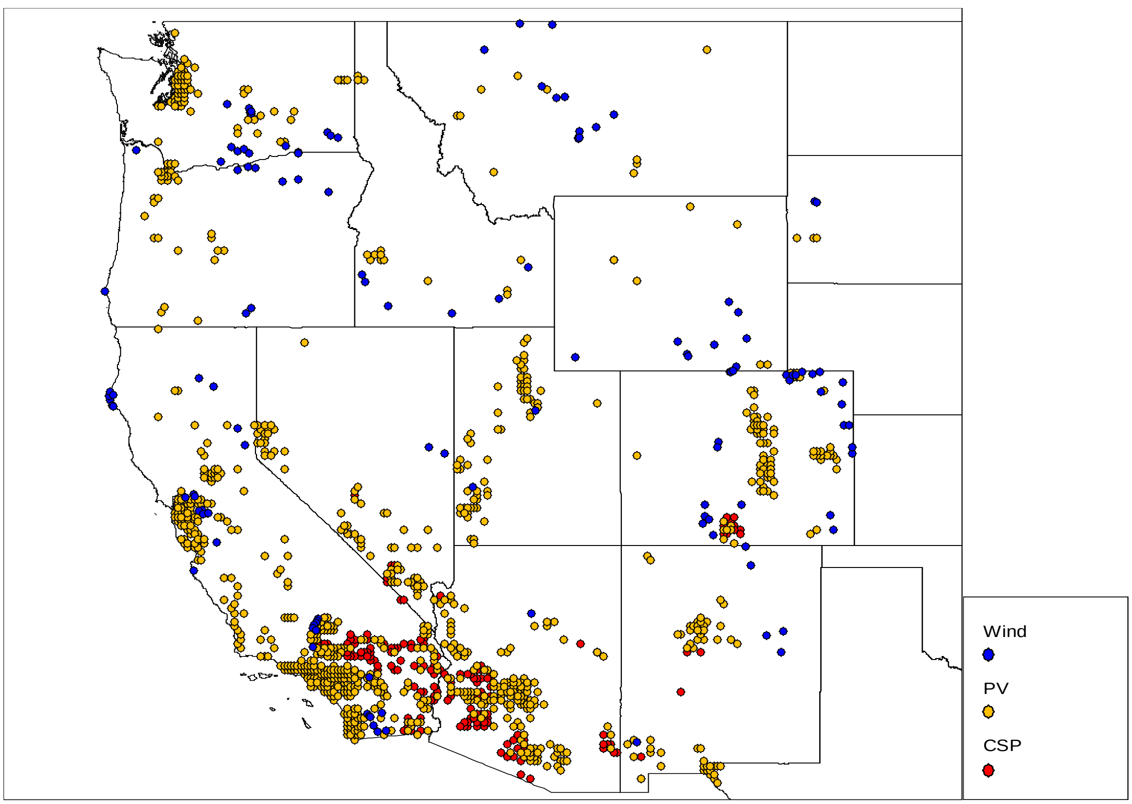


Figure 2-4 - Resource map for high-solar scenario

Table 2-5 – High solar mix variable generation by reserve zone

	Load		Wind			Rooftop PV			Utility PV			CSP			Total		
Area	Peak (MW)	Energy (TWh)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)	Capacity (MW)	Energy (GWh)	Pen. (%)
Alberta	15843	114	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Arizona	21801	98	270	784	1%	4585	7839	8%	10020	20875	21%	9644	35237	36%	24519	64735	66%
British Columbia	11981	66	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
California North	12489	58	2014	5329	9%	484	743	1%	1490	2719	5%	0	0	0%	3988	8790	15%
California South	21824	98	2924	10039	10%	5150	8184	8%	8683	17723	18%	6635	24609	25%	23392	60556	62%
Colorado	12564	73	4577	13827	19%	1141	1827	3%	4417	8557	12%	1440	4481	6%	11575	28692	40%
Idaho	5376	27	628	1621	6%	0	1	0%	0	1	0%	0	0	0%	629	1623	6%
IID	1202	5	797	1806	40%	76	131	3%	1361	2686	59%	950	3627	80%	3185	8250	182%
LDWP	8188	39	0	0	0%	2132	3386	9%	1263	2584	7%	1043	3995	10%	4438	9965	25%
Mexico (CFE)	3443	18	235	507	3%	15	24	0%	50	123	1%	0	0	0%	300	654	4%
Montana	1982	12	928	2934	24%	21	27	0%	28	43	0%	0	0	0%	976	3004	25%
Nevada_North	2155	13	206	501	4%	432	708	5%	3331	6694	52%	110	394	3%	4079	8296	64%
Nevada_South	6725	29	0	0	0%	341	589	2%	3311	7156	25%	686	2401	8%	4338	10146	35%
New Mexico	5120	28	644	1846	7%	1088	1921	7%	3239	6917	25%	574	1921	7%	5545	12606	45%
Northwest	30589	172	9576	24789	14%	552	641	0%	903	1512	1%	0	0	0%	11030	26942	16%
San Diego	4816	24	58	106	0%	394	618	3%	275	564	2%	0	0	0%	727	1288	5%
San Francisco	8933	47	0	0	0%	753	1115	2%	300	512	1%	0	0	0%	1053	1627	3%
SMUD	4230	16	682	1341	8%	246	368	2%	880	2059	13%	446	1598	10%	2254	5367	33%
Utah	8479	39	323	907	2%	1740	2623	7%	2463	4671	12%	0	0	0%	4526	8201	21%
Wyoming	1849	14	1004	3713	27%	392	605	4%	739	1336	10%	0	0	0%	2135	5654	41%
Total (US Only)	161763	810	24866	70050	9%	19543	31351	4%	42755	86731	11%	21526	78262	10%	108691	266394	33%

Statistical Analysis

Monthly Energy

This section presents variable generation energy information for several study regions. This data is based upon the three mixes discussed in the previous section and provides a breakdown to the monthly timeframe. From the tables and graphs, one can determine the monthly and seasonal delivery of the variable energy.

The first region is the SMUD BA. Table 2-6 and Figure 2-5 show these results. Production peaks in the spring for all mixes but the peak in penetration even more pronounced in March or April depending on the mix. With its higher solar penetration, the 50% mix peaks a little bit later with the solar peak occurring in April or May. Wind tends to peak in the winter to early spring as seen in the 33% mix.

Table 2-6 - VG penetration (GWh) for the SMUD BA

		Reference Mix		33% Wind Mix		50% Mix		High Solar	
	Load (GWh)	**VG (GWh)**	**%**	**VG (GWh)**	**%**	**VG (GWh)**	**%**	**VG (GWh)**	**%**
Jan	**1307**	**173**	**13%**	**503**	**38%**	**643**	**49%**	**330**	**25%**
Feb	**1091**	**137**	**13%**	**403**	**37%**	**563**	**52%**	**316**	**29%**
Mar	**1225**	**239**	**19%**	**600**	**49%**	**795**	**65%**	**435**	**36%**
Apr	**1195**	**223**	**19%**	**531**	**44%**	**804**	**67%**	**492**	**41%**
May	**1324**	**224**	**17%**	**472**	**36%**	**794**	**60%**	**553**	**42%**
Jun	**1472**	**206**	**14%**	**414**	**28%**	**711**	**48%**	**510**	**35%**
Jul	**1703**	**219**	**13%**	**444**	**26%**	**736**	**43%**	**513**	**30%**
Aug	**1660**	**194**	**12%**	**379**	**23%**	**681**	**41%**	**513**	**31%**
Sep	**1440**	**176**	**12%**	**416**	**29%**	**677**	**47%**	**454**	**32%**
Oct	**1277**	**170**	**13%**	**418**	**33%**	**617**	**48%**	**387**	**30%**
Nov	**1229**	**130**	**11%**	**419**	**34%**	**566**	**46%**	**312**	**25%**
Dec	**1370**	**174**	**13%**	**520**	**38%**	**636**	**46%**	**304**	**22%**
Total	**16293**	**2264**	**14%**	**5520**	**34%**	**8222**	**50%**	**5121**	**32%**

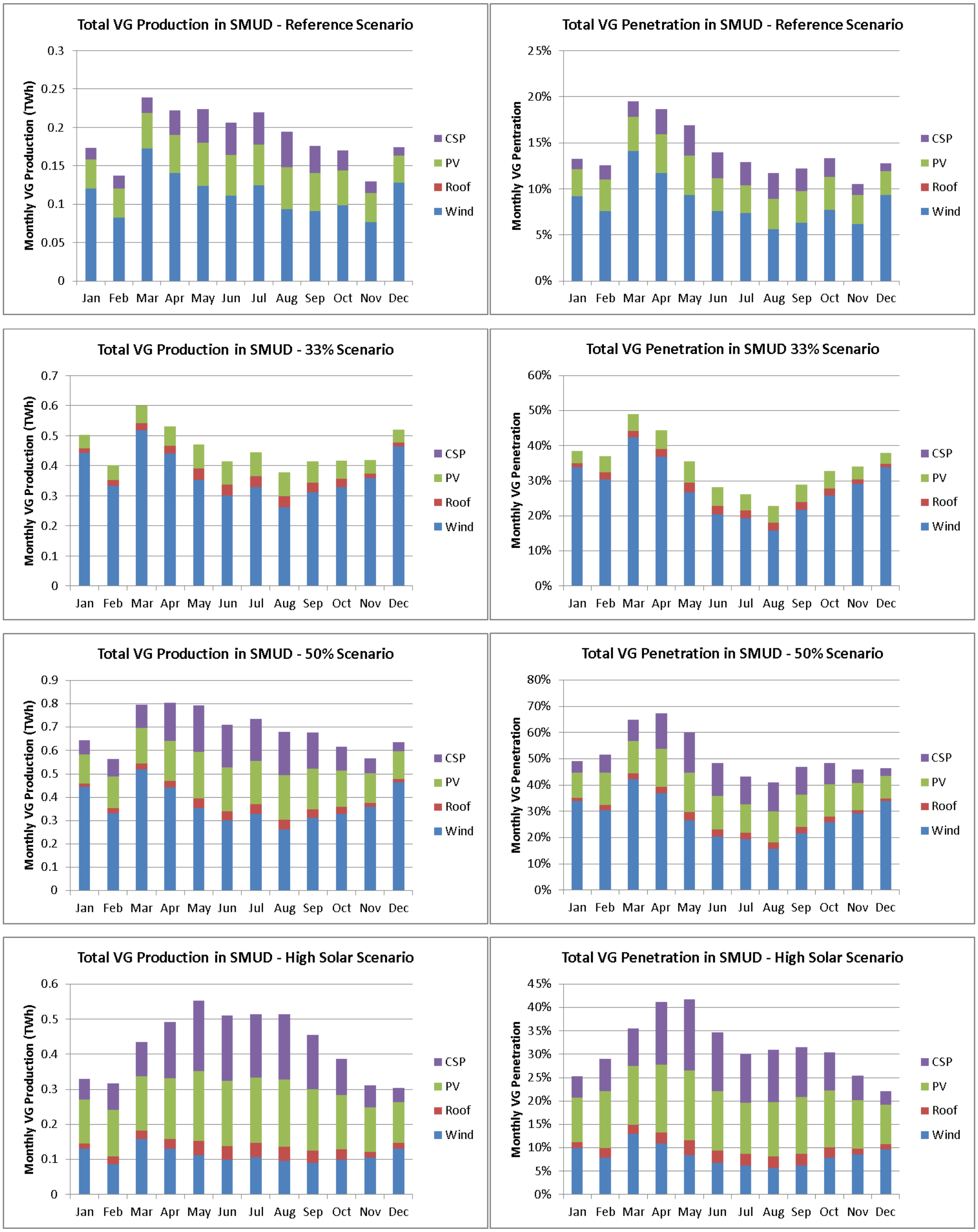


Figure 2-5 - Monthly variable resources energy for the SMUD BA

Table 2-7 and Figure 2-6 show the monthly production for a region including all BAs in California. Recall that the overall penetration for California BAs other than the SMUD BA is less than the overall 33% and 50% targets for the Western Interconnect. The overall pattern is similar to the SMUD BA but difference in penetration from summer to winter is lower because of the relatively high amount of solar resources in all of California compared to the SMUD BA.

Figure 2-6 - Monthly variable resource energy for all of California

Table 2-7 - VG penetration (GWh) for all of California

		Reference Scenario		33% Scenario		50% Scenario		High Solar Scenario	
	Load (GWh)	VG (GWh)	%	VG (GWh)	%	VG (GWh)	%	VG (GWh)	%
Jan	22320	2782	12%	4663	21%	7112	32%	5943	27%
Feb	19145	2561	13%	4220	22%	6877	36%	5922	31%
Mar	21836	3505	16%	5598	26%	8821	40%	7478	34%
Apr	21447	3555	17%	5579	26%	9815	46%	8635	40%
May	23894	3955	17%	6025	25%	11072	46%	10051	42%
Jun	25791	3407	13%	5281	20%	9939	39%	9206	36%
Jul	28490	3451	12%	5436	19%	10070	35%	9303	33%
Aug	28598	3459	12%	5268	18%	10119	35%	9417	33%
Sep	25258	2948	12%	4723	19%	8974	36%	8282	33%
Oct	23770	2690	11%	4324	18%	7617	32%	6806	29%
Nov	22720	2474	11%	4084	18%	6575	29%	5706	25%
Dec	23407	2078	9%	3742	16%	5836	25%	4973	21%
Total	286677	36866	13%	58942	21%	102825	36%	91721	32%

The northwest zone is made up of BAs from Washington and Oregon. This zone has relatively low penetration overall penetration in the high penetration cases. This is due to several factors. There is very low solar resource in this area so the increment in variable energy between the 33% and 50% mixes is minor. More importantly, the northwest region is hydro rich. Very high variable generation penetrations would result in backing down of hydro frequently, and ultimately spilling water.

Table 2-8 and Figure 2-7 show the results for the northwest zone. Most of the variable resources in the northwest are wind which peaks in the winter for this zone with November and January showing the highest production. This lead to a more than 2:1 energy ratio (4:1 in the reference case) for winter months compared to summer. However, the northwest is a winter peaking load so the penetration ratios are not as large.

Table 2-8 - VG penetration (GWh) for northwestern zone

		Reference Scenario		33% Scenario		50% Scenario		High Solar Scenario	
	Load (GWh)	VG (GWh)	%	VG (GWh)	%	VG (GWh)	%	VG (GWh)	%
Jan	16465	3818	23%	5153	31%	5170	31%	3934	24%

Feb	**14192**	**2294**	**16%**	**3261**	**23%**	**3292**	**23%**	**2483**	**17%**
Mar	**14489**	**2034**	**14%**	**2978**	**21%**	**3014**	**21%**	**2215**	**15%**
Apr	**13357**	**1502**	**11%**	**2406**	**18%**	**2449**	**18%**	**1752**	**13%**
May	**13348**	**1692**	**13%**	**2763**	**21%**	**2813**	**21%**	**2001**	**15%**
Jun	**13255**	**1460**	**11%**	**2466**	**19%**	**2515**	**19%**	**1767**	**13%**
Jul	**14089**	**1233**	**9%**	**2389**	**17%**	**2447**	**17%**	**1588**	**11%**
Aug	**14045**	**1326**	**9%**	**2412**	**17%**	**2468**	**18%**	**1665**	**12%**
Sep	**12935**	**1386**	**11%**	**2275**	**18%**	**2320**	**18%**	**1651**	**13%**
Oct	**13712**	**1840**	**13%**	**2784**	**20%**	**2820**	**21%**	**2072**	**15%**
Nov	**15189**	**3429**	**23%**	**4655**	**31%**	**4672**	**31%**	**3537**	**23%**
Dec	**16610**	**1990**	**12%**	**2946**	**18%**	**2964**	**18%**	**2104**	**13%**
Total	**171686**	**24004**	**14%**	**36488**	**21%**	**36944**	**22%**	**26769**	**16%**

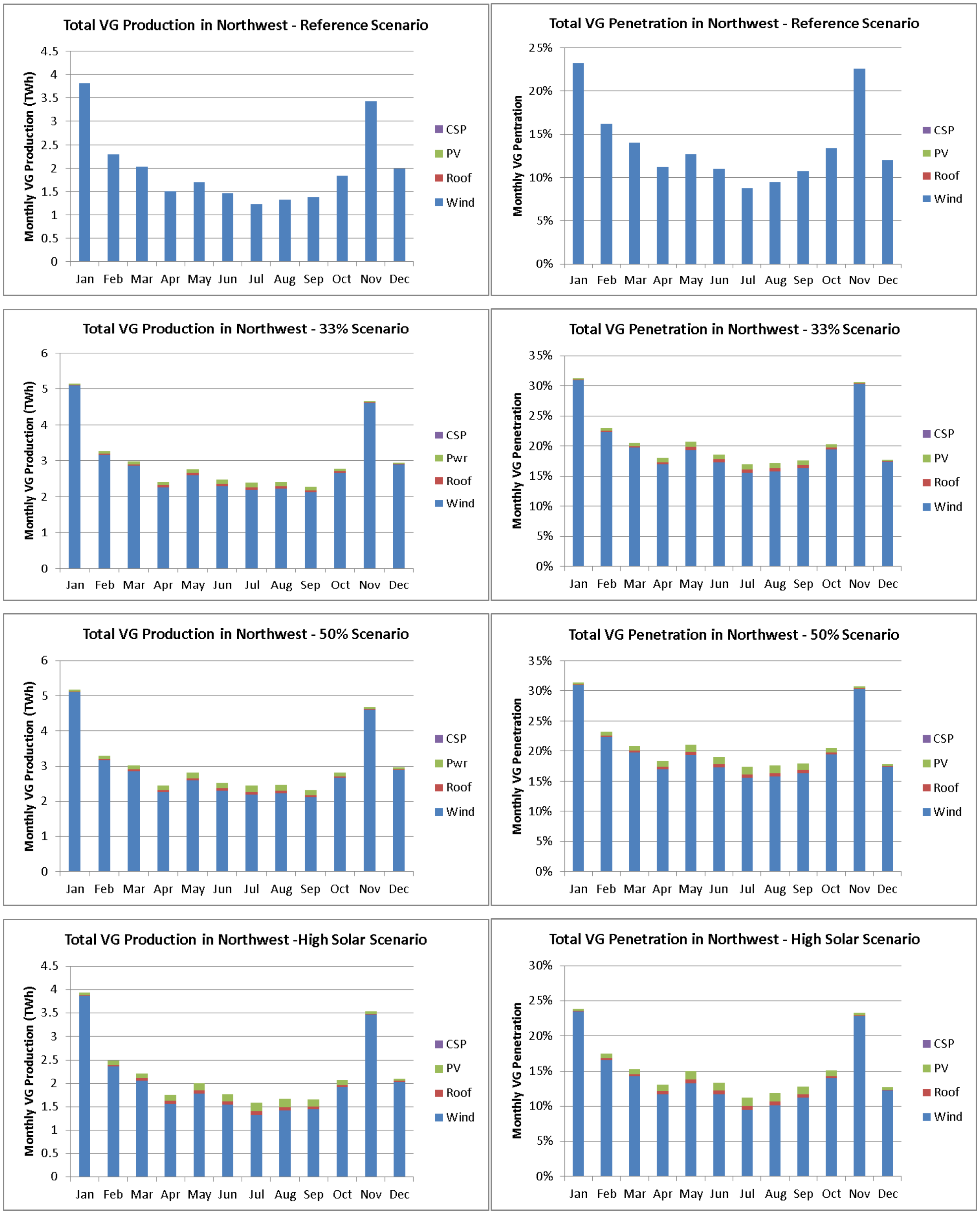


Figure 2-7 - VG penetration (GWh) for northwestern zone

Finally, Table 2-9 and Figure 2-8 show the results for the entire US Western Interconnect.

Table 2-9 - VG penetration (GWh) for US Western Interconnect

		Reference Scenario		33% Scenario		50% Scenario		High Solar Scenario	
	Load (GWh)	VG (GWh)	%	VG (GWh)	%	VG (GWh)	%	VG (GWh)	%
Jan	66828	11311	17%	29743	45%	37189	56%	19970	30%
Feb	57790	8944	15%	24552	42%	32838	57%	18867	33%
Mar	62684	9926	16%	24282	39%	33794	54%	20750	33%
Apr	60220	9380	16%	23735	39%	36328	60%	24115	40%
May	66348	9174	14%	21769	33%	36451	55%	26790	40%
Jun	71489	7785	11%	18222	25%	31736	44%	24309	34%
Jul	79381	6908	9%	15621	20%	28010	35%	22299	28%
Aug	78293	7032	9%	15815	20%	28367	36%	22527	29%
Sep	68207	7282	11%	18281	27%	30002	44%	21713	32%
Oct	64611	8190	13%	21745	34%	31239	48%	19585	30%
Nov	64152	9693	15%	25092	39%	32709	51%	18753	29%
Dec	69003	7725	11%	22864	33%	29049	42%	15306	22%
Total	809005	103350	13%	261720	32%	387713	48%	254984	32%

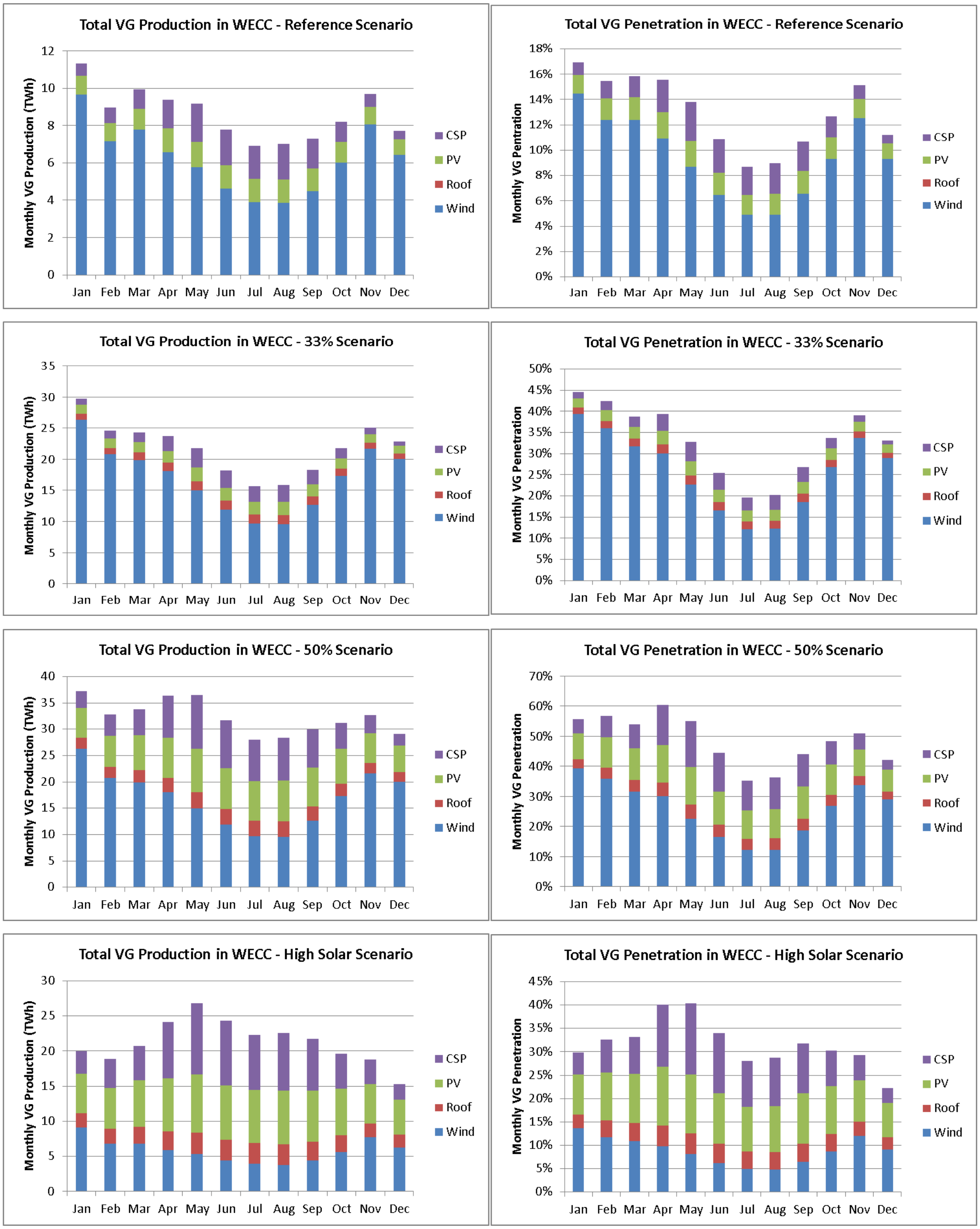


Figure 2-8 - Monthly variable resources energy for the entire US Western Interconnect

Uncertainty – Forecast Error

It was mentioned that load, wind and solar forecasts were generated as part of synthesis of the data for used in this project. The forecast error associated with these forecasts is the major driver behind the size and timing of reserve requirements for variable resources.

Forecast error has several measures but the most common are Mean Absolute Error (MAE) and Root-Mean-Square Error (RMSE). MAE error is probably the most common measure used for wind and solar forecasting. The lower the MAE, the closer the forecast is to what actually happens.

A typical day-ahead forecast MAE for a single wind plant may be in 15% to 17% range. As plants become larger covering more geographic area the errors combine to lower the overall error. As more plants are combined into a region the aggregate error can be further reduced to less than 10% for day-ahead.

Also, as the forecast horizon becomes shorter, the forecast tends to improve. A forecast made 4 hours ahead is much more accurate than a forecast made 24 to 36 hours in advance. Figure 2-9 shows the relationship between the monthly and annual MAE for 1 hour-ahead (1HA), 4 hour-ahead (4HA) and day-ahead (DA) forecasts for the SMUD BA wind plant selections in the 33% and 50% mixes. The wind regimes in these mixes are identical has 1915 MW of wind nameplate in individual 14 plants.

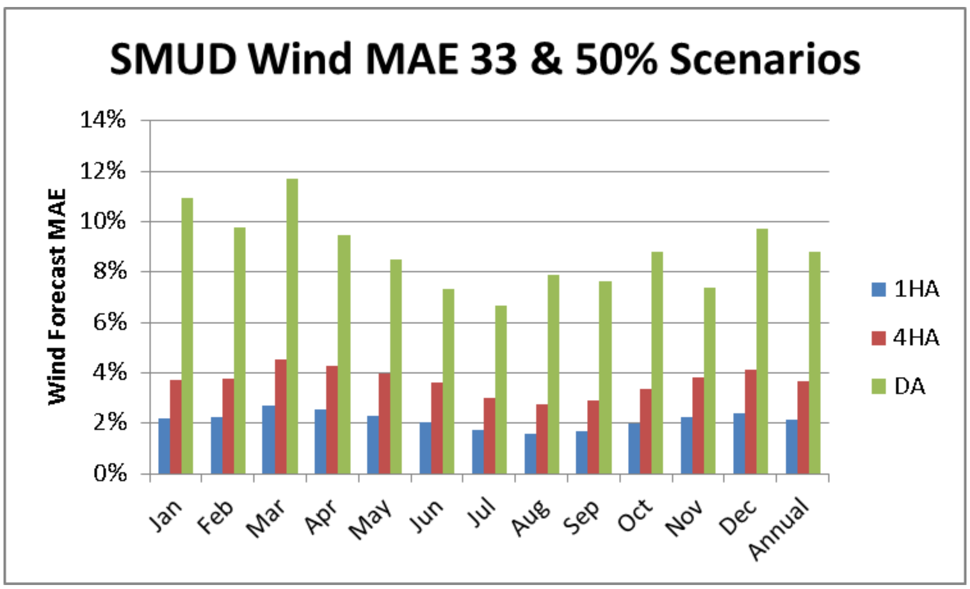


Figure 2-9 - Wind forecasts MAE for the SMUD BA for 33% and 50% mixes, 1915 MW wind nameplate

The MAE for day-ahead ranges from a low of about 7% to a high of about 12% while the 4 hour-ahead ranges from 3% to 5%. The hour-ahead forecast is further reduced to around 2%. Note that the annual pattern for MAE is the same shape for each of the forecast horizons. That pattern shows the highest forecast error in March and generally higher in the winter months with the best forecasting in the summer when wind is blowing the least.

Figure 2-10 shows the same information for an aggregation area consisting of all California zones. Comparing to Figure 2-9 we can see that the day-ahead MAE is reduced to 8% from 9%.

This further reduction is due to the larger averaging of the forecast errors over the aggregated area. Note that the shorter term forecasts improve significantly over the day-ahead but that they do not improve as much in the full California aggregation as for the SMUD BA zone. This indicates that some of the incremental wind has high variability making close-in forecasting less accurate than for the SMUD BA.

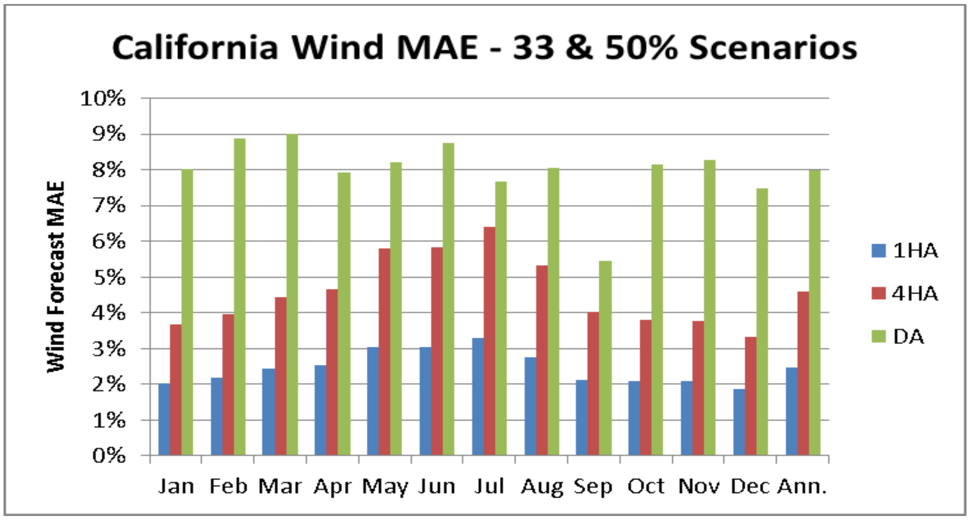


Figure 2-10 – Wind forecast MAE for California for 33% and 50% mixes, 11475 MW wind nameplate

Figure 2-11 through Figure 2-14 show the solar forecast MAE data for the SMUD BA and California areas. The MAE for each forecast tends to be somewhat higher than wind forecasts, particularly the day-ahead. This may be due to the difficulty in forecasting sky conditions a day or more in advance. Again, as the amount of nameplate increases the overall error pattern tends to decrease and this is particularly true for the day-ahead forecasts.

The solar forecasts have a similar pattern as the wind forecasts in that the forecasts are best in the summer and worst in early spring. The reasons are much different though. In the summer, the sky tends to be clear with good forecastability. In the spring, there are more cloudy days that are difficult to forecast. The short term forecasts are also less accurate in spring because the clouds are more variable during these times.

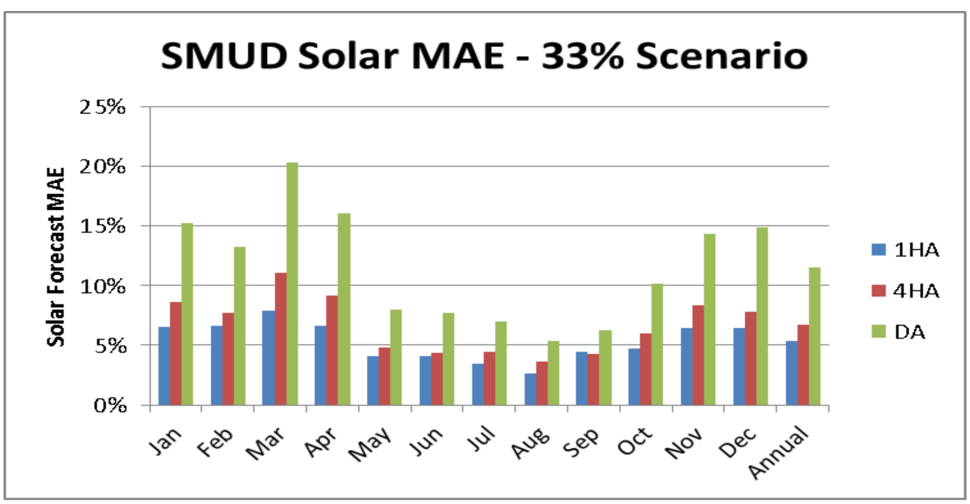


Figure 2-11 - Solar forecast MAE for the SMUD BA for 33% mix, 580 MW PV nameplate

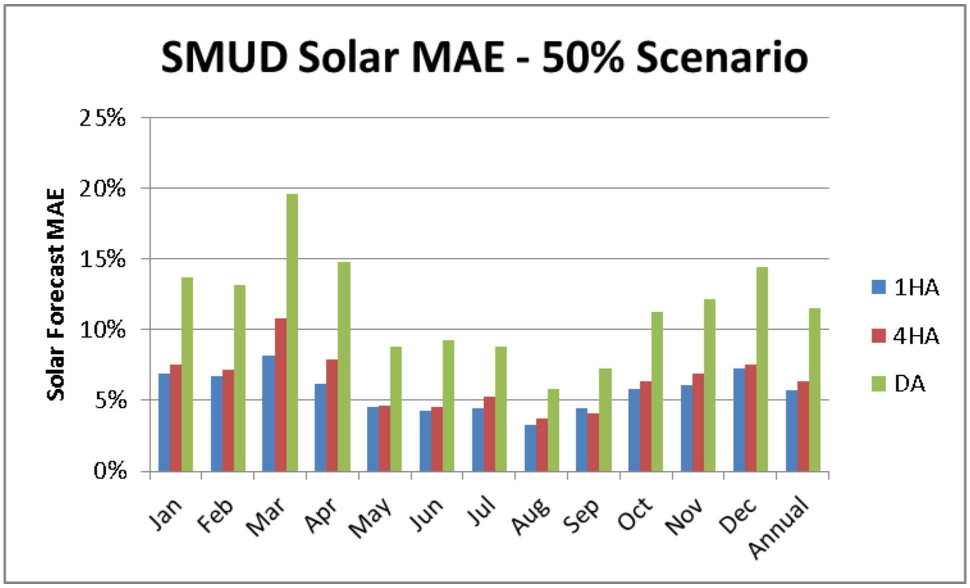


Figure 2-12 - Solar forecast MAE for the SMUD BA for 50% mix, 1126 MW PV nameplate

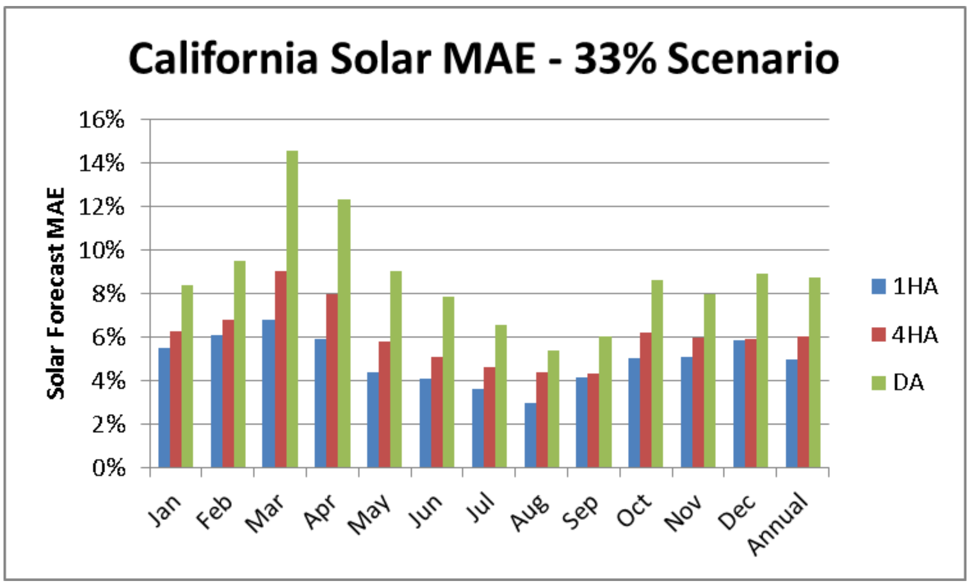


Figure 2-13 - Solar forecast MAE for California for 33% mix, 10397 MW PV nameplate

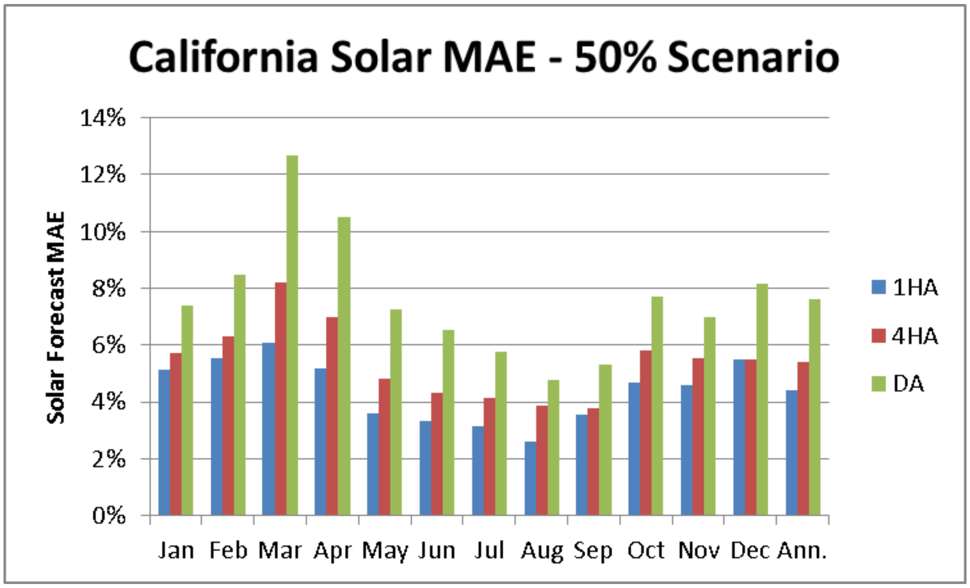


Figure 2-14 - Solar forecast MAE for California for 50% mix, 23488 MW PV capacity

3 RESERVE CALCULATIONS

NREL Method for Estimating Reserve Requirements with Variable Generation

The procedures used to calculate reserves are based on methods developed by the National Renewable Energy Laboratory (NREL). These methods examine the historical behavior of the variability of wind and solar resources, generating statistical information used to predict reserve needs at various timeframes. Several types of requirements are calculated at important timeframes including regulation and flexibility reserves and a special capacity set-aside to account for longer term forecast errors.

Variable generation, as well as load, introduces variability and uncertainty into the power supply. Wind and solar vary over time in an uncontrollable way so the system must follow and compensate for changes in the output of these resources. They are not perfectly predictable in planning timeframes so it is difficult to know what other resources might be required if predicted values are incorrect. To compensate for these characteristics the power system must keep reserves available at all times to cover this variability and uncertainty. These reserves must be able to supply additional energy if there is an unanticipated reduction in VG or reduce output if there is an increase in VG. If the reserves are underestimated, it leaves the system vulnerable to supply imbalance and potential reliability issues. Overestimating leads to inefficient commitment and utilization of conventional resources increasing costs.

We will calculate multiple reserves that are *dynamic* or can change with each simulation interval. The different reserves are appropriate for the different planning horizons that are done to operate the power system. The timeframes of interest in this study are day-ahead, four hour-ahead and real-time. Each of these timeframes has an associated planning or operations function associated with it.

The reserve requirements are specific to a given set of VG resources so they must be evaluated for each situation. Factors that influence the magnitude of the reserves beyond the capacity are geographic diversity, mix of VG technologies and size of the region that reserves are aggregated over.

Wind, solar and load each have different explanatory variables that help predict the variability associated with them. Also, available data affects the nature of the analysis that can be performed. In each case, the procedures are slightly different to give the best result for each type of data. The requirements for wind, solar and load are calculated separately and then combined into a single time series for each reserve type and timeframe of importance to the analysis. The time frames of importance to this study are:

- Day-ahead – Day-ahead unit commitment that uses best forecasts of load and VG to create a plan for the next day.
- Four hour-ahead – A second, faster unit commitment cycle that can recommit fast starting resources. The day-ahead commitment for longer starting resources is honored in this stage.
- Real-time – This is the operational timeframe where economic dispatch of the committed system is performed to meet load on a second to second basis. Adjustments to generation in this timeframe are made automatically.

The types of reserves calculated are and deployed in various time frames:

- Regulation Reserve – These are spinning, synchronized capacity available for deployment in seconds to minutes timeframe, up to the re-dispatch interval of the system. These resources must be on Automatic Generation Control (AGC) since it is assumed that there is no other mechanism to command generation changes in this timeframe.
- Flex Reserves – Flex or Flexibility reserves are held to cover larger unpredicted changes in net load outside the regulation timeframe. These movements are primarily due to uncertainty in forecasts of wind and solar. Load uncertainty may be included in flex reserves. The timeframe for these reserves is from the system re-dispatch interval to when replacement reserves can be activated and on-line. A portion of these reserves may be made up from spinning and synchronized units if the reserve amounts necessary require starting up longer-start units (units with two to 6 hour start times).
- RUC Capacity – RUC (Reliability Unit Commitment) capacity is offline capacity or longer-start on line capacity needed in planning timeframe to make sure the system has enough capacity available to handle a prescribed portion of possible forecast errors. For instance, day-ahead RUC capacity is dependent upon the day-ahead forecast errors that one can expect based on experience.

In addition to these resources, the system must maintain contingency reserves that are available to mitigate an unexpected system change like the sudden, unexpected loss of generation, load or transmission. These reserves are not affected in any way by the calculation of regulation, flex and RUC capacity reserves and are completely independent.

Reserve Rules

Overview

The approach for all of the components of the reserves (wind, solar and load) involves the analysis of historical data for each. It is typical that historical information about wind and solar resources does not exist. In these cases, the data must be simulated in a hindcast. In a hindcast, some form of numerical model is used to simulate conditions in the past at the site of each resource. These simulations are guided by historical atmospheric measurements.

The variability information is isolated from the historical production information. The variability in data is typically calculated as the forecast error in the timeframe of interest. This data is then analyzed to find the variables that best explain the variability. Once the explanatory variables are determined rules are formulated that allow prediction of variability based on conditions. This analysis is repeated for relevant timeframes, day-ahead, four hour-ahead and real-time for this study. Finally, the rules are applied in each timeframe to produce time series of reserves that can be used as input to the production cost model.

Wind Reserves Procedures

The variability associated with wind resources is calculated as the forecast error in each timeframe. In each interval, the forecasted value is subtracted from realized value to form the forecast error.

For example, for regulation, we assume a persistence forecast where the wind production is assumed to stay the same throughout the interval. Figure 3-1 shows how the forecast and short-term forecast error is formed. In this example, the persistence interval is a total of 10 minutes where the forecast is made 5 minutes before the beginning of a 5 minute dispatch period. The short red lines show the dispatch interval where the forecast is in effect. The forecast error is taken as the difference between the wind production and the forecast at the end of the interval.

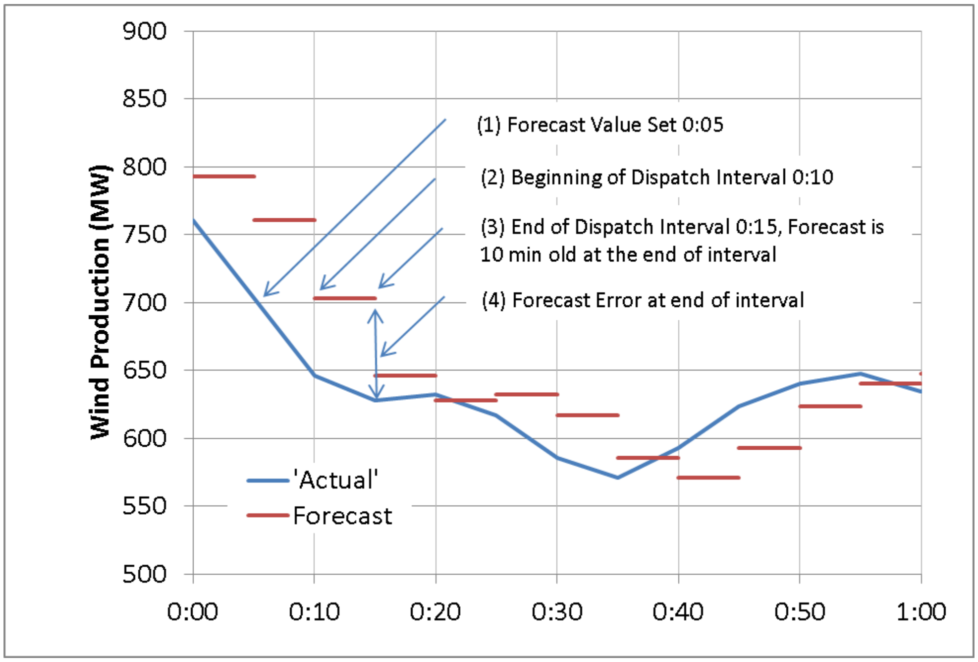


Figure 3-1 – Short-term forecast error

Flexibility reserves are calculated based on a one hour persistence forecast with the forecast value set at beginning of the dispatch interval. The forecast error is then the difference between the value of the production data at the beginning and end of the interval. Figure 3-2 – Hour forecast error used for flex reservesshows how the forecast error is calculated for flex reserves.

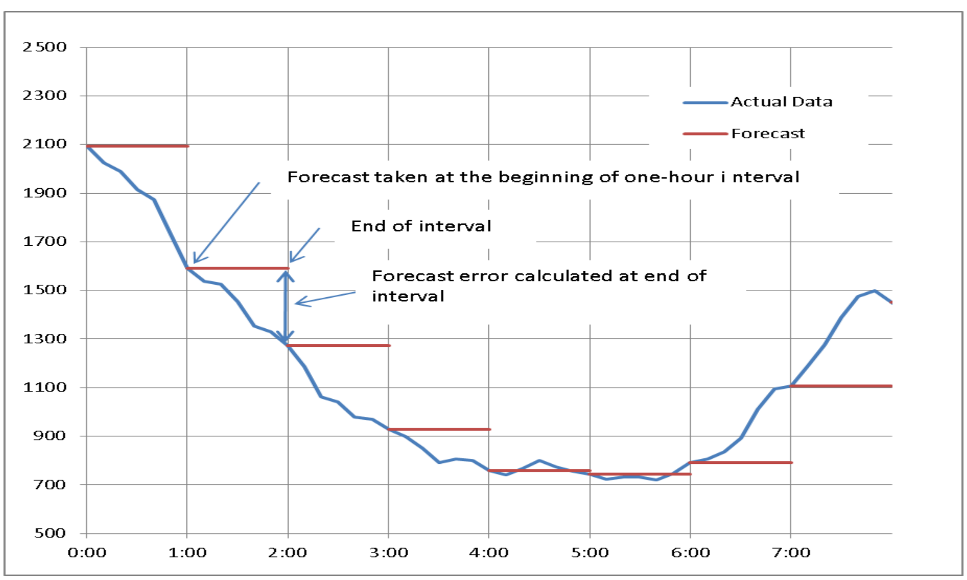


Figure 3-2 – Hour forecast error used for flex reserves

In other timeframes we need also need a forecast but persistence is not a viable forecasting method beyond an hour or two. Skill forecasts from weather forecasters are typically obtained for longer horizons where they perform better than persistent forecast. The historical data used in this study also includes forecasts made for day-ahead and four-hour-ahead horizons as used in the NREL studies mentioned earlier. In these cases, the forecast error is simply the difference between the realized production and the forecasted value. For example the day ahead forecast error for hourly interval 6-7am the next day is the difference between actual wind production and forecast value for hourly interval 6-7am.

Forecast errors are bidirectional in that sometime there is an over-forecast and others and under-forecast. When an over-forecast occurs, up reserves are need to cover the shortfall. When an under-forecast occurs, down reserves are required to make room for the additional wind energy.

A statistical analysis was performed to find the best explanatory variable for the wind forecast error. That variable was found to be the value of wind production. In other words, forecast error is a function of production level.

Once the forecast errors have been determined, the errors are binned into deciles based on the associated production values. Once those values are assembled, a representative statistic is chosen to determine how much of the possible forecast error is to be covered by the reserve. For instance, a 95% confidence interval could be applied to each bin to find the level of reserves that would cover 95% of all forecast errors seen in each bin. There are separate levels for up and down reserves.

Figure 3-3 shows the results of these calculations for regulating reserves for an example area containing 3675 MW of wind. This example assumes 5 minute dispatch with a five minute delay on the forecast as shown in Figure 3-1. Note the shape of the curves with the peak value in near the middle of the production range. This is because wind plant output is most variable in the middle of their power curve with less variability low and high output.

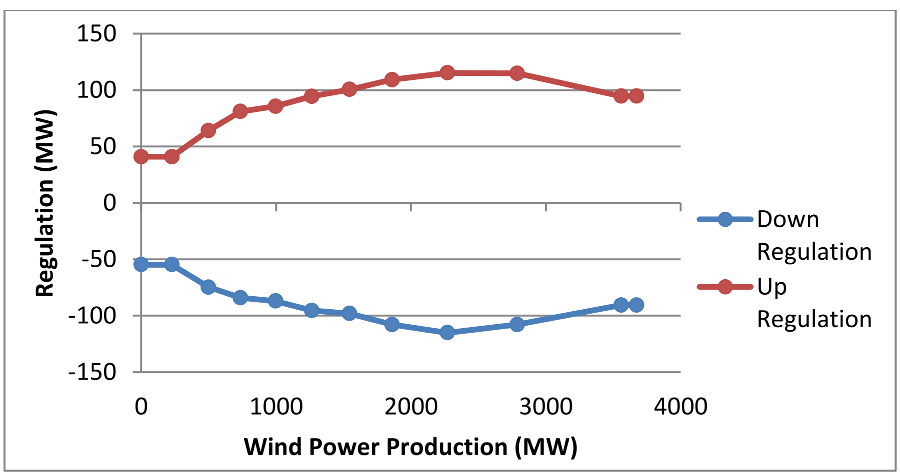


Figure 3-3 – Example regulation requirements for 3675MW of wind

With these curves determined, it is a straight forward process to calculate the regulation reserve requirement for any production level in the range.

In the same way, flex reserve requirements can be calculated from the hour-ahead forecast errors. The same procedure is applied, binning the forecast error by deciles of production cost and choosing a confidence interval appropriate for the flex reserve timeframe.

Figure 3-4 shows the flex reserve calculations for the same set of wind plants shown in Figure 3-3. For this example, we have used 70% confidence interval. The confidence level is lowered in the flex calculation because it is assumed that offline resources can be brought online in the flex reserve timeframe, so not all of the flex reserve is required to be spinning. Note that this study has chosen to use a 95% confidence interval for all reserve types.

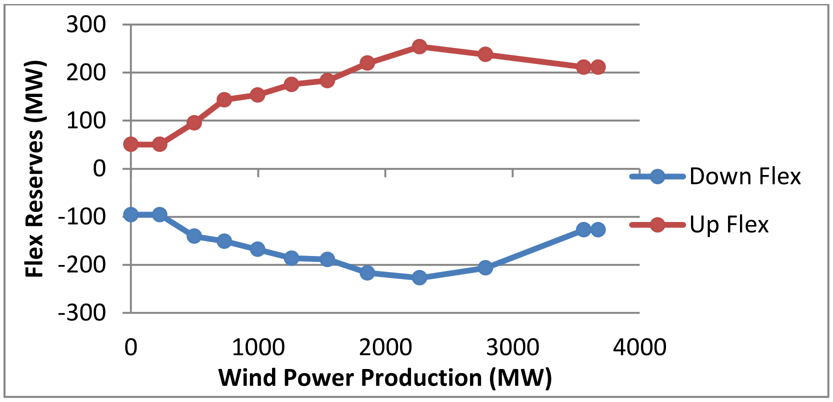


Figure 3-4 - Example flex reserve calculations

The effect of varying the confidence interval on regulation can be seen in Figure 3-5. As coverage moved towards 100% the regulation requirement goes up dramatically since we are seeking to cover more and more tail events. Requirements for 99% coverage can be as much as 200% of those for 95% coverage in some ranges.

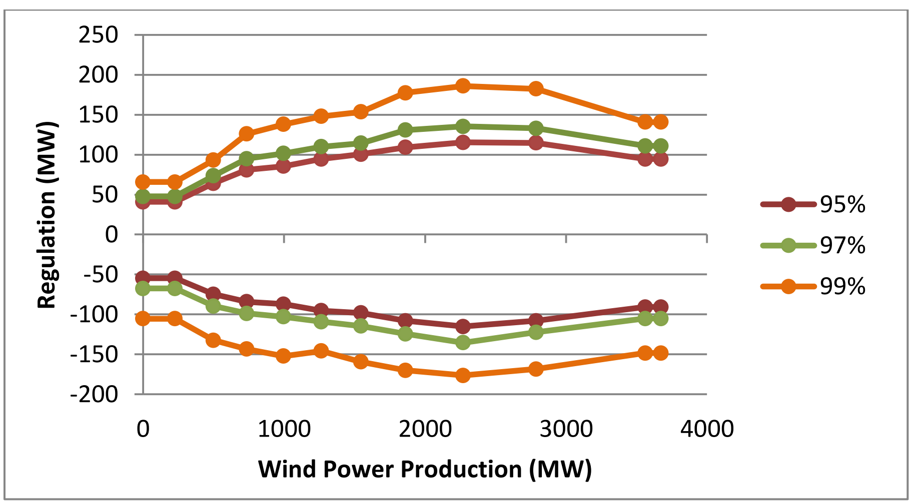


Figure 3-5 - Effect of various confidence intervals on regulation requirements

Solar Reserve Procedures

The procedure for wind described in the previous section is simple and straight forward to implement so it would be a natural candidate to use for solar resources as well. However, this approach leads to very excessive reserve requirements. In the case of solar, the interval to interval change in the solar output is dominated by the movement of the sun, a perfectly predictable phenomenon. The reserves we are discussing here are meant to cover variability and uncertainty of the resource so it is inappropriate to cover these predictable changes with regulation and flex. Instead, the daily pattern of solar generation can be taken into account by the unit commitment, committing the solar resources based on that pattern. For solar, a method is needed that can separate the uncertainty and variability from the perfectly forecastable.

Ideally, we would have method for forecasting what the value of the output would be in the next interval if nothing changed about the sky conditions except the sun's position. To this end, we introduce the concepts of clear sky power and solar power index (SPI). Clear sky power is the production one would expect from a given solar plant with perfectly clear conditions. This power can be calculated for every interval of interest in advance based on a plant's location.

The SPI is an index that we can define at each point in time that is the ratio of the actual plant output to the clear sky power. This represents the fraction of possible output from the plant at time (t).

$$SPI(t) = \frac{Plant\ Output(t)}{Clear\ Sky\ Power(t)}$$

By assuming that the SPI is constant over the dispatch interval we can produce a short-term forecast of what we expect for output at the end of the interval. Once we have a forecast of the value, we can calculate a forecast error to use in our estimate of reserves. Figure 3-6 demonstrates how this is done.

$$\Delta CSP(t) = Clear\ Sky\ Power(t+1) - Clear\ Sky\ Power\ (t)$$

$$Forecast(t+1) = Plant\ Output(t) + SPI(t) \times\ \Delta CSP(t)$$

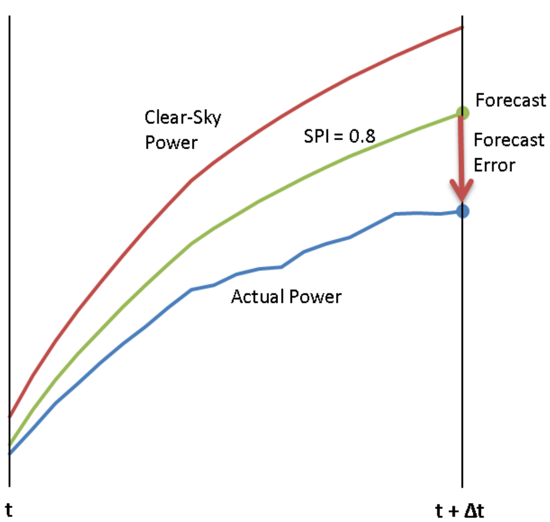


Figure 3-6 - Short-term forecast error for solar using SPI and clear sky power

In the case of wind, wind production was found to be the explanatory variable. In the case of solar, the current value of output did not adequately predict what the forecast error for the interval would be. The best explanatory variables were found to be the SPI and the slope of the clear sky power (ΔCSP). To generate the statistical description of the solar variability and/or uncertainty a method analogous to the wind method described above was developed. The SPI and clear sky slope ranges are divided into deciles forming 100 bins. For each data point in the historical sample, the SPI, synchronous clear sky delta and forecast error are calculated and the forecast error is recorded in the appropriate bin. As with wind, we apply a confidence interval to each of the bins to determine a reserve level associate with the parameters of the bin.

Since we are using two variables to describe the forecast error the resulting data is 3-dimensional. Figure 3-7 shows how the up regulation requirement varies for an example area with approximately 5500MW of solar PV capacity. This example uses a 95% confidence interval to define the requirement up regulation.

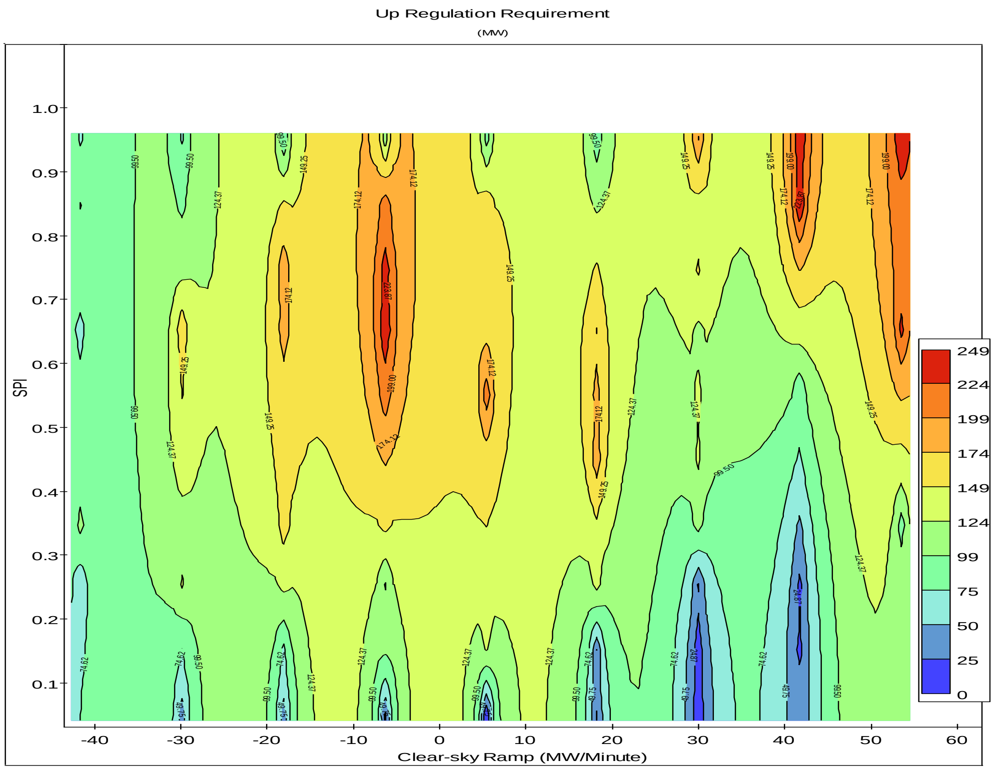


Figure 3-7 – Example up regulation requirements for 5500MW solar PV data at 95% confidence interval

As with wind, we can use different timeframes to calculate different reserve types. Our example above calculates regulation using 5 minute dispatch with a 5 minute forecast delay. Using hourly data we can calculate the flexibility reserve as we did with wind.

Load Reserve Procedures

Limited load forecasting and explanatory variable information was available for this study making detailed analysis of load forecast error difficult. Multiple approaches were tried, mostly based on the value of load as the explanatory variable but the results did not correlate well. Instead an approach using a fixed percentage of load based on the RMSE of the load forecast was used. It is expected that explanatory variables measuring temperature, change in temperature and/or humidity would be useful for this analysis but that information was not available to the study.

RUC Capacity

Reliability Unit Commitment (RUC) capacity is an extra capacity requirement that must be met in unit commitment timeframes. This requirement is meant to address longer term forecast error like day-ahead which can be quite high but does not need to meet in the unit commitment phase with committed resources.

Earlier attempts to include day-ahead forecast error using the methods described in earlier sections lead to excessively high reserve requirements that the system had difficulty providing. The effect those requirements were having on the production cost simulation was examined and it was seen that the simulation was requiring all of those requirements to be committed and online in day-ahead timeframe. Those resources could not be de-committed in subsequent phases regardless of the need for them even with better forecast information available. This lead to chronic over commitment of resources to cover forecast errors that rarely occur.

This component is a reserve capacity that does not need to be committed in the planning timeframe. It is just checked to be sure that enough capacity with startup times shorter than the time horizon of the next planning phase are available. For instance, in the day-ahead unit commitment there must be enough resources with 4 hour or less start time running with unloaded capacity or available to started in the 4-hour-ahead commitment phase. In the 4-hour-ahead commitment, there must be enough quick start turbine capacity in real-time to meet the 4 hour RUC capacity requirement. This does not imply commitment of those resources, just that they are available to be committed if required.

In each subsequent phase of the simulation, the timeframes are shorter and the forecast error improves and can improve dramatically. As forecast error improves, the RUC capacity requirement decreases. This implies that if commitment decisions are delayed as long as possible for resources that have short start times, a better more optimal solution can be found.

The RUC capacity is calculated by developing a flex-like reserve for the day-ahead and 4-hour-ahead timeframes using appropriate forecasts. For instance, the day-ahead RUC capacity requirement is calculated using the day-ahead load, wind and solar forecasts using procedures for flex reserves. These reserves are calculated and combined into a single requirement as described in the following section. So as to not double count the reserves we will hold out, the flex reserve requirement calculated at each timeframe is subtracted from its raw RUC capacity.

Reserve Calculations

With all the rules for each component of reserves determined we can calculate the reserve requirements for a particular case for each of the 20 reserve zones shown in Tables 2-2 to 2-4 in Chapter 2 (these are aggregations of the WI BAs which share reserves). The case specifies a specific set of VG resources aggregated in a particular way. For each aggregation region in the model we must calculate the following reserves.

	RUC Capacity	FLEX	Regulation
Day-ahead	X	X	X
4-hour-ahead	X	X	X

Real-time		Released	X

The regulation calculation for all timeframes uses the short-term forecast rules developed in the previous sections. Likewise, the flex reserves are based on the hour-ahead rules regardless of the timeframe. These reserves are calculated by applying the rules with the forecasted values in the timeframe. This results in regulation reserves that are similar in magnitude in all timeframes and flex that are similar to each other. As discussed in the previous section, longer term forecast errors are used to calculate the RUC capacity components.

With the calculation of regulation and flex requirements for load, wind and solar, we need to combine those into single requirements at each timeframe to apply in the model. We make the assumption that load, wind and solar variability are independent and thus can be combined geometrically as the square root of the sum of the squares of each component. This procedure is performed for both regulation and flex in each timeframe.

Figure 3-8 demonstrates how the load, wind and solar components of the regulation combine to form the total regulation used in the simulations. The figure shows approximately one day of data.

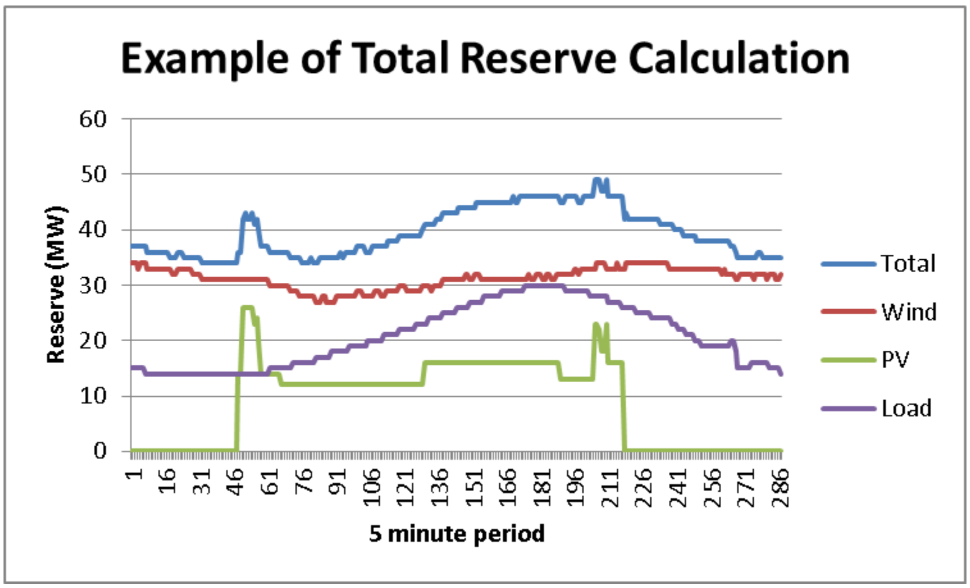


Figure 3-8 – Combining regulation reserve components to make the total regulation

Reserve Results

Overview

This section provides a summary of the results of reserve calculations described in the previous sections for the study areas. The study focuses on the SMUD BA, the remainder of California and the Northwest zone.

When the reserves are calculated, regulation uses the same rule set for all timeframes using the best available information for each. The same is true for flex reserves. The four-hour-ahead flex calculations are done using the same rules as the day-ahead, but the four-hour-forecast data is used for those calculations instead of the day-ahead-forecasts. This has the effect of making the statistics quite similar for both. Because of this, only the 4-hour-ahead flex is reported with the understanding that the day-ahead is similar. The same is true for regulation.

Reserve Summaries

The following two tables show summaries of reserves for the important study regions in the 33% and 50% mixes. Table 3-1 contains the summary for the 33% mix. We can see from this data that the regulation component is the smallest since it covers the smallest time increment, 5 minutes. This is followed by the 4 hour-hour-flex reserve. The 4 hour-ahead RUC capacity is less than the flex because the 4 hour-ahead load, wind and PV forecasts are accurate enough that the forecast error less the flex reserve is smaller than the flex reserve itself. Finally, the day-ahead RUC capacity is the largest, since it is based on the much larger day-ahead forecast error for load, wind and PV. These levels of reserves are calculated using the assumptions that regulation is covered at a 95% confidence interval, flexibility reserves are covered at 70% confidence interval and RUC capacity covers 70% of the forecast errors not covered by flexibility reserves.

Table 3-1 - Reserve summary for 33% high wind mix

	SMUD BA	CA_North	CA_South	Northwest	WECC
Real-Time Regulation (Typical of 4HA and DA)					
Average	**44**	**84**	**183**	**276**	**2014**
Max	**79**	**153**	**412**	**400**	**2709**
4 Hour-ahead Flex Reserves (Typical of DA)					
Average	**73**	**164**	**402**	**664**	**4202**
Max	**143**	**288**	**921**	**1002**	**5688**
4 Hour-ahead RUC Capacity					
Average	**32**	**32**	**222**	**224**	**1634**
Max	**102**	**122**	**718**	**561**	**3088**
Day-ahead RUC Capacity					
Average	**122**	**146**	**361**	**921**	**4974**
Max	**440**	**555**	**1353**	**2259**	**10268**

Table 3-2 – Reserve summary for 50% mix

	SMUD BA	CA_North	CA_South	Northwest	WECC
Real-Time Regulation (Typical of 4HA and DA)					
Average	**51**	**87**	**210**	**276**	**2235**
Max	**117**	**164**	**629**	**400**	**3688**
4 Hour-ahead Flex Reserves (Typical of DA)					
Average	**76**	**166**	**425**	**664**	**4390**
Max	**211**	**320**	**1223**	**1003**	**8081**
4 Hour-ahead RUC Capacity					
Average	**33**	**34**	**255**	**225**	**1805**
Max	**157**	**157**	**1160**	**561**	**5768**
Day-ahead RUC Capacity					
Average	**125**	**156**	**471**	**923**	**5519**
Max	**444**	**637**	**3151**	**2259**	**15640**

Comparing Table 3-2 to Table 3-1 shows a relatively modest change in the average reserve requirements in each of the zones except California_South. In most of the zones, the incremental PV resources are not large enough for the solar component of the reserves to dominate the wind and load. This is not the case in California_South were the incremental PV is larger than the wind and load reserve components.

Table 3-3 and Table 3-4 show greater detail of the reserve requirements for the SMUD BA. These provide a monthly analysis as well as providing additional statistics about each reserve, with confidence intervals as specified above. Figure 3-9 illustrates the meaning of the probability values in the tables using the annual real-time regulation for SMUD BA.

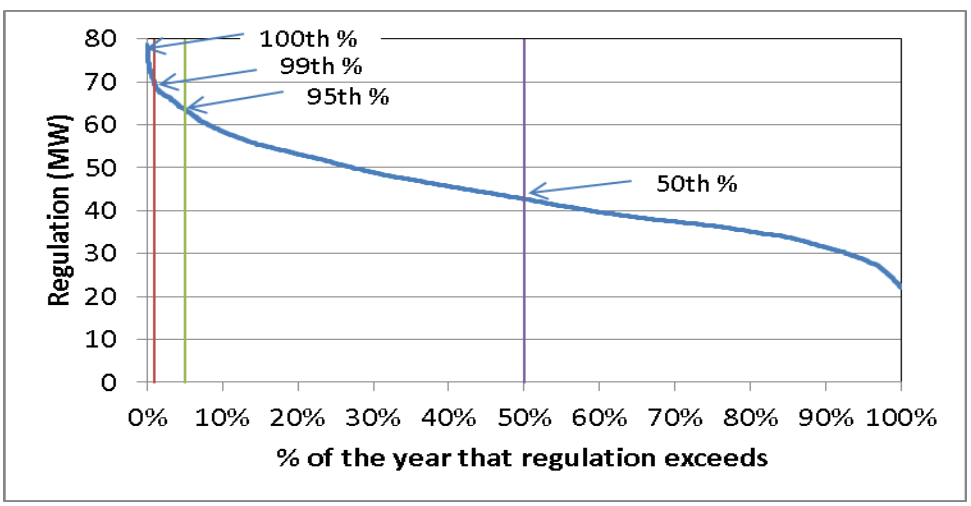


Figure 3-9 - Illustration of distribution points

Table 3-3 - Detailed SMUD BA reserves for 33% high wind mix

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Real-Time Regulation													
Average	45	45	49	48	43	43	44	41	42	41	43	47	44
50th (median)	45	42	50	47	41	42	44	40	39	40	44	47	43
95th	62	65	69	67	61	57	58	54	64	58	62	67	64
99th	66	68	75	74	71	62	62	59	70	65	67	69	69
100th	74	74	78	78	79	70	68	68	79	68	73	77	79
4 Hour-ahead Regulation (Typical of DA)													
Average	43	43	48	47	42	42	44	40	41	41	42	46	43
50th (median)	44	41	49	46	41	42	44	40	39	39	42	46	42
95th	60	63	69	65	58	54	56	53	63	56	60	67	62
99th	64	66	72	71	68	59	59	56	68	63	65	69	69
100th	71	73	78	74	76	64	65	59	75	67	71	75	78
4 Hour-ahead Flex Reserves (Typical of DA)													
Average	73	73	80	77	69	70	76	70	70	67	70	78	73
50th (median)	72	66	81	76	67	70	75	68	65	64	71	78	70
95th	102	107	111	107	101	94	100	95	107	99	101	110	105
99th	108	115	115	112	112	99	106	104	114	109	109	115	112
100th	113	143	125	117	120	104	112	107	122	115	112	129	143
4 Hour-ahead RUC Capacity													
Average	34	36	41	41	31	27	28	23	26	29	32	37	32
50th (median)	36	31	44	41	29	26	27	22	23	26	33	40	29
95th	62	65	66	65	60	53	51	48	59	58	61	62	62
99th	68	87	82	87	67	60	59	58	63	64	73	66	70
100th	85	100	102	98	91	67	80	71	67	84	95	80	102
Day-ahead RUC Capacity													
Average	135	140	185	126	112	110	106	96	99	90	124	141	122
50th (median)	135	86	162	123	101	91	95	80	74	75	129	120	97
95th	293	404	399	308	227	233	192	207	325	237	268	390	317
99th	389	411	415	389	314	307	259	276	409	298	342	405	404
100th	419	424	440	429	362	332	304	335	439	391	413	421	440

Table 3-4 - Detailed SMUD BA reserves for 50% mix

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Real-Time Regulation													
Average	**51**	**51**	**58**	**56**	**49**	**50**	**52**	**46**	**47**	**48**	**49**	**53**	**51**
50th (median)	**50**	**50**	**56**	**53**	**47**	**47**	**48**	**44**	**44**	**45**	**46**	**52**	**48**
95th	**82**	**85**	**90**	**90**	**78**	**81**	**78**	**66**	**73**	**76**	**83**	**85**	**83**
99th	**93**	**96**	**99**	**99**	**94**	**92**	**91**	**79**	**89**	**87**	**95**	**95**	**95**
100th	**111**	**105**	**110**	**109**	**105**	**100**	**98**	**97**	**114**	**112**	**110**	**117**	**117**
4 Hour-ahead Regulation (Typical of DA)													
Average	**49**	**50**	**57**	**55**	**48**	**49**	**51**	**46**	**46**	**47**	**48**	**52**	**50**
50th (median)	**47**	**48**	**55**	**52**	**46**	**47**	**48**	**45**	**44**	**44**	**45**	**49**	**47**
95th	**81**	**84**	**89**	**88**	**74**	**75**	**76**	**64**	**66**	**75**	**82**	**85**	**80**
99th	**89**	**97**	**97**	**97**	**92**	**90**	**83**	**72**	**82**	**84**	**93**	**95**	**93**
100th	**101**	**100**	**102**	**102**	**104**	**96**	**95**	**80**	**104**	**89**	**101**	**100**	**104**
4 Hour-ahead Flex Reserves (Typical of DA)													
Average	**78**	**77**	**84**	**81**	**72**	**73**	**79**	**72**	**74**	**71**	**75**	**82**	**76**
50th (median)	**76**	**70**	**86**	**80**	**71**	**72**	**78**	**70**	**68**	**68**	**73**	**81**	**74**
95th	**109**	**116**	**119**	**113**	**102**	**99**	**106**	**98**	**113**	**103**	**109**	**115**	**110**
99th	**167**	**172**	**161**	**155**	**117**	**107**	**111**	**107**	**161**	**153**	**163**	**168**	**157**
100th	**178**	**211**	**181**	**172**	**130**	**115**	**118**	**115**	**179**	**162**	**210**	**183**	**211**
4 Hour-ahead RUC Capacity													
Average	**35**	**36**	**43**	**43**	**31**	**28**	**29**	**24**	**26**	**30**	**32**	**38**	**33**
50th (median)	**37**	**33**	**46**	**42**	**29**	**26**	**27**	**21**	**23**	**27**	**33**	**40**	**30**
95th	**63**	**70**	**72**	**73**	**61**	**56**	**56**	**55**	**59**	**61**	**63**	**64**	**64**
99th	**75**	**88**	**88**	**96**	**70**	**81**	**79**	**76**	**67**	**82**	**75**	**78**	**83**
100th	**153**	**151**	**113**	**151**	**141**	**117**	**157**	**98**	**149**	**148**	**101**	**103**	**157**
Day-ahead RUC Capacity													
Average	**136**	**142**	**190**	**131**	**114**	**113**	**112**	**98**	**101**	**97**	**124**	**141**	**125**
50th (median)	**132**	**86**	**167**	**125**	**106**	**93**	**100**	**81**	**75**	**78**	**127**	**120**	**102**
95th	**293**	**402**	**400**	**318**	**233**	**250**	**219**	**210**	**300**	**247**	**272**	**390**	**318**
99th	**382**	**428**	**420**	**385**	**313**	**307**	**259**	**276**	**409**	**299**	**343**	**406**	**404**
100th	**419**	**439**	**444**	**439**	**364**	**373**	**304**	**332**	**439**	**391**	**413**	**421**	**444**

Figure 3-10 shows relationships between the reserve components for the SMUD BA through duration plots. Each reserve is shown as a curve indicating the percentage of hours in the year that the reserve exceeds a particular value. Comparing the two mixes, we can see that the plots are quite similar except near 0% where the regulation, flex and 4HA RUC curves all have increase in the 50% mix. This is due to the effect of the additional PV in the 50% mix. There is not a great difference in the DA RUC as wind forecast error dominates this component.

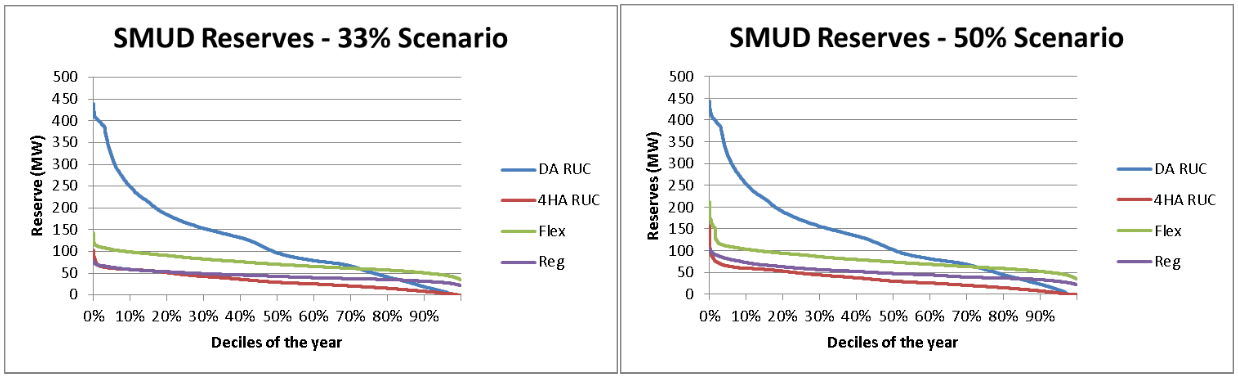


Figure 3-10- Duration curves for the SMUD BA reserve components

Figure 3-11 shows the duration plots for the aggregate California zone. This zone includes all balancing authorities in California including the SMUD BA. Their resources are aggregated together before the calculation of the reserve requirements. There is a more obvious change between the two mixes in this case. For all of California, there is a large change in the PV such that the PV components start to dominate the calculations.

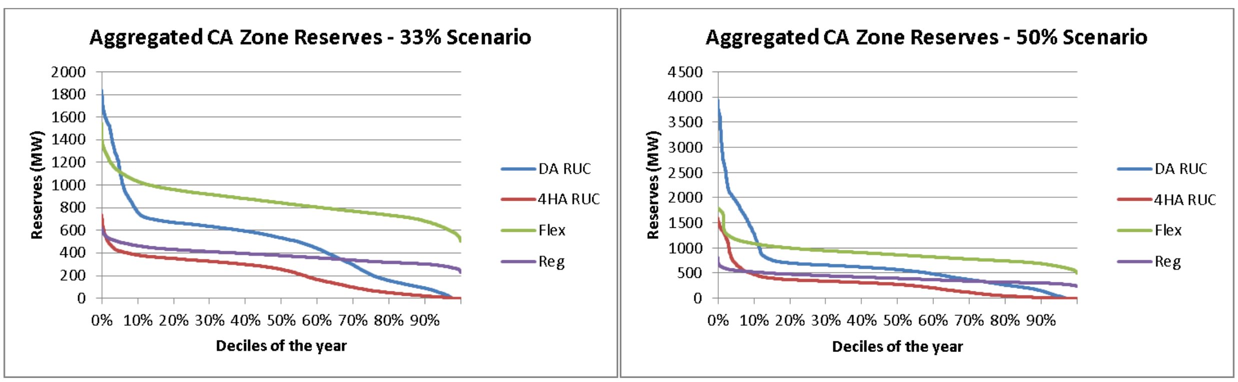


Figure 3-11 - Duration curves for aggregated California zone reserve components

Figure 3-12 shows the duration plots for the Northwest zone aggregated with the SMUD BA. This zone contains all BAs in Washington and Oregon as well as the SMUD BA. Note that the mixes are almost identical. This is because the Northwest zone is heavily dominated by wind resources. The wind in resources in the 33% and 50% mixes are identical. With small increases in the PV in the 50% mix the calculations are dominated by wind so little change is seen.

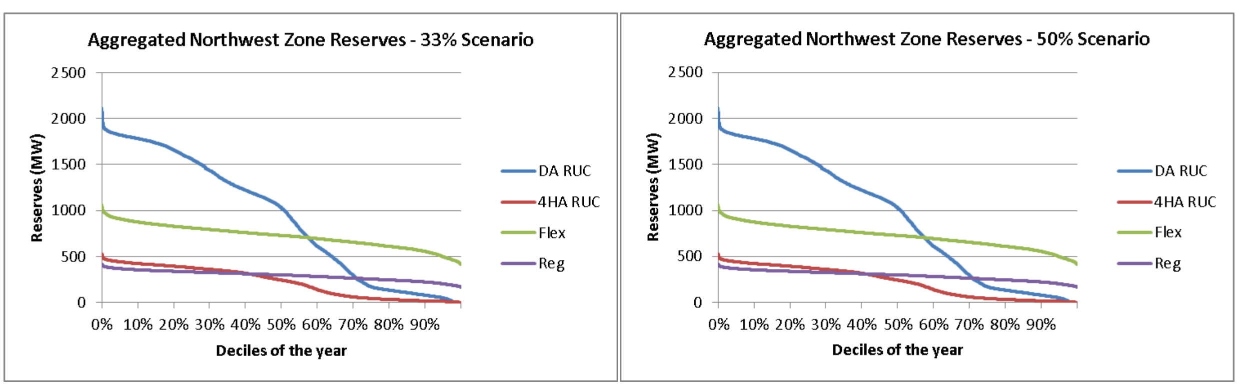


Figure 3-12 – Reserve component duration curves for Northwest zone aggregated with the SMUD BA

Figure 3-13 shows duration curves for the load, wind and PV components of the total regulation requirement for the SMUD BA and compares the 33% and 50% mixes.

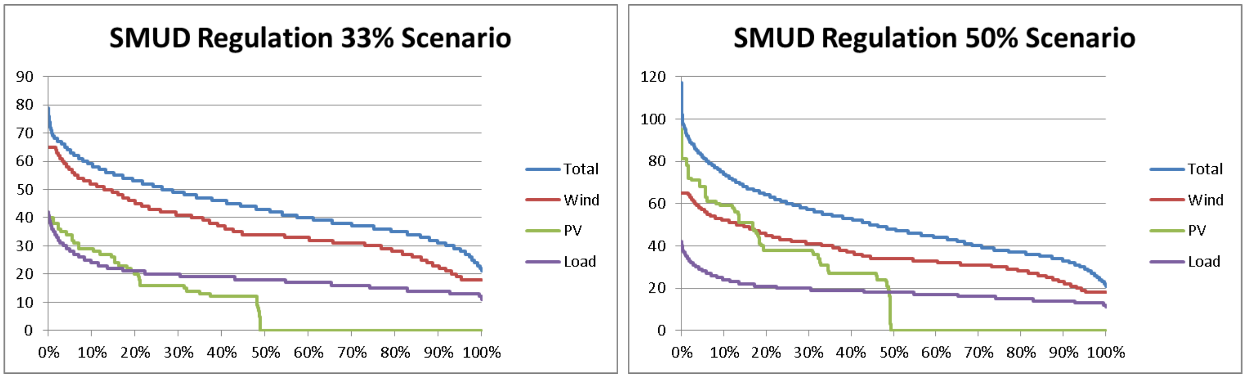


Figure 3-13 - Regulation reserve components duration curves for the SMUD BA

4 MODELING VALUE OF IOWA HILL: WESTERN INTERCONNECTION DATABASE

Introduction of Western Interconnection Database

The Region used for the simulations in this study is the Western Interconnection (WI). The WECC TEPPC 2022 database is translated into PLEXOS. The database covers power systems in 39 load regions in the west coast of United States, plus provinces of British Columbia and Alberta in Canada, and Comision Federal de Electricidad (CFE) in northern Mexico as shown in Figure 4-1.

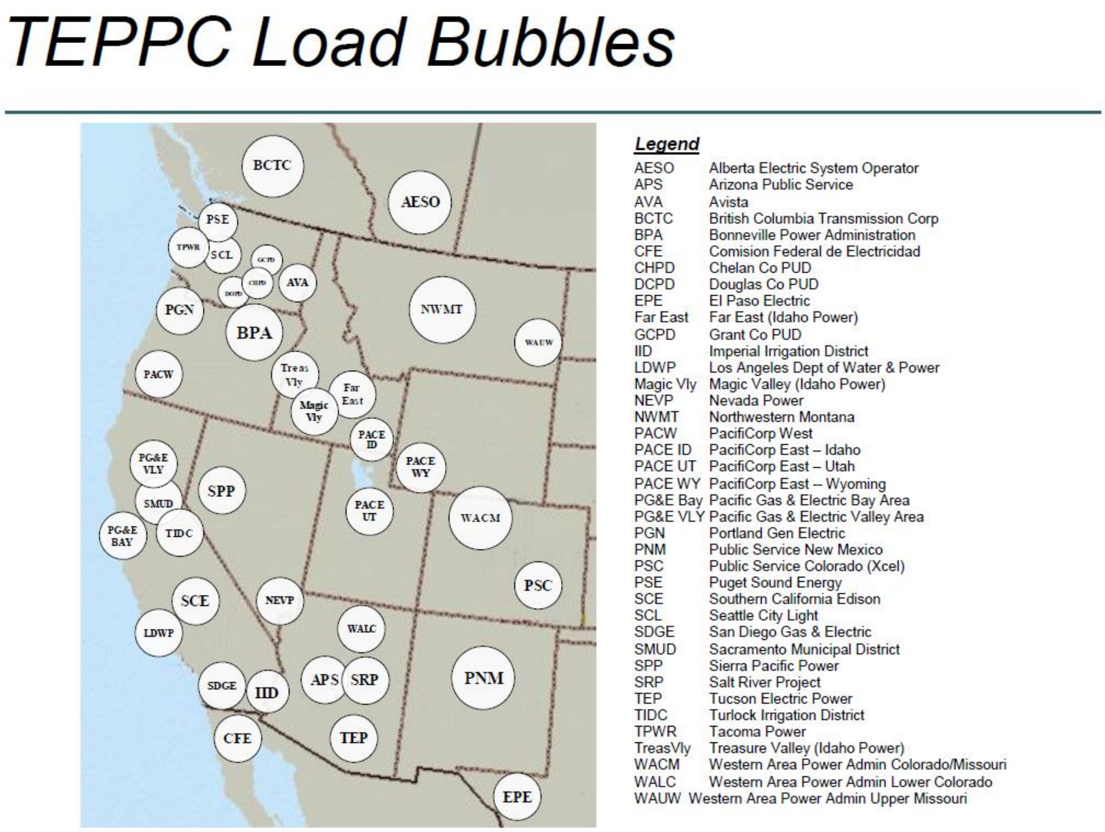


Figure 4-1 Diagram of the WI Load Regions

The Balancing Authority Areas (BAA) in the WI operates independently in term of unit commitment meeting their demands while performing the economic exchange with each other.

The WI network is represented by

- Over 17,000 buses
- Over 22,000 transmission lines (1045 lines are enforced)
- 91 interfaces (enforced) and 33 Nomograms (enforced)

The generation facilities consist of

- Over 3,700 generators (including renewables)
- 8 existing Pumped-Storage Hydro Plants (20 units)
- 3 New Pumped-Storage Hydro Plants (11 units)

The gas price is = $4.6/mmBTU.

The forecasted energy and peak for the WI in year 2022 are

- Energy Demand for the WI = 997,514 GWh; Energy Demand for the USA part in the WI is 798,332 GWh;
- Coincident Peak for the WI = 168,972 MW; Coincident Peak for the USA part in the WI is 146,718 MW.

The forecasted energy demand includes the transmission losses[2] [3].

The various renewable energy mix assumptions for the USA part of the WI for year 2022 are described in Chapter 2 for different scenarios

Data readiness for the simulations

Regional load representation

The day-ahead (DA) and hour-ahead (HA) load forecasts and 5-min actual loads in year 2020 are received from PNNL for the WECC VGS study[4]. The load forecasts and actual loads in year 2020 are translated to year 2022 with the weekly patterns synchronized in these two years. Then the DA and HA load forecasts and the RT 5-minutes actual loads in year 2022 are scaled by the peak ratios between year 2022 and year 2020. The peak ratios are calculated using the load regional peaks in the WECC TEPPC 2020 and 2022 database documents[2,3]. Load information is given in Chapter 2 for each region.

Renewable Generation Profile Representations

The wind and solar hourly day-ahead (DA) and 4-hour-ahead (4-HA) generation forecasts and the real-time (RT) 5-min actual generations in year 2022 are generated by EPRI and its subcontractor. The wind and solar generation forecasts and actual generation profiles in year 2022 are generated from year 2006 with the weekly patterns synchronized in these two years.

Contingency, Flexibility and Regulation Reserve Representations

Contingency Reserves

The requirements of contingency reserves, i.e. spinning and non-spinning reserves are defined for eight spinning reserve sharing groups. The mapping between the eight spinning reserve sharing groups and the thirty-nine balancing authorities in WI is specified in the following table.

[2] WECC TEPPC, "*Assumptions Matrix for the 2020 TEPPC Dataset.pdf*", 2020
[3] WECC TEPPC, "*2022_CommonCase_InputAssumptions.doc*", 2022
[4] Matt Hunsaker, Nader Samaan, Michael Milligan, Tao Guo, Guangjuan Liu, Jake Toolson, "*Balancing Authority Cooperation Concepts to Reduce Variable Generation Integration Costs in the Western Interconnection: Intra-Hour Scheduling",* WECC Variable Generation Subcommittee project report, march 29, 2013

Spinning Reserve Sharing Group	Load Region
AESO	**AESO**
AZNMNV	**APS**
	EPE
	NEVP
	PNM
	SRP
	TEP
	WALC
BASIN	**FAR EAST**
	MAGIC VLY
	PACE_ID
	PACE_UT
	PACE_WY
	SPP
	TREAS VLY
BCH	**BCH**
CALIF_NORTH	**PG&E_BAY**
	PG&E_VLY
	SMUD
	TIDC
CALIF_SOUTH	**CFE**
	IID
	LDWP
	SCE
	SDGE
NWPP	**AVA**
	BPA
	CHPD
	DOPD
	GCPD
	NWMT
	PACW
	PGN
	PSE
	SCL
	TPWR
	WAUW
RMPP	**PSC**
	WACM

Table 4-1 Mapping of the load regions and the contingency reserve sharing groups

The spinning reserve requirement in a contingency reserve sharing group is 3% of the load in the group. In the detailed simulations for SMUD-CA-NW region described later, the SMUD BA contingency reserve requirements are separated from the rest of Northern California. The spinning reserve is provided by the eligible on-line generators in the group. The eligible generators to provide the spinning reserve are specified by generator type in Table 4-1.

The non-spinning reserve requirement in a contingency reserve sharing group is 3% of the load in the group. The non-spinning reserve is provided by the eligible on-line generators and the off-line quick startup generators in the group. The eligible generators to provide the non-spinning reserve are specified by generator type inTable 4-2.

Flexibility and Regulation Reserves

The hourly flexibility and regulation reserve requirements for the DA, 4-HA simulations and the 5-min regulation reserve requirements for the 5-min RT simulations in year 2020 are generated as described in Chapter 3 for the base, high-wind and high-mix renewable scenarios[5].

The flexibility and regulation reserve requirements are defined for twenty flexibility / regulation reserve sharing groups, which correspond to those shown in Chapters 2 and 3. The mapping between the twenty flexibility / regulation reserve sharing groups and the thirty-nine load regions is specified in the following table.

[5] Lew, D., Brinkman, G., Ibanez, E., Florita, A., Heaney, M., Hodge, B.-M., Hummon, M., Stark, G., King, J., Lefton, S., Kumar, N., Agan, D., Jordan, G., Venkataraman, S. (2013). "*The Western Wind and Solar Integration Study Phase 2*", NREL/TP-5500-55588. Golden, CO: National Renewable Energy Laboratory

Table 4-2: Mapping of the load regions and the regulation / flexibility reserve sharing groups

Flex/regulation Reserve Sharing Group	Load Region
Alberta	AESO
Arizona	APS
	SRP
	TEP
	WALC
British Columbia	BCH
California, North	PG&E_VLY
	TIDC
California, South	SCE
Colorado	PSC
	WACM
Idaho	FAR EAST
	MAGIC VLY
	PACE_ID
	TREAS VLY
IID	IID
LDWP	LDWP
Mexico (CFE)	CFE
Montana	NWMT
	WAUW
Nevada, North	SPP
Nevada, South	NEVP
New Mexico	EPE
	PNM
Northwest	AVA
	BPA
	CHPD
	DOPD
	GCPD
	PACW
	PGN
	PSE
	SCL
	TPWR
San Diego	SDGE
San Francisco	PG&E_BAY
SMUD	SMUD BA
Utah	PACE_UT
Wyoming	PACE_WY

Adjustable Speed PSH Representation

There are eight existing Fixed Speed PSH (FS PSHs) plants in the WI. The existing PSHs can pump only at the full pumping capacity. Therefore, the existing FS PSHs cannot provide regulation reserve in the pumping mode. In the generating mode, the existing FS PSHs have the minimum generating capacity at 70% of their maximum generating capacity. Therefore the existing FS PSHs can provide reserves in the dispatchable generating capacity range of 30% of the maximum generating capacity in the generating mode. There are three proposed Adjustable Speed PSHs (AS PSHs) to be built in California and its adjacent areas. The table below provides key technical characteristics of the three PSH projects as they were specified in PLEXOS simulation runs. Please note that these projects are still in planning stage and final project characteristics may be different.

Properties	IOWA HILL	EAGLE MOUNTAIN	SWAN LAKE North
Units	**3**	**4**	**4**
Max Cap per Unit (MW)	**133**	**350**	**345**
Min Cap per Unit (MW)	**39.9**	**105**	**103.5**
Max Pump Load (MW)	**133**	**350**	**345**
Min Pump Load (MW)	**79.8**	**210**	**207**
Upper Storage (GWh)	**5**	**25.5**	**10**
Lower Storage (GWh)	**5**	**25.5**	**10**
Cycle Efficiency	**80.472%**	**80.472%**	**80.472%**
Connected Bus	**37001_CAMINOS (230KV)**	**28195_Red Bluff (500KV)**	**45035_CAPTJACK (500KV)**

Table 4-3 Characteristics of three proposed adjustable speed PSHs

The AS PSHs have the minimum pumping capacity at 70% of the maximum pumping capacity. Therefore the AS PSHs can provide reserves in the dispatchable pumping capacity range of 30% of the maximum pumping capacity in the pumping mode. The AS PSHs have the minimum generating capacity at 30% of the maximum generating capacity. Therefore, the AS PSHs can provide reserves in the dispatchable generating capacity range of 70% of the maximum generating capacity in the generating mode.

The location and installed capacity of the existing FS and proposed AS PSHs are summarized in the following table.

PSH	Location Region	Spinning Reserve Sharing Group	Regulation Reserve Sharing Group	Number of Units	Total Capacity (MW)	Generator Type
Cabin Creek	**PSC**	**RMPP**	**Colorado**	**2**	**324**	**Fixed Speed**
Castaic	**LDWP**	**CALIF_SOUTH**	**LDWP**	**6**	**1175**	**Fixed Speed**
Eastwood	**SCE**	**CALIF_SOUTH**	**SCE**	**1**	**199**	**Fixed Speed**
Elbert	**WACM**	**RMPP**	**Colorado**	**2**	**200**	**Fixed Speed**
Helms	**PG&E_VLY**	**CALIF_NORTH**	**PG&E Valley**	**3**	**1212**	**Fixed Speed**
Horse Mesa	**SRP**	**AZNMNV**	**Arizona**	**3**	**96**	**Fixed Speed**
Lake Hodge	**SDGE**	**CALIF_SOUTH**	**SDGE**	**2**	**40**	**Fixed Speed**
Mormon Flat	**SRP**	**AZNMNV**	**Arizona**	**1**	**50**	**Fixed Speed**
Eagle Mount	**SCE**	**CALIF_SOUTH**	**SCE**	**4**	**1400**	**Adjustable Speed**
Iowa Hill	**SMUD**	**CALIF_NORTH**	**SMUD**	**3**	**399**	**Adjustable Speed**
Swan Lake	**BPA**	**NWPP**	**NWPP**	**4**	**1380**	**Adjustable Speed**
Grand Total				**31**	**6475**	

Table 4-4 Locations and Installed Capacity of the Existing FS PHS and Proposed AS PSHs in WI

Reciprocating Engine Representation

Reciprocating engines were also represented in the model for comparison as a nother balancing resource. Reciprocating generators are designed to cover the load and renewable generation variability and uncertainty. Under hot start conditions, a reciprocating generator can achieve full power in 5 minutes after receiving the startup instruction. And its ramp up and down rate is 3.6 MW/min. The minimum and maximum generating capacities are about 3 MW and 9 MW respectively. Due to its short startup time and fast ramp rate, the reciprocating generators are adequate energy balancing resources. In this study, the reciprocating generators are modeled as one of the alternative energy balancing resources. Since the reciprocating generators would not be able to absorb excess renewable generations, its energy balancing capability is not as strong as the pumped storage generators.

In the simulations, one generator is created to model three reciprocating generators with minimum and maximum capacity of 10.821 MW and 27.405 MW respectively. The ramp rate is 10.95 MW/min and the heat rate blocks represent non-linear heat rates ranged from 10,196 Btu/kWh to 8640 Btu/kWh. The minimum up and down time is 0.5 hour and 0.1667 hour respectively.

Data Assumption Revisions

The WI database of year 2022 is translated from the WECC TEPPC 2022. A few data revisions were performed to ensure that the assumptions in the database are close to the real world. The data revisions are listed in the following table.

Items	Revision Descriptions	Notes
1	**The existing FS PSHs are changed to be modeled by individual unit**	
2	**The Min Pump Capacity is changed to be the Max Pump Capacity for the existing FS PSHs**	**The existing PSHs cannot provide reg in pumping mode.**
3	**The Min Generating Capacity is changed to be 70% of the Max Generating Capacity for the existing FS PSHs**	
4	**The Min Generating Capacity is changed to 90% of the Max Generating Capacity for the nuclear generators**	
5	**The Economic Demand Responses are modeled as dispatchable with the dispatch prices in the range of $500/MWh and zero minimum capacity**	
6	**The Interruptible Demand Responses are modeled as dispatchable with the dispatch prices in the range of $1,200~$1,872/MWh and zero minimum capacity**	
7	**Un-served energy penalty price is changed to $3,500/MWh. And the dump power price is changed to: - $100/MWh**	
8	**Regulation reserve shortfall penalty price is set to $1,100/MW**	
9	**Spinning reserve penalty price is $900/MW**	
10	**Non-spinning reserve shortfall penalty price is set to $700/MW**	
11	**Flexibility up reserve shortfall penalty price is set to $600/MW**	
11b	**Flexibility down reserve shortfall penalty price is set to $10/MW**	
12	**Transmission line and interface limit penalty price is changed to $6,000/MWh**	
13	**All Co-gen generators cannot provide reserves**	
14	**Fixed hydro generation profiles and renewable generation profiles can be curtailed at the penalty price of: -$22/MWh**	
15	**Three-Block Heat Rate (HR) curves are created for generators of CC, Coal and CT, by escalating the HR curves from the NREL WWSIS Phase 2 study with the ratio of HR at Max Capacity in the TEPPC database over the HR at Max Capacity from NREL WWSIS phase 2 Study.**	**See the rest of this subsection for details**
16	**The start cost of CCs and CTs is determined by only the start-up fuel cost from the TEPPC database. The start cost of other thermal generators is determined by the start cost from the TEPPC database.**	

Table 4-5 Assumptions revisions in the database

Further generator characteristic revisions are listed in the following table. Their eligibilities to provide different types of reserve are listed in the table as well. The yellow marked cells indicate the data revisions.

Table 4-6: Generator Characteristic Revisions and Eligibility for the Reserve Provisions

Generator Type	Min Capacity (% of Max Cap)	Provide Regulation?	Provide Spin non-Spin ?	Provide 60-min Flexibility Reserve
Biomass RPS	31			
CC Cogen	51.7			
CC Frame F	53.2	Yes	Yes	Yes
CC Frame G	48.3	Yes	Yes	Yes
CC G + H	55.0	Yes	Yes	Yes
CC Old	57.1			
CC Recent	53.2	Yes	Yes	Yes
Coal Cogen	55			
Coal Large Old	80	Yes	Yes	Yes
Coal Large Recent	80	Yes	Yes	Yes
Coal Small	70			
Coal Small Old	70			
Coal Small Recent	70	Yes	Yes	Yes
Coal SuperC	80	Yes	Yes	Yes
Conventional Hydro	~44	Yes	Yes	Yes
Conventional Hydro_Fixeddispatch	-			
CT Cogen	43			
CT Future	50		Yes	Yes
CT Large			Yes	Yes
CT LM 6000			Yes	Yes
CT Old Gas			Yes	Yes
CT Old Oil			Yes	Yes
CT Small			Yes	Yes
Demand CHP	99			
Econ DR	0			
Geothermal	50			
IC	23		Yes	Yes
Interrupt. DR	0		Yes	Yes
Negative Bus Load	-			
Nuclear	90			
Other Steam	34		Yes	Yes
PC Cogen	50			
PC Steam	8		Yes	Yes
Fixed Speed Pumped Storage	70	Yes	Yes	Yes
Pumping Load	-			
Small Hydro RPS	-			
Small Hydro RPS_Fixeddispatch	-			
Solar	-			
Steam Cogen	30			
Steam Large Old	80		Yes	Yes
Steam Large Recent	80		Yes	Yes
Steam Small Old	70		Yes	Yes
Steam Small Recent	70		Yes	Yes
Wind	-			
Adjustable Speed Pumped Storage	30	Yes	Yes	Yes

For the generators of Coal, CC and CT, the heat rates are defined at the 50%, 80% and 100% of the max capacities. In the simulation, the heat rates are linearly interpolated for the load points at 50%, 80% and 100% of the max capacities. In reference[6], the typical average heat rate curves derived from the Continuous Emission Monitoring System (CEMS) are shown in Figure 4-1.

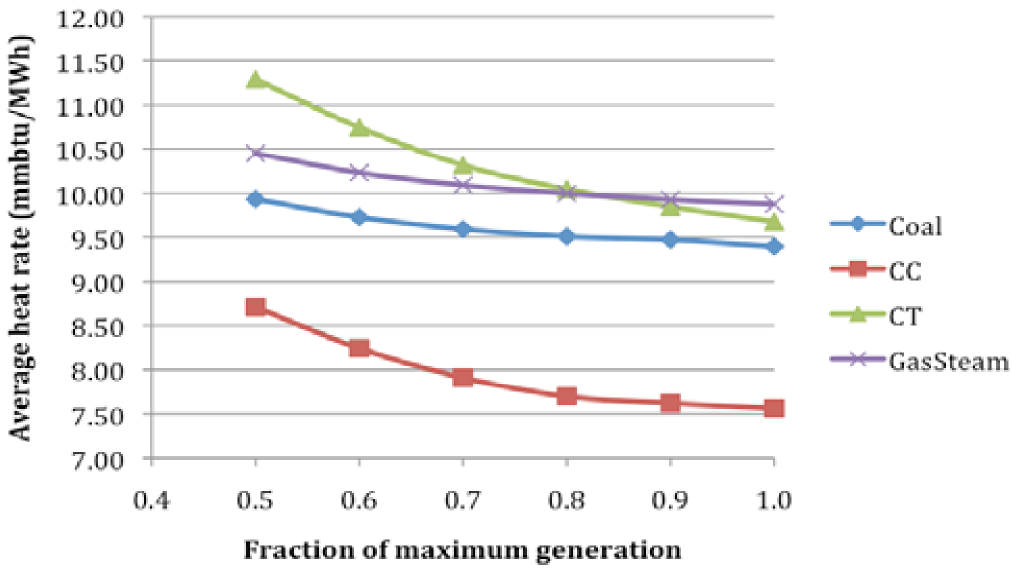


Figure 4-1 The Average Heat Rates for Coal, CC, CT and Gas Steam Generators[7].

These generator heat rate curves are scaled by the average heat rate at the maximum capacity from the WECC TEPPC 2022 database before being applied to the generator heat rates in the database for this study.

The non-spinning reserve requirements for eight contingency reserve sharing groups are changed to 3% of the loads in the contingency reserve sharing groups. The CT generators with the max capacity equal to or less than 100 MW can provide the non-spinning off-line.

Maintenance and Forced Outage Modeling

The maintenance outages are scheduled by the PLEXOS Projected Assessment of Supply Adequacy module (PASA) to level the regional capacity reserve margin over the days in year 2022 by using the user-defined maintenance rates and durations. The forced outages are generated by using random draws on the user-defined annual forced outage rates and durations.

---

[6] D. Lew and G. Brinkman, National Renewable Energy Laboratory, N. Kumar, P. Besuner, D. Agan, and S. Lefton, Intertek APTECH, "*Impacts of Wind and Solar on Fossil-Fueled Generators*", Presented at IEEE Power and Energy Society General Meeting, San Diego, California July 22–26, 2012

[7] D. Lew and G. Brinkman, National Renewable Energy Laboratory, N. Kumar, P. Besuner, D. Agan, and S. Lefton, Intertek APTECH, "*Impacts of Wind and Solar on Fossil-Fueled Generators*", Presented at IEEE Power and Energy Society General Meeting, San Diego, California July 22–26, 2012

After a forced outage occurs in few hour, the system operator will revise the unit commitment to ensure that the spinning reserve deployed to cover the forced outage while bring the reserve provision back to the requirement level. To model this operation practice, in the DA and HA, the maintenance outage and forced outages are modeled but the forced outage start intervals are postponed 5 hour. In the 5-min RT simulation, the maintenance outages and the forced outages with the original start intervals are modeled.

Analysis of fossil generation cycling costs included in model

A key lesson learned in many variable generation studies is that, with increased levels of variable generation, fossil plant will be cycled significantly more. Cycling here is defined as either ramping between minimum and maximum output or starting/stopping a given unit. There is good evidence that this behavior induces costs for the generator. These costs may be due to a combination of increased maintenance, increased outage rates, reduced efficiency and reduced lifetimes. Some of these costs are capital in nature as they may mean an increased amount of plant maintenance or overhauls, or even retrofits. With increased levels of wind and PV, this cycling behavior and wear and tear damage is likely to increase. Several studies are underway to quantify this and improve knowledge in the area, most notable the Western Wind and Solar Study Phase II, conducted by NREL.[8] That study used work done by Intertek/Aptech which quantifies wear and tear and fuel costs separately for different cycling operations, particularly ramping and start/stop behavior. The costs are then in included in a Plexos model of the Western Interconnection so that both the fuel and wear and tear impact of increased fossil cycling is accounted for in the modeling results. The modeling approach used here is very similar to the one employed by that study, with similar methods for reserves, multi stage modeling, etc. as outlined elsewhere in this report.

The purpose of this section is to describe analysis carried out in this project to identify the inputs which should be used. There is a number of different cost numbers available to represent cycling costs for the Western Interconnection. The Transmission Expansion Planning Policy Committee (TEPPC) production cost cases have fuel and energy costs lumped together. Additionally, the Intertek/Aptech report produced for the NREL study[9] has outlined mean lower bound estimates for the cost for different generator types. Finally, there are other datasets where fuel-only start and shut down costs are used. Note that this study will not include any other cycling costs other than hot start costs. Ramping and warm or cold hot starts would add significantly to modeling burden and would likely not materially impact results so they were not utilized.

To investigate the different assumptions and how they impact on total start costs, hot start costs were examined for a variety of unit types for different assumptions before deciding on a final figure which, in the opinion of the project team, made most sense and lined up closest with existing experience. The first numbers examined were the costs implied in the APTECH report. Firstly, start fuel costs are calculated based on the fuel used; with gas priced between $4-$7/mmBtu, depending on location and time of year (for example, the SMUD BA prices assumed were $4.3 - $6.5). This is shown as an average of all

[8] See "Western Wind and Solar Integration Study Phase II", available at http://www.nrel.gov/electricity/transmission/western_wind.html

[9] See http://www.nrel.gov/docs/fy12osti/54864.pdf

generators across the Western Interconnection in the blue bar in Figure 4-2. The red bar shows wear and tear costs. APTECH define these per MW of installed capacity, with only a lower bound given for public us, which is shown here. As shown, particularly in the case of coal and CTs, the start costs for fossil plant are based significantly on wear and tear costs.

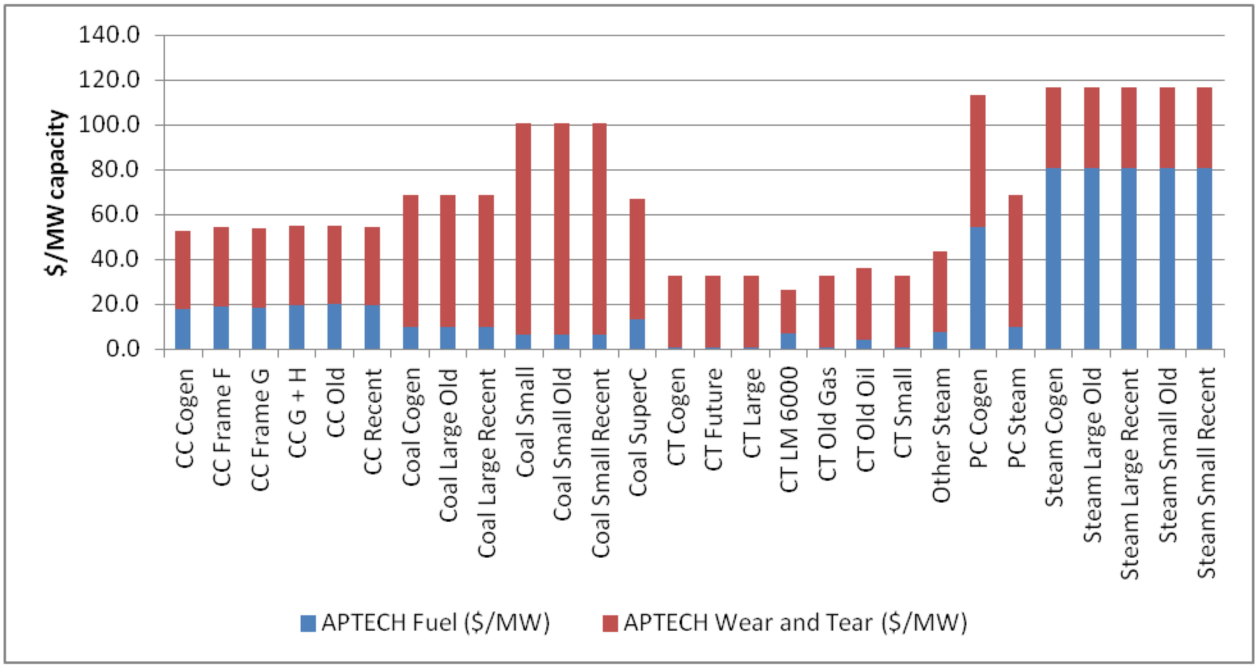


Figure 4-2: Start costs assumed based on APTECH report

The next step was to examine the costs already included in the Plexos database. One thing which was noted is that, instead of using coal price numbers for starts, gas prices should be used. Therefore, this was done for both the APTECH wear and tear costs and those already in the TEPPC database. Wear and tear costs were taken from both case – APTECH and Plexos, and added to fuel costs already in the database. This is shown in Figure 4-3. This shows why the datasets available needed to be examined some more. In the TEPPC model, there is both a start cost (in $/start) and a fuel usage (in mmbtu/start). Combining these should get the total cost, and it may be assumed that the start cost represents some wear and tear. The orange column in Figure 4-3 shows the 'fuel only' costs. What is clear here is that, for coal at least, this likely includes some component of wear and tear, as coal units are almost 10 times more expensive to start than a CC based on fuel costs, which does not seem likely. However, when TEPPC costs for starts not including fuel are included it can be seen that they more closely resemble the APTECH costs, which are based on experience from hundreds of generators over a long time period. The difference in costs between CC/CT and coal does not seem reasonable

It was decided that APTECH wear and tear costs be used for CT and coal, and added to the existing fuel cost to give the blue bars. For the coal units, it was assumed that the fuel usage was gas, whereas the wear and tear was that used in the existing dataset. Therefore, the numbers shown here were used as inputs to the model.

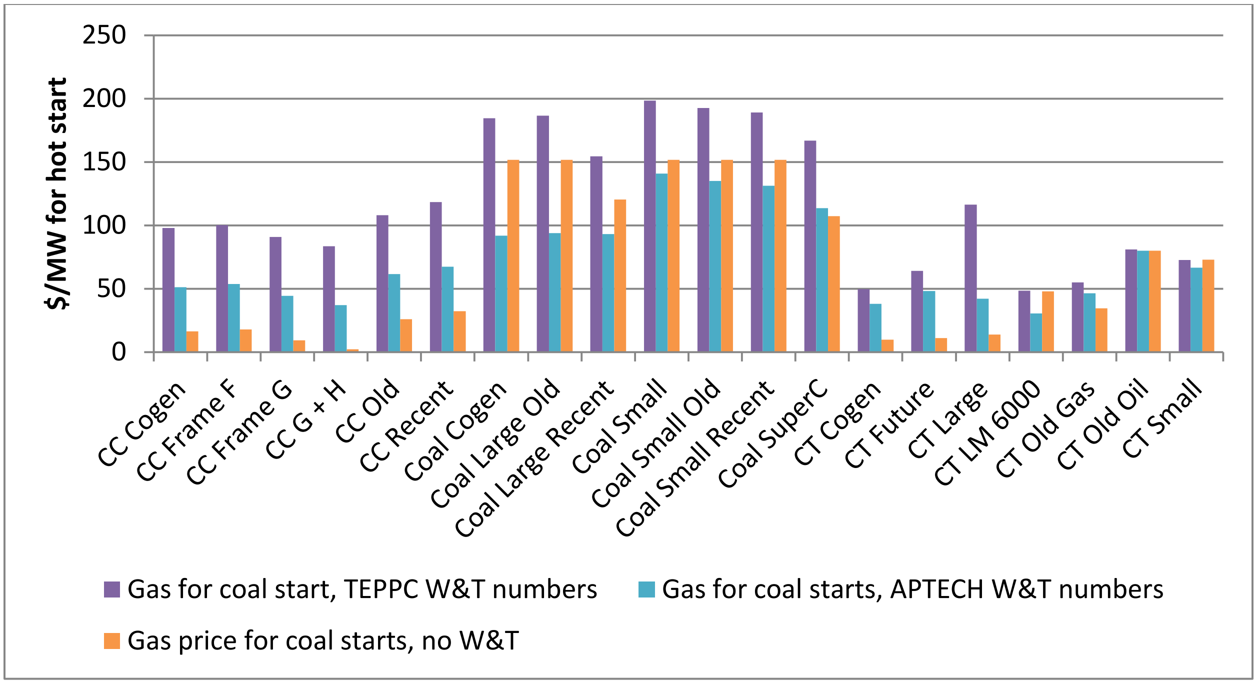


Figure 4-3: Comparison of total costs between existing numbers and APTECH numbers, based on gas being used as start fuel for coal plants. The final database used the blue bars for the gas plants and purple bars for coal generation

5 MODELING METHODOLOGY FOR STUDYING PUMPED HYDRO STORAGE

This chapter describes the overall methodology employed, in terms of how the PLEXOS model is setup. Included in this is description of the PLEXOS unit commitment and economic dispatch, the 3 stage modeling approach and transmission expansion. As some of these contributions are relatively new to this study, they are described here.

PLEXOS SCUC/ED algorithm

PLEXOS' Security Constrained Unit Commitment (SCUC) algorithm consists of two major logics: Unit Commitment using Mixed Integer Programming and Network Applications. The SCUC / ED simulation algorithm is illustrated in the following figure.

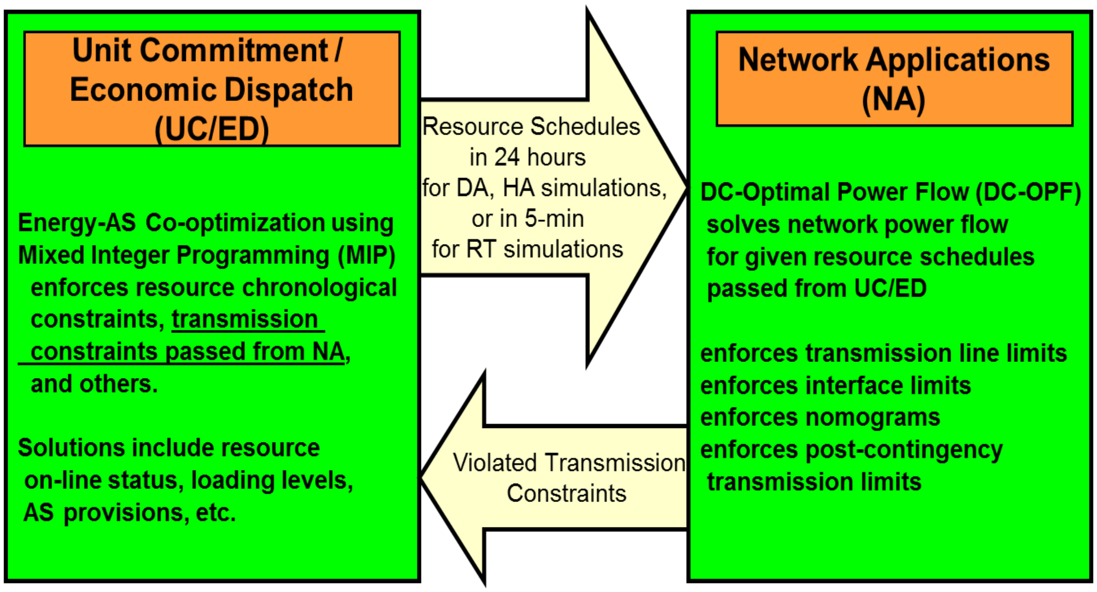


Figure 5-1 PLEXOS Security Constrained Unit Commitment and Economic Dispatch Algorithm

The unit commitment and economic dispatch (UC/ED) logic performs the Energy-AS co-optimization using Mixed Integer Programming enforcing all resource and operation constraints. The UC/ED logic commits and dispatches resources to balance the system energy demand and meet the system reserve requirements.

The resource schedules from the UC/ED are passed to the Network Applications logic. The Network Applications logic solves the DC-OPF to enforce the power flow limits and nomograms. The Network Applications logic also performs the contingency analysis if the contingencies are defined. If there are any transmission limit violations, these transmission limits are passed to the UC/ED logic for the re-run of UC/ED. The iteration continues until all transmission limit violations are resolved. Thus the co-optimization solution of Energy-AS-DC-OPF is reached.

The same algorithm for the SCUC/ED is used by many ISO market scheduling software (some ISO market scheduling software may use AC-OPF in the Network Applications).

One of the advantages of the MIP algorithm is its transparency. Any cost component or constraint in the MIP formula can be examined and explained.

The MIP mathematical formulation for the Energy-AS-DCOPF-PSH co-optimization can be illustrated by the following formula.

$$\min \sum_{t=1}^{T} \left\{ \sum_{k=1}^{K} \left[c_k^t \cdot g_k^t + sc_k^t \cdot (u_k^t - u_k^{t-1}) + \sum_{as=1}^{AS} asc_{k,as}^t \cdot as_{k,as}^t \right] \right\}$$

Subject to

$$\sum_{k=1}^{K} g_k^t + \boldsymbol{eff_g} \cdot \boldsymbol{g_{psh}^t} = \sum_{l=1}^{L} load_l^t + \boldsymbol{pump_{psh}^t} + \sum_{m=1}^{M} loss_m^t \quad \forall t,$$

(Energy Balance Constraint)

$$\boldsymbol{sto^t} = \boldsymbol{sto^{t-1}} - \boldsymbol{g_{psh}^t} + \boldsymbol{eff_p} \cdot \boldsymbol{pump_{psh}^t} \ \forall t,$$

(PSH Storage Balance Constraint)

$$\sum_{k=1}^{K} as_{k,as}^t \geq as_{as}^{t,min} \quad \forall t,\ as,$$

(AS as Requirement Constraints)

$$as_{k,as}^{t,min} \leq as_{k,as}^t \leq as_{k,as}^{t,max} \quad \forall t,\ as, k,$$

(Generator k AS capacity Constraints)

$$g_k^{t,min} \cdot u_k^t \leq g_k^t \pm \sum_{as=1}^{AS} as_{k,as}^t \leq g_k^{t,max} \cdot u_k^t \quad \forall t, k,$$

(Generation and AS Capacity Constraints)

$$g_k^t - g_k^{t-1} \pm \sum_{as=1}^{AS} as_{k,as}^t \leq ramp_k^{t,max} \cdot u_k^t \quad \forall t, k,$$

(Generation and AS Ramp Capacity Constraint)

$$f_j^{t,min} \leq f_j^t = \sum_{k=1}^{K} PTDF_j^{c,k} \cdot (g_k^t - load_k^t) \leq f_j^{t,max} \ \forall t, j, c$$

(Transmission line j Limit Constraints)

$$i_j^{c,t,min} \leq \sum_{j \in i} I_{line}{}_j^i \cdot f_j^{c,t} \leq i_j^{c,t,max} \quad \forall t, i, c$$

(Interface i Limit Constraints)

Generator Chronological Constraints

Resource Constraints

User-Defined Constraints

Where

g_k^t - Generation from generator k at interval t;

c_k^t - Generation cost of generator k at interval t;

u_k^t - Unit commitment status of generator k at interval t; 1=on-line, 0=off-line

sc_k^t - Startup / shut down cost of generator k at interval t;

$as_{k,as}^t$ - AS provision from generator k to AS as at interval t;

$asc_{k,as}^t$ - AS provision cost of generator k to AS as at interval t;

$\boldsymbol{eff_g}$ **-** PSH generating efficiency;

$\boldsymbol{eff_p}$ **-** PSH pumping efficiency;

$\boldsymbol{g_{psh}^t}$ **-** PSH generation at interval t;

$\boldsymbol{pump_{psh}^t}$ **-** PSH pump at interval t;

$load_l^t$ - Load at bus l at interval t;

$loss_m^t$ - Transmission losses of line m at interval t;

$g_k^{t,min}$ - Min capacity of generator k at interval t;

$g_k^{t,max}$ - Max capacity of generation k at interval t;

$ramp_k^{t,max}$ - Max ramp up / down rate;

$as_{as}^{t,min}$ - Min AS requirement for AS as at interval t;

$as_{k,as}^{t,min}$ - Min AS provision of generator k for AS as at interval t;

$as_{k,as}^{t,max}$ - Max AS provision of generator k for AS as at interval t;

$PTDF_j^{c,k}$ - Power Transfer Distribution Factor of bus k to transmission line j for post-contingency network c ($c = 0$ is the pre-contingency network);

$f_j^{c,t}$ - Line flow in transmission line j at interval t for post-contingency network c;

$f_j^{c,t,min}$ - Min line flow of transmission line j at interval t for post-contingency network c;

$f_j^{c,t,max}$ - Max line flow of transmission line j at interval t for post-contingency network c;

$I_{line_j}^{i}$ - Line coefficient of transmission line j in interface ;

$i_j^{c,t,min}$ - Min interface flow of interface i at interval t for post-contingency network c;

$i_j^{c,t,max}$ - Max interface flow of interface i at interval t for post- contingency network c;

The PSH pumping and generating are incorporated in Constraints "(Energy Balance Constraint)" and "(PSH Storage Balance Constraint)". By so doing, the PSH operation is co-optimized with other variables: energy, ancillary services, power flow, etc. This formula is different from other legacy PSH dispatch algorithm: generating a thermal cost curve, then dispatching PSH against thermal cost curve, and finally re-dispatching thermal generators with the PSH operation frozen. This legacy PSH dispatch algorithm assumes that PSH is a price-taker facility and its operation does not impact the system prices. Actually, PSH can provide energy and ancillary service simultaneously and the market energy and AS prices will be impacted by the PSH operation.

Reliability Unit Commitment

We have considered a few options of simulating the unit commitment (UC) process in a system with high variable generation (more than 33% VG), including stochastic unit commitment and 3-stage unit commitment. We decided to start with the 3-stage unit commitment and conduct a limited test case of stochastic unit commitment later. In the 3 stage unit commitment process that simulates Day-ahead unit commitment (DA UC), Hour-ahead unit commitment (HA UC) and Real time (RT) dispatch, it is critical to decide how much generation and reserve to schedule in the DA and HA time frame. The intermediate UC time frame can be hour ahead (HA) or 4 hour ahead (4HA). The first attempt was to require the DA UC to set back enough flexible reserve to cover the DA forecast uncertainty. The forecast uncertainty includes load, wind and PV forecasts, or we can call the combined the uncertainty the net load forecast uncertainty [10](See figure below for net load forecast uncertainty). In our first attempt, even when setting the reserve to cover a moderate 70% confidence interval of net load forecast error in DA, the reserve requirement was too high for the system to perform.

---

[10] In this study for practical purposes, the forecast error analysis is done for load, wind and solar separately and then combining into a single forecast error for "net load". This is necessary in part to eliminate predictable clear-sky ramps from the solar forecast error calculation. Otherwise, forecast error will include coverage for the predicable clear-sky portion. In a similar way, the wind forecast error calculation uses statistics specific to wind behavior to calculate the wind component. Finally, load forecast error is characterized by other drivers and treated differently.

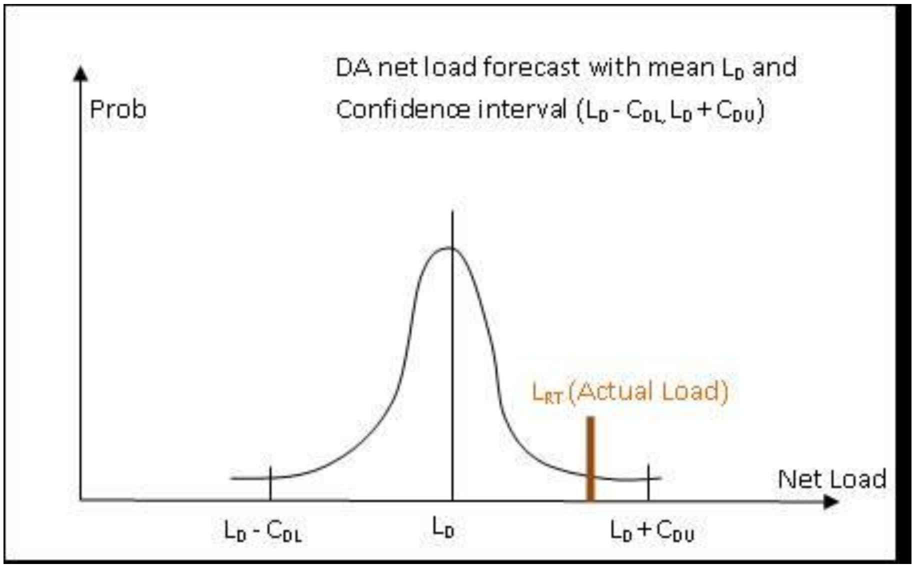


Figure 5-2: Illustration of forecast error level[11]

Further deliberation suggests that the DA UC does not need to cover DA forecast error of Net Load with flexible reserves, and most DA Error can be covered by any types of generation capacity (including DR). This is due to the fact that there is plenty of time for the system to move up generation from DA to RT if the actual hourly net load moves up to the upper bound of the forecast confidence interval, e.g. from L_D to L_{RT} in Figure 5-2 Similar reason applies if load turns out to be at the lower bound of the forecast confidence interval. Most generation resources can be dispatched to accommodate the slow adjustment in net load forecast from DA to RT. It can be long start units, medium start units and quick start units, and it can be slow ramping resources as well as fast ramping resources. For net load forecast uncertainty, the only time when reserves are needed would be in real time (Regulation reserve) and hour ahead and real time (Flexible reserve). These time frames are short and therefore require fast or moderate ramping generation resources.

[11] . Note: The distribution may not be symmetric. So CDU and CDL may not be the same.

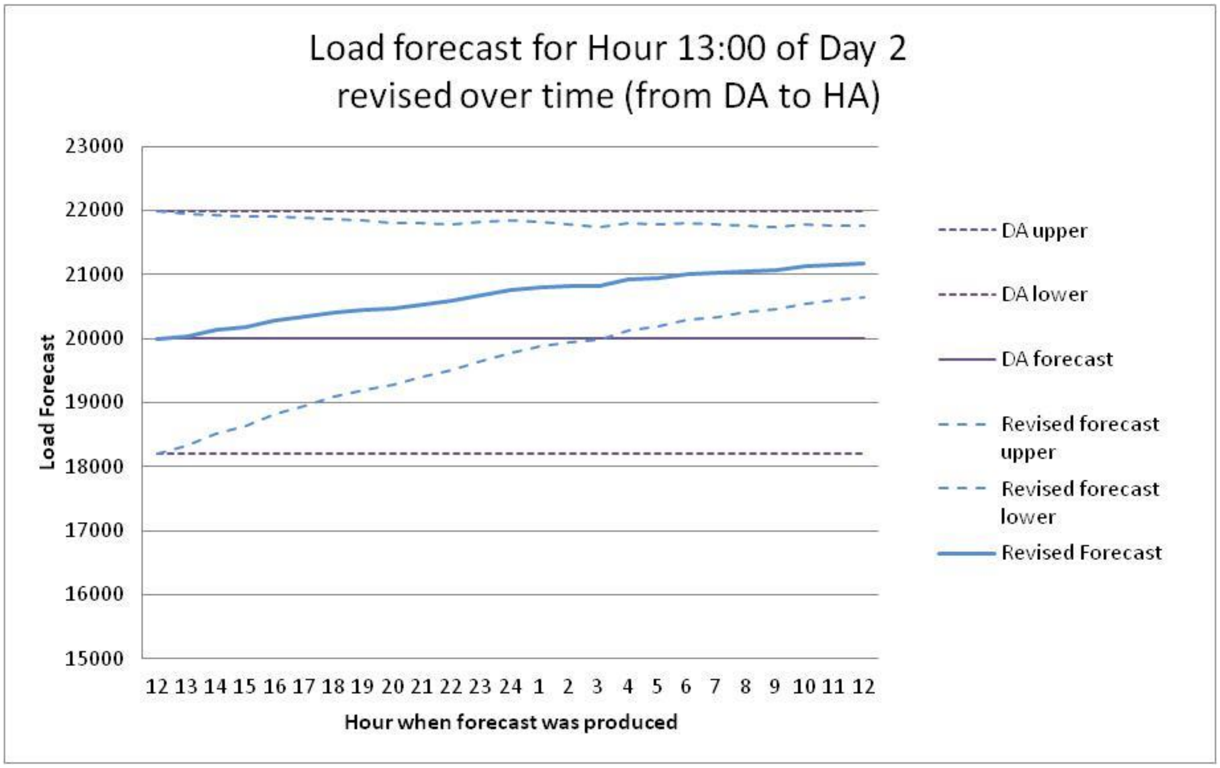


Figure 5-3: Load Forecast Error evolution over day

With this understanding, we propose the following unit commitment process in our simulation. It would be a 3 stage simulation for DA, 4HA and RT. In both the DA and 4HA, we are going to use the HA and RT net load forecast error to set regulation and flex reserve requirement. The DA, 4HA forecast error will be used to set extra capacity requirement (any capacity) to make sure there will be enough resource to cover the upper bound (at certain level of confidence, e.g., 95%) of net load. As noted above, this is done by calculating the forecast error for load, wind and solar separately and combining into a single "net load" forecast error. Also note that at the 4-hour ahead process, we propose to use the hour ahead forecast errors for reserve requirement.

To define the process further, let us assume the following forecast distribution for net load. For example, the DA net load forecast is assumed to be with mean L_D and Confidence interval (L_D - C_{DL}, L_D + C_{DU}).

Table 5-1: Forecast distribution example[12]

		Confidence Interval	
Time frame	**Mean**	**Upper range**	**Lower range**
DA	L_D	C_{DU}	C_{DL}
4HA	L_{4H}	C_{4HU}	C_{4HL}
HA	L_H	C_{HU}	C_{HL}
RT	L_R	C_{RU}	C_{RL}

Assume the system has three types of generation resources based on their start-up time:

Table 5-2: Start time and generator capacity

Generation Type	**Generation Capacity (MW)**
LS, Long start (>12 hours)	G_{LS}
MS, Mid start (> 1 hours)	G_{MS}
QS, Quick start (< 1 hour?)	G_{QS}

The generation and reserve requirements for each stage of unit commitment or dispatch will then be set up as the following:

---

[12] Note: The DA, 4HA and HA load is hourly average. The RT load will be 10 min interval average.

Also the distribution may not be symmetric and the upper range and lower range may not be the same.

Table 5-3: Generation and reserve requirements example

	Day Ahead Process	4-Hour Ahead Process	Real Time Dispatch
Generation Schedule	L_D	L_{4H}	L_R
RUC Capacity[13]	$C_{DU} - C_{HU}$	$C_{4HU} - C_{HU}$	**none**
Flex Reserve	C_{HU}	C_{HU}	**Released**
	C_{HL}	C_{HL}	
Reg Reserve	C_{RU}	C_{RU}	C_{RU}
	C_{RL}	C_{RL}	C_{RL}
Contingency Reserve	**As usual**	**As usual**	**As usual**

At the DA UC time, the system requirement will be to meet the expected load L_D, and various reserve requirement C_{HU}, C_{HL}, C_{RU}, C_{RL} and contingency reserves. These are the typical system requirement. Note the flexible reserve requirement and regulation requirement are all based on the hour ahead and real time forecast errors, not the DA forecast error. The main new feature in the DA UC (and 4-hour ahead processes) is the extra capacity (RUC Capacity)) requirement, that will cover the DA (or 4-hour ahead) forecast errors, respectively, minus the HA error, which is covered by flex reserve. Note the extra capacity can be met by any generation capacity, regardless of generation type, ramp rate or dispatchable range. It also uses the full capacity of any generation resources instead of the dispatchable or flexible range of it. The extra capacity to mitigate forecast uncertainty is somewhat similar to the residual unit commitment process in CA ISO and the reliability unit commitment in some other markets. So we propose to name it the RUC Capacity in this study.

After the Day Ahead unit commitment, only the long-start generator UC patterns are passed to the 4HA process and frozen in the 4HA simulation. By so doing the medium- and quick-start generator unit commitment can be re-determined in the HA simulation based on the updated forecasts of net load.

---

[13] Reliability Unit Commitment Capacity (RUC capacity) doesn't need to be flexible reserve capable (ramping up and down) generation resources. It can be any combination of Steam Turbine, Gas Turbine, Combined Cycle and Hydro generation. It is similar to residual unit commitment process in CA ISO and the reliability unit commitment in some other markets.

Similar set up is used for the 4HA UC process. This 4HA UC process can help to achieve two conflicting objectives that we previously debated extensively. That is the objective to conduct an intra-day UC to commit medium start units (such as CCGT's with more than 1 hour of start-up time and with a few hours of min up time and min down time), and the objective to minimize flex reserve requirement. The first objective suggests a 4HA UC to give enough lead time to start medium start units. The second objective suggests a HA UC to utilize the most up to data forecast to minimize the flex reserve need. The revised 4HA UC process will be able to meet both objectives. It is done at 4 hour ahead time but using the hour ahead error to set the flex reserve requirement. The real time regulation also remain the same in all DA, 4HA and RT process. Again helps to keep regulation cost down.

When passing the unit commitment patterns from 4HA to RT, the UC patterns of the long- and medium-start generators are passed to RT dispatch and frozen in the RT simulation. The quick-start generator unit commitment will be determined in the RT simulation based on the actual net load.

This DA and 4HA UC approach mimics some aspect of the stochastic unit commitment process: the long-start generator unit commitment is the first stage decision variables that need to be determined for all possible uncertainty ($C_{DU} \sim C_{DL}$). The medium-start generators are the second stage decision variables that will be determined based on the updated uncertainty ($C_{HU} \sim C_{HL}$). Finally the quick-start generators are the recourse decision variables that will be determined based on the actual realization (L_{RT}) where L_{RT} is the actual load net actual renewable generation.

The proposed UC process aims to commit enough generation resources to meet the upper bound of the net load. It doesn't take care of the possible lower bound net load condition, and therefore over generation is possible. Over generation won't occur immediately when the actual load is below $L_D + C_{DU,}$ the upper bound of DA load forecast. There are a few mechanisms the system can use to adjust to meet the lower load. The system may decide not to start the medium start and quick start unit in the intra-day and hour ahead UC process and bring generation capacity below $L_D + C_{DU.}$ The system can further dispatch the long start units, committed in the DA process, to generation levels below their maximum capacity. So as long as the sum of minimum capacity committed in the DA process is lower than LD - C_{DL} the system won't experience over generation condition.

The other rationale of this one-sided maximum load scheduling approach is that low net load condition is most likely caused by unexpected high generation of Wind or PV. Curtailment of Wind or PV will be an option in this condition. We should keep track of possible dump energy and assess the amount of GV curtailment.

In the Day-ahead and Hour-ahead scheduling simulations, the flexibility up reserve covers 70% CI of the load and renewable energy variability and forecast error. To be prepared for the remaining load and renewable energy variability and forecast error and to cover the difference between 95% CI and 70% CI, the system should have enough generating and ramping capacity. The generating and ramping capacity could be on-line un-used capacity or off-line quick start generators. For DA unit commitment, off-line generation which could be started during the day of operation can also be used. The Reliability Unit Commitment (RUC) is modeled as operational reserves with a requirement based on the difference between the 95% CI and 70% CI of forecast error at DA or HA scheduling time. The RUC is provided by on-line un-used capacity and off-line quick start or mid start generators. Ramp rates are honored when the on-line generators provide the RUC reserves.

Scope of Simulations

The simulation scope covers the base, the high-wind and the high-mix renewable generation scenario with and without Iowa Hills. The SMUD BA has energy transaction with the North West (NW) region of the WI and CAISO. The SMUD BA also possibly has reserve transactions with CAISO. To evaluate the Iowa Hill in varieties business models, the simulation focus area is California-SMUD BA-NW.

In the WECC TEPPC database, the load region the SMUD BA represents the Balancing Authority of Northern California (BANC) that includes

- Sacramento Municipal Utility District (SMUD),
- Modesto Irrigation District (MID),
- Roseville Electric, and
- Redding Electric Utility.

For consistency, the name of the SMUD BA is used in the remaining of this document for BANC.

Other two proposed PSHs, Swan Lake and Eagle Mountain, are model in both the cases without and with Iowa Hill.

The renewable scenario combinations for the simulations in CA-SMUD BA-NW and WI are listed in the following table.

Renewable Scenario	**Renewable Penetration levels**			
	CA	**SMUD BA**	**NW**	**Rest of WI**
A	**Base TEPPC from WWSIS 2 Study**			
B	**High-Wind (33%) from WWSIS 2 Study**			
C	**High-Wind (33%)**		**TEPPC**	
D	**High-Mix (50%)**		**TEPPC**	
E	**High-Mix (50%)**		**High Wind (33%)**	
F	**High-Solar (33%) from WWSIS 2 study**			

Table 5-4 Combinations of Renewable Penetration Levels in Different Regions

In the high-max (50%) scenario, the wind generation is from the high-wind scenario and the solar generation is from the high-solar scenario in the WWSIS 2 Study.

When simulating the focused area CA-SMUD-NW, the WI system is simulated to produce the power exchange between CA-SMUD-NW and the rest of the WI for different renewable penetration levels as in the above tables. In addition to the Iowa Hill evaluation, the alternative resources, such as reciprocating generator, are evaluated as comparisons. The simulation cases with and without Iowa Hill or alternative resources for different renewable combination scenarios are listed in the following table.

Description of Simulation Cases for A Variety of Renewable Scenarios				
Case	Focus BA	New Balancing Resource	AS-trading between CA and SMUD	Renewable Scenario Combination
1	SMUD	No	No	WI TEPPC
2	SMUD	Iowa Hill PSH	No	WI TEPPC
2b	SMUD	Iowa Hill PSH	Yes	WI TEPPC
3	SMUD	Reciprocating Generator	Yes	WI TEPPC
4	SMUD	No	No	WI High-wind
5	SMUD	Iowa Hill PSH	No	WI High-wind
6	SMUD	Iowa Hill PSH	Yes	WI High-wind
7	SMUD	FS Iowa Hill PSH	Yes	WI High-wind
8	SMUD	Reciprocating Generator	Yes	WI High-wind
11	SMUD	No	No	CA High-Wind, WI TEPPC
13	SMUD	Iowa Hill PSH	No	CA High-Wind, WI TEPPC
15	SMUD	Iowa Hill PSH	Yes	CA High-Wind, WI TEPPC
17	SMUD	Reciprocating Generator	Yes	CA High-Wind, WI TEPPC
12	SMUD	No	No	CA High-Mix, WI TEPPC
14	SMUD	Iowa Hill PSH	No	CA High-Mix, WI TEPPC
16	SMUD	Iowa Hill PSH	Yes	CA High-Mix, WI TEPPC
18	SMUD	Reciprocating Generator	Yes	CA High-Mix, WI TEPPC
19	SMUD	No	No	CA High-Mix,WI-High-WInd
20	SMUD	Iowa Hill PSH	No	CA High-Mix,WI-High-WInd
21	SMUD	Iowa Hill PSH	Yes	CA High-Mix,WI-High-WInd
22	SMUD	Reciprocating Generator	Yes	CA High-Mix,WI-High-WInd

Table 5-5 List of Basic Simulation Cases

Where "Focus BA" specifies the BA that is responsibility to balance its energy; "New Balancing Resource" specifies the resources under study; "FS Iowa Hill" indicates that the Iowa Hill is modeled as the fixed speed PSHs in the simulations.

Before simulating the focus area CA-SMUD-NW, the WI is simulated to produce the exchange between CA-SUMD-NW and the rest of WI for the different renewable scenarios. These exchanges are frozen in the CA-SMUD-NW simulations.

The sensitivity cases are listed in the next phase report, and the sensitivities will include the different focus BA combinations, hydro scenarios, other alternative resources such as Compressed Air Energy System (CAES), etc.

CA-SMUD-NW Bid-base Market Simulation Approach

In the focus area CA-SMUD-NW, majority of CA footprint belongs to the bid-based market CAISO. Though the SMUD BA, NW and a few utilities in CA are not in a bid-based market, the focus area CA-SMUD-NW needs to model as a bid-base market in order to closely evaluate the Iowa Hill.

Power Market Bidding Prices

A critical factor in the power market simulation is to determine the generator bidding prices for the generator energy and ancillary services. The approach of the generator bidding price determination adopted in this study is to benchmark the regional prices from the simulations against the CAISO historical market prices.

Energy Market Bidding Prices

The CAISO 2012 annual market report[14] is reviewed. The chart extracted from section 2.2 "Overall Market Competitiveness" of the report shows that the average energy market prices are close to the cost-based simulations by the CAISO department of market monitoring. The price-cost mark-up is the difference of the market clearing price and the market marginal cost. The negative price-cost mark-up indicates the average CAISO market clearing price is lower than the average market marginal cost. Therefore, for the energy market simulation, the generator marginal cost price is used as the energy bidding price.

[14] Department of Market Monitoring, CAISO, "*2012 Annual Report on Market Issues and Performance*", April 2013, http://www.caiso.com/Documents/2012AnnualReport-MarketIssues-Performance.htm

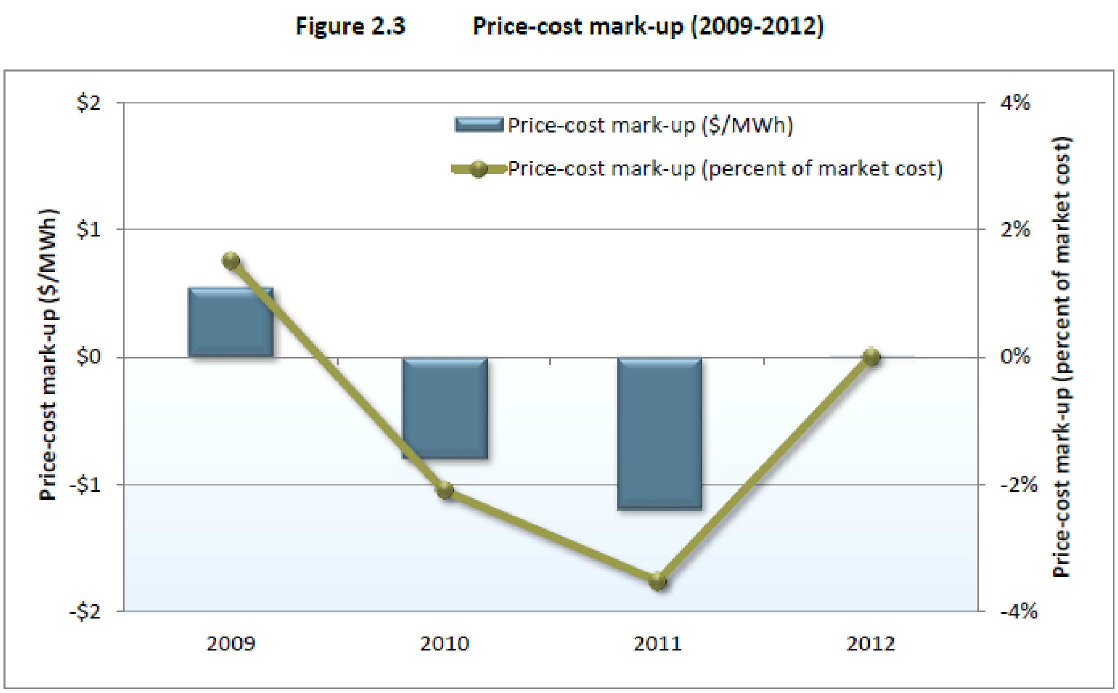


Figure 5-4 CAISO Energy Price-cost mark-up (2009-2012)

Ancillary Service Market Bidding Prices

The historical AS market clearing prices in year 2012 are analyzed. The analysis shows that the AS market clearing price is closely correlated with the energy market LMP that, in turn, is closely correlated with the regional load. The statistics and correlation of the CAISO NP15 LMP and AS clearing prices in year 2012 are shown in the following table.

Table 5-6 Statistics of CAISO Historical NP15 LMP and AS Clearing Prices in Year 2012

Statistics of CAISO Historical NP15 LMP and AS Clearing Price in Year 2012					
	NP15 LMP	**AS Clearing Prices**			
		Non-Spinning	**Spinning**	**Regulation Down**	**Regulation Up**
Mean	**36.77**	**0.60**	**4.07**	**4.98**	**5.62**
Max	**113.15**	**66.36**	**66.36**	**74.75**	**66.36**
Min	**(10.45)**	**-**	**-**	**-**	**-**
STDEV	**10.49**	**2.45**	**4.80**	**4.13**	**5.28**
STDEV %	**29%**	**410%**	**118%**	**83%**	**94%**

The following table shows strong correlations between the ancillary service prices and NP15 LMP.

Correlation of CAISO Historical NP15 LMP and AS Clearing Prices in Year 2012							
		NP15 LMP	**AS Clearing Prices**				
			Non-Spinning	**Spinning**	**Regulation Down**	**Regulation Up**
NP15 LMP		**0.93**	**0.34**	**0.28**	**(0.43)**	**0.24**
AS Clearing Prices	**Non-Spinning**		**0.71**	**0.49**	**(0.05)**	**0.43**
	Spinning			**0.71**	**0.13**	**0.91**
	Regulation Down				**0.69**	**0.17**
	Regulation Up					**0.67**

Table 5-7 Correlation of CAISO Historical NP15 LMP and AS Clearing Prices in Year 2012

From the analysis, the following approach is adopted to mimic the generator AS bidding price in the simulations.

- The hourly upward AS bidding prices in a region follow the hourly regional load profiles, and the hourly downward AS bidding prices follows the inverse of the hourly regional load profiles;
- The generators with a higher generation marginal cost will have lower AS bidding prices and the generators with a lower generation marginal cost will have higher AS bidding prices. The reason so doing is that the generators with higher generation marginal cost have lower energy profit margin, and the generators with lower generation marginal cost have higher energy profit margin.
- The final hourly AS bidding price for a generator is the normalized hourly AS bidding price profiles times the AS bidding price scalar. The normalized hourly AS bidding price profiles is the normalized hourly regional load profile for the upward AS, and the inverse of the normalized hourly regional load profile for the downward AS.
- The generator AS bidding price scalar has a higher value for higher quality reserves.
- Hydro generators and PSHs have fast ramp capability, and are assumed to provide the AS before thermal generators.

The AS bidding price scalars, proportional to the generator energy profit margin, by generator type and by AS type are shown in the following table.

AS Bidding Price Scalar by Generator Type ($/MW)						
Generator Type	**Non-Spin**	**Spin**	**Flex Dn**	**Flex Up**	**Reg Dn**	**Reg Up**
CC	**3**	**9**	**15**	**15**	**30**	**30**
Coal	**5**	**15**	**35**	**35**	**60**	**60**
CT	**2**	**6**	**10**	**10**		
DR	**2**	**6**	**10**	**10**		
Hydro	**1**	**3**	**5**	**5**	**10**	**10**
IC	**2**	**6**	**10**	**10**		
PSH	**1**	**3**	**5**	**5**	**10**	**10**
STEAM	**2**	**6**	**10**	**10**		

Table 5-8 CA-SMUD-NW AS Bidding Price Scalar by Generator Type

Transmission Expansion for the High-wind Renewable Scenario

The transmission in the existing TEPPC 2022 network was not adequate to accommodate the High-wind renewable Scenario, so some transmission expansion assumptions had to be made. The transmission expansion assumptions were added to allow the simulations to deliver the renewable energy at the high-wind renewable level. Without the transmission expansion assumptions, the simulation would not have been able to generate results for the High-wind renewable scenario.

Given that this study is not a transmission expansion study, it is important to note that the transmission expansion methodology was simplistic. And the transmission expansion methodology did not include detailed economic or reliability analyses. Nor did it take into account issues such as rights of way, environmental concerns, policy constraints, or any other factor that might normally be considered in detailed transmission planning activities.

The following steps were taken to generate the transmission expansion assumptions:

- Perform PLEXOS nodal simulation with the renewable generation at the high-wind renewable penetration level,
- For any congested transmission line with the yearly average shadow price greater than $10/MWh, build a parallel transmission with the exact same characteristics of the congested transmission line,
- For a congested transmission interface with the yearly average shadow price greater than $10/MWh, increase the transmission interface rating by 500 MW and build a parallel transmission line in the transmission interface if necessary,

- Perform PLEXOS nodal simulation again and repeat the process until all monitored transmission lines and interfaces have the congestion prices less than $10/MWh.

The transmission expansion steps can be illustrated in the following diagram

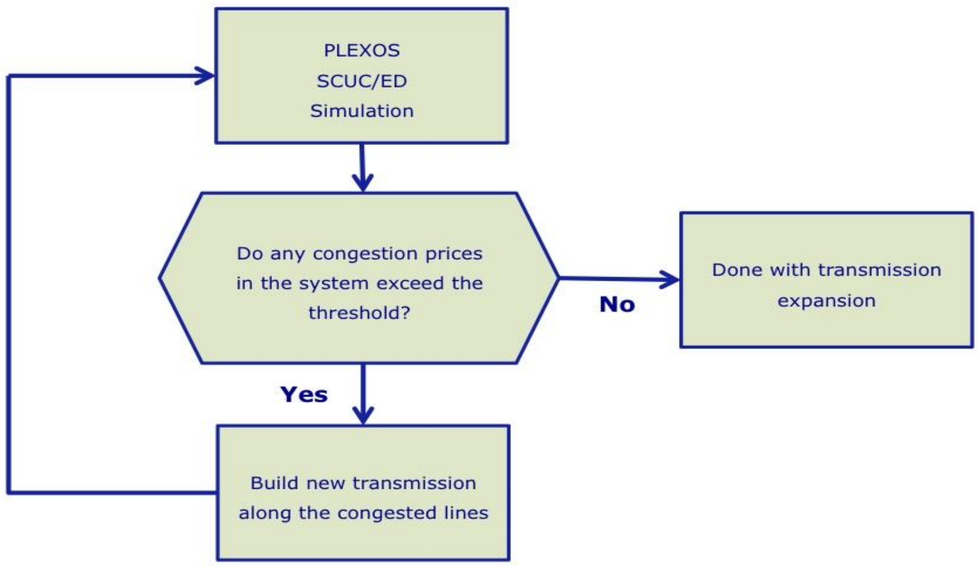


Figure 5-5 Logic flow for the Transmission Expansion Using Congestion Shadow Price Approach

The transmission expansion assumptions for the high-wind renewable scenario are listed in Appendix – Transmission Expansion Assumptions for High-wind Renewable Scenario.

The solutions of the transmission expansion indicate that there is more transfer capacity needed to deliver the renewable generation to the load centers under the High-wind renewable scenari

6 OVERVIEW OF PLEXOS SIMULATION RESULTS

This section gives an overview of the most relevant results for the simulations. Detailed results are given in the next chapter. Previous studies of renewable integration and the value of storage have shown the value of pumped hydro storage increases with increasing variable generation. The detailed methodology, datasets and reserve requirements described in the previous four chapters will ensure that results described here better represent the value of Iowa Hill, to the SMUD BA and the entire region, than many previous methodologies. Even still, there are clearly many assumptions and modeling limitations that the results described here and in the next chapter are just a sampling of future scenarios that can unfold in the future. For example, the generation mix and transmission system examined here may not be the same as will occur in the future with high penetrations of variable generation. Additionally, to reduce computational time, the system modeled here wasn't a full network but a 'pipe and bubble' model so detailed transmission limitations aren't represented. Finally, the model uses a Mixed Integer Programming optimization with an optimality gap of 0.5%, so the answer is not fully optimal; therefore any small difference in costs or generation may be a result of 'noise'; however the simulations results give some insight into high level results and trends.

Results here are examined for a number of areas. Firstly, Iowa Hill operations for different scenarios are examined. Then the production cost savings, including netting of energy and AS imports/export, are examined for various scenarios and multiple cases in each scenario, including examining how Iowa Hill impacts market prices of ancillary services and energy. Then other potential benefits of Iowa Hill are examined: potential reduction in curtailment of variable generation, benefits to cycling and ramping of conventional generation, emissions reductions, efficiency improvements of other power sources in the SMUD BA portfolio, and improvements in portfolio balancing capabilities. More detail on each result is given in the next chapter.

In general, the results here are for a number of cases within each scenario described in Chapter 3. In particular, results were examined for both a case with Ancillary Service (AS) trading allowed between the SMUD BA and the rest of study area, and a case where this is not possible. As Iowa Hill is likely to be a useful AS resource, and California and the Northwest could require significant additional reserves to manage variability and uncertainty of wind and PV, this case will be important to illustrate the value of Iowa Hill when it can participate in other markets. Other cases examined included an alternative option of reciprocating engines, or a fixed speed PHS instead of the variable speed case assumed in most results; these results are not examined in as much detail but will be described where relevant.

Operation of Iowa Hill

The first thing to examine is how Iowa Hill operates at different scenarios. This is shown in Figure 6-1 for the case where AS trading is allowed. As shown, capacity factor (which is total generation as a percentage of the total possible if the unit was to generate in every hour) lies between approx 23% and 29%, showing that different scenarios will not significantly impact the energy production of Iowa Hill.

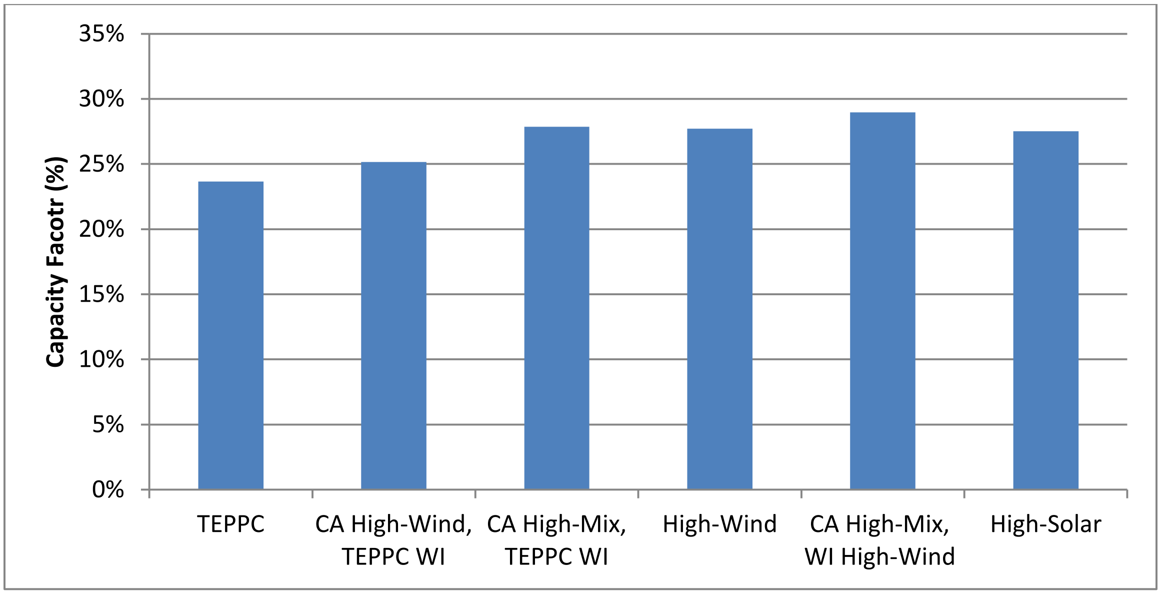


Figure 6-1: Capacity Factor of Iowa Hill for different scenarios, with AS trading allowed

The provision of regulating reserve, the highest value reserve, from Iowa Hill was shown to be more dependent on the scenario and case, with AS trading increasing the amount it was used for reserves, and the higher wind and solar penetrations also including usage for providing reserves. This is shown in Figure 6-2; note the high solar case was not examined without trading of ancillary services from Iowa Hill.

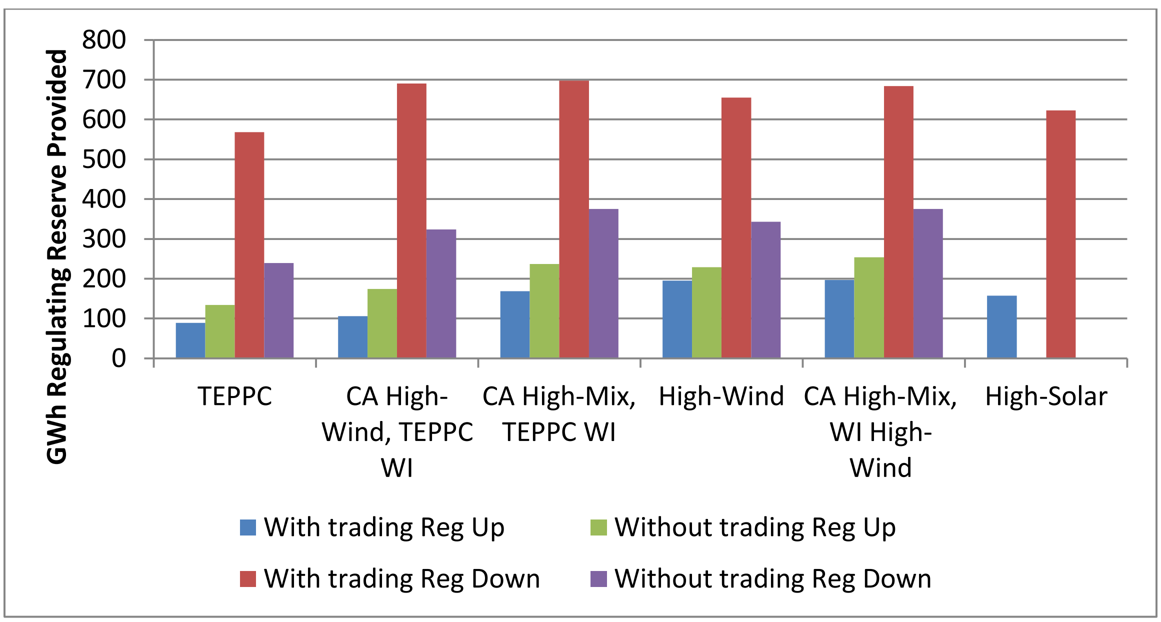


Figure 6-2: Regulation provision in the SMUD BA for different scenarios and cases (note high solar only examined for cases with trading

A final figure which shows how Iowa Hill provides reserves is to examine how much of the total reserve requirements in the SMUD BA are met by Iowa Hill, as shown in Figure

6-3. This shows that Iowa Hill provides a very significant amount of total reserves, particularly downwards regulation, and downwards flexibility (which is a new reserve added as described in Chapter 3). It also shows that Iowa Hill provides more of the SMUD BA's reserve when it can't be traded into other areas (though that may result in more revenue as described later as Iowa hill can take advantage of higher prices in other areas). Note also that, once again, the high solar case was not modeled for the case with AS trading from Iowa Hill.

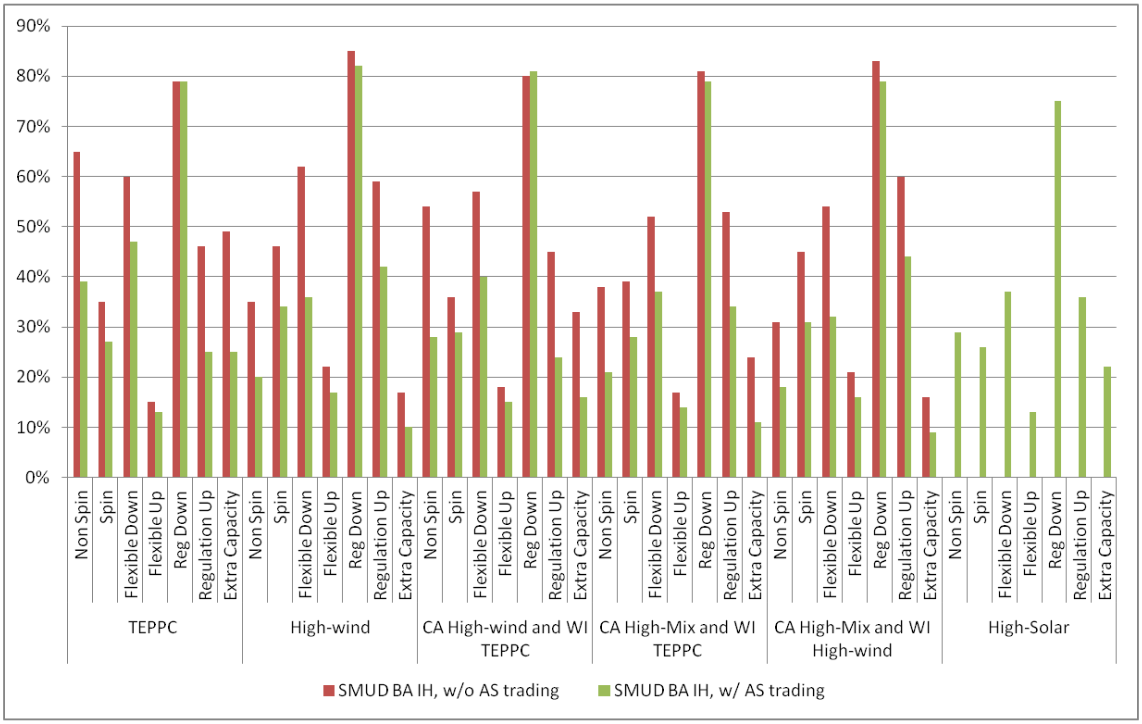


Figure 6-3: Percentage of each reserve category provided by Iowa Hill for different scenarios and cases (High Solar Case did not examine trading of AS from Iowa Hill)

Overall, therefore, Iowa Hill is used significantly both for energy and reserves, with significant interaction with energy and AS in other regions. In terms of how Iowa Hill impacts energy imports, adding Iowa Hill in the base case means the SMUD BA moves from paying for imports to receiving money from exports. However, in all other cases, adding Iowa Hill actually increases net energy imports for the SMUD BA; this is likely due to the fact that the SMUD BA can take advantage of cheaper energy to import at off-peak times. The difference is greater in the cases with higher wind in the WI as expected. Also expected would be the fact that the SMUD BA is a net exporter of energy (due to its lower marginal costs) when California has higher penetrations and the WI doesn't, but as the WI sees higher wind penetrations, imports increase. More details are given in the next chapter.

Financial and Cost Impacts

It was shown therefore that Iowa Hill operated as expected, providing significant reserves and being used more with increasing wind and solar penetrations. The impact on costs could generally be measure in two ways: the total production costs reduction and the revenues. As production costs are optimized, and as SMUD is a vertically integrated utility which would thus be more concerned with total costs rather than revenue, these are more important and examined in more detail. Revenues of Iowa Hill if it is considered part of a larger California market are also examined in the next chapter. The benefits to the California and Northwest regions (including the SMUD BA) were examined to see if there are additional benefits to other regions than the SMUD BA. Production cost numbers were calculated for the SMUD BA based on the net savings when including imports and export, thus considering the revenues from wholesales to neighboring areas. This shows how markets are impacted, potential revenues from these sales, and how Iowa Hill could benefit the region in general. As can be seen in Table 6-1, for the case with AS trading, study wide energy and ancillary services costs savings (which are what is being optimized in PLEXOS) are between $55/kW and $190/kW. Most of those production cost reductions are due to savings in the SMUD BA. Production cost savings in the SMUD BA include savings due to change in imports – Iowa Hill generally increases net import costs, but uses this to reduce overall costs later. As can be seen, the SMUD BA gains approximately 70% to 90% of the production costs savings in the whole study area; in the case without AS trading, the SMUD BA savings are greater, but overall system cost savings are lower, and revenue of Iowa Hill is lower. One thing to note is that savings due to high solar across the WI are not as high than either high wind or high-mix cases, showing how important the underlying VG mix is.

Table 6-1: Summary of AS revenue and production savings impacts due to Iowa Hill for different scenarios, case with AS trading

Scenario	SMUD BA Cost Savings (net of wholesale energy and AS revenues) ($/kW)	Study Area Cost Savings ($/kW)
TEPPC	30	33
CA High-Wind, WI TEPPC	30	20
CA High-Mix, WI TEPPC	48	38
High-Wind	65	90
High Solar	35	50
CA High-Mix, WI High-Wind	130	168

Table 6-2 shows the production simulation savings differences with the addition of Iowa Hill. As shown, for the SMUD BA only, not having AS trading increases savings due to Iowa Hill; however this reduces the benefit to the other parts of the study area. It can also be seen that the production cost savings increases with increasing wind and solar penetration, though high solar does not show as much value as high wind. Finally, it can be seen that a similar amount of reciprocating engines do not show nearly the same cost reduction benefits.

Table 6-2 Summary of Production and AS Cost Reduction ($m) due to Iowa Hill or Reciprocating Engines for each Renewable Scenarios for a number of cases (note high solar did not examine cases without trading or with recips)

RPS Scenario	SMUD BA			Study Areas of SMUD BA-CA-NW		
	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading
TEPPC	11	12	3	8	13	2
CA High-Wind and WI TEPPC	11	12	2	7	8	2
CA High-Mix and WI TEPPC	18	19	3	3	9	3
WI High-Wind	47	43	10	49	59	21
WI High Solar		14			20	
CA High-Mix and WI High-Wind	53	52	17	47	67	36

Variable Generation Curtailment Reduction by Iowa Hill

One of the main reasons that Iowa Hill was seen to see revenues higher than its cost savings may be due to renewable curtailment. This can instead be stored by Iowa Hill and used at a later time (with some efficiency losses).Figure 6-4 shows the reduction in curtailment due to the presence of Iowa Hill. As can be deduced from the figure, at lower penetrations, there is not enough curtailment for Iowa Hill to make a big difference under average conditions. Similarly, for high solar penetrations but not high wind, there is less curtailment in the base case; this is a major reason Iowa Hill shows less value in the high solar case in the cost results above. However, at higher wind penetrations, there is more curtailment. At higher penetrations, up to 1% of wind and solar may be curtailed under average conditions. This isn't very significant, but can have significant financial implications. For example, in the total study region total curtailment varies between 12GWh and 1800 GWh, which while a small percentage of total generation, is still relatively significant. This is reduced by almost 20% here showing another value of Iowa Hill in the presence of high renewable penetrations. The financial implications of this could be up to $1.5m per year in the SMUD BA and $35m in the entre study area, based on a renewable value of $22/MWh.

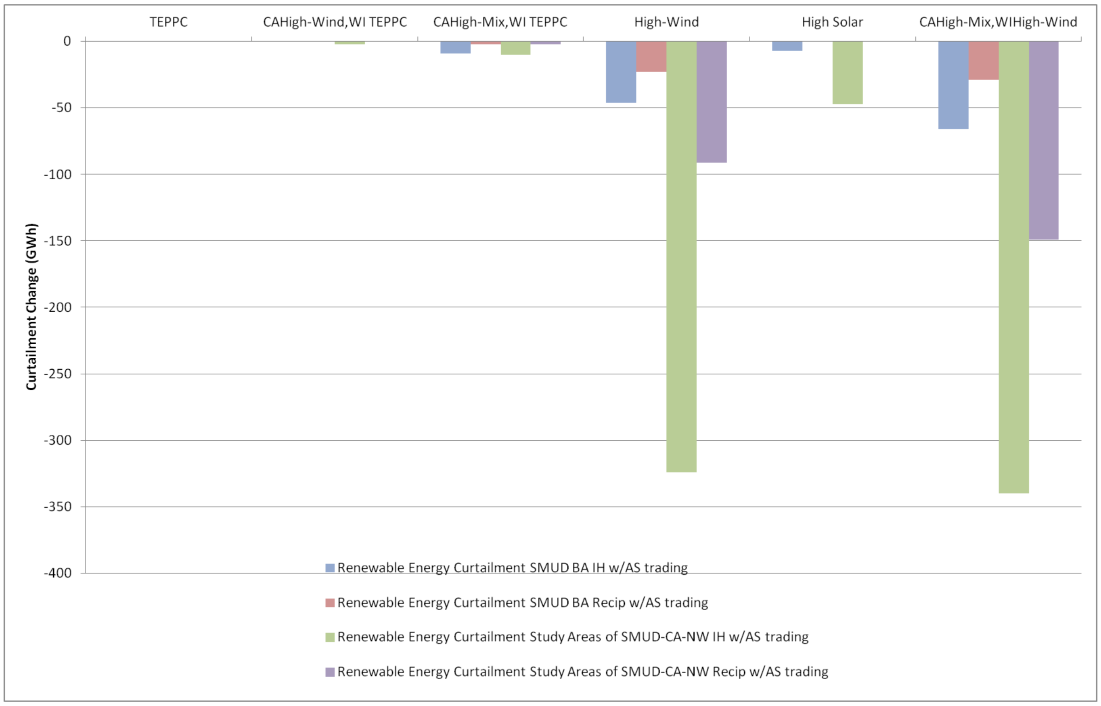


Figure 6-4: Reduction in Renewable Curtailment when Iowa Hill is added to system

Reliability and Reserve Impacts

Another benefit of Iowa Hill is in reducing reserve shortfalls and thus increasing reliability. While most reserve categories didn't see significant reserve shortfalls the downwards flexibility reserve described earlier as a new reserve type may see a significant number of hours in which it is not met. The presence of Iowa Hill was shown to dramatically reduce this by up to 50% of total GWh in the SMUD BA region, or up to 18% in the entire study region. While the financial impact is difficult to quantify, it is an indication of higher reliability in terms of meeting NERC balancing requirements measured by Control Performance Standards 1and 2 (CPS1and CPS2) .

Cycling and Emissions Impacts

Cycling of conventional plant (starting and stopping and ramping) becomes increasingly prevalent with high penetrations of variable generation. Results from simulations show that, with Iowa Hill on the system, cycling can be significantly reduced as shown in Figure 6-5. The SMUD BA generation shows reductions between 30% (in lower penetration cases) and 85% (in higher penetration cases when AS isn't traded between regions). In the entire study area, the results show a reduction between 5% and 15% of the total number of units started. From a costs perspective, this means a reduction in costs related to cycling by between 15% and 75% in the SMUD BA (depending on wind and solar penetration and whether AS is traded between regions), and 2%-12% study area wide. Meanwhile, ramping is reduced by between 15% and 60% in the SMUD BA (depending on wind and solar penetration and AS trading between regions) and a lower number area wide.

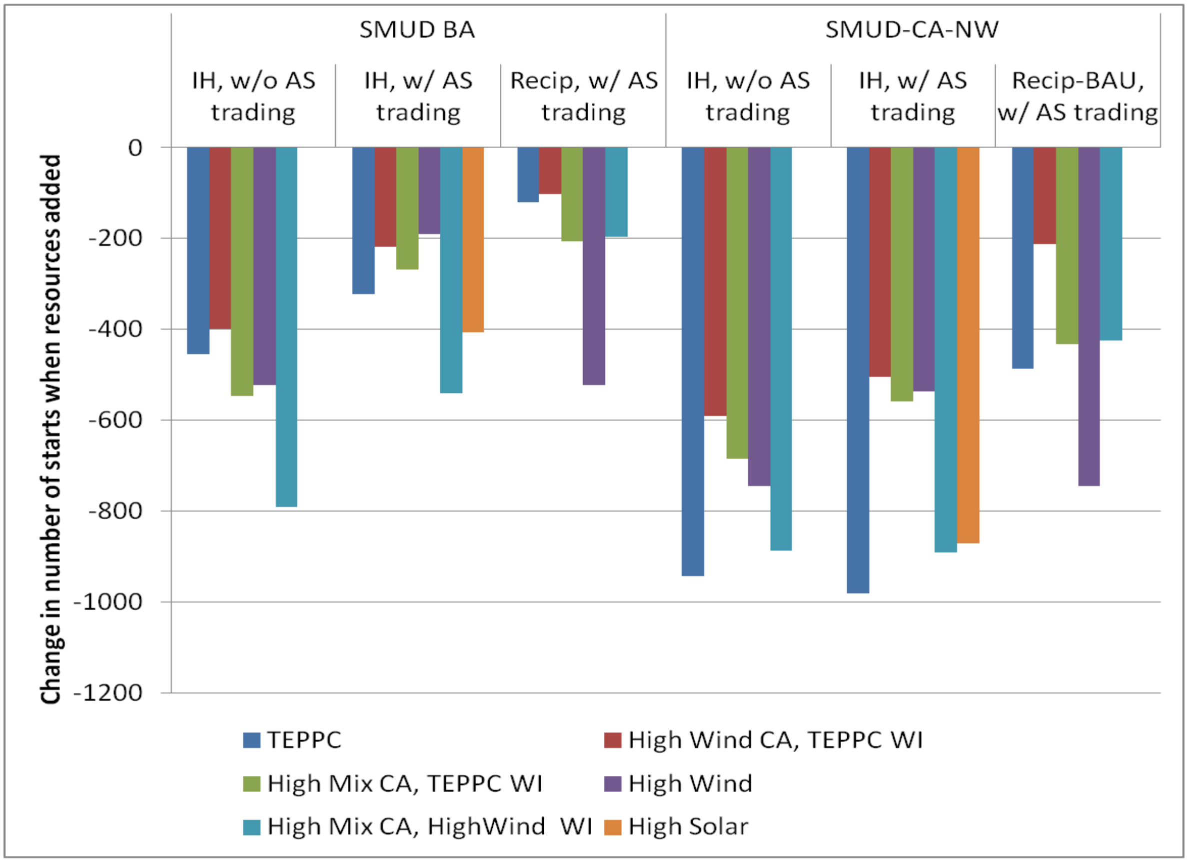


Figure 6-5: Change in number of starts in the SMUD BA and study region

Error! Reference source not found. From an emissions perspective, it is not always the ase that Iowa hill reduces emissions, as shown in for CO_2. Here, it can be seen that in many cases, Iowa Hill may not reduce emissions, other than in the high wind scenario and the high mix scenario with AS trading. Otherwise Iowa Hill increases emissions system wide. Future work will look at extracting the emissions for the SMUD BA footprint, while accounting for imports and exports and associated emissions.

Fixed Speed vs Variable Speed.

Fixed speed was only examined for the case with high wind throughout the Western Interconnection. From this set of simulations, it was shown that cost savings seen were approximately half that of the variable speed results; this is consistent with the fact that emissions savings and start savings were also about 50%, while reserve provision was approximately 25%, with a particular reduction in regulating capability.

Summary

This section describes a range of system values from the proposed Iowa Hill project:

- Reduces production costs in both the SMUD BA and the study area (the SMUD BA sees approximately 75% of total cost reduction).

- Improves ability to meet reserves (less shortages) and Iowa Hill provides a large portion, from 10% to 80% depending on reserve type, ability to trade AS with the rest of the study region, and wind/solar penetration of all reserve categories
- Reduces wind and solar curtailment, especially at high penetrations, by up to 50%
- Can reduce emissions (depending on wind and solar penetration)
- Reduces Cycling by more than 50% (costs and number of starts).

It is clear that results vary significantly across scenarios, and so care should be given to ensuring that the scenarios are well understood and the most realistic are paid most attention. For example, Iowa Hill does not seem to provide as much value with high solar cases. In addition, the value of deferring generation and transmission investments are another value of the project. These are discussed in section 9 below.

7 DETAILED SIMULATION RESULTS

The simulation results for the focus areas, of California-SMUDNW, are presented in this section for the cases of without and with Iowa Hill for the base (TEPPC), the high-wind and the scenarios representing 3 combinations of high-mix/high wind across CA and the rest of WI. The simulation results for the study areas of SMUD-California-NW are presented in this section for the cases of without and with Iowa Hill (IH) pumped storage generator for the base, the high-wind and the high-mix renewable scenarios. For each result, the main insights are pointed out. The next chapter then collates overall insights into the study results.

Before the simulations for the study areas of SMUD-CA-NW, the Western Interconnection is simulated for a variety of renewable scenarios. The following table summarizes the WI simulation results in a variety of renewable scenarios. Here, the WI is the entire Western Interconnection, including the US, Canadian and Mexican parts of the Western Interconnection. Flows to and from those areas not in the California or Northwest regions are fixed based for each of the 6 scenarios based on a run without Iowa Hill. For the detailed simulations examined in the remainder of this chapter, only the California-Northwest region is simulated (the 'Study Area'), with flows to and from this region fixed. This was done to reduce computation time and allow for greater detail in the Study Area, including the three stage modeling described previously. As can be seen in the table, increasing penetrations of variable generation in the WI reduce the production costs, as would be expected. Note that the average costs shown in the fourth column appear low; this is due to the large amount of zero marginal cost hydro and wind/solar generation in the system (if only fossil generation was examined, the production cost would be a lot higher).

Results of WI Simulations for a Variety of Renewable Scenarios				
RPS Scenario	**Load (End-use) (GWh)**	**Renewable Gen (GWh)**	**Production Cost (Million $)**	**Average Production Cost($/MWh)**
TEPPC	**985,457**	**161,483**	**16,302**	**16.2**
CA High-Wind and WI TEPPC	**985,457**	**185,727**	**15,366**	**15.3**
CA High-Mix and WI TEPPC	**985,457**	**225,979**	**13,344**	**13.2**
WI High-Wind	**985,457**	**298,178**	**11,731**	**11.6**
CA High-Mix and WI High-Wind	**985,457**	**324,575**	**11,150**	**11.0**
WI High-Solar	**985,457**	**269,306**	**13,028**	**12.8**

Table 7-1 Results of WI Simulations for a Variety of Renewable Scenarios

Scenarios and Cases examined

The abbreviation for the simulation cases used in the tables are described as follows.

- **BAU, w/o AS Trading.** Simulations for the Business As Usual, without AS trading between the SMUD BA and the rest of California.
- **BAU, w/AS-Trading.** Simulations with AS-trading between the SMUD BA and the rest of California.
- **IH w/o AS trading** Simulations with Iowa Hill without AS-trading between the SMUD BA and the rest of California.
- **FS IH.** Simulations with Fixed Speed Iowa Hill (all others assume variable speed)
- **IH w/ AS-Trading**. Simulations with Iowa Hill with AS-trading between the SMUD BA and the rest of California
- **Recip**. Simulations with Reciprocating generators added to the system.

Each of the 6 study scenarios described previously is studied for a number of the above cases; the high solar was only studied for the BAU w/AS-Trading and IH w/AS-Trading cases. In all other scenarios, BAU with and without AS trading and IH with and without AS trading are examined. The Recip and FS IH cases are examined in select scenarios.

The following table summarizes the load and renewable energy in the SMUD BA and in the study areas of SMUD-CA-NW for a variety of renewable scenarios. Also this table summarizes the SMUD BA net import from other areas and the net imports between the study areas of SMUD-CA-NW and the non-study areas, fixed from the WI simulations, for a variety of renewable scenarios (negative numbers mean net export). It can be seen that in general, SMUD is a net exporter in all cases s except the high solar cases, and the study area is a net importer, with highest imports in the high wind cases.

Table 7-2: Summary of Load, Renewable Generation and Outside Import (GWh) for a Variety of Renewable Scenarios from the WI Simulations

RPS Scenario	SMUD BA (GWh)			Study Area SMUD-CA-NW (GWh)		
	Load	Renewable Energy	Net Import	Load	Renewable Energy	Net Import
TEPPC	16,442	2,678	(286)	456,713	103,740	12,780
CA High Wind and WI TEPPC	16,442	6,146	(2,420)	456,713	126,468	12,681
CA High Mix and WI TEPPC	16,442	8,571	(4,149)	456,713	160,212	10,646
WI High Wind	16,442	6,117	(48)	456,713	130,874	83,900
WI High Solar	16,442	5,202	250	456,713	148,190	50,686
CA High Mix and WI High Wind	16,442	8,525	(2,094)	456,713	166,472	60,167

Production Cost Savings due to Iowa Hill

This subsection presents the production cost for the different cases in a variety of renewable scenarios. Clearly, pumped hydro storage would be expected to improve production costs of the system; here, the study examined how much benefit would be seen, where it would occur and how different wind/solar scenarios or the different cases would impact on the results. Table 7-3 summarizes the production cost differences of the case with Iowa Hill (IH) pumped-storage generator and the case of Business As Usual (BAU) in the SMUD BA and the study area of SMUD-CA-NWPP in five renewable penetration levels for year 2022. The impact of the AS-trading between the SMUD BA and CA to the production cost is included. Note that the production costs do not include the export revenue to the non-study areas in WI and the import cost from the non-study areas in WI. Note also that, as with any production cost model, costs are indicative only (as there is an integer gap used in solution) and more important are overall trends. In particular, looking at SMUD costs only when the model is optimizing over a larger Study Area can mean that there may be over or underestimations in cost. Therefore it is more important to think of these costs as approximate in nature. Note also that in these cases, the cost of providing Ancillary Services is not attributed to load costs, which reflects current practices. More detail on cases where that cost is attributed are given in details below.

For the SMUD BA, the following can be observed.

- The production cost differences with and without Iowa Hill are the highest when there is AS-trading between the SMUD BA and CA, ranging from $12m to $52m per year for the different renewable penetration levels.
- What appears to be more important in driving results is the WI-wide penetrations. Notice that the higher range of savings correspond to higher WI-wide penetration, whereas increasing penetrations within California (including the SMUD BA) do not have significant an impact.
- With ancillary services trading between the SMUD BA and CA, the savings with Iowa Hill are decreased to the range of $18m to $52m. Again, higher penetration levels mean more savings, with the biggest differences coming not when wind or PV is added within California, but when it is added throughout the WI.
- The highest savings accumulated to the SMUD BA production costs due to adding Iowa Hill is the scenario of CA high-mix and WI high wind in all cases. Again, this shows how important the wind and solar penetration in areas other than the SMUD BA is to the value of Iowa Hill. High solar does not have as much of an impact on value of Iowa Hill as high wind (likely due to less curtailment in base case)
- With the energy balancing resource of Reciprocating generator, the production cost savings ranges from $3m $17m, significantly less than the value of Iowa Hill, for approximately the same capacity.

The production cost savings for the study areas of SMUD-CA-NW follow the same pattern. Comparing the savings across the study area and SMUD only area, it can be seen that when trading of AS is allowed, the value is generally increased (as Iowa Hill is a good resource for AS both for the SMUD BA and CAISO), whereas if looking at value to study area if AS trading is not allowed, the value to the study area is less than the value to the SMUD BA only. This implies that the presence of Iowa Hill can be beneficial to the remainder of California and more generally the Northwest and beyond if there is a possibility to trade ancillary services between regions; otherwise the presence of Iowa Hill in the SMUD BA may actually increase costs elsewhere, as it changes the net imports to and from the SMUD BA.

RPS Scenario	SMUD BA			Study Areas of SMUD BA-CA-NW		
	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading
TEPPC	11	12	3	8	13	2
CA High-Wind and WI TEPPC	11	12	2	7	8	2
CA High-Mix and WI TEPPC	18	19	3	3	9	3
WI High-Wind	47	43	10	49	59	21
CA High-Mix and WI High-Wind	53	52	17	47	67	36

Table 7-3 Summary of Production Cost Reduction ($m) due to Iowa Hill or Reciprocating Engines for each Renewable Scenarios for a number of cases

Table 7-3 shows the total production costs (including accounting for net imports and counting no AS cost to load). As can be seen there are significant differences between the BAU cases and the cases with Iowa Hill; while the specific $ numbers may not be exactly what would be realized, there is a clear difference which shows significant benefits due to the presence of Iowa Hill. It can be seen that Iowa Hill results in approximately the same costs with or without AS trading, whereas that's not the case in the BAU case. Finally, this shows that even though Iowa Hill will generally have a greater impact in the WI High Wind Case indicating its value is linked to wind penetration elsewhere, there is a lower cost in the CA High Mix - WI TEPPC case, as expected.

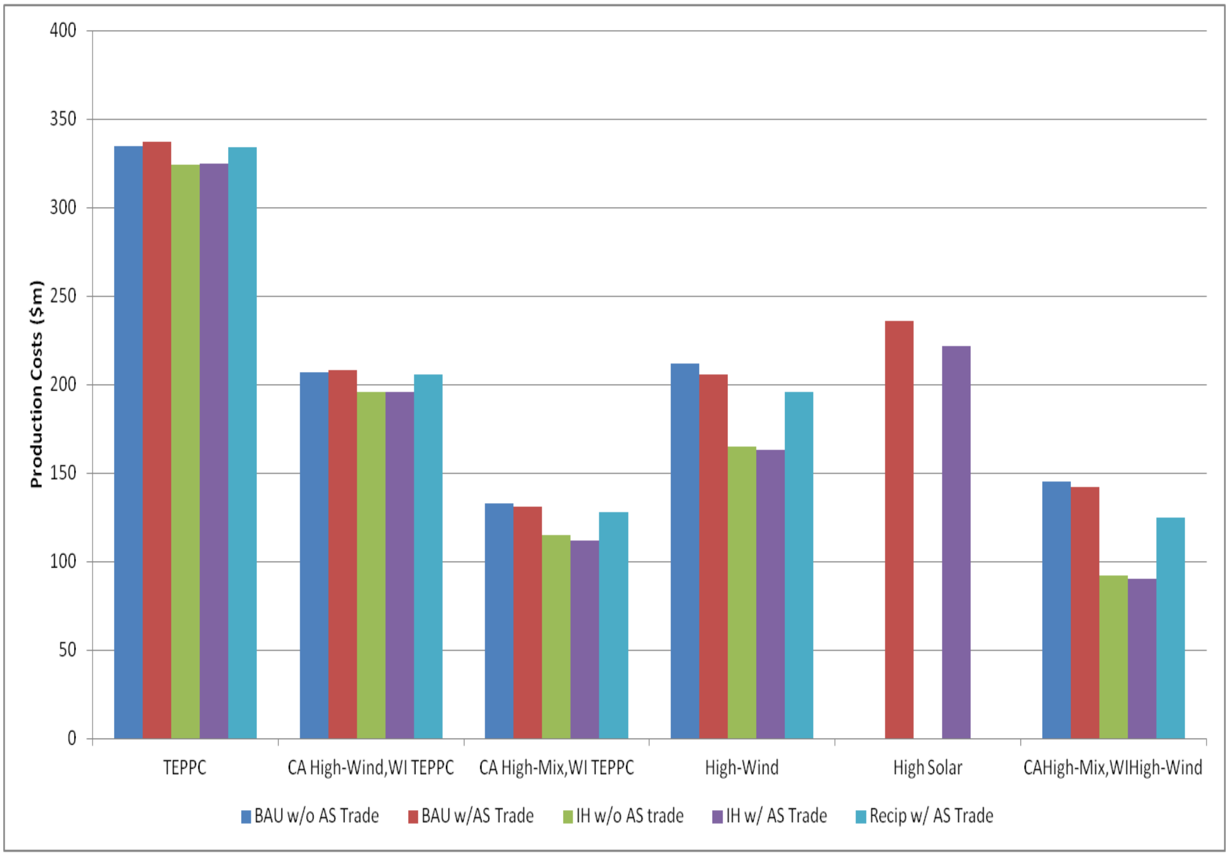


Figure 7-1: Production Costs for the SMUD BA footprint for different cases

The following table shows the production cost savings in $/kW installed for Iowa Hill. This is compared to wind and solar penetration levels in the particular area being studied.

Table 7-4: Value to different regions for different scenarios, in the case with AS trading and 0% of AS cost to load

	Scenario	VG penetration in region (%)	Value of Iowa Hill ($/kW-yr)
Value to the SMUD BA	**TEPPC**	**16%**	**30**
	High-Wind	**37%**	**30**
	High Solar	**32%**	**35**
	CA High-Wind, WI TEPPC	**37%**	**48**
	CA High-Mix, WI TEPPC	**52%**	**65**
	CA High-Mix, WI High-Wind	**52%**	**130**
Value to Study Area	**TEPPC**	**23%**	**33**
	High-Wind	**29%**	**20**
	High Solar	**32%**	**50**
	CA High-Wind, WI TEPPC	**28%**	**38**
	CA High-Mix, WI TEPPC	**35%**	**90**
	CA High-Mix, WI High-Wind	**38%**	**168**

As can be seen in the table, the $/kW installed savings vary significantly, again with wind penetration in the WI more important than penetration levels in California. This shows the interconnected nature of balancing variable generation; however it also shows a limit in using the production simulation tool which optimizes over the entire study area, rather than the SMUD BA alone as would be done in the SMUD BA operations. It appears that the most value from Iowa Hill is when there is so much wind in the WI that importing and exporting can no longer be used to balance. As shown later, there is also significantly more curtailment, both within and without the SMUD BA, in the scenarios with high wind penetration throughout the WI. Iowa Hill can then store this wind which would otherwise have been wasted. This does not happen as much with solar as solar energy comes during the day when load is higher. Figure 7-2 shows this in graphical form, where the savings do not clearly follow a penetration level, instead depending on where the penetration occurs (in the Study Area cases much of the high penetration in the WI high wind cases are outside the study area in other areas of the WI as described in Chapter 2). In general, the SMUD BA sees a majority of the benefit to the study area, if not actually seeing greater benefits to the SMUD BA footprint alone than the total study area sees.

One important note of caution here is that the results here are based on a generation mix developed to meet the base case variable generation mix. Therefore, as increased penetrations are examined, the generation mix is likely less and less optimal. In reality, if the higher levels were likely to be seen, then the generation mix would be very different, possibly reducing the benefit of Iowa Hill. For example, some or all of other storage units, demand response, increased transmission capacity between areas or CTs would likely be present; this means that the very high savings for the high wind WI cases (last 2) should be considered with caution.

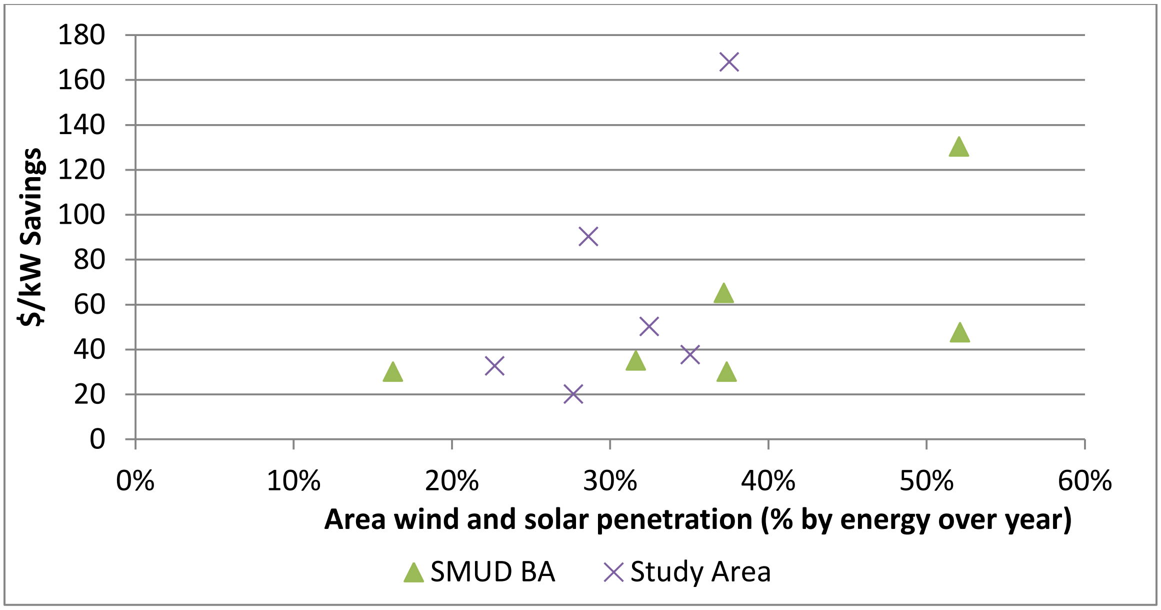


Figure 7-2: Savings due to presence of Iowa Hill for the SMUD BA and study area at different penetrations of wind and solar

The following tables, Table 7-5 to Table 7-9, show the production costs by components by three areas, the SMUD BA, CA and NW, for the different cases in a variety of renewable scenarios. The production cost components are calculated as follows.

- **Production Cost.** This is the generation production cost, including VO&M cost, fuel cost, and start cost.
- **Import Cost (Energy).** This is the area import energy cost for the energy import from other areas in the study areas. It is calculated as the sum of the hourly area import energy times the hourly export area LMP plus the wheeling charge from the export area and import area. Please note that this import cost does not include the import cost from the non-study areas in WI.
- **Export Revenue (Energy).** This is the area energy export revenue from the energy export to other areas in the study areas. It is calculated as the sum of the hourly area export energy times the hourly area LMP plus the wheeling charge from the export area to the import area. Please note that this export revenue does not include the export revenue from the non-study areas in WI.
- **Import Cost (AS).** This is the ancillary service import cost for the AS import from the other areas in the study areas. It is calculated as the sum of the hourly area import AS times the hourly area AS clearing price in the exporting area.

- **Export Revenue (AS).** This is the ancillary service export revenue for the AS export to other areas in the study areas. It is calculated as the sum of the hourly area export AS times the hourly area AS clearing price in the importing area.
- **AS Cost to Load.** This is calculated as the hourly AS provision from the area times the hourly AS clearing price, added to the net import cost (import cost (AS) minus export cost (AS)).
- **Net Production Cost (plus 0% AS Cost to Load).** This is the sum of above cost minus revenues except "AS Cost to Load".
- **Net Production Cost (plus 50% AS Cost to Load).** This is the sum of above cost minus revenues but 50% of "AS Cost to Load" is included.
- **Net Production Cost (plus 100% AS Cost to Load).** This is the sum of above cost minus revenues with 100% of "AS Cost to Load" counted. Note this is the value used in the summary tables above.

The comparisons of the cases with and without Iowa Hill and reciprocating generators are listed in the last four columns. The total costs of the study areas of SMUD-CA-NW for the cases are listed at the last three rows. Each of the tables are shown in the next few pages, and then summarized together after all are shown.

Region	Properties	BAU w/o AS Trade	BAU w/AS Trade	IH w/o AS trade	IH w/ AS Trade	Recip w/ AS Trade	Case 1b-Case 1	Case 2 - Case 1	Case 2b-Case 1b	Case 3-Case 1b
		Case 1	**Case 1b**	**Case 2**	**Case 2b**	**Case 3**				
SMUD BA	Production Cost (M$)	334	325	329	334	328	(9)	(6)	9	3
	Import Cost (Energy) (M$)	43	43	36	38	38	1	(7)	(5)	(5)
	Export Revenue (Energy) (M$)	42	34	40	43	34	(8)	(2)	9	0
	Import Cost (A/S) (M$)	-	3	-	1	3	3	-	(3)	(1)
	Export Revenue(A/S) (M$)	-	1	-	5	1	1	-	4	0
	AS Cost to Load	26	25	15	17	24	(1)	(11)	(8)	(0)
	Net Prod. Cost (0% AS Cost)	335	337	324	325	334	2	(11)	(12)	(3)
	Net Prod. Cost (100% AS cost)	361	359	339	341	356	(2)	(22)	(18)	(3)
Rest of CA	Production Cost (M$)	5,722	5,733	5,724	5,719	5,732	11	1	(14)	(1)
	Import Cost (Energy) (M$)	501	498	496	496	491	(3)	(4)	(2)	(7)
	Export Revenue (Energy) (M$)	29	28	25	26	26	(1)	(5)	(3)	(2)
	Import Cost (A/S) (M$)	-	1	-	5	1	1	-	4	0
	Export Revenue(A/S) (M$)	-	3	-	1	3	3	-	(3)	(1)
	AS Cost to Load	284	288	285	283	286	4	0	(4)	(2)
	Net Prod. Cost (0% AS Cost)	6,194	6,199	6,195	6,189	6,194	5	2	(10)	(5)
	Net Prod. Cost (100% AS cost)	6,478	6,487	6,480	6,472	6,480	9	2	(14)	(7)
NWPP	Production Cost (M$)	835	827	836	837	833	(7)	1	9	6
	Import Cost (Energy) (M$)	889	882	889	891	888	(7)	1	9	6
	Export Revenue (Energy) (M$)	943	936	943	944	942	(7)	0	9	6
	AS Cost to Load	7,782	7,781	7,762	7,758	7,778	(1)	(19)	(24)	(4)
	Net Prod. Cost (0% AS Cost)	835	827	836	837	833	(7)	1	9	6
	Net Prod. Cost (100% AS cost)	943	936	943	944	942	(7)	0	9	6
Total Study Area	Net Prod. Cost (0% AS Cost)	7,363	7,364	7,355	7,351	7,362	1	(8)	(13)	(2)
	Net Prod. Cost (100% AS cost)	7,782	7,781	7,762	7,758	7,778	(1)	(19)	(24)	(4)

Table 7-5 Comparison of Production Cost ($m) for different cases for the TEPPC Scenario

Region	Properties	BAU w/o AS Trade	BAU w/AS Trade	IH w/o AS trade	IH w/ AS Trade	Recip w/ AS Trade	Case 11b-Case 1	Case 13 -Case 11	Case 15-Case 11b	Case 17-Case 1b
		Case 11	**Case 11b**	**Case 13**	**Case 15**	**Case 17**				
SMUD BA	Production Cost (M$)	285	248	242	243	247	(37)	(43)	(5)	(1)
	Import Cost (Energy) (M$)	22	23	20	22	20	1	(2)	(1)	(2)
	Export Revenue (Energy) (M$)	100	68	66	65	66	(33)	(34)	(3)	(2)
	Import Cost (A/S) (M$)	-	6	-	1	6	6	-	(5)	(0)
	Export Revenue(A/S) (M$)	-	1	-	5	1	1	-	4	0
	AS Cost to Load	34	32	21	22	32	(2)	(13)	(10)	(1)
	Net Prod. Cost (0% AS Cost)	207	208	196	196	206	2	(10)	(12)	(2)
	Net Prod. Cost (100% AS cost)	241	235	217	217	232	(6)	(24)	(18)	(2)
Rest of CA	Production Cost (M$)	4,967	5,005	5,003	5,005	5,004	38	36	0	(1)
	Import Cost (Energy) (M$)	485	449	449	447	447	(37)	(36)	(2)	(2)
	Export Revenue (Energy) (M$)	26	24	23	22	22	(3)	(4)	(1)	(1)
	Import Cost (A/S) (M$)	-	1	-	5	1	1	-	4	0
	Export Revenue(A/S) (M$)	-	6	-	1	6	6	-	(5)	(0)
	AS Cost to Load	332	333	330	329	331	0	(2)	(4)	(1)
	Net Prod. Cost (0% AS Cost)	5,426	5,425	5,430	5,433	5,424	(2)	4	8	(1)
	Net Prod. Cost (100% AS cost)	5,758	5,757	5,760	5,757	5,755	(2)	2	0	(2)
NWPP	Production Cost (M$)	849	850	848	846	851	1	(1)	(4)	1
	Import Cost (Energy) (M$)	903	904	902	900	905	1	(1)	(4)	1
	Export Revenue (Energy) (M$)	957	958	956	954	959	1	(1)	(4)	1
	AS Cost to Load	6,956	6,949	6,933	6,928	6,946	(7)	(24)	(22)	(4)
	Net Prod. Cost (0% AS Cost)	849	850	848	846	851	1	(1)	(4)	1
	Net Prod. Cost (100% AS cost)	957	958	956	954	959	1	(1)	(4)	1
Total Study Area	Net Prod. Cost (0% AS Cost)	6,482	6,483	6,475	6,475	6,481	1	(7)	(8)	(2)
	Net Prod. Cost (100% AS cost)	6,956	6,949	6,933	6,928	6,946	(7)	(24)	(22)	(4)

Table 7-6 Comparison of Production Cost ($m) for different cases for the CA High-Wind and WI TEPPC Renewable Scenario

Region	Properties	BAU w/o AS Trade	BAU w/AS Trade	IH w/oAS trade	IH w/ AS Trade	Recip w/ AS Trade	Case 12b-Case 12	Case 14-Case 12	Case 16-Case 12b	Case 18-Case 12b
		Case 12	Case 12b	Case 14	Case 16	Case 18				
SMUD BA	Production Cost (M$)	261	198	192	186	194	(63)	(69)	(13)	(4)
	Import Cost (Energy) (M$)	15	17	15	17	16	2	1	0	(1)
	Export Revenue (Energy) (M$)	143	92	93	88	90	(51)	(50)	(4)	(2)
	Import Cost (A/S) (M$)	-	8	-	1	7	8	-	(7)	(1)
	Export Revenue(A/S) (M$)	-	0	-	4	0	0	-	3	0
	AS Cost to Load	39	35	23	25	35	(4)	(16)	(10)	1
	Net Prod. Cost (0% AS Cost)	133	131	115	112	128	(1)	(18)	(19)	(4)
	Net Prod. Cost (100% AS cost)	172	158	138	136	156	(13)	(34)	(22)	(2)
Rest of CA	Production Cost (M$)	3,951	4,018	4,004	4,007	4,012	67	53	(11)	(6)
	Import Cost (Energy) (M$)	463	404	413	412	407	(59)	(50)	8	3
	Export Revenue (Energy) (M$)	43	42	36	36	41	(1)	(8)	(6)	(2)
	Import Cost (A/S) (M$)	-	0	-	4	0	0	-	3	0
	Export Revenue(A/S) (M$)	-	8	-	1	7	8	-	(7)	(1)
	AS Cost to Load	369	369	368	368	371	0	(1)	(1)	2
	Net Prod. Cost (0% AS Cost)	4,371	4,372	4,381	4,385	4,373	1	10	14	1
	Net Prod. Cost (100% AS cost)	4,740	4,741	4,749	4,750	4,743	1	9	9	2
NWPP	Production Cost (M$)	812	816	809	807	813	4	(3)	(9)	(3)
	Import Cost (Energy) (M$)	867	870	863	861	867	4	(4)	(10)	(3)
	Export Revenue (Energy) (M$)	921	925	917	915	922	4	(4)	(10)	(3)
	AS Cost to Load	5,833	5,824	5,804	5,800	5,821	(9)	(29)	(24)	(3)
	Net Prod. Cost (0% AS Cost)	812	816	809	807	813	4	(3)	(9)	(3)
	Net Prod. Cost (100% AS cost)	921	925	917	915	922	4	(4)	(10)	(3)
Total Study Area	Net Prod. Cost (0% AS Cost)	5,316	5,319	5,305	5,304	5,313	3	(11)	(15)	(6)
	Net Prod. Cost (100% AS cost)	5,833	5,824	5,804	5,800	5,821	(9)	(29)	(24)	(3)

Table 7-7 Comparison of Production Cost ($m) for different cases for the CA High-Mix and WI TEPPC Renewable Scenario

Region	Properties	BAU w/o AS Trade	BAU w/AS Trade	IH w/o AS trade	IH w/ AS Trade	FS IH Plus AS Trading	Recip Plus AS Trading	Case5 - Case4	Case6 - Case4b	Case7 - Case4b	Case8 - Case4b
		Case 4	Case 4b	Case 5	Case 6	Case 7	Case 8				
SMUD BA	Production Cost (M$)	201	182	136	137	157	169	(65)	(45)	(25)	(12)
	Import Cost (Energy) (M$)	44	46	55	57	51	49	11	10	5	3
	Export Revenue (Energy) (M$)	33	21	26	25	25	22	(7)	4	4	1
	Import Cost (A/S) (M$)	-	4	-	0	2	2	-	(4)	(3)	(3)
	Export Revenue(A/S) (M$)	-	5	-	6	6	3	-	1	0	(3)
	AS Cost to Load	35	35	22	26	34	35	(13)	(8)	(1)	1
	Net Prod. Cost (0% AS Cost)	212	206	165	163	179	196	(47)	(43)	(26)	(10)
	Net Prod. Cost (100% AS cost)	247	236	187	189	211	229	(60)	(47)	(24)	(6)
Rest of CA	Production Cost (M$)	2,875	2,906	2,886	2,887	2,891	2,888	12	(19)	(15)	(18)
	Import Cost (Energy) (M$)	398	385	412	422	396	391	14	37	12	6
	Export Revenue (Energy) (M$)	11	11	13	14	12	13	2	3	1	2
	Import Cost (A/S) (M$)	-	5	-	6	6	3	-	1	0	(3)
	Export Revenue(A/S) (M$)	-	4	-	0	2	2	-	(4)	(3)	(3)
	AS Cost to Load	356	355	355	354	356	357	(0)	(0)	1	2
	Net Prod. Cost (0% AS Cost)	3,262	3,276	3,285	3,295	3,274	3,266	23	19	(2)	(10)
	Net Prod. Cost (100% AS cost)	3,618	3,630	3,641	3,649	3,630	3,623	23	19	(1)	(8)
NWPP	Production Cost (M$)	745	743	749	748	747	748	4	5	4	6
	Import Cost (Energy) (M$)	4	4	4	4	4	4	(0)	0	0	0
	Export Revenue (Energy) (M$)	403	403	432	443	415	410	29	40	12	7
	AS Cost to Load	122	122	123	122	122	123	0	0	0	1
	Net Prod. Cost (0% AS Cost)	347	344	321	308	336	342	(26)	(35)	(7)	(1)
	Net Prod. Cost (100% AS cost)	469	465	444	431	459	465	(25)	(35)	(7)	(1)
Total Study Area	Net Prod. Cost (0% AS Cost)	3,821	3,825	3,772	3,766		3,804	(49)	(59)	(36)	(21)
	Net Prod. Cost (100% AS cost)	4,334	4,332	4,272	4,268		4,317	(62)	(63)	(32)	(14)

Table 7-8 Comparison of Production Cost ($m) for different cases for the High-Wind (everywhere) Renewable Scenario

Region	Properties	BAU w/o AS Trade	BAU w/AS Trade	IH w/oAS trade	IH w/ AS Trade	Recip w/ AS Trade	Case19b-Case19	Case20-Case19	Case21-Case19b	Case22-Case19b
		Case19	**Case19b**	**Case20**	**Case21**	**Case22**				
SMUD BA	Production Cost (M$)	191	162	107	107	143	(28)	(83)	(56)	(19)
	Import Cost (Energy) (M$)	24	22	29	31	28	(2)	5	9	7
	Export Revenue (Energy) (M$)	69	46	45	43	46	(23)	(24)	(3)	(1)
	Import Cost (A/S) (M$)	-	8	-	0	2	8	-	(8)	(5)
	Export Revenue(A/S) (M$)	-	3	-	5	3	3	-	2	(0)
	AS Cost to Load	40	38	25	31	40	(3)	(15)	(7)	3
	Net Prod. Cost (0% AS Cost)	145	142	92	90	125	(3)	(54)	(52)	(17)
	Net Prod. Cost (100% AS cost)	185	172	117	120	163	(13)	(68)	(52)	(9)
Rest of CA	Production Cost (M$)	2,486	2,539	2,514	2,515	2,515	53	28	(24)	(24)
	Import Cost (Energy) (M$)	385	349	393	389	368	(36)	8	40	19
	Export Revenue (Energy) (M$)	11	11	14	14	14	0	3	3	2
	Import Cost (A/S) (M$)	-	3	-	5	3	3	-	2	(0)
	Export Revenue(A/S) (M$)	-	8	-	0	2	8	-	(8)	(5)
	AS Cost to Load	402	404	402	397	402	2	(1)	(7)	(2)
	Net Prod. Cost (0% AS Cost)	2,860	2,872	2,892	2,894	2,870	12	32	23	(2)
	Net Prod. Cost (100% AS cost)	3,262	3,272	3,294	3,286	3,269	10	32	14	(4)
NWPP	Production Cost (M$)	379	390	353	352	372	11	(26)	(38)	(17)
	Import Cost (Energy) (M$)	440	450	414	412	433	11	(26)	(38)	(17)
	Export Revenue (Energy) (M$)	501	511	474	473	494	11	(26)	(38)	(17)
	AS Cost to Load	3,948	3,955	3,885	3,879	3,925	7	(63)	(76)	(30)
	Net Prod. Cost (0% AS Cost)	379	390	353	352	372	11	(26)	(38)	(17)
	Net Prod. Cost (100% AS cost)	501	511	474	473	494	11	(26)	(38)	(17)
Total Study Area	Net Prod. Cost (0% AS Cost)	3,384	3,403	3,337	3,336	3,367	19	(47)	(67)	(36)
	Net Prod. Cost (100% AS cost)	3,948	3,955	3,885	3,879	3,925	7	(63)	(76)	(30)

Table 7-9 Comparison of Production Cost ($m) for different cases for the CA High-Mix and WI High-Wind Renewable Scenario

Table 7-10: Comparison of Production Cost ($m) for different cases for the High-Solar Renewable Scenario

Rest of CA	Production Cost	AS Trading	IH Plus AS Trading	Case6 - Case4b
		Case 4b	Case 6	
SMUD BA	Production Cost	221	204	(17)
	Import Cost (Energy)	42	45	3
	Export Revenue (Energy)	26	27	1
	Import Cost (A/S)	3	-	(3)
	Export Revenue(A/S)	1	-	(1)
	AS Cost to Load	26	18	(8)
	Net Production Cost (plus 0% AS Cost to Load)	236	222	(14)
	Net Production Cost (plus 50% AS Cost to Load)	249	231	(18)
	Net Production Cost (plus 100% AS Cost to Load)	262	240	(22)
Rest of CA	Production Cost	27	27	(0)
	Import Cost (Energy)	1	-	(1)
	Export Revenue (Energy)	3	-	(3)
	Import Cost (A/S)	340	336	(5)
	Export Revenue(A/S)	3,562	3,559	(3)
	AS Cost to Load	3,733	3,727	(6)
	Net Production Cost (plus 0% AS Cost to Load)	3,562	3,559	(3)
	Net Production Cost (plus 50% AS Cost to Load)	3,733	3,727	(6)
	Net Production Cost (plus 100% AS Cost to Load)	3,903	3,895	(8)
NWPP	Production Cost	514	512	(2)
	Import Cost (Energy)	569	567	(2)
	Export Revenue (Energy)	625	622	(3)
	AS Cost to Load	4,790	4,757	(33)
	Net Production Cost (plus 0% AS Cost to Load)	514	512	(2)
	Net Production Cost (plus 50% AS Cost to Load)	569	567	(2)
	Net Production Cost (plus 100% AS Cost to Load)	625	622	(3)
Total Study Area	Net Production Cost (plus 0% AS Cost to Load)	4,312	4,293	(20)
	Net Production Cost (plus 50% AS Cost to Load)	4,551	4,525	(26)
	Net Production Cost (plus 100% AS Cost to Load)	4,790	4,757	(33)

The following observations can be made, beyond the details given earlier:

- If 100% of AS cost to load reductions are counted, Iowa Hill is more valuable, both to the SMUD BA and to the study region. It is not clear exactly how much of this should be counted, but it is shown to be relatively important to the overall results.
- If AS trading is allowed, the value to the study area increases, but the value to the SMUD BA decreases. This shows that from a total societal benefit, allowing Iowa Hill to sell into other markets increases savings, however not all of these savings will accrue to the SMUD BA (see later for how Iowa Hill revenue is increases, even though the SMUD BA costs savings are reduced)
- The highest saving in the SMUD BA is to reduce production costs by approximately 36% (for the case with no AS trading and no AS cost to load in the High Mix CA-High Wind WI scenario), whereas the lowest is approximately 0.5% (TEPPC scenario with no costs to load and with AS trading). This shows the range of value Iowa Hill can provide. Again, the MIP gap of 0.5% should be considered here, which is for the entire WI. This could therefore be read that in the base case, benefits are marginal, whereas in a high wind/solar scenario, benefits could be very significant (though plant mix is likely not correct for those high penetrations).
- For the study area, the reductions are obviously far smaller, with the range from close to 0% to 2% of total costs depending on scenario and case.
- The High Solar cases, only examined for AS trading with and without Iowa Hill, shows that value is not as high for solar integration, due to the different nature of the resource; even though same energy is met by variable generation, the fact it happens during the day reduces arbitrage opportunities for Iowa Hill.
- In general, NWPP, which has a lot of hydro, sees a reduction in costs when Iowa Hill is added (except in base case where its use is increased), whereas California (not including the SMUD BA) sees a varying impact on costs when Iowa Hill is added. In the case with AS trading allowed, costs are generally reduced, whereas in the case with AS trading not allowed, costs are often increased (likely as generation from rest of California is used to store energy in Iowa Hill, but then Iowa Hill uses this to meet the SMUD BA load and AS).

The impact on net import cost is shown in Figure 7-3 – this is for import costs to and from the study area only – net imports from the WI are fixed based on the simulations described earlier. This shows a number of things about the SMUD BA net imports (note this isn't actual imports but import costs, but this would be very similar). As can be seen, adding Iowa Hill in the base case means the SMUD BA moves from paying for imports to receiving money from exports. However, in all other cases, adding Iowa Hill actually increases net imports costs for the SMUD BA; this is likely due to the fact that the SMUD BA can take advantage of cheaper energy to import at off-peak times. The difference is greater in the cases with higher wind in the WI as expected. Also expected would be the fact that the SMUD BA is a net exporter (based on costs) when California has higher penetrations and the WI doesn't, but as the WI sees higher wind penetrations, imports increase. Again, the fact that the higher penetrations may not be based on an optimal (or even likely) generation mix for high wind/PV should be considered – in reality the results may not differ as much at higher penetrations.

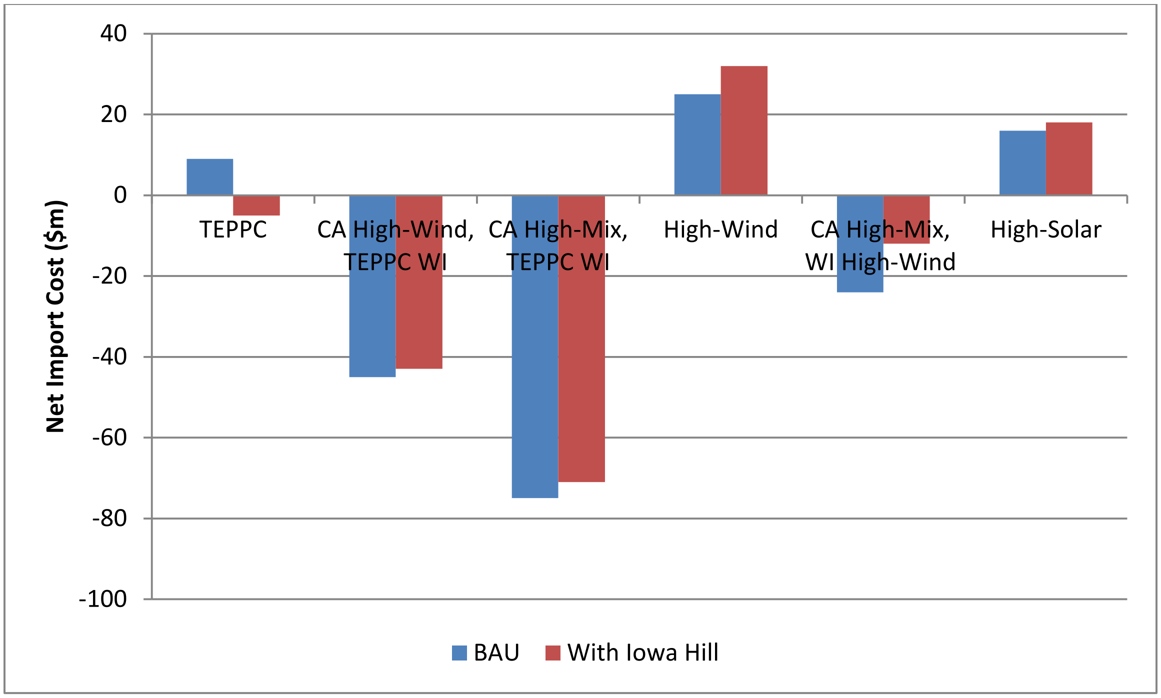


Figure 7-3: SMUD BA net import costs with and without Iowa Hill, with AS trading

System Reserve Shortage and Provision by Iowa Hill and Existing pumped storage

This subsection presents the reserve provision and shortage from the simulations for the study areas of SMUD-CA-NW. One of the key benefits of Iowa Hill is expected to be in the area of reserve provision, which becomes more valuable with increased penetrations of wind and solar, which increase requirements as described to Chapter 3. Note that what is described in Chapter 3 as 'RUC' reserve is described here as 'extra capacity'.

In the model, flexible down reserve is designed to have lower penalty price (15$/MWh) because it was observed there were a lot of over-generation that made the LMP price negative when flexible down shortage penalty was high (900$/MWh). Because of low penalty price, flexible down reserve exhibited more shortage than other types of reserve (in general other reserve types didn't see significant shortages and so aren't shown here). One thing to note here is that flexible down reserves are currently not carried; however CAISO and others are worried enough about overgeneration and the need to be able to reduce generation output that this product may be carried in the future. It should also be noted that in some cases it may be possible for wind or PV to contribute some of their expected production to this reserve. As this reserve is mainly to cover increases in wind and solar, then it may be possible in those hours when there is not significant flexible down reserves, wind and solar could contribute. In those hours, it is likely that they may be curtailed anyway, as those hours are often associated with overgeneration. However, by providing flexibility down reserve, these are not actually curtailed, but only scheduled to be curtailed if the flex down is called upon, which may not happen often. On the other hand, if they cannot contribute, then it may be more likely that they get curtailed as it is cheaper to pay the penalty price. It should also be noted that in reality, fossil generation may reduce minimum stable levels (at a capital, O&M and/or efficiency cost) and thus reduce the number of hours flexible down reserves cannot be met.

The changes in flexible down reserve shortages are shown in Table 7-11 and Table 7-12 for change in GWh shortage and % change respectively (negative numbers in brackets indicate reduction) In the SMUD BA, the flexible down reserve shortage was reduced by 11% to 67% (1 to 160 GWh) when Iowa Hill is introduced into the system. With AS-trading allowed the flexibility down reserve shortfall is reduced, as expected, and reduction due to Iowa Hill are also reduced. In the whole study area, the flexible down shortage changes from 6% to 12% depending on scenario, while it changed from 10% to 18% when AS trading was allowed. Recip units didn't impact the shortage obviously compared with Iowa Hill. It was also observed during simulation that most of shortage occurred in Winter and Spring and much less in Summer; as before, solar saw less shortages than wind due to the different nature of the resources. In general, this shows that Iowa Hill can contribute significantly to improving reserve provision and thus reliability, both within the SMUD BA and across the study area, especially with high wind/solar penetrations (again note that the plant mix may not be optimal here, leading to more shortages than might be seen in reality).

Table 7-11: Flexible Down Shortages for the different scenarios (GWh change)

Scenario	SMUD BA			Study Areas of SMUD-CA-NW		
	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading
TEPPC	**(1)**	**(0.5)**	**0.1**	**(5.6)**	**(16.8)**	**(4.6)**
High Wind CA, WI TEPPC	**(1.8)**	**(1.2)**	**(0.1)**	**(37.4)**	**(33.2)**	**(0.9)**
High Mix CA, WI TEPPC	**(20.2)**	**(14.8)**	**0.4**	**(150.7)**	**(151.0)**	**(23.0)**
High Wind	**(160.8)**	**(78.5)**	**6.5**	**(331.2)**	**(369.0)**	**(7.1)**
High Solar		**(31)**			**(276)**	
High Mix CA, High Wind WI	**(148.2)**	**(94.0)**	**3.8**	**(342.0)**	**(426.8)**	**(60.4)**

Table 7-12: Flexible Down Shortages for the different scenarios (% change)

Scenario	SMUD BA			Study Areas of SMUD-CA-NW		
	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading
TEPPC	**-45%**	**-50%**	**14%**	**-6%**	**-18%**	**-5%**
High Wind CA, WI TEPPC	**-11%**	**-10%**	**-1%**	**-12%**	**-11%**	**0%**
High Mix CA, WI TEPPC	**-40%**	**-33%**	**1%**	**-12%**	**-12%**	**-2%**
High Wind	**-67%**	**-32%**	**3%**	**-9%**	**-10%**	**0%**
High Solar		**-13%**			**-7%**	
High Mix CA, HighWind WI	**-59%**	**-34%**	**1%**	**-8%**	**-10%**	**-1%**

The following tables compare the reserve provisions from pumped hydro storage units or reciprocating generators for different reserve types. This is shown for both the SMUD BA and the Study Area. Obviously, some of the reserve types are higher value – regulation and spinning reserves in particular are more important than some of the other categories, so these should be considered more important. Generally, adding Iowa Hill to the mix increases balancing resources in the SMUD BA and the rest of California, and reduces the use of pumped hydro in the Northwest. The increases in the SMUD BA are roughly the same for all mixes, with slightly more for high wind in WI cases, and less for low wind and solar case. The increase in California depends on WI renewables - higher wind increases the use of balancing resources. This is mainly due to the fact that requirements are increases, as shown in Chapter 3. NWPP balancing resources are used less in all cases other than high wind case when wind is added. Additionally, the high wind everywhere case shows that fixed speed pumped hydro makes significantly less contribution to regulation reserves, as expected.

In general, the down reserve in particular are helped a lot by the variable speed pumped hydro; note that in the rest of California there are also new pumped hydro units, but these are in all cases. It is noticeable that the downward reserve provision from the all of the balancing pumped hydro resources are increased in the higher renewable scenario than in the base TEPPC scenario.

As with the other results, therefore, the use of Iowa Hill to provide reserve in the SMUD BA depends on the renewable mix both in the SMUD BA and the rest of California and in the Western Interconnection in general. For example, compare regulation up provision in the SMUD BA across all scenarios, as shown in Figure 7-4 (only for As trading case in high solar). As can be seen there, trading of AS has more of an impact as to how regulation is provided than renewable scenarios. However, it is clear that increasing penetrations, both in California and WI-wide, increase the use of Iowa Hill for regulation.

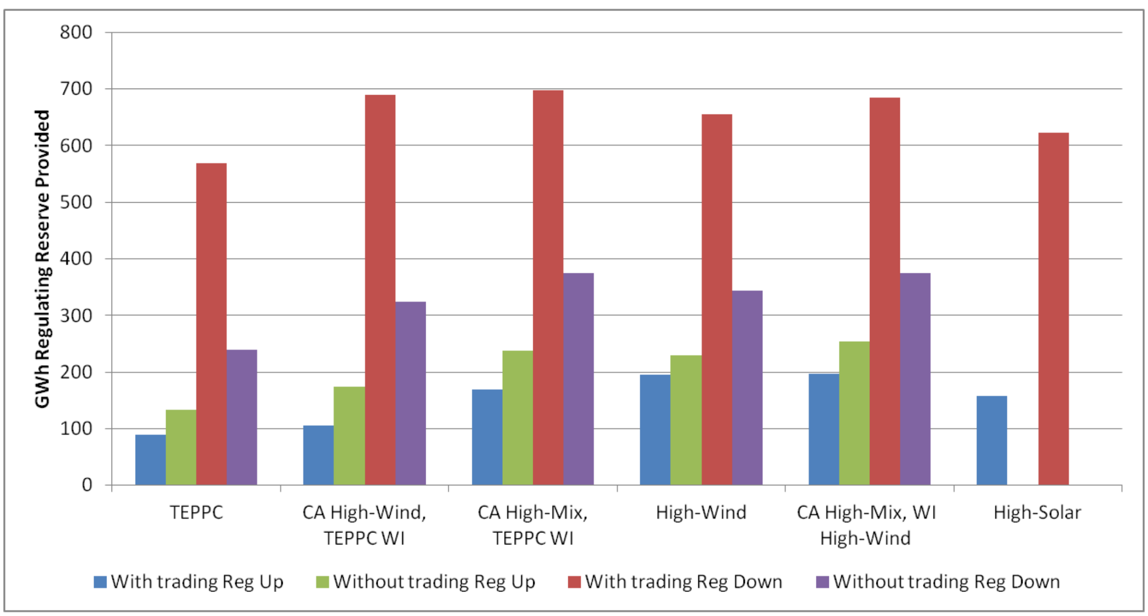


Figure 7-4: Regulation provision in the SMUD BA for different scenarios and cases

Table 7-13 shows a summary of the proportion of total reserve requirements met by Iowa Hill in various scenarios and cases. This is graphed for the SMUD BA region for the case with and without AS trading in Figure 7-5. One thing that can be seen here is that reg down in particular is mostly met by Iowa Hill in many cases (it's not clear in reality whether operators would prefer to have reserves met by more than one unit). Otherwise, at least 10% on average of all requirements are met by Iowa Hill. In general, flexibility up and extra capacity reserve, which can be met by offline units easily, are not provided significantly, (also, these requirements tend to be bigger). Another aspect which is not surprising is that in the case without AS trading, more of the SMUD BA's requirements are met by Iowa Hill as it cannot take advantage of potentially higher prices in CAISO or the NW.

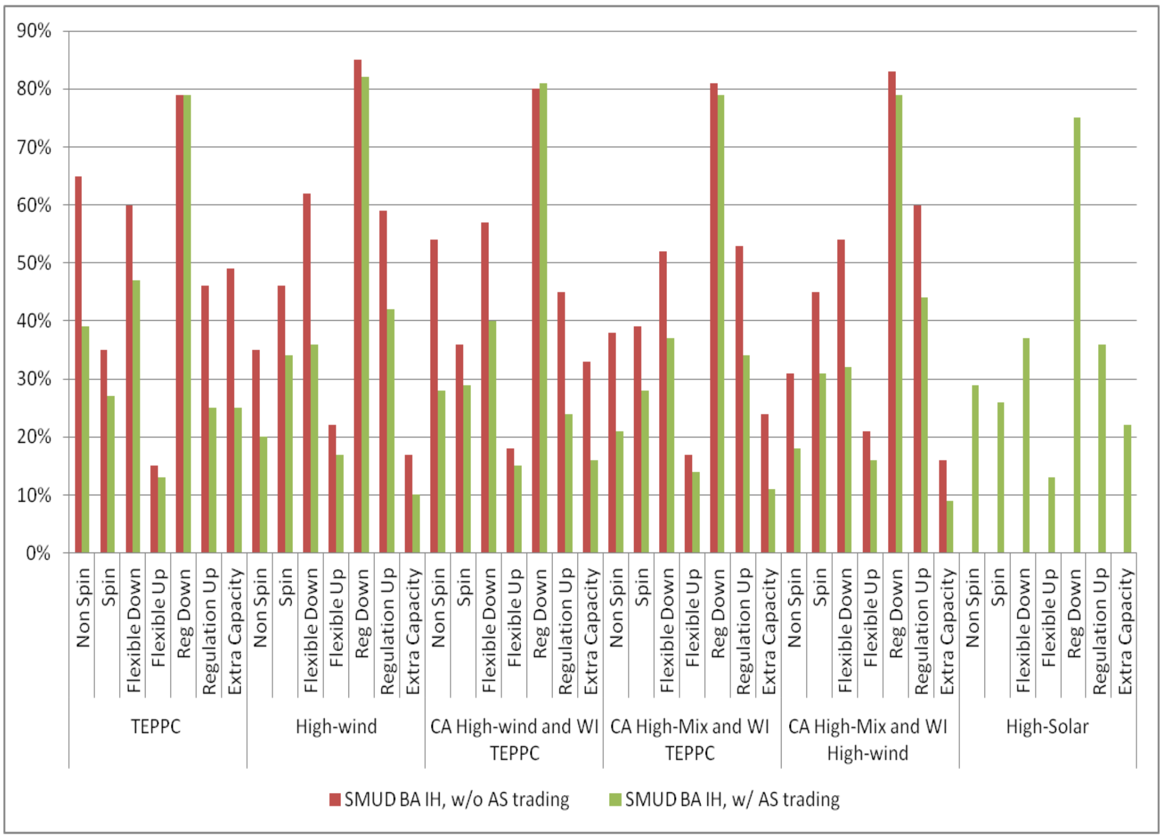


Figure 7-5: Percentage of each reserve category provided by Iowa Hill for different scenarios and cases

Table 7-13: Comparison of Reserve Requirement and Provision of reserves by Iowa Hill and Recip for different cases and scenarios

RPS Scenario	Reserve Category	SMUD BA				SMUD BA, CA, NW			
		Reqt (GWh)	IH, w/o AS trading	IH, w/ AS trading	Recip, w/ AS trading	Reqt (GWh)	IH, w/o AS trading	IH, w/ AS trading	Recip, w/ AS trading
TEPPC	Non Spin	493	65%	39%	0%	13,701	2.3%	1.4%	0.0%
	Spin	493	35%	27%	1%	13,701	1.3%	1.5%	0.0%
	Flexible Down	478	60%	47%	2%	13,695	2.1%	2.7%	0.1%
	Flexible Up	507	15%	13%	6%	14,016	0.5%	0.7%	0.2%
	Reg Down	300	79%	79%	0%	6,055	3.9%	9.4%	0.0%
	Regulation Up	294	46%	25%	0%	6,060	2.2%	1.5%	0.0%
	Extra Capacity	499	49%	25%	0%	11,376	2.1%	1.1%	0.0%
High-wind	Non Spin	493	35%	20%	0%	13,701	1.3%	0.7%	0.0%
	Spin	493	46%	34%	2%	13,701	1.7%	1.6%	0.1%
	Flexible Down	639	62%	36%	0%	14,904	2.6%	2.3%	0.0%
	Flexible Up	652	22%	17%	5%	15,212	0.9%	0.8%	0.2%
	Reg Down	403	85%	82%	13%	6,808	5.0%	9.6%	1.0%
	Regulation Up	388	59%	42%	0%	6,825	3.4%	2.9%	0.0%
	Extra Capacity	1,068	17%	10%	1%	15,925	1.2%	0.7%	0.0%
CA High-wind and WI TEPPC	Non Spin	493	54%	28%	0%	13,701	1.9%	1.0%	0.0%
	Spin	493	36%	29%	2%	13,701	1.3%	1.4%	0.1%
	Flexible Down	639	57%	40%	1%	14,654	2.5%	2.4%	0.0%
	Flexible Up	652	18%	15%	4%	14,996	0.8%	0.9%	0.2%
	Reg Down	403	80%	81%	1%	6,668	4.9%	10.3%	0.0%
	Regulation Up	388	45%	24%	0%	6,694	2.6%	1.6%	0.0%
	Extra Capacity	1,068	33%	16%	1%	14,203	2.5%	1.2%	0.0%
CA High-Mix and WI TEPPC	Non Spin	493	38%	21%	0%	13,701	1.4%	0.8%	0.0%
	Spin	493	39%	28%	2%	13,701	1.4%	1.3%	0.1%
	Flexible Down	653	52%	37%	1%	14,996	2.3%	2.2%	0.0%
	Flexible Up	679	17%	14%	2%	15,277	0.8%	0.7%	0.1%
	Reg Down	463	81%	79%	3%	7,046	5.3%	9.9%	0.2%
	Regulation Up	444	53%	34%	0%	7,157	3.3%	2.4%	0.0%
	Extra Capacity	1,094	24%	11%	1%	15,688	1.7%	0.8%	0.0%
High Solar	Non Spin	493		29%		13,702		35%	
	Spin	493		32%		13,702		17%	
	Flexible Down	460		66%		14,081		23%	
	Flexible Up	493		16%		14,227		4%	
	Reg Down	347		180%		6,647		56%	
	Regulation Up	338				6,745		30%	
	Extra Capacity	524		22%		13,689		13%	
CA High-Mix and WI High-wind	Non Spin	493	31%	18%	0%	13,701	1.1%	0.7%	0.0%
	Spin	493	45%	31%	3%	13,701	1.6%	1.3%	0.1%
	Flexible Down	653	54%	32%	0%	15,246	2.3%	2.1%	0.0%
	Flexible Up	679	21%	16%	5%	15,493	0.9%	0.8%	0.2%
	Reg Down	463	83%	79%	17%	7,186	5.3%	9.4%	1.4%
	Regulation Up	444	60%	44%	0%	7,289	3.6%	3.0%	0.0%
	Extra Capacity	1,094	16%	9%	1%	17,410	1.0%	0.6%	0.1%

Table 7-14: Comparison of Reserve Requirement and Provision by pumped hydro storage and Reciprocating Engines for the TEPPC

Scenario

Region	Reserves Category (GWh)	Res Reqt (GWh)	BAU	AS Trading	IH w/o AS trade	IH w/ AS Trade	Recip w/ AS Trade	1b - 1	2 - 1	2b - 1b	3 - 1b
			Case 1	Case1b	Case 2	Case2b	Case3				
SMUD BA	Non Spinning Reserve	493	-	-	319	191	-	-	319	191	-
	Spinning Reserve	493	-	-	175	199	6	-	175	199	6
	Flexible Down	478	-	-	288	365	13	-	288	365	13
	Flexible Up	507	-	-	77	95	33	-	77	95	33
	Regulation Down	300	-	-	239	568	1	-	239	568	1
	Regulation Up	294	-	-	134	89	-	-	134	89	-
	Extra Capacity	499	-	-	243	123	1	-	243	123	1
Rest of CA	Non Spinning Reserve	8,012	6,011	5,978	6,040	6,011	5,968	(33)	29	33	(10)
	Spinning Reserve	8,012	2,338	2,319	2,301	2,317	2,359	(19)	(37)	(2)	40
	Flexible Down	7,600	1,375	1,393	1,373	1,365	1,353	18	(2)	(28)	(40)
	Flexible Up	7,835	551	543	513	518	570	(8)	(38)	(26)	27
	Regulation Down	3,462	1,177	1,182	1,188	1,190	1,182	6	12	7	0
	Regulation Up	3,457	943	935	931	917	940	(8)	(12)	(17)	5
	Extra Capacity	4,536	1,977	1,972	2,025	2,026	1,957	(5)	48	54	(15)
NWPP	Non Spinning Reserve	5,197	212	218	218	206	208	6	6	(12)	(10)
	Spinning Reserve	5,197	66	62	66	69	66	(4)	(0)	7	4
	Flexible Down	5,618	1,569	1,567	1,545	1,539	1,549	(2)	(24)	(28)	(17)
	Flexible Up	5,673	21	21	20	22	24	(1)	(1)	2	3
	Regulation Down	2,293	1,611	1,614	1,607	1,612	1,611	3	(4)	(2)	(3)
	Regulation Up	2,309	240	237	232	233	248	(4)	(8)	(4)	12
	Extra Capacity	6,342	123	131	135	128	136	8	12	(3)	5
Study Area	Non Spinning Reserve	13,701	6,223	6,196	6,577	6,409	6,176	(27)	354	212	(21)
	Spinning Reserve	13,701	2,404	2,381	2,542	2,585	2,431	(23)	138	204	51
	Flexible Down	13,695	2,944	2,960	3,206	3,269	2,915	16	262	309	(44)
	Flexible Up	14,016	573	564	610	635	627	(9)	37	71	63
	Regulation Down	6,055	2,787	2,796	3,033	3,370	2,795	9	246	574	(2)
	Regulation Up	6,060	1,183	1,171	1,297	1,239	1,188	(12)	113	68	17
	Extra Capacity	11,376	2,100	2,104	2,404	2,277	2,094	4	304	174	(10)

Table 7-15: Comparison of Reserve Requirement and Provision by pumped hydro storage and Reciprocating Engines for the CA High-

Wind and WI TEPPC Renewable Scenario

Region	Reserve Type	Reserve Requirement (GWh)	BAU	AS Trading	IH	IH Plus AS Trading	Recip Plus AS Trading	Case 11b-Case 11	Case 13-Case 11	Case 15-Case 11b	Case 17-Case 11b
			Case 11	Case 11b	Case 13	Case 15	Case 17				
SMUD BA	Non Spinning Reserve	493	-	-	265	140	-	-	265	140	-
	Spinning Reserve	493	-	-	177	193	10	-	177	193	10
	Flexible Down	639	-	-	363	356	6	-	363	356	6
	Flexible Up	652	-	-	119	128	26	-	119	128	26
	Regulation Down	403	-	-	324	690	2	-	324	690	2
	Regulation Up	388	-	-	174	106	-	-	174	106	-
	Extra Capacity	1,068	-	-	355	167	7	-	355	167	7
Rest of CA	Non Spinning Reserve	8,012	6,140	6,151	6,221	6,197	6,132	11	81	45	(19)
	Spinning Reserve	8,012	2,229	2,239	2,233	2,250	2,239	10	4	12	1
	Flexible Down	8,397	1,453	1,451	1,424	1,413	1,437	(2)	(29)	(38)	(13)
	Flexible Up	8,670	520	526	524	516	535	6	4	(10)	9
	Regulation Down	3,972	1,447	1,437	1,427	1,426	1,440	(9)	(20)	(11)	3
	Regulation Up	3,997	1,087	1,085	1,070	1,070	1,093	(2)	(17)	(15)	8
	Extra Capacity	6,793	2,316	2,297	2,397	2,406	2,321	(19)	81	109	24
NWPP	Non Spinning Reserve	5,197	227	242	239	227	230	16	12	(15)	(12)
	Spinning Reserve	5,197	65	67	62	65	64	2	(2)	(2)	(3)
	Flexible Down	5,618	1,548	1,539	1,541	1,516	1,530	(9)	(8)	(24)	(10)
	Flexible Up	5,673	23	24	22	21	23	1	(1)	(2)	(1)
	Regulation Down	2,293	1,603	1,593	1,595	1,590	1,598	(10)	(8)	(3)	5
	Regulation Up	2,309	249	247	245	247	248	(1)	(4)	(1)	0
	Extra Capacity	6,342	140	131	134	139	134	(9)	(6)	7	3
Total Study Area	Non Spinning Reserve	13,701	6,367	6,393	6,725	6,564	6,362	27	358	170	(32)
	Spinning Reserve	13,701	2,293	2,305	2,472	2,508	2,313	12	178	203	8
	Flexible Down	14,654	3,001	2,990	3,327	3,284	2,973	(11)	326	294	(17)
	Flexible Up	14,996	543	550	665	666	584	7	122	116	33
	Regulation Down	6,668	3,050	3,030	3,346	3,705	3,041	(20)	296	675	10
	Regulation Up	6,694	1,336	1,332	1,489	1,422	1,341	(4)	153	90	8
	Extra Capacity	14,203	2,456	2,428	2,887	2,711	2,462	(27)	431	283	34

Table 7-16: Comparison of Reserve Requirement and Provision by pumped hydro storage and Reciprocating Engines for the CA High-Mix and WI TEPPC Renewable Scenario

Region	Reserve Type	Reserve Requirement (GWh)	BAU	AS Trading	IH	IH Plus AS Trading	Recip Plus AS Trading	Case12b-Case12	Case14-Case12	Case16-Case12b	Case18-Case12b
			Case12	Case12b	Case14	Case16	Case18				
SMUD BA	Non Spinning Reserve	493	-	-	189	103	-	-	189	103	-
	Spinning Reserve	493	-	-	191	174	8	-	191	174	8
	Flexible Down	653	-	-	343	336	5	-	343	336	5
	Flexible Up	679	-	-	117	112	12	-	117	112	12
	Regulation Down	463	-	-	375	698	12	-	375	698	12
	Regulation Up	444	-	-	237	169	-	-	237	169	-
	Extra Capacity	1,094	-	-	262	125	8	-	262	125	8
Rest of CA	Non Spinning Reserve	8,012	5,331	5,339	5,480	5,425	5,286	8	149	86	(52)
	Spinning Reserve	8,012	2,051	2,018	2,040	2,046	2,027	(32)	(11)	28	8
	Flexible Down	8,725	1,406	1,413	1,382	1,373	1,404	7	(24)	(41)	(9)
	Flexible Up	8,924	476	461	458	470	463	(15)	(18)	9	1
	Regulation Down	4,290	1,709	1,718	1,715	1,703	1,714	9	6	(15)	(4)
	Regulation Up	4,405	1,472	1,474	1,449	1,460	1,475	2	(23)	(14)	1
	Extra Capacity	8,253	1,944	1,946	2,062	2,061	1,950	2	118	115	4
NWPP	Non Spinning Reserve	5,197	180	196	194	199	187	16	14	4	(8)
	Spinning Reserve	5,197	101	90	84	87	98	(11)	(17)	(4)	8
	Flexible Down	5,618	1,580	1,571	1,558	1,546	1,572	(9)	(22)	(25)	1
	Flexible Up	5,673	21	25	24	17	21	3	3	(8)	(4)
	Regulation Down	2,293	1,617	1,620	1,618	1,610	1,615	3	1	(9)	(5)
	Regulation Up	2,309	309	306	296	296	318	(3)	(13)	(10)	12
	Extra Capacity	6,342	104	102	110	114	113	(1)	7	12	10
Total Study Area	Non Spinning Reserve	13,701	5,510	5,534	5,863	5,727	5,474	24	353	193	(61)
	Spinning Reserve	13,701	2,152	2,109	2,315	2,307	2,132	(44)	163	199	24
	Flexible Down	14,996	2,987	2,985	3,283	3,255	2,981	(2)	297	271	(3)
	Flexible Up	15,277	498	486	599	599	495	(12)	102	113	9
	Regulation Down	7,046	3,326	3,338	3,709	4,011	3,341	12	383	673	3
	Regulation Up	7,157	1,781	1,780	1,982	1,925	1,792	(1)	201	145	12
	Extra Capacity	15,688	2,048	2,048	2,434	2,300	2,070	0	387	252	22

Table 7-17: Comparison of Reserve Requirement and Provision by pumped hydro storage and Reciprocating Engines for the High-wind (everywhere) Renewable Scenario

Region	Reserves Type	Reserve Requirement (GWh)	BAU	AS Trading	IH	IH Plus AS Trading	FS IH Plus AS Trading	Recip Plus AS Trading	Case5 - Case4	Case6 - Case4b	Case7 - Case4b	Case8 - Case4b
			Case 4	Case 4b	Case 5	Case 6	Case 7	Case 8				
SMUD BA	Non Spinning Reserve	493	-	-	174	97	308	-	174	97	308	-
	Spinning Reserve	493	-	-	229	216	74	9	229	216	74	9
	Flexible Down	639	-	-	394	338	26	1	394	338	26	1
	Flexible Up	652	-	-	143	126	56	32	143	126	56	32
	Regulation Down	403	-	-	343	655	118	70	343	655	118	70
	Regulation Up	388	-	-	229	195	27	0	229	195	27	0
	Extra Capacity	1,068	-	-	185	105	479	8	185	105	479	8
Rest of CA	Non Spinning Reserve	8,012	4,066	4,050	4,204	4,235	4,125	4,085	138	184	75	35
	Spinning Reserve	8,012	2,219	2,236	2,254	2,256	2,245	2,241	36	20	9	5
	Flexible Down	8,397	1,778	1,779	1,756	1,767	1,760	1,756	(22)	(12)	(18)	(22)
	Flexible Up	8,670	394	395	420	411	405	401	26	16	10	6
	Regulation Down	3,972	1,651	1,647	1,631	1,612	1,635	1,638	(19)	(36)	(13)	(9)
	Regulation Up	3,997	1,400	1,402	1,409	1,395	1,403	1,407	8	(7)	1	5
	Extra Capacity	6,793	956	935	984	997	958	949	28	62	22	14
NWPP	Non Spinning Reserve	5,197	163	170	165	170	171	168	2	0	1	(1)
	Spinning Reserve	5,197	107	111	107	105	105	112	(0)	(6)	(6)	1
	Flexible Down	5,867	1,850	1,849	1,879	1,861	1,856	1,843	29	12	7	(6)
	Flexible Up	5,890	21	18	18	20	19	19	(3)	2	0	1
	Regulation Down	2,433	1,810	1,806	1,815	1,813	1,814	1,800	5	6	8	(7)
	Regulation Up	2,440	440	427	403	407	418	433	(37)	(20)	(8)	6
	Extra Capacity	8,064	91	83	99	88	88	96	8	5	5	13
Total Study Area	Non Spinning Reserve	13,701	4,229	4,220	4,544	4,502	4,605	4,254	315	282	384	34
	Spinning Reserve	13,701	2,326	2,347	2,590	2,577	2,423	2,362	264	230	76	15
	Flexible Down	14,904	3,627	3,627	4,028	3,966	3,643	3,600	401	338	15	(28)
	Flexible Up	15,212	415	413	581	557	479	453	166	143	66	40
	Regulation Down	6,808	3,461	3,454	3,789	4,080	3,567	3,508	328	626	113	54
	Regulation Up	6,825	1,840	1,828	2,041	1,997	1,848	1,840	200	168	19	12
	Extra Capacity	15,925	1,047	1,018	1,269	1,191	1,525	1,053	222	172	506	35

Table 7-18: Comparison of Reserve Requirement and Provision by pumped hydro storage and Reciprocating Engines for the CA High-Mix and WI High-Wind Renewable Scenario

Region	Reserve Type	Reserve Requirement (GWh)	BAU	AS Trading	IH w/o AS trade	IH w/ AS Trade	Recip w/ AS Trade	Case19b-Case19	Case20-Case19	Case21-Case19b	Case22-Case19b
			Case19	Case19b	Case20	Case21	Case22				
SMUD BA	Non Spinning Reserve	493	-	-	169	90	-	-	169	90	-
	Spinning Reserve	493	-	-	206	178	13	-	206	178	13
	Flexible Down	653	-	-	344	333	2	-	344	333	2
	Flexible Up	679	-	-	127	111	21	-	127	111	21
	Regulation Down	463	-	-	375	684	38	-	375	684	38
	Regulation Up	444	-	-	254	197	0	-	254	197	0
	Extra Capacity	1,094	-	-	229	111	10	-	229	111	10
Rest of CA	Non Spinning Reserve	8,012	4,967	4,926	5,111	5,099	4,915	(41)	144	174	(10)
	Spinning Reserve	8,012	2,069	2,106	2,086	2,084	2,073	37	17	(22)	(33)
	Flexible Down	8,725	1,449	1,445	1,419	1,427	1,467	(4)	(30)	(18)	22
	Flexible Up	8,924	451	445	445	436	430	(7)	(7)	(9)	(15)
	Regulation Down	4,290	1,702	1,693	1,709	1,701	1,706	(9)	7	8	13
	Regulation Up	4,405	1,555	1,555	1,538	1,540	1,539	(1)	(17)	(15)	(15)
	Extra Capacity	8,253	1,668	1,665	1,783	1,788	1,676	(4)	115	123	12
NWPP	Non Spinning Reserve	5,197	164	176	182	184	174	12	18	8	(2)
	Spinning Reserve	5,197	126	120	116	118	133	(6)	(9)	(2)	13
	Flexible Down	5,867	1,712	1,710	1,682	1,677	1,690	(2)	(30)	(33)	(20)
	Flexible Up	5,890	20	19	17	17	17	(0)	(2)	(3)	(2)
	Regulation Down	2,433	1,742	1,739	1,751	1,737	1,725	(2)	9	(2)	(14)
	Regulation Up	2,440	373	375	354	360	382	2	(19)	(15)	7
	Extra Capacity	8,064	128	136	147	159	142	7	18	23	6
Total Study Area	Non Spinning Reserve	13,701	5,131	5,101	5,462	5,374	5,089	(29)	332	272	(12)
	Spinning Reserve	13,701	2,194	2,225	2,408	2,379	2,219	31	214	154	(7)
	Flexible Down	15,246	3,160	3,155	3,445	3,437	3,160	(5)	284	282	5
	Flexible Up	15,493	471	464	589	563	467	(7)	118	100	4
	Regulation Down	7,186	3,444	3,433	3,834	4,123	3,469	(11)	390	690	37
	Regulation Up	7,289	1,928	1,930	2,146	2,097	1,921	2	217	167	(9)
	Extra Capacity	17,410	1,797	1,800	2,160	2,057	1,828	4	363	257	27

Table 7-19: Comparison of Reserve Requirement and Provision by IH for the High-solar Renewable Scenario

Region	Reserves Provided by PSHs (GWh)	Reserve Requirement (GWh)	AS Trading Case30b	IH Plus AS Trading Case31	Case31-Case30b
SMUD	Non Spinning Reserve	493	0	141	141
	Spinning Reserve	493	0	160	160
	Flexible Down	460	0	303	303
	Flexible Up	493	0	79	79
	Regulation Down	347	0	623	623
	Regulation Up	338	0	157	157
	Extra Capacity	524	0	113	113
Rest of CA	Non Spinning Reserve	8,012	4,392	4,504	112
	Spinning Reserve	8,012	2,010	2,033	23
	Flexible Down	7,977	1,395	1,384	-11
	Flexible Up	8,044	396	402	6
	Regulation Down	3,989	1,483	1,496	13
	Regulation Up	4,072	1,461	1,452	-10
	Extra Capacity	6,619	1,439	1,497	58
NWPP	Non Spinning Reserve	5,197	126	136	10
	Spinning Reserve	5,197	177	158	-19
	Flexible Down	5,644	1,511	1,513	2
	Flexible Up	5,690	16	17	1
	Regulation Down	2,311	1,592	1,608	17
	Regulation Up	2,335	441	416	-25
	Extra Capacity	6,546	118	113	-5
Total Study Area	Non Spinning Reserve	13,702	4,518	4,781	263
	Spinning Reserve	13,702	2,187	2,351	164
	Flexible Down	14,081	2,906	3,200	294
	Flexible Up	14,227	412	498	86
	Regulation Down	6,647	3,075	3,727	653
	Regulation Up	6,745	1,902	2,025	122
	Extra Capacity	13,689	1,557	1,723	166

The following table summarizes the Iowa Hill contributions to a variety of reserves in a variety of renewable scenarios. From the summary, we can observe that contributes to a variety of reserves, and that the contributions increase as the renewable energy penetration level increases in the system. For example, for the SMUD BA, Iowa Hill contributes 79% of regulation down reserve and 46% of regulation up reserve for the TEPPC scenario. Iowa Hill contributes 83% of regulation down reserve and 60% of regulation down reserve in the CA high-mix and WI high-wind renewable scenarios.

Table 7-20: Comparison of Reserve Requirement and Provision by Iowa Hill and Recip for different scenarios and cases (high solar not shown here due to small number of cases run for that scenario)

RPS Scenario	RPS Scenario	SMUD BA				SMUD BA, CA, NW				SMUD BA			SMUD BA, CA, NW		
		Reserve Requirement (GWh)	Reserve Provision by IH and Recip (GWh)			Reserve Requirement (GWh)	Reserve Provision by IH and Recip (GWh)			Reserve Provision by IH and Recip (%)			Reserve Provision by IH and Recip (%)		
			IH, w/o AS trading	IH, w/ AS trading	Recip, w/ AS trading		IH, w/o AS trading	IH, w/ AS trading	Recip, w/ AS trading	IH, w/o AS trading	IH, w/ AS trading	Recip, w/ AS trading	IH, w/o AS trading	IH, w/ AS trading	Recip, w/ AS trading
TEPPC	Non Spin	493	319	191	-	13,701	319	191	-	65%	39%	0%	2.3%	1.4%	0.0%
	Spin	493	175	135	6	13,701	175	199	6	35%	27%	1%	1.3%	1.5%	0.0%
	Flexible Down	478	288	223	10	13,695	288	365	13	60%	47%	2%	2.1%	2.7%	0.1%
	Flexible Up	507	77	67	33	14,016	77	95	33	15%	13%	6%	0.5%	0.7%	0.2%
	Regulation Down	300	239	237	1	6,055	239	568	1	79%	79%	0%	3.9%	9.4%	0.0%
	Regulation Up	294	134	73	-	6,060	134	89	-	46%	25%	0%	2.2%	1.5%	0.0%
	Extra Capacity	499	243	123	1	11,376	243	123	1	49%	25%	0%	2.1%	1.1%	0.0%
High-wind	Non Spin	493	174	97	-	13,701	174	97	-	35%	20%	0%	1.3%	0.7%	0.0%
	Spin	493	229	170	9	13,701	229	216	9	46%	34%	2%	1.7%	1.6%	0.1%
	Flexible Down	639	394	233	1	14,904	394	338	1	62%	36%	0%	2.6%	2.3%	0.0%
	Flexible Up	652	143	111	32	15,212	143	126	32	22%	17%	5%	0.9%	0.8%	0.2%
	Regulation Down	403	343	329	51	6,808	343	655	70	85%	82%	13%	5.0%	9.6%	1.0%
	Regulation Up	388	229	165	0	6,825	229	195	0	59%	42%	0%	3.4%	2.9%	0.0%
	Extra Capacity	1,068	185	105	8	15,925	185	105	8	17%	10%	1%	1.2%	0.7%	0.0%
CA High-	Non Spin	493	265	140	-	13,701	265	140	-	54%	28%	0%	1.9%	1.0%	0.0%
	Spin	493	177	142	10	13,701	177	193	10	36%	29%	2%	1.3%	1.4%	0.1%

RPS Scenario	RPS Scenario	SMUD BA				SMUD BA, CA, NW				SMUD BA			SMUD BA, CA, NW		
		Reserve Requirement (GWh)	Reserve Provision by IH and Recip (GWh)			Reserve Requirement (GWh)	Reserve Provision by IH and Recip (GWh)			Reserve Provision by IH and Recip (%)			Reserve Provision by IH and Recip (%)		
			IH, w/o AS trading	IH, w/ AS trading	Recip, w/ AS trading		IH, w/o AS trading	IH, w/ AS trading	Recip, w/ AS trading	IH, w/o AS trading	IH, w/ AS trading	Recip, w/ AS trading	IH, w/o AS trading	IH, w/ AS trading	Recip, w/ AS trading
wind and WI TEPPC	Flexible Down	639	363	256	5	14,654	363	356	6	57%	40%	1%	2.5%	2.4%	0.0%
	Flexible Up	652	119	101	26	14,996	119	128	26	18%	15%	4%	0.8%	0.9%	0.2%
	Regulation Down	403	324	326	2	6,668	324	690	2	80%	81%	1%	4.9%	10.3 %	0.0%
	Regulation Up	388	174	93	-	6,694	174	106	-	45%	24%	0%	2.6%	1.6%	0.0%
	Extra Capacity	1,068	355	167	7	14,203	355	167	7	33%	16%	1%	2.5%	1.2%	0.0%
CA High-Mix and WI TEPPC	Non Spinning Reserve	493	189	103	-	13,701	189	103	-	38%	21%	0%	1.4%	0.8%	0.0%
	Non Spin	493	191	138	8	13,701	191	174	8	39%	28%	2%	1.4%	1.3%	0.1%
	Spin	653	343	243	4	14,996	343	336	5	52%	37%	1%	2.3%	2.2%	0.0%
	Flexible Up	679	117	97	12	15,277	117	112	12	17%	14%	2%	0.8%	0.7%	0.1%
	Regulation Down	463	375	365	12	7,046	375	698	12	81%	79%	3%	5.3%	9.9%	0.2%
	Regulation Up	444	237	152	-	7,157	237	169	-	53%	34%	0%	3.3%	2.4%	0.0%
	Extra Capacity	1,094	262	125	8	15,688	262	125	8	24%	11%	1%	1.7%	0.8%	0.0%
CA High-Mix and WI High-wind	Non Spin	493	153	89	-	13,701	153	89	-	31%	18%	0%	1.1%	0.7%	0.0%
	Spin	493	220	153	15	13,701	220	181	15	45%	31%	3%	1.6%	1.3%	0.1%
	Flexible Down	653	354	211	0	15,246	354	317	1	54%	32%	0%	2.3%	2.1%	0.0%
	Flexible Up	679	145	109	37	15,493	145	120	37	21%	16%	5%	0.9%	0.8%	0.2%
	Regulation Down	463	383	364	79	7,186	383	678	98	83%	79%	17%	5.3%	9.4%	1.4%
	Regulation Up	444	265	197	0	7,289	265	221	0	60%	44%	0%	3.6%	3.0%	0.0%
	Extra Capacity	1,094	179	97	12	17,410	179	97	12	16%	9%	1%	1.0%	0.6%	0.1%

Impact of Iowa Hill on Emissions

This subsection presents the impact of Iowa Hill and reciprocating generators to the system emission production. To better understand emissions, the total emissions in the business as usual cases (with AS trading from the SMUD BA) are shown in Figure 7-6. This is shown for the entire study footprint as adding Iowa Hill in the SMUD BA may change emissions elsewhere. As expected, increasing penetrations of wind and solar reduce emissions – it can again be seen that having wind added in the rest of the WI can also reduce emissions in California, while . Trading of AS also reduces emissions. A similar pattern is seen for NOx and SO2 emissions A similar pattern is also seen for the SMUD BA alone, though when AS trading is allowed, there is a slight reduction in emissions in CA versus the no-trading case. However, it is hard to extract the emissions reductions in the SMUD BA from total area, so this is main focus here.

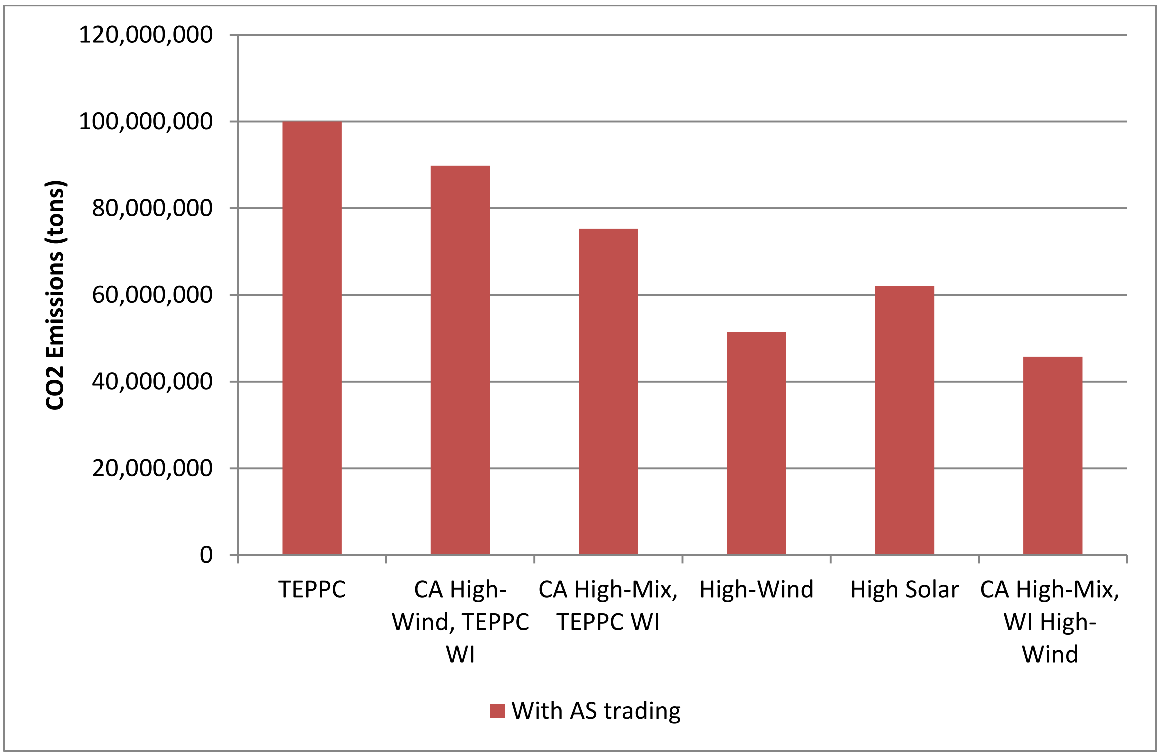


Figure 7-6: CO2 emissions for the SMUD BA for AS trading base case for each scenario

The next result to examine is the reduction in emissions due to addition of Iowa Hill. The reduction in tons of CO_2 the total study area is shown in. For the total study area (including the SMUD BA), emissions benefits of Iowa Hill follow no clear pattern; for lower penetrations there is an increase in total emissions in the study area – for higher penetrations, the high wind case shows a reduction in emissions whereas for the high mix/high wind case, it depends on AS trading. Note here that SO2 emissions are not shown in figures; tables later show that the difference is very small. Again, the high solar case doesn't show the case without AS trading; also emissions are seen to go up.

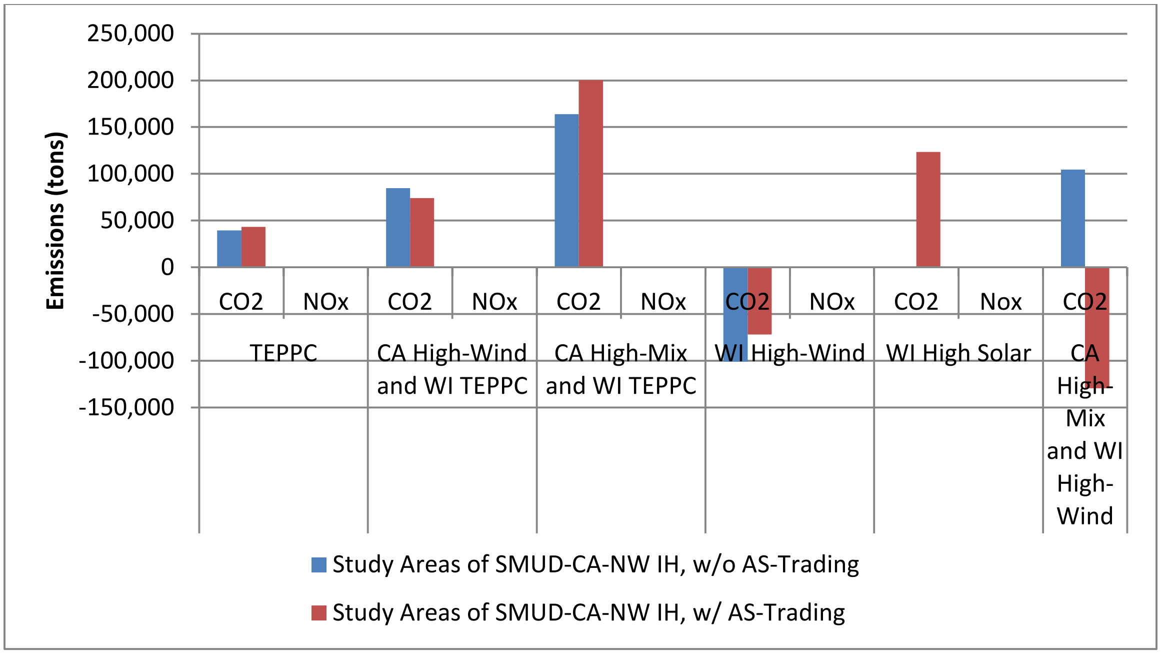


Figure 7-7: Change in CO2 due to Iowa Hill for different scenarios and cases in study area

Figure 7-8 shows the change in NOx emissions. System wide Iowa Hill increases NOx emissions at most wind and solar penetrations, as other plant are used more when charging Iowa Hill, particularly at part load.

The final figure of interest shows the reduction in NOx and CO_2 emissions in the SMUD BA as a percentage of business as usual emissions. Both CO2 and Nox can be seen to follow very similar patterns, with increasing benefits as wind and solar penetrations increase system wide. Note also that AS trading results in Iowa Hill being less beneficial in all cases However, it is also important to note here that SMU may be reducing emissions in its footprint, but when accounted for though increased imports, they may increase.

Overall, the CO_2 emissions are shown to change in the SMUD BA between a reduction of 2000 ton or increase of 370 tons per MW installed per year. Study area wide, the change is between an increase of 400 tons and reduction of 1250 tons per MW. This shows how much the emissions are based on the particular study scenario. This is for a case of zero carbon costs, so carbon is in no way optimized, and thus it would be expected that there is no clear emissions benefit to Iowa Hill, other than allowing more variable generation to be integrated. In order for storage to actually contribute to reducing emissions, there would need to be a cost associated with them. The emissions are summarized in Table 7-21, and then detailed results are given for each scenario in Table 7-22 to Table 7-26. These show more detailed results which inform the figures shown here.

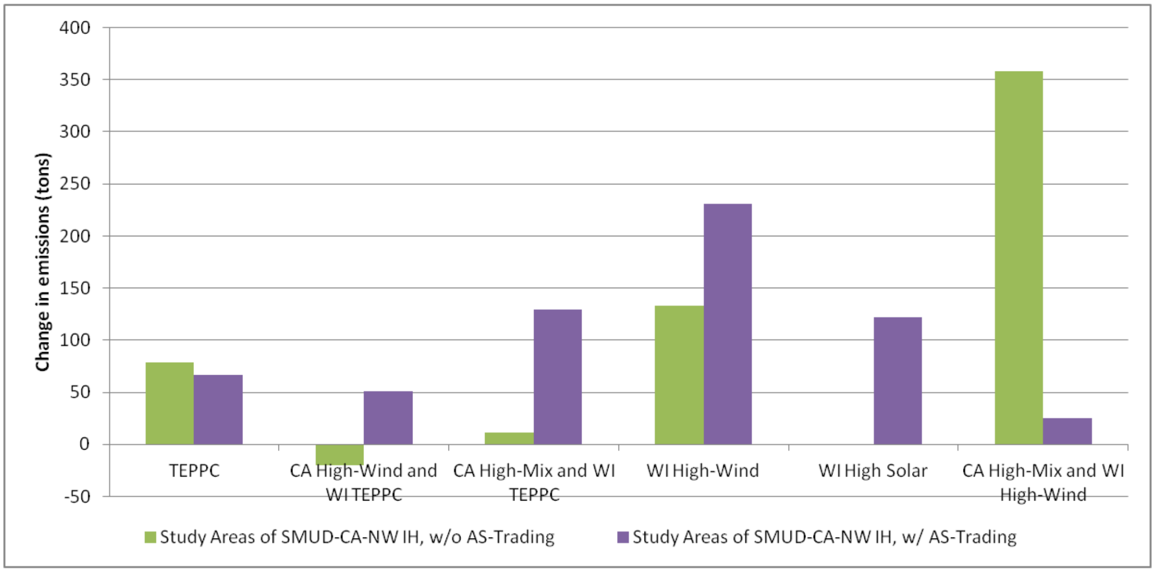


Figure 7-8: Change in NOx emissions due to Iowa Hill

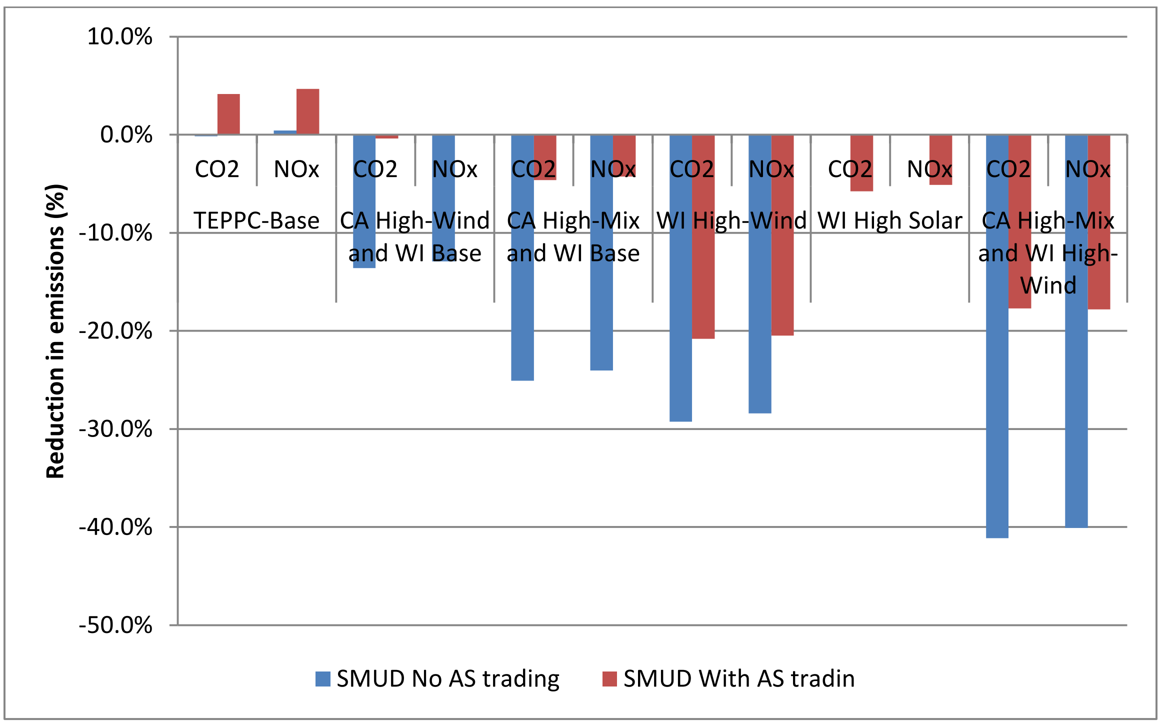


Figure 7-9: % reduction in CO2 and NOx emissions in the SMUD BA

Table 7-21: Summary of Emission Production Differences for a Variety of Renewable Scenario (GWh)

RPS Scenario	Emission	SMUD BA			Study Areas of SMUD-CA-NW		
		IH, w/o AS-Trading	IH, w/ AS-Trading	Recip, w/ AS-Trading	IH, w/o AS-Trading	IH, w/ AS-Trading	Recip, w/ AS-Trading
TEPPC	CO2	(5,989)	146,202	(23,839)	39,694	43,461	(54,310)
	NOx	10	109	(11)	79	67	(23)
	SO2	(1)	(1)	(1)	11	10	(2)
CA High-Wind and WI TEPPC	CO2	(415,264)	(10,479)	(37,425)	84,794	74,123	(18,050)
	NOx	(263)	1	(21)	(20)	51	(34)
	SO2	(1)	-	-	28	37	9
CA High-Mix and WI TEPPC	CO2	(691,584)	(97,195)	(61,470)	163,708	200,300	10,319
	NOx	(442)	(60)	(39)	11	129	(59)
	SO2	-	-	-	305	326	(2,179)
WI High-Wind	CO2	(611,573)	(391,517)	(194,807)	(101,009)	(71,856)	(13,927)
	NOx	(396)	(259)	(132)	133	231	211
	SO2	-	-	-	470	519	450
WI High-Solar	CO2		(134,413)			123,394	
	NOx		(80)			122	
	SO2						
CA High-Mix and WI High-Wind	CO_2	(797,847)	(289,388)	(501,011)	104,593	(129,481)	137,446
	NO_x	(517)	(196)	(333)	358	25	521
	SO_2	(0)	(0)	(0)	702	513	1,065

The above table summarizes the differences between different scenarios and different cases for the addition of Iowa Hill and reciprocating engines, with and without ancillary services trading. Notice that, compared to most other results, the impact of reciprocating engines on emissions is close to the impact of Iowa Hill (in most other cases reciprocating engines have far less benefit than Iowa Hill).

Table 7-22: Comparison of Emission Production for the TEPPC Scenario

Zone	Emission (ton)	BAU	AS-Trading	IH	IH Plus AS-Trading	Recip Plus AS-Trading	Case1b - Case 1		Case 2 - Case 1		Case2b - Case1b		Case 3 - Case1b	
		Case 1	Case1b	Case 2	Case2b	Case3	ton	%	ton	%	ton	%	ton	%
SMUD BA	CO2	3,627,505	3,530,182	3,621,517	3,676,384	3,506,343	(97,324)	-2.7	(5,989)	-0.2	146202	4.1	-23839	-0.7
	NOx	2,405	2,343	2,415	2,452	2,332	(62)	-2.6	10	0.4	109	4.7	-11	-0.5
	SO2	1	1	0	1	1	(0)	-20.6	(1)	-69.7	-1	-55.3	-1	-45.4
Rest of CA	CO2	76,243,800	76,351,966	76,299,251	76,258,409	76,352,728	108,166	0.1	55,451	0.1	-93557	-0.1	763	0.0
	NOx	56,171	56,225	56,235	56,176	56,237	55	0.1	64	0.1	-49	-0.1	12	0.0
	SO2	5,896	5,896	5,896	5,896	5,896	(0)	0.0	1	0.0	0	0.0	0	0.0
NWPP	CO2	20,148,402	20,146,823	20,138,633	20,137,639	20,115,590	(1,579)	0.0	(9,769)	0.0	-9185	0.0	-31233	-0.2
	NOx	14,097	14,093	14,102	14,100	14,069	(3)	0.0	5	0.0	6	0.0	-25	-0.2
	SO2	18,407	18,411	18,419	18,421	18,409	4	0.0	12	0.1	10	0.1	-2	0.0
Total	CO2	100,019,707	100,028,971	100,059,401	100,072,432	99,974,661	9,264	0	39,694	0	43,461	0	-54,310	-0
	NOx	72,673	72,661	72,752	72,728	72,638	-12	-0	79	0	67	0	-23	-0
	SO2	24,304	24,308	24,315	24,318	24,306	4	0	11	0	10	0	-2	-0

Table 7-23: Comparison of Emission Production for the CA High-Wind and WI TEPPC Renewable Scenario

Zone	Emission (ton)	BAU	AS-Trading	IH	IH Plus AS-Trading	Recip Plus AS-Trading	Case 11b - Case 11		Case 13 - Case 11		Case 15 - Case 11b		Case 17 - Case 11b	
		Case 11	Case 11b	Case 13	Case 15	Case 17	ton	%	ton	%	ton	%	ton	%
SMUD BA	CO2	3,052,275	2,652,665	2,637,011	2,642,185	2,615,239	(399,611)	13%	(415,264)	14%	(10,479)	0%	(37,425)	-1%
	NOx	2,035	1,773	1,773	1,774	1,752	(262)	13%	(263)	13%	1	0%	(21)	-1%
	SO2	1	1	0	0	0	(0)	31%	(1)	96%	(0)	-88%	(0)	-54%
Rest of CA	CO2	67,631,631	68,030,113	68,091,521	68,107,688	68,032,700	398,482	1%	459,891	1%	77,575	0%	2,587	0%
	NOx	52,664	52,827	52,888	52,878	52,816	163	0%	224	0%	51	0%	(10)	0%
	SO2	5,880	5,880	5,882	5,882	5,881	0	0%	3	0%	2	0%	0	0%
NWPP	CO2	19,128,106	19,137,980	19,168,274	19,145,008	19,154,769	9,874	0%	40,168	0%	7,028	0%	16,788	0%
	NOx	13,665	13,672	13,683	13,671	13,670	7	0%	18	0%	(0)	0%	(2)	0%
	SO2	18,240	18,236	18,267	18,272	18,245	(4)	0%	26	0%	35	0%	8	0%
Total	CO2	89,812,012	89,820,758	89,896,806	89,894,881	89,802,708	8,746	0%	84,794	0%	74,123	0%	-18,050	0%
	NOx	68,364	68,272	68,344	68,323	68,238	-92	0%	-20	0%	51	0%	-34	0%
	SO2	24,121	24,117	24,149	24,154	24,126	-4	0%	28	0%	37	0%	9	0%

Table 7-24: Comparison of Emission Production for the CA High-Mix and WI TEPPC Renewable Scenario

Zone	Emission (ton)	BAU	AS-Trading	IH	IH Plus AS-Trading	Recip Plus AS-Trading	Case12b - Case12		Case14 - Case12		Case16 - Case12b		Case18 - Case12b	
		Case12	Case12b	Case14	Case16	Case18	ton	%	ton	%	ton	%	ton	%
SMUD BA	CO2	2,758,475	2,093,997	2,066,891	1,996,802	2,032,526	(664,478)	-24%	(691,584)	-25%	(97,195)	-5%	(61,470)	-3%
	NOx	1,838	1,408	1,396	1,348	1,369	(429)	-23%	(442)	-24%	(60)	-4%	(39)	-3%
	SO2	0	0	0	0	0	(0)	-63%	(0)	-99%	(0)	-100%	(0)	-90%
Rest of CA	CO2	55,271,248	55,944,463	55,951,569	56,001,625	55,941,821	673,216	1%	680,321	1%	57,162	0%	(2,642)	0%
	NOx	47,380	47,669	47,675	47,661	47,607	289	1%	295	1%	(8)	0%	(61)	0%
	SO2	5,813	5,811	5,824	5,825	5,269	(2)	0%	10	0%	13	0%	(543)	-9%
NWPP	CO2	17,296,536	17,275,167	17,471,507	17,515,500	17,349,599	(21,369)	0%	174,971	1%	240,333	1%	74,432	0%
	NOx	12,875	12,859	13,033	13,056	12,901	(16)	0%	159	1%	197	2%	42	0%
	SO2	17,688	17,677	17,982	17,989	16,040	(11)	0%	294	2%	312	2%	(1,637)	-9%
Total	CO2	75,326,259	75,313,627	75,489,967	75,513,927	75,323,946	-12,632	0%	163,708	0%	200,300	0%	10,319	0%
	NOx	62,093	61,936	62,104	62,065	61,877	-157	0%	11	0%	129	0%	-59	0%
	SO2	23,501	23,488	23,806	23,814	21,309	-13	0%	305	1%	326	1%	-2,179	-9%

Table 7-25: Comparison of Emission Production for the High-wind (everywhere) Renewable Scenario

Zone	Emission (ton)	BAU	AS-Trading	IH	IH Plus AS-Trading	FS IH Plus AS-Trading	Recip Plus AS-Trading	Case5 - Case4		Case6 - Case4b		Case7 - Case4b		Case8 - Case4b	
		Case 4	Case 4b	Case 5	Case 6	Case 7	Case 8	ton	%	ton	%	ton	%	ton	%
SMUD BA	CO2	2,090,491	1,879,916	1,478,919	1,488,399	1,664,827	1,685,109	(611,573)	-29%	(391,517)	-21%	(215,089)	-11%	(194,807)	-10%
	NOx	1,394	1,264	998	1,005	1,121	1,132	(396)	-28%	(259)	-21%	(143)	-11%	(132)	-10%
	SO2	0	0	0	0	0	0	(0)	-100%	(0)	-99%	(0)	-96%	(0)	-83%
Rest of CA	CO2	39,883,459	40,041,679	40,216,755	40,145,296	40,118,289	40,023,354	333,295	1%	103,617	0%	76,610	0%	(18,324)	0%
	NOx	37,119	36,928	37,448	37,200	37,177	37,063	329	1%	272	1%	248	1%	135	0%
	SO2	4,875	4,839	4,920	4,904	4,887	4,869	44	1%	65	1%	49	1%	31	1%
NWPP	CO2	9,690,281	9,572,405	9,867,548	9,788,449	9,761,369	9,771,610	177,267	2%	216,044	2%	188,964	2%	199,205	2%
	NOx	7,009	6,864	7,209	7,082	7,067	7,072	200	3%	218	3%	203	3%	208	3%
	SO2	8,320	8,013	8,745	8,467	8,443	8,433	425	5%	454	6%	430	5%	420	5%
Total	CO2	51,664,231	51,494,000	51,563,222	51,422,144	51,544,485	51,480,073	-101,009	0%	-71,856	0%	50,485	0%	-13,927	0%
	NOx	45,522	45,056	45,655	45,287	45,365	45,267	133	0%	231	1%	309	1%	211	0%
	SO2	13,195	12,852	13,665	13,371	13,330	13,302	470	4%	519	4%	478	4%	450	4%

Table 7-26: Comparison of Emission Production for the CA High-Mix and WI High-Wind Scenario

Zone	Emission (ton)	BAU	AS Trading	IH	IH Plus AS Trading	Recip Plus AS Trading	Case19b-Case19		Case20-Case19		Case22-Case19b		Case21-Case19b	
		Case19	Case19b	Case20	Case22	Case21	ton	%	ton	%	ton	%	ton	%
SMUD BA	CO_2	1,939,084	1,634,236	1,141,237	1,344,848	1,133,225	(304,848)	-16%	(797,847)	-41%	(289,388)	-18%	(501,011)	-31%
	NO_x	1,290	1,101	773	904	767	(189)	-15%	(517)	-40%	(196)	-18%	(333)	-30%
	SO_2	0	0	-	-	-	(0)	-4%	(0)	0%	(0)	-100%	(0)	-100%
Rest of CA	CO_2	35,136,301	35,622,515	35,747,278	35,547,166	35,817,354	486,214	1%	610,977	2%	(75,349)	0%	194,839	1%
	NO_x	35,084	35,411	35,657	35,389	35,791	326	1%	573	2%	(22)	0%	381	1%
	SO_2	4,846	4,846	4,928	4,875	4,939	(1)	0%	81	2%	29	1%	94	2%
NWPP	CO_2	8,725,583	8,548,059	9,017,046	8,783,316	8,991,677	(177,524)	-2%	291,463	3%	235,257	3%	443,619	5%
	NO_x	6,196	6,008	6,498	6,252	6,482	(187)	-3%	302	5%	244	4%	474	8%
	SO_2	6,909	6,543	7,531	7,028	7,514	(366)	-5%	621	9%	484	7%	971	15%
Total	CO_2	45,800,968	45,804,810	45,905,560	45,675,329	45,942,257	3,843	0%	104,593	0%	(129,481)	0%	137,446	0%
	NO_x	42,570	42,520	42,928	42,545	43,041	(50)	0%	358	1%	25	0%	521	1%
	SO_2	11,756	11,389	12,458	11,903	12,454	(367)	-3%	702	6%	513	5%	1,065	9%

Impact on Curtailment of Renewable Resources

A key benefit of energy storage is the ability to reduce curtailments. Iowa Hill (or other PHS) can pump during periods of overgneration (typically off-peak, but with increasing wind and solar, this may also happen during the day). As can be seen in scenarios Table and Figure 7-10, most of the lower penetration scenarios do not have significant curtailment to begin with, so Iowa Hill cannot reduce it significantly. What can be seen is that, including AS trading increases the amount of reduction in the entire study area; on the other hand in the SMUD BA region the case with no AS trading sees a greater reduction; the mode of trading does make a significant difference. Comparing the 3rd and 5th scenarios, where the main difference is additional wind added to the regions outside California, it can be seen that much of the reduction in curtailment is related to overgeneration which happens more often when there is a lot of wind WI-wide, and therefore the SMUD BA and California in general cannot export its own wind and solar. Iowa Hill allows for storage of this wind and solar for use in the future. Future work will examine when this happens. It can be seen from the figure that Iowa Hill is about twice as good at reducing curtailment than recips.

By multiplying the curtailment reduction by $22/MWh (an approximate value for the PPA price of wind), an additional savings can also be found. For example, in the case of the SMUD BA only, this results in an additional savings of between zero and $638,000 for recips, or zero and $1.45m for Iowa Hill. Similarly, system wide, this is between zero and $7.5m for Iowa Hill or $3.3m for recips. These results would need to be treated with caution as they are not in the optimization; however they do show an upper bound on curtailment savings due to Iowa Hill.

Table 7-27: Comparison of Renewable Energy Curtailment for different scenarios

RPS Scenario	*Renewable Energy Curtailment*						*Renewable Energy Curtailment Reductions*			
	SMUD BA			*Study Areas of SMUD-CA-NW*			*SMUD BA*		*Study Areas of SMUD-CA-NW*	
	BAU W/ AS Trading	**IH, w/ AS trading**	**Recip, w/ AS trading**	**BAU W/ AS Trading**	**IH, w/ AS trading**	**Recip, w/ AS trading**	**IH - BAU, w/AS trading**	**Recip - BAU, w/ AS trading**	**IH - BAU, w/AS trading**	**Recip - BAU, w/ AS trading**
TEPPC	-	-	-	12	12	12	-	-	(0)	(0)
High-Wind	75	29	52	1,134	810	1,043	(46)	(23)	(324)	(91)
High Solar	9	2	-	309	262	-	-7	-	-47	-
CAHigh-Wind,WI TEPPC	-	-	-	19	17	19	-	-	(2)	(0)
CAHigh-Mix,WI TEPPC	17	8	15	383	373	381	(9)	(2)	(10)	(2)
CAHigh-Mix,WIHigh-Wind	109	43	80	1,789	1,449	1,639	(66)	(29)	(340)	(149)

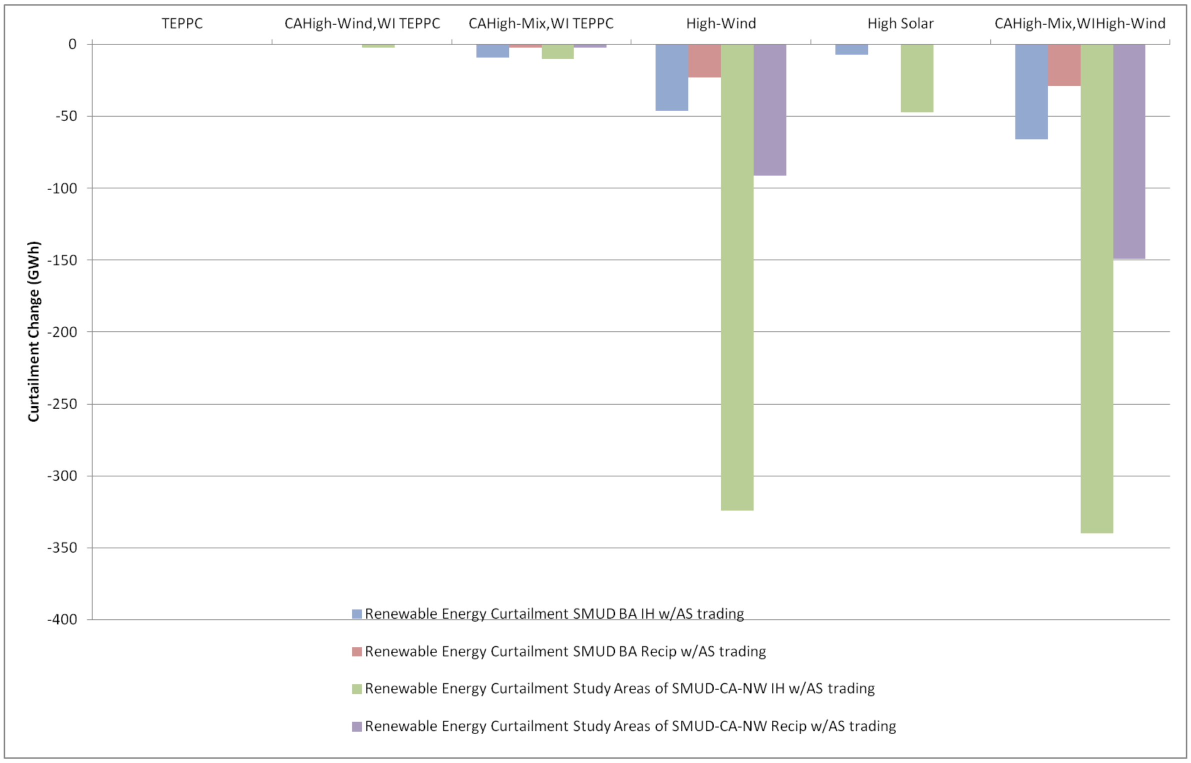


Figure 7-10: Impact on Renewable Curtailment when Iowa Hill is added to system

Impact on Start Up Times, Start Up Cost and Ramping

This subsection presents thermal start cost and cycling from the simulations for the difference cases in a variety of renewable scenarios. The change in starts will reduce the cycling of conventional plant, which reduces O&M, outage rates and avoids significant lifetime reductions. Figure 7-11 shows the reduction in starts for both the SMUD BA and study region when Iowa Hill or recips are added. As can be seen, consistent with other results, the SMUD BA sees the largest reduction; however there are reductions outside the SMUD BA due to the presence of Iowa Hill. Also, AS trading reduces the benefits of Iowa Hill to the SMUD BA units starts, though most of this is captured in the rest of the study area (there is very little difference between with and without trading in total study area). Note also that there are greater reduction in the TEPPC case Finally, recips are not as effectives in general, except in the high wind case.

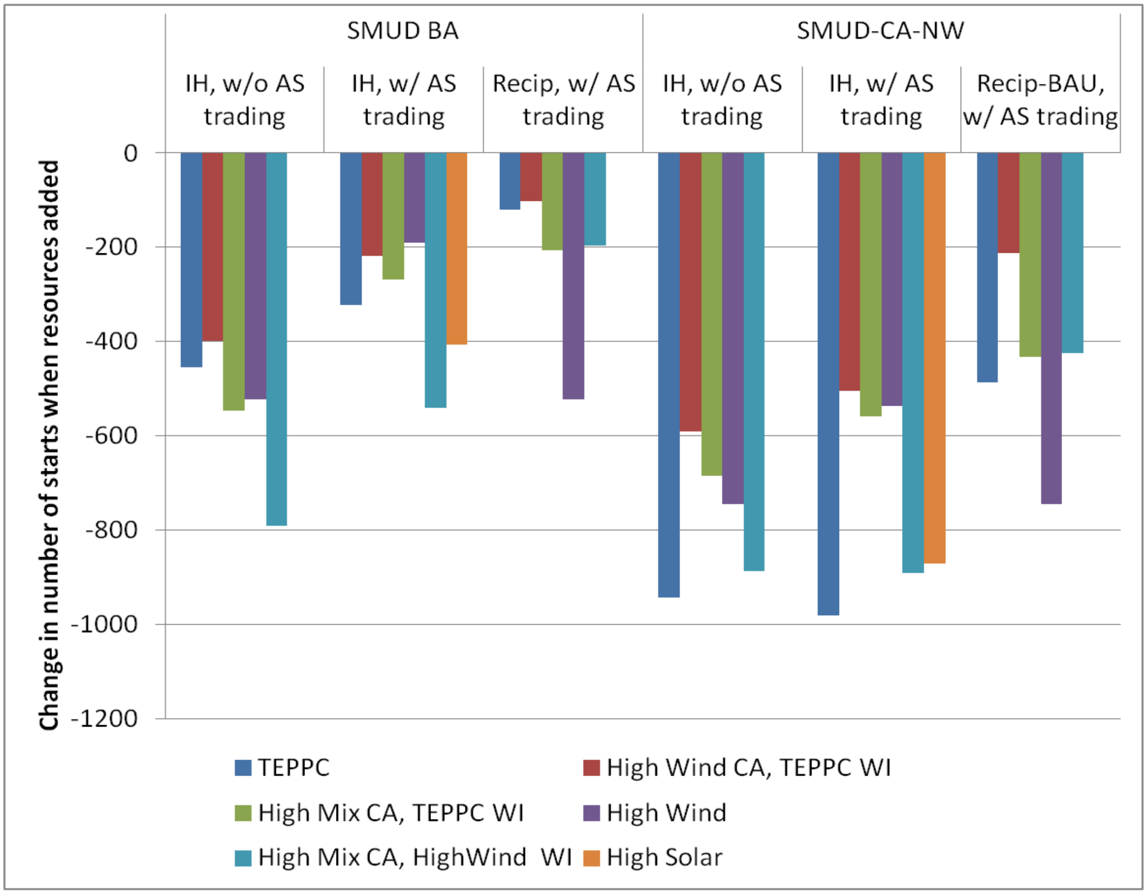


Figure 7-11: Change in number of starts in the SMUD BA and study region

Summary tables of cycling-related issues are provided in Table 7-28 to Table 7-30. In general, it can be seen that there is significant cycling benefit, both within the SMUD BA and also entire study area, with the introduction of Iowa Hill. One thing to note is that, contrary to most other results, Iowa Hill has more of a benefit to starts in the high solar case than high wind case, due to a large number of unit starts during the day from CTs being reduced

Table 7-28: Summary of change in unit starts over the year for different scenarios and cases

RPS Scenario	Number of Starts						%					
	SMUD BA			Study Areas of SMUD-CA-NW			SMUD BA			Study Areas of SMUD-CA-NW		
	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading
TEPPC	(454)	(323)	(120)	(943)	(981)	(487)	-55%	-45%	-17%	-8%	-8%	-4%
High Wind CA, WI TEPPC	(399)	(219)	(103)	(591)	(505)	(212)	-58%	-42%	-20%	-7%	-6%	-2%
High Mix CA, WI TEPPC	(546)	(269)	(206)	(684)	(558)	(432)	-73%	-58%	-44%	-10%	-9%	-7%
High Wind	(522)	(191)	(522)	(745)	(536)	(745)	-71%	-33%	-90%	-9%	-7%	-9%
High Solar		(406)			(871)			-70%			-11%	
High Mix CA, HighWind WI	(792)	(541)	(196)	(888)	(892)	(424)	-85%	-78%	-28%	-15%	-15%	-7%

Table 7-29: Summary of change in start costs for different scenarios and cases

RPS Scenario	(M$)						%					
	SMUD BA			Study Areas of SMUD-CA-NW			SMUD BA			Study Areas of SMUD-CA-NW		
	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading
TEPPC	(2)	(3)	(0)	(6)	(8)	(3)	-35%	-38%	-7%	-5%	-7%	-2%
High Wind CA, WI TEPPC	(2)	(2)	(0)	(4)	(6)	(1)	-31%	-29%	-5%	-4%	-6%	-1%
High Mix CA, WI TEPPC	(3)	(2)	(1)	(5)	(7)	(4)	-49%	-33%	-20%	-6%	-8%	-4%
High Wind	(1)	(1)	(1)	(0)	(0)	(3)	-8%	-8%	-9%	0%	0%	-3%
High Wind		(2)			(8)							
High Mix CA, HighWind WI	(6)	(4)	(1)	(6)	(10)	(5)	-75%	-68%	-26%	-9%	-15%	-8%

The table above summarizes thermal start cost reductions for the different cases. Thermal start cost reductions of several $m can be observed when Iowa Hill is introduced to the system; the cost reduction in the SMUD BA are a significant % of total start costs, while even in the total study area, start costs are reduced significantly more than total production costs shown earlier. Overall, cost savings from starts seem to follow a similar pattern as number of costs, though start cost reduction in the AS trading case may be a little higher than expected (indicating its saving the more expensive starting plant in those cases).

Table 7-30: Summary of Impact of Iowa Hill or recips on ramping Reductions for a Variety of Renewable for different scenarios and cases

RPS Scenario	(M$)						%					
	SMUD BA			Study Areas of SMUD-CA-NW			SMUD BA			Study Areas of SMUD-CA-NW		
	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading	IH-BAU, w/o AS trading	IH-BAU, w/ AS trading	Recip-BAU, w/ AS trading
TEPPC	(88)	(38)	(15)	(361)	(391)	(120)	-15%	-6%	-2%	-4%	-4%	-1%
High Wind CA, WI TEPPC	(96)	(13)	(5)	(271)	(296)	(112)	-17%	-3%	-1%	-3%	-4%	-1%
High Mix CA, WI TEPPC	(193)	(60)	(13)	(286)	(350)	(81)	-33%	-13%	-3%	-3%	-4%	-1%
High Wind	(148)	(99)	(24)	(231)	(221)	(18)	-41%	-28%	-7%	-5%	-5%	0%
High Solar		(84)			(332)							
High Mix CA, HighWind WI	(190)	(128)	(50)	(124)	(203)	(22)	-58%	-47%	-19%	-3%	-5%	-1%

The table above summarizes thermal generation ramp reductions for the different cases in a variety of renewable scenarios when Iowa Hill or the reciprocating generators are introduced to the system. Noticeable thermal generation ramp reductions can be observed when Iowa Hill or the reciprocating generators are introduced to the system; again the reductions in the rest of the study are almost as significant as those in the SMUD BA. In general, therefore, it can be deduced that, from a cycling perspective, there is significant benefits from Iowa Hilll (more than recips), of which the SMUD BA sees approximately half, with a very significant reduction in cycling in the SMUD BA. The remaining tables in this subsection show detailed results for the different scenarios and cases related to cycling.

Table 7-31: Comparison of Thermal Cycling and Start Costs for the TEPPC Scenario

Region	Properties	Unit	BAU	AS-Trading	IH	IH Plus AS-Trading	Recip Plus AS-Trading	Case 1b - Case 1		Case 2 - Case 1		Case 2b - Case 1b		Case 3 - Case 1b	
			Case 1	Case 1b	Case 2	Case 2b	Case 3	M$	%	M$	%	M$	%	M$	%
SMUD BA	# of Starts		781	701	378	394	584	(80)	-10.2%	(403)	-51.6%	-307	-43.8%	(117)	-16.7%
	Start Cost	M$	7	7	4	4	7	0	6.0%	(2)	-34.7%	-3	-38.4%	(0)	-6.7%
	Ramp Up	GW	271	275	238	268	270	4	1.4%	(34)	-12.5%	-7	-2.5%	(5)	-1.9%
	Ramp Down	GW	332	340	278	309	330	8	2.4%	(54)	-16.2%	-31	-9.2%	(10)	-2.8%
Rest of CA	# of Starts		9,970	10,085	9,604	9,533	9,787	115	1.2%	(366)	-3.7%	-552	-5.5%	(298)	-3.0%
	Start Cost	M$	90	91	88	87	89	1	0.9%	(2)	-2.6%	-4	-4.4%	(2)	-1.9%
	Ramp Up	GW	2,437	2,466	2,367	2,363	2,441	29	1.2%	(70)	-2.9%	-103	-4.2%	(25)	-1.0%
	Ramp Down	GW	3,382	3,419	3,285	3,274	3,373	37	1.1%	(97)	-2.9%	-145	-4.2%	(46)	-1.3%
NWPP	# of Starts		1,475	1,479	1,359	1,375	1,425	4	0.3%	(116)	-7.9%	-104	-7.0%	(54)	-3.7%
	Start Cost	M$	23	23	22	22	22	0	0.2%	(1)	-5.9%	-1	-5.8%	(1)	-3.2%
	Ramp Up	GW	975	974	929	927	960	(1)	-0.1%	(45)	-4.7%	-47	-4.8%	(14)	-1.4%
	Ramp Down	GW	1,208	1,207	1,148	1,147	1,186	(1)	-0.1%	(60)	-4.9%	-60	-5.0%	(21)	-1.7%

Table 7-32: Comparison of Thermal Cycling and Start Costs for the CA High-Wind and WI TEPPC Renewable Scenario

Region	Properties	Unit	BAU	AS-Trading	IH	IH Plus AS-Trading	Recip Plus AS-Trading	Case 11b - Case 11		Case 13 - Case 11		Case 15 - Case 11b		Case 17 - Case 11b	
			Case 11	Case 11b	Case 13	Case 15	Case 17	M$	%	M$	%	M$	%	M$	%
SMUD BA	# of Starts		659	514	294	306	422	(145)	-22%	(365)	-55%	(208)	-40%	(92)	-18%
	Start Cost	M$	7	7	5	5	6	(0)	-5%	(2)	-31%	(2)	-29%	(0)	-5%
	Ramp Up	GW	243	221	205	223	220	(22)	-9%	(38)	-16%	3	1%	(1)	0%
	Ramp Down	GW	306	282	249	266	278	(24)	-8%	(57)	-19%	(16)	-6%	(4)	-1%
Rest of CA	# of Starts		6,597	6,700	6,464	6,432	6,608	103	2%	(133)	-2%	(268)	-4%	(92)	-2%
	Start Cost	M$	77	78	76	75	78	2	2%	(1)	-2%	(4)	-5%	(1)	-3%
	Ramp Up	GW	2,281	2,334	2,219	2,236	2,290	53	2%	(63)	-3%	(99)	-4%	(44)	-2%
	Ramp Down	GW	3,068	3,138	2,992	3,000	3,084	70	2%	(75)	-2%	(137)	-4%	(54)	-2%
NWPP	# of Starts		1,281	1,278	1,232	1,242	1,260	(3)	0%	(49)	-4%	(36)	-3%	(18)	-1%
	Start Cost	M$	20	20	19	20	20	0	0%	(1)	-3%	(1)	-3%	(0)	-1%
	Ramp Up	GW	886	889	871	867	885	3	0%	(16)	-2%	(22)	-3%	(4)	0%
	Ramp Down	GW	1,088	1,089	1,066	1,062	1,083	2	0%	(21)	-2%	(27)	-2%	(6)	-1%

Table 7-33: Comparison of Thermal Cycling and Start Costs for the CA High-Mix and WI TEPPC Renewable Scenario

Region	Properties	Unit	BAU	AS-Trading	IH	IH Plus AS-Trading	Recip Plus AS-Trading	Case 12b - Case 12		Case 14 - Case 12		Case 16 - Case 12b		Case 18 - Case 12b	
			Case 12	Case 12b	Case 14	Case 16	Case 18	M$	%	M$	%	M$	%	M$	%
SMUD BA	# of Starts		650	387	203	194	253	(263)	-40%	(447)	-69%	(193)	-50%	(134)	-35%
	Start Cost	M$	7	5	3	3	4	(2)	-29%	(3)	-49%	(2)	-33%	(1)	-20%
	Ramp Up	GW	262	205	179	182	202	(57)	-22%	(83)	-32%	(23)	-11%	(3)	-2%
	Ramp Down	GW	321	247	211	211	238	(73)	-23%	(110)	-34%	(36)	-15%	(10)	-4%
Rest of CA	# of Starts		4,923	5,054	4,813	4,776	4,842	131	3%	(110)	-2%	(278)	-6%	(212)	-2%
	Start Cost	M$	66	68	65	64	66	2	3%	(1)	-2%	(5)	-7%	(3)	-3%
	Ramp Up	GW	2,444	2,542	2,441	2,447	2,517	98	4%	(2)	0%	(95)	-4%	(25)	-1%
	Ramp Down	GW	3,104	3,219	3,087	3,080	3,168	114	4%	(17)	-1%	(139)	-4%	(51)	-2%
NWPP	# of Starts		928	937	907	902	917	9	1%	(21)	-2%	(35)	-4%	(20)	-2%
	Start Cost	M$	14	14	13	13	14	0	1%	(0)	-3%	(0)	-3%	(0)	-2%
	Ramp Up	GW	934	936	898	909	941	2	0%	(35)	-4%	(27)	-3%	6	1%
	Ramp Down	GW	1,064	1,068	1,026	1,038	1,070	4	0%	(38)	-4%	(30)	-3%	2	0%

Table 7-34: Comparison of Thermal Cycling and Start Costs for the High-wind Renewable Scenario

Region	Properties	Unit	BAU	AS-Trading	IH	IH Plus AS-Trading	FS IH Plus AS-Trading	Recip Plus AS-Trading	Case5 - Case4		Case6 - Case4b		Case7 - Case4b		Case8 - Case4b	
			Case 4	Case 4b	Case 5	Case 6	Case 7	Case 8	M$	%	M$	%	M$	%	M$	%
SMUD BA	# of Starts		582	444	208	207	284	336	-374	-64%	(237)	-53%	(160)	-36%	(108)	-24%
	Start Cost	M$	8	7	3	3	5	6	(4)	-57%	(3)	-52%	(2)	-27%	(1)	-9%
	Ramp Up	GW	147	135	91	99	110	125	(57)	-38%	(36)	-26%	(25)	-18%	(10)	-7%
	Ramp Down	GW	212	191	121	128	151	176	(92)	-43%	(63)	-33%	(40)	-21%	(15)	-8%
Rest of CA	# of Starts		6,110	6,245	6,002	6,004	5,980	6,100	(108)	-2%	(241)	-4%	(265)	-4%	(145)	-2%
	Start Cost	M$	77	80	76	76	77	78	(1)	-1%	(4)	-5%	(4)	-5%	(2)	-3%
	Ramp Up	GW	1,349	1,381	1,328	1,337	1,341	1,373	(20)	-2%	(44)	-3%	(40)	-3%	(8)	-1%
	Ramp Down	GW	2,114	2,174	2,079	2,085	2,100	2,146	(35)	-2%	(88)	-4%	(74)	-3%	(28)	-1%
NWPP	# of Starts		671	669	642	640	642	672	(29)	-4%	(29)	-4%	(27)	-4%	3	0%
	Start Cost	M$	7	7	7	7	7	7	(0)	-5%	(0)	-3%	(0)	-3%	0	0%
	Ramp Up	GW	430	422	424	436	422	444	(5)	-1%	14	3%	(1)	0%	22	5%
	Ramp Down	GW	486	479	476	490	476	501	(10)	-2%	11	2%	(3)	-1%	22	5%

Table 7-35: Comparison of Thermal Cycling and Start Costs for the High Solar Scenario

Region	Properties	Unit	AS Trading	IH Plus AS Trading	Case31 - Case30b	
			Case30b	Case 31	M$	%
SMUD	# of Starts		608	202	(406)	-67%
	Start Cost	M$	6	4	(2)	-40%
	Ramp Up	GW	271	239	(32)	-12%
	Ramp Down	GW	322	270	(52)	-16%
Rest of CA	# of Starts		6,560	6,153	(407)	-6%
	Start Cost	M$	91	85	(5)	-6%
	Ramp Up	GW	2,472	2,409	(63)	-3%
	Ramp Down	GW	3,396	3,271	(125)	-4%
NWPP	# of Starts		848	790	(58)	-7%
	Start Cost	M$	10	9	(0)	-4%
	Ramp Up	GW	938	908	(30)	-3%
	Ramp Down	GW	1,017	986	(31)	-3%
Sum	# of Starts		8,016	7,145	(871)	-11%
	Start Cost	M$	106	98	(8)	-8%
	Ramp Up	GW	3,681	3,556	(125)	-3%
	Ramp Down	GW	4,735	4,527	(207)	-4%

Table 7-36: Comparison of Thermal Cycling and Start Costs for the CA High-Mix and WI High-Wind Renewable Scenario

Region	Properties	Unit	BAU	AS-Trading	IH	IH Plus AS-Trading	Recip Plus AS-Trading	Case19B - Case19		Case20 - Case19		Case21 - Case19B		Case22 - Case19B	
			Case19	Case19B	Case20	Case21	Case22	M$	%	M$	%	M$	%	M$	%
SMUD BA	# of Starts		933	692	141	151	496	(241)	-26%	(792)	-85%	(541)	-78%	(196)	-28%
	Start Cost	M$	8	6	2	2	4	(2)	-29%	(6)	-75%	(4)	-68%	(1)	-26%
	Ramp Up	GW	129	112	58	63	93	(17)	-13%	(71)	-55%	(49)	-44%	(19)	-17%
	Ramp Down	GW	197	158	78	79	126	(40)	-20%	(120)	-61%	(78)	-50%	(31)	-20%
Rest of CA	# of Starts		4,490	4,761	4,415	4,447	4,540	271	6%	(75)	-2%	(314)	-7%	(221)	-2%
	Start Cost	M$	53	59	53	53	55	6	12%	0	0%	(6)	-11%	(4)	-3%
	Ramp Up	GW	1,217	1,267	1,230	1,230	1,268	50	4%	13	1%	(38)	-3%	0	0%
	Ramp Down	GW	1,706	1,821	1,718	1,718	1,781	115	7%	11	1%	(104)	-6%	(41)	-2%
NWPP	# of Starts		606	617	585	580	610	11	2%	(21)	-3%	(37)	-6%	(7)	-1%
	Start Cost	M$	5	6	6	6	5	0	1%	0	1%	(0)	0%	(0)	-1%
	Ramp Up	GW	372	350	393	384	385	(21)	-6%	21	6%	33	9%	35	10%
	Ramp Down	GW	416	394	437	427	429	(22)	-5%	21	5%	33	8%	35	9%
Sum	# of Starts		6,029	6,070	5,141	5,178	5,646	41	1%	(888)	-15%	(892)	-15%	(424)	-7%
	Start Cost	M$	66	70	60	60	65	4	6%	(6)	-9%	(10)	-15%	(5)	-8%
	Ramp Up	GW	1,718	1,730	1,682	1,676	1,746	12	1%	(36)	-2%	(54)	-3%	16	1%
	Ramp Down	GW	2,320	2,373	2,233	2,225	2,336	53	2%	(88)	-4%	(149)	-6%	(38)	-2%

Impact on Regional LMP

This subsection presents the regional LMP for the areas in the study areas of SMUD-CA-NW for the different cases in a variety of renewable scenarios. Figure 7-12 shows the average load-weighted LMP for the SMUD BA area. As expected, in general there is a reduction in prices as penetration levels are increased (again, note the high penetrations have not had a generation expansion study and are likely not what would actually occur but this does give an expected shape as penetration levels are increased). One interesting difference compared to previous results is that here, increasing wind penetrations in only CA show a bigger difference than having high wind penetrations throughout the WI, or than a similar case when there is high solar. However, this is only for the SMUD BA region – later results show that study area-wide, the patterns shown previously, with high wind in the WI, are those which have bigger impact.

Table 7-37 and Figure 7-12 show a summary of LMPs for the different cases and scenarios. As expected, the cases with high wind in WI show the lowest prices, due to higher penetration in the NW region. It can also be seen that, while Iowa Hill increases prices in the SMUD BA it reduces them elsewhere.

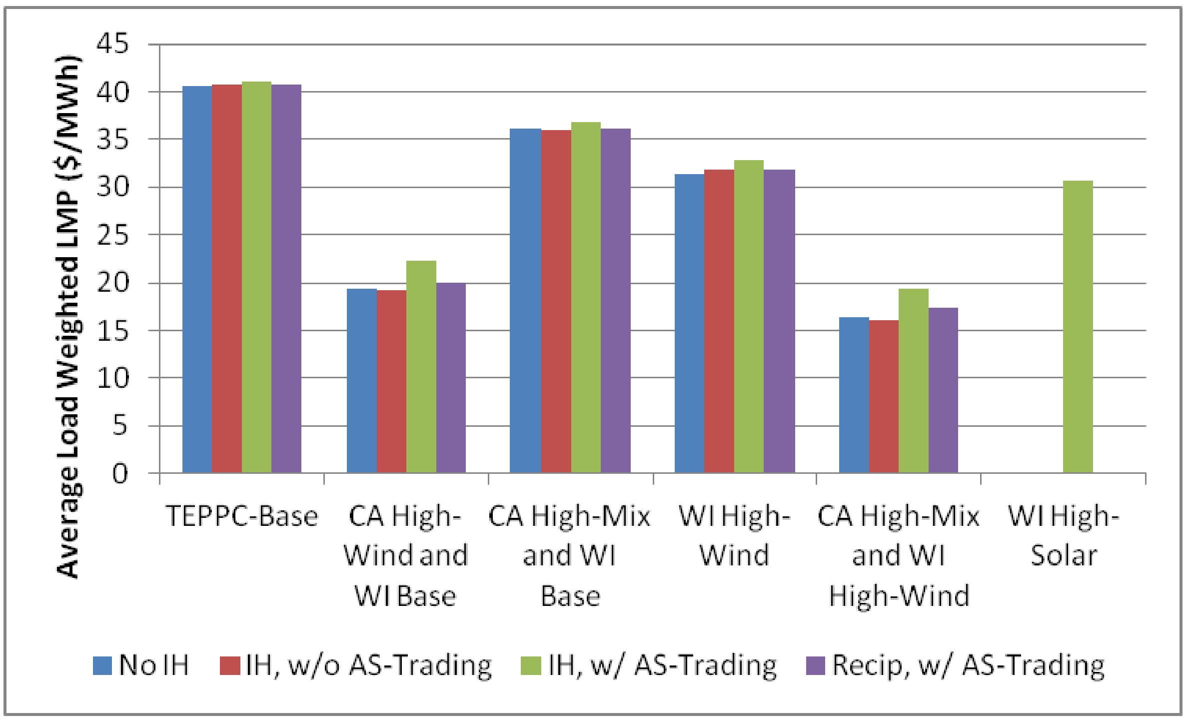


Figure 7-12: Average Load-Weighted LMP in the SMUD BA for different scenarios and cases

Table 7-37: Summary of Annual Average Regional LMP for a Variety of Renewable Scenarios ($/MWh)

RPS Scenario	SMUD BA					Study Areas of SMUD-CA-NW				
	No IH, w/o AS trading	No IH, w/ AS trading	IH, w/o AS-Trading	IH, w/ AS-Trading	Recip, w/ AS-Trading	No IH, w/o AS trading	BAU, w/AS trade	IH, w/o AS-Trading	IH, w/ AS-Trading	Recip, w/ AS-Trading
TEPPC	40.64	40.74	41.02	40.73	37.75	37.64	37.74	37.78	40.74	41.02
CA High-Wind and WI TEPPC	31.33	31.81	32.82	31.87	30.69	30.73	31.17	30.74	31.81	32.82
CA High-Mix and WI TEPPC	36.15	36.02	36.75	36.11	34.84	35.09	35.13	34.79	36.02	36.75
WI High Wind	19.37	19.22	22.34	20.07	15.29	15.53	17.23	15.91	19.22	22.34
CA High-Mix and WI High-Wind	16.44	16.03	19.43	17.40	13.23	15.74	15.15	14.18	16.03	19.43

From Table 7-37, it can be seen that in the base case, Iowa Hill and cases with low wind in the WI, there is very little difference. With no trading, there is an increase of between 50c and $1.50 for low wind in the WI, whereas for the high wind, the increases are greater ($2-$3). With AS trading allowed, Iowa Hill generally increases average price (due to pumping losses), but by less than in the case without AS trading (between zero and approx $2). Study area-wide (above shows an average of all regions in CA and NW), Iowa Hill increases prices in the trading case by between 55c and $2, while with trading there are both increase and decreases, all less than $1.50. In general, most cases see less than $2 difference. Therefore, it can be summarized that in general Iowa Hill will only impact average prices slightly; however it can be surmised that it is likely to do so to some extent, and may increase average marginal prices. As the SMUD BA is vertically integrated, this may not be important in the sense that average may be more important than marginal for a vertically integrated utility. However it does show that it may impact on CAISO prices and thus how the SMUD BA interacts with rest of study area. Interestingly, recips seem to impact more than Iowa Hill; it is not clear why this is so, other than the fact they only act to reduce load, rather than increase load. The remaining tables give more detail including peak and off peak prices for each scenario.

From these detailed tables, a number of interesting observations can be made about the impact of Iowa Hill on peak and off peak prices. In general, Iowa Hill increases peak prices for the Study Area in both trading and non-AS trading scenarios, except in the base case, where it reduces peak prices. In some cases the difference is negligible, but others it is significant, e.g. high wind is an increase of $1.80/MWh in AS trading case. the SMUD BA follows similar pattern but sees greater increases or decreases with the addition of Iowa Hill. Off peak, there is an increase of price; here again we see the greatest difference in the high wind in WI cases. This is true for both the SMUD BA and the full study area regions.

While it would be expected that an increase in load during off peak prices would increase the average off peak price, it would not be expected that pumped hydro would increase peak prices. There are a number of possible reasons for this. Foremost is that, here peak prices are calculated based on time of day. However, with high variable generation, there is likely to be a far more variable price profile – for example, solar will reduce peak prices, while wind may also turn up more some days than nights (though on average is higher at night). This may mean that the current hours used are not actually capturing those periods with highest net load. Another reason may be that Iowa Hill allows larger baseload generation to be turned off (as shown with reduction in starts). This may reduce costs overall, but it may mean that peaker units are used more in combination with Iowa Hill, in order to turn off baseload generation; this would result in higher peak prices. It is the opinion therefore of the project team that, while the result is unusual, peak prices (as measured by time of day rather than net load) could be increased by pumped hydro being added to the system. However, this is an area in which further work will be done to understand this result.

One last result related to LMP is the difference in peak and off peak for different scenarios. This is shown in Figure 7-13 for the case with AS trading. As can be seen Iowa Hill generally reduces peak/off-peak differential, with the exception of the case with high mix and WI TEPPC; this would be expected as high mix would mean reducing peak prices, but the lack of additional wind will not see off-peak reduced as much. As expected, the case with high wind but lower solar would result in highest peak/off-peak differential, while it can be seen that Iowa Hill significantly reduces this. On the other hand, the high solar case doesn't have much differential; this is expected as solar erodes peak demand; this is another reason, as well as curtailment as to why Iowa Hill shows less value in the high solar case. This result is good for explaining other results shown later in terms of the impact of Iowa Hill on peak prices. Normally, it would be expected that storage would significantly alter the peak/off-peak differential. However, here as the peak times are not necessarily the most expensive times, just using time of day as an indicator for peak prices may no longer be valid. Thus, when PLEXOS optimizes the operation of Iowa Hill, it may often be generating in shoulder or even off-peak periods, while pumping in shoulder or peak periods; this is a good reason to use the full optimization offered by PLEXOS and shows why storage can provide significant value in high wind and solar penetrations.

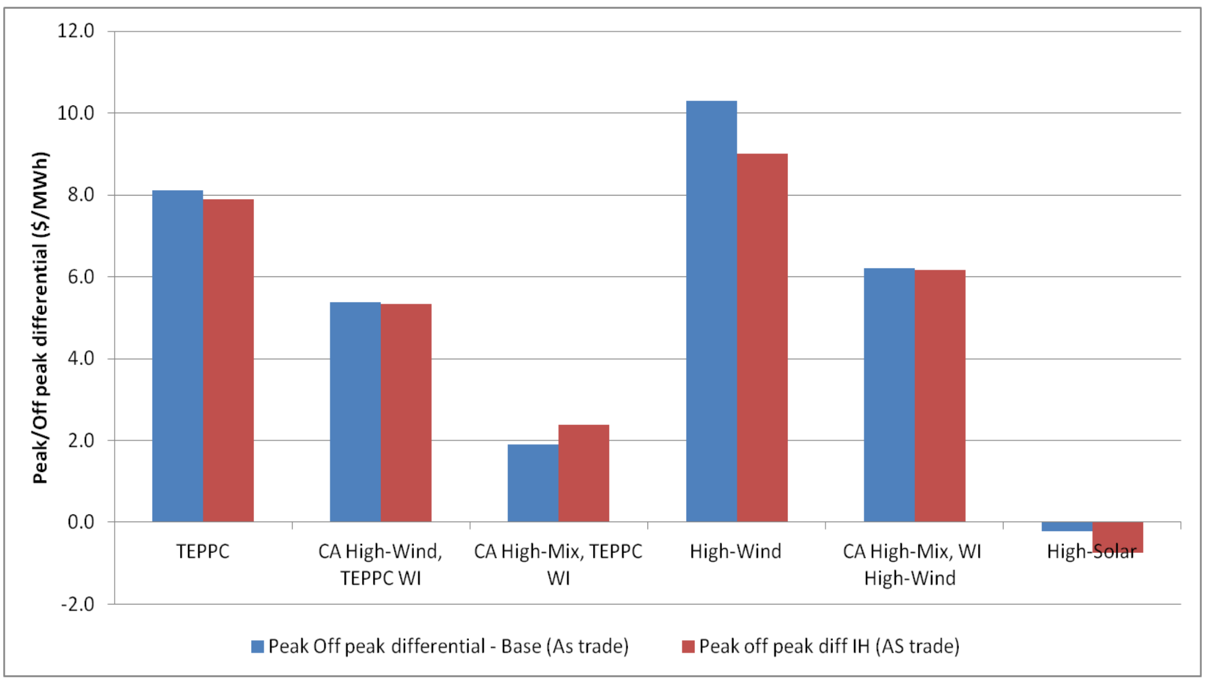


Figure 7-13: Peak/off peak average difference for different scenarios, with and without Iowa Hill in AS trading case

By examining the hourly LMP in SCE in the week of July 17, 2022 from the simulation shown in the following diagram, it is observed that PSHs pump in the low LMP hours and drive the LMP up in these pumping hours. There are some price reductions in the high LMP hours due to the generation from PSHs. However the magnitude of the price increase in the low LMP hours is much higher than the magnitude of the price reduction in the high LMP hours. This observation explains the reason that the average regional LMP increases as more PSHs are introduced into the system.

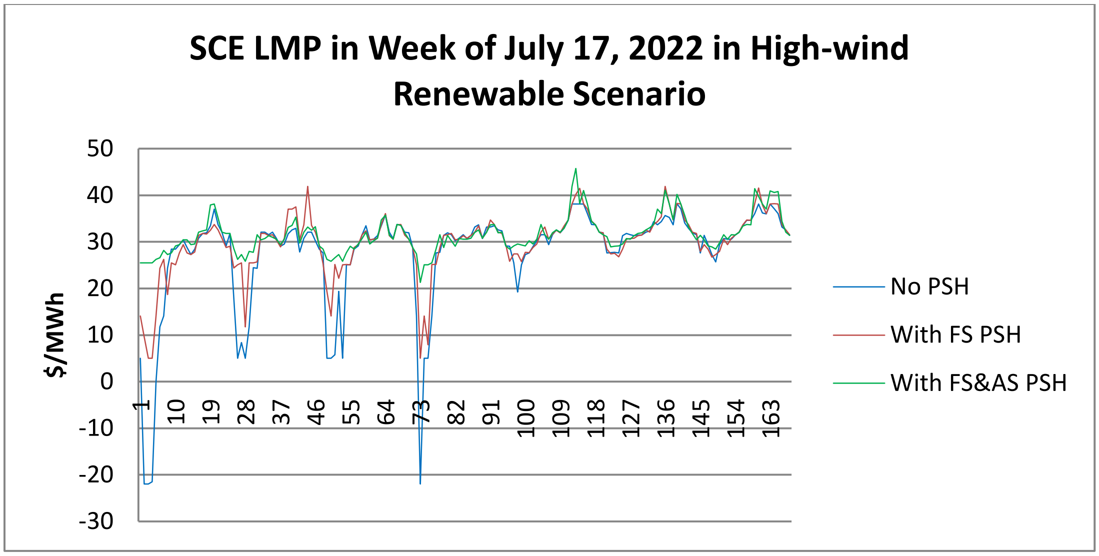


Figure 7-14 SCE LMP in Week of July 17, 2022, in Three Cases for the High-wind Renewable Scenario

Table 7-38: Annual Average Regional LMP ($/MWh) for the TEPPC Scenario

Region	All Periods					Peak					Off-Peak				
	BAU	BAU w/AS trade	IH	IH w/AS-Trade	Recip w/ AS-Trade	BAU	BAU w/AS trade	IH	IH w/AS-Trade	Recip w/ AS-Trade	BAU	BAU w/AS trade	IH	IH w/AS-Trade	Recip w/ AS-Trade
	Case 1	Case1b	Case 2	Case2b	Case 3	Case 1	Case1b	Case 2	Case2b	Case 3	Case 1	Case1b	Case 2	Case2b	Case 3
BPA	35.66	35.66	35.28	35.75	35.71	38.62	38.81	38.07	38.86	38.73	30.99	30.70	30.90	30.83	30.93
PG&E_VLY	39.05	39.10	38.61	39.19	39.21	41.67	41.95	41.09	42.02	41.96	34.78	34.44	34.58	34.53	34.73
SCE	41.23	41.55	40.95	41.24	41.43	43.99	44.61	43.54	44.23	44.40	36.44	36.26	36.51	36.05	36.30
SMUD BA	40.64	40.74	40.30	41.02	40.73	43.46	43.76	42.42	43.43	43.59	35.61	35.38	36.57	36.67	35.66
Total Study Area	37.64	37.75	37.29	37.74	37.78	40.43	40.76	39.89	40.67	40.69	32.93	32.66	32.92	32.77	32.88

Table 7-39: Annual Average Regional LMP ($/MWh) for the CA High-Wind and WI TEPPC Renewable Scenario

Region	All Periods					Peak					Off-Peak				
	BAU	BAU w/AS trade	IH	IH w/AS-Trade	Recip w/ AS-Trade	BAU	BAU w/AS trade	IH	IH w/AS-Trade	Recip w/ AS-Trade	BAU	BAU w/AS trade	IH	IH w/AS-Trade	Recip w/ AS-Trade
	Case 11	Case 11b	Case 13	Case 15	Case 17	Case 11	Case 11b	Case 13	Case 15	Case 17	Case 11	Case 11b	Case 13	Case 15	Case 17
BPA	33.66	33.39	33.49	33.68	33.38	36.07	35.65	35.82	35.99	35.65	29.86	29.83	29.83	30.05	29.79
PG&E_VLY	36.57	36.29	36.45	36.68	36.34	38.45	38.02	38.24	38.49	38.08	33.51	33.48	33.54	33.71	33.48
SCE	38.42	38.24	38.30	38.27	37.98	40.17	40.06	40.09	39.97	39.58	35.38	35.09	35.22	35.33	35.20
SMUD BA	36.15	36.02	36.30	36.75	36.11	38.09	37.81	37.81	38.21	37.88	32.71	32.86	33.65	34.15	32.96
Total Study Area	35.09	34.84	34.96	35.13	34.79	37.19	36.85	36.98	37.12	36.74	31.58	31.48	31.57	31.78	31.50

Table 7-40: Annual Average Regional LMP ($/MWh) for the CA High-Mix and WI TEPPC Renewable Scenario

Region	All Periods					Peak					Off-Peak				
	BAU	BAU w/AS trade	IH	IH w/AS-Trade	Recip w/ AS-Trade	BAU	BAU w/AS trade	IH	IH w/AS-Trade	Recip w/ AS-Trade	BAU	BAU w/AS trade	IH	IH w/AS-Trade	Recip w/ AS-Trade
	Case12	Case12b	Case14	Case16	Case18	Case12	Case12b	Case14	Case16	Case18	Case12	Case12b	Case14	Case16	Case18
BPA	30.61	30.66	30.61	30.98	30.64	32.18	32.14	32.05	32.61	32.30	28.17	28.32	28.33	28.42	28.05
PG&E_VLY	33.03	32.93	32.99	33.44	32.99	33.63	33.43	33.48	34.14	33.65	32.05	32.11	32.20	32.31	31.92
SCE	33.46	33.20	33.60	33.88	33.35	33.91	33.47	33.99	34.44	33.86	32.69	32.72	32.96	32.93	32.46
SMUD BA	31.33	31.81	32.14	32.82	31.87	31.71	32.05	32.40	33.19	32.30	30.64	31.34	31.68	32.14	31.10
Average Price of Total Study Area	30.73	30.69	30.79	31.17	30.74	31.57	31.42	31.53	32.08	31.66	29.39	29.52	29.61	29.69	29.27

Table 7-41: Annual Average Regional LMP($/MWh) for the High-Wind Renewable Scenario

Region	All Periods						Peak						Off-Peak					
	BAU	BAU w/AS trade	IH	IH w/AS trade	FS IH w/ AS trade	Recip Plus AS-Trading	BAU	AS-Trading	IH	IH w/ AS trade	FS IH w/ AS trade	Recip w/AS trade	BAU	AS-Trading	IH	IH Plus AS-Trading	FS IH Plus AS-Trading	Recip Plus AS-Trading
	Case4	Case4b	Case5	Case6	Case7	Case8	Case4	Case4b	Case5	Case6	Case7	Case8	Case4	Case4b	Case5	Case6	Case7	Case8
BPA	13.0	12.7	14.3	14.7	13.7	13.4	16.7	16.4	17.6	18.3	16.9	16.9	7.1	7.1	9.2	9.1	8.8	7.8
PG&E_VLY	18.1	17.8	19.3	19.6	18.7	18.4	21.6	21.2	22.4	23.0	21.7	21.7	12.4	12.3	14.3	14.1	13.9	13.0
SCE	18.5	18.2	19.6	20.1	19.0	18.9	22.1	21.6	22.7	23.5	21.9	22.3	12.4	12.4	14.3	14.2	13.9	13.1
SMUD BA	19.4	19.2	22.0	22.3	20.8	20.1	22.9	22.6	24.6	25.3	23.3	23.4	13.3	13.3	17.4	17.2	16.4	14.2
Total Study Area	15.5	15.3	16.9	17.2	16.2	15.9	19.1	18.7	19.9	20.6	19.2	19.3	9.6	9.6	11.7	11.6	11.3	10.3

Table 7-42: Annual Average Regional LMP ($/MWh) for the High-Solar Scenario

Region	All Periods		Peak		Off-Peak	
	BAU w/AS trade	IH w/AS trade	BAU w/AS trade	IH w/AS trade	BAU w/AS trade	IH w/AS trade
BPA	**24.87**	**25.43**	**25.57**	**25.92**	**23.78**	**24.67**
PG&E_VLY	**27.59**	**28.14**	**27.17**	**27.51**	**28.29**	**29.17**
SCE	**27.41**	**27.95**	**26.9**	**27.24**	**28.31**	**29.18**
SMUD	**29.1**	**30.7**	**28.85**	**30.52**	**29.53**	**30.99**
Average Price	**25.54**	**26.13**	**25.48**	**25.88**	**25.71**	**26.61**

Table 7-43: Annual Average Regional LMP ($/MWh) for the CA High-Mix and WI High-Wind Scenario

Region	All Periods					Peak					Off-Peak				
	BAU	BAU w/AS trade	IH	IH w/AS-Trade	Recip w/ AS-Trade	BAU	BAU w/AS trade	IH	IH w/AS-Trade	Recip w/ AS-Trade	BAU	BAU w/AS trade	IH	IH w/AS-Trade	Recip w/ AS-Trade
	Case19	Case19b	Case20	Case21	Case22	Case19	Case19b	Case20	Case21	Case22	Case19	Case19b	Case20	Case21	Case22
BPA	12.31	11.63	13.54	13.54	12.61	15.21	14.44	16.26	16.28	15.38	7.76	7.24	9.30	9.26	8.29
PG&E_VLY	17.10	16.37	18.37	18.32	17.33	19.59	18.76	20.83	20.79	19.69	13.05	12.48	14.39	14.33	13.52
SCE	17.13	16.42	18.36	18.31	17.37	19.50	18.73	20.69	20.64	19.63	13.06	12.48	14.38	14.32	13.51
SMUD BA	16.44	16.03	19.45	19.43	17.40	18.40	17.89	21.22	21.22	19.22	13.04	12.83	16.36	16.33	14.30
Average Price of Total Study Area	15.74	15.11	17.43	17.40	16.18	18.18	17.46	19.75	19.73	18.48	11.73	11.26	13.61	13.56	12.40

Potential Revenue if Iowa Hill was merchant plant

An interesting result to look at would be to consider the revenue for Iowa Hill as a merchant plant buying and selling energy and AS from SMUD and CAISO. This is not realistic to SMUD's current situation, where the net production costs of meeting load shown earlier are more important. However, it may be interesting to examine whether there would be a possible profit to be made, based purely on marginal cost prices seen by Iowa Hill. The revenue therefore is the marginal cost of energy in SMUD (i.e. the shadow price) multiplied by Iowa Hill generation, added to revenues from Iowa Hill providing AS to SMUD and/or CAISO, less the cost of pumping energy in SMUD. Results for the different scenarios are summarized in Table 7-44. As shown here, when compared to results in Table 7-4, it can be seen that in general the value to Iowa Hill of selling and buying power is not as large as the total value to SMUD, indicating additional portfolio benefits beyond arbitrage and AS only, where Iowa Hill would allow the remaining fleet to operate more efficiently.

Table 7-44: Summary of Potential Revenue if Iowa Hill was merchant plant

RPS Scenario	Net Revenue ($K)			Profit Rate($/KW)		
	IH, w/o AS-Trading	IH, w/ AS-Trading	Recip, w/ AS-Trading	IH, w/o AS-Trading	IH, w/ AS-Trading	Recip, w/ AS-Trading
TEPPC	8,446	11,249	3,911	21.17	28.19	14.27
CA High-Wind and WI TEPPC	9,562	12,204	1,840	23.96	30.59	6.72
CA High-Mix and WI TEPPC	11,673	15,450	1,607	29.26	38.72	4.51
WI High-Wind	22,419	33,279	3,913	56.19	70.39	14.28
CA High-Mix and WI High-Wind	26,182	33,764	11,530	65.62	84.62	32.39

The other result of note concerning a hypothetical market is shown in Table 7-45. This shows that profit rate for a hypothetical market scenario for different technologies. As expected, adjustable speed can make more revenue, particularly for provision of ancillary services.

Table 7-45: Projected revenue of Iowa Hill operating in a hypothetical market for fixed speed and adjustable speed in high wind case

Energy	Hypothetical Case	
	Iowa Hill Operating as a Merchant Plant in California Earning Marginal Costs of Balancing Services	
	Fixed Speed Iowa Hill	Adjustable Speed Iowa Hill
Generation (GWh)	**1,010**	**1,056**
Pump Load (GWh)	**1,255**	**1,312**
Total Generation Cost ($000)	**-**	**-**
Pump Cost ($000)	**11,770**	**16,052**
Pool Revenue ($000)	**23,777**	**27,615**
Extra Capacity		
Provision (GWh)	**45**	**5**
Revenue ($000)	**35**	**4**
Flexible Down	**-**	**-**
Provision (GWh)	**48**	**338**
Revenue ($000)	**340**	**2,594**
Flexible Up	**-**	**-**
Provision (GWh)	**15**	**21**
Revenue ($000)	**88**	**122**
Non Spinning Reserve	**-**	**-**
Provision (GWh)	**82**	**13**
Revenue ($000)	**107**	**16**
Regulation Down	**-**	**-**
Provision (GWh)	**79**	**661**
Revenue ($000)	**7,222**	**6,894**
Regulation Up	**-**	**-**
Provision (GWh)	**12**	**116**
Revenue ($000)	**228**	**959**
Spinning Reserve	**-**	**-**
Provision (GWh)	**49**	**153**
Revenue ($000)	**689**	**1,844**
Total AS Provision (GWh)	**331**	**1,306**
Subtotal AS Revenue ($000)	**8,708**	**12,434**
Total Profit ($000)	**20,715**	**23,996**
Capacity (MW)	**399**	**399**
Annual Profit Rate ($/kW-Year)	**52**	**60**

8 FUTURE WORK: THREE STAGE MODELING APPROACH

Note: In upcoming simulations, the Plexos tool will be employed using a three-stage modeling approach, which wasn't used here. This will more accurately capture wind and solar variability and uncertainty, and thus more accurately show the value of Iowa Hill. The approach is described here to prepare for future work.

Wind and Solar Variability and Uncertainty – the case for three stage modeling

The intermittent renewable generation variability and uncertainty places challenges to the power system planning and operation. One of the questions that the power industry needs to answer is: what is the impact of the sub-hourly renewable generation variable and uncertainty to the system operation?

The following four charts show the 5-minute solar and wind generation variability and uncertainty in the Southern California in the high-wind renewable generation scenario in a typical winter week and a typical summer week of year 2022. The source of the data is the WWSIS Phase 2 study by NREL. This shows how day ahead, hours ahead and real time wind and solar output changes from forecast time frames to real time.

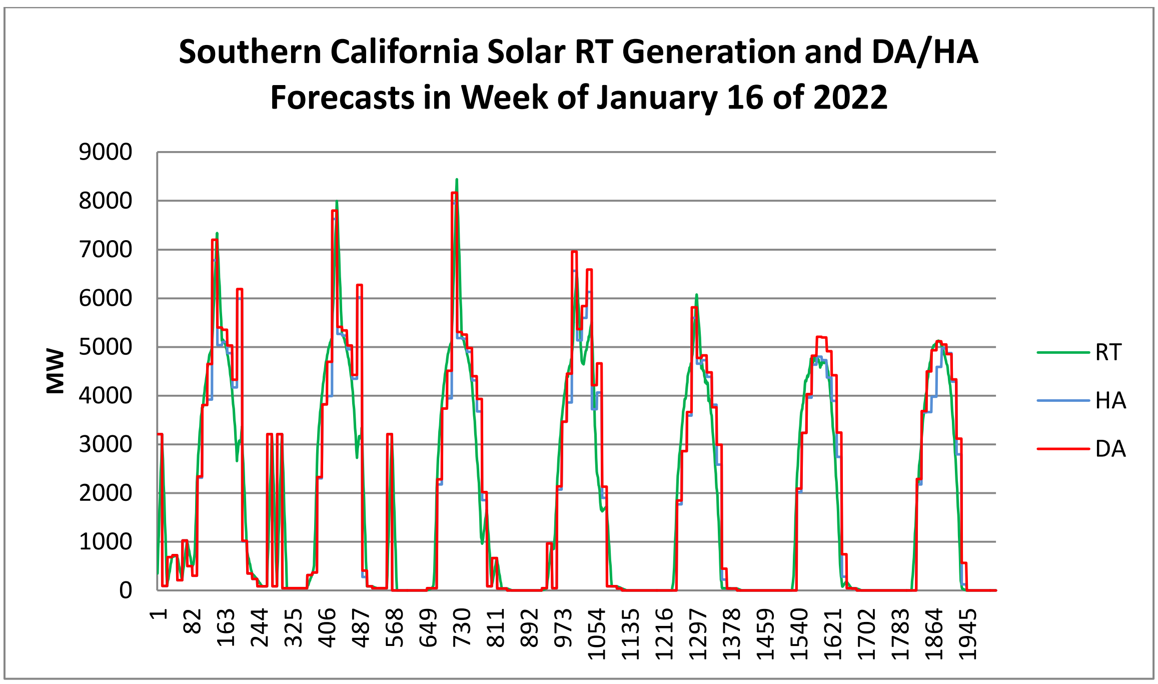


Figure 8-1 5-minute Actual Solar Generation and Hourly DA / HA Forecasts in Southern California in a Typical Winter Week of Year 2022

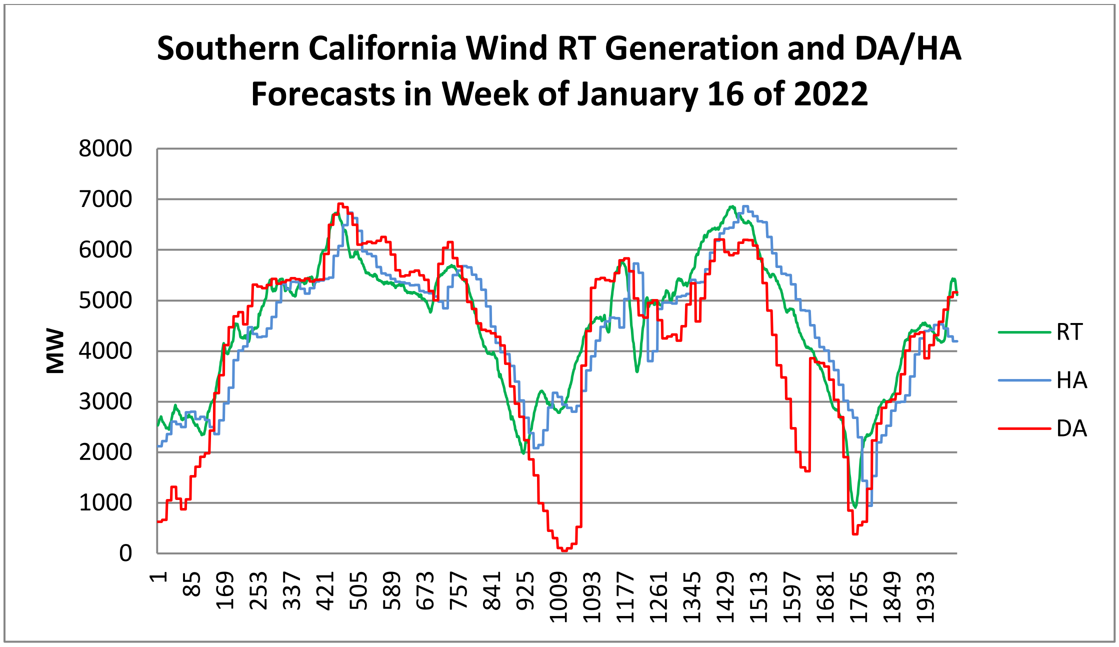


Figure 8-2 5-minute Actual Wind Generation and Hourly DA / HA Forecasts in Southern California in a Typical Winter Week of year 2022

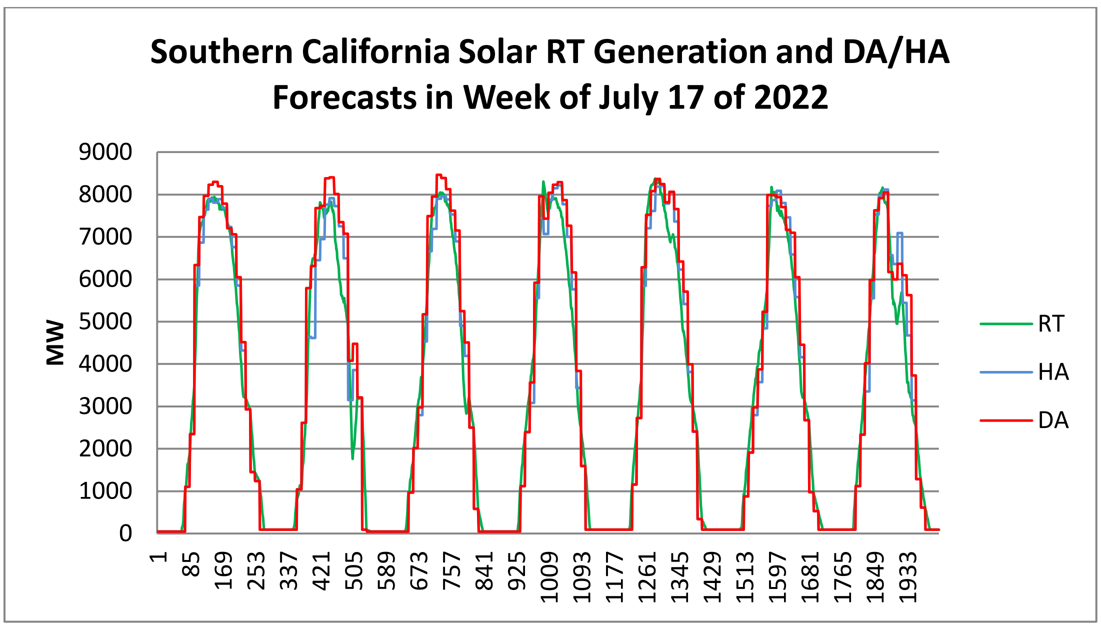


Figure 8-3 5-minute Actual Solar Generation and Hourly DA / HA Forecasts in Southern California in a Typical Summer Week of year 2022

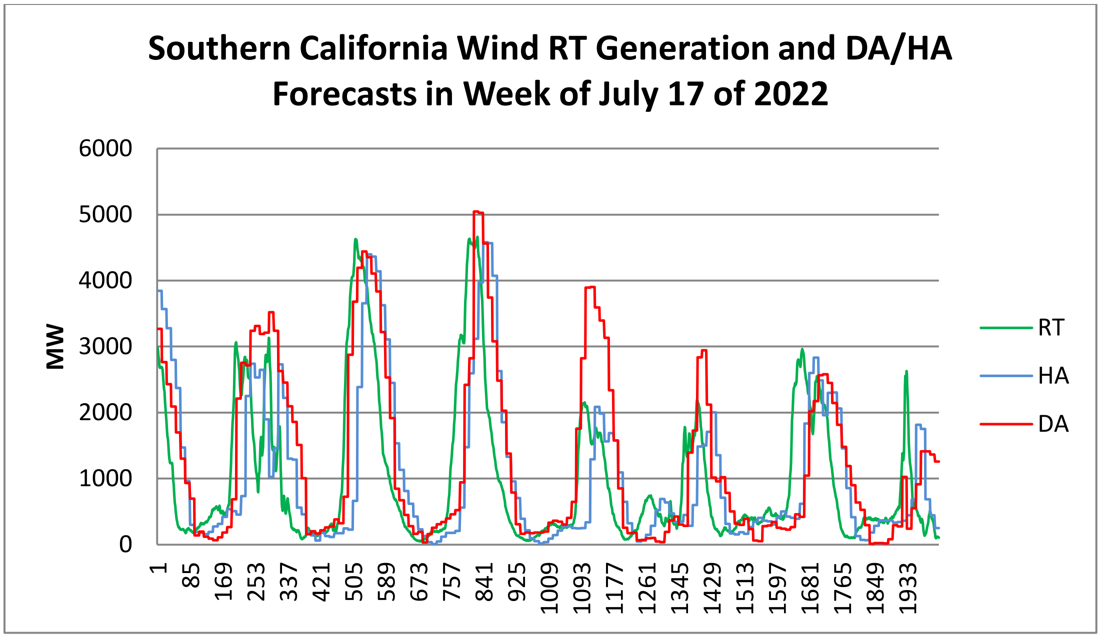


Figure 8-4 5-minute Actual Wind Generation and Hourly DA / HA Forecasts in Southern California in a Typical Summer Week of Year 2022

3-Stage DA-HA-RT Sequential Simulations

Note: Current modeling results are not for three stage simulation, but rather single day ahead stage; this is described here as it will be used in the future.

As shown before, to accurately capture system operations in the presence of high wind and PV, it will be necessary to perform modeling which captures forecast accuracy at different time periods (day ahead, hour ahead and in real time), to properly assess how reserves will be held and commitment decisions can be made. PLEXOS is capable of simulating power markets at a sub-hourly interval. This feature is very useful when evaluating the ramp capacity adequacy for renewable generation variability and uncertainty. Usually, the sub-hourly economic dispatch capability works in conjunction with the day-ahead (DA) and hour-ahead (HA) unit commitment to mimic real world market operation in the context of variability and uncertainty. The 3-stage DA-HA-RT sequential simulation approach is described as follows.

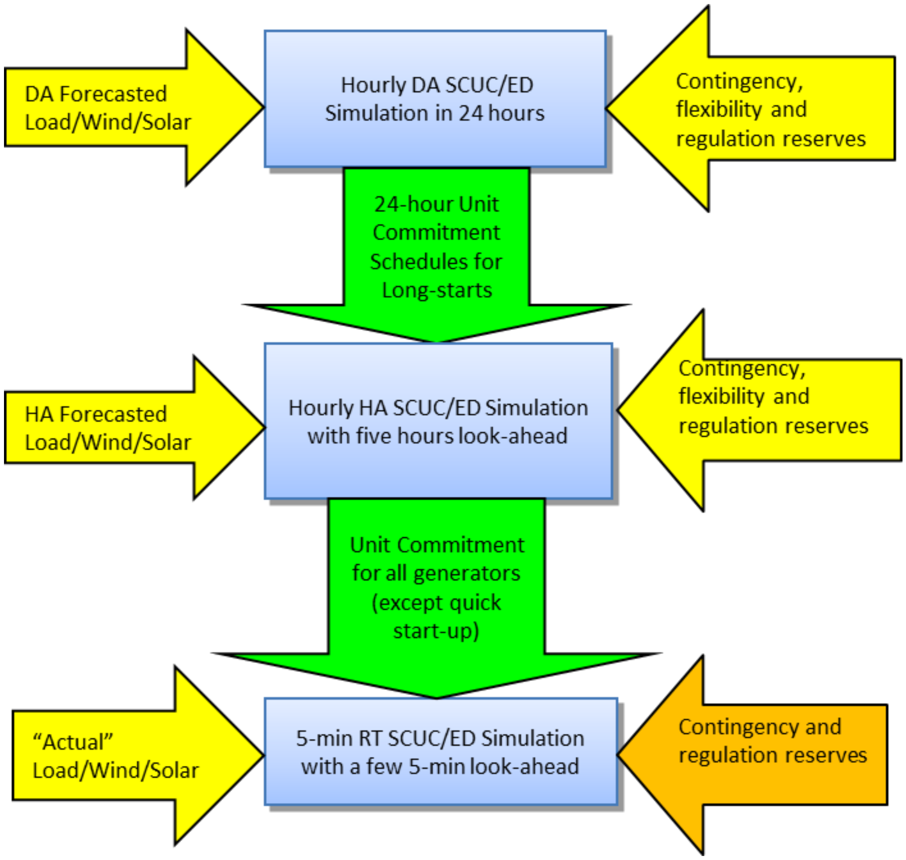


Figure 8-5 DA-HA-RT 3-stage Sequential Simulations

- DA simulation mimics the DA SCUC/SCED
- Day-ahead forecasted load/wind/solar generation time series are used;
- The SCUC/ED optimization window is 24 hours at hourly interval;
- The transmission network is modeled at the zonal level;
- The contingency, flexibility up/down, regulation up/down reserves are modeled.
- HA simulation mimics the intra-day SCUC/SCED
- The 4-hour-ahead forecasted wind / solar generation time series are used;
- The hour-ahead forecasted load time series are used;
- The SCUC/ED optimization window is 4-hour plus 20-hour look-ahead with 2-hour interval;
- The unit commitment patterns from the DA simulation are frozen for generators with Min Up/Down Time greater than 4 hours;
- The transmission network is modeled at the zonal level;
- The contingency, flexibility up/down, regulation up/down reserves are modeled.
- RT simulation mimics the 5-min real-time SCED
- The "Actual" 5-min load/wind/solar generation time series are used;
- The SCED optimization window is twelve 5-min plus 23 look-ahead with hourly interval;

- The unit commitment patterns from the HA simulation are frozen;
- The transmission network is modeled at the zonal level;
- The contingency, regulation up/down reserves are modeled. However, the flexibility up/down reserves are not modeled. The implication is that the capacity held in the HA simulation for the flexibility reserves is deployed to cover the load and renewable generation variability and uncertainty at the 5-min interval;
- CT with max capacity less than 100MW could be committed or de-committed in the 5-min RT simulation.

PSH Storage Modeling in 3-stage Sequential Simulations

In the DA simulation, the SCUC/ED is performed in a 24-hour window. The PSHs are dispatched by PLEXOS SCUC/ED according to the formulation shown previously. The storage volume of a PSH at the end of the 24-hour optimization window is constrained to the storage volume at the beginning of the optimization window. A penalty price of $1,000/MWh is applied to the storage volume constraints.

In the HA simulation, the SCUC/ED is performed in a 4-hour plus 20-hour look-ahead window. The simulation solution in the first 4 hours is saved; then the SCUC/ED is performed for the next 4-hours in a 4-hour plus 20-hour look-ahead window, and so on. The PSHs are re-dispatched in the HA simulation according to the formulation. The storage volume of a PSH at the end of the optimization window is constrained to the storage volume from the DA simulation. A penalty price of $1,000/MWh is applied to the storage volume constraints.

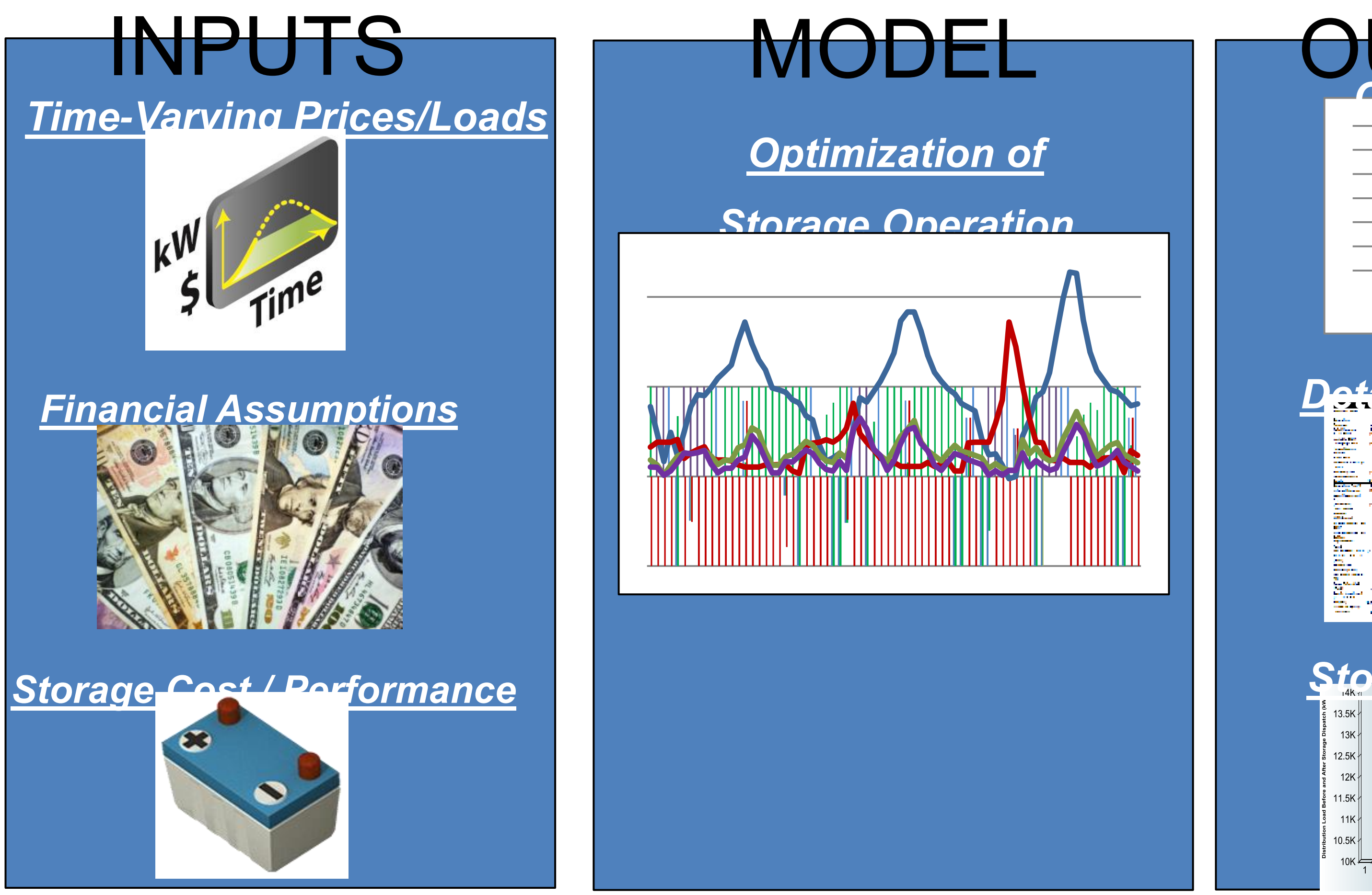
In the 5-min RT simulation, the SCUC/ED is performed in a twelve 5-minutes plus 23-hour look-ahead window. The simulation solution in the first twelve 5-minutes is saved; then the SCUC/ED is performed for the next twelve 5-minutes in a twelve 5-minutes plus 23-hour look-ahead window, and so on. The PSHs are re-dispatched in the RT simulation according to the formulation. The storage volume of a PSH at the end of the optimization window is constrained to the storage volume from the HA simulation. A penalty price of $1,000/MWh is applied to the storage volume constraints.

9 EPRI ENERGY STORAGE VALUATION TOOL (ESVT) PRELIMINARY ANALYSIS

The EPRI Energy Storage Valuation Tool (ESVT) is a user-friendly, customizable, and transparent simulation tool used to understanding the economics of energy storage under different conditions, including grid services performed, location, technology, and others. Due to diversity of energy storage use cases and technology characteristics, economic analysis of energy storage use cases has been historically challenging. Benefits of a single energy storage system operation may accrue to multiple stakeholders within the electricity system, including customers, distribution, transmission, generation and society at large. Due to market and regulatory structure, benefits cutting across stakeholder groups may be challenging to monetize; however, accurate modeling of system need and energy storage system capability can informed the technically achievable and quantifiable benefits. This can be achieved with the support of the ESVT software. The ESVT can provide and estimate of the lifetime cost-effectiveness of energy storage use cases to inform decisions related to demonstration, deployment, or even modeling studies.

How the Energy Storage Valuation Tool Works

A summary diagram of the ESVT inputs, model, and outputs is shown below.



Inputs

The Energy Storage Valuation Tool requires inputs defining grid services, such as time-varying load and price data, financial data related to the owner, and energy storage technology characteristics. The grid services address include the full scope of the electric system, including generation, transmission and distribution, and customers. These services include energy, ancillary services, system capacity, T&D upgrade deferrals, reliability, and others.

Model

Incorporating the user-defined inputs, ESVT simulates the hourly energy storage operational dispatch for a combination of chosen grid services at a specific location. A hierarchical dispatch heuristic prioritizes long-term commitments, such as multi-year investment deferrals, over shorter ones, like day-ahead energy and ancillary service market participation. The ESVT co-optimizes day-ahead market service participation for maximum profitability.

Outputs

After completion of the simulation,a number of economic and technical outputs are available to the user, including project net present value (NPV), hourly charge-discharge behavior, and breakeven energy storage capital cost..

Used appropriately, it has potential to streamline identification of high-value energy storage use cases, prior to investing in system production cost modeling, which is setup and calculation intensive.

Recent Applications of the Energy Storage Valuation Tool

The Energy Storage Valuation Tool is currently being used in case studies with multiple utilities across North America to investigate different storage valuation scenarios.

Most notably, in the spring of 2013, the ESVT was applied to a cost-effectiveness study performedto inform stakeholders of the California Public Utility Commission in its Energy Storage Rulemaking proceeding (R.10-12-007), directed by California Assembly Bill AB2514. In this study, the cost-effectiveness of energy storage was analyzed in over 30 different scenarios, including bulk and distributed storage use cases. The analysis used inputs provided by a stakeholder group of California utilities and the California Energy Storage Alliance organized by the CPUC.. The goal of the analysis was to assess the cost-effectiveness and expected operation of energy storage under a given sets of assumptions and input sensitivities including: 1) energy storage system technology and configuration; 2) grid services provided under each use case; 3) point of interconnection; 4) future market scenario; and 5) installation year. Detailed information about this study can be found in a public EPRI report.[15]

Potential Value of ESVT to This Study

Benchmarking of Results with Historical Years

Compared to a production simulation tool like PLEXOS, which simulates the entire generation fleet and transmission system, the ESVT models only the prices and loads that are relevant to energy storage operation and cost-effectiveness. As a result, input assumptions are far fewer can be altered and investigated more quickly, with combined model configuration and runtime occurring in significantly less than one hour. This enables quick benchmarking of energy storage operation using historical prices and loads.

Sensitivity analysis

Due to the numerous inputs and model variables to consider in production cost models, it can be cumbersome to identify which variables have the greatest impact on the results. The ESVT can be configured with the output prices and loads from a production cost modeling run and keyeconomic and technical input sensitivities can be altered quickly in ESVT for sensitivity analysis, to tailor investigations to focus on the most impactful variables.

[15] *Cost-Effectiveness of Energy Storage in California: Application of the Energy Storage Valuation Tool to Inform the California Public Utility Commission Proceeding R. 10-12-007.* EPRI, Palo Alto, CA: 2013. 3002001162.

Modeling Additional Grid Services

Additionally, ESVT has the capability to analyze the value of system capacity, T&D investment deferrals, and voltage support, which are not considered within production cost models.

Project Lifetime Cost-Effectiveness

The ESVT models the entire net present value of fixed and variable costs and benefits over project lifetime. This is in contrast to production cost models, which are limited to the variable costs and benefits of a year. Though there is significant uncertainty as to the actual characteristics of the electric system 10 to 20 years in the future, there is potential to utilize the ESVT calculation capabilities in conjunction with the production simulation outputs of focus years to better estimate the lifetime cost-effectiveness of the energy storage investment.

ESVT Historical Price Benchmarking Analysis for the SMUD BA Iowa Hill

As an initial step to support this study, the EPRI study performed for the California PUC was referenced. In the CPUC study, one scenario was investigated which calculated the cost-effectiveness of a generic pumped hydro project, assumed to be commissioned in 2020.

The input assumptions of the CPUC study were re-assessed and updated to better approximate the technology characteristics for the SMUD BA Iowa Hill pumped hydro storage project. The comparison of CPUC and the SMUD BA inputs is provided in Table 1.

Table 9-1: PHS Input Comparison

Category	Input	2020	
		CPUC PHS	**SMUD BA PHS**
Technology Cost / Performance	**Nameplate Capacity (MW)**	**300**	**400**
	Nameplate Duration (hr)	**8**	**12**
	Capital Cost ($/kWh) -Start Yr Nominal	**166**	**167**
	Capital Cost ($/kW) - Start Yr Nominal	**1325**	**2000**
	Project Life (yr)	**100**	**80**
	Roundtrip Efficiency	**82.50%**	**90%**
	Variable O&M ($/kWh)	**0.001**	**0.001**
	Fixed O&M ($/kW-yr)	**7.5**	**7.5**
	Ownership Type	**IPP**	**MUNI**
	WACC (after tax)	**7.57%**	**6.5%**
	MACRS Depreciation Term (yr)	**7**	**N/A***
	Minimum Pump Load	**100%**	**20%**
	Minimum Turbine Load	**50%**	**10%**
	Start Up Cost	**0**	**0**
	Turbine Efficiency Curve (PHS)	**Realistic**	**Flat**
	Pump Efficiency (PHS)	**Realistic**	**Flat**

*MACRS term does not apply since a MUNI financial model was used.

The original CPUC case output is presented in the figure below next to the case performed with inputs adjustments provided by the SMUD BA. The detailed inputs for the PHS system provided by the SMUD BA is shown next to the CPUC PHS inputs in Figure 1 above. The SMUD BA case returned significantly better cost-to-benefit ratio, which may be the result of multiple contributions. First, the SMUD BA Iowa Hill input assumption assumes 80% roundtrip efficiency with no increase in efficiency at part load, resulting in significantly higher utilization and an increased number of economic opportunities. Additionally, the Iowa Hill plant was modeled with significantly more flexible pumping and turbine characteristics, allowing it to provide significantly more substantial bids into the frequency regulation market (practically speaking, such a significant frequency regulation revenue may not be available). Finally, the discount rate is lower, causing future revenue present values to increase.

Due to the comparatively high performance assumptions of the Iowa Hill PHS system, these results should be considered subject to additional validation in future work; the purpose here was to perform high level screening.

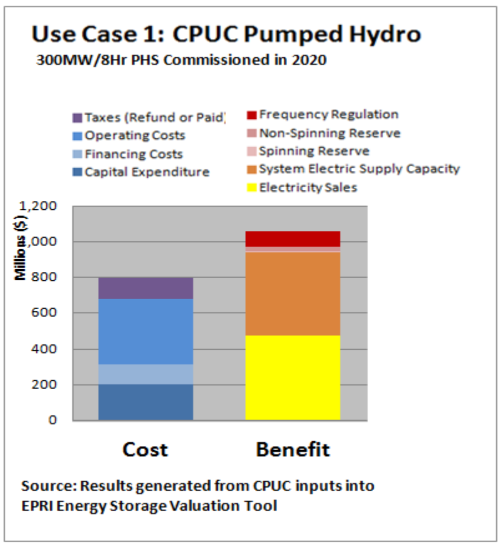


Figure 9-1: SMUD BA PHS Output

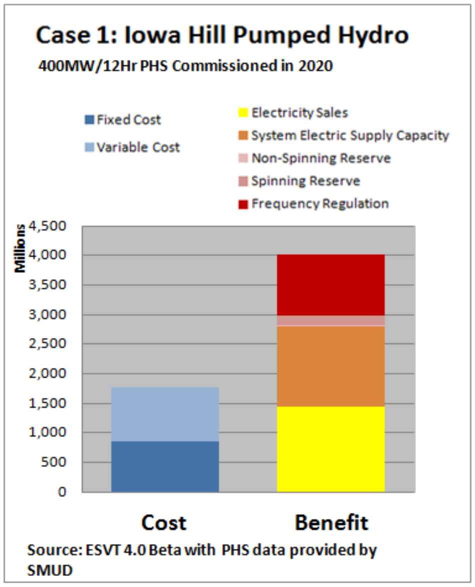


Figure 9-2: SMUD PHS Output

In addition to the case re-run with the SMUD BA Iowa Hill Inputs, two sensitivity runs were performed. The first one examined the situation where the value to provide regulation service has been driven to zero due to the massive adoption of energy storage to provide regulation. In this case, it was shown that without bidding frequency regulation service, both the cost and the benefit dropped. Moreover, spinning reserve benefit significantly increased, resulting in a slightly lower net present value, but still substantially positive benefit-to-cost ratio.

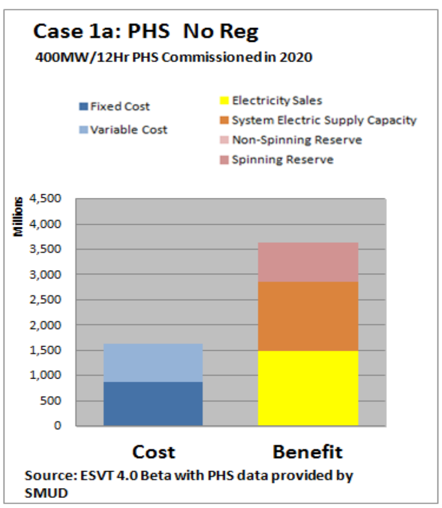
- 

Figure 9-3: No value for provision of regulation

The second sensitivity run looked at the scenario where the system capacity (resource adequacy) value is significantly lower. Instead of the 161 $/kw-yr used in case 1, the capacity value in this case is 50 $/kw-yr. This is intended to model a scenario where no new peaking generation is required; instead, recovery of a fixed capacity payment may be required for existing generation plant to recover part or all of its fixed O&M costs to remain available for peak load events. In this scenario, the Iowa Hill PHS plant earns less revenue from system capacity , leading to a lower cost-to-benefit ratio, but still has substantially positive lifetime net present value.

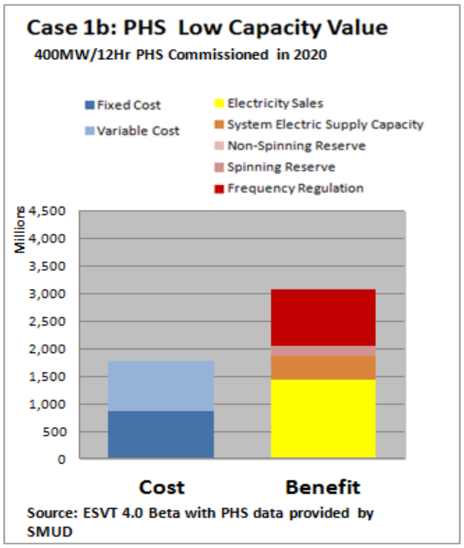


Figure 9-4: Low Capacity Value of storage

A fourth case was performed to get a preliminary understanding of the impact of adding transmission investment deferral and voltage support to the use case. Due to lack of site-specific data at time of simulation, the default load and value data in ESVT was used to perform the case. This case saw a slight reduction in system capacity revenue, because the transmission deferral takes priority in the simulation. Along with the added revenue from transmission investment deferral and voltage support, the overall project net present value increased. This case is representative of an application where operations of the pumped storage is frequently influenced by transmission constraints. In SMUD's application however, this would rarely be the case. As can be seen, the value of Iowa Hill in the case where it is used for transmissions deferral means, as the capacity is held back to provide transmission relief, the energy and capacity benefits decrease significantly; it seems that transmission deferral has positive value only is the capacity value is in the lower end.

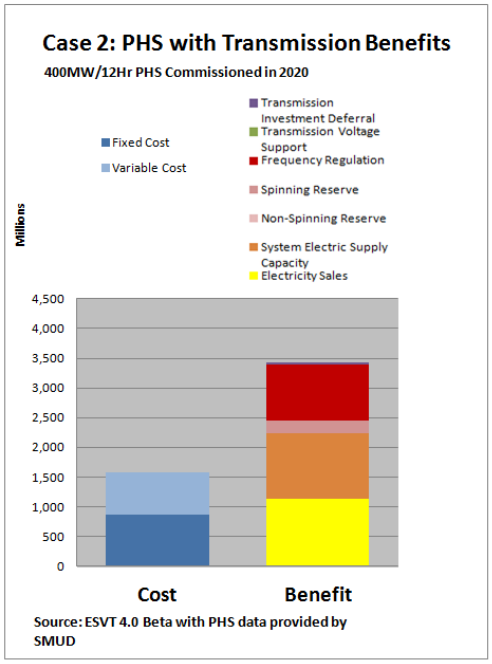


Figure 9-5: Transmission benefits included

A summary table is shown below for different cases. As can be seen, the value in the cases with inputs from SMUD show significantly greater value; this is likely due to the fact that the variable speed PHS unit is significantly more flexible and the cost of capital lower. It can also be seen that capacity value has more of an impact than regulating reserves, and that transmission deferral may actually reduce benefits if it is considered a function, as it takes priority over energy sales and capacity value.

Table 9-2: Summary of Iowa Hill values for different cases as determined in ESVT, with generic assumptions for most values. All values in $m

Case	Case 1 CPUC	Case 1 SMUD	Case 1a No regulation	Case 1b Low capacity value	Case 2 transmission deferral
Electricity Sales	**473**	**1445**	**1493**	**1445**	**1126**
Capacity Value	**467**	**1366**	**1364**	**424**	**1115**
Regulating Reserve	**8**	**1021**		**1021**	**941**
Spin	**23**	**173**	**760**	**173**	**213**
Non-spin	**88**	**3**	**7**	**3**	**3**
Voltage Support					**0**
Transmission deferral					**40**
Total	**1042**	**4008**	**3624**	**3066**	**3437**

Next steps

Due to the unavailability of PLEXOS output data to-date, only a few cases have been performed at this stage. This phase of the analysis relied on historical data and assumed that the storage system to be a price taker—meaning that it would not influence the market price by participating in the market. However, given the size of the PHS system, it may be important to investigate the scenario where the storage system is causing changes to market prices by participating, particularly when considering the grid services with less demand, like frequency regulation. A storage cost-benefit analysis with prices generated from production simulation is the desired next step analysis this effect.

In future stages, it will be possible to benchmark historical prices with prices generated from production simulation and investigate the impact on pumped hydro's dispatch behavior and its cost-effectiveness.

ESVT could be used to investigate the impacts of different production simulation scenarios, storage configurations, and grid services, on the lifetime net present value of the PHS project.

10 SMUD HYDRO PORTFOLIO MODELING OF EFFECTS OF IOWA HILL TO THE UPPER AMERICAN RIVER PROJECT

To augment the value streams identified in the Plexos model, additional work was carried out, as described in the next 3 chapters. This chapter outlines the impact of the proposed Iowa Hill project on operations of the existing hydro fleet operated by SMUD. This involved performing power simulations on the SMUD BA's portfolio to evaluate the effect of Iowa Hill on its existing Upper American River Project (UARP) hydro system and other SMUD resources.

SMUD used results from the TEPPC Reference Case and High Wind Case in the regional WECC study of this project for the detailed SMUD portfolio modeling. Results from the WECC study include new renewable resource additions, ancillary service requirements, and market prices. In addition, the portfolio modeling includes detailed UARP modeling with four different water runoff scenarios – dry, below normal, above normal, and wet.

In SMUD portfolio modeling we determine the value of Iowa Hill to SMUD by simulating day-ahead cases with and without Iowa Hill. These two cases result in different resource commitment, dispatch, and market interactions from Iowa Hill's ability to provide system reserve and ability to arbitrage between energy prices. We represent the difference between these two cases as the value of Iowa Hill.

This section briefly describes the data included in the detailed SMUD portfolio modeling and findings on the effects of Iowa Hill on the UARP.

SMUD Portfolio and Modeling Assumptions

The SMUD portfolio study uses a smaller footprint than the regional WECC study with greater emphasis on detailed modeling of the SMUD BA's cascaded Upper American River Project (UARP) hydro system. Simulation of the smaller portfolio has two main benefits for evaluation of the impact of Iowa Hill on the UARP:

- Allows detailed modeling and analysis of the UARP whereas detailed hydro modeling in a larger footprint is not feasible.
- Optimizes just SMUD portfolio which reflects how SMUD would operate Iowa Hill with its resource portfolio.

In this section, we describe SMUD portfolio modeling footprint, market assumptions, cascaded UARP hydro model, portfolio resources, and renewable resource build-out.

SMUD Portfolio Modeling Footprint

The SMUD portfolio footprint includes the area that SMUD interacts with on a daily basis to cover the SMUD BA's retail customer load, including SMUD and surrounding energy and ancillary service markets. Resources in the footprint include SMUD-owned resources, SMUD power contracts, and NP15 and California-Oregon markets. Figure 10-1 shows SMUD Portfolio Modeling Footprint.

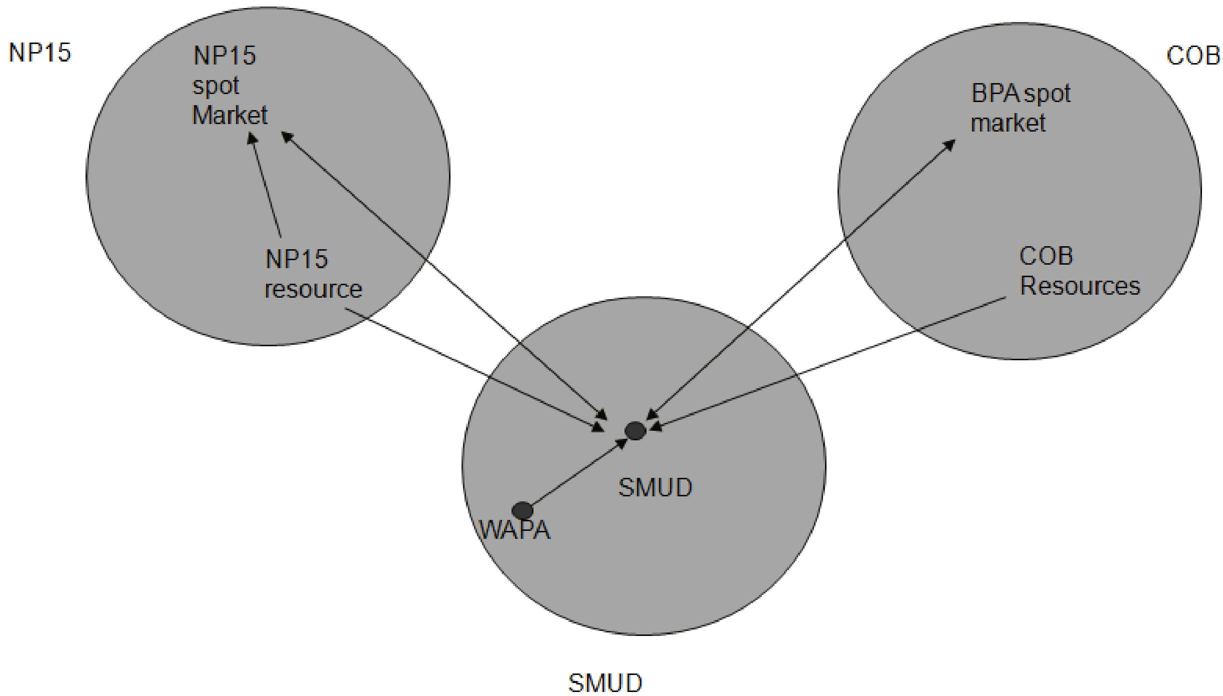


Figure 10-1: SMUD Portfolio Modeling Footprint

SMUD Generation Resources

In 2022, the SMUD BA's power resources include about 500 MW of contracted power, 1,100 MW of thermal power plants capacity, and 650 MW of dispatchable UARP capacity. The addition of Iowa Hill increases capacity by another 400 MW (at 80.5% round-trip efficiency). Thermal, UARP, and Iowa Hill resources can provide ancillary services for SMUD reserve requirements.

Detailed UARP Modeling

Figure 10-2 and Figure 10-3 illustrate the detailed UARP representation in SMUD portfolio model. Water runoff (natural inflow) enters the UARP at different times of the year, and SMUD manages the storage and release of water to meet all water demand requirements. Water demand requirements include fish bypass, recreational, and pulse stream flows, minimum reservoir storage levels, reservoir elevation ramping rate limits, and minimum daily water releases out of the SMUD BA's UARP system.

In the detailed UARP hydro modeling, we include four water runoff scenarios; dry, below normal (median), above normal, and wet runoff. Table 10-1 shows the annual water runoff (AF) to the UARP reservoirs for the four scenarios. These water runoff scenarios correspond with the "water year type," and each "water year type" includes a different set of water demand requirements for fish and wildlife habitat, recreation, and other water demands.

To help manage water demands, the UARP has seven main storage facilities (Loon, Gerle-Robbs, Ice House, Union Valley, Junction, Camino, and Slab) which stores about 400,000 acre-feet (AF) of water. Most of the UARP storage capacity resides in the upper section of the UARP (Loon, Ice House, and Union Valley) whereas the lower UARP section (Junction, Camino, and

Slab) can store only about 9,000 AF. With limited storage capacity in the lower section, Junction, Camino and Slab reservoirs spill during periods of high water runoff.

Table 10-1: Annual Water Runoff Scenarios for UARP (AF)

Annual Inlfow	Dry (75%)	BN (50%) median	AN (25%)	Wet (10%)
Loon	71,249	100,934	144,077	191,377
Robbs	48,300	76,200	110,300	153,500
Ice House	36,400	54,400	78,000	104,800
Union	99,900	157,900	236,300	323,900
Junction	29,300	48,200	74,400	104,200
Camino	28,900	47,600	73,600	106,800
Slab	223,900	373,800	569,400	796,600
Total	537,949	859,034	1,286,077	1,781,177

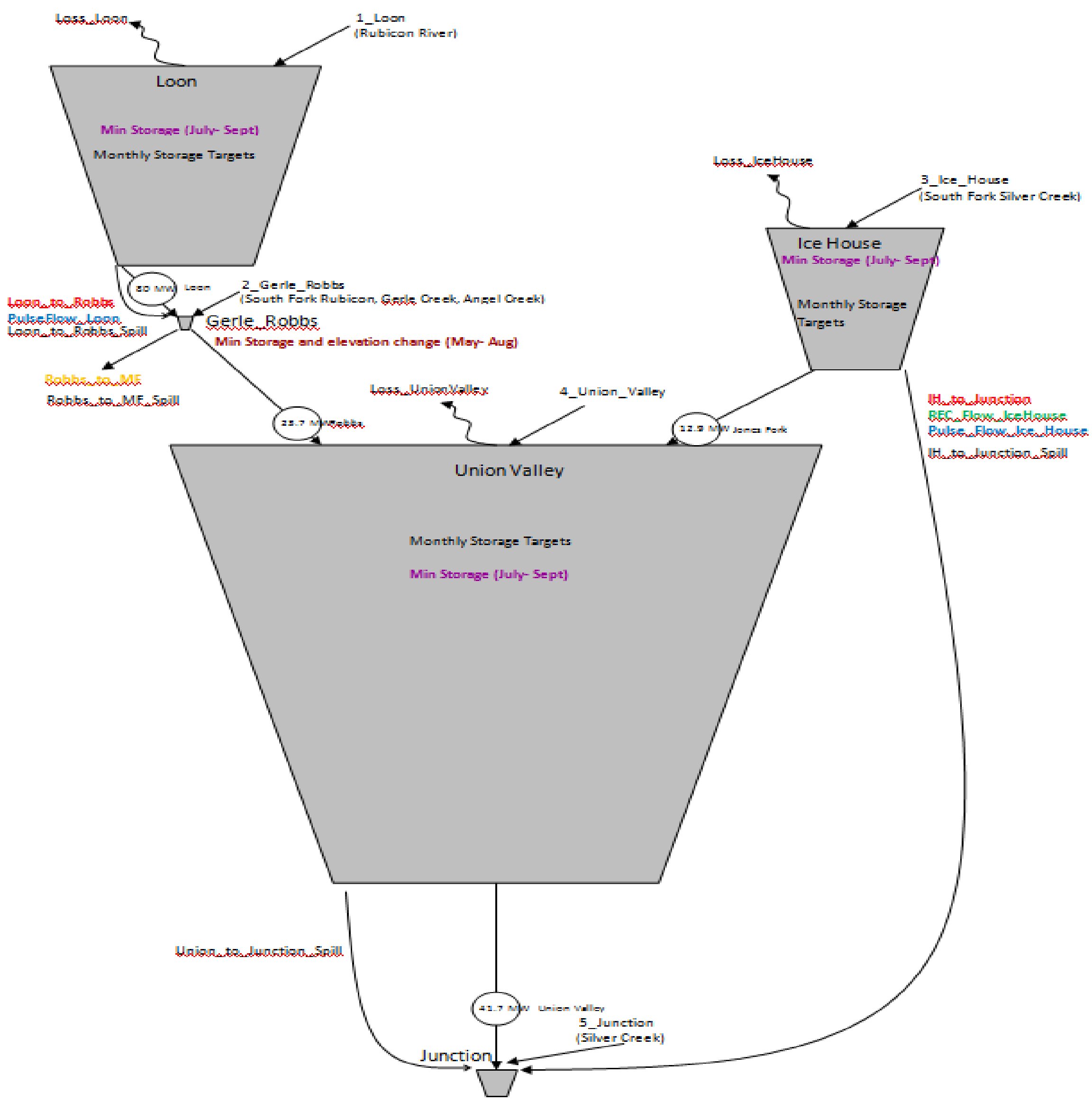


Figure 10-2: Detailed UARP Representation (Upper UARP Section)

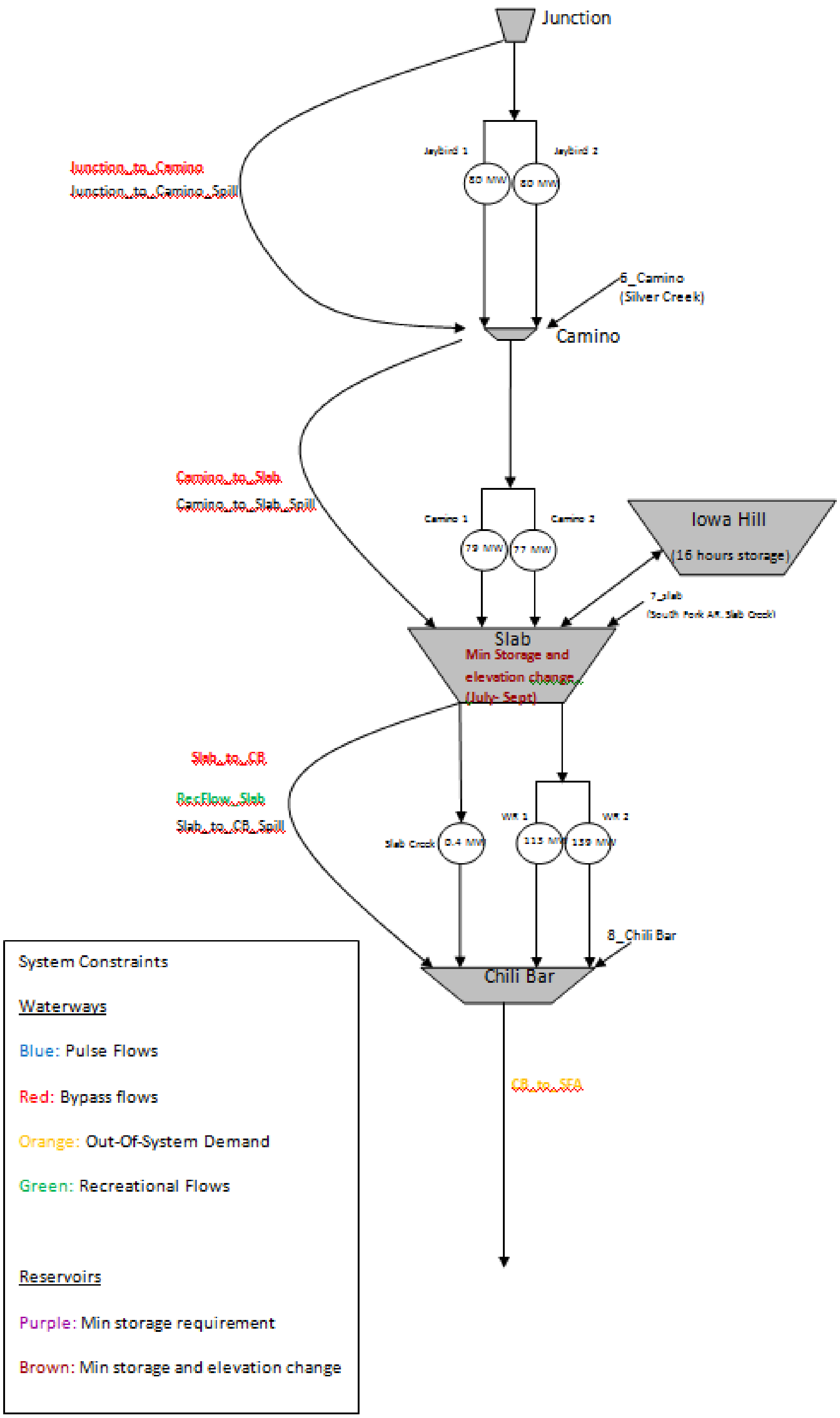


Figure 10-3: Detailed UARP Representation (Lower UARP Section)

Reference Case Day-Ahead Market Prices

Reference Case NP15 and BPA market heat rates are relatively low (7,443 and 6,632 Btu/kWh) compared to SMUD thermal resource heat rates. Annual average spreads between on-peak and off-peak market heat rates are about 1,600 Btu/kWh for NP15 and 1,800 Btu/kWh for BPA. Reference Case regulation down prices are about 2 times higher than regulation up and 3 times higher than spin market prices.

High Wind Case Day-Ahead Market Prices

High Wind Case market heat rates are relatively low for both NP15 and BPA (3,788 and 2,179 Btu/kWh). Annual average spreads between on-peak and off-peak market heat rates are about 2,200 Btu/kWh for both NP15 and BPA. NP15 market prices are negative as a result of intermittent resource curtailment from over-generation about 11% of the year, and COB market prices are negative about 24% of the year. The greater spread in market heat rate in the High Wind Case compared to the Reference Case suggests greater utilization of Iowa Hill for energy cost arbitrage. High Wind Case regulation down prices are about 8 times higher than regulation up prices and 17 times higher than spin prices.

New Renewable Resources for SMUD Portfolio in Year 2022

As part of the SMUD BA's renewable planning process, SMUD has developed and procured renewable resources in anticipation of meeting future renewable and carbon goals. Existing renewable resources make up about 50% of the SMUD BA's total renewable need in year 2022. Table 3 shows the 2022 SMUD renewable portfolio mix, which includes 1,754 GWh of existing renewable resources, excluding Solano Wind. Table 3 accounts for the Solano Wind resource in the "New Wind" resource totaling 1,054 GWh for the Reference Case and 1,366 GWh for the High Wind Case. Reserve requirements for SMUD portfolio were added in direct proportion to the amount of new intermittent renewable resources in SMUD (from the regional WECC study).

Results

Reference Case

Annual average Iowa Hill capacity factor ranges from 18% to 20% in the four water runoff scenarios, and Iowa Hill increases UARP generation by 6.8 to 21.6 GWh due to improvements in operating efficiency and spillage reduction.

Table 4 shows the average annual increase in UARP generation with Iowa Hill in the four water runoff scenarios. For example, in the wet runoff scenario, UARP generation increases by about 21.6 GWh with Iowa Hill. Average operating UARP efficiency increases by 1.68 kWh/AF due to less upward regulation provision, and reservoir spillage decreases by 13,890 AF. Efficiency improvement increases generation by 6.2 GWh, and spillage reduction increases generation by 15.4 GWh. Notice that with greater runoff, the value of Iowa Hill to the UARP shifts from efficiency improvements to spillage mitigation.

Table 10-2: SMUD Renewable Portfolio in 2022 for Reference and High Wind Cases

Resource	Reference Case	High Wind Case
Renewable Energy Need		
SMUD Retail Sales (GWh)	10,528	10,528
SMUD RPS Goal (%)	33%	33%
Renewable Energy Need (GWh)	3,474	3,474
Renewable Resources		
Existing SMUD Renewables		
Shell Renew Gas	386	386
Timberline Renew Gas	327	327
Geothermal Contract	226	226
Geothermal Contract	227	227
Carson D Contract	93	93
UARP	61	61
FIT	195	195
Buena Vista	120	120
Camp Far West	21	21
Yolo (3.4MW)	21	21
SB1 Customer PV	78	78
Total	1,754	1,754
New Renewables		
New PV	406	354
New Wind	1,054	1,366
New CSP	260	-
Total	1,720	1,720
Total Existing and New Renewable	3,474	3,474

Table 10-3: Reference Case, UARP Spillage, Generation and Reserve Provision with and without Iowa Hill

Case	Water Runoff Scenario	Spillage (AF)	Throughput (AF) [1]	Efficiency (kWh/AF)	Generation (GWh)	Gain from Efficiency Improvement (GWh) [2]	Gain from Spillage Reduction (GWh)	FlexDown Provision (GWh)	FlexUp Provision (GWh)	RegDown Provision (GWh)	RegUp Provision (GWh)	RUC Provision (GWh)	Spin Provision (GWh)
With Iowa Hill													
	Dry	215	1,425,482	752	1,071			160	129	90	60	225	152
	BN	420	2,251,984	756	1,702			203	120	119	53	204	135
	AN	66,799	3,362,002	758	2,547			255	106	155	43	173	122
	Wet	268,351	4,504,849	757	3,411			287	82	179	31	134	99
Without Iowa Hill													
	Dry	560	1,423,702	748	1,065			152	172	85	91	227	202
	BN	297	2,251,527	753	1,697			193	152	114	74	203	173
	AN	73,713	3,353,206	756	2,537			245	128	150	61	170	147
	Wet	282,241	4,486,231	755	3,389			282	109	176	47	130	128
With - Without													
	Dry	(345)	1,780	3.87	6.8	5.5	1.3	9	(43)	5	(31)	(1)	(50)
	BN	124	457	2.36	5.7	5.2	0.5	10	(32)	5	(20)	1	(38)
	AN	(6,914)	8,795	1.17	10.6	5.3	5.3	9	(22)	6	(18)	4	(25)
	Wet	(13,890)	18,618	1.68	21.6	6.2	15.4	5	(28)	3	(16)	4	(29)

[1] Increased throughput in BN scenario with greater spillage. Increased throughput due to location of spillage.

[2] Gain from efficiency improvement = Unit efficiency Improvement (kWh/AF) x total unit throughput (AF). Total throughput in case without Iowa Hill (GWh/AF).

High Wind Case

Annual average Iowa Hill capacity factor ranges from 20% to 23% in the four water runoff scenarios, and Iowa Hill increases UARP generation by 7.7 to 183.9 GWh due to improvements in operating efficiency and spillage reduction.

Table 5 summarizes the annual increase in UARP generation with Iowa Hill in the four runoff scenarios. Increase in UARP generation results from improvements in UARP operating efficiency but generation increases more significantly from reduction in spillage. For example, in the wet runoff scenario with Iowa Hill, UARP generation increases by 183.9 GWh. Average operating UARP efficiency increases by 8.45 kWh/AF, and spillage (mainly in the lower UARP) decreases by 172,469 AF. Efficiency improvement increases generation by 27.4 GWh whereas spillage reduction increases generation by 156.7 GWh.

During periods of high water inflow and negative energy market prices, the UARP spills water to avoid generation and energy payments. However, Iowa Hill reduces spillage by pumping water to the upper Iowa Hill reservoir during hours with low prices. By pumping to the upper reservoir, Iowa Hill creates more storage room at Slab which reduces spillage at Slab. Also, the additional pumping load creates a shorter position for SMUD and allows more generation from the Junction-Camino units using water that would have otherwise been spilled to avoid energy payments.

Table 10-4: High Wind Case, UARP Generation and Reserve Provision with and without Iowa Hill

Case	Water Runoff Scenario	Spillage (AF)	Throughput (AF) [1]	Efficiency (kWh/AF)	Generation (GWh)	Gain from Efficiency Improvement (GWh) [2]	Gain from Spillage Reduction (GWh)	FlexDown Provision (GWh)	FlexUp Provision (GWh)	RegDown Provision (GWh)	RegUp Provision (GWh)	RUC Provision (GWh)	Spin Provision (GWh)
With Iowa Hill													
	Dry	196	1,426,059	753	1,074			93	42	56	17	200	71
	BN	976	2,252,469	755	1,701			116	50	72	19	181	83
	AN	82,125	3,325,190	757	2,517			143	47	90	18	153	72
	Wet	351,270	4,372,957	755	3,300			164	48	104	18	123	72
Without Iowa Hill													
	Dry	46	1,423,963	749	1,066			95	69	58	34	198	131
	BN	28,113	2,217,608	749	1,661			117	66	73	29	180	126
	AN	170,551	3,227,768	749	2,416			146	74	92	35	149	129
	Wet	514,262	4,187,195	746	3,124			163	74	105	35	116	124
With - Without													
	Dry	150	2,096	4.28	7.7	5.9	1.8	(2)	(27)	(2)	(17)	2	(60)
	BN	(27,136)	34,861	5.94	39.5	5.7	33.8	(1)	(17)	(1)	(10)	1	(43)
	AN	(88,426)	97,422	8.26	100.4	14.6	85.8	(2)	(27)	(2)	(17)	4	(56)
	Wet	(162,992)	185,762	8.59	176.2	26.4	149.8	0	(26)	(0)	(18)	7	(53)

[1] Increased throughput in Dry scenario with greater spillage. Increased throughput due to location of spillage.

[2] Gain from efficiency improvement = Unit efficiency Improvement (kWh/AF) x total unit throughput (AF). Total throughput in case without Iowa Hill (GWh/AF).

11 CAPACITY VALUE ANALYSIS OF WIND AND SOLAR AND RETIREMENT OF GENERATION

As part of this study, resource adequacy is a key concern: sufficient capacity to meet planning standards will result in the most realistic energy and service prices, upon which the economic project evaluation can be based. At the same time, excessive capacity may result in lower prices which affect the value of the storage resource in turn. The aim of this analysis is to determine an appropriate generation capacity level for each of the scenarios in the study, such that fair comparison can be made on the value of the storage resource being investigated. To do this, the capacity value of VG resources needs to be calculated Note that these are not generally used in the study at this point, but will be incorporated in future analyses.

In recognition of the impact of capacity adequacy on the value of a storage resource, the contribution of variable generation (VG) resources to capacity adequacy is sought. This report provides the results from an analysis of the variable generation which is assumed in eight regions of the Western Interconnection (regions are based on geography and state-level resources). The capacity value of a resource represents the equivalent extra demand which a system could meet with the addition of resource while maintaining a constant level of reliability.

Based on the capacity value results, conventional capacity adjustment targets are proposed for each region in the 33% and 50% renewable generation penetration scenarios, having taken the Western Electricity Coordinating Council's Transmission Expansion Planning Policy Council 2022 scenario as the baseline level of reliability. The only additional resources added compared to the TEPPC cases are wind and solar; the equivalent load carrying capability value of these additional resources is used to estimate how much conventional capacity might be retired in different scenarios to accommodate this VG

The capacity value calculations are carried out using the loss of load expectation (LOLE) and equivalent load carrying capability (ELCC) methods outlined in next subsection. The data and case study results are presented in the subsequent subsection.

Capacity value calculation

Ensuring capacity adequacy is the primary aim of long-term power system planning. The reliability of the system, in this regard, can be measured by a variety of metrics including the loss of load expectation (LOLE), the expected unserved energy (EUE), etc. Regulatory agencies have established minimum standards for capacity adequacy in their respective areas based on these metrics such as the one day in ten years outage standard.

Loss of Load Expectation

In order to measure the capacity value of a resource, or set of resources, the measure of capacity adequacy must be established. In this case, the LOLE is set as the standard reliability metric. The LOLE can be measured in a variety of ways, but all depend on two basic steps:

- Create the generation availability model and,
- Assess the risk at each demand level

Generation Availability Model

The generation availability model of a system's resources is developed from a two state Markov chain model of the availability of a generating resource. The two state model supposes that a generator is either available or unavailable, and has given failure and repair rates. The model for each generator is then convolved with the models of all the other generators in the system to form the aggregate available capacity distribution. An example distribution is shown in Figure 11-1.

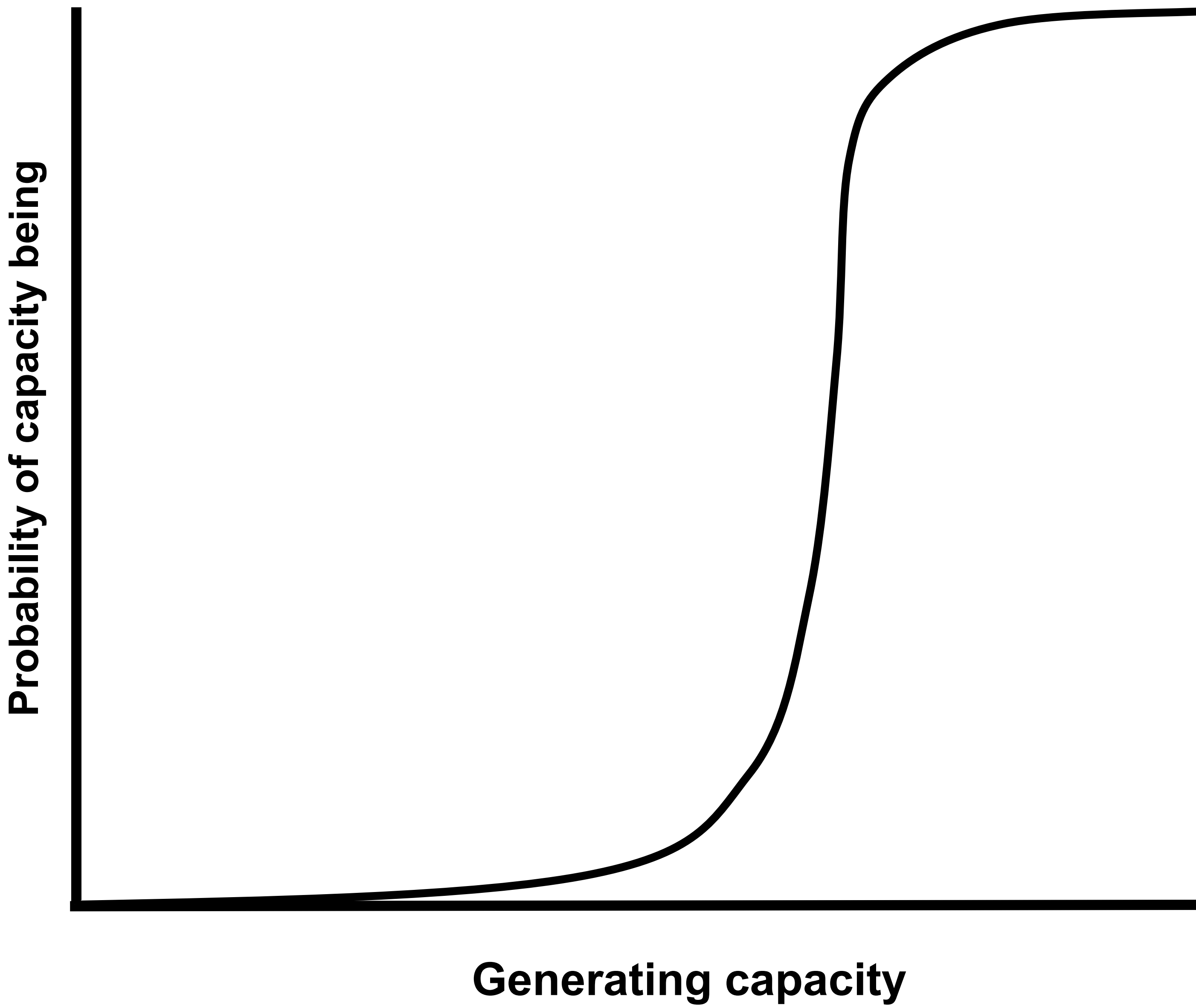


Figure 11-1: Available generation capacity distribution

From this probability distribution function, the cumulative capacity distribution function is determined. The cumulative function relates a given capacity level to the probability that the available capacity will be less than the given capacity. This cumulative function is the generation availability model required for LOLE calculations.

Inherent to the modeling process described are some assumptions including statistical independence between a resource's failures and repairs and the failure and repair of other resources. The process also assumes that generators are either fully available or unavailable, which may not be appropriate for resources such as wind and solar generation which are dependent on environmental conditions. As a result, only conventional generators are included in the generation model and variable generation is included in the next step.

Assess the risk at each demand level

Whereas the process of developing the generation availability model is quite similar in most systems, calculation of the Loss of Load Expectation from it can differ. Various combinations of the generation model and demand levels have been used to determine the risk to a system, ranging from single peak demand observations over a multi-year period to sub-hourly observations over a shorter period.

The principle is the same in all cases: the risk of having insufficient capacity to meet the load is measured at a set of demand levels, and the expected value of the risk values at each observation is calculated. In many systems, the final LOLE value is strongly influenced by the peak demand hours, when the scarcity of capacity is the highest, resulting in elevated risk levels. Current trends have tended to favor assessment of the reliability at every demand level for as long a study period as possible[16].

Variable Generation in LOLE

The generation availability model as previously described is unsuitable for resources such as wind and solar with varying effective capacities. While some methods exist to characterize the availability of the variable generation resources in a multi state Markov model, a non negligible correlation is observed between VG output, specifically solar output, and demand, rendering the independence assumption void.

Current techniques favor considering VG output as negative demand, and is simply subtracted from the system demand at each time period. The effect of including the VG output as a negative demand is to reduce the net load, decreasing the probability of insufficient generation capacity being available and increasing system reliability.

Using time series of VG output sustains the correlation between VG output and demand but increases the data burden significantly on the user. Furthermore, since the wind resource varies from year to year, so too does the LOLE when calculated in this manner. However, this method is the most convenient and accurate method to include VG, if sufficiently long time series are available.

---

16 See the following papers for more details on this topic: B. Hasche, A. Keane, and M.J. O'Malley, "Capacity value of wind power, calculation, and data requirements: the Irish power system case", IEEE Transactions on Power Systems. Vol. 26, No. 1, p. 420-430 (2011), A. Keane, M. Milligan, C.J. Dent, B. Hasche, C. D'Annunzio, K. Dragoon, H. Holttinen, N. Samaan, L. Soder, M.J. O'Malley, "Capacity Value of Wind Power", IEEE Transactions on Power Systems. Vol. 26, No. 2, p564 – 572 (2011), E. Ibanez, M. Milligan, "A Probabilistic Approach to Quantifying the Contribution of Variable Generation and Transmission to System Reliability", 11thAnnual International Workshop on Large-Scale Integration of Wind Power into Power systems as Well as on Transmission Networks for Offshore Wind Power Plants, Lisbon, Portugal (2012)

Capacity Value

The method to determine the capacity value of a generator was developed and incorporated into standard planning practices in the 1960s. The capacity value, or credit, was required to determine the firm capacity which would be expected to be available at the peak load hour in a planning study. Sensitivity analyses could then be carried out to determine the impact of higher or lower demand years in the system. A variety of capacity values exist, but the most appropriate for this application is the effective load carrying capability (ELCC) metric, which is based in turn on the LOLE metric.

Effective Load Carrying Capability

The ELCC of a resource is the additional demand, or net load, which a system could meet when a new resource is added, to the same level of reliability as the original demand was met with. By means of illustration Figure 11-2**Error! Reference source not found.** shows a plot of the system LOLE as a function of the total demand in a hypothetical system in a study period. At lower peak demand levels, a small reduction in the LOLE is experienced since the system's resources are unlikely to all go on outage at the same time. Conversely at high demand levels, the LOLE increases at a rapid rate as the increased demand will result in the loss of load for a larger set of generation outage combinations.

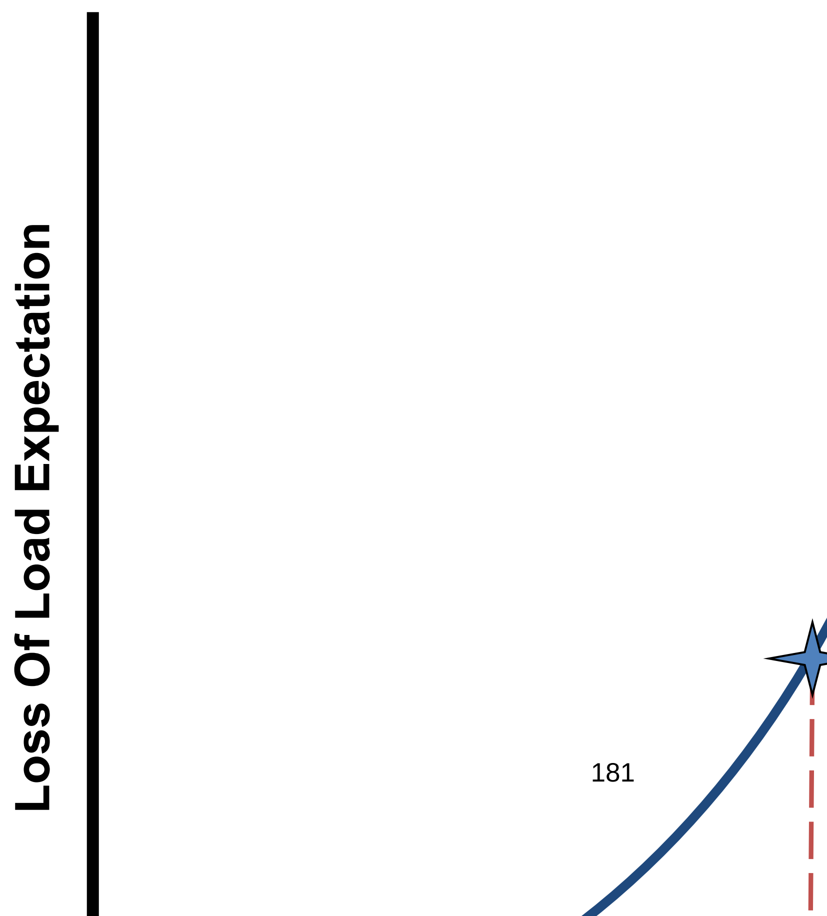

Loss Of Load Expectation

Figure 11-2: Loss of Load Expectation as a function of peak load level

When an additional resource is added to the generation availability model, the curve in Figure 11-2 is seen to move downwards, reducing the risk of load curtailment at each energy level and increasing the reliability. Figure 11-3 shows the both curves for the original and the new set of resources. The ELCC at a given LOLE level is the difference between the energy values for both curves divided by the number of hours in the study to obtain a power, or MW value.

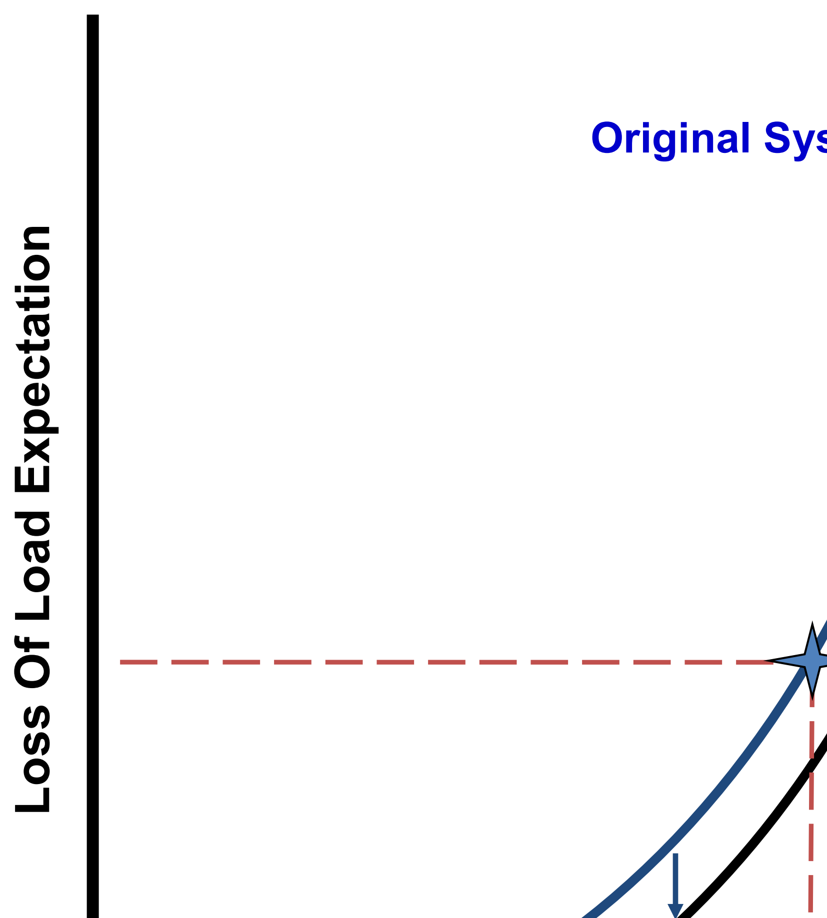

Loss Of Load Expectation
Original Sys

Figure 11-3: New LOLE-Peak Load curve with new generator addition

In practice, the procedure followed is to determine the original generation availability model and then to measure the LOLE. The new resource is added to the availability model and the LOLE is recalculated. The load time series is then uniformly adjusted until the LOLE equals the original LOLE. The ELCC is the sum total of all the adjustments made to the net load. However, this method is not appropriate for VG, since it is not included in the generation availability model.

Effective Load Carrying Capability with VG

As VG is treated as a negative demand in the LOLE calculations to date, the ELCC method is altered. The first step to create the capacity distribution is the same as the case detailed in the previous section. However, when the VG is added to the system in this case, the net load is reduced, pushing the new LOLE curve to the right of the original, Figure 11-4. The ELCC at a given LOLE level is the difference in energy between the two curves divided by the number of hours in the time series.

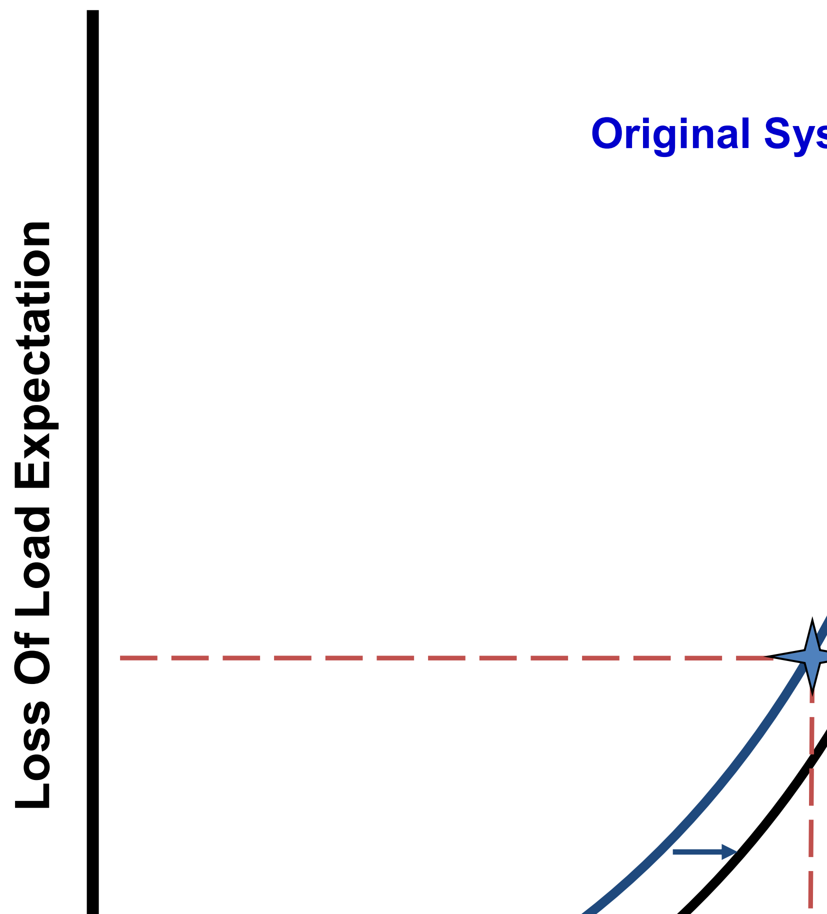

Loss Of Load Expectation

Figure 11-4: New LOLE-Peak Load curve with the addition of variable generation

In practice, the ELCC is calculated by forming the original generation availability model and then to measure the LOLE. The VG output is then subtracted from the demand and the LOLE measured again. The net load time series is then uniformly adjusted until the LOLE equals the original LOLE. As before, the ELCC is the sum total of all the adjustments made to the net load.

Some general limitations apply to the accuracy of the capacity value results in this study. The study data set included the system demand and the production time series of each of the variable generation resources for a period of one year in each scenario. The short duration of those time series do not allow for the effect of yearly variability or the effect of extreme events to be included in the overall capacity value. Some evidence suggests that as long as 10 years of data are required to characterize the capacity value of a variable generation resource to an acceptable level, using this method.

The second general limitation to the results presented concerns the order in which resources are added. In this analysis, the purpose was to determine the average capacity value of all VG resources so that recommendations could be made on the amount of capacity to remove from the system while maintaining the reliability at the same level as the TEPPC case. As a consequence, the precise order of VG resource additions is not adhered to, but rather capacity is added by resource type. The incremental capacity factor is dependent on the order in which resources are added to the system. The incremental capacity values reported here assume that wind generation is added first, followed by CSP and then by PV generation.

Capacity adequacy study results

System data

This study was principally concerned with evaluating the value of a pumped storage unit in SMUD service area. The capacity value of the variable generation is therefore assessed for SMUD and neighboring regions, which influence prices in SMUD. The Western Interconnection was split into six regions:

- Southern California
- Northern California
- Arizona, New Mexico and Nevada
- Northwest Power Pool
- Rocky Mountain Power Pool
- Basin

The Canadian part of the Western Interconnection was not considered. The utilities mapped to each area were as shown in Table 11-1.

Table 11-1: Study regions and constituent utilities

Region	Region Acronym	Utilities
Southern California	*SCAL*	**CFE, IID, LADWP, SDGE, SCE**
Northern California	*NCAL*	**PG&E, SMUD,TIDC**
Arizona, Nevada, New Mexico	*AZNVNM*	**APS, EPE, NEVP, PNM, SRP, TEP, WALC**
Northwest Power Pool	*NWPP*	**AVA,BPA, CHPD, GCPD, NWMT, PACW, PGN, PSE, SCL, TPWR, WAUW**
Rocky Mountain Power Pool	*RMPP*	**PSC, WACM**
Basin	*BAS*	**Far East, Magic Valley, PACE, SPP, TREAS**

Three scenarios were considered in this study, the TEPPC case, the 33% renewable penetration case and the 50% renewable penetration case. The TEPPC case was taken as the base case on which sensitivity cases were carried out (i.e. capacity value was based on maintaining reliability at approximately the same levels as that case, rather than a 1-day-in-10-years or similar measure. A summary is provided in Table 11-2 of the demand and generation capacity in each region.

Table 11-2: Regional demand, capacity and LOLE

Region	Demand (Energy)	Demand (Peak)	Non VG Generating Capacity	Capacity Margin (%)	LOLE (Base Case)
SMUD	**16.2 TWh**	**4.2 GW**	**5 GW**	**19%**	**0.19 h/y**
SCAL	**184 TWh**	**39 GW**	**44.6 GW**	**14%**	**0 h/y**
NCAL	**121 TWh**	**25.1 GW**	**37.9 GW**	**50%**	**0 h/y**
AZNVNM	**155 TWh**	**33 GW**	**43.6 GW**	**32%**	**0 h/y**
NWPP	**182 TWh**	**32 GW**	**46.3 GW**	**44%**	**0.0001 h/y**
RMPP	**72 TWh**	**12.5 GW**	**17.1 GW**	**37%**	**0 h/y**
BAS	**93 TWh**	**17 GW**	**15.8 GW**	**-7%**	**136 h/y**

The demand, capacity and adequacy show in table for each region show the LOLE values for each system in the TEPPC case when VG assumed in that case is considered as a negative demand. These LOLE values are calculated with a single year's load and VG output data. Therefore this may not be the stable, long term LOLE, but is sufficient for the study period.

In most regions, the capacity margin and LOLE values all indicate that the system has sufficient capacity to meet the demand. Very high capacity margins are experienced in northern California and in the Northwest Power Pool where annual variations in the production from hydro generation require additional capacity (in order to properly study this region in particular, the energy as well as capacity requirements would need to be examined; this was deemed out of scope of this study). The Basin region, in contrast to the others, is seen to depend on imports to meet its peak load with only 15.8 GW of generation capacity to meet a peak load of 17 GW. Consequently, the LOLE in this region is high, indicating that load is likely to be shed in 136 hours of the study year without a facility to import. It is important to note here though that the purpose of this calculation of LOLE for the TEPPC case was to ensure a base case of reliability, against which new VG resources would be measured, was established. Therefore the absolute numbers may be less important, other than how they impact on VG ELCC as described later.

Capacity value: SMUD

The first part of the analysis is based on the evaluation of the capacity value of wind, photovoltaic (PV) and concentrating solar power (CSP) in each of the three cases as well as the value of the combined resources in SMUD area. To measure the capacity of each individual VG type, it is measured against the capacity adequacy of the existing generation fleet, rather than assuming that the other VG units are also present.

Wind generation, which is less cyclical than PV has a lower overall capacity value, but contributes to reducing the net load at all times of the day. Solar generation, on the other hand only contributes during the hours of daylight, coinciding with the higher load period of the day.

Since solar generation has a higher correlation with the peak demand, solar generation contributes strongly to the reduction of the risk of insufficient capacity during higher load hours. As a result, solar generation is seen to have a high capacity value when compared to wind generation, particularly at lower penetration levels when the highest net demand occurs during daylight hours.

The average capacity credit of the total VG in each of the three cases is dependent on the ratio of each technology type, Figure 11-5. In the TEPPC and 50% case, solar generation plays a significant role, resulting in average capacity values closer to that of the solar technology types than to that of wind generation. Total VG capacity values ranged from 28% of capacity to 32%.

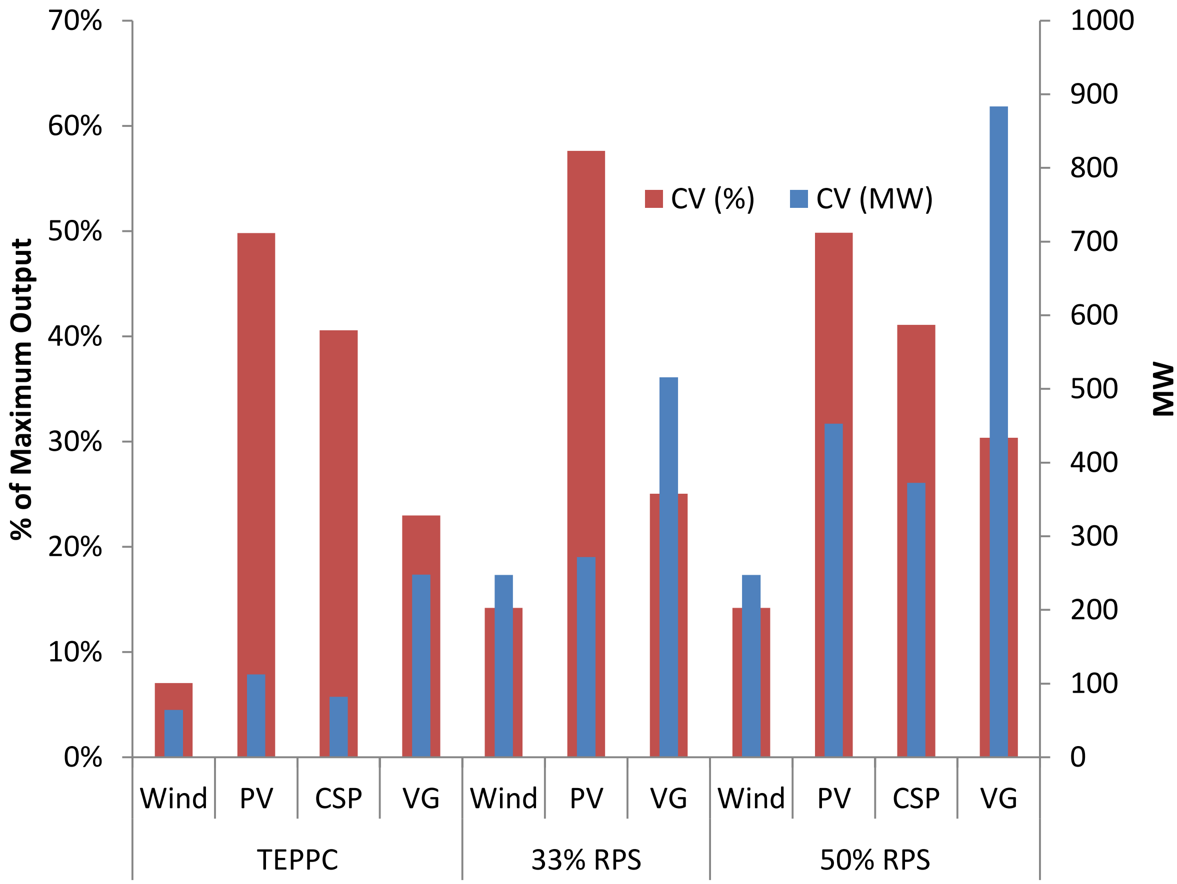


Figure 11-5: Average capacity value of each VG resource type in each scenario

Wind generation in the SMUD BA region returns an average capacity value in the range of 12% -18%, which is comparable to other studies for the region. PV and CSP generation are found to have average capacity values in the 42% - 58% range due to the strong correlation between production and the peak demand, and risk (Figure 11-6). In this analysis CSP is treated as having no thermal storage capability. However, elsewhere in the study the CSP is assumed to have the capability to store thermal energy for up to six hours. This enables the CSP plant's output to meet the evening peak while at maximum output. If storage is used to shift the output of CSP towards the peak load hours, the capacity value of the CSP would be expected to increase. As an approximation of the actual capacity value of CSP, two time shifts are examined. Since the output of a CSP resource is dispatched in reality, it is assumed that the dispatch will concentrate the CSP output on the higher demand and higher marginal cost hours. Figure 11-5 shows the output profile of PV and CSP for a single day in the study in the SMUD BA region. Also shown is the CSP profile shifted by one and two hours, to shift production towards the evening peak.

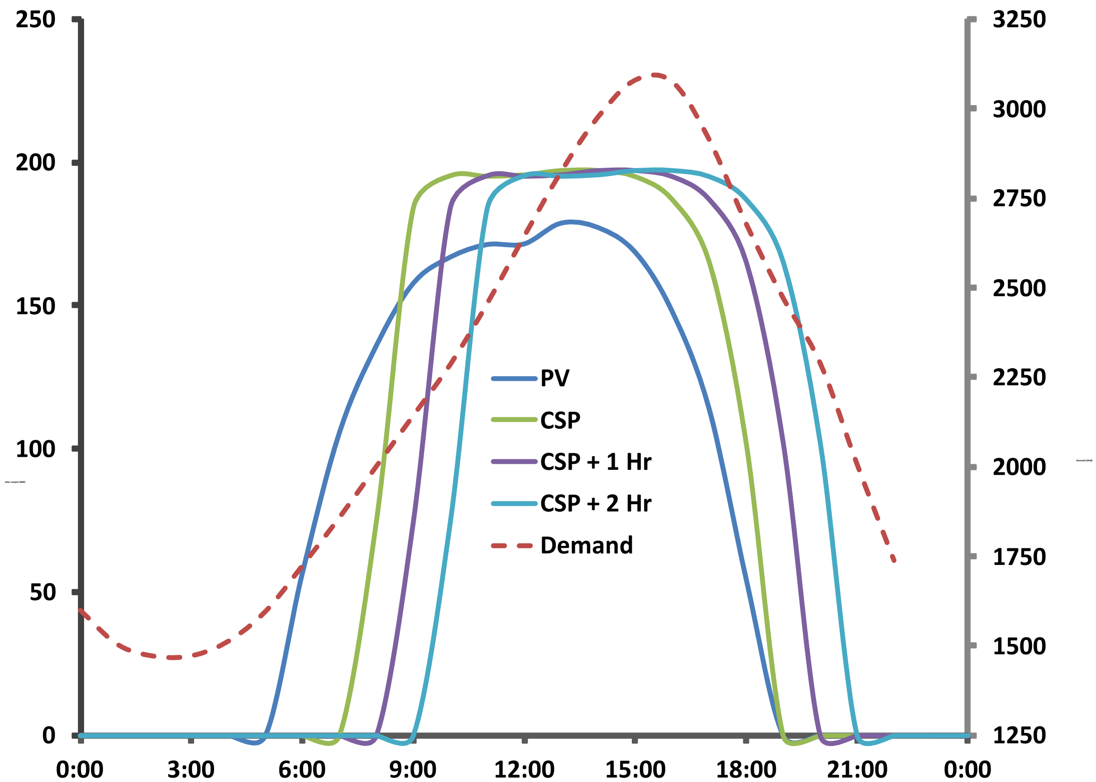


Figure 11-6: Production and Demand for Solar Resources

With a one hour shift, the capacity values are seen to increase by 4% and 8%, in the TEPPC and 50% cases respectively, Figure 11-7. There is a further increase by 2% when the storage acts to shift the output by two hours. This is as expected since the CSP units make a larger contribution to reducing the risk during the peak load hours. It should be noted, however, that this is not an exhaustive treatment of the capacity value of CSP with a storage capability. A CSP resource may charge its stores earlier in the day and may release the stored energy, as well as the regular power output during peak load hours. This would yield a significantly different output profile to those in Figure 11-6

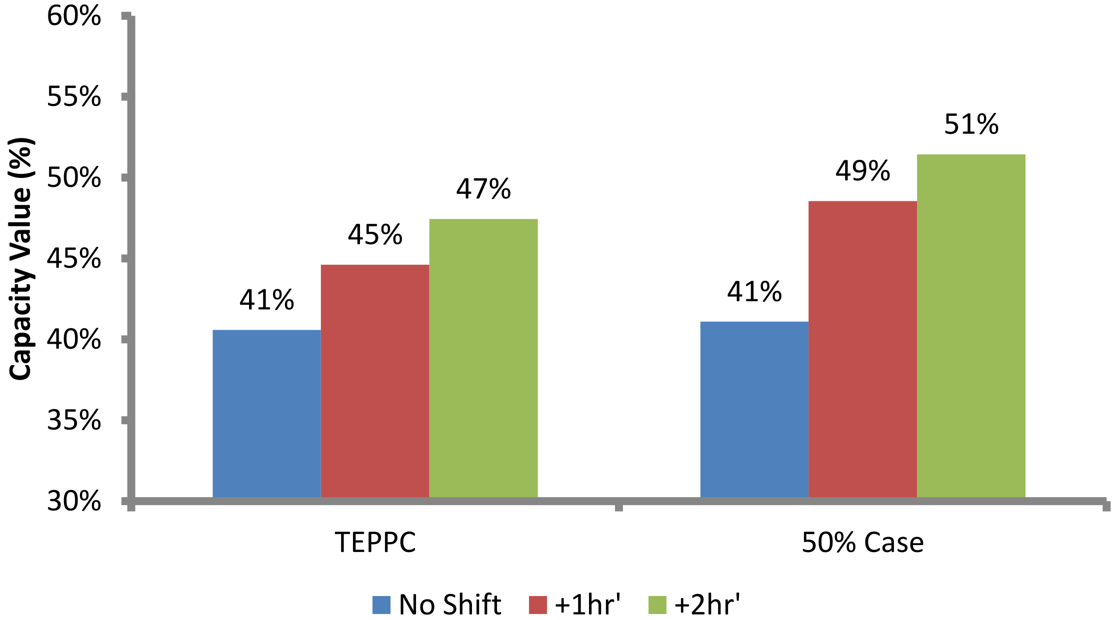


Figure 11-7: Capacity value of CSP resources with time shifting

It should be noted that the results presented are for average capacity values, rather than incremental capacity values. As more and more capacity is added to a system, the risk of loss of load reduces. This in turn results in a diminishing marginal capacity value for new resources added. The issue of incremental or marginal, capacity value is explored in the next section.

Capacity value: Regions

The average capacity value of the incremental additional VG, added to the TEPPC case to get to 33% and to 50%, was evaluated in each of the study regions. Figure 11-8 shows the additional VG capacity which was added to the base case to reach 33% and the further VG added to reach 50% penetrations. The original TEPPC case has a renewable energy penetration of 13% in the 2022 study year.

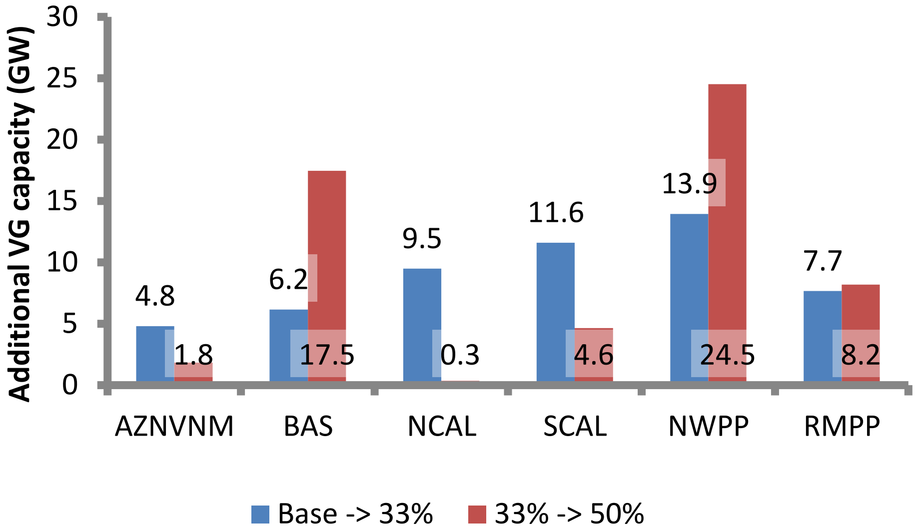


Figure 11-8: Additional VG capacity additions between scenarios

Figure 11-9 below shows the capacity value in percentage terms, as measured with the ELCC method, for the extra VG added in both cases. Two trends are apparent here: the capacity value of the first set of VG added is greater than the capacity value of the resources added to reach a 50% penetration and that the LOLE of the system in the base case strongly influences the capacity value of the added resources.

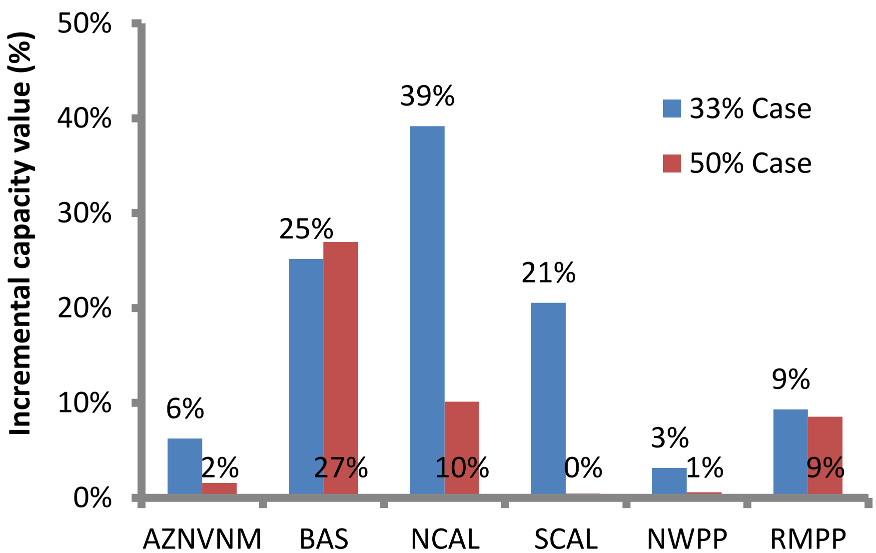


Figure 11-9: Incremental capacity values of VG in reach region

Depending on the region, a mixture of solar and wind generation is added up to the 33% case. To reach 50% renewable energy penetration, only solar generation resources are added to each region. The capacity value of the first set of VG is seen to be higher than the second set since in the first instance the additional VG capacity reduces the probability of insufficient available capacity at the peak net load periods; at higher penetrations the correlation of output across VG means that the incremental benefit in meeting peak load decreases for VG; this is even more true for solar generation due to its regular output and the fact that it only produces energy during daylight hours – at first this means a high ELCC, but as the penetration increases and peak net demand occurs after daylight hours, then solar can no longer contribute

The first set of variable generation, consisting of both wind and solar generation will reduce the risk of capacity shortages, even in systems with comfortable capacity margins. In the northern California case, 9.4 GW of VG is added to a system with a 50% capacity margin already existing. However, the addition of solar generation to this system in this case significantly increases the average capacity value.

Based on the capacity values determined for all regions, the following generation capacity removal targets were reached in each of the study areas. The reliability in the TEPPC case was taken as the baseline and conventional fossil (i.e. not nuclear and not hydro) generating resources will be removed from each of the areas as shown in Table 11-3.

Table 11-3: Conventional generation removal targets in 33% and 50% scenarios

Removal Targets (MW)	NCAL	SCAL	NWPP	RMPP	AZNVNM	BASIN
33% Scenario	**1,584**	**1,152**	**441**	**1,099**	**830.51**	**1,481**
50% Scenario	**1,777**	**1,432**	**453**	**1,384**	**1,200.51**	**3,886**

12 CONCLUSIONS AND FURTHER WORK

This report outlines models used, methodology employed, and results for a study on the SMUD BA system in the context of increased wind and solar PV. This study aims to complete earlier value analysis of the value of the proposed Iowa Hill project for the SMUD BA. Results described are for the first set of runs of the PLEXOS tool, which includes extensive modeling of system operations with high wind/solar.

Detailed modeling was carried out for a portion of the Western Interconnection covering the SMUD BA, the rest of California and much of the Northwest (less detailed modeling for each variable renewable scenario was carried out for all of the WI to fix flows). This region was examined for five different renewable energy scenarios in a multiple of cases, the principal ones being the presence or not of trading of Ancillary Services between the SMUD BA and neighbors, the presence of reciprocating engines. Wind and solar generation profiles, including forecasts, were developed based on NREL datasets. Reserves were calculated based on methods previously developed by NREL, but extended to also capture day ahead uncertainty and 4 hour ahead uncertainty in load.. Additionally, care was given to model the storage unit accurately in this context. Cycling costs for conventional generation were examined and included in the model. Based on this extensive database setup, at least 30 PLEXOS simulations were carried out. High level conclusions include the following insights into Iowa Hill from the detailed simulations:

- Iowa Hill reduces production costs in both the SMUD BA ($30/kW-yr to $130/kW-yr) and the study area, by between $20/kW-yr and $168/kW-yr, depending on renewable generation scenario and whether Iowa Hill can trade AS.
- Improves ability to meet reserves (less shortages) and Iowa Hill provides a large portion, from 10% to 80% depending on reserve type, ability to trade AS with the rest of the study region, and wind/solar penetration of all reserve categories
- Reduces wind and solar curtailment, especially at high penetrations, by up to 50%
- Can reduce emissions (depending on wind and solar penetration)
- Iowa Hill is not as valuable in a high solar scenario as a high wind scenario
- Reduces Cycling by more than 50% (costs and number of starts).

Follow-on work in PLEXOS simulations could include a three –stage approach to the PLEXOS model to capture additional variability and uncertainty of wind and solar, and the contribution storage can make to manage that in daily and real-time operations. Additionally, the following could also be examined:

- The SMUD and neighboring BAs may share balancing and reserve resources under future market designs enabled by advances in information and control technologies.
    - This could mean combining reserve and balancing requirement and resources,
    - This would be modeled for a high wind and high solar scenario
- Develop a plausible plant retirement scenario for the high mix case. In this scenario, the value of both storage and conventional flexible capacity are likely to be higher.

- Look at different hydro conditions (e.g. a dry year)
- Examine Compressed Air Energy Storage – reciprocating engines were not shown to be as good as Iowa Hill (though may be cheaper) – CAES can charge and discharge at the same time and may have greater energy storage amounts
- Utilize a 3 stage modeling approach to more accurately represent the interaction between day ahead, hour ahead and real time scheduling and dispatch. This is explained in more detail in Chapter 8.

In addition to the PLEXOS results, three other smaller studies were described here. The EPRI Energy Storage Valuation Tool (ESVT) was used to give an indication of the overall financial value. ESVT is a higher level financial analysis tool compared to PLEXOS, but it does use prices as an input and determine the feasibility of different storage technologies. It also examines more of the values associated with storage beyond energy and AS, though at a less granular level. Here, it was shown that the benefits, including energy arbitrage, reserve provision (including the fact that storage provide regulation more rapidly and accurately than most conventional generation), capacity benefits and transmission deferral (all based on generic numbers provided either by the SMUD BA or based on recent EPRI work with CPUC) can outweigh the costs by 25% to 250%, depending on assumptions made. Future work here could utilize the prices produced in PLEXOS in the financial analysis, provide more accuracy on transmission and capacity benefits, which are not captured in PLEXOS, and repeat the financial analysis for a variety of assumptions.

SMUD also ran a different model looking at the value of Iowa Hill to the Upper American River Project. This showed that the presence of Iowa Hill can improve the efficiency of all of the SMUD BA's hydro through both reduction in spillage and improvement in efficiency due to less upward regulation provision. It was shown that for base case (low wind penetration), the total generation could be increased by approximately 0.5% with Iowa Hill across different hydro years, whereas for high wind penetration, due to increased curtailment reduction, the increase is between 0.5% and 2% of total generation.

Finally, the team examined the issues of resource adequacy and examined how increased levels of wind and solar can improve resource adequacy. Therefore, we examined how much capacity credit could be assumed for different wind and solar buildouts, and thus how much additional plant may retire. This showed that at higher penetrations, the capacity credit of wind and solar is very low, but varies significantly depending on the region examined and whether the resource is wind or solar. By the time 50% penetration by energy scenarios are examined, the incremental capacity credit is very low. This study could be used in the future to determine how the plant mix may change in the higher penetration scenarios; the PLEXOS results here do not examine significant plant retirements which could be done using results from this study.

A APPENDIX – TRANSMISSION EXPANSION ASSUMPTIONS FOR HIGH-WIND RENEWABLE SCENARIO

Line	From Bus	From Bus Region	To Bus	To Bus Region	Capacity (MW)
ARR___PS_11014 to ARROYO_11017 1 1	**11014_ARR___PS**	**EPE**	**11017_ARROYO**	**EPE**	**275**
ARR___PS_11014 to ARROYO_11017 1 2	**11014_ARR___PS**	**EPE**	**11017_ARROYO**	**EPE**	**275**
B-A_10025 to GUADLUPE_10116 1 1	**10025_B-A**	**PNM**	**10116_GUADLUPE**	**PNM**	**1076**
B-A_10025 to GUADLUPE_10116 1 2	**10025_B-A**	**PNM**	**10116_GUADLUPE**	**PNM**	**1076**
BILINGS_62082 to BLGS PHA_62045 1 1	**62082_BILINGS**	**NWMT**	**62045_BLGS PHA**	**NWMT**	**300**
BILINGS_62082 to BLGS PHA_62045 1 2	**62082_BILINGS**	**NWMT**	**62045_BLGS PHA**	**NWMT**	**300**
BONANZA_65193 to MONA_65995 1 1	**65193_BONANZA**	**PACE_UT**	**65995_MONA**	**PACE_UT**	**725**
CBK 500_50791 to CR_NEST1_54458 1 1	**50791_CBK 500**	**BCH**	**54458_CR_NEST1**	**AESO**	**940**
CBK 500_50791 to CR_NEST1_54458 1 2	**50791_CBK 500**	**BCH**	**54458_CR_NEST1**	**AESO**	**940**
FLAGSTAF_79024 to PINPKBRB_79053 1 1	**79024_FLAGSTAF**	**WALC**	**79053_PINPKBRB**	**WALC**	**747**
GATES_30055 to MIDWAY_30060 1 1	**30055_GATES**	**PG&E_VLY**	**30060_MIDWAY**	**PG&E_VLY**	**1931.2**
GLENCANY_79032 to GLENCANY_79031 1 1	**79032_GLENCANY**	**WALC**	**79031_GLENCANY**	**WALC**	**300**
GLENCANY_79032 to GLENCANY_79031 1 2	**79032_GLENCANY**	**WALC**	**79031_GLENCANY**	**WALC**	**300**
GLENCANY_79032 to GLENCANY_79031 2 1	**79032_GLENCANY**	**WALC**	**79031_GLENCANY**	**WALC**	**300**
H ALLEN_18001 to H ALLEN_18019 1 1	**18001_H ALLEN**	**NEVP**	**18019_H ALLEN**	**NEVP**	**300**
H ALLEN_18001 to H ALLEN_18019 1 2	**18001_H ALLEN**	**NEVP**	**18019_H ALLEN**	**NEVP**	**300**
H ALLEN_18001 to H ALLEN_18019 1 3	**18001_H ALLEN**	**NEVP**	**18019_H ALLEN**	**NEVP**	**300**
H ALLEN_18001 to H ALLEN_18019 1 4	**18001_H ALLEN**	**NEVP**	**18019_H ALLEN**	**NEVP**	**300**
HA PS_18002 to H ALLEN_18001 1 1	**18002_HA PS**	**NEVP**	**18001_H ALLEN**	**NEVP**	**300**
HA PS_18002 to H ALLEN_18001 1 2	**18002_HA PS**	**NEVP**	**18001_H ALLEN**	**NEVP**	**300**
HA PS_18002 to H ALLEN_18001 2 1	**18002_HA PS**	**NEVP**	**18001_H ALLEN**	**NEVP**	**300**
LANGDON2_54158 to CR_NEST1_54458 01 1	**54158_LANGDON2**	**AESO**	**54458_CR_NEST1**	**AESO**	**940**
LANGDON2_54158 to CR_NEST1_54458 01 2	**54158_LANGDON2**	**AESO**	**54458_CR_NEST1**	**AESO**	**940**
LANGDON2_54158 to CR_NEST1_54458 01 3	**54158_LANGDON2**	**AESO**	**54458_CR_NEST1**	**AESO**	**940**
LANGDON2_54158 to LANGDOB9_58158 T1 1	**54158_LANGDON2**	**AESO**	**58158_LANGDOB9**	**AESO**	**1200**
LANGDON2_54158 to LANGDOB9_58158 T1 2	**54158_LANGDON2**	**AESO**	**58158_LANGDOB9**	**AESO**	**1200**

Line	From Bus	From Bus Region	To Bus	To Bus Region	Capacity (MW)
LANGDON2_54158 to LANGDOB9_58158 T1 3	**54158_LANGDON2**	**AESO**	**58158_LANGDOB9**	**AESO**	**1200**
LAR.RIVR_73107 to LAR.RIVR_73108 1 1	**73107_LAR.RIVR**	**WACM**	**73108_LAR.RIVR**	**WACM**	**600**
MATLB1_54451 to MATL AB_56451 T1 1	**54451_MATLB1**	**AESO**	**56451_MATL AB**	**AESO**	**330**
NEWMAN_11111 to NEWMAN_B_11204 1 1	**11111_NEWMAN**	**EPE**	**11204_NEWMAN_B**	**EPE**	**184**
NEWMAN_11111 to NEWMAN_B_11204 1 2	**11111_NEWMAN**	**EPE**	**11204_NEWMAN_B**	**EPE**	**184**
NEWMAN_11111 to NEWMAN_B_11204 1 3	**11111_NEWMAN**	**EPE**	**11204_NEWMAN_B**	**EPE**	**184**
NLY 230_50784 to NLY 2PS2_50822 2 1	**50784_NLY 230**	**BCH**	**50822_NLY 2PS2**	**BCH**	**400**
NLY 230_50784 to NLY 2PS2_50822 2 2	**50784_NLY 230**	**BCH**	**50822_NLY 2PS2**	**BCH**	**400**
NLY 230_50784 to NLY 2PS2_50822 2 3	**50784_NLY 230**	**BCH**	**50822_NLY 2PS2**	**BCH**	**400**
OJO_10232 to TAOS_12082 1 1	**10232_OJO**	**PNM**	**12082_TAOS**	**PNM**	**299**
OJO_10232 to TAOS_12082 1 2	**10232_OJO**	**PNM**	**12082_TAOS**	**PNM**	**299**
PINPKBRB_79053 to PINPK_19062 1 1	**79053_PINPKBRB**	**WALC**	**19062_PINPK**	**WALC**	**600**
REDBUTTE_66280 to UTAH-NEV_67657 1 1	**66280_REDBUTTE**	**PACE_UT**	**67657_UTAH-NEV**	**PACE_UT**	**300**
REDBUTTE_66280 to UTAH-NEV_67657 1 2	**66280_REDBUTTE**	**PACE_UT**	**67657_UTAH-NEV**	**PACE_UT**	**300**
REDBUTTE_66280 to UTAH-NEV_67657 1 3	**66280_REDBUTTE**	**PACE_UT**	**67657_UTAH-NEV**	**PACE_UT**	**300**
REDBUTTE_66280 to UTAH-NEV_67657 1 4	**66280_REDBUTTE**	**PACE_UT**	**67657_UTAH-NEV**	**PACE_UT**	**300**
RIOPUERC_10390 to B-A_10025 2 1	**10390_RIOPUERC**	**PNM**	**10025_B-A**	**PNM**	**1195.1**
RIOPUERC_10390 to WESTMESA_10369 1 1	**10390_RIOPUERC**	**PNM**	**10369_WESTMESA**	**PNM**	**1195.1**
SANJN PS_79060 to SAN_JUAN_10292 1 1	**79060_SANJN PS**	**WACM**	**10292_SAN_JUAN**	**PNM**	**600**
UTAH-NEV_67657 to HA PS_18002 1 1	**67657_UTAH-NEV**	**PACE_UT**	**18002_HA PS**	**NEVP**	**300**
UTAH-NEV_67657 to HA PS_18002 1 2	**67657_UTAH-NEV**	**PACE_UT**	**18002_HA PS**	**NEVP**	**300**
UTAH-NEV_67657 to HA PS_18002 1 3	**67657_UTAH-NEV**	**PACE_UT**	**18002_HA PS**	**NEVP**	**300**
UTAH-NEV_67657 to HA PS_18002 1 4	**67657_UTAH-NEV**	**PACE_UT**	**18002_HA PS**	**NEVP**	**300**
WABAMUN9_54134 to CARVEL02_55364 96 1	**54134_WABAMUN9**	**AESO**	**55364_CARVEL02**	**AESO**	**121**
WABAMUN9_54134 to CARVEL02_55364 96 2	**54134_WABAMUN9**	**AESO**	**55364_CARVEL02**	**AESO**	**121**

Table 12-1 Transmission line expansion for high-wind renewable scenario

	Before Expansion		After Expansion	
Row Labels	**Max Flow**	**Min Flow**	**Max Flow**	**Min Flow**
Interstate AB-MT	**325**	**-300**	**325**	**-600**
Interstate WA-BC East	**400**	**-400**	**2400**	**-400**
Interstate WA-BC West	**3000**	**-2850**	**3000**	**-3850**
Intrastate CA PDCI South	**2780**	**-3100**	**3780**	**-3100**
P01 Alberta-British Columbia	**700**	**-720**	**700**	**-2160**
P03 Northwest-British Columbia	**3000**	**-3150**	**3000**	**-4150**
P18 Montana-Idaho	**337**	**-256**	**674**	**-256**
P24 PG&E-Sierra	**160**	**-150**	**160**	**-300**
P26 Northern-Southern California	**4000**	**-3000**	**4000**	**-4000**
P31 TOT 2A	**690**	**-690**	**1380**	**-690**
P35 TOT 2C	**600**	**-580**	**2400**	**-1160**
P36 TOT 3	**1680**	**-1680**	**2680**	**-1680**
P38 TOT 4B	**829**	**-829**	**1658**	**-829**
P40 TOT 7	**890**	**-890**	**1335**	**-890**
P45 SDG&E-CFE	**408**	**-800**	**2448**	**-800**
P48 Northern New Mexico (NM2)	**1970**	**-1970**	**1970**	**-2970**
P52 Silver Peak-Control 55 kV	**17**	**-17**	**34**	**-170**
P59 WALC Blythe - SCE Blythe 161 kV Sub	**218**	**-218**	**436**	**-218**
P80 Montana Southeast	**600**	**-600**	**600**	**-1200**

Appendix D

DE-EE0005414 Assistance Agreement

Preliminary Functional Design Basis of Design and Design Requirements Report

Iowa Hill Pumped-Storage Development Project

Preliminary Functional Design Basis of Design and Design Requirements Report

July 2015

SMUD™

Prepared by:

JACOBS ASSOCIATES
Engineers/Consultants

Jacobs Associates
2365 Iron Point Road, Suite 220
Folsom, CA 95630

Distribution

To:	Clint Schelbert SMUD
	Scott Flake SMUD
From:	Blake Rothfuss Jacobs Associates
Prepared By:	Rachel Martin Jacobs Associates
	Renee Fippin Jacobs Associates
	Alberto Pujol GEI Consultants, Inc.
	Ron Grady HDR Engineering, Inc.
	Dave Jermstad GHD Inc.
	Blake Heinlein IEC Corporation
Reviewed By:	Mike McRae Jacobs Associates
	Steve Verigin GEI Consultants, Inc.
	Rick Miller HDR Engineering, Inc.

Revision Log

Revision No.	Date	Revision Description
0	January 23, 2015	Conceptual PFD Deliverable to SMUD
1	July 2015	Final revisions

Table of Contents

Abbreviations, Acronyms, and Initialisms xiv

1 Introduction 1

1.1 Purpose and Scope 1

2 Project Background 2

2.1 Regulatory Oversight 4

2.2 Construction Considerations and Expectations 4

2.3 Authorization 4

3 Basis of the Preliminary Functional Design 5

3.1 Project Components 5

3.2 Water Conveyance System 11

3.2.1 General 11

3.2.2 Description of Components 11

3.2.3 Operating and Maintenance Requirements 14

3.2.4 Geometry 15

3.2.5 Water Conveyance Tunnels and Shaft Lining 15

3.2.6 References, Codes, and Standards 18

3.3 Underground Powerhouse Complex 21

3.3.1 Powerhouse 21

3.3.2 Powerhouse Cavern Operating and Maintenance Requirements 23

3.3.3 Geologic Requirements and Parameters 24

3.3.4 Mechanical Equipment and Systems 25

3.3.5 Electrical Equipment and Systems 62

3.3.6 Station Services 92

3.3.7 References, Codes, and Standards 105

3.4 Powerhouse Access Tunnel Portal and Tunnel 106

3.4.1 General 106

3.4.2 Operating and Maintenance Requirements 106

3.4.3 Security 107

3.4.4 Support Assessment 107

3.4.5 Groundwater Inflows 107

3.4.6 References, Codes, and Standards 107

3.5 Utility Shaft and Utility Shaft Building 109

3.5.1 General 109

3.5.2 Operating and Maintenance Requirements 109

3.5.3 Support Assessment 109
3.5.4 Groundwater Inflows 109
3.5.5 References, Codes, and Standards 110
3.6 Upper Reservoir and Dam 111
3.6.1 General and Facility Sizing Requirements 111
3.6.2 Hydraulic Requirements for Upper Reservoir I/O 114
3.6.3 Control of Maximum Water Level in Upper Reservoir 115
3.6.4 Hydraulic Requirements for Upper Reservoir Emergency Spillway 116
3.6.5 Control of Minimum Water Level in Upper Reservoir 117
3.6.6 Emergency Drainage of the Upper Reservoir 117
3.6.7 Upper Reservoir Dam 118
3.6.8 Embankment Foundation 120
3.6.9 Upper Reservoir Liner System 120
3.6.10 Seepage Monitoring System 122
3.6.11 Operating and Maintenance Requirements 122
3.6.12 Public Safety Precautions 123
3.6.13 Owner’s Dam Safety Monitoring Program Requirements 123
3.6.14 References, Codes, and Standards 124
3.7 Access Roads 126
3.7.1 General 126
3.7.2 Long Canyon Access Road 126
3.7.3 Lower Boat Ramp Road 127
3.7.4 References, Codes, and Standards 127
3.8 230KV Switchyard and HV Cable Trench 128
3.8.1 General 128
3.8.2 Station Emergency and Backup Power 131
3.8.3 Metering 132
3.8.4 Protection 132
3.8.5 Operating and Maintenance Requirements 133
3.8.6 Security 133
3.8.7 Public Safety Precautions 134
3.8.8 Recreation Access 134
3.8.9 Regulations, Codes, and Standards 134
3.9 230KV Generation Tie (Gen-Tie) 138
3.9.1 Operating and Maintenance Requirements 138
3.9.2 Security 138

3.9.3 Public Safety Precautions ... 138
3.9.4 Recreation Access ... 138
3.10 Telecommunications ... 139
3.10.1 General ... 139
3.10.2 Equipment Space Requirements and Clearances ... 139
3.10.3 Telecommunication Cables ... 139
3.10.4 Cable Management System ... 140
3.10.5 Inside Plant Pathways ... 140
3.10.6 Outside Plant Pathways and Structures ... 140
3.10.7 Microwave Radio Tower ... 140
3.10.8 Microwave Radio System ... 141
3.10.9 Telecommunications: 48V DC Power System ... 141
3.10.10 Wireless LAN Service ... 141
3.10.11 Satellite TV/MATV and Off-the-Air Television ... 141
3.10.12 In-Building Distributed Antenna System ... 141
3.10.13 Security ... 142
4 Preliminary Design Criteria ... 145
4.1 General Functional Design Criteria ... 145
4.1.1 General ... 145
4.1.2 Owner Occupational Safety Requirements ... 145
4.1.3 Visual Aesthetics Objectives ... 146
4.1.4 Operating Command and Control ... 146
4.1.5 Physical Security ... 146
4.1.6 Cyber Security Requirements ... 146
4.1.7 Public Safety Precautions ... 147
4.1.8 Fire Prevention, Detection, and Suppression ... 147
4.1.9 Design Service Life ... 148
4.1.10 Operating Conditions and Duty Cycle ... 149
4.1.11 Slab Creek Reservoir Design Flood Elevation ... 150
4.1.12 General Codes and Standards ... 150
4.2 Water Conveyance Tunnels and Shafts ... 151
4.2.1 Functional Requirements ... 151
4.2.2 Operating and Maintenance Requirements ... 151
4.2.3 Geometry ... 152
4.2.4 Structural Design ... 152

4.2.5 Contact Grouting of Cast-in-Place Concrete Linings, Steel Linings, and Penstocks 153
4.2.6 Component Requirements 153
4.2.7 Slab Creek Inlet/Outlet (I/O) Structure 156
4.2.8 Material Properties 158
4.3 Underground Powerhouse Complex 159
4.3.1 Powerhouse 159
4.3.2 Low Voltage Bus Tunnels 160
4.3.3 Transformer/Draft Tube Gate Gallery 160
4.3.4 Unit Draft Tube Tunnels and Gates 160
4.3.5 Operating and Maintenance Requirements 160
4.3.6 Geologic 161
4.3.7 Mechanical Equipment and Systems 162
4.3.8 Electrical Equipment and Systems 192
4.3.9 Station Services 208
4.4 Powerhouse Access Tunnel Portal and Tunnel 220
4.4.1 General 220
4.4.2 Operating and Maintenance Requirements 220
4.4.3 Security 221
4.4.4 Safety Precautions 221
4.4.5 Geometry 221
4.4.6 Minimum Support Requirements: 221
4.4.7 Water Inflows 222
4.5 Utility Shaft and Utility Shaft Building 223
4.5.1 General 223
4.5.2 Operating and Maintenance Requirements 223
4.5.3 Public Safety Precautions 223
4.5.4 Design/Minimum Ground Support Requirements 223
4.5.5 Water Inflows 224
4.6 Upper Reservoir and Dam 225
4.6.1 General 225
4.6.2 Hydrologic, Seismic, and Environmental Criteria 225
4.6.3 Hydraulic Design 228
4.6.4 Geotechnical Design: General 229
4.6.5 Embankment Design 230
4.6.6 Structural Design 238

4.6.7 Sediment and Erosion Control ... 240
4.6.8 Instrumentation and Monitoring ... 240
4.6.9 Construction Site Operations ... 241
4.6.10 Construction Inspection and Testing ... 243
4.6.11 Vehicle Access ... 243
4.6.12 Site Security and Safety ... 244
4.6.13 Maintenance ... 244
4.6.14 Dam Safety Monitoring Program ... 244
4.6.15 Emergency Action Plan ... 245
4.6.16 Basis and Limitations ... 245
4.7 Access Roads ... 246
4.7.2 Long Canyon Access Road ... 246
4.7.3 Lower Boat Ramp Road ... 247
4.8 230KV Switchyard and HV Cable Trench ... 249
4.8.1 General ... 249
4.8.2 Regulations and Codes ... 249
4.8.3 SMUD Standards ... 251
4.8.4 Civil Requirements ... 251
4.8.5 Structural Requirements ... 254
4.9 Electrical Requirements ... 258
4.9.1 Electrical Studies ... 258
4.9.2 Electrical Equipment ... 260
4.10 Switchyard Control Module ... 264
4.10.1 Service Conditions ... 265
4.10.2 Control Module Structural Requirements ... 265
4.10.3 Doors ... 267
4.10.4 Weatherproofing ... 267
4.10.5 Module Blockouts ... 267
4.10.6 Insulation ... 267
4.10.7 Paint ... 267
4.10.8 Fire Extinguishers ... 268
4.10.9 Wiring ... 268
4.10.10 Grounding ... 268
4.10.11 Ceiling Mount Cable Trays ... 269
4.10.12 Wall Wire Way ... 269
4.10.13 HVAC ... 269

4.10.14 Panelboards (AC and DC) ... 270
4.10.15 Fire Alarm ... 271
4.10.16 Lighting ... 272
4.10.17 Receptacles ... 272
4.10.18 Protective Relays and Control Panels ... 272
4.10.19 Relay Rack Panels (19-Inch) ... 273
4.10.20 Security ... 273
4.10.21 RTU Panel ... 273
4.10.22 Interface Termination Cabinet ... 273
4.10.23 Metering ... 274
4.10.24 RTU ... 274
4.10.25 SCADA Communications ... 275
4.10.26 Microwave Tower (Slate Mountain) ... 275
4.10.27 Testing and Inspection ... 275
4.11 230KV Generation Tie (Gen-Tie) ... 277
4.11.1 General Description ... 277
4.11.2 Regulations and Codes ... 277
4.11.3 Design Requirements ... 279
4.12 Telecommunications ... 281
4.12.1 General ... 281
4.12.2 Regulations, Codes, and Standards ... 282
4.12.3 Equipment Space Requirements and Clearances ... 282
4.12.4 Telecommunication Cables ... 282
4.12.5 Cable Management System ... 283
4.12.6 Inside Plant Pathways ... 283
4.12.7 Outside Plant Pathways & Structures ... 283
4.12.8 Microwave Radio Tower ... 283
4.12.9 Microwave Radio System ... 284
4.12.10 Telecommunications: 48V DC Power System ... 284
4.12.11 Wireless LAN Service ... 284
4.12.12 Satellite TV/MATV and Off the Air Television ... 284
4.12.13 In-Building Distributed Antenna System ... 284
4.12.14 Security ... 285
5 General References ... 288

List of Tables

Table 2-1. Project Characteristics 3
Table 3-1. Major Project Components 5
Table 3-2. Summary of Confinement Evaluation Criteria 17
Table 3-4. Rock Mass Parameters 25
Table 3-6. Motor-generator Equipment System Interfaces 37
Table 3-8. Functional Design Criteria and Key Parameters for Upper Reservoir and Dam (Preliminary) 111
Table 3-9. RF Coverage Areas 142
Table 4-1. Reservoir Water Surface Elevations 150
Table 4-4. Minimum Load Factors for Concrete Lining Design 153
Table 4-5. Summary of Confinement Evaluation Criteria 153
Table 4-7. Concrete Requirements 158
Table 4-8. Steel Properties 158
Table 4-9. Pump-Turbine Equipment System Interfaces 163
Table 4-10. Pump-turbine Equipment Functional Design Criteria 163
Table 4-11. Motor-generator Equipment Functional Design Criteria 175
Table 4-12. Motor-generator AC Excitation System Functional Design Criteria 177
Table 4-13. Summary of Presumptive Material Properties 230
Table 4-14. Minimum Factors of Safety 234
Table 4-15. Minimum Required Factor of Safety 238
Table 4-16. RF Coverage Levels 285

List of Figures

Figure 2-1. Project Location Map 3
Figure 3-1. Project General Arrangement 9
Figure 3-2. Total Pressure at Jacking / In Situ Stress / Operating Pressure (psi) 18
Figure 3-4. Governor Hydraulic System Conceptual Diagram 28
Figure 3-5. Spherical Valve Conceptual Diagram 31
Figure 3-6. Spherical Valve HPU Conceptual Diagram 32
Figure 3-7. Draft Tube Gate HPU Conceptual Diagram 34
Figure 3-8. Motor-generator Equipment Conceptual Diagram 36
Figure 3-9. Unit 1 Low Pressure Service Water System Conceptual Diagram 41
Figure 3-10. Unit 2 Low Pressure Service Water System Conceptual Diagram 42
Figure 3-11. Unit 3 Low Pressure Service Water System Conceptual Diagram 43

Figure 3-12. Generator-motor Air Coolers Conceptual Diagram (typical per unit) 44
Figure 3-13. Unit 1 Cooling Water System Conceptual Diagram 47
Figure 3-14. Unit 2 Cooling Water System Conceptual Diagram 48
Figure 3-15. Unit 3 Cooling Water System Conceptual Diagram 49
Figure 3-16. Powerhouse Chilled Water System Conceptual Diagram 51
Figure 3-17. Depressing Air System Conceptual Diagram 53
Figure 3-18. Station/Instrument Compressed Air System Conceptual Diagram 55
Figure 3-19. Station Drainage System Conceptual Diagram 57
Figure 3-20. Unwatering System Conceptual Diagram 59
Figure 3-21. Power Tunnel Filling System Conceptual Diagram 60
Figure 3-22. Toshiba Typical Supply ABB Generator Circuit Breakers, Vertical Installation Shown............. 64
Figure 3-23. ABB Generator Circuit Breaker Technical Data, Typical 65
Figure 3-24. Toshiba Typical Supply ABB Generator Circuit Breakers, Horizontal Installation Shown 66
Figure 3-25. Toshiba Typical Supply ABB Type HECPS-100/130L, Drawing 1HC0030002, Sheet 1 of 7 ... 68
Figure 3-26. Toshiba Typical Supply ABB Type HECPS-100/130L, Drawing 1HC0030002, Sheet 2 of 7 ... 69
Figure 3-27. Toshiba Typical Supply ABB Type HECPS-100/130L, Drawing 1HC0030002, Sheet 3 of 7 ... 70
Figure 3-28. Toshiba Typical Supply ABB Type HECPS-100/130L, Drawing 1HC0030002, Sheet 4 of 7 ... 71
Figure 3-29. Toshiba Typical Supply ABB Type HECPS-100/130L, Drawing 1HC0030002, Sheet 5 of 7 ... 72
Figure 3-30. Toshiba Typical Supply ABB Type HECPS-100/130L, Drawing 1HC0030002, Sheet 6 of 7 ... 73
Figure 3-31. Toshiba Typical Supply ABB Type HECPS-100/130L, Drawing 1HC0030002, Sheet 7 of 7 ... 74
Figure 3-32. Toshiba Typical Supply ABB Type HECPS-100/130L, Vertical, Drawing 1HDP80 1158, Sheet 1 of 1 75
Figure 3-33. Voith Siemens Supply Typical Isolated Phase Bus Elevation 78
Figure 3-34. Powerhouse Ventilation System Conceptual Diagram 95
Figure 3-35. Access Tunnel and Transformer Cavern Ventilation System Conceptual Diagram.................. 98
Figure 3-36. Wastewater Treatment System Conceptual Diagram 101

Appendices

Appendix A: SMUD Technical Specification FPLC-CR5 – Fire Alarm Standard

Appendix B: SMUD Standards

Abbreviations, Acronyms, and Initialisms

AASHTO	American Association of State Highway and Transportation Officials
AB	aggregate base
ACAMS	access control and monitoring system
ACI	American Concrete Institute
ADA	American Disability Act
AEIC	Association of Edison Illuminating Companies
AFBMA	Antifriction Bearing Manufacturers Association
AGMA	American Gear Manufacturers Association
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
AMCA	Air Movement and Control Association
ANSI	American National Standards Institute
API	American Petroleum Institute (where required only)
ARI	Air Conditioning and Refrigeration Institute
ASA	Acoustical Society of America
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning
asl	above sea level
ASME	American Society of Mechanical Engineers
ASNT	American Society of Nondestructive Testing
ASTM	American Society for Testing and Materials
ATS	automatic transfer switch
AWS	American Welding Society
AWWA	American Water Works Association
BOP	balance of plant
Caltrans	California Depart of Transportation
CBC	California Building Code
CCTV	camera television surveillance systems
CEMA	Conveyor Equipment Manufacturers Association
CFC	California Fire Code
CFR	Code of Federal Regulations
CIP	critical infrastructure protection
CMAA	Crane Manufacturers Association of America
CQCIP	Construction Quality Control Inspection Program
CRSI	Concrete Reinforcing Steel Institute
DCS	distributed control system
DFIM	double-fed induction machine (asynchronous machine [DFIM])
DOE	U.S. Department of Energy

DSOD	California Department of Water Resources, Division of Safety of Dams
EAPs	Emergency Action Plans
EIA	Electronic Industries Association
EJMA	Expansion Joint Manufacturing Association
El.	elevation
EMI	electromagnetic interference
EMS	energy management system
EPA	U.S. Environmental Protection Agency
ESG	emergency standby generator
FAA	Federal Aviation Administration
FERC	Federal Energy Regulatory Commission
FM	Factory Mutual
FWS	United States Fish and Wildlife Service
gen-tie	generation-tie
gpad	gallons per acre day
GSU	generator step-up
HDPE	high density polyethylene
HEI	Heat Exchange Institute
HI	Hydraulic Institute
HMI	human-machine interface
HMI	Hoist Manufacturers Institute
HPU	hydraulic pressure unit
HV	high voltage
HVP	high voltage protection
I/O	inlet/outlet
IBC	International Building Code
ICEA	Insulated Cable Engineers Association
IDF	inflow design flood
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
IP	internet protocol
IPB	isolated phase bus
ISA	Instrument Society of America
ISO	International Organization for Standardization
LLO	low-level outlet
LPSW	low pressure service water
LWS	minimum normal operating water surface elevation
LWS	minimum operating water surface elevation

MATV	master antenna television system
MCE	maximum credible earthquake
MNWS	maximum normal operating water surface
MOWS	maximum reservoir operating water surface at spillway crest
MRWS	Maximum reservoir water surface elevation during IDF
MSS	Manufacturers Standardization Society of the Valve and Fittings Industry
MTBF	mean times between failures
MVA	megavolt ampere
NAAMM	National Association of Architectural Metal Manufacturers
NACE	National Association of Corrosion Engineering
NBS	National Bureau of Standards
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NERC	National Electrical Reliability Standards
NESC	National Electrical Safety Code
NETA	National Electrical Testing Association
NFPA	National Fire Protection Association
NPV	net present value
NVRs	network video recorder
OPGW	optical ground wire
OSHA	Occupational Safety and Health Administration
Owner Sys Op Sac	Owner System Operations in Sacramento
P&IDs	piping and instrument diagrams
pcf	pounds per cubic feet
PFI	Pipe Fabrication Institute
pga	peak ground acceleration
PHAT	powerhouse access tunnel
PLCs	programmable logic controllers
PMF	probable maximum flood
PMP	probable maximum precipitation
psi	pounds per square inch
QA/QC	Quality Control/Quality Assurance
RF	radio frequency
RMA	Rubber Manufacturers Institute
SAMA	Scientific Apparatus Makers Association
SBC	Standard Building Code
SCADA	system control and data acquisition
SMACCNA	Sheet Metal and Air Conditioning Contractor's National Association
SMUD	Sacramento Municipal Utility District
SPS	special protection system

SSPC	Steel Structures Painting Council
SSVT	station service voltage transformer
TCW	total class weight
TIA	Telecommunication Industry Association
TIMA	Thermal Insulation Manufacturers Association
UARP	Upper American River Project
UBC	Uniform Building Code
UFC	Uniform Fire Code
UL	Underwriters Laboratories
UMC	Uniform Mechanical Code
UPC	Uniform Plumbing Code
UPS	uninterrupted power source
USACE	United States Corps of Engineers
USBR	U.S. Bureau of Reclamation
USCS	Unified Soil Classification System
USFS	U.S. Forest Service
VSPE	variable speed power electronics
WECC	Western Electricity Coordinating Council
WS	water surface

THIS PAGE DELIBERATELY LEFT BLANK

1 Introduction

1.1 Purpose and Scope

The purpose of this report is to document the design basis for the Preliminary Functional Design as well as to provide the foundation for the preliminary design criteria that will be further developed into the Owner's Design Requirements for the Design-Build contract.

The information contained in this report, along with the Preliminary Functional Design Drawings dated June 2015, served as the basis for the initial regulatory processes and the Opinion of Probable Construction Cost dated June 1, 2015. This report describes the operational, functional, and technical design criteria and will serve as the starting point for developing the Project's technical requirements of the design/builder RFP.

The information contained in this report is based on limited geotechnical information, volunteered turbine/generator supplier information, and preliminary hydraulic analyses. These documents are for information only and are not intended for procurement or construction.

2 Project Background

The Sacramento Municipal Utility District (SMUD) is a community-owned electric utility governed by a seven-member Board of Directors. Serving 614,000 customers and a total population of 1.46 million, SMUD is the sixth-largest public utility in the United States. SMUD is also a Balancing Authority (BA) within California, ensuring real-time system operations and engineering that support the reliable, safe, and cost-effective operation, control, and monitoring of bulk electric system generation and transmission assets within the BA area in a manner that is consistent with reliability standards established by WECC, NERC, and FERC.

SMUD is among the nation's leaders in promoting a sustainable power supply. In 2008, the SMUD Board adopted the most aggressive long-term carbon reduction goal of any utility in California. SMUD aims to reduce its greenhouse gas emissions from the generation of electricity to 10 percent of its 1990 levels by 2050. SMUD has also set a goal of attaining a renewable energy account of 20 percent by 2010 and 33 percent by 2020. To achieve these goals, SMUD is pursuing a wide range of alternatives, including energy efficiency, renewable power supplies, distributed technologies, and energy storage.

Within this mission of developing and implementing advanced technologies to achieve a sustainable power supply, SMUD is planning to construct the Iowa Hill Pumped-Storage Project. As a utility-scale energy storage technology, pumped-storage will play an important role in meeting a number of electric system challenges, including load following, regulation, renewable resource integration, capacity services, system reliability, grid stability, and voltage control.

The proposed Iowa Hill Pumped-Storage Project is a 400 MW development that highlights a number of advanced concepts and new technologies, including:

- Use of existing facilities, such as Slab Creek Reservoir to minimize environmental impacts, reduce overall costs, and shorten construction times.
- A new 6,300 ac-ft upper reservoir created by an embankment with advanced lining technology to minimize leakage and improve efficiency, built on top of the mountain adjacent to Slab Creek Reservoir.
- Three 133 MW variable-speed pump-generators, housed in an underground complex approximately 1,200 feet below the upper reservoir.
- An underwater inlet/outlet structure in Slab Creek Reservoir designed and operated to reduce fish entrainment, minimize turbidity, and preserve recreational opportunities.

Operation of the Iowa Hill Project would optimize the use of water to provide essential grid services, based on the cycling of water between the two reservoirs. During off-peak hours, when power is abundant and inexpensive, water would be pumped from Slab Creek Reservoir to the new reservoir for storage. During peak hours, water would be released from the new reservoir to flow down into the powerhouse.

The project is adjacent to and directly east of Slab Creek Reservoir, on the South Fork American River, about 6 miles northeast of Placerville (Figure 2-1). This area is referred to as Iowa Hill, named for a small peak on a ridge top overlooking Iowa Canyon and the South Fork American River canyon. The project area encompasses part of Slab Creek Reservoir and the adjacent canyon wall and rim of the South Fork

American River. The higher topography of the project area consists of numerous dissected and gently rounded peaks and ridges, with elevations ranging from about 3,100 feet to 2,800 feet (NGVD 29). From the top of the canyon rim, the steep canyon wall of the South Fork American River descends for over 1,000 feet down to Slab Creek Reservoir. A small, intermittent, west-flowing drainage flows through the project area and down the canyon wall to the South Fork American River. Numerous other gullies occur on the steep canyon slopes.

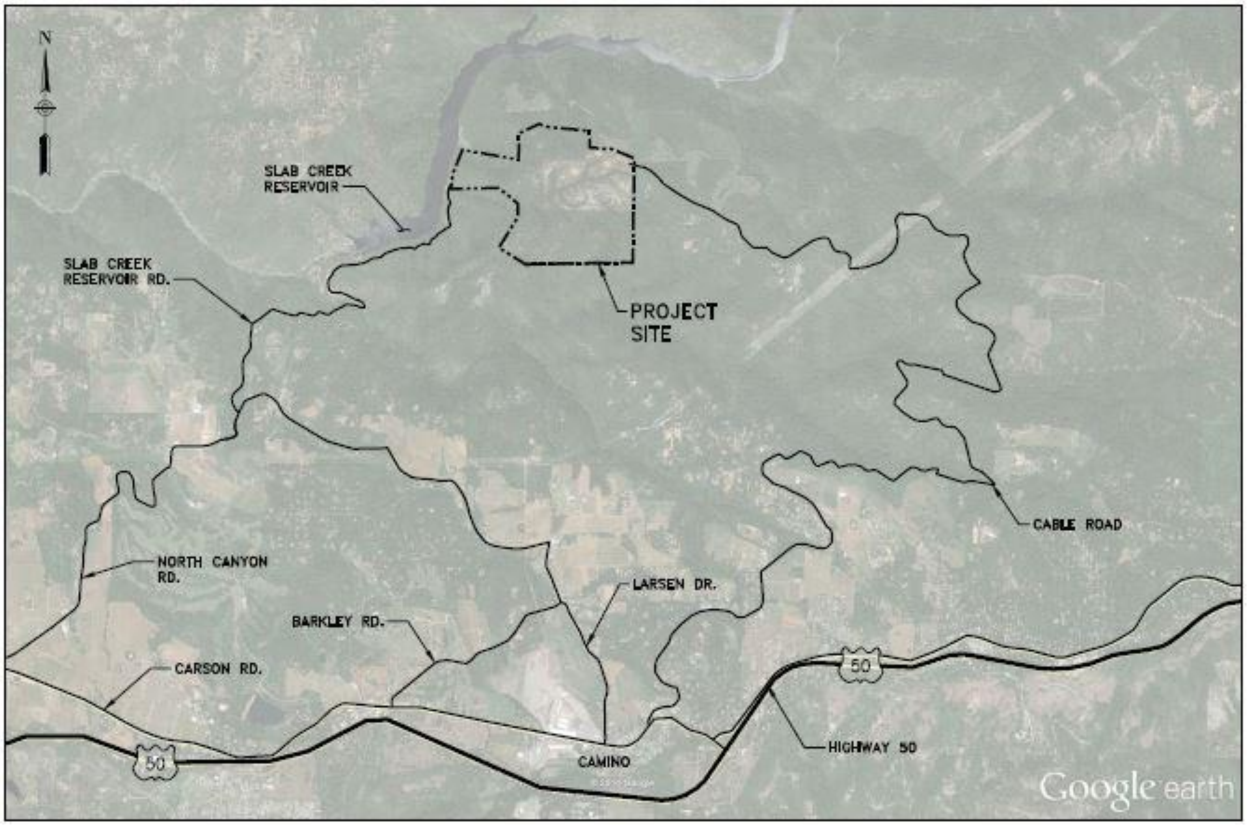


Figure 2-1. Project Location Map

Table 2-1 summarizes the key project characteristics.

Table 2-1. Project Characteristics

Project Location	Camino, California
Plant Type:	Pumped-Storage
Installed Plant:	400 MW nominal consisting of three 133 MW units (variable speed generator/motors)
Preliminary Plant Design Flow (Gen):	4,789 cfs maximum plant flow 303 to 1,590 cfs per unit
Preliminary Plant Design Flow (Pump):	4,549 cfs maximum plant flow 948 to 1,557 cfs per unit

Maximum Gross Head:	1,258 feet
Minimum Gross Head:	1,095 feet
Control:	Remote and local supervisory control Plant will serve as central supervisory control facility for the Upper American River Project (UARP) hydroelectric facilities

2.1 Regulatory Oversight

- The Federal Energy Regulatory Commission (FERC) is the lead federal agency having jurisdiction over the design, construction, and operation of the IHPSD.
- The State of California Department of Water Resources, Division of Safety of Dams (DSOD) is the lead state agency having jurisdiction over the design, construction, and operation of the Upper Reservoir and Dam.
    - The dam will be designed to be operated safely and in compliance with all FERC and DSOD design, monitoring, and operating criteria.
    - The Upper Reservoir and Dam will be integrated with SMUD's existing Owner's Dam Safety Program to ensure that the reservoir is operated and the dam maintained to preserve public safety and prevent a dam failure.
- The State of California State Water Resources Control Board is the lead state agency having jurisdiction over the design, construction, and operation of the Slab Creek Inlet/Outlet Structure.
- Other regulatory stakeholders include:
    - U.S. Forest Service
    - U.S. Fish and Wildlife Service
    - California Department of Fish and Wildlife
- The FERC Board of Consultants will provide oversight of the design and construction.

2.2 Construction Considerations and Expectations

SMUD has committed to the local community that the project will be constructed to minimize adverse impacts on the community and environment. The Upper American River Project (UARP) license includes the requirements for designing, constructing, and operating the IHPSD. The Relicensing Settlement Agreement dated January 2007 describes the requirements. Refer to SMUD's Compliance Management Tracking Tool, Attributes for Power Generation's Regulatory Requirements, for all license conditions related to the design and construction of the project. These license conditions will be incorporated into the Final Functional Design requirements.

2.3 Authorization

The project was authorized by the owner, Sacramento Municipal Utilities District.

3 Basis of the Preliminary Functional Design

This section describes the specific components of the IHP and provides the basis of the PFD for each of these project components.

3.1 Project Components

The major project components are outlined in Table 3-1, and the Project General Arrangement is shown in Figure 3-1.

Table 3-1. Major Project Components

Slab Creek (Lower) Reservoir:	Existing.
Slab Creek (Lower) Reservoir Inlet/Outlet Structure:	Reinforced concrete structure equipped with trash racks, isolation gates, a tunnel fill system, a tunnel drain vent, and equipment access into the tailrace tunnel.
Upper Dam and Reservoir:	Embankment dam consisting of impermeable lining, emergency spillway, leakage monitoring system, and emergency low-level outlet with trash rack and water control gate. Also includes a power inlet/outlet (below), and access road along dam crest. Total reservoir capacity: Approximately 6,700 acre-feet. Active reservoir capacity: Approximately 6,300 acre-feet. Maximum depth: 142 feet. Surface area: 71 acres at maximum normal operation water surface elevation. Instrumentation: Water level indication, geotechnical, and leak detection. Security: Vinyl coated chain linked fence with barbed wire, public safety signage, and video cameras.
Upper Reservoir Inlet/Outlet Structure:	A vertical, reinforced concrete hooded structure equipped with a trash rack. This inlet/outlet is ungated.
Power Shaft:	Concrete lined shaft, 19 feet nominal internal diameter, approximately 1,200 feet deep.
Headrace (High Pressure) Tunnel:	Concrete lined tunnel, approximately 900 feet long, 19 feet nominal internal diameter with a 19-foot-diameter manifold transition.
Headrace Tunnel Manifold:	Concrete lined tunnels, approximately 200 feet long, 14 feet nominal diameter.

Penstock Manifold:	Three penstocks, approximately 470 to 520 feet long, 9 feet nominal internal diameter. Approximately 250 feet of steel lining in each penstock extending from grout curtain to the isolation valves to prevent hydro jacking and water exfiltration. Concrete lined outside of steel lined section.
Draft Tube Extensions and Draft Tube Manifold:	Three Draft Tube Tunnels approximately 260 to 300 feet long, 12 feet nominal diameter. Partially steel lined to prevent hydro jacking and water exfiltration.
Tailrace (Low Pressure) Tunnel:	Concrete lined tunnel, approximately 1,700 feet long, 26 foot nominal internal diameter with a 19-foot-diameter manifold transition.
Surge Shaft/Facility:	None anticipated.
Powerhouse Access Tunnel (PHAT) & Portal:	Lined tunnel, approximately 2,950 feet long, 25 feet wide nominal internal width and 25 feet tall, horseshoe shaped. Serves as the primary vehicular access route for operations and maintenance.
Underground Powerhouse:	Approximately 66 feet wide by 370 feet long by 135 feet tall, located approximately 1,300 feet below the ground surface. Permanent support: Crown – Rock reinforcement with shotcrete-lining. Side and End Walls – Rock reinforcement with shotcrete lining as required. Groundwater control: Crown -Corrugated plastic, fiberglass, or steel roof drip shield groundwater collection system. Sidewalls - groundwater deflection/collection system at prominent joints if present, drain holes to collect and direct water. Equipped with three fast-responding variable-speed pump-turbine generator/motors, power electronics, electrical and mechanical auxiliary equipment, switch-gear, protection, control equipment, and an overhead crane. Includes IHPSD as described below.
IHPSD Education Center (IHPSD):	Provides an educational interface between the community and the IHPSD, one of the units will be designed and configured to facilitate the public's viewing of the generator and control systems that make the IHPSD a unique hydroelectric station.
Pump-turbine:	Three single-stage Francis-type units; each unit's nameplate capacity rated at approximately 133.3 MW nominal.
Motor-generator:	Three direct-coupled 16.5 (or 18) kV fast responding variable

	speed motor-generators; each rated at approximately 150 MVA.
Bus Tunnels:	Three tunnels, approximately 26 feet wide by 100 feet long by 50 feet tall, located at the main deck elevation. Same support and groundwater control strategy as used for the underground powerhouse.
Draft Tube/Transformer Cavern:	Approximately 47 feet wide by 345 feet long by 45 feet tall, located approximately 1,300 feet below the ground surface. Same support and groundwater control strategy as used for the underground powerhouse. Equipped with 16.5 (or 18 kV) / 230 kV step-up transformers rated at 175 MVA, overhead raceway, and high voltage cables. Includes independent smoke control system and blast panels.
Utility Shaft:	Vertical shaft with rock reinforcement, approximately 19 feet nominal diameter by 1,400 feet deep. Lined or unlined, to be developed based on infiltration limits that will be determined with the groundwater monitoring program and USFS agreement. Provides passage for the high voltage cables to the surface, and ventilation and stairs for emergency egress and inspection. Communications (voice/data), auxiliary power cables, and lighting will also be provided in the utility shaft.
Utility Shaft Building:	Building on top of the utility shaft to secure the utility shaft and house the ventilation fans, communication equipment, and backup battery banks, and also provide emergency egress from the underground powerhouse. A stationary backup generator will be located outside the utility shaft building.
Switchyard:	Switchyard will be a breaker-and-half configuration and located on the surface adjacent to the Upper Reservoir to accommodate 230 kV and Station Service equipment. There will be three 230 kV circuits connecting the switchyard to the Powerhouse, one circuit for each motor-generator.
Generation-Tie:	There will be three 230 kV circuits connecting the switchyard to SMUD’s existing transmission lines. The generation-tie (gen-tie) transmission line will connect the switchyard and the existing transmission lines. The gen-tie will be approximately 1.8 miles long, crossing through private property, U.S. Forest Service lands, and connected with existing SMUD 230 kV circuits. The gen-tie transmission towers will be brown-tinted galvanized steel mono-pole type.
Telecommunications:	Communications, voice, and radio communications will be provided by digital microwave and fiber optic cables. A

	microwave tower will be constructed near the switchyard and switchyard control module and integrated with SMUD's telecommunication system. A new microwave tower will be constructed at Slate Mountain because there is no space for an additional microwave dish on the existing microwave tower. Fiber optic cables will be carried on the 230 kV transmission towers via OPGW and integrated with SMUD's telecommunication system.
Access Roads:	The following access roads will be constructed or improved: • Slab Creek Reservoir Road will be improved and maintained to provide project access to the site. Public access will be controlled at security control stations near the intersection of Slab Creek Reservoir Road and North Canyon Road and Chute Camp Road. • Boat Ramp Road will be improved to an 18-foot travel width over a length of 5,000 feet with an all-weather surface consisting of 8 inches of compacted Class 2 Aggregate Base Rock. Boat Ramp Road includes 3,600 feet along Chute Camp Road and an additional 1,400 feet from Chute Camp Road to Slab Creek Reservoir. The improvements are per agreement with the USFS and are to support the Design-Build Contractor's approved construction work plan and to improve recreation access to the Slab Creek boat ramp. • Long Canyon Access Road will be constructed as a 14-foot travel width over a length of 8,800 feet with an all-weather surface consisting of 8 inches of compacted Class 2 Aggregate Base Rock. Long Canyon Access Road will be constructed from Boat Ramp Road (Chute Camp Road) up to the existing Cable Point Road. The new road will provide construction and O&M access to the Upper Reservoir from Slab Creek Reservoir Road.
Visitor's Center (Camino):	Provides an interface between the project stakeholders and the IHPSD, a visitor's center will be constructed and equipped to demonstrate the value of hydroelectric generation and the benefits of variable speed pumped storage to SMUD's customers and the public.

Figure 3-1. Project General Arrangement

THIS PAGE DELIBERATELY LEFT BLANK

3.2 Water Conveyance System

3.2.1 General

In generate mode, the water conveyance system transports water from the Upper Reservoir to the turbines and to Slab Creek Reservoir via the Slab Creek Inlet/Outlet Structure. In pump mode, the water conveyance works in reverse to provide water for the pumps to elevate to the Upper Reservoir. The water conveyance system consists of the following components, listed in order from the Upper Reservoir to Slab Creek Reservoir:

- Upper Reservoir Inlet/Outlet (see Upper Reservoir)
- Power Shaft
- Headrace Tunnel
- Penstock Manifold (to the upstream flange face of the Turbine Isolation Valve)
- Draft Tube Manifold (from the downstream flange of the Draft Tube Gate Valve)
- Tailrace Tunnel
- Slab Creek Inlet/Outlet

3.2.2 Description of Components

3.2.2.1 Upper Reservoir Inlet/Outlet Structure

The Upper Reservoir I/O structure is located within an excavated area in the Upper Reservoir, extending about 70 feet outward from the outer perimeter of the cylindrical I/O structure. The Upper Reservoir invert (set at approximately Elevation [El.] 2,933 feet) will slope down to the excavated area at a slope of 1 Horizontal (H) to 4 Vertical (V). The 1H to 4V slope was based on initial findings indicating that the subsurface ground is expected to be bedrock. The invert of the excavated area will be paved and slope toward the I/O structure at 10H to 1V. There will be a 4-foot-high ledge around the perimeter of the I/O inlet to guard against equipment or personnel accidentally entering the I/O. The I/O structure and concrete-paved perimeter apron are an integral part of the lined Upper Reservoir, and must be designed with water stops and watertight connections to the adjacent reservoir lining system.

The I/O structure is octagonal in plan and includes a central “cone” to help guide the flow toward 1H to 20V transition section leading to the 19-foot-diameter shaft. The transition section will assist in spreading (or converging) the flow and decreasing head losses during pumping and generating operating modes. The structure includes a hood to decrease the potential for surface vortices to form during the generate mode. In addition, the structure includes eight vanes to guide flow, dissipate vortices, and support the hood.

3.2.2.2 Headrace Tunnel

The headrace tunnel for the project will include a 1,200-foot-deep vertical power shaft; an elbow; and a 900-foot-long, near-horizontal high-pressure tunnel. It is assumed that the headrace system, measured from the Upper Reservoir transition section to the manifold will be 19 feet in diameter and fully lined. This preliminary tunnel size was based on permissible water velocities and regulating characteristics.

It is assumed that excavated material will be removed via the penstock bypass and access tunnel. Following construction, a tunnel plug would need to be installed. On the dry side of the plug, a sump and dewatering system will be installed to remove seepage from the low point in the access system.

3.2.2.3 Manifold and Penstocks

The manifold configuration extends from the headrace tunnel and narrows down to diameters of 14 and 9 feet, respectively. The manifold will be concrete lined. Waters collected will be pumped to the powerhouse station dewatering sump for proper disposal.

3.2.2.4 Penstocks

Three penstocks extend from the manifold to the powerhouse (one for each unit). Each penstock will be 9 feet in diameter and approximately 381 to 454 feet long. As currently configured, the penstocks will be constructed with a steel lining measuring 289 feet long, with the remainder lined with reinforced concrete. The steel lining will be encased in structural backfill and contact grouted. The rock mass at the end of the steel lining will be pressure grouted to seal the rock mass at and near the transition of the steel lining and concrete lining. A triple radial pressure grout curtain will be located on each side of the steel/concrete interface.

3.2.2.5 Surge Chambers

Phase 1 hydraulic transient analysis determined that no surge chambers will be required at the project for the assumed hydraulic and operational parameters. A more detailed hydraulic analysis is expected to be performed by the original equipment manufacturer/engineering, procurement, and construction (OEM/EPC) contractor. This would include confirmed unit rotational inertia, pump-turbine-specific hydraulic characteristics, and more detailed modeling of the water conveyance system to further support the initial indication that a surge chamber will not be required.

3.2.2.6 Unit Draft Tube Tunnels and Gates

The unit draft tube tunnels will connect the pump-turbine draft tubes to the tailrace tunnel. It is assumed that the unit draft tube tunnels will have a circular cross section with a diameter of approximately 12 feet. The draft tube manifold will expand to 19 feet and then to 26 feet at the beginning of the tailrace tunnel. It is assumed that the bifurcations will be formed by the intersection of conical sections to minimize hydraulic losses in both pump and generate modes.

The unit draft tube tunnels will be steel lined for a distance of approximately 156 feet downstream of the power and concrete lined for the remaining tunnel section extending to the concrete-lined tailrace tunnel. The draft tube tunnels will vary in length from approximately 245 feet to 213 feet—from the end of the pump-turbine draft tubes to the centerline intersection at the tailrace bifurcation. Hydraulically operated draft tube gates will be located approximately 100 feet downstream of the powerhouse wall.

3.2.2.7 Tailrace Tunnel

A single 26-foot-diameter tailrace tunnel will extend approximately 1,580 feet from the draft tube tunnels to the Lower Reservoir I/O. This tunnel alignment was selected to provide the most direct route for the I/O and powerhouse. It is assumed that excavation of the tailrace tunnel will be initiated from the powerhouse side. It should be noted that the underground power complex is expected to have redundant means of protection against flooding (from the Slab Creek Reservoir) during construction. Such protections could include any combination of the following systems:

- Slab Creek Reservoir Temporary Cofferdam
- Slab Creek Reservoir Permanent I/O Structure Gates
- Tailrace Tunnel Temporary Bulkhead
- Hydraulically Operated Draft Tube Gates

3.2.2.8 Tunnel Plugs

Access tunnels utilized for construction shall be appropriately plugged from the water conveyance tunnels with a watertight wedge-shaped concrete plug. Plugs shall be designed to hydraulically isolate select components of the facility.

3.2.2.9 Slab Creek Inlet/Outlet (I/O) Structure

3.2.2.9.1 General

The Slab Creek inlet/outlet structure will provide the hydraulic portal between the IHPSD and the existing Slab Creek Reservoir.

The Slab Creek Reservoir I/O will consist of a gated structure constructed in the dry behind a natural rock plug cofferdam. After the vertical gated structure is constructed, the natural rock plug would be removed via controlled blasting and underwater excavation; the canal invert would be prepared and precast concrete segments would be lowered in place extending from the I/O into the waters of the Slab Creek Reservoir. The reinforced concrete gated will measure approximately 30 feet x 52 feet wide and 160 feet high. The tailrace tunnel will bifurcate approximately 50 feet downstream of the vertical gates and penetrate the vertical gate structure near the invert elevation of 1,720 feet. The structure will contain two steel headgates to isolate the tailrace tunnels from Slab Creek Reservoir. The headgates will be permanently stored in slots within the structure and raised/lowered into position by a mobile crane. A vertical access shaft will be located within the vertical gate structure to provide personnel access to the unwatered tailrace tunnel.

The structure will have an extended entrance that tapers from the inlet area (at the trash racks) to the tailrace tunnel. The proposed arrangement was selected to improve hydraulics; prevent formation of inlet vortices during the pump mode; reduce flow separation, causing hydraulic losses and trash rack vibration.

The structure will be constructed within a sinking cut adjacent to the water of the Slab Creek Reservoir such that the natural cofferdam remains in place during erection of the structure. All excavated rock faces are assumed to require some rock bolting for stability. The orientation of the joint sets that control the rock face stability are not yet known; however, a bolting pattern of 20-foot-long bolts on a 5-foot grid has been assumed, with longer bolts directly over the tunnel at the portal face. Rock faces against which the intake concrete will be placed are to be excavated vertically.

Once the vertical gate structure has been constructed, excavation of the remaining channel will commence. The discharge channel will be approximately 50 feet wide at the front face of the structure and extend approximately 120 feet into the waters of the Slab Creek Reservoir. Once the channel has been excavated, an I/O extension will be constructed via placement of precast concrete sections on a prepared invert surface. Once the I/O extension is constructed, rockfill will be placed on top of it to create a natural shoreline effect.

The vertical gate structure will be constructed with a 24-inch-diameter bypass line and valve to permit controlled filling of the tailrace tunnel. The headgates are not designed to be lowered into place under flow; therefore, pressure equalization across the gate will need to occur prior to raising and lowering of the gate. It is assumed that a lifting beam is will be provided with the headgates.

The I/O will include two vertical gates (bulkheads) capable of sealing and isolating the tailrace tunnel from Slab Creek Reservoir. The service gates will be lowered and raised by a mobile crane. Fixed barriers will prevent access from the outboard edge of the I/O structure to the water surface in order to prevent jumping and diving into the water.

3.2.3 Operating and Maintenance Requirements

3.2.3.1 Access

3.2.3.1.1 Tunnels and Shafts

- Dry access to the upper reservoir I/O, power shaft, and headrace tunnel is accomplished by draining the Upper Reservoir.
- Service gates in the lower reservoir I/O provide isolation from the Slab Creek Reservoir to permit dewatering of the water conveyance system below tailwater via the station unwatering sump.
- A personnel access hatch is provided in the lower reservoir gate structure on the powerhouse side of the service gates.
- The vertical shaft is accessed via lowering a personnel basket by mobile crane.
- The penstocks and draft tube may also be accessed via penstock manway and draft tube manway located in the powerhouse basement.

3.2.3.1.2 Slab Creek I/O

- Vehicle access to the I/O will be provided by the Chute Camp and Boat Ramp Access Roads.
- Parking will be provided adjacent to the I/O for commercial vehicles. Provisions for trailers will not be provided.

- The top of the gated I/O structure will be at elevation 1,875 feet, approximately the same elevation as the adjacent parking area.
- A vertical access shaft will be located within the vertical gate structure to provide personnel access to the unwatered tailrace tunnel.

3.2.3.2 Design Occupancy

- Water conveyance tunnels, shaft, and both the Upper I/O and Slab Creek I/O will not be designed for continuous occupancy. Unwatered access by personnel will be necessary for condition assessments and maintenance and will follow the permit required confined space requirements.
- Access hatches for inspection are included.

3.2.3.3 Groundwater Inflows and Exfiltration

- Tunnel/shaft infiltration/exfiltration estimates will be developed during Final Functional Design and will be integrated into the overall hydrogeologic model for the project to assess impacts on the groundwater regime and associated environment impacts. Anticipated infiltration/exfiltration rates will be used to develop groundwater control requirements that will be included in the Design Requirements.

3.2.4 Geometry

- Sizing and lining requirements are provided in Table 2-1.
- Straight tunnel sections were utilized to the maximum extent possible.
- Minimum curve radius was 100 feet at bifurcation.
- Tunnel intersections were maintained at a minimum angle of 60 degrees.
- Maximum tunnel inclination was approximately 12% for ease of construction.

3.2.5 Water Conveyance Tunnels and Shaft Lining

3.2.5.1 Lining Requirements

The power shaft, headrace, and tailrace tunnels will be fully lined with concrete. Penstocks are to be steel-lined upstream of the powerhouse for a distance of approximately 250 feet.

The water conduit sizes were developed based on the hydraulic parameters, performance objectives and operational requirements of the system as well as economic considerations.

3.2.5.2 Minimum Rock Cover Criteria for Unlined High-pressure Headrace Tunnels

The results of hydraulic jacking tests indicate the ratio of minimum stress (across fractures) to lithostatic stress ranges from 0.55 to 0.70. A minimum stress of 0.55 was used as a basis to confirm that the headrace tunnel as depicted in the PFD Drawings has adequate rock cover.

Table 3-2 summarizes the main criteria used in the confinement evaluation. Figure 3-2 provides total pressure at jacking, in situ stress, and operating pressure (psi).

Table 3-2. Summary of Confinement Evaluation Criteria

Rock Unit Weight (Max.)	172 pcf
Maximum Pool Elevation	3,073 feet
Pump-Turbine Elevation	1,531 feet
Minimum Static Factor of Safety	1.25
Minimum Transient Factor of Safety	1.10
Maximum Static Pressure	668 psi
Maximum Transient Pressure	802 psi

Preliminary confinement evaluations indicate that positioning the powerhouse cavern and downstream end of the high-pressure headrace tunnel, such that there is approximately 1,350 feet of vertical rock cover, will provide sufficient confinement.

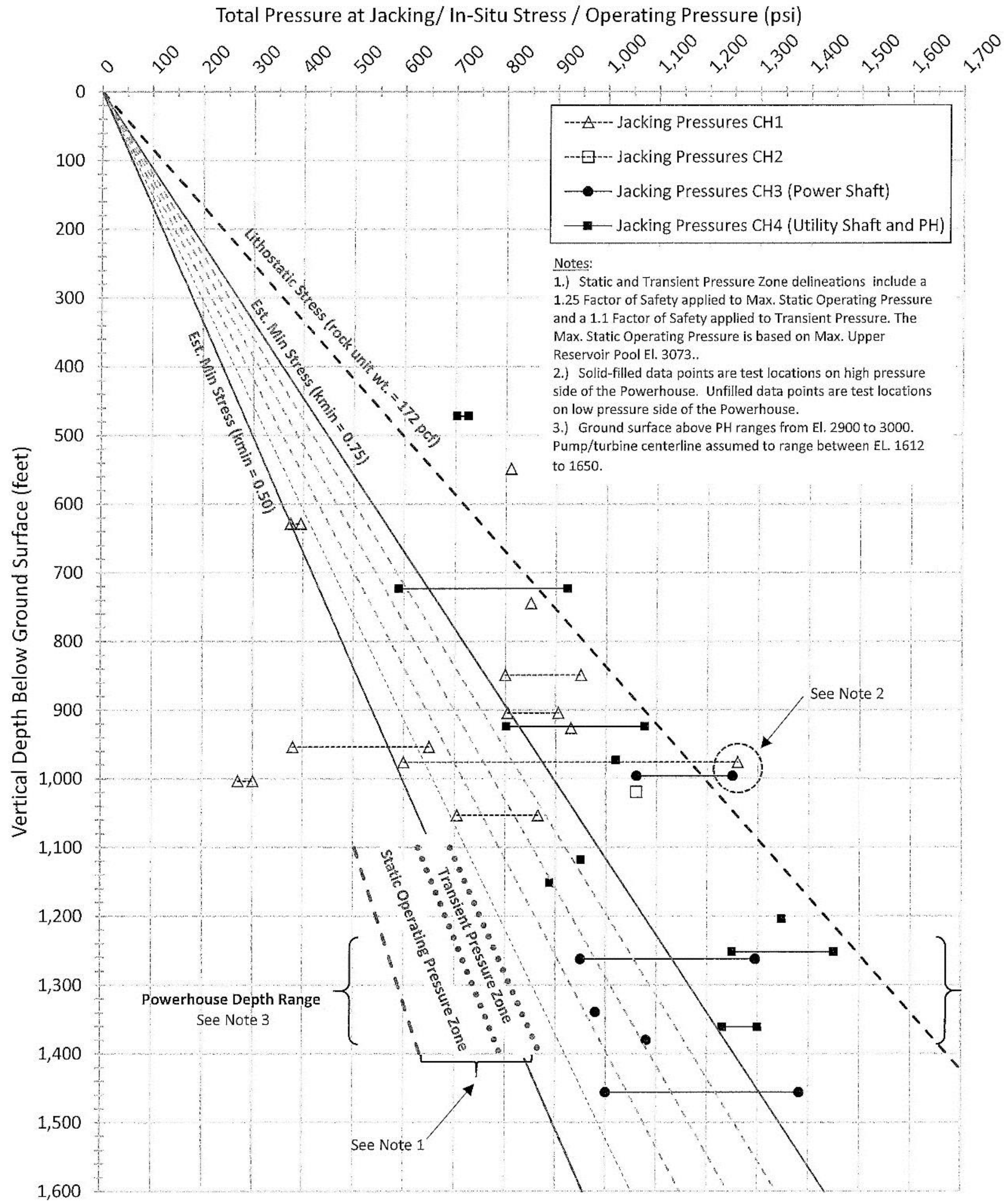


Figure 3-2. Total Pressure at Jacking / In Situ Stress / Operating Pressure (psi)

3.2.6 References, Codes, and Standards

3.2.6.1 Concrete Design

- American Concrete Institute (ACI) 350, Code Requirements for Environmental Engineering Concrete Structures.

3.2.6.2 Steel Design

- American Institute of Steel Construction (AISC), Steel Construction Manual, 14th Edition.

3.2.6.3 Plug Design

- Lang, B. 1999. Permanent Sealing of Tunnels to Retain Tailings or Acid Rock Drainage. In *Proceedings of the IMWA Congress (Mine, Water, and Environment),* Sevilla, Spain.

3.2.6.4 Penstock Design

3.2.6.4.1 General

- Electric Power Research Institute (EPRI). June 1987. *Design Guidelines for Pressure Tunnels and Shafts*. EPRI AP-5273.
- U.S. Army Corps of Engineers (USACE). May 1997. *Engineering and Design, Tunnels and Shafts in Rock*. EM 1110-2-2901.

3.2.6.4.2 Buckling

- Berti, D., R. Stutzman, E. Lindquist, and M. Eshghipour. 1998. Buckling of Steel Tunnel Lining under External Pressure. *Journal of Energy Engineering,* 124(3).

3.2.6.5 Underground Support Design

- American Society of Civil Engineers (ASCE). 1989. *Civil Engineering Guidelines for Planning and Designing Hydroelectric Developments, Volume 2 – Waterways (Division 2, Part A)*. New York, NY: ASCE.
- Barton, N., R. Lien, and J. Lunde. 1974. Engineering Classification of Rock Masses for the Design of Tunnel Support. *Rock Mech*. 6: 189–236.
- Brekke, T.L., and B.D. Ripley. 1986. Design Strategies for Pressure Tunnels and Shafts, Final Report prepared by University of California, Berkeley for Electric Power Research Institute, EPRI Contract No. RP-1745-17.
- Deere, D.U. 1983. Unique Geotechnical Problems at Some Hydroelectric Projects. In *Proceedings of 7th Pan-American Soil Mechanics Conference*, Vancouver, 865–888.
- Grimstad, E., and N. Barton. 1993. Updating the Q system for NMT. In *Proceedings of the International Symposium on Sprayed Concrete: Modern Use of Wet Mix Sprayed Concrete for Underground Support*. Oslo: Norwegian Concrete Association.
- Hoek, E., and M.S. Diedrichs. 2006. Estimation of Rock Mass Modulus. *International Journal of Rock Mechanics and Mining Sciences*, 43: 203–215.
- Proctor, R.V. and T.L. White. 1968. *Rock Tunneling with Steel Supports,* with an Introduction to Tunnel Geology by Karl Terzaghi. Youngstown, Ohio: Commercial Shearing.
- U.S. Bureau of Reclamation (USBR). 1994. Chapter 4: Tunnels, Shafts, Caverns. In *Design Standards No. 3 – Water Conveyance Systems*. Denver, Colorado: United States Department of the Interior, Bureau of Reclamation, Technical Service Center, DS-3(4)-2.

3.2.6.6 I/O Facility Design

- Jacobs Associates and HDR. 2015. Iowa Hill Pumped Storage Development Project Preliminary Functional Design – Power Complex, Volume 3: Slab Creek Inlet/Outlet Design Basis Memorandum.

3.3 Underground Powerhouse Complex

The powerhouse complex will include the main access tunnel, powerhouse, low-voltage bus tunnels, transformer gallery, and high-voltage utility shaft. Listed below are brief descriptions of each. It should be noted that, depending on the results of future geologic subsurface exploration, an upstream drainage tunnel may be an option to intercept seepage and relieve hydrostatic pressure imposed on the upstream powerhouse wall and steel-lined penstock sections (during tunnel unwatering). An intercept tunnel has not been assumed in the PFD and preliminary wall and tunnel support designs reflect an assumption of full hydrostatic pressure.

A transient analysis was performed as part of the preliminary functional design utilizing ***SIMSEN*** software, representative operational and unit characteristics, and the water conduit sizing and general arrangement shown. The results of the transient analysis recommend a minimum unit centerline elevation of 1,531 feet, based on a critical load case of two units tripping simultaneously with a delayed trip of the third unit a few seconds later. The actual unit centerline elevation shall be based on more detailed studies, including specific unit characteristics and data provided by the selected OEM as well as operational objectives as defined by SMUD.

3.3.1 Powerhouse

The powerhouse cavern will measure approximately 376 feet long by 66 feet wide by 119 feet tall (measured from the basement floor to the cavern spring line). The machine hall floor will accommodate three vertical, Francis-type reversible pump-turbine/motor-generator units rated at 133.33 MW each; the control room; a visitor area; and an area for an erection and loading bay.

The powerhouse substructure, which encases and supports the pump-generating units, will be constructed of reinforced concrete with floors and passages provided to accommodate all balance of plant (BOP) and ancillary equipment, cabling, piping, and support facilities. In addition to normal operation and maintenance, there will be sufficient space available to accommodate construction as well as the complete disassembly of a single unit.

A suspended/or self-supporting metal ceiling will be included to shield the machine hall floor from any minor rock spalls or water inflows, and allow access to the crown of the cavern for monitoring and maintenance if required.

As currently configured, the primary floor elevations are as follows:

- Isolation valve and basement floor elevation: 1,519 feet
- Distributor centerline elevation: 1,531 feet
- Pump-turbine floor elevation: 1,540 feet
- Motor-generator floor elevation: 1,558 feet

- Machine hall floor elevation: 1,579 feet

The pump-turbine scroll cases will be fully embedded with the runner centerline elevation. The main thrust bearing will be supported from concrete haunches immediately below the motor-generator. Access to the draft tubes will be from a man-door at basement floor level. The head covers and servomotors can be accessed from the pump-turbine floor level and the underside of the motor-generator from the motor-generator floor. Removable hatch covers on the machine hall and motor-generator floors will provide access to the inlet valves by the main crane. Hatches will also be provided in the main service bay to allow access to the main transformer for servicing or maintenance.

3.3.1.1 Control Room

The control room is located on the machine hall floor, and is expected to include the following equipment and facilities:

- Operator console
- Relief operator console
- Voice and radio requirements
- Data requirements
- Wi-Fi requirements
- Storage requirements
- Security (access control, CCTV)
- Fire alarm system

3.3.1.2 Powerhouse Public Access Area

As instructed by SMUD, public access areas will be provided at the machine hall, generator, and turbine floor levels in the southwest area of the powerhouse.

3.3.1.3 Low Voltage Bus Tunnels

Three low voltage tunnels measuring approximately 26 feet wide, 106 feet long, and 50 feet tall containing variable speed electronics will extend from the powerhouse to the transformer gallery. Each tunnel will contain a suspended metal roof to protect the power electronics from loose rock fragments and seepage emanating from the crown.

3.3.1.4 Transformer/Draft Tube Gate Gallery

The transformer/draft tube gate gallery will be approximately 300 feet long, 47 feet wide, and 35 feet tall (floor elevation to spring line). A suspended metal ceiling will protect the gallery from minor roof spalls and water inflows. The gallery invert will be concrete lined. It is assumed that the gallery will house four 3-phase main transformers (including one spare). It is assumed that the transformers will be SF_6 technology. A rail system will allow removal of the transformers for maintenance and/or repair. Pits will provide access to the bonneted draft tube gates.

3.3.1.5 Unit Draft Tube Tunnels and Gates

The unit draft tube tunnels will connect the pump-turbine draft tubes to the tailrace tunnel. The unit draft tube tunnels will have a circular cross section with a diameter of approximately 12 feet. The draft tube manifold will expand to 19 feet and then to 26 feet at the beginning of the tailrace tunnel. The bifurcations are will be formed by the intersection of conical sections to minimize hydraulic losses in both pump and generate modes.

The unit draft tube tunnels will be steel lined for a distance of approximately 156 feet downstream of the powerhouse and concrete lined for the remaining tunnel section extending to the concrete-lined tailrace tunnel. The draft tube tunnels will vary in length from approximately 245 feet to 213 feet from the end of the pump-turbine draft tubes to the centerline intersection at the tailrace bifurcation. Hydraulically operated draft tube gates will be located approximately 100 feet downstream of the powerhouse wall.

3.3.2 Powerhouse Cavern Operating and Maintenance Requirements

3.3.2.1 Access

- Diesel vehicle access will be provided to the powerhouse complex.
- Access will be provided to haul in, haul out, load, and unload the largest pieces of equipment that will be transported to or from the powerhouse complex during and after construction to support future outages.
- Refer to Section 3.4 for Powerhouse Access Tunnel requirements.

3.3.2.2 Design Occupancy

The powerhouse complex will be designed for continuous occupancy.

3.3.2.3 Climate Controls

In general, the powerhouse temperature will be controlled to the approximately 72°F to 78°F range, largely for the electrical equipment protection and personnel comfort. The relative humidity should be in the 35% to 40% range. Because of some concentrated heat loads within the powerhouse, the temperature in some spots of the powerhouse will be higher than this average design temperature.

3.3.2.4 Watertightness

3.3.2.4.1 Groundwater Inflows

An estimate of the water inflow into the cavern complex will be developed during Final Functional Design and will be integrated into the overall hydrogeologic model for the project to assess impacts on the groundwater regime and associated environment impacts. The anticipated infiltration rates will be used to develop groundwater control requirements that will be included in the Design Requirements.

3.3.2.4.2 Groundwater Control

- A drip canopy water collection system is indicated in the caverns and bus tunnels. The canopy provides a 5-foot minimum clear space at the sidewall for inspection and future maintenance.
- A hanging pedestrian gangway is indicated for inspection/maintenance above the drip canopy.
- Collected groundwater is directed to the powerhouse sump locations.

3.3.3 Geologic Requirements and Parameters

- Orientation
    - Powerhouse and Transformer Caverns' longitudinal axis shall be aligned perpendicular to the strike of bedding/foliation +/- 15 degrees. The angle deviation will be evaluated during the secondary investigation phase.

- Support Evaluation (Kinematic)
    - Cavern support will have to stabilize rock wedges defined by the rock mass discontinuities (Table 3-3).

Table 3-3. Average Joint Set Orientation used for Preliminary Kinematic Evaluation

Source	Discontinuity Type		Strike (degrees)	Dip (degrees)	Dip Direction (degrees)
COBL Data	Bedding/ Foliation	CH-1	N36W	78NE	54
	Joint 1	J1	N44E	46NW	314
	Joint 2	J2	N32W	20SW	238
Field Mapping	Joint 3	J3	N5W	55SW	265
	Joint 4	J4	N53W	53SW	217
	Joint 5	J5	N81E	57SE	171
	Joint 6	J6	N32E	54SE	122

Key geologic parameters are presented in Table 3-4.

Table 3-4. Rock Mass Parameters

Unit	Rock Mass Parameters							
	Unit Weight (pcf)	UCS (psi)	GSI	m_b	s	a	Rock Mass Modulus (ksi)	Poisson's Ratio
Phyllite (Mean)	165	20,000	65	3.595	0.0144	0.502	3000	0.3
Phyllite (LB)	165	12,000	50	1.299	0.0023	0.506	800	0.3

- Cavern Support Summary
    - Bolts are double corrosion protected for longevity.
    - Overall factor of safety for wedge stability is at least 1.5.
    - Dowel/bolt steel yield factor of safety is greater than 1.8.
    - Rock dowels are cement grouted.

3.3.4 Mechanical Equipment and Systems

Listed below are the principal functional design characteristics for the mechanical equipment and systems.

3.3.4.1 Pump-turbine Equipment

3.3.4.1.1 Pump-turbine

3.3.4.1.1.1 System Function

Pump operation: The unit, driven by the motor-generator, pumps water from the Lower Reservoir (Slab Creek) to the Upper Reservoir.

Turbine operation: The unit drives the motor-generator, and the water stored in the Upper Reservoir flows into the Lower Reservoir.

3.3.4.1.1.2 Major Components

- Runner
- Shaft, pump-turbine
- Guide bearing
- Shaft seal
- Stay ring
- Spiral case
- Head cover
- Bottom ring
- Guide vanes and operating mechanism
- Servomotors
- Pump-turbine pit lining, walkways, and stairs
- Draft tube (steel lined)

- Set of operating equipment and systems

3.3.4.1.1.3 System Description

The pump-turbine will be installed with a vertical shaft; the guide bearing will be arranged in the head cover. The combined thrust and guide bearing of the motor-generator will be arranged in the lower bracket, with the upper guide bearing in the upper bracket.

The spiral case of the pump-turbine will be completely embedded in concrete, except for the access to the manhole.

Dewatering of the pump-turbine runner for start-up of the pump or during condenser operation (if applicable) will be achieved by compressed air.

Pressurization of the governor oil will be carried out by oil pumps. The necessary energy for closing of the pump-turbine wicket gates in case of an emergency will be stored in the oil-nitrogen accumulator / piston accumulator of the oil hydraulic pressure unit (HPU). The pump-turbine will be designed for a lifetime cycle of minimum 25 years with a minimum of 2,000 and a maximum of 4,000 starts/stops or mode changes per year. As an alternative, a synchronous motor-generator with a full-sized converter may be chosen (converter-fed synchronous machine, CFSM). As an alternative, a synchronous motor-generator with a full-sized converter may be chosen (converter-fed synchronous machine, CFSM).

The following shifting capabilities between operation modes will be required:

- Pump operation to turbine operation
- Turbine operation to pump operation
- Condensing mode operation

3.3.4.1.1.4 System Interfaces

- Cavern for the units, main building
- Main inlet valve (spherical valve)
- Cranes in cavern for the units and hoisting equipment
- Motor-generator
- Cooling water system
- Air pressure system
- Mobile oil cleaning system
- Auxiliary power supply
- Control system
- Protection system
- Cables (low voltage / sensor / fiber optics)

3.3.4.1.2 Governor Hydraulic System

3.3.4.1.2.1 System Function

There will be a dedicated governor hydraulic system consisting of an HPU and control cabinet for each pump-turbine.

3.3.4.1.2.2 Major Components

- Unit/speed governor control panel with human-machine interface (HMI) screen and programmable logic controllers (PLCs)
- Hydraulic fluid sump
- Multiple positive displacement pumps
- Pump suction strainers
- Filters
- Proportional control valves
- Directional control valves
- Hydraulic valve manifold
- Nitrogen pressurized accumulators for stored energy
- Heaters
- HPU instrumentation

3.3.4.1.2.3 System Description

The governor HPU will be located as close as possible to the pump-turbine wheel pit and servomotors to minimize the run of high-pressure hydraulic piping and system oil volume. Welded stainless steel piping is recommended. Flanges will be used only where necessary to facilitate piping disassembly for maintenance and will be of the SAE Code 61, O-ring, four-bolt type.

The control cabinet that interfaces with the HPU will provide local control and operating status for the HPU. This will include such information as what pumps are running, system pressure, and high-filter differential pressure alarms. The control cabinet will also provide local indication and control of pump-turbine speed, wicket gate position, spherical valve position, penstock pressure, pump prime indication, and runner tip pressure.

3.3.4.1.2.4 System Interfaces

Mechanical

- Governor hydraulic power unit (Figure 3-3)
- Pump-turbine
- Cooling water

Electrical

- Monitoring instrumentation
- Spherical valve controls
- Auxiliary AC power
- Auxiliary DC power
- Cables (low voltage / sensor / fiber optics)

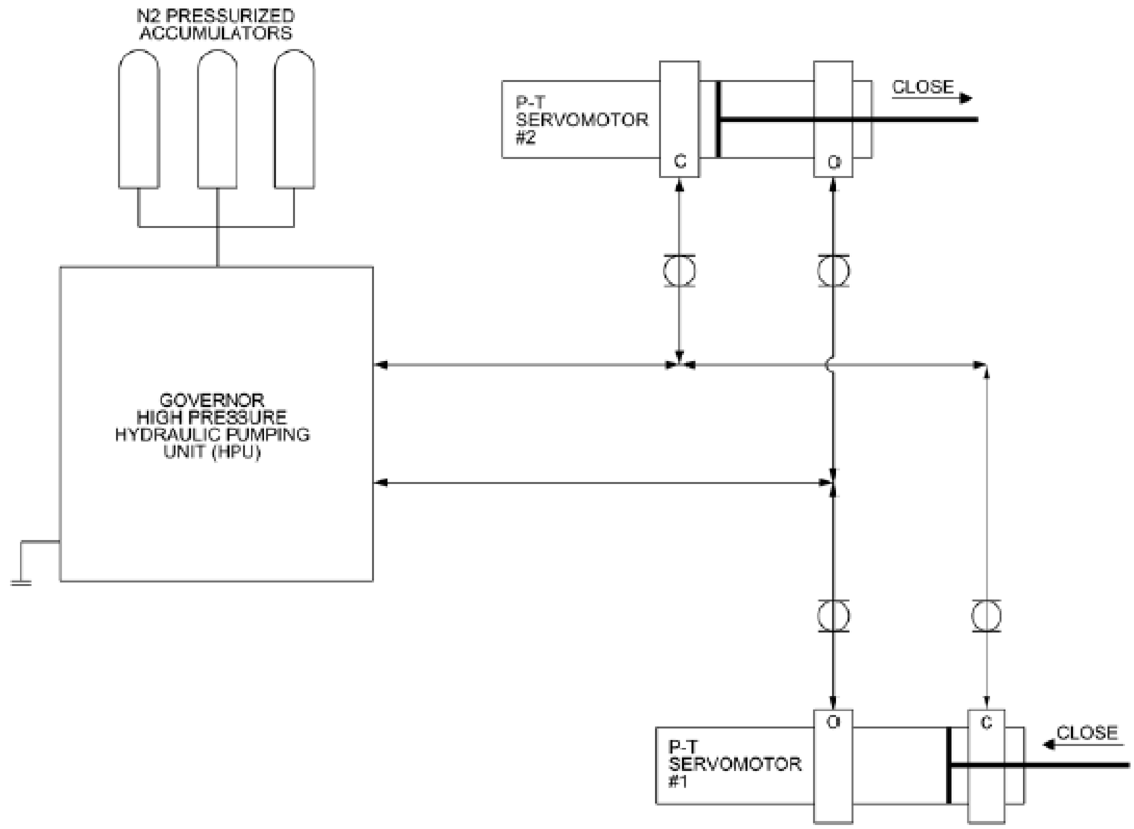


Figure 3-3. Governor Hydraulic System Conceptual Diagram

3.3.4.2 Water Conveyance Isolation

3.3.4.2.1 Pump-turbine Inlet Valves and Hydraulic System

3.3.4.2.1.1 System Function

Spherical-type inlet valves having an internal diameter of an estimated 6 feet will be provided to allow the pump-turbines to be isolated from the high-pressure penstocks.

3.3.4.2.1.2 Major Components

- Spherical valve body
- Spherical valve rotor with trunnions

- Upstream and downstream rotor seals
- Rotor lever arm and counterweights
- Valve hydraulic cylinder actuator, double acting
- Hydraulic power unit and stored energy accumulators
- Control panel
- Penstock expansion coupling
- Bypass piping, isolation valves, and pressure reducing valve

3.3.4.2.1.3 System Description

The upstream end of the valve will be bolted to a diffuser that extends from the penstock to the valve, and the downstream end will be joined to the scroll case through a flexible coupling. The flexible coupling will be removable to facilitate installation and removal/maintenance of the inlet valve. Provision will be made to allow access to the valve from the powerhouse crane through hatchways in the floors above.

Leakage through the inlet valve will be limited by seals upstream (i.e., maintenance) and downstream of the closed valve rotor. Movable seal pistons in the valve body, actuated by water under full head pressure, will slide into contact with fixed seal rings attached to the valve rotor when the valve is in the closed or open position.

The valve will be operated by a double-acting hydraulic cylinder actuated by high-pressure hydraulic fluid. The cylinder will be clevis-mounted to a bearing bracket bolted to an embedded baseplate. The cylinder will receive stored energy from a high-pressure hydraulic power unit with nitrogen-bottle-charged accumulators attached to the operating lever arm of the valve rotor. The valve will also be fitted with counterweights that are sized to close the valve on loss of pressure. The HPU will be located as close as possible to the inlet valve cylinder to minimize the run of high-pressure hydraulic piping and system oil volume. Welded, stainless steel piping is recommended. Flanges will be used only where necessary to facilitate piping disassembly for maintenance. (See Figure 3-4 and Figure 3-5.)

3.3.4.2.1.4 System Interfaces

Mechanical

- Penstock pressure for seal actuation
- Spherical valve hydraulic power unit
- Pump-turbine
- Penstock
- Drainage and dewatering
- Draft tube gates
- Cranes in cavern for the units and hoisting equipment

Electrical

- Monitoring instrumentation

- Governor and unit control
- Auxiliary AC power
- Auxiliary DC power
- Cables (low voltage / sensor / fiber optics)

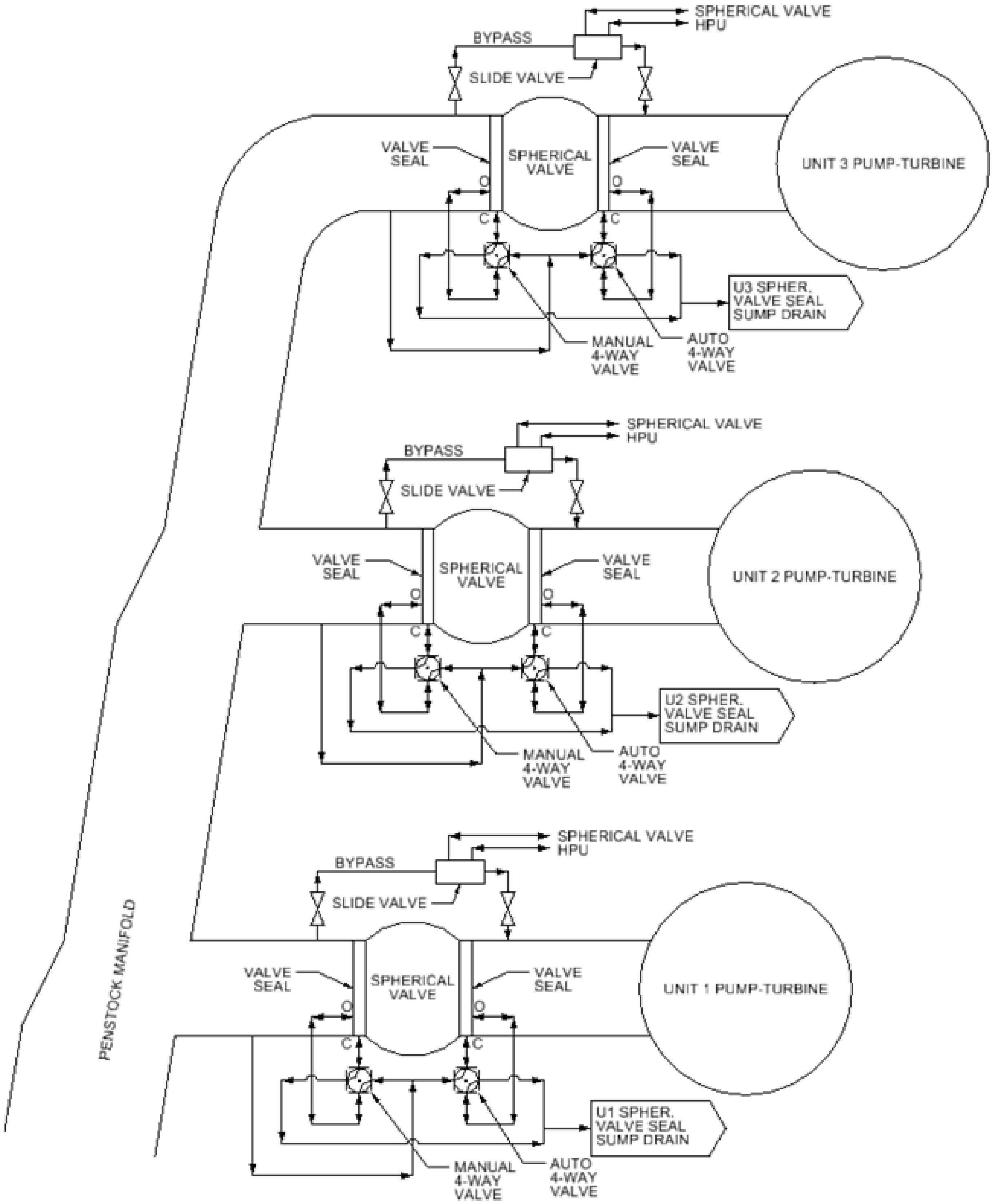


Figure 3-4. Spherical Valve Conceptual Diagram

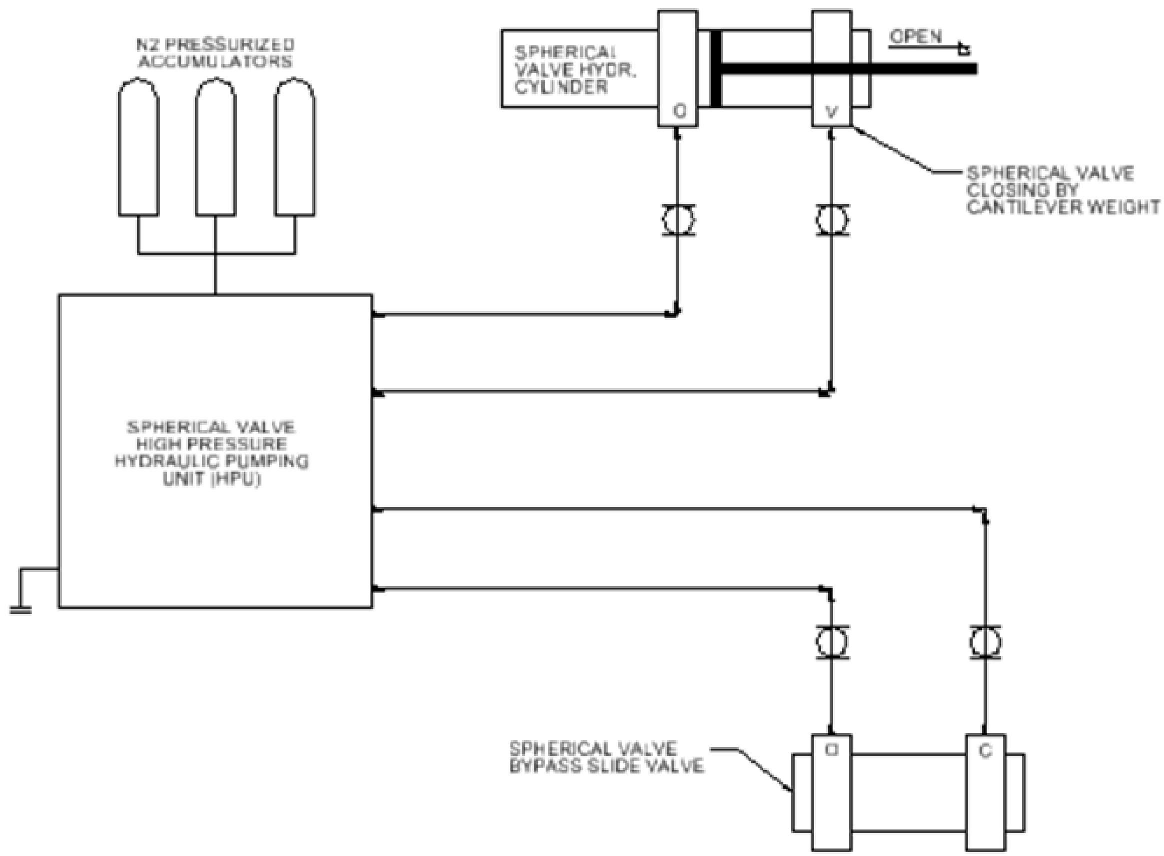


Figure 3-5. Spherical Valve HPU Conceptual Diagram

3.3.4.2.2 Draft Tube Gates

3.3.4.2.2.1 System Function

Draft tube gates will be installed in the draft tube tunnels. The draft tube gates will isolate the pump-turbine elbow from tailwater if other units are in operation so that maintenance work may be performed. The draft tube gates will only be closed for maintenance purposes. The gates shall be able to close under balanced water conditions (no flow).

3.3.4.2.2.2 Major Components

- Bonneted gate valve
- Bypass piping with isolation and pressure reducing valves
- Hydraulic cylinder actuator
- Gate locks with antiflutter provisions
- Hydraulic power unit
- Control panel

- Instrumentaion

3.3.4.2.2.3 System Description

The draft tube gates (Figure 3-6) will be of the bonneted gate type, oriented to operate vertically, with the gate being completely retracted from the flow path when in the open position. The assemblies will be of welded steel construction, reinforced on the outside by means of ribs or structural shapes, and provided with means for secure embedment in the surrounding concrete. The draft tube gates will be operated by hydraulic cylinders and equipped with locking devices that will secure the gate in the open position and prevent flutter and vibration due to flow.

3.3.4.2.2.4 System Interfaces

Mechanical

- Hydraulic power unit
- Pump-turbine
- Spherical valve
- Draft tube

Electrical

- Monitoring instrumentation
- Unit controls
- Auxiliary AC power
- Auxiliary DC power
- Cables (low voltage / sensor / fiber optics)

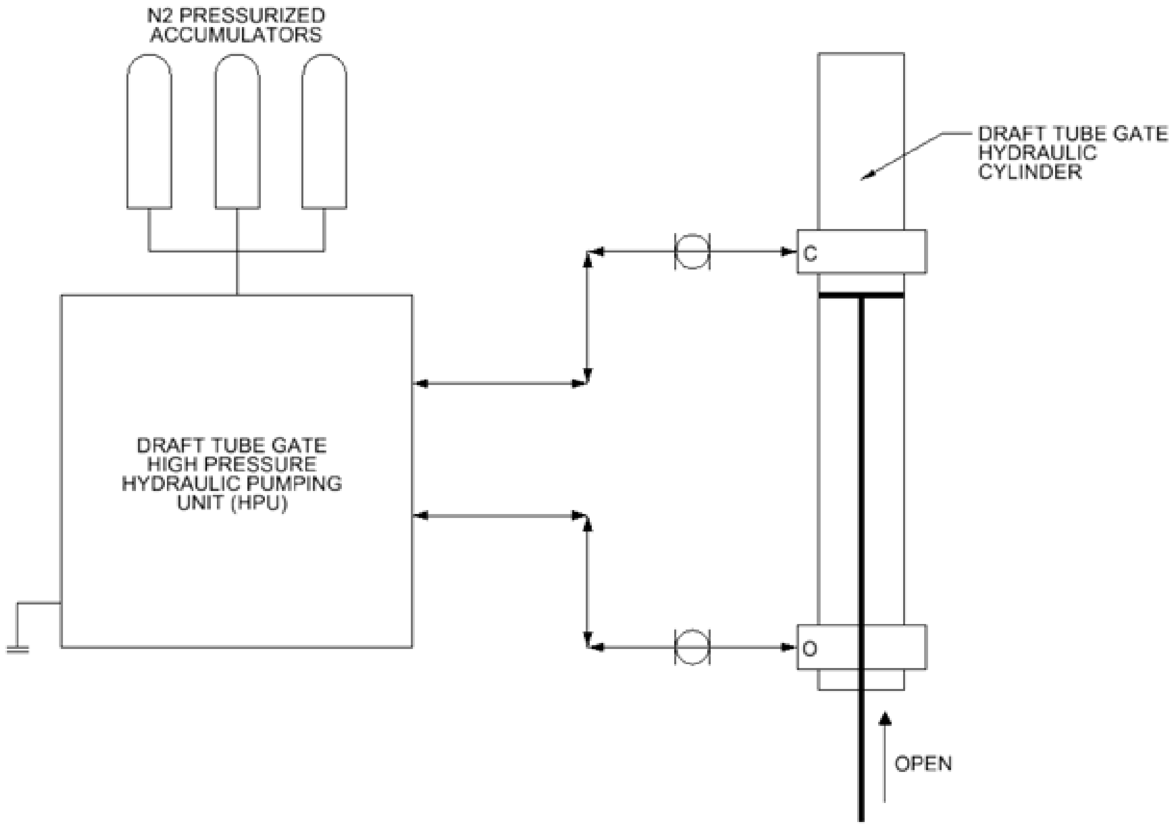


Figure 3-6. Draft Tube Gate HPU Conceptual Diagram

3.3.4.3 Motor-generator Equipment

3.3.4.3.1 Motor-generator Adjustable Speed

3.3.4.3.1.1 System Function

- Motor mode or pump mode: The unit will consume electrical energy from the grid and drive the pump-turbine.
- Generate mode or turbine mode: The unit will convert the mechanical torque into electrical energy.
- Active power and reactive power are generated or are consumed.

3.3.4.3.1.2 Major Components

- Stator
- Rotor
- Line side terminals and neutral terminals
- Slip rings including cover
- Upper bracket with guide bearing
- Lower bracket with combined thrust and guide bearing

- Main shaft
- Cooling system with air to water heat exchangers
- Brakes / hydraulic jacks
- Sensors with complete cabling within the motor-generator pit to the terminal boxes outside the motor-generator pit
- Platforms, stairways, hatches, and railings
- Fire protection system

3.3.4.3.1.3 System Description

The double-fed induction machine (asynchronous machine [DFIM]) will be considered for variable speed with reversal of rotation. With the AC excitation, the speed can be varied both in pump mode and in turbine mode. By changing the rotor speed, with utilization of the kinetic energy stored in the rotating masses, it will be possible to adjust the active power dynamically, which will support the regulation of frequency and power as well. This will apply to both the pumping and generate mode. Adjustment of reactive power in the pump mode and generate mode will be made via the AC excitation.

Fire protection will be carried out via gas technology (one system per unit).

The static and dynamic loads imposed by the rotating assembly of the vertical units will be handled with a combined thrust and guide bearing within the lower bracket and a guide bearing within the upper bracket of the motor-generator. The rotor will be specifically designed for asynchronous technology. A bearing lubrication system will provide a cooled and filtered supply of oil to the bearings for both the motor-generator and pump-turbine. A typical system conceptual diagram is shown in Figure 3-7.

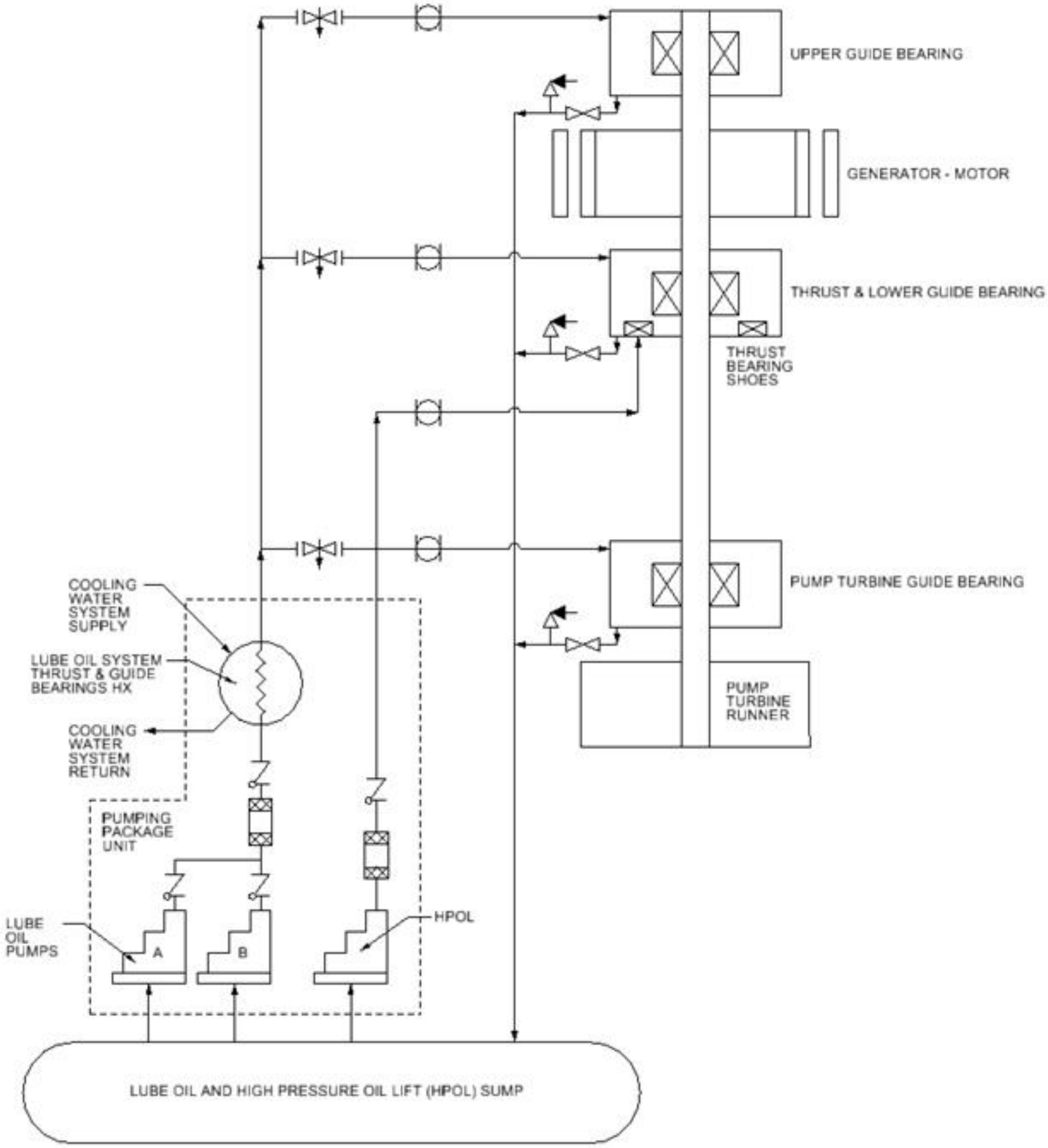


Figure 3-7. Motor-generator Equipment Conceptual Diagram

Operating Modes

- Generate mode
- Motor mode
- Synchronous condenser mode without motor-generator running (only with operation of rectifiers and DC-link of the AC excitation)
- Start-up in motor mode
- Electrical braking mode
- The following changes of the operating modes with reversal of rotation shall be possible:

- Generate mode to motor mode (via synchronous condenser mode)
- Motor mode to generate mode (direct change)

3.3.4.3.1.4 System Interfaces

Table 3-5. Motor-generator Equipment System Interfaces

System Number	System Name
242	Powerhouse
421	Pump-turbine
442.1	AC excitation
520.1	Generator voltage equipment
481	Powerhouse crane
451.1	Cooling water system
462	Low pressure air system
550	Auxiliary power supply
560	Control system (including process control and network)
570	Protection systems
590	LV, control, fiber-optic cables, cable trays, and earthing systems

3.3.4.3.2 Motor-generator AC Excitation System

3.3.4.3.2.1 System Function

The function of this system is generation or absorption of the three-phase alternating current, which will be needed by the rotor for the following functions:

- Start-up of power unit in motor mode
- Variation of speed, regulation of frequency, both in motor mode and in generate mode
- Voltage regulation and regulation of reactive power both in motor mode and in generate mode
- Braking of power unit during shutdown

3.3.4.3.2.2 Major Components

- Three-phase excitation transformer
- Converter
    - Rectifier module
    - DC-link
    - Inverter module

    - Control devices
    - Harmonic filter (if required)
    - Pure water in closed cooling water circuit
- Bus bars from excitation transformer to AC excitation system
- Bus bars from AC excitation to the brush holders at rotor of DFIM
- Fire protection system
- Short-circuit limiting reactor (optional)

3.3.4.3.2.3 System Description

With the converter, the speed of the motor-generator can be varied both in motor and generate modes. Through this variation, the power of the DFIM stator can be adjusted and regulated. By changing the rotor speed quickly, with utilization of the kinetic energy stored in the rotating masses, a fast, dynamically adjustment of the active power will be supported and the frequency and power will be regulated. This will apply to both the motor and generate modes. The consumption or supply of reactive power of the DFIM will be adjusted via the AC excitation system.

Operating Modes

- Generate mode
- Motor mode
- Synchronous condenser mode in turbine direction
- Synchronous condenser mode in pumping direction
- Synchronous condenser mode without motor-generator running (only with operation of rectifiers and DC-link of the AC excitation)
- Start-up in pump mode (with stator winding short circuited)
- Electrical braking mode

3.3.4.3.2.4 System Interfaces

- Powerhouse
- Motor-generator
- Cooling water system
- Generator voltage equipment
- Auxiliary power supply
- Control system
- Protection systems
- LV, control, fiber-optic cables, cable trays, and grounding systems

3.3.4.4 Cooling Systems

3.3.4.4.1 Low Pressure Service Water System

3.3.4.4.1.1 System Function

A closed loop cooling water system is recommended to reduce corrosion problems from raw water and minimize heat transfer surface fouling. There will be a closed loop system for component cooling water on the primary side that will reject heat through a single pass, main heat exchanger in a secondary side low pressure, raw water system. The low pressure service water (LPSW) system will provide sufficient cooling water flow to remove the heat load of the powerhouse equipment through a single pass, shell and tube heat exchanger. The LPSW system will be on the tube side. Plant cooling water will be located on the shell side.

See Figure 3-8, Figure 3-9, and Figure 3-10 for units 1 to 3 conceptual diagrams, respectively. See Figure 3-11 for the motor-generator air coolers conceptual diagram.

3.3.4.4.1.2 Major Components

- Pumps with motors
- Strainers
- Heat exchanger
- Valves
- Instrumentation

3.3.4.4.1.3 System Description

The system will be equipped with two 100% capacity, horizontal, double-suction, split-case, centrifugal pumps per unit. An automatic self-cleaning strainer with a separate manual bypass strainer will be installed in the suction line running to each pump. Service water flow will be controlled by pneumatically operated control valves. Full port (i.e., ball type) valves will be utilized for isolation wherever possible.

The suction source for the LPSW system will be a pipeline with an isolation valve that will be connected to the draft tube of each unit and then joined into a common distribution manifold located in the dewatering valve pit. Suction lines will be routed from this distribution manifold to each of the LPSW water pumps.

An alternate source of water will be required to ensure low-pressure service water system operation if all units are dewatered. The service water system will discharge to the Lower Reservoir through a pipeline embedded in the tailrace tunnel. A second pipeline will be installed to serve as the intake for the alternate source as well as a redundant line for discharge to the Lower Reservoir if needed. An evaluation of the potential for environmental impact due to the thermal discharge will be completed.

The LPSW pumps will circulate raw water from the Lower Reservoir through strainers, valves, and a single pass heat exchanger to withdraw heat from the closed loop cooling water system. All surfaces of the heat exchanger exposed to raw water will be manufactured from corrosion-resistant materials. The heat exchanger will be designed to facilitate cleaning of the heat transfer surfaces to ensure optimum heat transfer.

3.3.4.4.1.4 System Interfaces

Mechanical

- Cooling water system
- Motor-generator air coolers
- Flush/lube water for the station drainage and dewatering sump pump shaft bearings
- Water supply to the penstocks, draft tubes, and tailrace tunnels during filling and pressurization
- Fire protection system

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

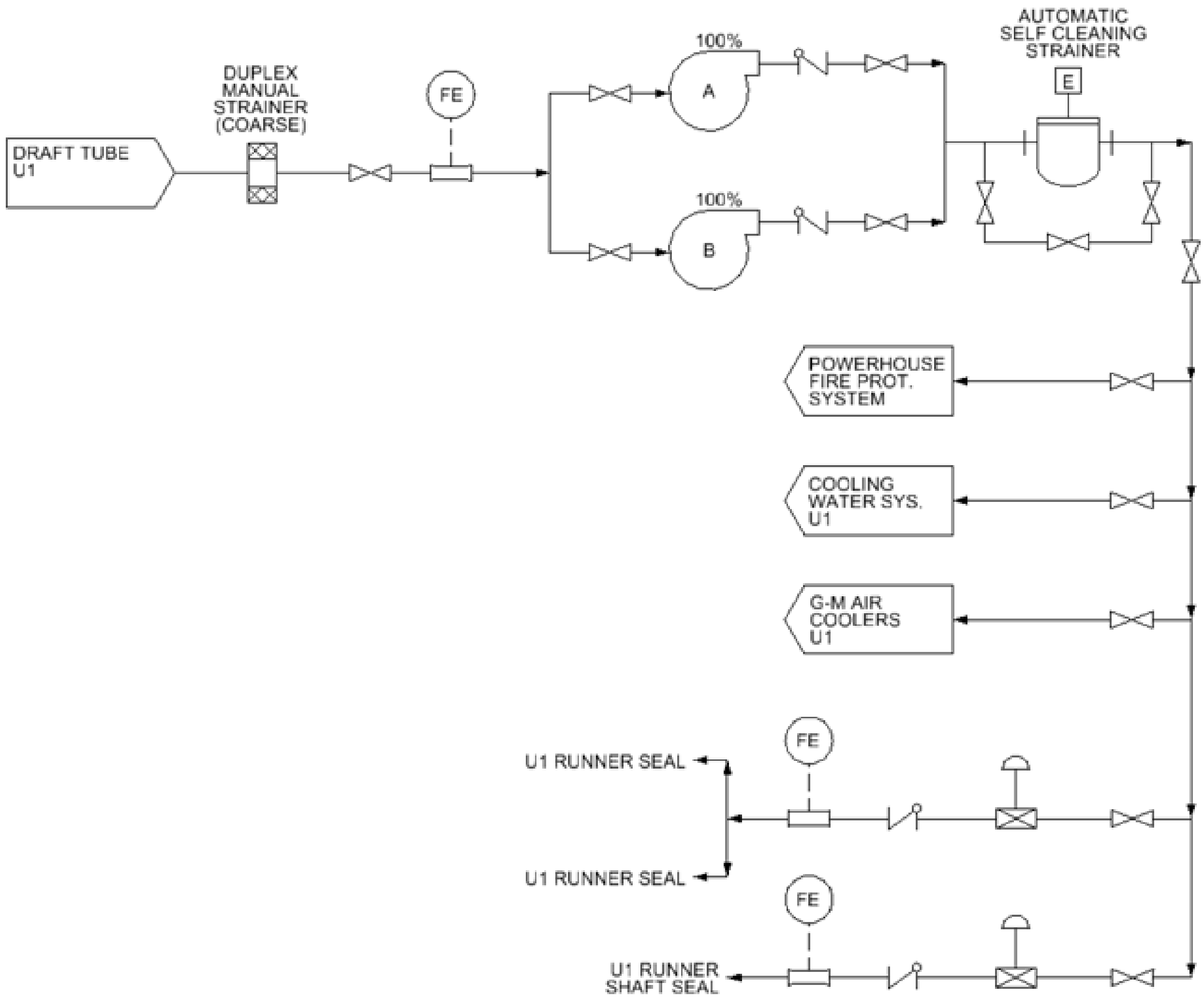


Figure 3-8. Unit 1 Low Pressure Service Water System Conceptual Diagram

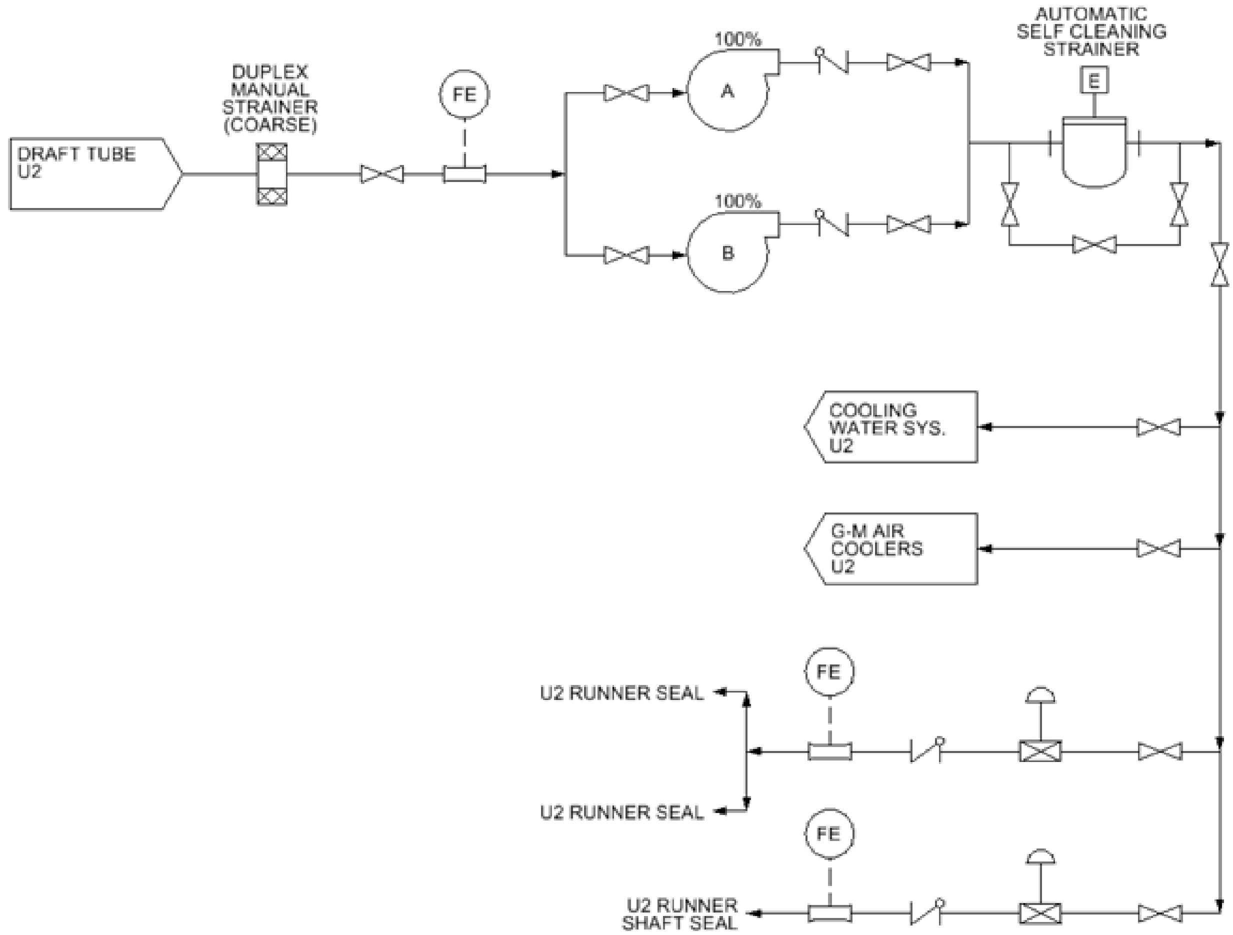


Figure 3-9. Unit 2 Low Pressure Service Water System Conceptual Diagram

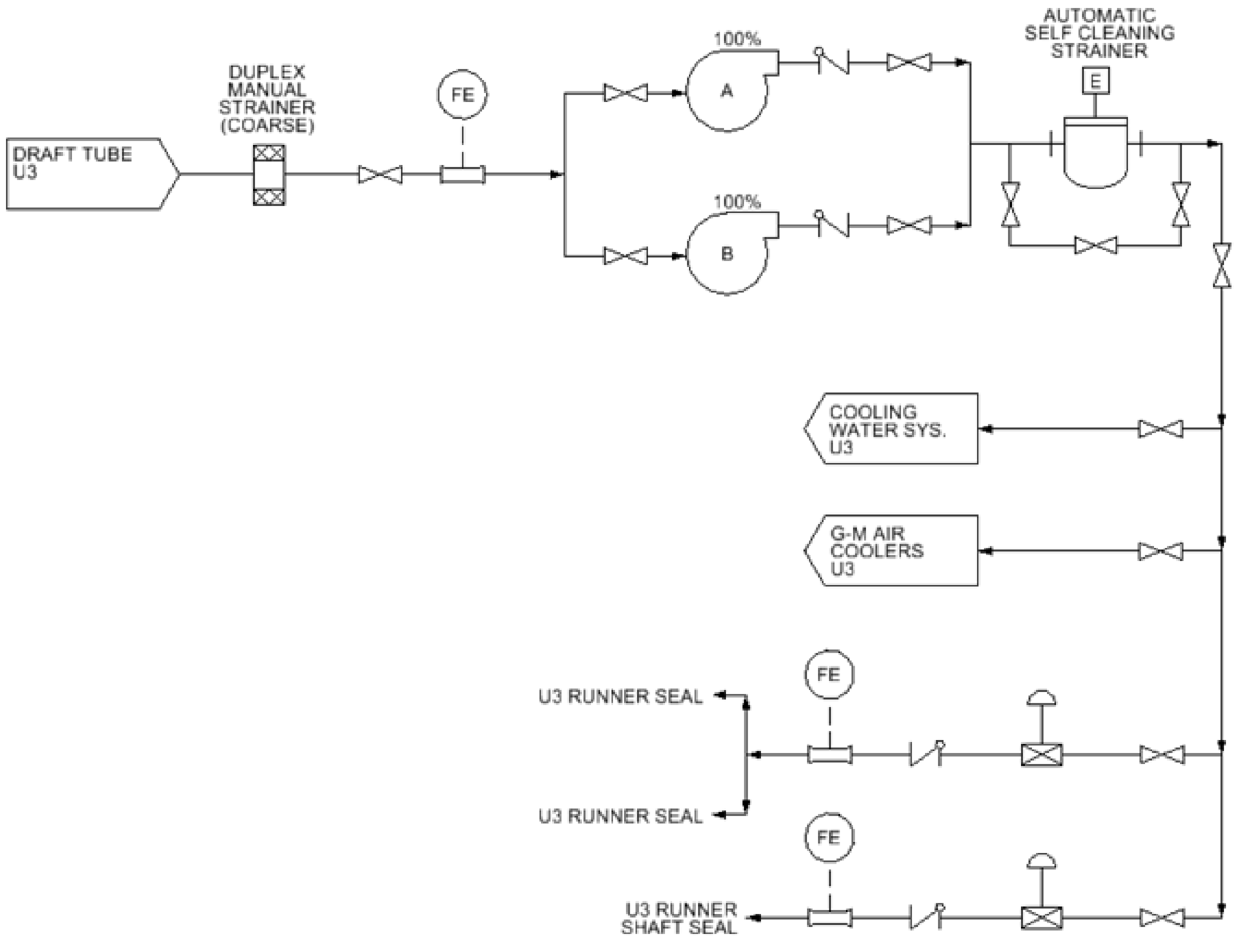


Figure 3-10. Unit 3 Low Pressure Service Water System Conceptual Diagram

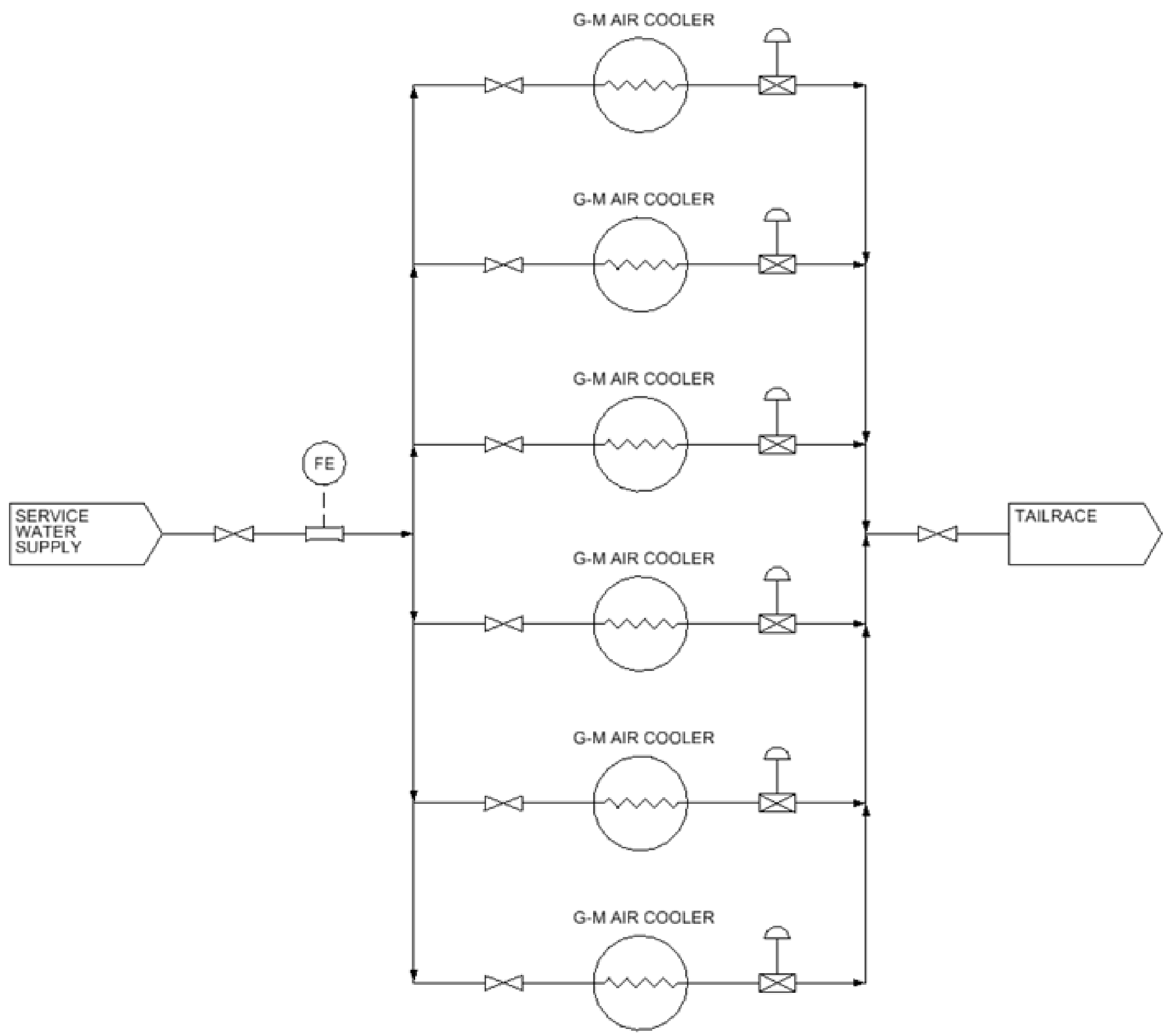


Figure 3-11. Generator-motor Air Coolers Conceptual Diagram (typical per unit)

3.3.4.4.2 Cooling Water System

3.3.4.4.2.1 System Function

The closed loop cooling water system will provide cooling water, treated with corrosion inhibitors, for such applications as:

- Motor-generator thrust and guide (upper and lower) bearing oil coolers
- Motor-generator stator coolers
- Pump-turbine guide bearing oil cooler
- Pump-turbine runner seals when pump suction is depressed
- Powerhouse HVAC chiller condensers
- Depressing air compressors

- Station / instrument air compressors
- Pump-turbine shaft mechanical seals
- Main dewatering pump motor coolers

See Figure 3-12, Figure 3-13, and Figure 3-14 for units 1 to 3 cooling water conceptual diagrams, respectively.

3.3.4.4.2.2 Major Components

- Pumps with motors
- Filters
- Heat exchangers
- Valves
- Instrumentation
- Chemical treatment system

3.3.4.4.2.3 System Description

The system will be equipped with two 100% capacity, horizontal, double-suction, split-case, centrifugal pumps per unit. An automatic self-cleaning strainer with a separate manual bypass strainer will be installed in the suction line running to each pump. Service water flow will be controlled by pneumatically operated control valves. Full port (i.e., ball type) valves will be utilized for isolation wherever possible.

Cooling water system chemistry will be controlled to minimize fouling of the various heat exchangers. This will reduce the spread of corrosion throughout the plant cooling systems and ensure optimum cooling performance. Cooling water makeup to the closed loop system will be from the low pressure service water system.

The cooling water system will provide sufficient cooling water flow to remove the heat load of the powerhouse equipment through a single pass, shell and tube heat exchanger. The LPSW system will be on the tube side. Plant cooling water will be located on the shell side. The raw water will be placed on the tube side to facilitate cleaning of any fouling that may occur on the heat transfer surfaces.

3.3.4.4.2.4 System Interfaces

Mechanical

- Motor-generator bearing lube oil
- Motor-generator cooling
- Pump-turbine bearing lube oil
- Pump-turbine cooling and lubrication
- HVAC
- Depressing air
- Station / instrument air
- AC excitation cooling system

- Generator step-up transformer coolers

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary power supply
- Cables (low voltage / sensor / fiber optics)

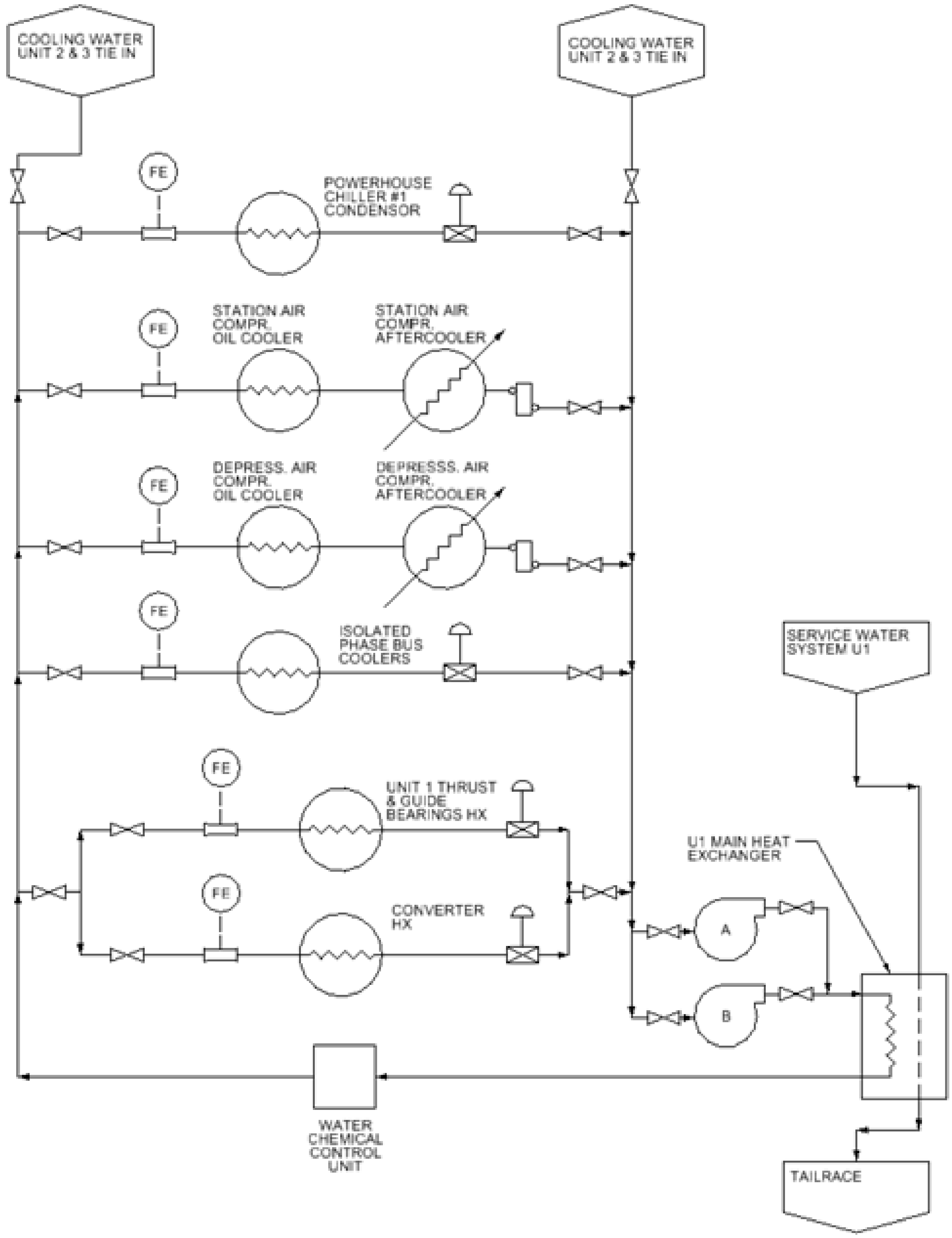


Figure 3-12. Unit 1 Cooling Water System Conceptual Diagram

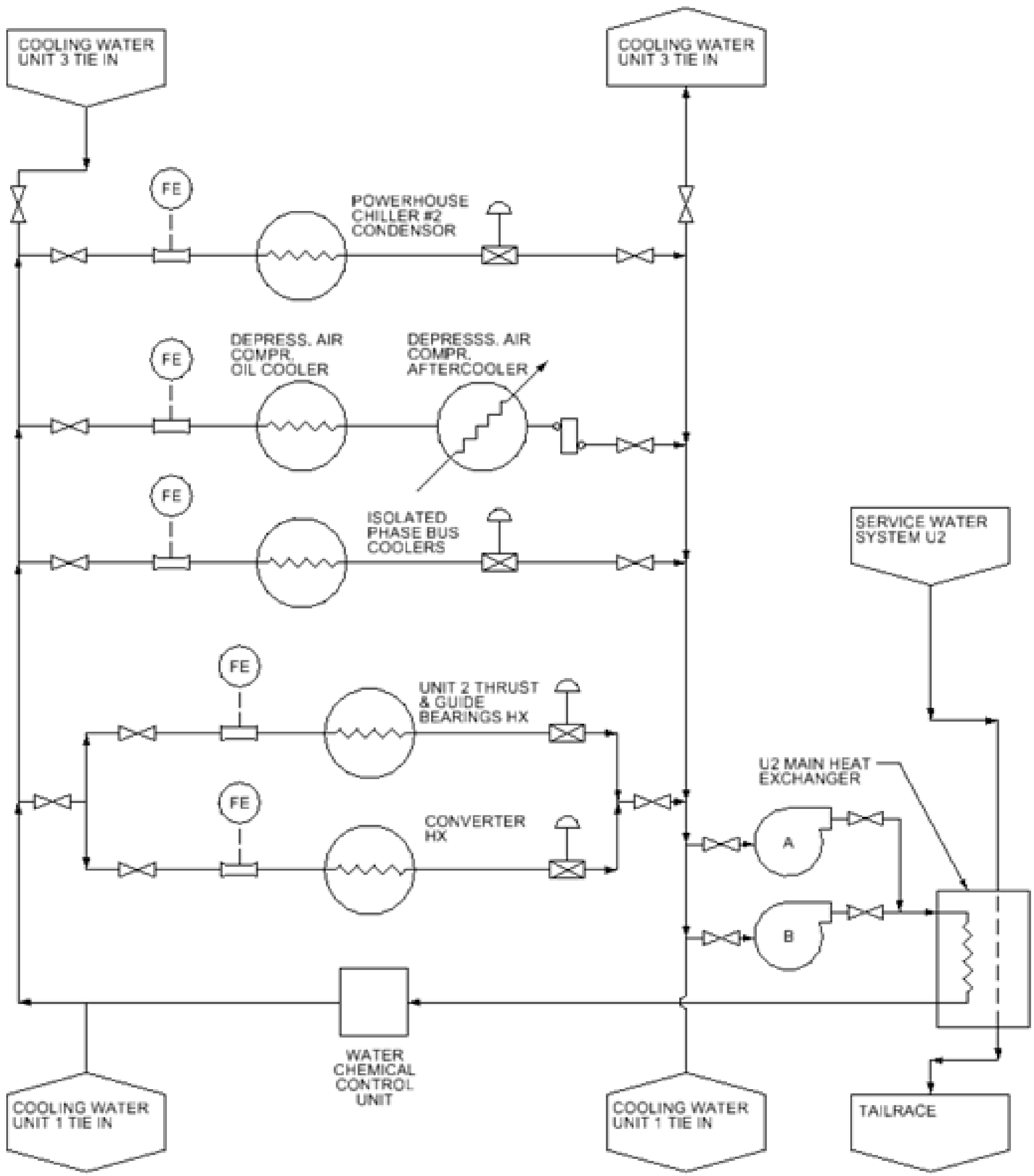


Figure 3-13. Unit 2 Cooling Water System Conceptual Diagram

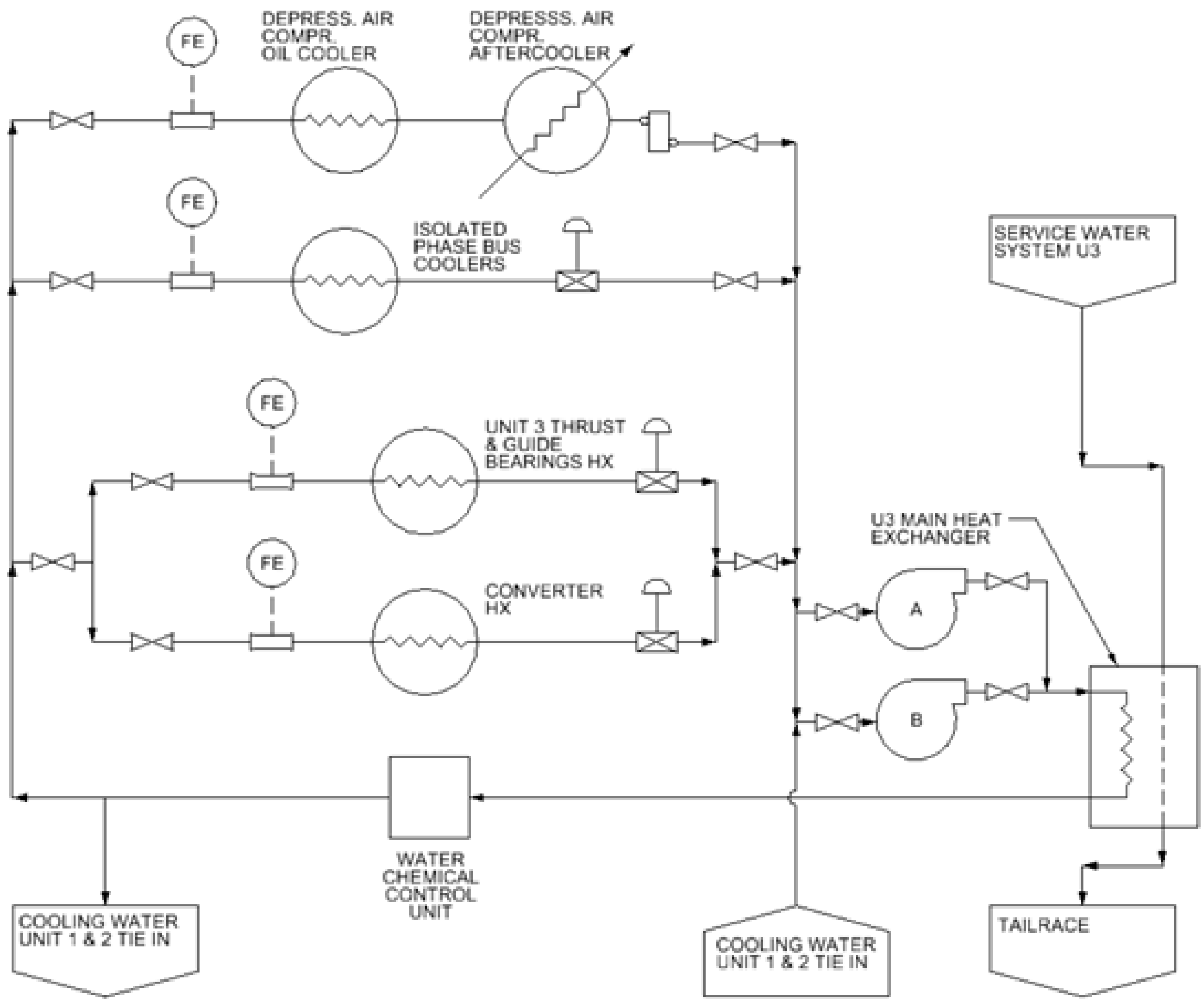


Figure 3-14. Unit 3 Cooling Water System Conceptual Diagram

3.3.4.4.3 Powerhouse Chilled Water System

3.3.4.4.3.1 System Function

The chilled water system will be a closed loop system that provides cold water for cooling purposes to all the air handling units distributed throughout the powerhouse.

3.3.4.4.3.2 Major Components

- Chillers
- Pumps
- Chemical treatment system
- Valves

3.3.4.4.3.3 System Description

The closed loop chilled water system will consist of mechanical chillers and recirculating pumps supplying chilled water to the air cooling coils of the powerhouse air handling units and most likely the cooling coil of the control room air handling unit as well (see Figure 3-15). A chemical treatment skid will be installed so that the chemistry of the water in the system can be controlled to minimize corrosion of the air handling unit heat exchangers.

3.3.4.4.3.4 System Interfaces

Mechanical

- Powerhouse ventilation system
- Cooling water system

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

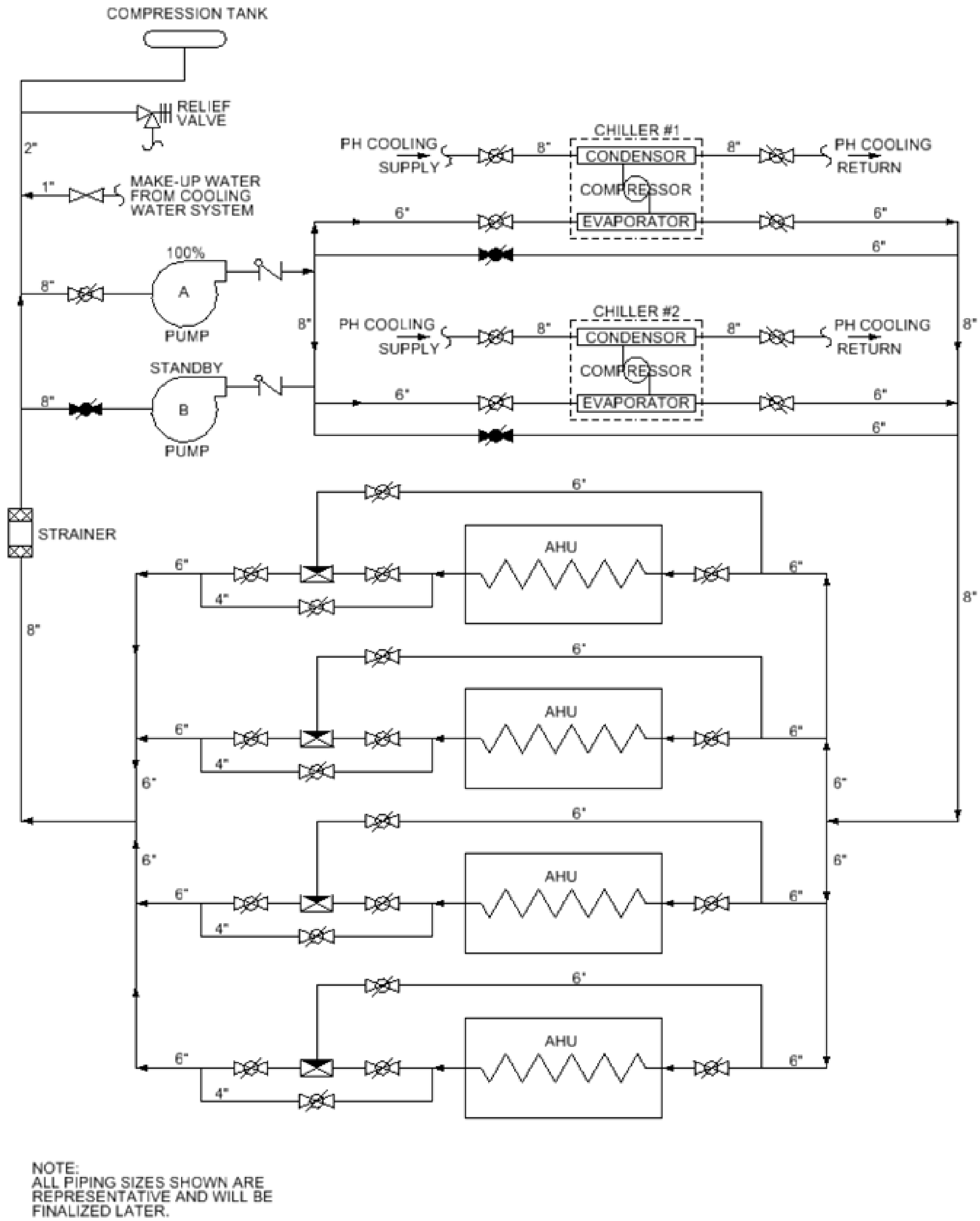


Figure 3-15. Powerhouse Chilled Water System Conceptual Diagram

3.3.4.5 Compressed Air Systems

3.3.4.5.1 Depressing Air

3.3.4.5.1.1 System Function

The depressing air system (Figure 3-16) will depress the water column in the draft tube away from the pump-turbine runner to minimize drag during pump start and synchronous condensing modes of operation. The depressing air system can serve as an alternate source of compressed air for both station and instrument air should the station air compressors fail. Self-contained pressure regulating valves will be used to reduce pressure automatically to the appropriate level, if necessary.

3.3.4.5.1.2 Major Components

- Air compressors with motors
- Air receivers
- Valves
- Draft tube level instrumentation
- Monitoring instrumentation

3.3.4.5.1.3 System Description

Based on experience with both screw-type and reciprocating-type compressors in this application, multistage, reciprocating-type air compressors are recommended for this intermittent duty. The relatively large air receivers will be located on the basement floor with fully redundant air compressors located in close proximity. Air will be admitted to the area of the pump-turbine inside of the closed wicket gates by relatively large piping connected to the head cover. There must be sufficient volume of compressed air available to manage any in-leakage of water past the wicket gate end and vertical seals.

3.3.4.5.1.4 System Interfaces

Mechanical

- Station air system
- Cooling water system
- Pump-turbine

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

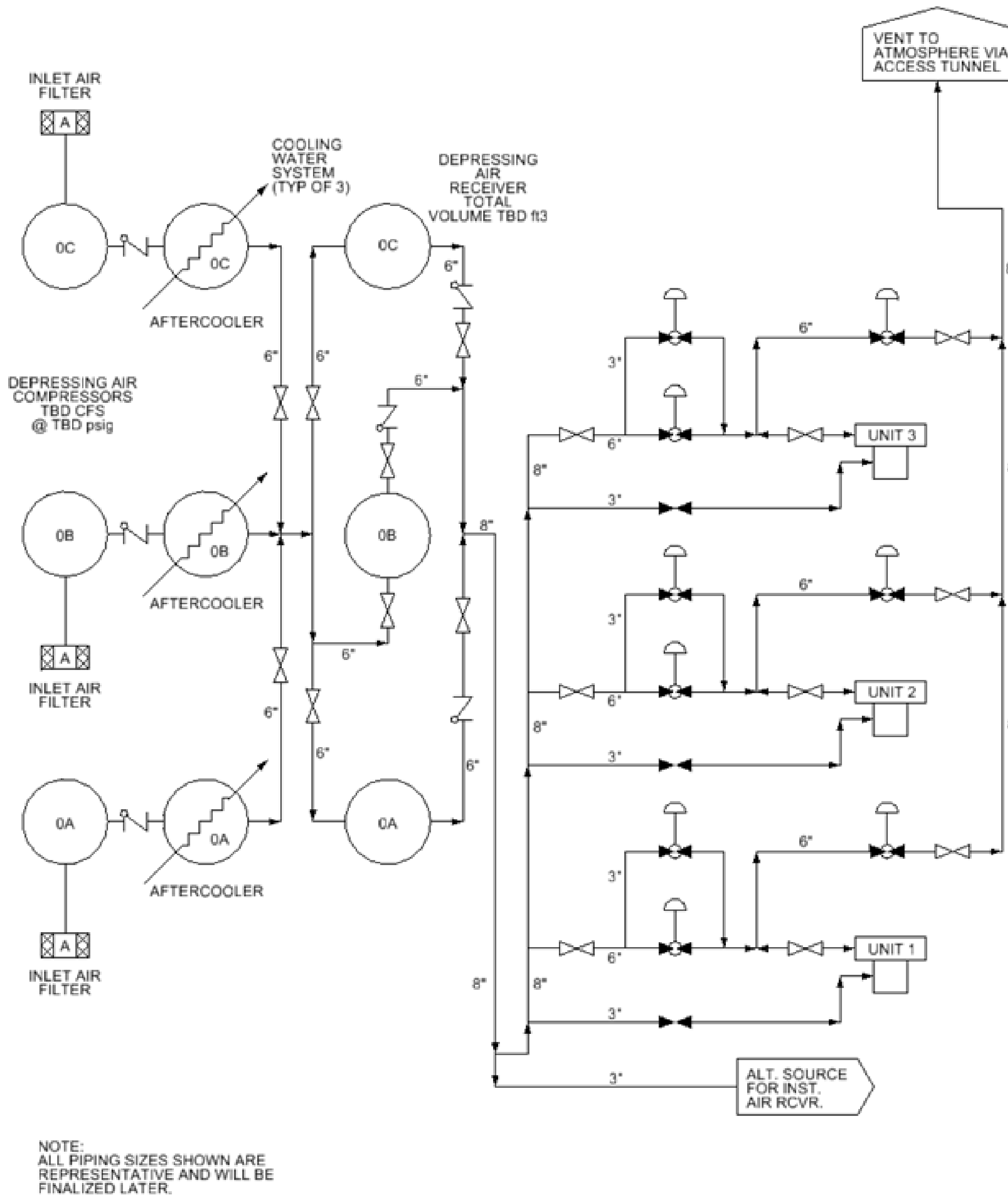


Figure 3-16. Depressing Air System Conceptual Diagram

3.3.4.5.2 Station / Instrument Air

3.3.4.5.2.1 System Function

The station / instrument air system (Figure 3-17) will provide a source of compressed service air during various duties for such tools as pneumatic tools and equipment used for maintenance, the pump-turbine shaft inflatable maintenance seal, and the sewage ejectors.

The system also provides instrument quality air for the motor-generator brakes as well as any pneumatic valve operators or dampers that may be used throughout the powerhouse. The station air will be dried and filtered to provide the instrument quality air.

Interconnection with the depressing air system is also recommended as a means of backup if the station air compressors fail.

3.3.4.5.2.2 Major Components

- Air compressors with motors
- Air receivers
- Valves
- Air dryers
- Monitoring instrumentation

3.3.4.5.2.3 System Description

Rotary screw-type compressors will be employed to provide station service and instrument quality compressed air throughout the powerhouse. Station air will be dried and filtered to produce instrument quality air. Separate air receivers will be provided to store the compressed air for use upon demand.

Station air will be supplied from the station air receiver to each floor elevation by separate headers. Air drops will be located next to equipment requiring compressed air for maintenance. Drain traps will be provided to remove any moisture accumulated in the lines.

Instrument quality air will be processed downstream of the dedicated instrument air receiver by one of two 100% capacity contaminant removal packages consisting of a refrigerated air dryer, particulate filter, and coalescing filter. Air will be processed on demand and supplied to each floor elevation by separate headers, which are interconnected to form a closed loop.

3.3.4.5.2.4 System Interfaces

Mechanical

- Depressing air system
- Cooling water system
- Pump-turbine
- Motor-generator

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

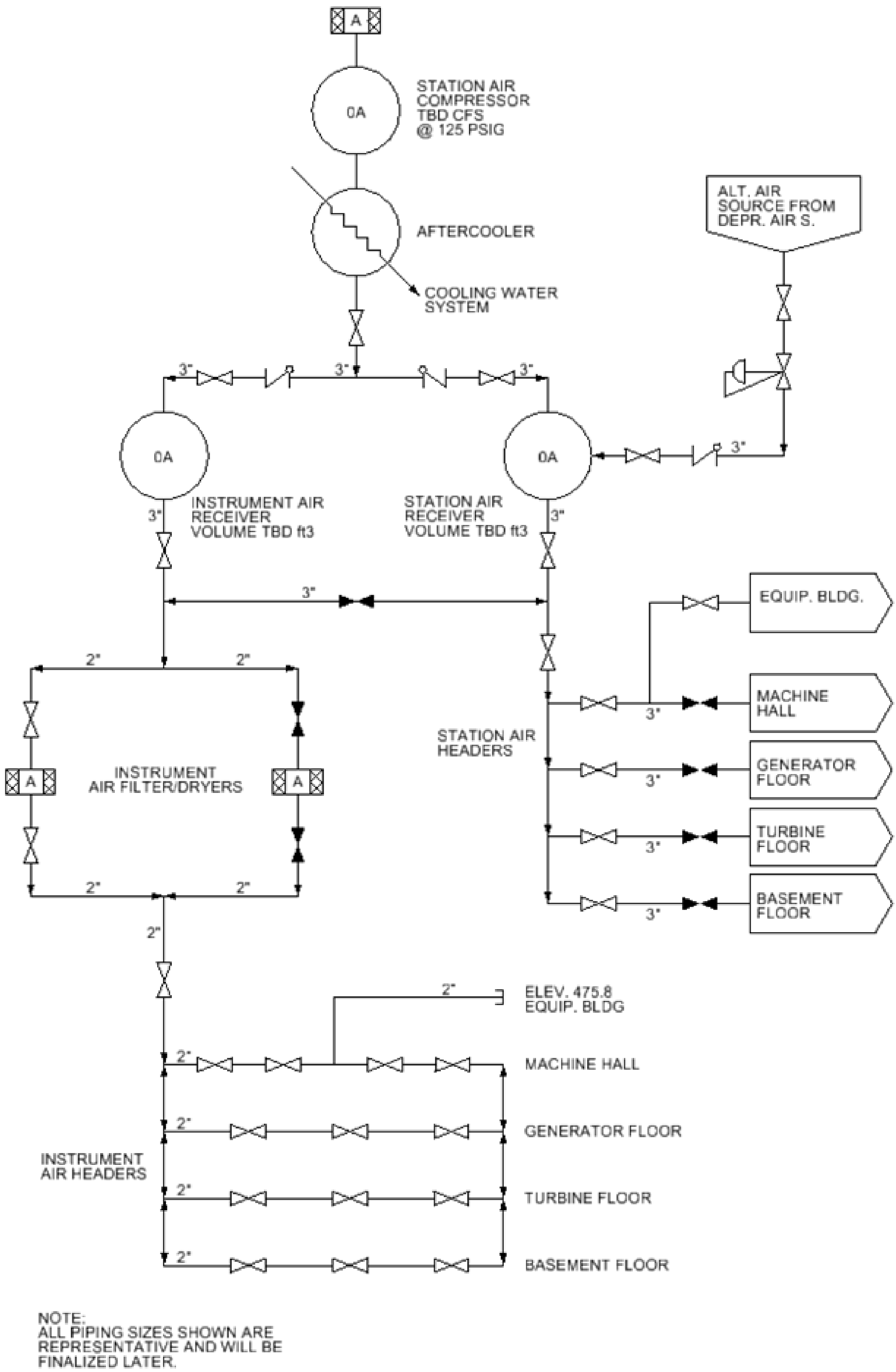


Figure 3-17. Station/Instrument Compressed Air System Conceptual Diagram

3.3.4.6 Station Drainage, Unwatering, and Power Tunnel Filling Systems

3.3.4.6.1 Station Drainage System

3.3.4.6.2 System Function

The station drainage system (Figure 3-18) will be designed to collect all drainage from the powerhouse into one sump. Any oil will be separated with an oil skimmer. The accumulated drainage will then be pumped to a waste treatment holding pond on site.

3.3.4.6.3 Major Components

- Pumps with motors
- Valves
- Instrumentation

3.3.4.6.3.1 System Description

The station drainage sump will be equipped with two 100% capacity sump pumps. These pumps will be required to pump all leakage flow coming into the sump from the powerhouse up to the waste treatment facility located near the entrance of the access portal. The station drainage sump will also include oil detection and removal equipment. Any oil captured will be stored in a container for proper disposal.

3.3.4.6.3.2 System Interfaces

Mechanical

- HVAC
- Low pressure service water system

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

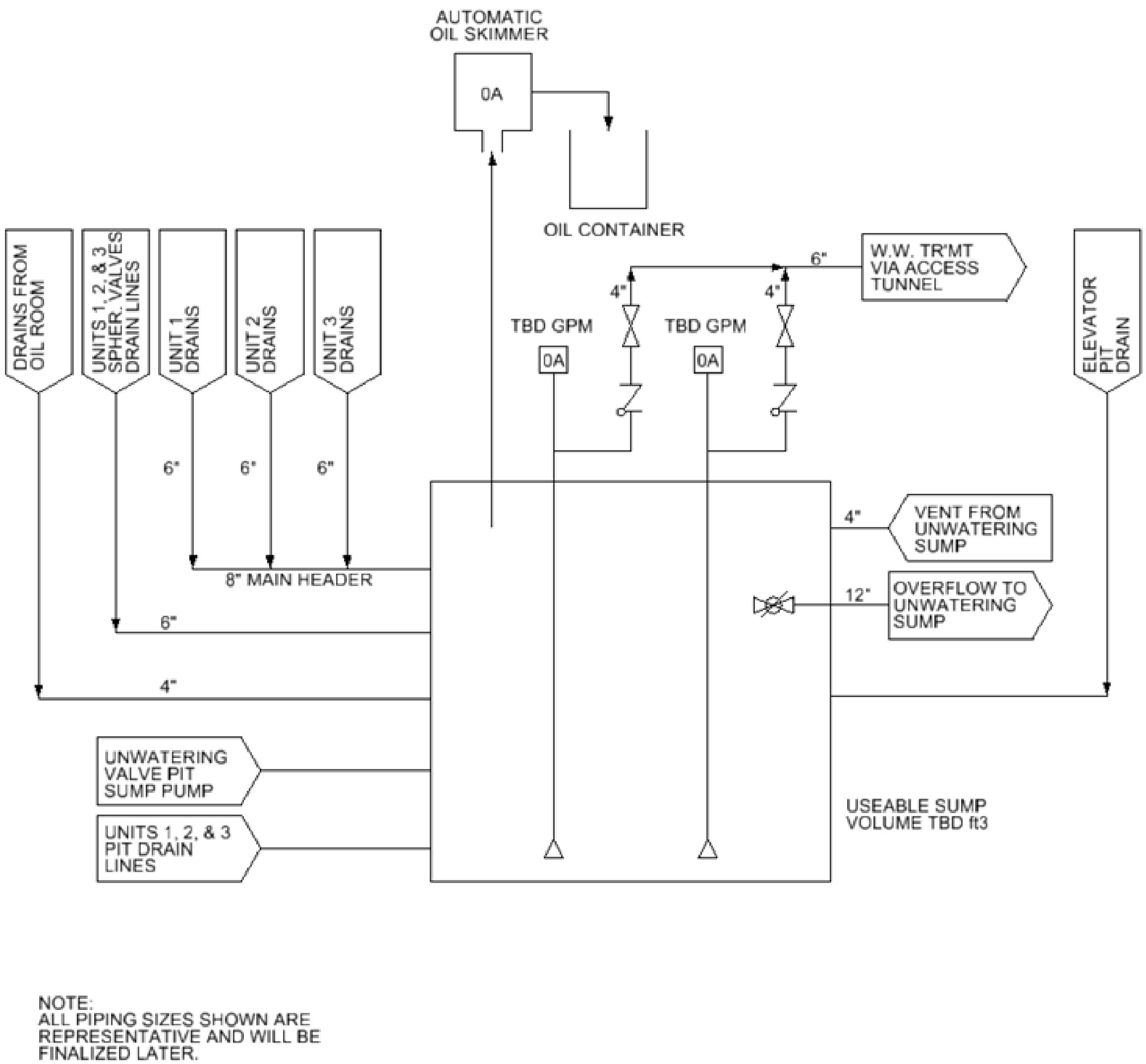


Figure 3-18. Station Drainage System Conceptual Diagram

3.3.4.6.4 Unwatering System

3.3.4.6.4.1 System Function

The unwatering system (Figure 3-19) will facilitate dewatering the pump-turbine and draft tube from the spherical valve to the draft tube gate to allow access to these areas while the power tunnel and tailrace tunnels are still watered up. The system can also be used to assist with dewatering the entire water conveyance system if necessary.

3.3.4.6.4.2 Major Components

- Pumps with motors
- Valves

- Instrumentation

3.3.4.6.4.3 System Description

The dewatering sump will be equipped with three pumps: two 100% capacity main dewatering pumps and a dewatering holding pump. As with the station drainage pumps, the total head required for these pumps is expected to be high enough to require the use of vertical turbine-type pumps. The dewatering pumps will have the same general design features as the station drainage pumps. The main dewatering pumps will, however, need to be much larger than the station drainage pumps to expedite dewatering of the pump-turbines, penstocks, draft tubes, and tunnels. The pump motors for the main dewatering pumps will likely be in the 350 kW to 400 kW range. The water from the dewatering sump will be discharged to the Lower Reservoir.

The dewatering sump will be designed to be a pressurized sump. Water admitted to the sump will be throttled by valves until the sump is pressurized. After full pressure is reached, the valves will be opened fully. The dewatering sump will be manually isolated from the nonpressurized station drainage sump.

3.3.4.6.4.4 System Interfaces

Mechanical

- Pump-turbine
- Sperical valve
- Draft tube

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

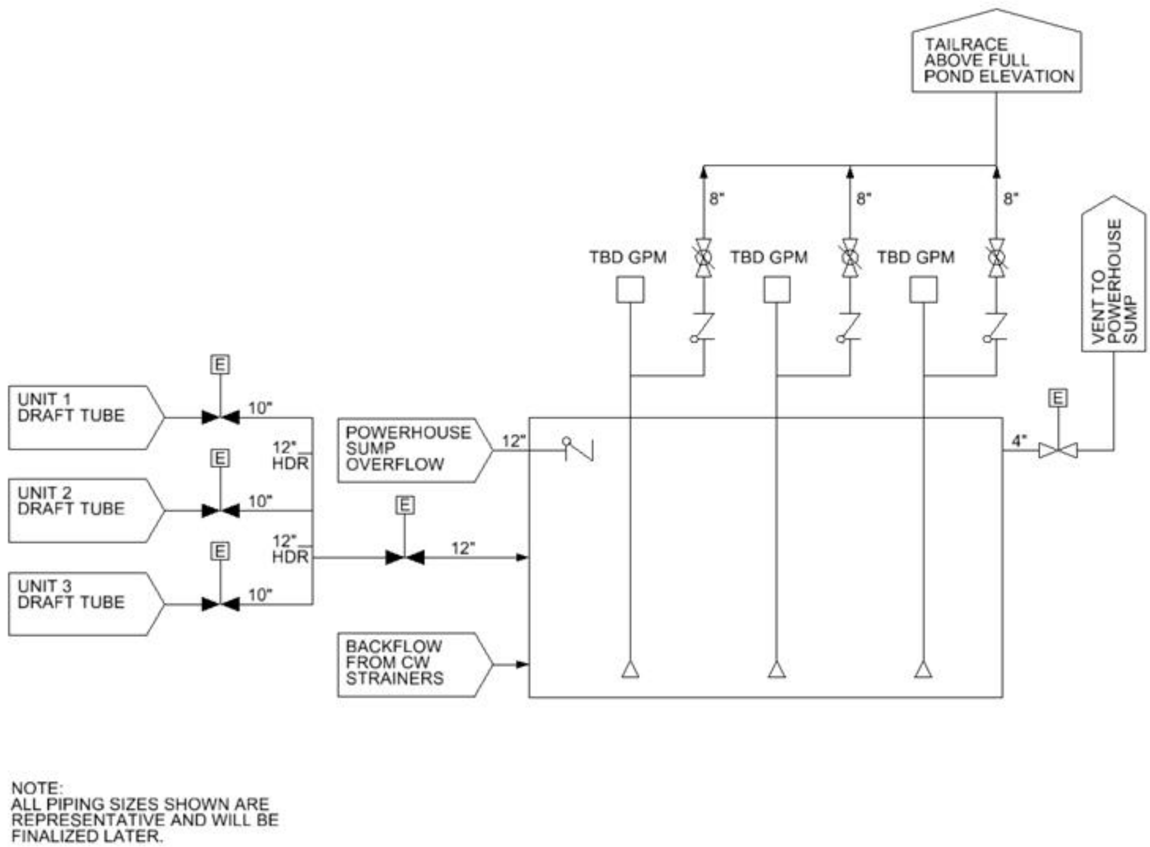


Figure 3-19. Unwatering System Conceptual Diagram

3.3.4.6.5 Power Tunnel Filling System

3.3.4.6.5.1 System Function

The power tunnel filling system (Figure 3-20) is designed to fill the power tunnel up to the Upper Reservoir intake level during initial filling of the Upper Reservoir and after complete unwatering of the power tunnel for inspections. After charging the power tunnel to the Upper Reservoir intake level, the pump-turbines take over for Upper Reservoir filling.

3.3.4.6.5.2 Major Components

- Pumps with motors
- Strainers
- Valves
- Instrumentation

3.3.4.6.5.3 System Description

The system will be equipped with two 50-percent-capacity pumps. The pump discharge rate will be sized so that the fill rate in the power tunnel vertical shaft is controlled to 50 feet per hour. During water-up of the power tunnel, the headrace tunnel and a portion of the vertical shaft will be filled to Lower Reservoir elevation by allowing water through the pump-turbines. The pumps will then be used to fill from the Lower Reservoir elevation to the point where water is discharged from the Upper Reservoir intake. The water for filling the power tunnel will be withdrawn from the Lower Reservoir. The pumps will be multistage, horizontal pumps. Discharge rate will be controlled (i.e., kept constant) using control valves as the water column rises and total head increases as a result. The motors for the pumps will likely be in the 300 kW to 350 kW range each.

3.3.4.6.5.4 System Interfaces

Mechanical

- Cooling water system

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary AC power

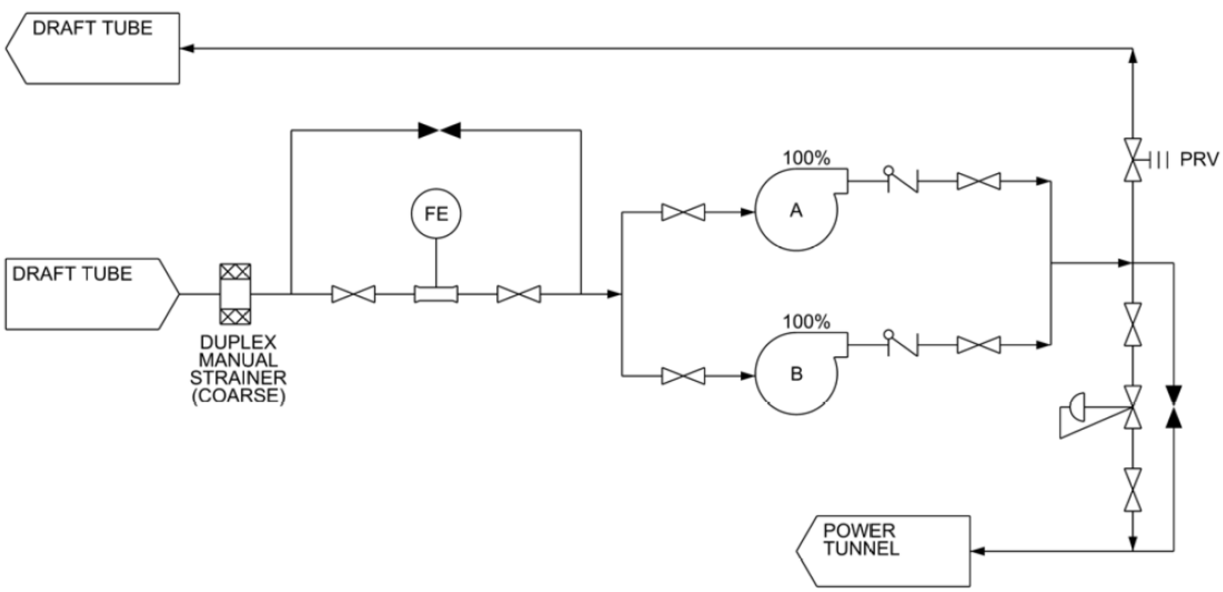


Figure 3-20. Power Tunnel Filling System Conceptual Diagram

3.3.4.7 Cranes and Hoists

3.3.4.7.1 Powerhouse Crane

3.3.4.7.1.1 System Function

A double bridge crane will be provided in the main powerhouse cavern to facilitate construction and maintenance of the major equipment once the facility is operational. The two cranes of this system will be designed for a combined lift and transport of the heaviest components, such as the motor-generator rotor and pump-turbine inlet isolation valve. The two single cranes may be used individually in order to accelerate the erection of the units. Each of these cranes will have direct access to the generating units as well as the pump-turbine spherical valves. Strategically located hatches will provide access to equipment through all floors of the powerhouse. Removal and installation of the main transformers will be accomplished by a combination of rail car, hoists, and crane. A gantry-type crane will be provided for installation of stop logs to seal off the tailrace tunnel when inspection or maintenance is required.

3.3.4.7.1.2 Major Components

- Double bridge–type crane with multiple trollies / hooks
- Gantry-type crane with single trolley
- Crane remote controls
- Hoists

3.3.4.7.1.3 System Description

The powerhouse crane will be radio as well as cab controlled, double girder, bridge type, with two main hoists, each mounted on a separate trolley and designed for precision control of lifts. An auxiliary lift hook will also be provided, and will be used for smaller lifts.

3.3.4.7.1.4 System Interfaces

Mechanical

- Pump-turbine
- Spherical valve
- Motor-generator

Electrical

- Station control system
- CCTV
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

3.3.4.7.2 Transformer Cavern Crane

For the purposes of the preliminary functional design, there are no cranes installed in the transformer cavern.

3.3.5 Electrical Equipment and Systems

Listed below are the principal functional design characteristics for the electrical equipment and systems.

3.3.5.1 Motor-generator Voltage Equipment

3.3.5.1.1 Motor-generator Circuit Breakers

3.3.5.1.1.1 System Function

Motor-generator circuit breakers will allow isolation of the motor-generator in the event of a fault or abnormal condition. The 16.5 kV (or 18 kV) circuit breaker will provide for the unit to be paralleled with the system at the medium voltage level instead of being synchronized directly into the transmission system, hundreds of feet removed from the unit. Medium voltage generator circuit breakers will be designed for heavy duty use, while 230 kV switchyard circuit breakers will have lower limits for switching cycles. (Motor-generator circuit breakers are illustrated in Figure 3-21, Figure 3-22, Figure 3-23, Figure 3-24, Figure 3-25, Figure 3-26, Figure 3-27, Figure 3-28, Figure 3-29, Figure 3-30, and Figure 3-31,)

3.3.5.1.1.2 Major Components

- Grounding switch
- Current transformer
- Potential transformer
- Isolated phase bus (IPB)

3.3.5.1.1.3 System Description

The breakers will be designed to withstand many operations without requiring inspections because pumped storage facilities require multiple operations per day. Current transformers and potential transformers will be installed in the breaker bushings. Breakers will be opened/closed automatically through the distributed control system (DCS) with every startup and shutdown. The breaker status will be monitored by the DCS, and auxiliary contacts will be used to provide the status of the protective relays, excitation, and governor system. Provisions for remotely racking the breaker in and out will be provided.

3.3.5.1.1.4 System Interfaces

Mechanical

- None

Electrical

- Protective relay boards
- Auxiliary AC power
- Auxiliary DC power
- Excitation system
- Reversing switch
- Motor-generator
- Isolated phase bus duct

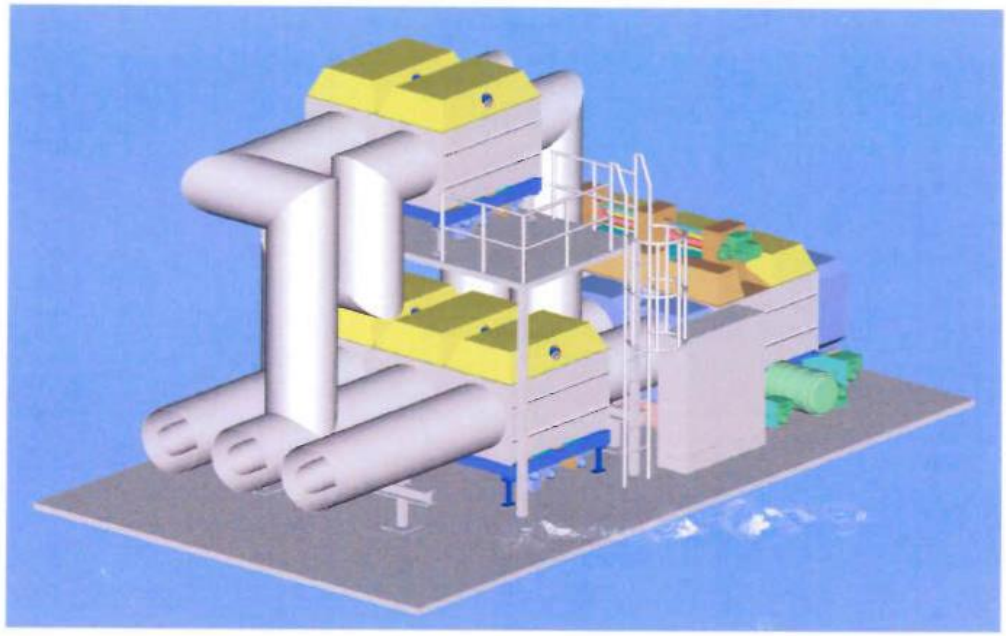


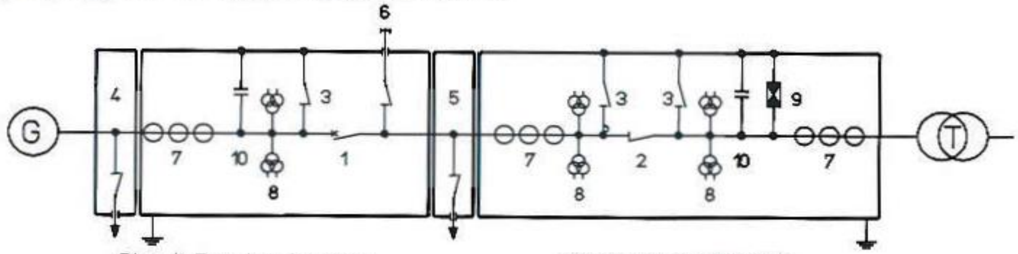
ABB Generator Circuit-Breaker System Type HECPS 3/5

Application

The HECPS circuit breaker integrated system is designed for the needs of pump storage power plants. The system equipment is covering all basic and extended operational functions of the most pump power plants world wide.

The single-line diagram shown below illustrates the features of the HECPS circuit breaker system. The individual components can be installed in two modules the circuit breaker and the disconnector module, as shown on to the single-line diagram below. The HECPS is a fully integrated system, which includes the IPB's for the connection between modules, see figures 1 and 2. The circuit breaker module can optionally be equipped with SFC and Back to Back starting switch enclosed modules. The equipment limits of the two modules and of the individual components installed are given below.

Fully equipped execution of the HECPS



1	Circuit Breaker	6	Braking Switch
2	Disconnector	7	Current Transformer
3	Earthing Switch	8	Voltage Transformer
4	Starting Switch (SFC)	9	Surge Arrester
5	Starting Switch (Back to Back)	10	Capacitor

Figure 3-21. Toshiba Typical Supply ABB Generator Circuit Breakers, Vertical Installation Shown

Technical data

Generator circuit-breaker system type		HECPS 3	HECPS 5	
General				
Rated maximum voltage		25.3	25.3	kV
Rated frequency		50/60	50/60	Hz
Rated continuous current	50Hz	13.5	13.5	kA, rms
Rated continuous current	60Hz	12.5	12.5	kA, rms
Rated insulation level:				
Rated power frequency withstand voltage:				
• to earth and across circuit- breaker / switch contacts		60/80*	60/80*	kV, rms
• across isolating distance of disconnector		70/88*	70/88*	kV, rms
Rated lightning impulse withstand voltage:				
• to earth and across circuit- breaker / switch contacts		125/150*	125/150*	kV, peak
• across isolating distance of disconnector		145/165*	145/165*	kV, peak
Circuit -Breaker				
Rated peak withstand current		300	360	kA, peak
Rated short-time withstand current		100	120	kA, 3s
Rated short-circuit making current		300	360	kA, peak
Rated short-circuit breaking current		100	120	kA, 3s
Rated operating sequence		CO-30min-CO		
Rated interrupting time		60	60	ms
Disconnector				
Rated peak withstand current		300	360	kA, peak
Rated short-time withstand current		100	120	kA, 3s
Operating time		2	2	s
Earthing Switch, Starting Switch (SFC, BtB), Braking Switch				
Rated peak withstand current		300	360	kA, peak
Rated short-time withstand current		100	120	kA, 1s
Operating time		2	2	s

* Depending on type of voltage transformer

Figure 3-22. ABB Generator Circuit Breaker Technical Data, Typical

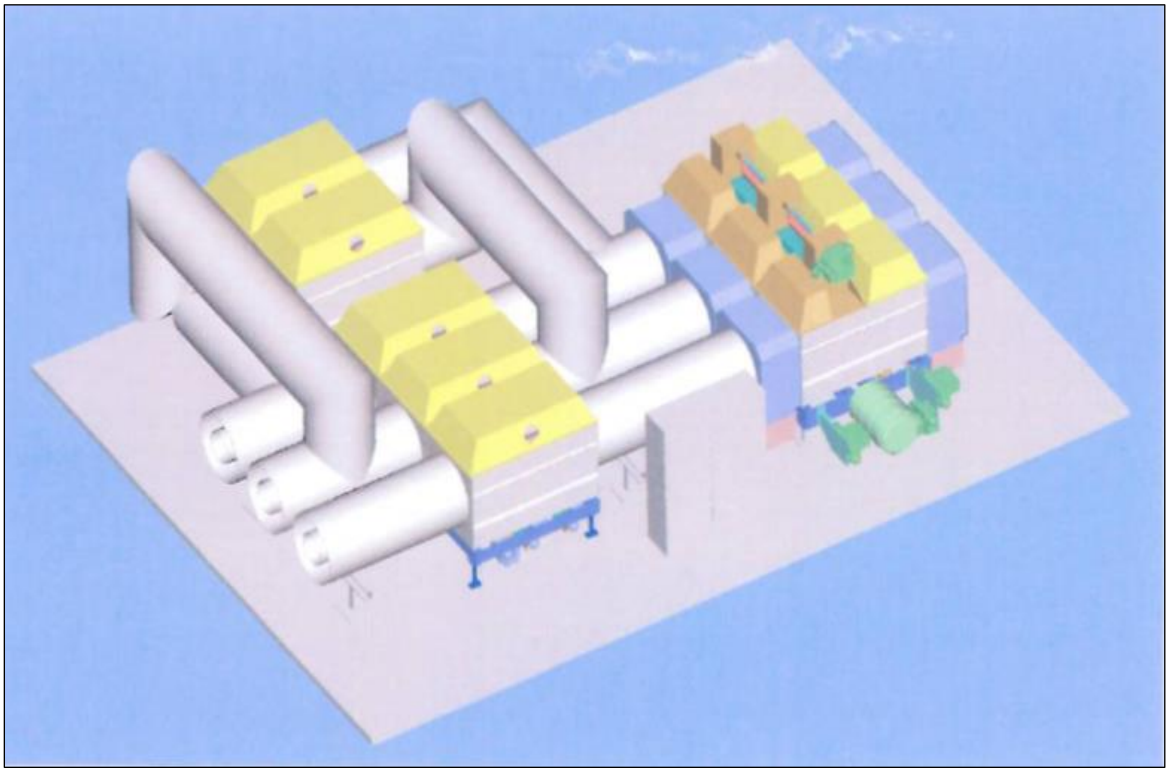


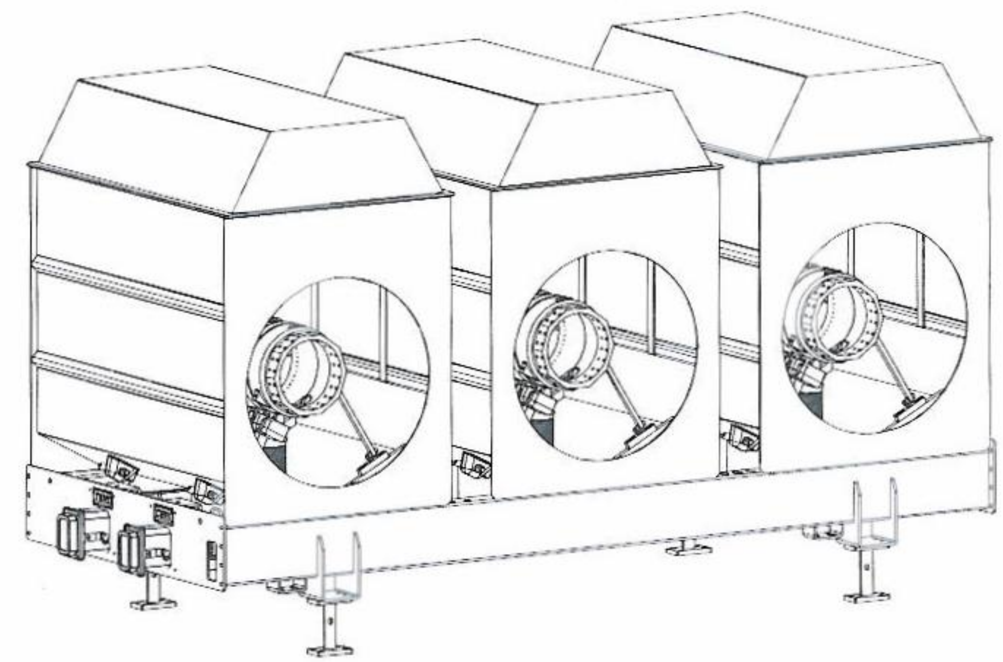
Figure 3-23. Toshiba Typical Supply ABB Generator Circuit Breakers, Horizontal Installation Shown

THIS PAGE DELIBERATELY LEFT BLANK

OUTLINE DRAWING

GENERATOR CIRCUIT-BREAKER SYSTEM HECPS-3S/5S
DISCONNECTOR MODULE HECSPS-100/130L

VALID ONLY FOR QUOTATIONS



TITLE OF SHEET	SHEET NO.
COVER SHEET	1
SCHEMATIC DIAGRAM	2
VARIANT	3
TOP VIEW / FRONT VIEW / SIDE VIEW	4
FLOOR PLAN	5
DETAILS	6
INSTALLATION	7

Prepared 2005.03.24 MUEHLEMANN	Derived from / Replaces	Sep.Pl. same no. ☐ Without sep. Pl. ☒ Sep.Pl. anoth.no. ☐	Scale %	Doc.type ZEI	Format A3
Checked 2005.03.24 ROTH	Responsible department PTHG-T2	Title: DISCONNECTOR MODULE OUTLINE DRAWING			
Approved 2005.03.24 MANZ	Take over department	TYPE HECSPS-100/130L			Language EN
	Revision AB 2005.03.24 MUEHLEMANN	COVER SHEET			No. Shts. 7
ABB	ABB Switzerland Ltd	Document number: 1HC0030002			Sht. no. 1

Figure 3-24. Toshiba Typical Supply ABB Type HECPS-100/130L, Drawing 1HC0030002, Sheet 1 of 7

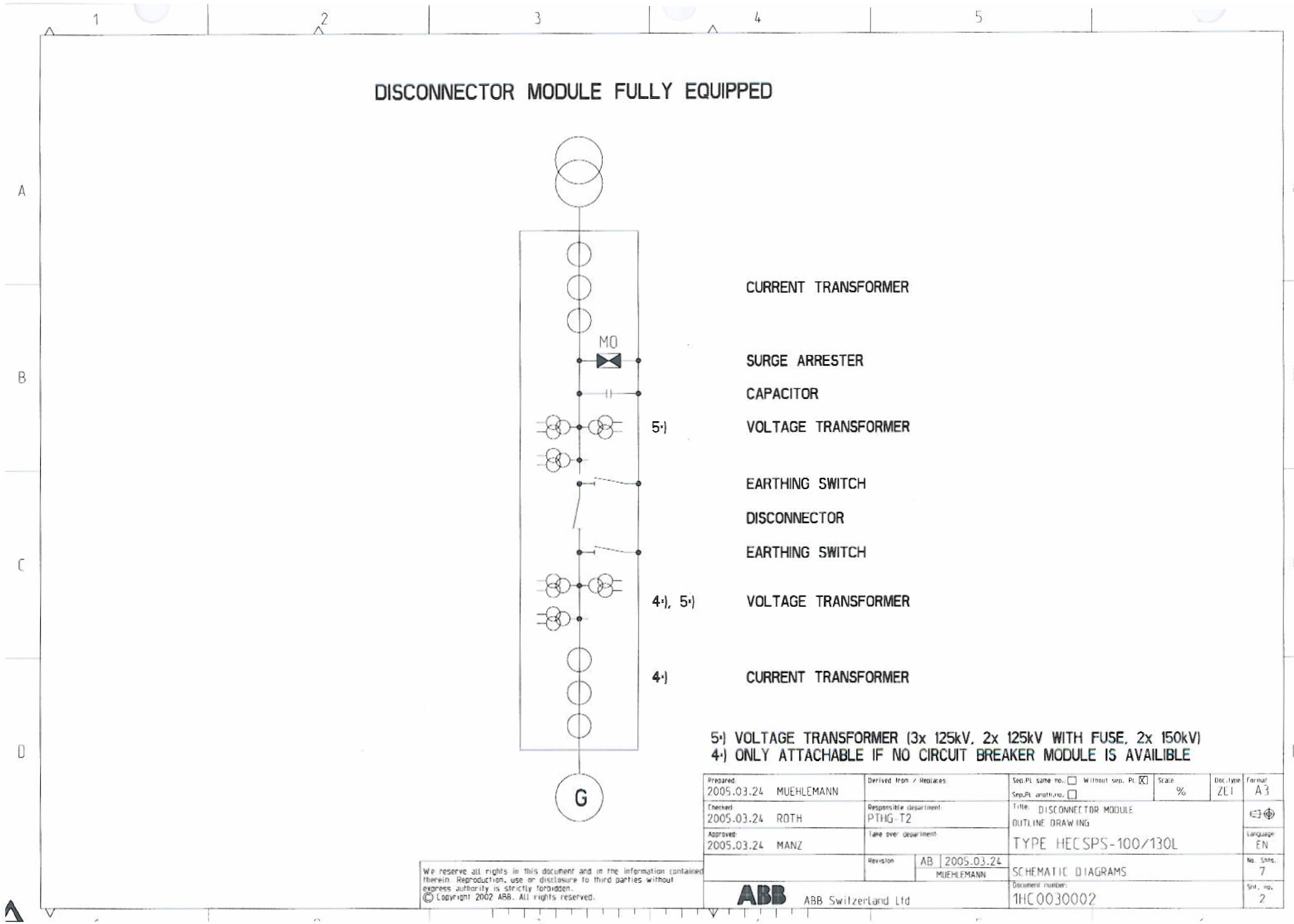


Figure 3-25. Toshiba Typical Supply ABB Type HECPS-100/130L, Drawing 1HC0030002, Sheet 2 of 7

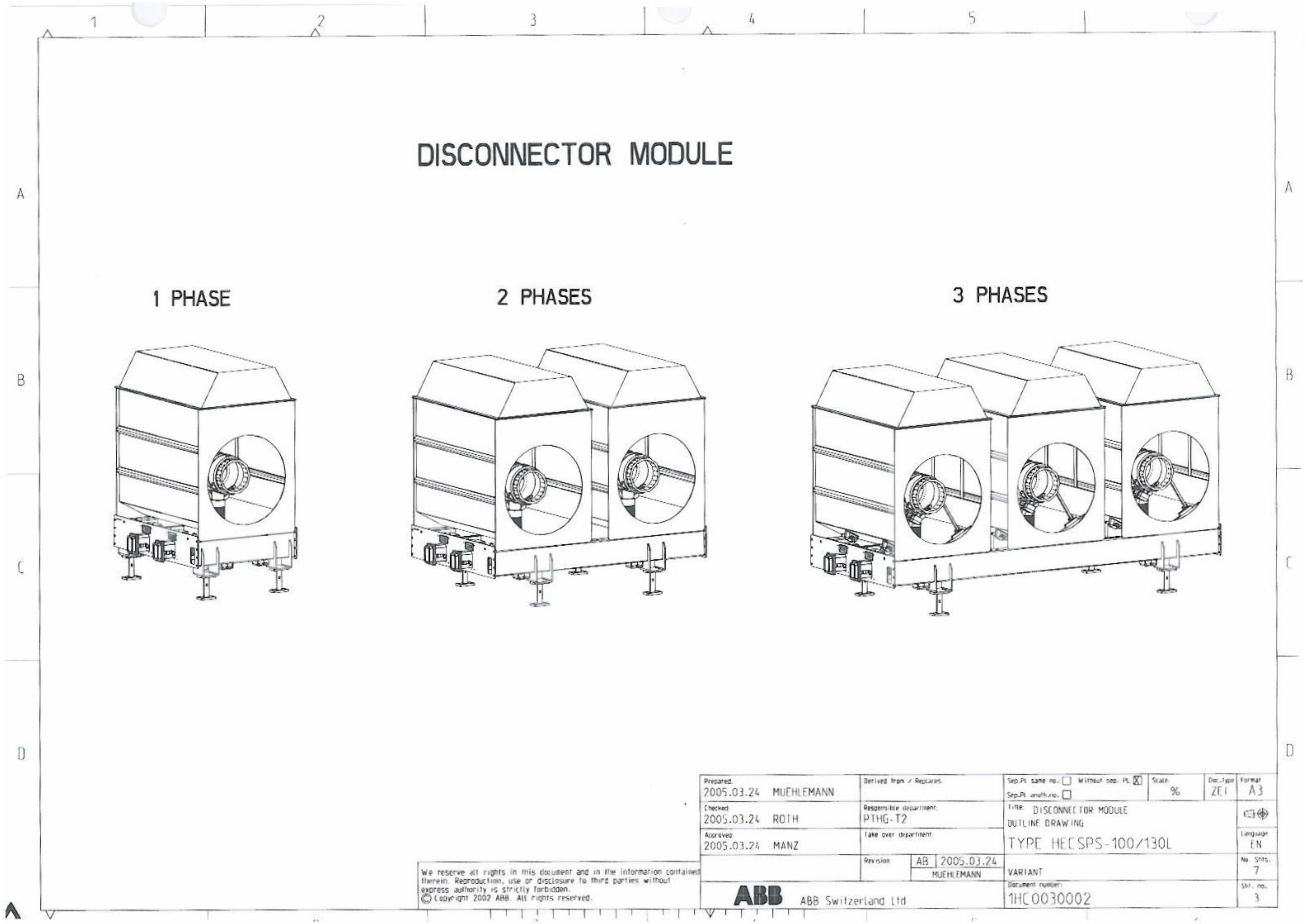


Figure 3-26. Toshiba Typical Supply ABB Type HECPS-100/130L, Drawing 1HC0030002, Sheet 3 of 7

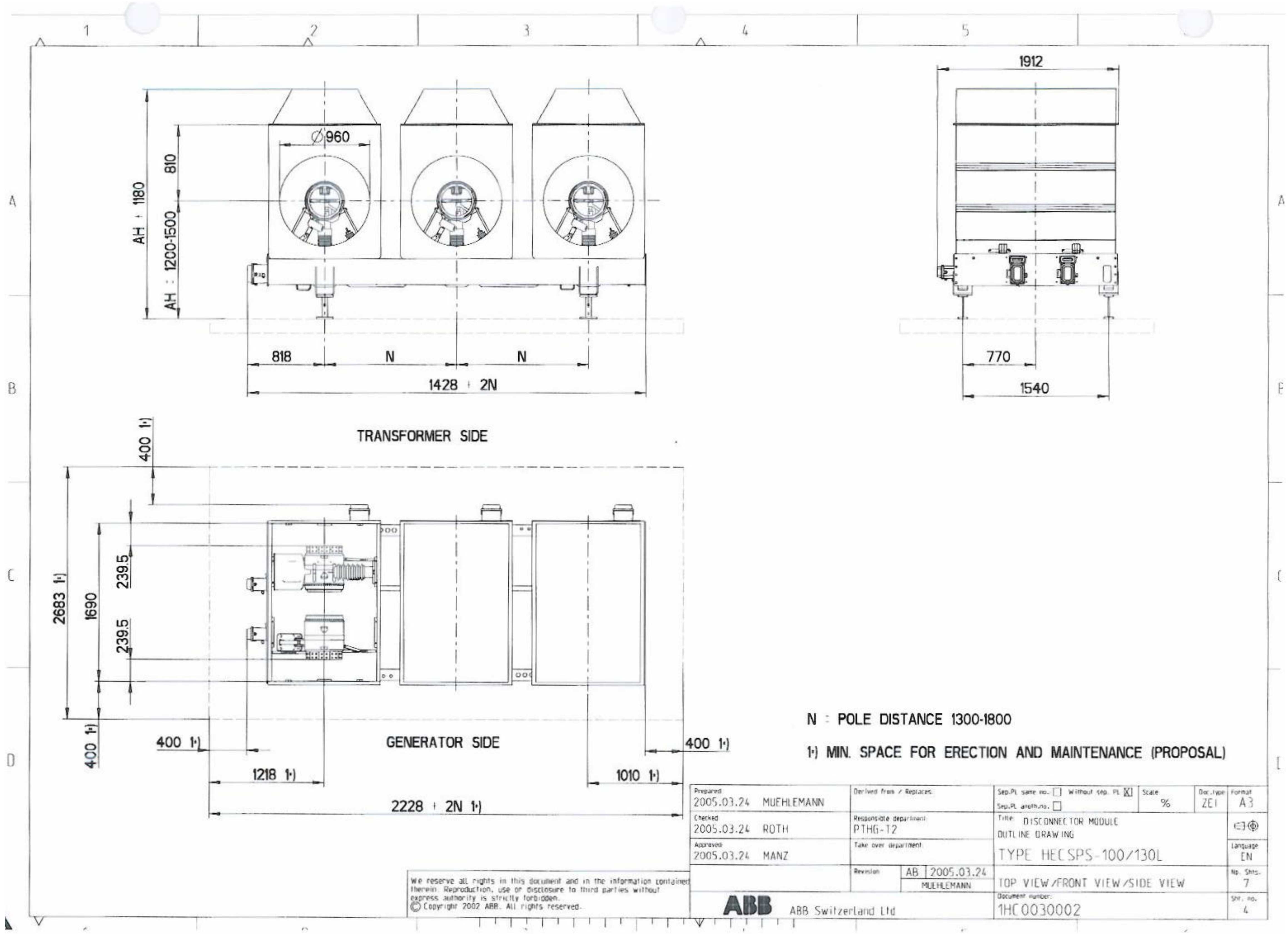


Figure 3-27. Toshiba Typical Supply ABB Type HECPS-100/130L, Drawing 1HC0030002, Sheet 4 of 7

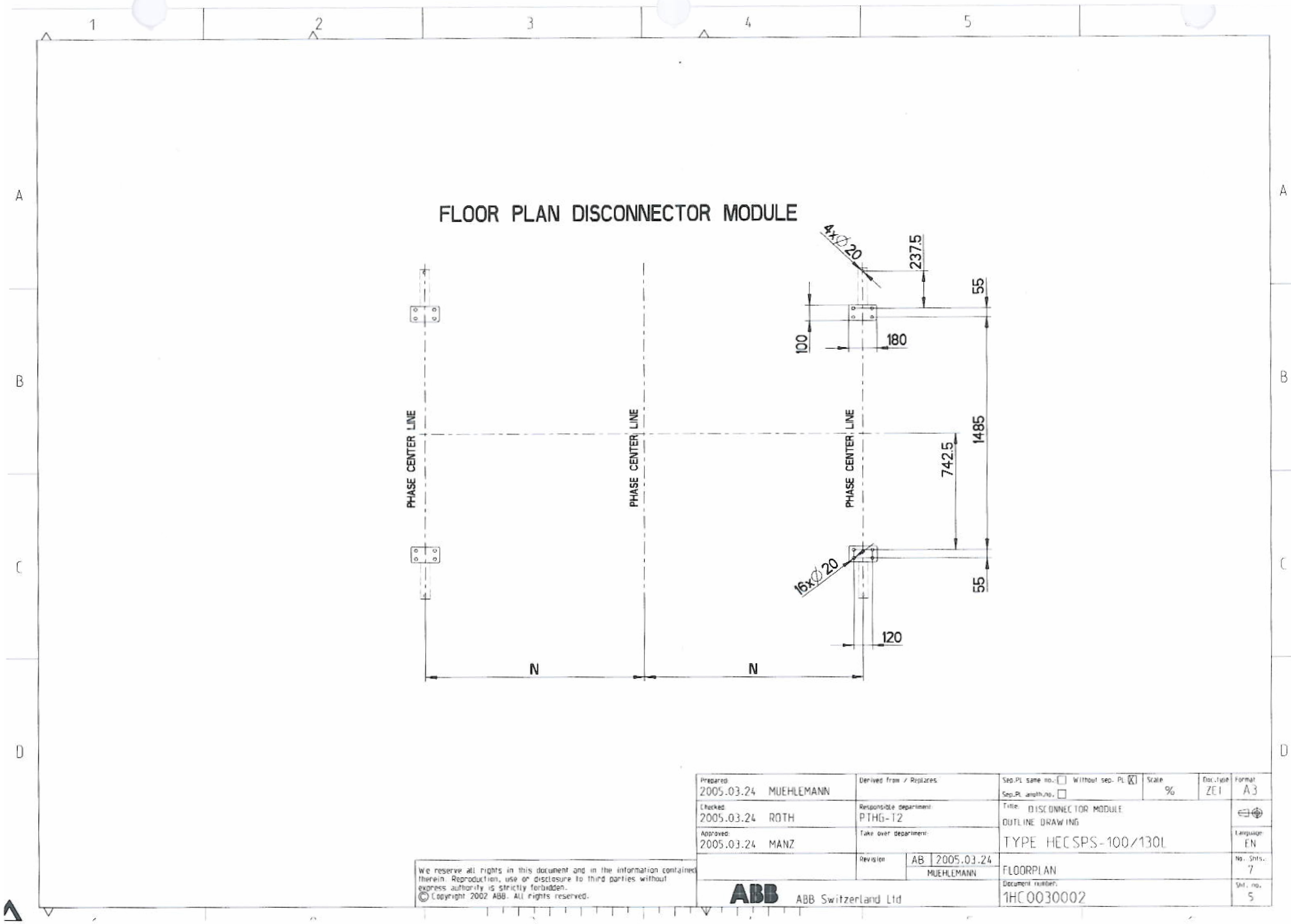


Figure 3-28. Toshiba Typical Supply ABB Type HECPS-100/130L, Drawing 1HC0030002, Sheet 5 of 7

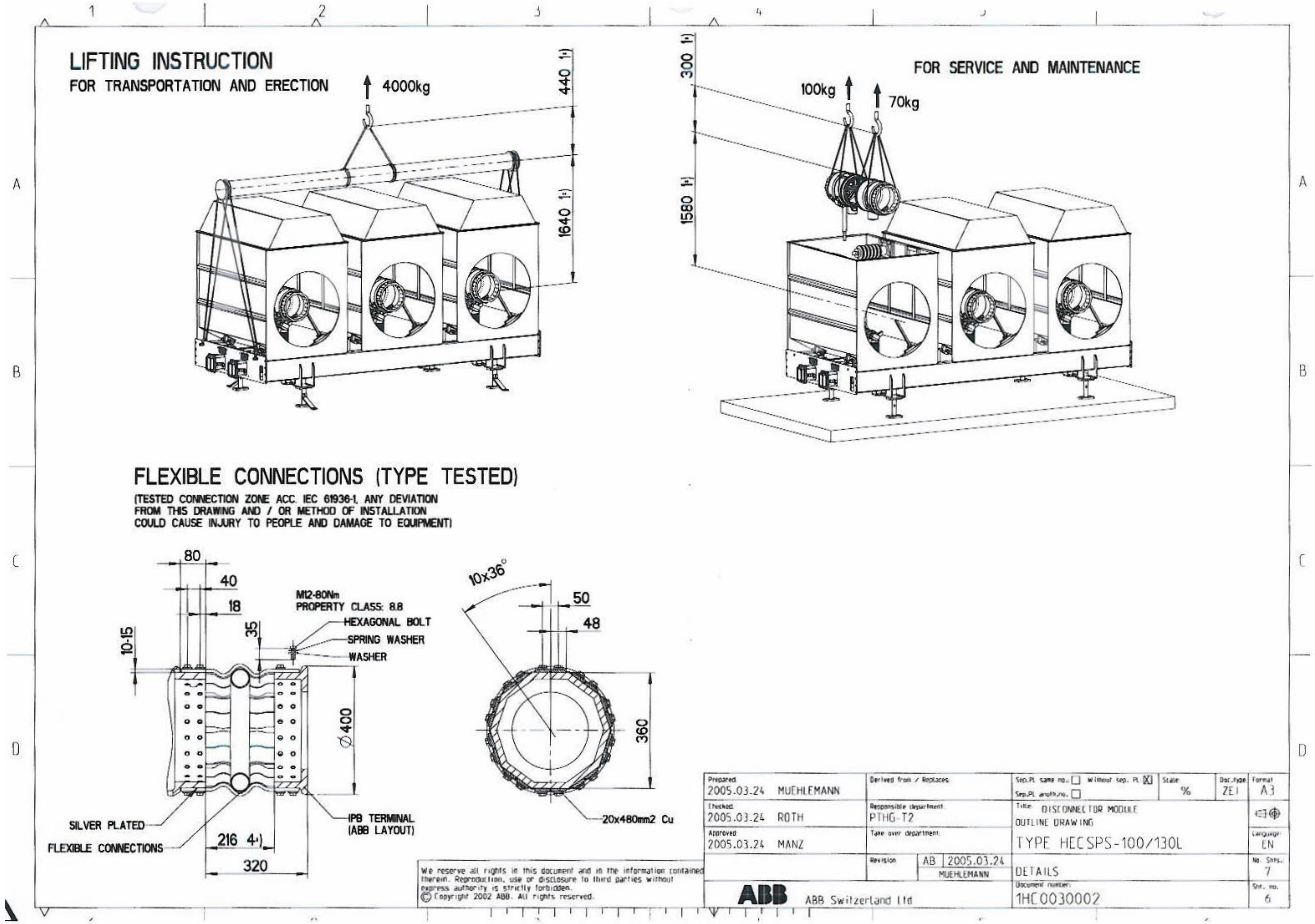


Figure 3-29. Toshiba Typical Supply ABB Type HECPS-100/130L, Drawing 1HC0030002, Sheet 6 of 7

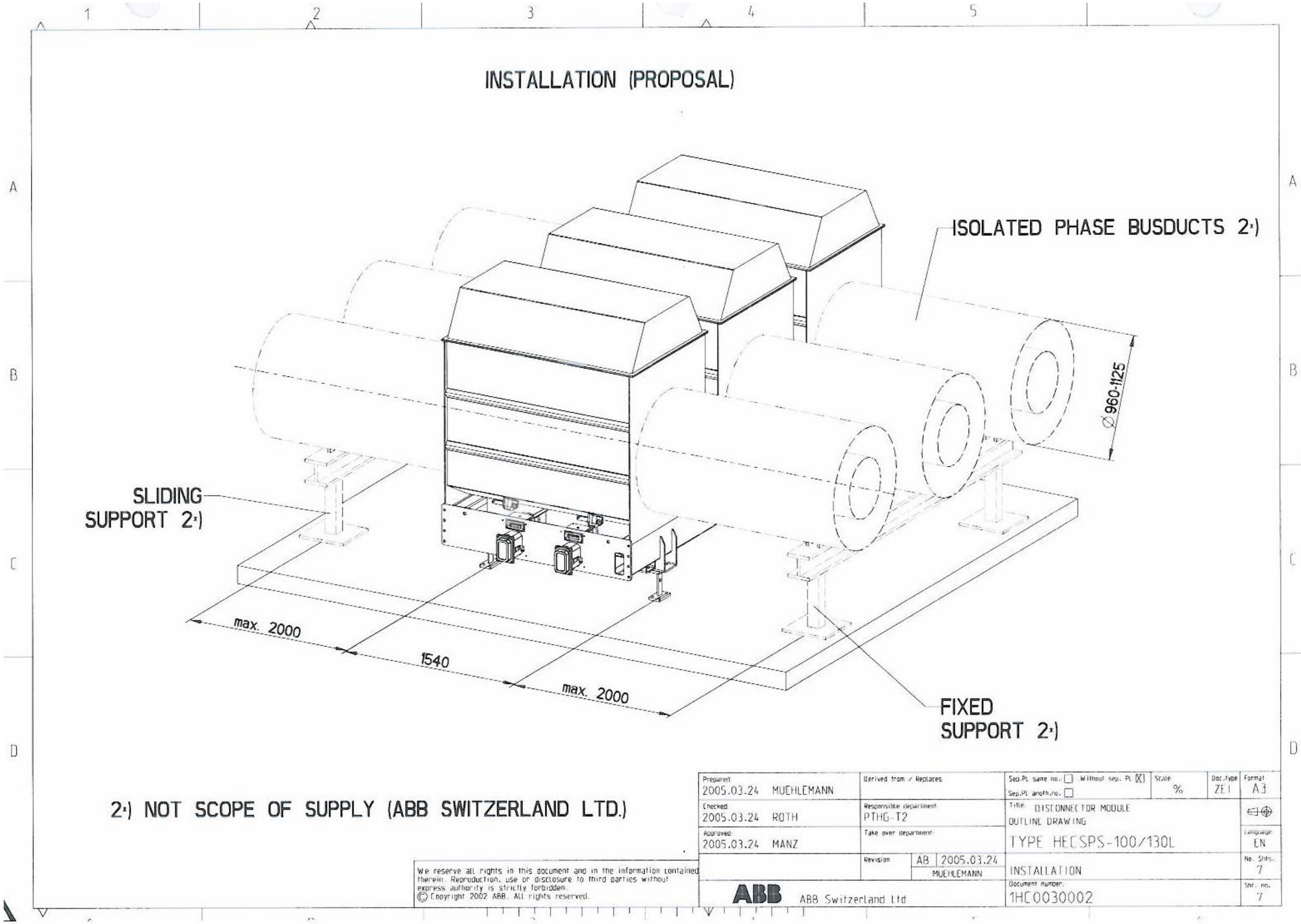


Figure 3-30. Toshiba Typical Supply ABB Type HECPS-100/130L, Drawing 1HC0030002, Sheet 7 of 7

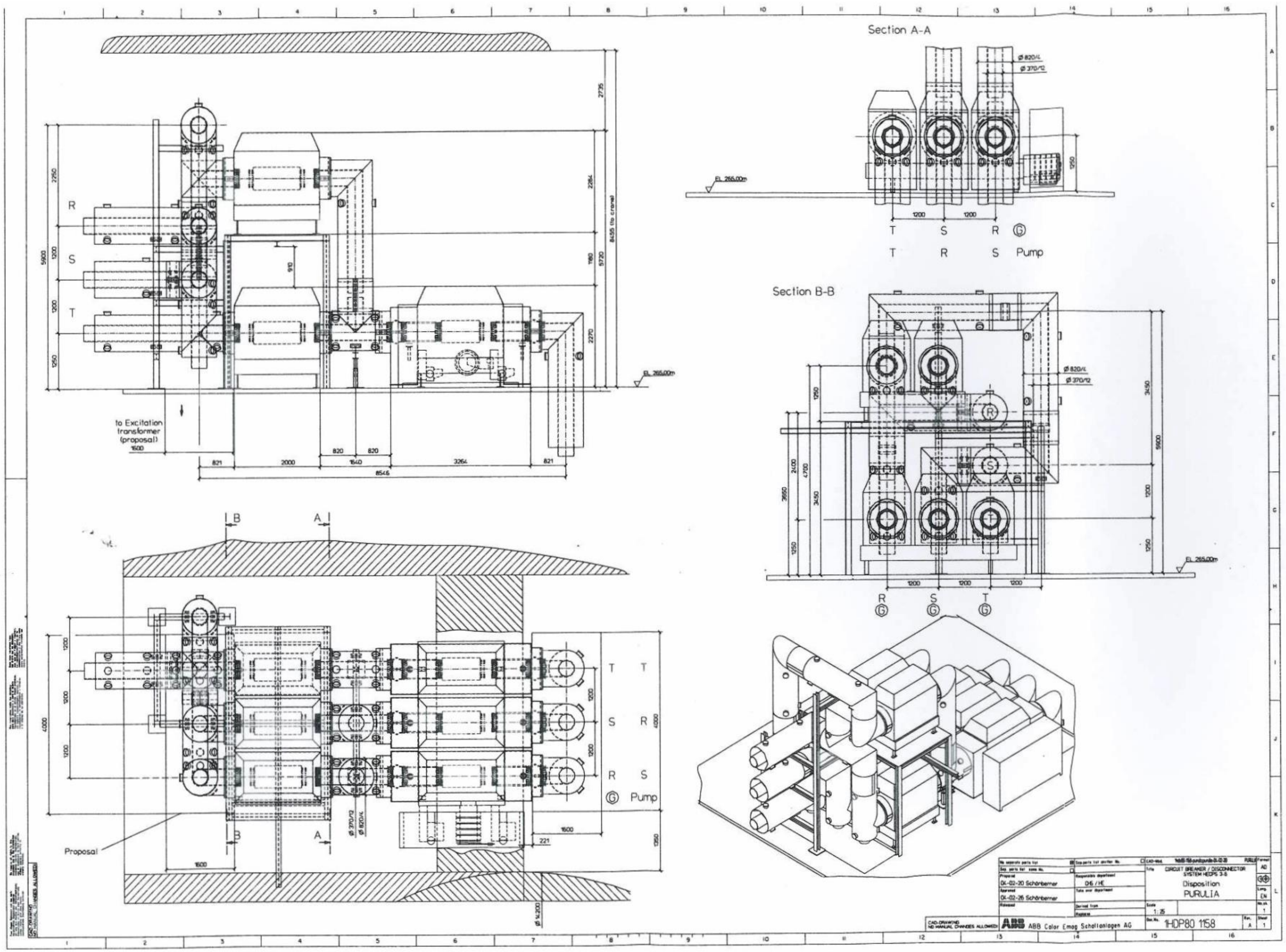


Figure 3-31. Toshiba Typical Supply ABB Type HECPS-100/130L, Vertical, Drawing 1HDP80 1158, Sheet 1 of 1

3.3.5.1.2 Phase Reversing Switch

3.3.5.1.2.1 System Function

A phase reversing switch will be integrated into the supplied circuit breaker skid. The phase reversing switch will be a buildup of disconnector modules. The switch will be motorized and used for switching between pump and generate mode. The switch will have five poles. B-phase and C-phase poles will be switched when changing modes of operation depending on which mode the unit is in.

3.3.5.1.2.2 Major Components

- Reversing switch
- IPB

3.3.5.1.2.3 System Description

The switch will be motorized and its position status will be monitored by the DCS and protection relays. IPB going from generator breaker terminals will be routed to one side of the reversing switch and the other side of the reversing switch will have IPB going towards the main generator step-up transformer. The enclosure for the reversing switch will have viewable windows so that the physical position of the switch can be seen. An example of a Voith-supplied IPB is shown in Figure 3-32.

3.3.5.1.2.4 System Interfaces

Mechanical

- None

Electrical

- Protective relay board
- Auxiliary DC power
- Plant control system
- Generator circuit breaker
- Isolated phase bus duct
- Cables (low voltage / sensor / fiber optics)

3.3.5.1.3 Isolated Phase Bus

3.3.5.1.3.1 System Function

The IPB will connect the generator terminals to the main generator step-up transformer. The five-pole phase reversing switch, motor-generator circuit breaker, and disconnector module will be mounted in the bus. Surge protection, potential transformers, the AC excitation system, and station service transformers will be tapped from the bus. Metering and relaying current transformers will be installed around each phase of the bus as well.

3.3.5.1.3.2 Major Components

- Current transformer
- Disconnector module
- Phase reversing switch

3.3.5.1.3.3 System Description

The IPB will be routed from the generator terminals to the motor-generator breaker, continue from the motor-generator breaker to the phase reversing switch, and then continue to the main transformer low side terminals. Taps for potential transformers, the AC excitation system, and station service transformers will be needed on the bus. The bus will be rated for 18 kV, 5,000 Å, and will be self-cooled.

3.3.5.1.3.4 System Interfaces

Mechanical

- None

Electrical

- Motor-generator
- Generator step-up transformer
- Station service transformer
- Motor-generator circuit breaker
- Phase reversal switch
- Potential transformer
- Monitoring instrumentation
- Protective relay board
- Relaying and metering
- Cables (low voltage / sensor / fiber optics)

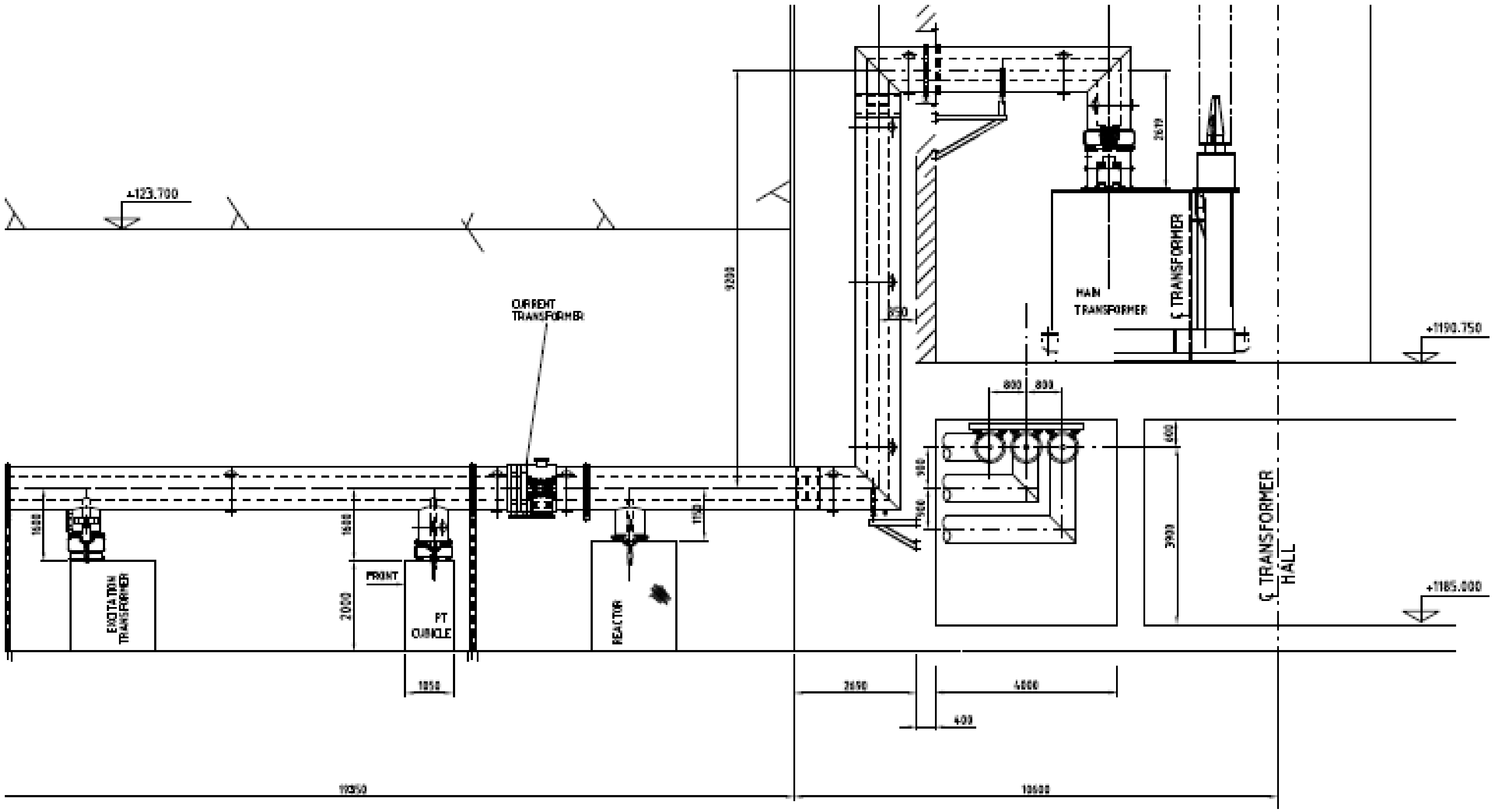


Figure 3-32. Voith Siemens Supply Typical Isolated Phase Bus Elevation

3.3.5.2 Generator Step-up Transformers

3.3.5.2.1 Functional Design Criteria

The generator step-up (GSU) transformers shall be SF6 type and will be located in the powerhouse transformer cavern. The GSUs will be connected to the iso-phase bus from the motor-generator and will step-up the voltage. The 230 kV high voltage cables will connect to the GSUs with pluggable connections. Cooling water will be provided to the heat exchangers mounted on the transformers. CTs will be located on the transformer bushing for protection relaying and metering. The transformer cavern will have embedded rails for moving the transformers on wheels.

A spare GSU transformer shall be provided that is assembled, dressed, filled, and tested. It shall be stored in the transformer cavern and shall be ready to be installed and put into service.

3.3.5.2.2 Optional GSU Configuration

An allowable optional GSU transformer configuration is to use mineral-oil-filled GSU transformers that are located at the utility shaft building or in the switchyard. Oil-filled GSU transformers will not be allowed in the powerhouse cavern. In order for SMUD to approve this option, the DBE shall provide backup information with capital cost and life cycle cost net present value (NPV) calculations. The cost evaluations shall compare the SF6 configuration and the optional configuration to show that there will be a capital cost savings and a life cycle cost savings to SMUD.

3.3.5.2.3 System Description

There will be one 3-phase generator step-up (GSU) transformer for each motor-generator unit. The GSU transformers shall meet the requirements specified in SMUD SPEC-001 - 230-18KV, 175MVA, GSU TRANSFORMER (SF6).

3.3.5.2.4 System Interfaces

The GSU transformer will interface with the following equipment in the powerhouse.

- High voltage cables to switchyard.
- Iso-phase bus to generator.
- Embedded rail system for moving transformer in powerhouse.
- Closed loop cooling water system.
- Plant DCS system input. Automated functions shall include: (1) derate motor-generators if cooling is lost to the transformer, (2) alarm plant evacuation if there is a rapid pressure drop in the transformer.
- 480V aux power system for SF6 blower power.
- Relay protection system.

3.3.5.2.5 High Voltage Breakers and Disconnects

A high voltage 230 kV breaker, disconnect, and earthing switch is required on the high side of each GSU transformer in the transformer cavern of the powerhouse. This equipment may be integrated into the high side of the GSU transformer. This will allow operators to disconnect the HV cables and isolate the GSU transformers for inspection, testing, and maintenance. The lock-out/tag-out process for the GSU transformers can be completed in the powerhouse without going to the switchyard to isolate the high voltage cables.

3.3.5.3 Protection Systems

3.3.5.3.1 Instrumentation

3.3.5.3.1.1 System Function

Instruments will be specified to monitor process conditions, providing feedback for control, operations monitoring of process conditions, and generating of alarms and trip signals through control logic. Alarms and trips will be displayed on the human-machine interface (HMI) in the control room when abnormal conditions have been detected. Instruments specified will be of the latest state-of-the-art technology and methods.

The instrumentation and control equipment/systems and materials and their installation will be designed in accordance with applicable codes and industry standards (Appendix A). Instruments and valves will be precalibrated, tagged, and preprogrammed by the supplier when applicable. All instruments, control valves, switches, and process control philosophy will be shown on the piping and instrument diagrams (P&IDs) in sufficient detail to fully illustrate each instrument loop, its function, connection, and components.

Electronic smart digital transmitters and controllers will be specified for proportional output of 4 to 20 mÅ DC with a 24 VDC power supply. Transmitters requiring an external power supply will be connected to 115 VAC or 24 VDC.

3.3.5.3.1.2 Major Components

- Pressure instruments: Air system, oil accumulators, transformer tank level, penstock pressure, cooling water, redundant upper reservoir pressure transducers
- Temperature instruments: Generator bearings, cooling water, powerhouse fans
- Level instruments: Oil accumulators, oil reservoirs, sump system, unwatering systems
- Flow instruments: Cooling water system, penstock
- Control valves: Cooling water, service water, oil systems, air systems
- Air system: Tailwater depression system, oil accumulators, air compressor
- Upper and Lower Resevoir Level Monitoring and Overpumping Protection Sytem Instruments: Redundant water level indicators and communication systems including, but not limited to pressure transducters, radar water level detection, staff guage with camera and lighting, with approprate redundant communication means to the central control system (Refer to Section 3.6.2.6).

3.3.5.3.1.3 System Description

Pressure Instruments

Pressure gauges will be installed at locations where only local indication is required. Gauges will have white faces with black markings.

Pressure transmitters will be installed on several systems including the air compressor system, the oil accumulator, and the penstock. Pressure transmitters will also be used to measure static pressure on large transformers. The pressure signal will be used as the process variable to control processes such as the air compressor and turbine shutoff valve controls. In general, pressure instruments will have linear scales with units of measurement in pounds per square inch (PSI). Where needed, a 4–20 mÅ output from the transmitters will be used to display information remotely. Pressure instruments will generally have screwed connections. Pressure test points will have isolation valves and caps or plugs.

Pressure switches will be provided where it is determined that only discrete pressure indication is required for monitoring and control.

Temperature Instruments

Temperature instruments will be specified and scaled with temperature units in degrees Fahrenheit. Exceptions to this are electrical machinery resistance temperature detectors (RTDs) and transformer winding temperatures, which are in degrees Celsius. Temperatures of cooling water, generator bearings, and the powerhouse will be monitored and used to control different elements in the powerhouse.

RTDs will be dual, three- or four-wire 100-ohm platinum or 10-ohm copper. The element will be spring-loaded, mounted in a thermowell, and connected to a cast iron head assembly.

Thermocouples, unless otherwise noted, will be spring loaded, dual element, Type K ungrounded.

Level Instruments

Level measurement will be provided for by the following types of measuring devices:

- Conductivity
- Ultrasonic
- Displacement
- Differential pressure
- Level switches

Reflex-glass or magnetic-level gauges will be used. Level indication for corrosive service (if required) will use devices other than reflex-glass gauges. Level gauges for high-pressure service will have suitable personnel protection. Gauge glasses used in conjunction with level instruments will cover a range that includes the highest and lowest trip/alarm set points. Oil and water level alarms/trips will be monitored for various systems.

Flow Instruments

Process flow measuring devices will include:

- Orifice plate
- Annubar
- Vortex
- Magnetic flowmeter
- Positive displacement
- Turbine meter
- Flow switches
- Ultrasonic

Concentric-type orifice plates will be used as the primary elements for flow measurement. In general, 316 stainless steel orifice plates will be provided. For clean fluids, the square edge orifice will be used. Penstock excess flow and cooling water flow will be monitored and used to control valves.

Differential pressure flow transmitters will be supplied with three-valve manifolds for use with orifice plate flowmeters.

Ultrasonic flowmeters will be used to provide penstock flow measurement.

Control Valves

Control valves in throttling service will be the globe-body, cage-type with body materials, pressure rating, and valve trim suitable for the service involved. Each control modulating valve will be specified on the data sheet and will be sized per the manufacturer’s method based on the ISA-S75.01 sizing equations. All actuators, positioners, solenoid valves, limit switches, etc., will be mounted on the valve by the vendor. On/off valves will be full-port, line size, and selected to produce minimum pressure drop. Limit switches will be provided where it is necessary to know the valve position.

3.3.5.3.1.4 System Interfaces

Mechanical

- Monitoring instrumentation
- HVAC
- Compressed air system
- Lube oil system
- Cooling water system
- Tailwater depression system
- Motor-generator and pump-turbine bearings
- Station drainage sump system

- Unwatering system
- Fire protection system
- Penstock monitoring
- Governor hydraulic power unit

Electrical

- Auxiliary AC power
- Auxiliary DC power
- Plant control system

3.3.5.3.2 Relaying and Metering

3.3.5.3.2.1 System Function

A protective relaying system will be provided to initiate clearing of electrical faults and abnormal conditions that could be detrimental to the plant equipment or create hazardous situations for personnel. Metering will provide operators with information concerning the condition and status of plant equipment. Amps, megawatts, megavars, power factor, line frequency, generator bus frequency, and voltage are examples of the metering data that will be available to the operator in the control room.

3.3.5.3.2.2 Major Components

- Current transformers
- Potential transformers
- Motor-generator multifunction relays
- Main GSU transformer multifunction relays
- Station service transformer multifunction relays
- Multifunction meters

3.3.5.3.2.3 System Description

Relays

Protective relays included in the design will be microprocessor-based and will provide metering, event recording, and oscillography. Plant protective relays will communicate to plant-operating computers, and be accessible to SMUD’s protection engineers through an SEL-3530 communication relay or an approved equivalent. The minimum requirements for relay protection zones are shown on drawing E-SC-403.

Redundant generator and main step-up transformer multifunction relays will provide the following functions, as a minimum, for the motor-generator, main step-up transformer, and associated equipment:

- Motor-generator differential (87G), which protects the machine itself

- Motor-generator neutral ground (both a ground overvoltage relay [59N], which protects approximately 95% of the motor-generator winding, and a 180 Hz undervoltage relay [27TN], which protects the machine from faults near the neutral ground, are recommended)
- Motor-generator voltage restrained overcurrent (51VR) or distance (21) relaying to provide backup protection for faults on the system side of the motor-generator circuit breaker
- Motor-generator loss of field (40) to protect for damage due to loss of excitation
- Motor-generator negative sequence (46) to protect the motor-generator rotor from overheating due to unbalanced phase currents
- Motor-generator undervoltage (27) to protect the stator winding from damage due to an undervoltage condition
- Motor-generator underfrequency (81U) to protect the machine during pumping from an underfrequency condition
- Motor-generator phase imbalance (60) to detect blown fuses, which could cause misoperation of relays or the voltage regulator
- Motor-generator sync check (25) to prevent synchronizing out of phase
- Motor-generator breaker failure (50BF), which causes upstream breakers to trip on the failure of a motor-generator breaker due to a fault detected by the protective relaying
- Motor-generator out-of-step (78), which separates the unit from the system for a loss of synchronism
- Motor-generator volts/hertz (24) to protect the machine and transformer cores from overheating due to overexcitation
- Transformer differential (87T), which overlaps the motor-generator differential and includes the system side of the motor-generator breaker in its zone of protection
- Transformer high side overcurrent (50/51T)

The following relays are recommended for the balance of the 18 kV main power systems:

- Station service transformer overcurrent (SEL-501 or equivalent)
- 18kV bus undervoltage (27B)
- Generator step-up transformer differential (SEL-387E, GE-T60 or equivalent)
- Generator step-up transformer fault pressure relays (63 – provided by transformer manufacturer)
- Generator step-up transformer liquid detector relays (70L)
- Generator step-up transformer winding temperature (Qualitrol ITM or equivalent)
- Generator step- up transformer liquid (oil) temperature (Qualitrol ITM or equivalent)
- Generator step-up transformer gas pressure relays
- Auto synchronizer (25A – Basler BE1-25A or equivalent)
- Synchronizer check (25 – Basler BE1-25 or equivalent)

The following relays are recommended for the 480 V systems:

- Overcurrent trip devices with long time, short time, and ground fault current functions for all main and feeders on the 480 V load centers (switchgear)
- Time delay and instantaneous trip functions for motor control center feeder breakers

- Instantaneous magnetic trip breakers with overload protection for motor control center combination starters

Metering

Multifunction digital revenue metering will be provided as needed to supplement the metering provided by the protective relays. As a minimum, the following metering functions are recommended for the station:

- Motor-generator A, B, and C phase current
- Motor-generator power factor
- Motor-generator frequency
- Motor-generator megawatts
- Motor-generator megavars
- Motor-generator voltage
- Station 230 kV voltage
- Station 230 kV megawatts
- Station 230 kV megavars
- Station 230 kV frequency
- Station Service transformer low-side volts
- Station Service transformer low-side amps

Synchroscope, single-phase voltage meters and single-phase frequency meters will also be provided to allow for manual synchronizing when needed.

3.3.5.3.2.4 System Interfaces

Mechanical

- None

Electrical

- Motor-generator circuit breaker
- Line breaker
- Isophase bus
- Protective relay boards
- Plant control system
- Auxiliary AC power
- Auxiliary DC power
- AC Excitation system
- Governor control system

3.3.5.3.3 Protective Relay Boards

3.3.5.3.3.1 System Function

Each unit will have a set of protective relays mounted on a relay board located near the unit, and the unit control panel. All alarms/trips from these relays will be communicated to the control room and displayed on the monitors.

3.3.5.3.3.2 Major Components

- Protection relays
- Control switches
- Indicating lights
- Stand-alone panel

3.3.5.3.3.3 System Description

Panels will be stand-alone, 19-inch rack style with terminal blocks mounted behind the panel. The system will need to be secure from false tripping due to vibration. Microprocessor relays for motor-generator protection and transformer protection will be mounted on these panels. Control switches for manually adjusting voltage and speed, indicating lights, and breaker control switch will also be mounted on this board along with synch scope, voltage meters, and frequency meters. Auxiliary relays, auto synchronizing relays, and synch check relays will be mounted on this panel as well.

3.3.5.3.3.4 System Interfaces

Mechanical

- None

Electrical

- Relaying and metering
- AC excitation system
- Governor control system

3.3.5.4 Auxiliary Power

3.3.5.4.1 AC Auxiliary Power System

3.3.5.4.1.1 System Function

The AC auxiliary power system will supply AC power to station loads. AC loads will be 4160 V, 480 V, and 120/240 V, which will be provided by the station service transformer and low voltage auxiliary transformers. All of the transformers shall be either SF6 type or dry type. Loads will be both single-phase and three-phase loads. A conceptual single line of the auxiliary power system is shown on drawing E-SC-401.

3.3.5.4.1.2 Major Components

- 16.5 kV (or 18 kV) / 4160 V / 480 V station service transformers
- 4160 V / 480 V station service transformers
- 480 V 120/240 auxiliary transformers
- Low voltage panels
- Motor control centers
- Emergency standby generator (located at utility shaft)

3.3.5.4.1.3 System Description

16.5 kV (or 18 kV) / 4160 V / 480 V Station Service Transformers

It is estimated that the capacity of the station service transformer will be 5 MVA. A cast coil construction, 80°C rise, 16.5 kV (or 18 kV) / 4160 V / 480 V is recommended. The transformer will be connected delta-wye. This auxiliary transformer will be tapped from the main IPB, and it will be a three-phase transformer.

Motor Control Centers

The auxiliary transformer described above will feed a plant 4,160 V switchgear and 480-V motor control center supplying powerhouse motor loads. These loads will be used to feed most station motor loads via feeder breakers.

Low Voltage Panels

Dry-type auxiliary transformers will be used to step down voltage from 480 V to 120/240 V to feed powerhouse low voltage loads.

3.3.5.4.1.4 System Interfaces

Mechanical

- None

Electrical

- Megavar bus and GSU transformer
- Alternate station service feed (if available)
- Emergency standby generator

- Cables (low voltage / sensor / fiber optics)

3.3.5.4.2 DC Auxiliary Power System

3.3.5.4.2.1 System Function

The DC auxiliary power system will consist of batteries, chargers, and a distribution panel. Batteries will be either lead acid or gel type and rated for a nominal 125 VDC. A battery charger will be used to keep the battery voltage at correct levels.

3.3.5.4.2.2 Major Components

- Battery bank
- Battery charger
- Emergency standby generator (ESG)
- DC distribution panel
- Uninterrupted power source (UPS)

3.3.5.4.2.3 System Description

The system will provide DC control power to the plant's control system, protection relays, and emergency lighting, and an uninterrupted power source of AC power to vital plant equipment systems and services. Select lighting will be supplied by the DC source, while other lighting will be capable of being fed from the ESG. The battery charger will be sized to carry all DC loads as long as AC power is available. Upon loss of AC power, the battery bank will provide power to the protection relays and critical equipment like the motor-generator breaker trip coil. An ESG will feed the UPS through an automatic transfer switch (ATS), which will switch to the ESG feeder when sensing low voltage on the permanent power side. An undervoltage relay will be used to monitor low DC volts, and this relay will trip the unit when there is low voltage detected. The setting of undervoltage will be such that there will still be enough amps in the battery bank to trip the unit safely.

Batteries will be installed in a separate room with adequate ventilation. A rack for the battery bank will be chosen to meet seismic requirements. Installation will be in accordance with ANSI Z 358.1, and there will be an eye wash station located in the battery room. The DC distribution panel will be mounted outside the battery room. The amp-hour rating of the battery bank is still to be determined. The DC distribution panel will be sized based on the DC load requirements. The estimated size is an approximately 300 amp-hour battery bank that will carry all critical loads for at least 8 hours. Battery charger failure, UPS failure, and battery undervoltage alarms will be displayed on the monitor in the control room.

3.3.5.4.2.4 System Interfaces

Mechanical

- None

Electrical

- Protective relay board
- Relaying and metering
- Plant control system (DCS)
- Emergency lighting
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

3.3.5.5 Plant Computer Control

3.3.5.5.1 Plant Computer Control System

3.3.5.5.1.1 System Function

The plant computer control system will be a DCS. Its function will be to provide unit control, plant control, alarm monitoring, diagnostic troubleshooting, and data logging.

3.3.5.5.1.2 Major Components

- Touch screen monitors
- Engineering workstation
- Operator workstations
- Printers
- Keyboards

3.3.5.5.1.3 System Description

Touch screen monitors will be installed in the climate-controlled control room for operators to observe plant equipment alarms and status. Engineering workstations will have the capability to change settings of controlled equipment. All alarms will be recorded in the DCS system and time stamped. The units can be started and stopped from the operator workstations.

3.3.5.5.1.4 System Interfaces

Mechanical

- Cooling water system
- Sump pump system
- Unwatering system
- Fire pump system
- Governor hydraulic system

Electrical

- Instrumentation
- Relaying and metering
- Excitation system
- Motor control center

Civil

- Upper Reservoir level indicators
- Lower Reservoir level indicatiors

3.3.5.5.2 Emergency Power Generator System

3.3.5.5.2.1 System Function

A stationary propane-fueled, engine-driven electric generator will be used for emergency power. This generator automatically will turn on when grid power is not available. The emergency power generator will be located outside the Utility Shaft Building.

3.3.5.5.2.2 Major Components

- Automatic transfer switch
- Propane-fueled, engine-driven electric generator

3.3.5.5.2.3 System Description

A stationary propane-fueled, engine-driven electric generator, rated at 750 kVA and 480 V, will be located on the surface at the portal. It will be connected to a 4,160 V switchgear group via an automatic transfer switch, which will also be located at the Utility Shaft Building. Only critical loads will be powered by the standby generator. The normal station service power will be provided through the 18 kV iso-phase bus between the motor-generator and the GSU transformers. See drawing E-SC-401 for a switching single-line diagram of this system.

3.3.5.5.2.4 System Interfaces

Mechanical

- None

Electrical

- 480 V Motor control center
- 4,160 V Switchgear

3.3.5.6 Communications

3.3.5.6.1 Telephone, Paging, and Security Systems

3.3.5.6.1.1 System Function

The main switching termination and isolation equipment will be located in a communications room, and will consist of all site-switching equipment and phone line extensions. The telephone system will connect into the plant paging system, which will consist of dedicated handsets, speakers, amplifiers, and associated wiring. The telephone system capacity will be:

- Thirty extensions for voice, fax, and data communication
- A T-1 line for use by SMUD information systems
- A T-1 line for use by the transmission provided for communication and control of plant generation data

3.3.5.6.1.2 Major Components

- Isolation equipment
- Punch-out boards for termination
- Fiber optic
- Telephone
- Card readers
- Cameras

3.3.5.6.1.3 System Description

The plant communications system will consist of a telephone system and a public address paging system. Card readers will be used to limit access to areas where security is a concern. Only certain employees will have access cards to the powerhouse control room. Persons entering/exiting the room will be recorded by the DCS or RTU, and this information will be communicated to the SMUD headquarters via SCADA. Phones and cameras will be installed at the portal entrance and switchyard building so that the operator can be called from there. The operator will be able to see who is entering/exiting the powerhouse using this camera.

The security system provided will consists of zoom, tilt, and pan surveillance cameras located at the main gate, at the switchyard, and at other specified locations. Additional details regarding the plant security system are provided in Section 3.10.

The main gate will be controlled from a card reader at the gate outside of the portal, and from the control room. An intercom system will be provided from the main gate to the control room. Automatic opening and closing of the gate will be provided for vehicles exiting the powerhouse.

3.3.5.6.1.4 System Interfaces

Mechanical

- None

Electrical

- Plant control system
- SCADA (RTU)

3.3.6 Station Services

3.3.6.1 Heating, Ventilation, and Air Conditioning Systems

3.3.6.1.1 Powerhouse Smoke/Fume Control and Removal System

3.3.6.1.1.1 System Function

The system will be designed to remove potentially harmful smoke and vapors from the powerhouse complex.

3.3.6.1.1.2 Major Components

- Exhaust fans and motors
- Filters
- Ductwork

3.3.6.1.1.3 System Description

The lower floors of the powerhouse will be on separate exhaust systems from the upper generator floor because of a major difference in their volumes, with an exhaust duct at each lower floor level. The ducts will be isolated from each other, from floor to floor, by means of smoke/fire isolation dampers. Low-capacity smoke removal fans will discharge smoke/air to the smoke discharge header located in the cable tunnel, from which it will eventually be discharged outside.

The upper generator floor will have its own smoke exhaust system because of its larger volume. Smoke will be removed via a large ductwork exhaust routed at the crown above the crane. Smoke will then be exhausted to the inlet of the high-capacity smoke removal fans and discharged to the discharge header located in the cable tunnel, from which it will eventually be discharged outside.

Miscellaneous exhaust fans will be connected to a miscellaneous exhaust ductheader. This system will be responsible for battery room exhaust, welding fume exhaust (pump-turbine work), restroom/shower room exhausting, refrigerant escape from chillers, and other miscellaneous fumes. Makeup air is from the powerhouse environment. The air/fumes will be exhausted to the discharge header located in the vertical access shaft, from which it will eventually be discharged outside. All of the above-described fans will be located outside the powerhouse in the tunnels.

3.3.6.1.1.4 System Interfaces

Mechanical

- None

Electrical

- Fire detection system
- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

3.3.6.1.2 Powerhouse Ventilation System

3.3.6.1.2.1 System Function

Air conditioning of the powerhouse is recommended in lieu of direct outside air ventilation. With ventilation, the temperature and humidity of the powerhouse is dependent on the outdoor weather and the powerhouse conditions cannot be controlled. The installation of powerhouse air conditioning will permit control of temperature and humidity, which in turn will allow the electrical equipment, electronic equipment, and mechanical equipment to operate in a cooler and less humid environment. This will allow the equipment to operate more reliably, efficiently, and with extended life. In addition, because of the less severe operating environment, the maintenance on equipment will be decreased.

3.3.6.1.2.2 Major Components

- Large air handling units
- Duct and dampers
- Duct heaters (backup)
- Filters

3.3.6.1.2.3 System Description

The powerhouse air conditioning system (Figure 3-33**Error! Reference source not found.**) will be dependent on the powerhouse being isolated by walls and doors from tunnels and the transformer room to control the environment within the powerhouse. The low voltage bus caverns are considered part of the powerhouse.

The powerhouse air conditioning will consist of large air handling units located within the powerhouse. There will supply air ducting to every floor from the units as well as return air ducting from every floor back to the unit. Approximately 10% to 15% fresh air makeup will be introduced to the system, and there will be an equivalent relief of air, as required, from the powerhouse.

The cooling medium for the air will be chilled water from the powerhouse chilled water system. The heating medium for the air will be internal plant equipment heat to the return air system. Electrical supply duct heaters will serve as a backup when plant equipment is shut down, or if additional heat is required.

The powerhouse floors will be isolated from each other for smoke and fire protection purposes, as described below. The powerhouse air conditioning system will be instrumental in isolating and containing smoke produced on one powerhouse floor level from other floors by means of fire and smoke dampers and air pressurization of the other floors.

3.3.6.1.2.4 System Interfaces

Mechanical

- Powerhouse chilled water system

Electrical

- Fire detection system
- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

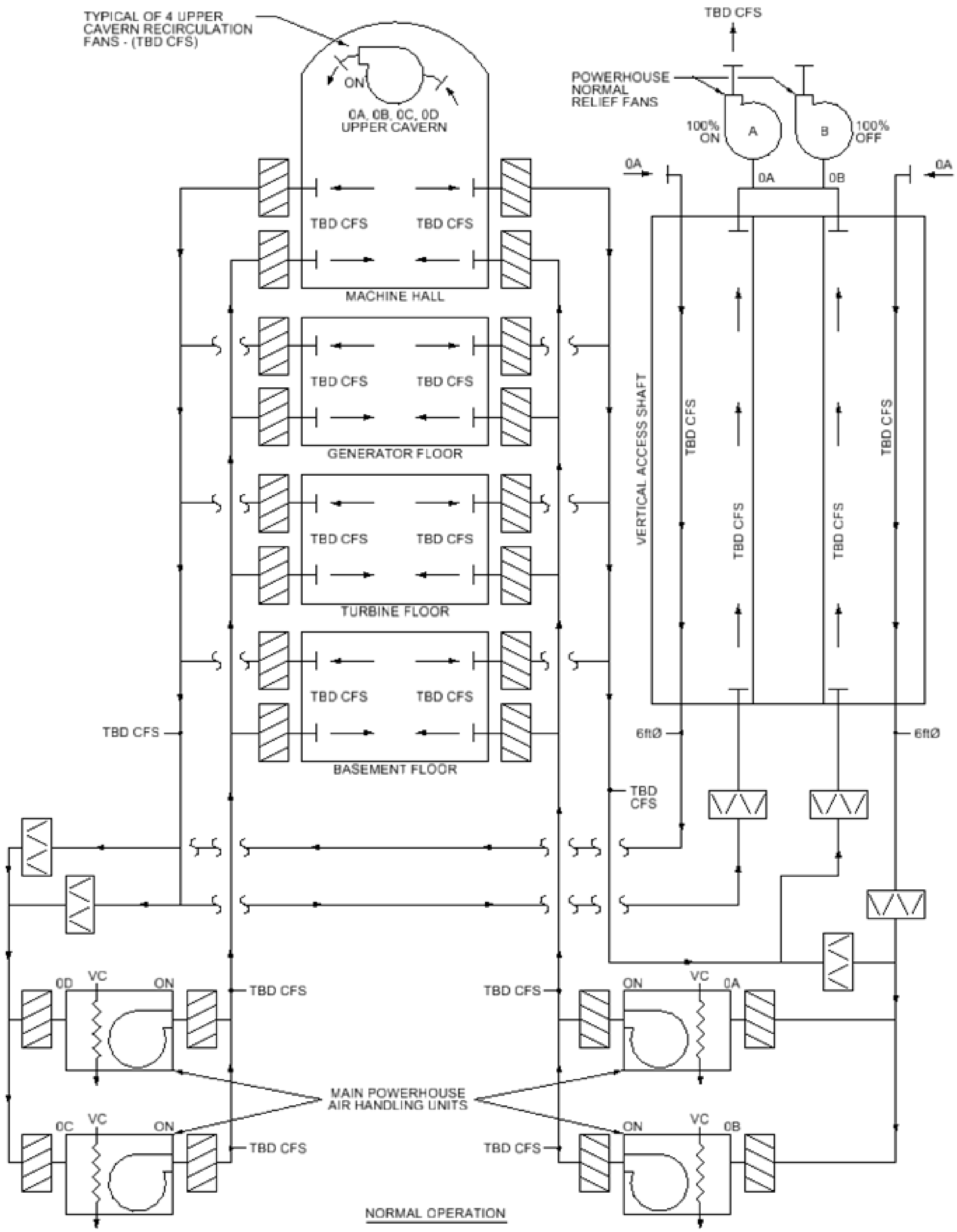


Figure 3-33. Powerhouse Ventilation System Conceptual Diagram

3.3.6.1.3 Stairwell Ventilation System

3.3.6.1.3.1 System Function

The stairwell ventilation system will provide fresh air under positive pressure to the stairwells between floors as well as in the stairwell to the surface. The stairwells provide the required path for emergency egress.

3.3.6.1.3.2 Major Components

- Air handling units
- Ductwork
- Fans and motors
- Filters
- Instrumentation

3.3.6.1.3.3 System Description

Air temperature will be controlled through dedicated air handling units. The air handling units will receive cold water from the powerhouse chilled water system. Ductwork will distribute the conditioned air throughout the stairwells to insure a source of clean, cool, fresh air at all times.

3.3.6.1.3.4 System Interfaces

Mechanical

- Powerhouse chilled water system

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

3.3.6.1.4 Main Access Tunnel and Transformer Cavern Ventilation System

3.3.6.1.4.1 System Function

This system will provide ventilation only to the main access tunnel and transformer caverns for the purpose of maintaining fresh air in these areas and removal of any smoke or fumes that may accumulate.

3.3.6.1.4.2 Major Components

- Large fans and motors

- Large ductwork
- Filters
- Instrumentation

3.3.6.1.4.3 System Description

The main access tunnel and the transformer cavern will be ventilated by means of a large fresh air supply duct and supply fans (Figure 3-34). The supply fans will be located in the vicinity of the entrance to the tunnel. The air intake duct to the fan inlets will be routed to a remote outdoor intake structure to prevent recycling of contaminated tunnel air. The large supply duct will be routed through the full length of the tunnel, from which air can be discharged at the end of the tunnel. A branch duct will be routed to the back side of the transformers, out of the tunnel, and outside.

3.3.6.1.4.4 System Interfaces

Mechanical

- None

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

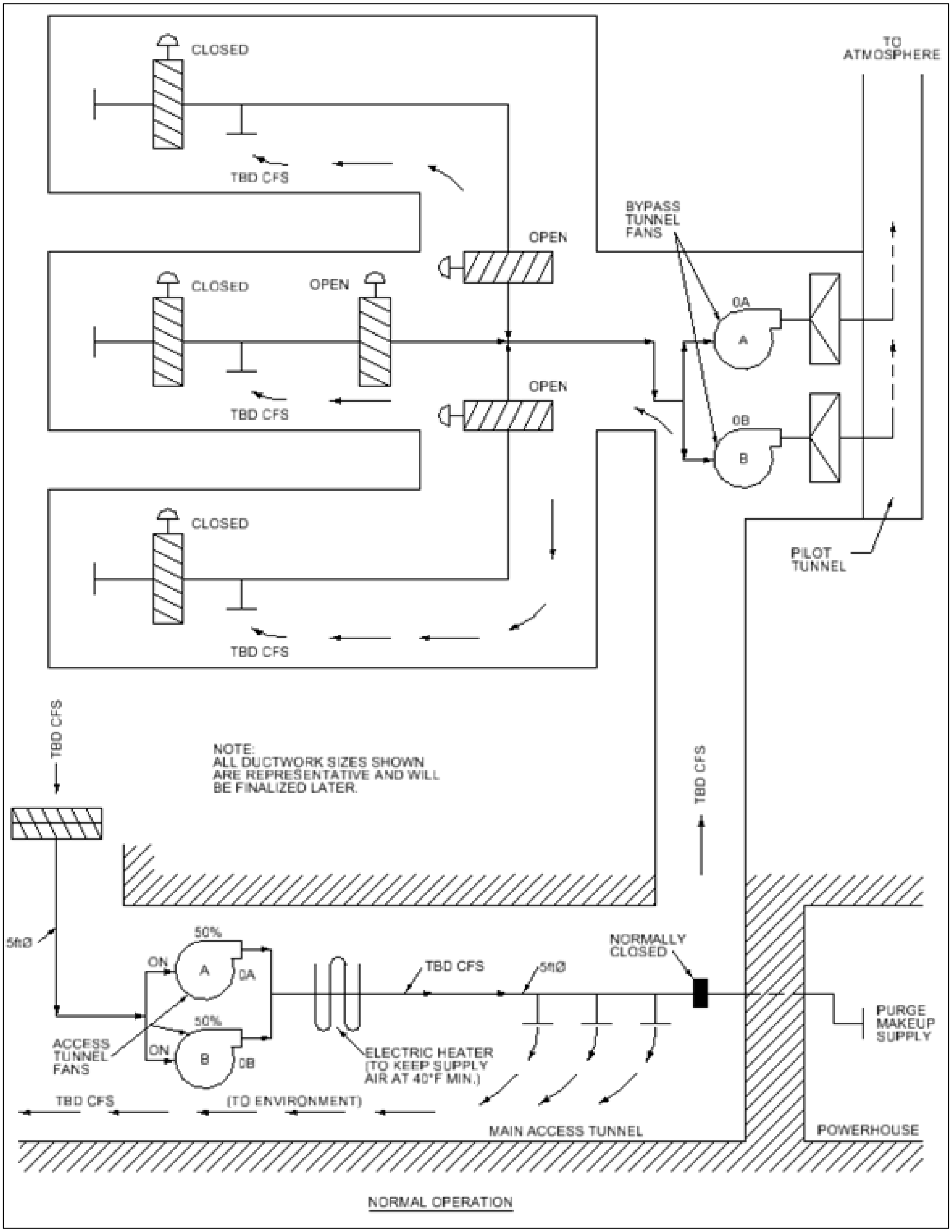


Figure 3-34. Access Tunnel and Transformer Cavern Ventilation System Conceptual Diagram

3.3.6.1.5 Control Room Air Conditioning System

3.3.6.1.5.1 System Function

The control room air conditioning system will provide a controlled temperature environment for personnel and control electronics.

3.3.6.1.5.2 Major Components

- Air handling unit
- Fans and motors
- Heaters
- Instrumentation

3.3.6.1.5.3 System Description

The control room air conditioning system will have an air handling unit located in close proximity. Depending on the size of the unit, it may either be a standard manufacturer's split DX system air conditioning unit, or a shop-fabricated unit using chilled water from the powerhouse-chilled water system. Typically, a control room located underground benefits from using the chilled water system, as there will be no condenser heat discharged (as with a refrigerant system). Fresh air will be introduced into the return air side of the system via a dedicated duct from an outside air intake header inside the main access tunnel. Heaters will be included to provide control of temperature if needed.

3.3.6.1.5.4 System Interfaces

Mechanical

- Powerhouse chilled water system

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

3.3.6.2 Sanitary Systems

3.3.6.2.1 Wastewater Treatment Systems

3.3.6.2.1.1 System Function

The wastewater treatment system will provide a means to treat the station drainage sump wastewater, transforming it from an influent, which is substandard for discharge, to an effluent that meets all environmental standards and is suitable for discharge to the Lower Reservoir.

3.3.6.2.1.2 Major Components

- Pumps with motors
- Valves
- Instrumentation
- Chemical treatment package
- Oil skimmer system
- Storage tank

3.3.6.2.1.3 System Description

The wastewater treatment system (Figure 3-35**Error! Reference source not found.**) will include two settling basins in series that will allow suspended solids to settle out; will have oil removal capability; and will provide chemical treatment of the wastewater if necessary. The wastewater treatment system will consist of a primary sedimentation basin, secondary sedimentation basin, chemical addition building, portable oil skimmer system, waste oil storage tank, and a Parwill flume for outflow measurement.

3.3.6.2.1.4 System Interfaces

Mechanical

- None

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

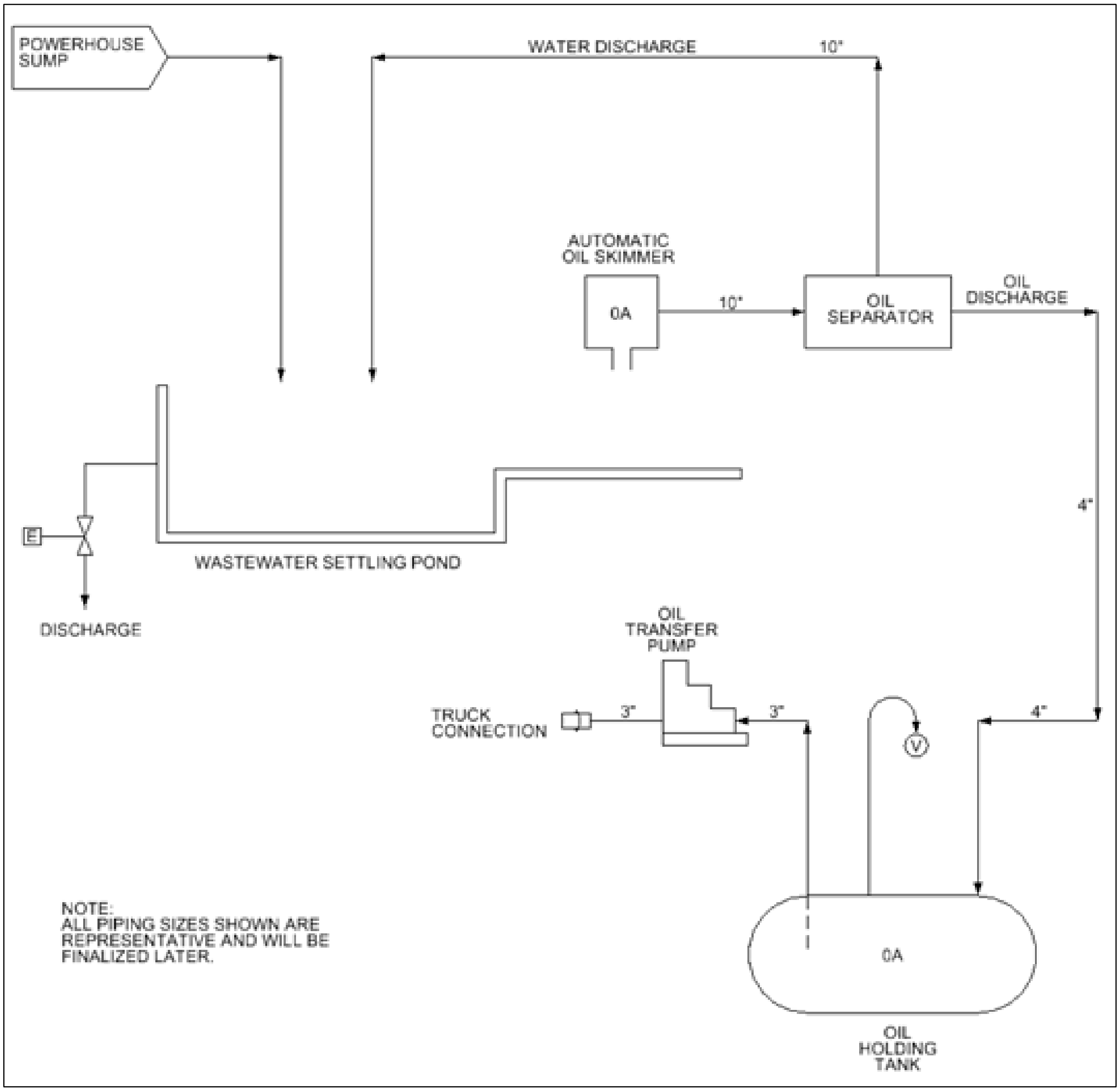


Figure 3-35. Wastewater Treatment System Conceptual Diagram

3.3.6.2.2 Sanitary Drains and Waste Treatment Systems

3.3.6.2.2.1 System Function

The sanitary waste system will process and dispose of all sanitary waste generated on site. All sanitary waste will be collected in holding tanks and then transferred to a treatment system.

3.3.6.2.2.2 Major Components

- Holding tanks

- Sewage ejectors

3.3.6.2.2.3 System Description

Sewage from various sources will drain to sewage holding tanks. It will then be pumped to a contractor's sewage tanker truck for treatment and disposal off-site.

3.3.6.2.2.4 System Interfaces

Mechanical

- None

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

3.3.6.2.3 Potable Water System

3.3.6.2.3.1 System Function

The potable water system will provide potable water to the powerhouse complex. Potable water will be used for drinking, sanitary facilities, and eye wash stations.

3.3.6.2.3.2 Major Components

- Pumps and motors
- Storage tank(s) with accumulator
- Water conditioning equipment
- Valves
- Instrumentation

3.3.6.2.3.3 System Description

Drinking-quality water will be obtained from either deep wells on site or treated water from the Lower Reservoir. Pumps will transfer the water through a water conditioning package to a pressurized holding tank. The degree of treatment required will be dependent upon the source. From there, various demand points will be supplied via a piping system that conforms to all requirements for potable water transfer.

3.3.6.2.3.4 System Interfaces

Mechanical

- None

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

3.3.6.3 Fire Protection

3.3.6.3.1 Fire Protection System

3.3.6.3.1.1 System Function

The powerhouse complex will be provided with a fire detection system consisting of different types of sensors that provide alarm signals to activate various fire suppression systems. A combination of fire suppression techniques will be employed to deal with any anticipated fire emergency. The fire detection systems shall meet the SMUD Technical Specification FPLC-CR5 – Fire Alarm Standard shown in Appendix A. Fire protection systems for IHPSP shall meet the minimum recommended requirements of NFPA 851 - Recommended Practice for Fire Protection for Hydroelectric Generating Plants.

3.3.6.3.1.2 Major Components

- Pumps and motors
- Strainers
- Filters
- Valves
- Preactivation equipment
- Sprinklers
- Misting system

3.3.6.3.1.3 System Description

A fire detection system will be installed. This control system will receive inputs from various heat detectors, smoke detectors, and manual pull stations throughout all areas of the powerhouse complex. Fire protection systems for IHPSP shall meet the minimum recommended requirements of NFPA 851 - Recommended Practice for Fire Protection for Hydroelectric Generating Plants. The fire detection systems shall meet the SMUD Technical Specification FPLC-CR5 – Fire Alarm Standard shown in Appendix A.

Fire suppression systems typically consist of two subsystems: (1) a deluge subsystem, which will consist of deluge and sprinkler systems in oil storage areas as well as in the transformer gallery and motor-generator barrel area; and (2) a standpipe subsystem, which will consist of two independent standpipes with hose reels to provide manual fire protection for all areas of the powerhouse, transformer gallery, and access tunnels. These types of fire suppression systems are typically supplied by connections to the low-pressure service water system pump discharge header.

Fire suppression in the motor-generator barrel area will be handled by an inert gas / water mist system to minimize water damage.

3.3.6.3.1.4 System Interfaces

Mechanical

- Low pressure service water

Electrical

- Fire detection
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

3.3.7 References, Codes, and Standards

- Jacobs Associates and HDR. 2015. Iowa Hill Pumped Storage Development Project Preliminary Functional Design – Power Complex, Volume 5: Description of Power Complex Memorandum.

3.4 Powerhouse Access Tunnel Portal and Tunnel

3.4.1 General

The powerhouse access tunnel (PHAT) portal will provide a secured entry for personnel, vehicles, and equipment in accordance with SMUD security protocols [SMUD to provide]. The horseshoe-shaped tunnel will be approximately 2,950 feet long, 25 feet wide nominal internal width and 25 feet tall. The invert will be a paved concrete road slab, sloped to drain.

The portal structure will incorporate the requirements for the primary air supply to the occupied areas of the powerhouse complex. The portal structure will also incorporate security monitoring systems necessary for SMUD to supervise access to the facility.

The PHAT will provide vehicle and equipment access between the surface and the powerhouse complex.

3.4.2 Operating and Maintenance Requirements

3.4.2.1 Access

- Vehicular access to the PHAT Portal will be possible during all conditions including the probable maximum flood (PMF) event for Slab Creek Reservoir and dam.
- The PHAT Portal structure invert elevation will be at the probable maximum flood elevation for Slab Creek Reservoir.
- The powerhouse access tunnel final configuration is sized for two 10-foot lanes, a 3-foot-wide utility corridor, and 6-inch curbs.
- The access tunnel is currently sized to accommodate a 14.5-foot-wide by 13-foot -tall piece of equipment on a 4-foot-tall trailer. This configuration does not govern the size of the powerhouse access tunnel.

3.4.2.2 Design Occupancy

- The PHAT will be designed for continuous occupancy.

3.4.2.3 General Layout Requirements

- Maximum slope is taken as 10% for constructability purposes.
- Curves in the PHAT will have a minimum radius of 300 feet.
- The staging area at the PHAT will be a maximum of 0.75 acre for construction and final configuration.
- The PHAT portal will aesthetically blend into the natural environment.

3.4.2.4 Utility Requirements

- The PHAT will contain 9-6 inch conduits for power distribution and 3-foot by 5-foot and 2-foot deep pull boxes along its length, as needed.
- The PHAT will be illuminated.
- The PHAT will contain a powerhouse unwatering discharge line.
- The PHAT will be sloped to one side to direct water into a drainage channel.
- It is assumed that the PHAT will contain a ventilation line during construction with exhaust at the portal.
- Temporary utilities may be hung along the PHAT sidewalls during construction.
- The PHAT access door will be louvered to allow for natural ventilation up the utility shaft.
- The PHAT portal will provide space for a settling basin to be used prior to discharging tunnel and powerhouse drainage water to the Slab Creek Reservoir.
- Cable trays, conduits, and all other utilities will be secured to the tunnel lining.
- Powerhouse Unwatering Line will be protected from vehicle impacts.
- The PHAT Portal will have shielded lighting.

3.4.3 Security

- Portal access will be secured with a locked steel door with a roll-up inset door for smaller vehicle access.
- A chain-link fence will separate the final portal area from Slab Creek Reservoir Road. A gate opening will be provided for truck access.

3.4.4 Support Assessment

- Refer to Section 3.3.3 for the support requirements.

3.4.5 Groundwater Inflows

An estimate of the water inflow into the PHAT will be developed during Final Functional Design and will be integrated into the overall hydrogeologic model for the project to assess impacts on the groundwater regime and associated environment impacts. The anticipated infiltration rates will be used to develop groundwater control requirements that will be included in the Design Requirements.

3.4.6 References, Codes, and Standards

3.4.6.1 Underground Support Design

- Barton, N., Lien, R., and Lunde, J., 1974, “Engineering Classification of Rock Masses for the Design of Tunnel Support,” Rock Mech. 6: 189–236.
- Grimstad, E. and Barton, N., 1993, Updating the Q system for NMT. Proceedings of the International Symposium on Sprayed Concrete: Modern Use of Wet Mix Sprayed Concrete for Underground Support, Oslo: Norwegian Concrete Association.

- Hoek, E. and Diedrichs, M.S., 2005, Estimation of Rock Mass Modulus, submitted for publication in the International Journal of Rock Mechanics and Mining Sciences, 14p.
- Proctor, R.V. and White, T.L., 1968, Rock Tunneling with Steel Supports, with an Introduction to Tunnel Geology by Karl Terzaghi, Commercial Shearing, Youngstown, Ohio.

3.5 Utility Shaft and Utility Shaft Building

3.5.1 General

The utility shaft will house emergency stairs, 230kV insulated power cables, a ventilation exhaust line, and communication cables to the utility shaft building. The utility shaft will extend 1,300 feet below the surface and be a minimum of 19 feet in diameter.

The utility shaft building will incorporate the requirements for the primary air exhaust from the occupied areas of the powerhouse complex. The building will also contain critical communications and backup power systems. The building will be provided with secured entry for personnel and equipment. Adjacent to and outside the utility shaft building will be the project stationary backup generator that will provide backup power for the utility shaft building, switchyard, and powerhouse.

3.5.2 Operating and Maintenance Requirements

3.5.2.1 Access

- A removable hatch will provide access to the Utility Shaft beneath the building.
- A fence will control access around the building.
- Appropriate signage will be placed advising the public of the hazards present in the structure.
- Parking will be provided adjacent to the building for two commercial vehicles.

3.5.2.2 Design Occupancy

- The Utility Shaft and Utility Shaft Building will be designed for continuous occupancy.

3.5.3 Support Assessment

- Refer to Section 3.3.4 for support requirements.
- For moderately weathered or higher quality rock, the utility shaft support is anticipated to utilize spot and pattern bolts with some shotcrete lining. Rock bolts will not be required to be permanent.
- For soil to severely weathered rock, a shaft lining system such as secant piles may be necessary to adequately handle earth pressures and control groundwater inflow.

3.5.4 Groundwater Inflows

An estimate of the water inflow into the utility shaft will be developed during Final Functional Design and will be integrated into the overall hydrogeologic model for the project to assess impacts on the groundwater regime and associated environment impacts. The anticipated infiltration rates will be used to develop groundwater control requirements that will be included in the Design Requirements

3.5.5 References, Codes, and Standards

Goodman, R.E., D.G. Moye, A. Van Schalkwyk, and I. Javandel. 1965. Ground Water Inflows during Tunnel Driving. *Engineering Geology, Bulletin of AEG*, 2(1), 39–56.

3.6 Upper Reservoir and Dam

3.6.1 General and Facility Sizing Requirements

The Upper Reservoir will provide the hydraulic head and storage capacity for operation of the pumped-storage powerhouse. The Upper Reservoir will be located at the top of Iowa Hill. It will be formed by construction of a perimeter dam and excavation within the reservoir footprint to create the necessary storage capacity. The Upper Reservoir will include the inlet/outlet structure (I/O) connecting the reservoir with the headrace shaft.

The Upper Reservoir will be designed to contain the volume of water necessary to satisfy an operating duration of 16 hours at the maximum pumping rate of 4,698 cfs, defined in Table 2-1, which results in a required active reservoir capacity of approximately 6,300 acre-feet.

Key Upper Reservoir criteria and design parameters are summarized in Table 3-6, and addressed in the following subsections.

Table 3-6. Functional Design Criteria and Key Parameters for Upper Reservoir and Dam (Preliminary)

Description	Value	Comment
Operating		
Operating Storage Capacity	6,300 ac-ft	16 hours of powerplant operation in generate mode at 4,698 cfs.
Maximum Normal Operating Water Surface Elevation (MNWS)	3,073 ft	
Minimum Normal Operating Water Surface Elevation (LWS)	2,945 ft	
Inlet/Outlet (I/O) Sill Elevation	2,918 ft	From hydraulic modeling studies of I/O.
Max Normal Operating Depth	155 ft	Operational head over I/O sill.
Pumped Inflow Rate (peak/ minimum)	4,608 cfs / 948 cfs	Three 150 MVA pump units.
Operational Outflow Rate (peak/ minimum)	4,698 cfs / 303 cfs	Three 133 MW generating units.
DSOD Emergency Release Rate (7-day avg.)	71 cfs	Lower storage depth 10% within 7 days (average flow rate to Lower Reservoir 14 ft from spillway crest elevation in 7 days).
Maintenance Drawdown Release Rate	TBD cfs	Flow rate to Slab Creek Reservoir when generating units not in operation
Surface Area at Maximum Normal Water Surface (MNWS)	71 acres	
Surface Area at Dam Crest	76 acres	For inflow design flood (IDF) precipitation; based on dam crest at El. 3,085 ft to provide 2 ft operating + 10 ft flood freeboard.
Inflow Design Flood for Overflow Spillway	4,608 cfs	Greater of hydrologic IDF or maximum pumped inflow; pumped inflow controls.

Description	Value	Comment
Reservoir Drainage Area	86.4 acres	
Hydrologic IDF (peak inflow rate)	420 cfs	Direct precipitation from general 72-hr probable maximum precipitation (PMP) of 38.4 in., with peak intensity of 1.2 inches in 15 minutes.
Hydrologic IDF – Volume	277 ac-ft	Direct precipitation runoff from general 24-hr PMP of 38.4 in.
Environment		
Design Max Wind Speed	75 mph	For wave runup and liner design
Wind Setup and Wave Runup	3.5 ft	For freeboard and liner design.
Max. Temperature	110°F	For liner design.
Min. Temperature	10°F	For liner design.
Avg. Annual Solar Radiation	2.000 kWh/m^2 per year	For liner design.
Avg. Annual Snowfall	10 in.	
100-yr, 24-hr storm precipitation	7 in.	For roadway culvert/drainage ditch design.
Wildlife	Full exclusion terrestrial; bird exclusion not required	Full exclusion of deer or other terrestrial wildlife to prevent liner damage, and for wildlife safety due to slippery liner and I/O entrapment hazards.
Aquatic	N/A	Unsuitable habitat due to pumped storage operation and reservoir fluctuations.
Human	Restricted Access	Security fencing, gates, cameras, and patrol needed to protect liner from vandalism and for public safety due to slippery liner and I/O entrapment hazards.
Visual	Vegetated landscape fill on west-facing downstream slope of embankment above the American River Canyon	
Configuration / Design – Dam & Spillway		
Operating Freeboard (below spillway crest)	2 ft	To prevent nuisance spillway discharges due to waves and provide up to 20 minutes (for all three pumps) accidental/shutdown pumped operation storage to prevent spillway discharges.
Total Freeboard (spillway crest to dam crest)	10 ft	Includes estimated 7 ft for routing of uncontrolled pumping through spillway plus 3 ft residual freeboard for waves; >1.5 ft DSOD minimum.
Spillway Crest (max. storage) Elevation	3,075 ft	Based on 2 ft operating freeboard over max. operational water surface.
Spillway Capacity & Features	4,608 cfs @ 7 ft head	Broad-crested weir through rock cut with trafficable concrete crest slab including 40-ft bottom crest plus 10H:1V concrete-lined approach ramps. Discharges to hillside that drains to Slab Creek Reservoir; except for riprap blanket at outlet, no erosion protection provided beyond terminus of

Description	Value	Comment
		concrete-lined chute. Emergency use only to prevent dam failure in uncontrolled overpumping; no operational use.
Dam Crest Elevation	3,085 ft	Based on 10 ft flood freeboard over spillway crest.
Reservoir Floor Elevation (outside I/O Structure)	2,933 ft minimum	Reservoir invert slopes down at 1% toward I/O sump. Lowest elevation of reservoir floor for liner maintenance.
Reservoir Invert Elevation (at I/O structure)	2,913 ft	Sump floor elevation around I/O structure.
Maximum Depth	142 ft	Spillway crest to reservoir invert outside I/O sump; maximum head on liner.
Dam Crest Width	25 ft min.	Drawn as 40 ft for preliminary layouts, allowance for camber, and quantities.
Upstream Embankment Slope	2.5H:1V	Liner system over rockfill and soil embankment.
Downstream Embankment Slope (dam structural fill)	2.0H:1V	Rockfill and soil embankment.
Downstream Berm Slope	3:1H:1V vegetated and 2H:1V rock toe	3H:1V and two benches 20-ft (upper) and 28-ft-wide (lower) provided for access roads, planting, and maintenance; 2H:1V rock toe to avoid thin sliver fills on American River Canyon slope.
Reservoir Cut Slope (interior, lined)	2.5H:1V	Liner system over excavated rock slope.
Reservoir Cut Slope (exterior, unlined)	2H:1V	Excavated slope in soil and rock; could be steepened in rock cut areas to 1H:1V.
Embankment Crest Length	5,400 ft	Portion of the reservoir perimeter that is in fill, measured along Service Road centerline.
Reservoir Perimeter Length	6,815 ft	Reservoir perimeter, measured along Service Road centerline.
Reservoir Liner Area	78 acres	Full liner of reservoir below dam crest elevation (slope measure).
Dam Hydraulic Height (Spillway Crest above Downstream Toe)	255 ft	Based on height of structural dam not including vegetated downstream berm.
Embankment Height (Dam Crest above Downstream Toe)	265 ft	Based on height of structural dam not including vegetated downstream berm.
Liner System / Material	Composite liner system with HDPE or Euro PVC geomembrane upper liner over asphalt-concrete lower liner	Liner system design criteria to be confirmed based on further discussions with vendors/installers during design.
Liner Anchorage	Runout length under dam crest; ballast tubes or mats perpendicular to slope	Spacing of ballast tubes or mats TBD.
Allowable Operational Leakage	25 gpm	Preliminary estimate based on expected leakage rate of 150 gpad, to be confirmed

Description	Value	Comment
		during design.
Underdrain	Geotextile drain under upper geomembrane, and lower granular drain blanket under liner system	
Leak Monitoring	Measurement of leakage/ seepage flows emanating from upper geotextile and from lower drainage blanket	
Dam Zonation	Homogeneous section with internal drains	Soil and rock embankment with bedding and drainage zones below liner
Drain Collection & Monitoring	Drain pipes discharging to weir boxes located at downstream toe of dam	
Geotechnical Instrumentation	Survey monuments, piezometers, seepage weirs	
Reservoir Access Ramps	1 ramp from dam crest to reservoir bottom	Max 10H:1V slope, 28-ft-wide, concrete slab with seal to geomembrane liner on both sides, or overlying the geomembrane liner.
Downstream Erosion Protection	Vegetated topsoil on downstream slope, woody vegetation on landscape fill	
Revegetation	See above item Downstream Erosion Protection	To be coordinated with overall IHPSD site restoration requirements.
Configuration / Design – Other		
Emergency Low-Level Outlet	24-inch-diameter outlet pipe with upstream sluice gate, plus dual downstream knife gate valves to allow annual exercise of sluice gate without significant water flows	DSOD requirement for emergency drawdown of the reservoir.
Fencing & Gates	10-ft-high fence along reservoir crest; locked gates at all roads leading to reservoir; breakaway fencing across spillway channel	To be coordinated with overall IHPSD requirements.
Other Security Provisions	Cameras; patrol	To be coordinated with overall IHPSD requirements.

3.6.2 Hydraulic Requirements for Upper Reservoir I/O

The following project operating criteria and parameters were utilized to support the upper reservoir I/O PFD:

- Maximum and minimum upper reservoir water levels will be elevation 3,073 feet and 2,945 feet, respectively.
- The range of flow for generating mode will be the following:

  - One Unit Minimum = 300 cfs
  - Three Units Maximum = 4,800 cfs
  - Three Units Overload = 5,200 cfs
- The range of flow for pumping mode will be the following:
  - One Unit Minimum = 800 cfs
  - Three Units Maximum = 4,800 cfs
- The maximum average velocity across the trash racks will be 2 feet/second.
- The internal hydraulic configuration of the structure should maintain constant acceleration of flow during generating mode, from the outer openings inward, and transitioning into the shaft.
- The elevation of the I/O structure should be set with a submergence value selected to minimize the potential for surface vortices to enter the intake structure during generating mode.
- The hydraulic configuration should minimize head losses.

3.6.3 Control of Maximum Water Level in Upper Reservoir

The upper and lower reservoirs shall include redundant level instruments/controls with backup power capable for the entire range of reservoir operation and include automatic features designed to initiate pump/turbine shutdown if the water level rises above or descends below preset maximum values.

Given the critical safety role of the emergency over-pumping protection system, its design should include the following elements:

- Fail Safe Design
- Direct Action Pump/Generation Mode Shutdown
- Redundancy
- Ease of Testing and Calibration

The Upper and Lower Reservoir water level will be monitored by closed-circuit television and a staff gate (complete with lighting and independent power source) and redundant water level transducers having redundant communication links to the plant control system. In addition, physical water level verification is recommended at reservoir elevations nearing 5 feet of normal full pond. Control of the maximum operating water level in the Upper Reservoir will be achieved with an accuracy of 0.1 foot. Multiple telecommunication and visual communication paths will be provided to achieve communication redundancy and supervisory control. Instrumentation will be used to satisfy dam safety instrumentation and monitoring requirements established by DSOD/FERC as well as overall IHPSD operating requirements.

In addition to the redundant instrumentation and monitoring system provided. the overpumping controls are expected to be tested at a frequency determined by SMUD. This test is considered a “hard test”.

In addition to the redundant water-level control systems summarized above, an emergency spillway will be provided to positively prevent overtopping of the dam. The following freeboard requirements will apply to the design of the Upper Reservoir:

- Operating freeboard is defined as the unused vertical difference between the maximum normal operating water surface level and the emergency spillway crest elevation. Sufficient operating freeboard will be provided to minimize nuisance spills under all foreseeable operating conditions. The operating freeboard will account for (1) reserve storage capacity associated with the anticipated range of response times for pump shutdown at the end of a pumping cycle; and (2) normal wave runup. The operating freeboard will not be less than 2 feet.
- Total freeboard is the vertical difference between the emergency spillway crest and the dam crest at its lowest point. The total freeboard will be approximately 4% to 5% of the vertical distance between the dam crest and the existing ground as measured under the dam crest centerline at the maximum section of the dam. The total freeboard will not be less than 10 feet.
- Residual freeboard is the unused vertical difference between the maximum reservoir water surface level under extreme conditions and the dam crest. The residual freeboard will not be less than 1.5 feet.

3.6.4 Hydraulic Requirements for Upper Reservoir Emergency Spillway

The Upper Reservoir will receive inflows from two sources: direct precipitation and pumped flows. The reservoir is a hilltop off-stream reservoir, with a drainage area essentially delineated by the perimeter of the reservoir itself. The emergency spillway will be designed to pass the peak flow that is the greater of the two potential inflows:

- The peak of the probable maximum flood (approximately 420 cfs) determined from the watershed reporting to the Upper Reservoir.
- The maximum pumped inflow of 4,608 cfs, as defined in Table 3-6.

It is expected that the controlling inflow for emergency spillway design will be the maximum pumped inflow.

The crest of the emergency spillway will be set at an elevation not lower than the maximum normal operating water surface (El. 3,073 feet) plus operating freeboard.

The emergency spillway will be designed to pass the peak flow, while providing a residual freeboard that is not less than the specified minimum.

At the crest of the dam, a spillway control section will be provided that meets two additional objectives:

- The spillway crest will be configured as an integral part of the Service Road along the dam crest and will be accessible (drivable) by the project design vehicle specified in Section 3.7, Access Roads.
- The spillway design will reasonably minimize potential Upper Reservoir discharges at reservoir levels that only slightly exceed the spillway crest elevation.

It is expected that these objectives will be met by a shallow trapezoidal shape with side slopes at a grade not exceeding 10% within the dam crest. The bottom width will be not less than 40 feet to allow for passage of trucks and other maintenance equipment.

The emergency spillway will be constructed of a nonerodible material such as reinforced concrete and will be located on an undisturbed rock foundation of suitable quality.

The emergency spillway design will provide safe conveyance of overflow releases, prevent erosion of the dam and foundations, and provide discharge to a natural slope, leading to an existing drainage that flows back to the Slab Creek Reservoir. An engineered chute will be provided to discharge to the natural slope and existing drainage feature. The chute will be lined with an erosion-resistant material and designed for the spillway peak flow. The chute will have enough length and an outlet protected with a cutoff wall. These will be sufficient to ensure that erosion and head cutting that result beyond (downstream of) the chute outlet as a result of unintended spills will not progress backward to endanger the integrity of the Upper Reservoir.

A seepage weir will be installed near the chute terminus to provide an independent indication and alarm of spillway flow to the facility operators. The weir will be an EAP-type weir, solar-powered and equipped with a wireless transmitter.

3.6.5 Control of Minimum Water Level in Upper Reservoir

The minimum normal operating water surface level will be at El. 2,945 feet (see Section 4.1.10). Control of the operating water level in the Upper Reservoir will be achieved with an accuracy of 0.1 foot using the reservoir level indication systems referred to above.

The operating water height above the I/O crest needs to be sufficient to supply the required flow to the headrace shaft in generate mode without formation of a vortex or entrainment of air. In addition, the reservoir storage capacity between the minimum normal operating level and the I/O crest needs to provide a suitable amount of storage reserve as needed for the anticipated range of response times for turbine shut-down at the end of a generating cycle.

Reservoir drawdown below the minimum normal operating water surface (for inspection of the reservoir floor and liner system) will be performed using the Upper Reservoir I/O. The minimum water level will be set by the I/O crest El. 2,918 feet. The residual storage below the I/O crest is the reservoir dead pool. The reservoir bottom will be sloped to a low point adjacent to the I/O structure, where a sump will be provided from which water could be pumped out if there is a need to completely drain the dead pool.

3.6.6 Emergency Drainage of the Upper Reservoir

An emergency low-level outlet will be provided for lowering the reservoir in case of emergency. The emergency low-level outlet will be positioned such that the full reservoir capacity, except for a small fraction of the volume, can be discharged by gravity. The emergency low-level outlet will be able to drain at least two-thirds of the reservoir volume.

The emergency low-level outlet will be an independent outlet system separate from the Upper Reservoir I/O. Based on early coordination with DSOD, a separate emergency low-level outlet will be provided in order to keep the requisite dam safety features at the dam site and exclude the Upper Reservoir I/O system from DSOD jurisdiction.

The emergency low-level outlet is a low-level outlet with discharge near the toe of the dam. This emergency low-level outlet is provided for dam safety regulatory requirements. That is, it is provided for the sole purpose of enabling the California Division of Safety of Dams to exclude the I/O works and water conveyance system (headrace shaft /tunnel /powerhouse /tailrace tunnel) from its jurisdiction (that is, from DSOD review, approval, inspection, and taxation). It is not a service facility. The emergency low-level outlet would only be used to lower the Upper Reservoir in the event of the following conditions occurring simultaneously: (1) an Upper Reservoir Dam safety emergency (imminent risk of dam failure); and (2) unavailability of the I/O works for drawing down the reservoir. The emergency low-level outlet will be closed at all other times except for annual testing.

The emergency outlet system will be capable of lowering the maximum storage depth by 10% within 7 days and draining the Upper Reservoir's full contents within 90 days. Based on the conceptual facility sizing described above, the emergency outlet system will have a capacity of approximately 75 cfs, which will entail a conduit with a diameter in the range of 22 to 24 inches. It is anticipated that the emergency low-level outlet will include the following main features:

- Reinforced-concrete intake located near the upstream toe of the dam approximately at El. 2,945 feet. The intake will be equipped with a trash rack and upstream control device such as a heavy-duty sluice gate. The sluice gate normally will be closed, and will be operated either with a submerged hydraulic cylinder or a hand wheel from the dam crest.
- Air vent pipe located just downstream of the control gate.
- A 22- to 24-inch-diameter outlet conduit, consisting of an inner liner (HDPE or steel pipe) encased in cast-in-place reinforced concrete. The conduit will run in a trench excavated in the dam foundation and will extend from the intake structure at the upstream toe of the dam to the outlet box at the downstream toe. The reinforced concrete encasement will be designed for internal pressure equal to the full reservoir head and for the superimposed embankment loads, acting separately.
- Outlet at the downstream toe of the dam, including two normally closed heavy-duty knife gate valves in series, an energy dissipater, and overflow weir to existing drainage, which will return emergency discharge flows to the Slab Creek Reservoir.

3.6.7 Upper Reservoir Dam

The dam will be designed to meet modern dam design and dam safety requirements. Key design considerations will include the following:

- The slopes will be stable and resistant to deformation under all operating conditions, including rapid reservoir drawdown.

- Seepage through the embankment and its abutments and foundation will be controlled so that piping and sloughing do not occur.
- The embankment will be safe from overtopping by both flood inflow and wave action.
- The embankment will be safe from catastrophic failure during reasonably expectable earthquakes at the site.
- The slopes will be safe from excessive damage from wave action or rain.

The embankment will be designed as an upstream-faced rockfill embankment with internal drainage. The impervious facing is discussed below. The embankment will be designed so it can be constructed using materials from required excavations to develop the Upper Reservoir. The structural section of the embankment will largely consist of random rockfill obtained from reservoir excavation in variably weathered metamorphic rocks. It is desirable to use excavated materials without the need for processing, except for (1) selective excavation and (2) removal of oversize materials, if necessary. Consequently, the embankment will be designed with relatively gentle slopes (versus more typical upstream-faced rockfill dam configurations) to maximize the range of acceptable rockfill materials. For preliminary engineering purposes, the selected slopes are 2.5 horizontal to 1 vertical (2.5H:1V) for the upstream slope and 2H:1V for the downstream slope.

Embankment crest width will be 25 feet wide as a minimum with a 20-foot-wide, paved access road in the center and 2.5-foot-wide minimum shoulders. The embankment crest will have a cross slope of at least 2% into the reservoir. The crest centerline curve radius will not be less than 45 feet to enable passage of the design vehicle specified in Section 3.7.

The embankment crest will be cambered to address postconstruction settlement. Camber is defined as additional height given to the crest in excess of the design crest elevation. Camber will vary with embankment height. At each location along the centerline, the camber will be at least 1% of the vertical distance between the dam crest and the estimated foundation surface measured under the dam crest centerline.

The downstream slope of the embankment will be vegetated. Vegetation species and planting palettes will require approval of SMUD, DSOD, and FERC. Two distinct treatments will be provided:

1. The downstream face of the embankment will be covered with up to 2 feet of vegetative soil placed with an erosion control matting. Native grass and/or forb seed mix combined with seeds of other shallow-rooted woody or perennial vegetation will be applied to the erosion control matting in conformance with U.S. Forest Service (USFS) guidelines. Woody perennials will be shallow-rooted and low-growing ground covers. Vegetative soil will be soil stripped from the reservoir area and stockpiled at the site for reuse.

2. In addition, the west-facing slope will be screened from views from across the American River canyon to minimize the visual/aesthetic impact of the facility for sensitive receptors across the canyon. A nonstructural landscape fill will be constructed over the downstream slope of the embankment so as to form a fill that can be planted with large woody vegetation. The nonstructural landscape fill will be developed with a vertical depth of at least 10 feet above the

plane of the downstream slope of the structure and will have a slope no steeper than 2H:1V. The nonstructural landscape fill will be constructed with compacted soil and rockfill materials from required reservoir excavation. The level of compaction will be the same as that specified for the structural section of the embankment. A layer of vegetative soil of up to 2 feet in thickness will be placed over the slope of the landscape fill as described above. The landscape fill will be planted with native trees that are suited to the specific site, exposure, and purpose. The top of the nonstructural landscape fill will be set at a distance below the crest of the dam that is consistent with the anticipated height and canopy development of the trees that will be planted on the slope. For preliminary engineering purposes, the top of the nonstructural landscape fill has been selected to be 20 feet below the design dam crest elevation.

3.6.8 Embankment Foundation

The embankment foundation will consist of weathered bedrock that has a shear strength equal or higher than the shear strength of the compacted rockfill in the embankment. Overburden soils will be removed from the embankment foundation. All loose or soft materials will also be removed from the embankment foundation.

Quaternary landslides have been identified on the west-facing hillside above Slab Creek reservoir, downslope from the Upper Reservoir site. No landslide has been identified impinging or threatening to impinge on the Upper Reservoir site. The rock that forms the foundation of the dam reservoir and adjacent canyon slopes will be characterized as needed to rigorously investigate and confirm the safety of the facility against slope failures. Geologic mapping, strength characterization, and stability analyses will address (1) the shear strength and global stability of the rock mass; and (2) the shear strength and stability for individual wedges along joint planes and along existing shear, bedding, and/or foliation orientations. Stability analyses will address both static and seismic loadings under all foreseeable reservoir seepage conditions.

3.6.9 Upper Reservoir Liner System

The Upper Reservoir's impervious element will consist of an upstream liner system that will cover the upstream face of the dam, the reservoir side slopes, and the reservoir floor. The dam will not have a separate core zone. The reservoir liner system will be a proven product or system appropriate for the daily reservoir cycling associated with pumped storage operations, and is expected to minimize seepage/leakage from the reservoir into the formation. The design of the liner system will include the following four basic elements:

1. A geomembrane liner that will be the first line of defense against uncontrolled reservoir leakage. The geomembrane liner will be placed over a nonwoven fabric underlayment of appropriate thickness or weight to prevent puncturing and provide membrane leak conveyance.

2. An asphalt-concrete layer (underneath the geomembrane liner), or alternative impervious surface, that will form a stable subgrade for the geomembrane liner while providing a second line of defense against uncontrolled reservoir leakage.

3. A granular layer, processed from tunnel muck, to serve as bedding for the asphalt-concrete layer. This granular bedding layer will also limit the quantity of leaks through cracks or defective seams in the upper and lower liners, if they should occur at the same location of the reservoir, to relatively small quantities (i.e., less than 1 cfs). The granular bedding layer will be designed following gradation criteria established for the design of the upstream zone (typically referred to as "Zone 2") in concrete-face rockfill dams. The granular bedding layer will be internally stable and filter-compatible with the underlying drainage layer.

4. A drainage layer, also processed from tunnel muck, that will drain the upstream liner system and convey the drainage to granular trunk drains or perforated pipes, which in turn will route the seepage along the embankment-foundation contact to various low points along the downstream toe of the embankment.

The geomembrane liner used on the reservoir slope may be the same or different than the liner used on the floor. The liner used on the slope will have a high resistance to UV deterioration and preferably will be white or light colored to minimize thermal warming from sunlight. The liner used on the floor will be able to resist traffic by rubber-tired service vehicles without damage. Selection of the membrane material(s) will be based on factors including the following:

- Durability / service life
- Resistance to UV radiation
- Thermal stability
- Ability to execute reliable seams in the field
- Flexibility
- Puncture resistance
- Workability and ease of installation
- Maintenance needs
- Cost

The selected liner materials will be tested during design under conditions simulating full-scale loading. Shop and field welding and installation procedures will follow ASTM standards. A rigorous QA/QC plan will be established and implemented addressing all aspects of manufacturing, fabrication, and installation for the geosynthetic, asphaltic, and aggregate materials of the liner system.

Perforated underdrain piping will be provided under the reservoir floor to collect and monitor leakage and, in the case of fluctuating or high groundwater, to function as a pressure relief system. The piping system will be placed in lined trenches below the drainage layer. Pipes crossing the dam foundation will be placed in trenches excavated in bedrock and will be encased in cast-in-place reinforced concrete.

The design will address the accumulation of air or gas under the lining. The bottom of the lined reservoir will be sloped upward toward the perimeter embankment at a slope of at least 0.5%. Gas vents will be provided within the drainage layer to vent accumulation of gas pressures and may be combined with seepage collection piping and clean-outs if practical.

3.6.10 Seepage Monitoring System

A seepage collection and return system will be provided—including seepage weirs, wet well(s), return pipeline(s), and appurtenant items—to capture, measure, and return the seepage from collection points along the downstream toe of the dam to either the Lower Reservoir or the Upper Reservoir.

Return flow rates will report to the facility operator's SCADA system.

3.6.11 Operating and Maintenance Requirements

- Vehicle access to the perimeter of the dam will be provided by means of a dam crest service road.
- Vehicle access ramp(s) to the interior of the reservoir and I/O will be provided to facilitate maintenance activities. At least one ramp into the reservoir will be provided. Ramp width will be not less than 28 feet, and ramp slope will not exceed 10%.
- Parking will be provided adjacent to the reservoir for commercial vehicles.
- The I/O will be accessed by removing a hatch in the roof of the structure. Provisions for temporary fall prevention barricades will be included in the roof.
- The dam crest will provide for maintenance vehicle access around the entire dam.

3.6.11.1 Design Occupancy

- The Upper Reservoir structure and associated inlet and outlet vaults will not be designed for continuous occupancy.
- Condition assessment and maintenance will follow the permit required confined space regulations.

3.6.11.2 Emergency Isolation Gate

- The I/O will not include an emergency isolation gate.

3.6.11.3 Service Gate

- The emergency low-level outlet will include at least one isolation or service gate capable of sealing and isolating the low-level outlet from the Upper Reservoir.
- The service gate operator will be capable of lowering and raising the gate from the dam crest.

3.6.11.4 Dam Crest

- The dam crest elevation is not a regulatory compliance point. That is, the crest elevation is not prescribed in regulatory compliance documents.

3.6.11.5 Emergency Spillway

- The reservoir will include an emergency spillway rated to surpass the maximum pumping flow of the units and that exceeds the inflow from the hydrologic IDF.
- An erosion protection structure will be provided to prevent erosion of dam and foundation materials at the downstream terminus of the spillway.
- The spillway discharge channel will be marked and include warning signage appropriate to sudden discharges of water.
- The spillway discharge channel will be hydraulically connected with at least one established water course leading back to Slab Creek Reservoir.
- The spillway apron at the dam crest may be driven over.
- With the reservoir at the maximum normal operating level (El. 3,073 feet), sustained wind speeds greater than approximately 40 mph are expected to result in intermittent wave washing over the spillway crest and nuisance flows down the spillway channel. If a wind storm is forecasted with sustained winds exceeding 40 mph, the reservoir operator should consider lowering the reservoir level 1 to 2 feet below the maximum normal operating level in order to minimize nuisance spillway flows and associated erosion in the existing slope downstream of the spillway outlet.

3.6.11.6 Upper Reservoir Emergency Drainage System

- As required by DSOD and/or FERC, the emergency drainage system will be exercised regularly in order to demonstrate the ability to draw down the reservoir during an emergency. Outlet controls will be exercised at least annually and, in DSOD's presence, also generally annually.
- Detailed operating plans and instructions will be developed to enable the operation of the emergency drainage system during routine dam safety inspections.
- A log detailing all operation and maintenance activities for the emergency outlet system will be maintained by the facility operator.

3.6.12 Public Safety Precautions

- The Upper Reservoir will be secured for authorized access only.
- Fencing will be provided to prevent unauthorized access.
- Warning signage will be provided to deter unauthorized entry, swimming, and boating.

3.6.13 Owner's Dam Safety Monitoring Program Requirements

Monitoring of the Upper Reservoir will be integrated into SMUD's overall Owner's Dam Safety Monitoring Program required under FERC. This is expected to include the instrumentation and monitoring of the following Upper Reservoir features:

- Independent reservoir water-level indication will be provided to the SMUD operation center continuously in real time.
- Embankment crest position and settlement will be monitored with crest survey monuments.

- Water level within the embankment will be monitored with standpipe or vibrating-wire piezometers.
- Liner permeability will be monitored. The liner seepage collection system will be segmented to enable traceability of seepage flows to discrete subareas of the liner not anticipated to exceed approximately 25 acres in plan surface area each. Seepage flows from each segmented area will be monitored separately.
- Downstream leakage from the embankment will be monitored at discrete points along the downstream toe.
- A detailed instrumentation operating plan and instructions will be developed and in place, including threshold and limit values to enable the facility operator to assess instrument data and determine when specialized assistance should be obtained.
- A log detailing all operation and maintenance activities for the instrumentation system, instrument readings, and trend curves will be maintained by the facility operator.

3.6.14 References, Codes, and Standards

Generally applicable design standards and codes for the Upper Reservoir include the following:

3.6.14.1 California DSOD Regulations and Guidelines

Applicable DSOD regulations are covered in *Statutes and Regulations Pertaining to Supervision of Dams and Reservoirs*, available on DSOD's website. This document covers key definitions, application/review processes and other practices. However, it does not define specific guidelines or criteria. DSOD requires that dams and appurtenant structures be designed to meet all anticipated normal, flood, and seismic design loading conditions, but does not publish specific design standards or requirements. DSOD refers to design standards published by other dam design agencies such as USACE or USBR. Published DSOD guidelines, such as *Guidelines for the Design and Construction of Small Embankment Dams*, will generally apply but do not cover all aspects of the Upper Reservoir and Dam. DSOD requirements applicable to the Upper Reservoir and Dam include but are not limited to the following:

- Seismic hazard, ground motion, and analysis guidelines
- Hydrologic analysis guidelines
- Emergency drawdown criteria for the emergency low-level outlet

3.6.14.2 U.S. Bureau of Reclamation (USBR) Design Standards

The primary applicable technical guidelines for design of the Upper Reservoir and Dam will be U.S. Bureau of Reclamation Design Standards (USBR Design Standards)*:*

- Design Standard No. 13: Embankment Dams
- Design Standard No. 14: Appurtenant Structures for Dams (Spillways and Outlet Works)

These design standards have been generally updated as of 2011–2014, and include particularly relevant chapters covering rockfill dams and geomembranes. Where specific chapters are referenced further below, they will be referred to, for example, as follows: USBR DS13-4 Static Stability Analyses.

3.6.14.3 FERC Engineering Guidelines for Dams

FERC Engineering Guidelines is not as current (typical chapters are from the 1990s) nor as specific as the USBR Design Standards. Therefore they will only be applicable for technical design if more specific or stringent than USBR Design Standards are desired. Several areas where they are expected to be applicable to the Upper Reservoir and Dam include but are not limited to the following:

- Chapter 1 – General Requirements
- Chapter 2 – Selecting and Accommodating Inflow Design Floods for Dams
- Chapter 4 – Embankment Dams
- Chapter 5 – Geotechnical Investigations and Studies
- Chapter 6 – Emergency Action Plans (EAPs)
- Chapter 7 – Construction Quality Control Inspection Program (CQCIP)
- Chapter 9 – Instrumentation and Monitoring
- Chapter 13 (draft) – Evaluation of Earthquake Ground Motions
- Chapter 14 – Dam Safety Performance Monitoring Program

3.6.14.4 Other Codes and Standards

Codes and standards for materials (e.g., concrete, steel, corrosion protection), site access/safety, security, environmental, and other general requirements will conform to those defined elsewhere for the overall IHPSD facilities.

3.7 Access Roads

3.7.1 General

The project access roads provide routes to the project facilities for the purposes of construction access, operations and maintenance access, and in some cases, public recreation access. The key design assumptions used in developing the preliminary function road design are:

- Use or improve existing roadways where possible.
- Minimize visual impact of the roadway by minimizing and balancing the amount of cut and fill.
- A maximum 7-axle radius is assumed during construction.
- Road alignments must provide alternative access to the existing Cable Road in order to minimize construction traffic on Cable Road.
- Two emergency evacuation routes will be available from the Upper Reservoir.
- All-weather Aggregate Base (AB) Rock surfacing will be used to minimize erosion and runoff; SMUD has selected a minimum of 8 inches of AB for light construction and O&M traffic.

3.7.2 Long Canyon Access Road

Several road alignments have been studied as a potential primary roadway access to the existing Cable Point Road and ultimately to the Upper Reservoir during and after construction. The primary preferred alignment is the 8,800-foot (+/-) Long Canyon Access Road, which is designed with a travel-width of 14-feet and provides access along the southern side of Slab Creek Reservoir and Long Canyon Creek. Access to this road would be from the existing Slab Creek Reservoir Road and along the existing Boat Ramp and Chute Camp Roads, both of which would require improvements to support the necessary construction vehicle size. The Long Canyon Access Road traverses very steep terrain, requiring cut and/or fill along much of the roadway. Due to the steep terrain, a maximum grade of 16% was assumed to minimize the road length while allowing access to construction vehicles. The majority of Long Canyon Access Road is on Sierra Pacific Industries (SPI) property and will require obtaining an easement through the property.

The 13,550-foot-long (+/-) Southwest Connector Road, which would run from the existing Slab Creek Reservoir Road to the southwest corner of the Upper Reservoir via a series of switchbacks, was considered as the primary Upper Reservoir access road in previous studies and is now considered to be the alternate access road for consideration moving into the final functional design. The majority of the Southwest Connector Road is on US Forest Service property and will require obtaining an easement through the property.

3.7.2.1 Upper Reservoir Crest Road

The Upper Reservoir Crest Road will encircle the Upper Reservoir at the crest and be one of the last access roads constructed. Its primary purpose will be for postconstruction operation and maintenance access; minor construction traffic is also anticipated.

3.7.2.2 Minor Access Roads

Minor access roads will be constructed for ancillary access to the project or neighboring features—for example, access to the existing microwave repeater and access to the switchyard from Cable Road. These roads are not anticipated to have any construction traffic and will have only minor postconstruction traffic.

3.7.3 Lower Boat Ramp Road

In addition to providing through access to the Long Creek Access Road, access to the I/O structure will be from the Lower Boat Ramp Road off Slab Creek Reservoir Road. The Lower Boat Ramp Road will also provide improved recreation access for car-top boating at Slab Creek Reservoir.

3.7.3.1 Boat Launch at Slab Creek Reservoir near Dam

FERC license conditions require improving the road and launch area. The minimum improvements include:

- Provide needed improvements to road access from North Canyon Road (County Road 8014 and FS Road 11N96) to provide for public safety, such as widening, turnaround at boat launch, turnouts, and signs (no trailer access).
- Provide parking for a minimum of 10 vehicles within a reasonable distance of the boat launch.
- Improve boat launch and harden to extend to the minimum reservoir level and restrict trailer use.
- Provide one-unit vault restroom.
- Address needs for garbage collection.
- Provide resource protection measures at the boat launch and along the access road from North Canyon Road (FS Road 11N96).
- Provide directional sign at the intersection of County Road ELD-8014 and North Canyon Road.
- Provide information kiosk or signboard at the boat launch.

3.7.3.2 Gen-Tie Tower Access Trails

Access to each mono-pole tower for the gen-tie transmission line will be constructed from the existing Cable Point Road. The trails will provide access to each tower for construction and future operations and maintenance.

3.7.4 References, Codes, and Standards

- The California Department of Forestry and Fire Protection. 2015. California Practice Rules. Title 14, California Code of Regulations, Chapters 4, 5, and 10.

3.8 230KV Switchyard and HV Cable Trench

3.8.1 General

The Switchyard will provide electrical protection and switching capabilities for the IHPSD and the 230KV Generation Tie and the existing SMUD transmission system. A high-voltage (HV) cable trench will connect the utility shaft building with the Switchyard and provide a secure raceway for the conductors from the Transformer Cavern generator step-up transformers. The trench will also contain station service, instrumentation, controls, and telecommunications conductors.

3.8.1.1 Utility Shaft

A vertical utility shaft will carry the 230 kV insulated power cables from the powerhouse cavern to the Utility Shaft Building. Access for inspection and monitoring will be required through the full length of the shaft. The vertical cables will be attached to the wall with cable clamps recommended by the cable manufacturers. The cables will need to be installed with a slight “S” shape in the shaft per manufacturer’s recommendations to prevent the conductor from sliding in the insulation sheath. Cable brackets and mounting shall be hot-dipped galvanized or stainless steel. Each set of cables shall be provided with RTDs to monitor cable temperature and smoke detectors which will be integrated with the powerhouse fire detection system.

3.8.1.2 Switchyard

- Grading and layout: The switchyard yard will have sheet flow drainage for storm-water runoff. Storm drain inlets and underground storm drain piping may be required since the area is large.
- Breaker configuration and type (230 kV): The switchyard will be a breaker-and-half configuration. Breakers will be three-phase SF6 breakers controlled through relays in the switchyard control module.
- Disconnect switches (230 kV): The disconnect switches will be gang-operated manual disconnect switches with position indicators on each switch.
- Bus (strain and rigid) (230 kV): A combination of rigid bus and strain bus will be used in the switchyard. The bus will be supported by insulators on galvanized structural steel members mounted on drilled pier foundations.
- Cable trenches and conduit: Control and instrumentation cables between the control module and switchyard equipment will run through concrete cable trenches with removable covers for future maintenance and expansion. Short lengths of underground conduit will be used between the trenches and the equipment.

3.8.1.3 Switchyard Control Module

3.8.1.3.1 General

- The control module will be a prefabricated insulated metal modular building consisting of approximately two to four modular sections that will be joined together to form one building that is approximately 30 feet by 80 feet. The switchyard control module is split into three separate rooms: relay control room, battery room, and communications room. The control module will be enclosed in a separate fenced area from the switchyard and will have its own parking area for technicians.

- Where cable tray and conduit penetrate room walls, appropriate UL listed fire blocking shall be installed.
- HVAC: Two 100% redundant wall mounted high efficiency heat pumps will be provided on the module. The HVAC units will be shut down by the fire alarm panel when smoke or heat is detected in the module.

3.8.1.3.2 Relay Control Room

The relay control room will be approximately 30 feet by 55 feet. It will house all the electrical equipment necessary for operation and control of the switchyard. In the corner of the relay control room will be a restroom.

- Battery chargers: Two 100% redundant 125 VDC battery chargers will be located in the relay control room.
- DC panelboards: The 125 VDC panelboards will be located adjacent to the respective battery chargers.
- AC panelboards: The AC panelboards will be fed by a station service transformer located outside the control module.
- Interface terminal board: Inside the relay control room will be an enclosed interface terminal board that will have all of the relay wiring terminated on with shorting terminal blocks. Field wires will enter through the bottom floor and terminate here.
- Relays: The relays will be mounted in floor standing racks with overhead cable trays and will be located in the control enclosure. The relay racks will be accessible from the front and back. All the relays will be wired in the module factory and arrive at the site prewired and terminated at the interface terminal board. The relays will receive backup power from the 125 VDC battery system.
- Restroom: A restroom will be located in the corner of the relay control room. It will have one toilet and one sink. It will be supplied with nonpotable water from the upper reservoir. The waste water will be sent to a septic tank located at the switchyard. The restroom will be ADA compliant.

3.8.1.3.3 Battery Room

The battery room will be approximately 12 feet by 20 feet. It will house the batteries and will be isolated and sealed from all of the other electrical systems in the control module.

- Battery systems (125 VDC batteries, 48 VDC batteries): A battery room within the control module that is approximately 12 feet by 15 feet will house the 125 VDC for switchyard breaker operation and 48 VDC batteries for telecommunications and SCADA operation. The battery room will have ventilation fans, fire detection, and hydrogen detection. Only the batteries will be located in this room.

- Hazard classification: The battery room shall be rated for the appropriate hazard classification per NFPA, and all electrical equipment in the battery room shall be properly rated for the area classification. Conduit and wall penetrations shall be sealed to prevent gas migration per NFPA.

3.8.1.3.4 Communications Room

The communications room will be an approximately 12 feet by 30 feet. It will house all of the communication equipment for the switchyard. It will also connect the transmission line communications systems to the IHPSD.

- RTU: The switchyard RTU will be located in the either the communications module or the control module. This will be determined by SMUD and is dependent on the security requirements of the hardware device.
- Communications equipment: Details of the communications equipment are specified in the Section 4.12 - Telecommunications and in SMUD SPEC-004 – Telecommunications Design Requirements.
- HVAC: Two 100% redundant wall mounted heat pumps will be provided on the module.
- Battery chargers: Two 100% redundant 48 VDC battery chargers will be located in the communications room.
- DC panelboards: The 48 VDC panelboards will be located adjacent to the respective battery chargers.

3.8.1.4 Maintenance Roads

The road within the switchyard will be 20 feet wide and asphalt paved with a minimum turning radius of 20 feet. Each breaker will be accessible on at least one side by a roadway.

3.8.1.5 Yard Lighting

Yard lighting will be LED lighting. Light fixtures shall be able to be serviced without de-energizing 230 kV switchyard circuits.

3.8.1.6 Microwave Tower

See Section 3.10.

3.8.1.7 Lightning Protection and Surge Arrestors:

The bus structure will have extensions that hold a grid of ground wire above the buswork. All incoming transmission lines and circuits to the motor-generators will have surge arrestors.

3.8.1.8 Grounding

Switchyard grounding will meet SMUD minimum requirements. The fence, structures, and equipment will be bonded to the ground grid.

3.8.1.9 Yard Rock

Switchyard yard rock will be washed 100% fractured face rock with a minimum cover thickness of 6 inches.

3.8.1.10 Fencing

Fencing will be galvanized no-climb chain link fencing that meets SMUD bulk switchyard standards, see SMUD specification C914 – Chain Link Fence. The fencing and gates will be bonded to the ground grid.

3.8.1.11 Security

See Section 3.10.13.

3.8.1.12 Septic System

A septic system including septic tank and leach lines will be installed near the switchyard to support the restroom in the switchyard control building.

3.8.1.13 Construction Power Substation

A temporary substation will need to be constructed by the DBE to support mining and construction work for the project. It is estimated that the electrical load for the construction activities will be approximately 8.3 MVA. The DBE will need to determine a location for the construction power substation. SMUD will construct the gen-tie from the existing 230 kV transmission lines to gen-tie tower “B.” SMUD will provide one 230 kV radial feed transmission line from Lake Substation to gen-tie tower “B”. The DBE will need to extend the gen-tie from tower “B” to the construction power substation and to the final IHPSP switchyard. The DBE will need to provide all of the equipment for the temporary substation and power distribution for use at the site during construction. The temporary substation must be completely removed by the completion of the IHPSP construction.

3.8.2 Station Emergency and Backup Power

Primary Station Service Power – AC: The switchyard station service power will be provided from two AC power sources. The primary source of power will be from the station service voltage transformer (SSVT), which is connected to one of the switchyard 230 kV buses and steps the voltage down to 120/240 VAC. The secondary source is provided by the 4160 V circuit from the powerhouse cavern, which will step down through the 4160:120/240 VAC station service transformer adjacent to the switchyard control module.

Backup Station Service Power – AC: The 4160 VAC circuit is connected to the IHPSP stationary emergency generator at the utility shaft building. Both sources will be connected to the control room AC panelboards via an automatic transfer switch. There will be a separate 240 VAC mobile generator receptacle at the control module. A permanent generator will not be installed at the switchyard. For a switching single line of this power system, see drawing E-SC-401.

Battery Backup Power – DC: The switchyard control module battery room will house 125 VDC and 48 VDC batteries for backup operations of the switchyard relays, breakers, and communication.

3.8.3 Metering

Gross revenue metering: Gross revenue metering will be the sum of the motor-generator stator and the variable speed power electronics (VSPE) circuit. The monitoring points and the meters will be installed in the powerhouse cavern. See Section 3.3.5.3.2 for more details.

Net revenue metering: Net revenue metering will be measured in the switchyard at the point where the high-voltage underground cables connect to the switchyard buswork. The metering current and voltages will be monitored through three sets of combination current transformers – potential transformers, one set for each motor-generator circuit. The following metering points shall be collected:

- Switchyard 230 kV voltage
- Switchyard 230 kV megawatts
- Switchyard 230 kV megavars
- Switchyard 230 kV frequency
- Switchyard power factor

The actual SMUD meters (and CA-ISO meters if necessary) will be located in the switchyard relay control room.

3.8.4 Protection

The switchyard protection scheme will be specific to a breaker-and-half switchyard. The three motor-generator units will connect to the switchyard with individual circuits. The three transmission lines from the gen-tie will connect to the switchyard. The zones of protection shall follow the concept shown on drawings E-SC-402 and E-SC-403.

Protective relays included in the design will be microprocessor-based and will provide metering, event recording, and oscillography. All protection systems will be fully redundant. Redundant relays will not use the same instrument transformers (CTs/PTs). All circuitry for redundant relays shall be separated so that a fault on one system does not affect other systems. Switchyard protective relays will be accessible to SMUD's protection engineers through an SEL-3530 communication relay or an approved equivalent. The minimum requirement for relay protection zones are shown in drawings E-SC-402 and E-SC-403.

The following relay functions are required for the 230 kV Switchyard:

- Line Distancing (21)
- Overcurrent (50/51)
- Breaker Ground Fault (50N/51N)
- Breaker Synch-Check (25)

- Breaker Failure (BF)
- Transfer Trip (TT)
- Bus Over/Undervoltage (27/59)
- Bus Differential (87B)
- Cable Differential (87C)

3.8.5 Operating and Maintenance Requirements

The switchyard will be designed to be unmanned. It will be able to be controlled from the Iowa Hill powerhouse control room and by the SMUD Power System Operation (PSO) in Sacramento.

SMUD Transmission Planning Group will determine if a Special Protection System (SPS) will be required for the IHPSP. The SPS may require automatic curtailment and other automatic operation to maintain system stability, acceptable voltage, and/or power flows.

The switchyard will be a break-and-half configuration. A single breaker can be isolated with disconnect switches and be taken out of service for maintenance without impacting operation of the IHPSP or the switchyard.

3.8.5.1 Access

Only authorized SMUD employees will have access to the switchyard, control module, communication module, and the HV cable trench. The general public will not be allowed inside the fenced areas.

3.8.5.2 Design Occupancy

- The Switchyard and Switchyard Control Module will be designed for continuous occupancy.
- The HV Cable Trench will not be designed for continuous occupancy. Condition assessment and maintenance of the cables will follow the required confined space and high voltage equipment safety procedures.

3.8.5.3 Equipment Clearances

The equipment and control modules will be designed with the required clearances so that maintenance staff can access and inspect equipment while maintaining the required clearances and procedures of OSHA, NEC, and IEEE. Overhead conductor clearances will exceed the minimum requirements of CPUC GO-95.

3.8.6 Security

All gates and enclosure doors will have SMUD locks and/or electronic badges to access the site. The switchyard will have motion sensors or video cameras monitoring the perimeter of the switchyard to detect and monitor for intruders.

3.8.7 Public Safety Precautions

- The Switchyard will be completely fenced and locked. Public access will not be allowed.
- Appropriate signage will be placed advising the public of the hazards present in the Switchyard.
- The HV Cable Trench will be underground and access points secured.

3.8.8 Recreation Access

- The Switchyard will not be accessible for recreation access.
- The HV Cable Trench will not impede the public's access and use of Public lands.

3.8.9 Regulations, Codes, and Standards

The following industry standards shall be followed in the design and development of the IHPSP.

- ACI, Standard 304 – Guide for Measuring, Mixing, Transporting, and Placing Concrete.
- ACI, Standard 318 – Building Code Requirements for Structural Concrete.
- ANSI C29.1 – Electrical Power Insulators – Test Methods.
- ANSI C29.11 – Composite Insulators – Test Methods.
- ANSI C29.12 – Composite Insulators – Transmission Suspension Type.
- ANSI C29.17 – Composite Insulators – Transmission Line Post Type.
- ANSI C29.9 – Wet-Process Insulators – Apparatus, Post Type.
- ANSI C37.2 – Electrical Power system Device Function Numbers, Acronyms, and Contact Designations.
- ANSI C84.1 – For Electric Power Systems and Equipment – Voltage Ratings (60 Hertz).
- ASTM A1064 – Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete.
- ASTM A615 – Standard Specification for Deformed and Plain Billet-Steel Bar for Concrete Reinforcement.
- ASTM B187 – Standard Specification for Copper, Bus Bar, Rod, and Shapes and General Purpose Rod, Bar, and Shapes.
- ASTM B188 – Standard Specification for Seamless Copper Bus Pipe and Tube.
- ASTM B230 – Standard Specification for Aluminum 1350-H19 Wire for Electrical Purposes.
- ASTM B231 – Standard Specification for Concrete-Lay-Stranded Aluminum 1350 Conductors.
- ASTM B232 – Standard Specification for Concentric-Lay-Stranded Aluminum Conductors, Coated-Steel Reinforced (ACSR).
- ASTM B241 – Standard Specification for Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube.
- ASTM B317 – Standard Specification for Aluminum-alloy Extruded Bar, Rod, Tube, Pipe, Structural Profiles, and Profiles for Electrical Purposes (Bus Conductor).
- ASTM B498 – Standard Specification for Zinc-Coated (Galvanized) Steel Core Wire for Aluminum Conductors, Steel Reinforced (ACSR).

- ASTM C143 – Standard Test Method for Slump of Hydraulic Cement Concrete.
- ASTM C150 – Standard Specification for Portland Cement.
- ASTM C33 – Standard Specification for Concrete Aggregates.
- ASTM C94 – Standard Specification for Ready-Mixed Concrete.
- ASTM A1011 – Standard Specification for Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy with Improved Formability, and Ultra-High Strength.
- ASTM A116 – Standard Specification for Zinc Coated (Galvanized) Steel Woven Wire Fence Fabric.
- ASTM A123 – Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products.
- ASTM A153 – Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware.
- ASTM A36 – Standard Specification for Carbon Structural Steel.
- ASTM A392 – Standard Specification for Zinc Coated (Galvanized) Steel Chain-Link Fence Fabric.
- ASTM A653 – Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process.
- ASTM B3 – Standard Specification for Soft or Annealed Copper Wire.
- ASTM B33 – Standard Specification for Tin-Coated Soft or Annealed Copper Wire for Electrical Purposes.
- ASTM B398 – Aluminum Alloy 6201-T81 and 6201-T83 Wire for Electrical Purposes.
- ASTM B415 – Standard Specification for Hard-Drawn Aluminum-Clad Steel Wire.
- ASTM B416 – Standard Specification for Concentric-Lay-Stranded Aluminum-Clad Steel Conductors.
- ASTM B483 – Standard Specification for Aluminum and Aluminum-Alloy Drawn Tubes for General Purpose Applications.
- ASTM B5 – Standard Specification for High Conductivity Tough-Pitch Copper Refinery Shapes.
- ASTM B8 – Standard Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft.
- ASTM C260 – Standard Specification for Air-Entraining Admixtures for Concrete.
- ASTM C494 – Standard Specification for Chemical Admixtures for Concrete.
- ASTM C857 – Standard Practice for Minimum Structural Design loading for Underground Precast Concrete Utility Structures.
- ASTM C858 – Standard Specification for Underground Precast Concrete Utility Structures.
- ASTM E1399 – Standard Test Method for Cyclic Movement and Measuring the Minimum and Maximum Joint Widths of Architectural Joint Systems.
- ASTM E1966 – Standard Test Method for Fire-Resistive Joint Systems.
- ASTM E2174 – Standard Practice for On-Site Inspection of Installed Firestops.
- ASTM E2307 – Standard Test Method for Determining Fire Resistance of Perimeter Fire Barriers Using Intermediate-Scale, Multi-Story Test Apparatus.
- ASTM E2393 – Standard Practice for On-Site Inspection of Installed Fire Resistive Joint Systems and Perimeter Fire Barriers.
- ASTM E814 – Standard Test Method for Fire Tests of Penetration Firestop Systems.

- ASTM E84 – Standard Test Method for Surface Burning Characteristics of Building Materials.
- IEEE 4 – IEEE Standard for High-Voltage Testing Techniques.
- IEEE NESC – National Electrical Safety Code.
- IEEE C37.1 – IEEE Standard Definition, Specification, and Analysis of Systems Used for Supervisory Control, Data Acquisition, and Automatic Control.
- IEEE C37.2 – IEEE standard Electrical Power System Device Function Numbers.
- IEEE 100 – Standard Dictionary of Electrical and Electronic Terms.
- IEEE 80 – Guide for Safety in Substation Grounding.
- IEEE 837 – Standard for Qualifying Permanent Connections Used in Substation Grounding.
- IEEE 1222 – Standard for All-Dielectric Self-Supporting Fiber Optic Cable.
- IEEE 1138 – Standard for Testing and Performance for Optical Ground Wire (OPGW) Use on Electric Utility Power Lines.
- IEEE C57.13 – IEEE Standard Requirements for Instrument Transformers.
- IEEE 693 – IEEE Recommended Practice for Seismic Design of Substations.
- IEEE C37.30.1 – IEEE Standard Requirements for AC High-Voltage Air Switches Rated Above 1000 V.
- IEEE 605 – IEEE Guide for Bus Design in Air Insulated Substations.
- IEEE C62.11 – IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits.
- IEEE C62.22 – IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems.
- IEEE C62.33 – IEEE Standard Test Specifications for Varistor Surge-Protective Devices.
- IEEE C57.19– IEEE Standard General Requirements and Test Procedure for Power Apparatus Bushings.
- IEEE 634 – IEEE Standard for Cable-Penetration Fire Stop Qualification Test.
- ICEA S-105-692 – 600V Single Layer Thermoset Insulated Utility Underground Distribution Cable.
- ICEA S-73-532 – Standard for Control, Thermocouple Extension and Instrumentation Cable.
- ICEA S-81-570 – Direct Burial, 600 Volt, Ruggedized Insulation.
- NEMA CC-1 – Electric Power Connectors for Substations.
- NEMA ICS-1 – Industrial Control and Systems: General Requirements.
- NEMA ICS-6 – Industrial Control and Systems: Enclosures.
- NEMA TC-2 – Electrical Plastic Tubing (EPT) and Conduit (EPC-40 and EPC-80).
- NEMA TC-3 – PVC Fittings for use with Rigid PVC Conduit and Tubing.
- NEMA TC-6 – PVC and ABS Plastic Utilities Duct for Underground Installation.
- NEMA TC-8 – Extra-Strength PVC Plastic Utilities Duct for Underground Installation.
- NEMA TC-9 – Fittings for ABS and PVC Plastic Utilities Duct for Underground Installation.
- NEMA WC-26 – Binational Wire and Cable Packaging Standard.
- NEMA WC-70 – Power Cables Rated 2,000V or Less for the Distribution of Electrical Energy.
- NFPA 13 – Standard for the Installation of Sprinkler Systems.
- NFPA 221 – Standard for High Challenge Fire Walls, Fire Walls, and Fire Barrier Walls.
- NFPA 70 – National Electrical Code.
- NFPA 72 – National Fire Alarm and Signaling Code.

- NFPA 850 – Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations.
- TIA 455 – Standard Test Procedure for Fiber Optic Fibers, Cables, Transducers, Sensors, Connecting and Terminating Devices, and Other Fiber Optic Components.
- TIA 598 – Color Coding of Fiber Optic Cables.
- UL 1277 – Standard for Electrical Power and Control Tray Cables with Optional Optical-Fiber Members.
- UL 1479 – Standard for Fire Tests of Penetration Firestops.
- UL 1581 – Reference Standard for Electrical Wires, Cables, and Flexible Cords.
- UL 2079 – Standard for Tests for Fire Resistance of Building Joint Systems.
- UL 44 – Thermoset-Insulated Wires and Cables.
- UL 62 – Flexible Cords and Cables.
- UL 83 – Thermoplastic-Insulated Wires and Cables.

- State of California, Department of Transportation, (CALTRANS), Standard Specification
- California Building Code
- Universal Building Code (UBC)
- El Dorado County Codes

3.9 230KV Generation Tie (Gen-Tie)

The following is a description of the generation tie (gen-tie) transmission line. The gen-tie will have three (3) transmission circuits that will connect the existing SMUD transmission lines to the Iowa Hill switchyard. The three gen-tie circuits will be routed on two mono-pole tower transmission lines constructed of hot-dipped galvanized steel that are tinted brown. One of the tower lines will have two circuits (6 conductors), and the second tower line will have one circuit (3 conductors). There will be no spare arms required on the second tower line. The gen-tie lines will connect the Iowa Hill switchyard to the existing SMUD transmission lines—Camino-Iowa Hill, Iowa Hill-Whiterock, and Iowa Hill-Lake. The length of the gen-tie line is approximately 1.8 miles. SMUD will be extending the Iowa Hill-Lake circuit from Lake Substation to support the additional capacity requirements of the IHPSP. SMUD will upgrade the existing transmission system and constructing the new Iowa Hill-Lake circuit. SMUD will design and construct the gen-tie transmission line from the point of connection with the existing transmission lines to tower "B", as shown on drawing E-PL-408. The DBE Contractor will need to extend the gen-tie to the final location of the IHPSP switchyard.

3.9.1 Operating and Maintenance Requirements

The gen-tie will require periodic inspection of the towers, foundations, conductors, insulators. The gen-tie right-of-way easement vegetation growth will need to be monitored and periodically cleared.

3.9.1.1 Access

Four-wheel drive vehicle access will be provided to each monopole.

3.9.1.2 Equipment Clearances

Overhead conductor clearances will exceed the minimum requirements of CPUC GO-95. The gen-tie easement is a 200-foot-wide corridor that the towers will be located in. The gen-tie easement will be clear cut of all vegetation according to SMUD Vegetation Management Plan to maintain clearances to the conductors to prevent potential fires.

3.9.2 Security

There are no known security requirements for the gen-tie line at this time.

3.9.3 Public Safety Precautions

When logging operations are occurring on neighboring properties, logging yarding machines will not be set closer than 50 feet from the edge of the SMUD gen-tie line easement. This precaution is to prevent yarder booms from contacting transmission lines in the event of a logging cable failures.

3.9.4 Recreation Access

The design and construction of the gen-tie will not impede the public's access and use of Public lands.

3.10 Telecommunications

3.10.1 General

This section provides the functional design criteria for telecommunications network infrastructure for the Iowa Hill Pumped-Storage Project. These systems provide communications for system control and data acquisition (SCADA), protective relaying, voice and data communications, and video surveillance and site security.

3.10.2 Equipment Space Requirements and Clearances

The powerhouse control room and switchyard control module will have rows assigned for telecommunication racks and/or cabinets. The following clearances will be provided for equipment and cross-connect fields in the telecommunication equipment space:

- A minimum of 36 inches of clear working space in front and rear of equipment cabinets, racks and backboards.
- A 10-inch depth off the wall for wall-mounted equipment and panels
- A minimum 36-inch aisle between each row of racks.
- A minimum aisle clearance of 36 inches is required at one end of each row of racks for an exit access.

The telecommunications rooms will not be located near electrical power supply transformers, elevators, pump motors, generators, radio transmitters, radar transmitters, induction heating devices, or other potential sources of electromagnetic interference. Piping and plumbing unrelated to telecommunications (other than what is required to support the room such as chilled water supply/return) will not be routed through the telecommunications rack row.

3.10.3 Telecommunication Cables

Inter-building backbone cable will be used to connect buildings together, in order to concentrate and distribute aggregated signals to and from a central hub location. At a minimum, 100 pairs of copper cable will be installed from the switchyard control module to the powerhouse cavern. A high-voltage protection (HVP) unit will be installed in the switchyard communications room, and be connected to any OSP twisted-pair copper cable leaving the switchyard yard. A minimum of two OPGW fiber cables on the gen-tie towers will be installed to the switchyard dead-end structures, and then the fibers shall be continued into the switchyard communications room. Between the switchyard communications room and the powerhouse cavern, a minimum of a 72 strand single mode fiber cable will be installed.

Intra-building backbone cable will be primarily used to carry signals between communications rooms and the edge-to-core communication electronics equipment. Multipair copper cable may be used to concentrate alarm and building control signals distributed throughout a building. Typically, intra-building backbone cable consists of multipair cable, high strand count optical fiber cable, and coaxial trunk cables.

3.10.4 Cable Management System

Horizontal and vertical wire managers are essential for proper installation of cable and equipment. The vertical and horizontal wire management systems will accommodate patch cords for a fully loaded patch panel rack and allow for an additional 20% growth.

3.10.5 Inside Plant Pathways

The telecommunications pathways will be located away from sources of electromagnetic interference (EMI), including:

- Electrical power cables and transformers
- Radio frequency (RF) sources
- Motors and generators
- Induction heaters
- Arc welders
- Photocopy equipment

3.10.6 Outside Plant Pathways and Structures

Inter-building communication ductbanks are communication infrastructure pathways that carry communication cables between buildings. The raceways will be constructed of contiguous segments of schedule 40 PVC, 80 PVC, RGS conduit, or dedicated cable tray.

3.10.7 Microwave Radio Tower

Two new microwave towers will be required for this project. One tower will be located within the new Iowa Hill switchyard. The second tower will be located at Slate Mountain, where there is an existing SMUD microwave tower that does not have enough room for an additional microwave transmitter/receiver. The microwave radio tower heights will be determined as required to provide a microwave path between Iowa Hill switchyard and Slate Mountain. The radio tower, foundation, and grounding will be designed in accordance with EIA/TIA 222G, including 1/2-inch radial ice on the tower and all attachments. The tower will be less than 198 feet, including lighting rod and all attachments, so FCC lighting is not required. The tower will be a three- or four-leg lattice-type structure, designed to last 30 years. The tower shall be hot-dipped galvanized steel with brown tinted color.

The towers will include an inside work platform and a single, inside climbing ladder. The climbing ladder will extend to the ground or to a platform one step aboveground. The safety cable or rail will be positioned so that personnel can clip into the safety device from the ground or platform. The climbing ladder will extend from the base of the tower to the top handrail of the top platform.

3.10.8 Microwave Radio System

The microwave radio system will provide 99.995% availability. The system will be a hot-standby radio system to SMUD's Slate Mountain telecommunications center. The microwave radio system consists of an antenna system, radios, and channel banks.

3.10.9 Telecommunications: 48V DC Power System

A DC power system will supply power to telecommunications equipment and hardware exclusively. The system will consist of the following: DC power board (includes rectifier/battery-charging equipment, primary distribution panel), equipment cabinet/rack, 48V DC battery, battery rack, battery disconnect, cable, wire, connectors, alarm interface, software, battery monitoring equipment, and other associated equipment and appurtenances.

3.10.10 Wireless LAN Service

SMUD IT network services has established Cisco model 3602i (indoor) and 1552E (for outdoor) wireless access points as the standard for wireless networks throughout SMUD facilities.

Site survey software planning tools may be employed in order to develop a predictive survey of new building structures that are not yet constructed using the goals listed above.

3.10.11 Satellite TV/MATV and Off-the-Air Television

In the powerhouse operations room, viewing TV programming is part of daily operations. The TV programming consists of local broadcast channels like KCRA (NBC), KXTV (CBS), FOX, and many news and information channels like CNN and Weather Channel. The powerhouse communications room will have a dedicated master antenna television system (MATV) distribution system, which consists of a satellite TV receiver, switchers, and RG-6 and RG-11 coaxial cables. An off-the-air television system will also be provided.

3.10.12 In-Building Distributed Antenna System

The in-building RF distributed antenna system (IBDAS) is a multioperator, multiservice system based on combining a number of services (e.g. voice and data) and distributing them to each remote location through a common antenna infrastructure. SMUD buildings are required to support radio communications from (1) the local public safety entities (Sacramento Metro Fire, Police, etc.) as per state and local codes; (2) SMUD's 900 MHz radio system (for voice and data services); and (3) cellular voice/data service (from AT&T, Verizon, and Sprint). The IBDAS system will conform with all FCC, OSHA, state/local codes, NFPA 72 standards, UL listings, and be NEMA 4x certified. The system will distribute RF coverage at levels described herein in the following minimum areas of the building(s) and as listed in

Table 3-7.

Table 3-7. RF Coverage Areas

Requirement	Functional Areas
Floor areas	Corridors, lobbies, concourse, interstitial spaces, penthouses, restrooms / bathrooms, elevator lobbies & shafts, mechanical rooms; electrical rooms, telecommunications rooms, conference rooms, class rooms, reception areas
External Building lobbies and floor area(s)	Bridges, tunnels and building links, public spaces (e.g., courtyards, patios)
General use spaces	Break room, staff, public, multipurpose rooms, etc.
Excluded Areas	NO AREAS ARE EXCLUDED

3.10.13 Security

The design will be based on current industry standards for high resolution IP video surveillance systems, video recording systems, card access control systems, and associated intrusion alarm systems for buildings, open spaces and perimeter alarm systems. Additional standards to be followed are those pertaining to security and access control systems from organizations such as BICSI and ASIS.

All cabling will be installed in conduit to provide protection against tampering and unauthorized access to security systems. All security components, power supplies, controllers, relays, interfaces, etc., will be installed in secured lockable enclosures with key access, complete with tamper-proof hardware. All security cabinets will be installed with tamper contacts to alert security personnel.

Conduits penetrating through rated walls and slabs between floors, and through roofs will be sealed with fire-resistant materials.

The design will include connectivity by multistrand fiber optic backbone optical feeds for all system connections. Security and access control that are Ethernet-based will reside on a dedicated Ethernet network and not share hardware, IP addressing, or VLAN schemes with any other network and will be dedicated to security infrastructure between buildings.

3.10.13.1 Security Infrastructure

The site will incorporate multiple modes of site and building security, which will involve card access, intrusion protection, and closed circuit surveillance systems. These systems will communicate with SMUD's current systems in use at its main campus; however, the site will be a standalone facility, able to operate without outside connections to servers, databases, NVRs, etc.

3.10.13.1.1 Access Control

The site will utilize a system comprising control software and hardware, complete with database programming, controllers, power supplies, card readers, door controls, door strikes, electronic locksets, and associated hardware.

An access control and monitoring system (ACAMS) is required and will be designated to coordinate with existing systems that are in place at SMUD HQ campus and other facilities. This will provide SMUD with one system to administer and maintain.

Intercom system integration will be included to give the operator the flexibility to program intercom functions directly from the graphical interface. In this manner, calls can be opened, closed, and redirected using a single intercom station dialog box.

Other included options will be threat level support, allowing operators to adjust security functions based on previously configured threat level parameters. In the event of an elevated security threat, modifications can be made to reader acceptance levels (from card only, to card plus PIN, to card plus PIN plus biometrics), and CCTV cameras and guard tours can be changed to reflect heightened security requirements.

The access control system will communicate over a dedicated Ethernet network, separate from in-house data networks and will be solely dedicated to access control. The network will utilize fiber optic cabling provided under the telecommunications contractor. Provisions will need to be coordinated with telecommunications to connect all networked attached devices with horizontal CAT-6 cabling.

Entry turnstiles will be provided at all employee entrances to the powerhouse control room. The entry turnstiles will be high-quality, high-security type, interface with the card access control system, provide for reader assemblies to be mounted to the turnstile assemblies, and interface as required with the access control and CCTV systems.

Card readers will be provided at main exterior doors in the switchyard control module, utility shaft building, and powerhouse.

3.10.13.1.2 Intrusion Protection

Intrusion protection into the site and buildings will be accomplished through interfaces with the access control system. Devices such as motion sensors, door position contacts, perimeter fence alarms, perimeter motion sensors will be connected to monitoring points within the access control system and programmed to general local and remote alarms to security personnel.

In-building devices will consist of passive infrared (PIR) motion sensors and door position contacts, each with their own unique point of connection. All active devices will be powered from secured low-voltage power supplies collocated in the equipment rooms and or ancillary rooms within buildings.

Exterior perimeter and boundary protection will be accomplished with the use of a perimeter cable detection system and associated controls and interfaces. Additionally, fencing areas that may be block wall, wrought iron, or systems not prone to disturbance or vibration will be protected with overlapping perimeter protection zones of microwave intrusion link type.

3.10.13.1.3 Closed Circuit Surveillance

The site will include closed circuit camera television surveillance systems (CCTV). Each camera will record to a network video recorder (NVR). Camera systems will be installed to monitor perimeter, exterior, and interior activity, as well as employee parking areas, SMUD vehicle parking areas, and interior and exterior storage areas. At designated rooms/areas with more than one door, all entries/exits will receive camera coverage.

The CCTV system will provide coverage of the entire site through a network of exterior building, pole, or PV canopy mounted units. Outdoor cameras will be color, fixed, or pan-tilt-zoom as application requires. All exterior cameras will include fans and heaters for adverse weather as found in the region.

NVRs are required and are designated to coordinate with existing systems that are in place at the SMUD HQ campus central monitoring station. This will provide SMUD with one system to administer and maintain.

Exterior camera coverage will include:

- Switchyard perimeter fence line
- Switchyard entry and exit gates
- Switchyard control building main door entrance
- Powerhouse building main door entrance
- Upper Reservoir fence line

Interior camera coverage will include:

- Powerhouse control room main door entrance
- Elevator cabin
- Transformer cavern
- Generator hall

4 Preliminary Design Criteria

The following sections present draft preliminary design criteria based on the Preliminary Functional Design and initial discussions with SMUD. The design criteria outlined within this section do not intend to represent all required project criteria, nor do they provide the final project criteria, but rather provide documentation of those preliminary criteria developed through the preliminary functional level of design. The final design criteria that will provide the basis of the Design Guidelines Project Book will be developed during final functional design and multiple design workshops.

4.1 General Functional Design Criteria

4.1.1 General

The facilities shall be designed in accordance with these requirements, good utility practice, and applicable codes and standards. The design shall also comply with all relevant legal and statutory requirements to ensure that:

- Facility and its components are safe, reliable, compliant, and economical to operate;
- Operations and maintenance considerations are incorporated into the design;
- Facility and its components are capable of operation by remote and local control with minimal attention and maintenance;
- Facility and its components are constructible with minimal interference to the operation of the existing Upper American River Project facilities; and
- Facility and its components are environmentally acceptable and compliant.

4.1.2 Owner Occupational Safety Requirements

All facilities shall be designed in such a manner that they can be constructed, tested, operated, maintained, and replaced in compliance with all occupational safety requirements.

4.1.2.1 ADA Compliant Design

Owner will provide these requirements.

4.1.2.2 Permit Required Confined Space Design

To the extent possible, all facilities within the project that are routinely accessed during operation and maintenance shall be designed for continuous occupancy. All confined spaces shall be identified in the drawings and include features to safely enter/exit and ventilate the space. These requirements will be developed with the Owner during Final Functional Design.

4.1.2.3 Lock-Out/Tag-Out Design

In accordance with Owner's lock-out/tag-out policy, all energized or potentially energized equipment and systems shall be capable of being isolated using engineering controls, including locking devices, breaker removals, double block and bleed valving, and barricades. These requirements will be developed with the Owner during Final Functional Design.

4.1.3 Visual Aesthetics Objectives

All surface project structures shall be designed in accordance with the visual aesthetics objectives agreed upon between Owner and the U.S. Forest Service. These requirements will be developed with the Owner during Final Functional Design.

4.1.4 Operating Command and Control

The design shall provide:

- A control room capable of remotely operating all project equipment and systems
- Command and control system to operate and dispatch all powerhouses in the UARP
- The capacity to be operated remotely from the Owner System Operations in Sacramento (Owner Sys Op Sac)
- Local and remote annunciation within the IHSPD and also Owner Sys Op Sac

4.1.5 Physical Security

The design shall consider Owner's security requirements and protocols, and appropriate precautions and safeguards to ensure the public's trust and safe use of authorized facilities. These requirements will be developed with the Owner during Final Functional Design.

Physical security shall be provided at the following locations:

- Powerhouse access tunnel portal
- Geo-drift tunnel (if integrated into the powerhouse design)
- Top of shaft building
- Upper Reservoir
- Switchyard

4.1.6 Cyber Security Requirements

All internal and external information protection and cyber security design shall satisfy Owner's, FERC's, and NERC's requirements. These requirements will be developed with the Owner during Final Functional Design.

4.1.7 Public Safety Precautions

The design shall provide public access to:

- The boat ramp launch.
- The powerhouse complex; access shall be restricted to specific areas designed to accommodate the public's viewing of specific pieces of equipment within the powerhouse.
- The Upper Reservoir shall be enclosed by security fencing with deterrents in accordance with the Owner's security policies. Escape ladders shall be placed on all sides of the reservoir, connected at the dam crest, and fastened to the dam floor. There shall be a minimum of four escape ladders in the Upper Reservoir.

4.1.8 Fire Prevention, Detection, and Suppression

Fire prevention, detection, and suppression systems shall be provided at all times, including all operating modes, maintenance, and overhaul periods. When the Upper Reservoir and water conveyance tunnels are drained, alternative water supply shall be provided. CO_2 fire suppression shall not be used anywhere on the project. The design shall conform to all Owner fire protection requirements and to all requirements mandated by the California State Fire Marshal. The fire detection systems shall meet the SMUD Technical Specification FPLC-CR5 – Fire Alarm Standard shown in Appendix A.

4.1.8.1 Powerhouse Complex

Fire protection and fire suppression systems, as well as a smoke control and removal system, shall be provided in the powerhouse complex.

4.1.8.2 Switchyard Control Module

Smoke and heat detectors shall be installed in the switchyard control module. In addition, there shall be a hydrogen detector in the battery room of the control module. These detectors shall be connected to a SMUD-approved fire alarm panel with battery backup and two communication channels to communicate with SMUD's central fire monitoring system at SMUD Energy Management System (EMS).

4.1.8.3 GSU Transformers

Smoke and heat detection systems shall be installed at each of the generator step-up (GSU) transformers in the powerhouse cavern. The transformers shall use SF6 gas as the insulating media and have no potential for fire or explosion. Fire suppression systems are not required on the GSU transformers. There shall be SF6 leak detectors near the transformers to signal a plant evacuation if there is a major gas leak. Oil-type transformers shall not be allowed in the powerhouse cavern.

4.1.8.4 Unit Auxiliary Transformers

The unit auxiliary transformers and the excitation transformers shall be either SF6 type or dry type. Oil transformers shall not be used in the powerhouse cavern. Each of the transformers shall have smoke detection systems near the transformers.

4.1.8.5 Utility Shaft

The 230 kV high voltage conductors running from the GSU transformers to the switchyard shall be in a utility shaft in the mountain. Smoke/heat detection systems will be installed in the shaft around the cables.

4.1.8.6 Emergency Access

Emergency access shall be provided to all facilities and satisfy the requirements of the California State Fire Marshal.

4.1.8.7 Fire Alarm Panels System

The fire detection and fire suppression systems shall be monitored and controlled by a master fire alarm panel located in the powerhouse control room. Local alarm panels shall be located around the powerhouse, around the utility shaft, at the switchyard, and at other critical locations, and will relay all individual alarms back to the master fire alarm panel. The systems shall communicate alarms back to the Owner's main security control room in Sacramento. The fire alarm systems shall meet the SMUD Technical Specification FPLC-CR5 – Fire Alarm Standard shown in Appendix A.

4.1.9 Design Service Life

- All facilities and components shall be designed to provide the service life listed below.
- Equipment shall be selected to minimize life cycle costs. Life cycle costs include initial capital, transportation and installation cost, operation and maintenance cost, intermittent component replacement costs, complete equipment replacement cost, final decommissioning cost, and the cost of lost revenue during major maintenance and component or equipment replacements.
- Individual equipment components (wearing elements) within the facilities may require replacement within the overall life expectancy of the facility because of normal wear and tear. Performance Specifications shall clearly indicate whenever a component life expectancy is less than that of the equipment of which it is a part.
- All auxiliary equipment and systems involving the use of mass-produced equipment to "standard designs" (e.g., pumps, electric motors, fans, valves, low voltage switchgear, piping, wiring) shall be of a class or kind usually applied in hydroelectric generating stations where high load factors are common and the risks of corrosion are ever present.
- All equipment and fabricated elements shall be maintained in accordance with the original equipment manufacturer recommendations.
- Components with maintenance intervals requiring unit equipment outages at less than one-year intervals shall be avoided wherever reasonably practicable.
- Components that are difficult to access and maintain (i.e., confined space), difficult to monitor the condition of, or pose a "single point of failure risk" to generating capability shall include additional design margins, and for these components, longer intervals between maintenance activities shall be considered.

- Access to the water conveyance conduits shall be provided to support routine tunnel and shaft inspection by personnel and maintenance.

4.1.9.1 Civil Works

The inlet/outlet structures, tunnels, shafts, civil structures, and embedded parts, in general, shall be designed for a life of at least 50 years with no replacement or significant repairs. All other structures and fundamental structural elements of equipment shall be designed for a life of 50 years with maintenance performed in accordance with the constructor's, supplier's, or builder's recommended maintenance instructions.

The design life of the primary civil works components shall be as follows:

• Steel structures and parts embedded in concrete	50 years
• Building envelopes and access roads	25 years
• Erosion protection	50 years
• Water conveyances	50 years
• Penstock coating	30 years
• Concrete structures	50 years
• Rock slopes and accessible surface excavations	50 years
• Reservoir lining	25 years

4.1.9.2 Mechanical and Electrical Equipment

The main water-to-wire equipment shall be integrated and supplied by a single OEM. The design life of mechanical and electrical equipment shall be as follows:

• Fixed/embedded parts	50 years
• Wearing/replaceable parts	25 years
• Main water-to-wire equipment	25 years
• Electronic control and protection systems	15 years
• Motor-generator switchgear	25 years
• Generator step-up transformer	25 years
• 230 kV conductors between GSU and switchyard	25 years
• 230 kV circuit breakers	25 years

4.1.10 Operating Conditions and Duty Cycle

The facility and the units shall be capable of:

- Operating over the full range of Upper Reservoir water levels from minimum flow conditions to the Maximum Operating Level as shown in Table 4-1
- Operating over the full range of Slab Creek Reservoir water levels from minimum flow conditions to the Maximum Operating Level as shown in Table 4-1

- Operating over the full range of turbine flow from the minimum recommended by the turbine supplier to the maximum continuous rated flow
- Operating at full capacity 24 hours a day, seven days a week when water and reservoir storage availability allows
- A minimum of 1,000, and a maximum of 2,000, starts/stops per year

Table 4-1. Reservoir Water Surface Elevations

Water Surface	Normal Elevation (ft)
Upper Reservoir, Maximum	3,073
Upper Reservoir, Minimum	2,945
Slab Creek Reservoir, Maximum	1,850
Slab Creek Reservoir, Minimum	1,815

4.1.11 Slab Creek Reservoir Design Flood Elevation

The Slab Creek Reservoir probable maximum flood elevation is 1,875 feet, based on the Upper American River Project Probable Maximum Flood Study (GEI, 2/2011). The powerhouse access tunnel portal invert elevation shall be set at a minimum elevation of 1,875 feet.

4.1.12 General Codes and Standards

All systems, equipment, materials, construction, and installation for the facility shall be designed in accordance with applicable law, codes, standards, and local, state, and federal regulations, as well as the design criteria, manufacturing process and procedures, materials selection, testing, welding and finishing procedures, and quality control programs specified herein.

In the event conflicts arise between this document, referenced codes and standards, and applicable law, the more stringent requirement shall apply.

4.2 Water Conveyance Tunnels and Shafts

4.2.1 Functional Requirements

The water conveyance tunnels and shaft provide the hydraulic connection between the Upper Reservoir I/O and the powerhouse turbine shutoff valves, and between the powerhouse draft tube gates and the Slab Creek I/O. The water conveyance tunnels and shaft shall provide the following:

- Conveyance of the full range of pump-turbine flows in all operational modes (normal, emergency, and exceptional conditions) without developing subatmospheric static pressure zones, water column separation, cavitation, or air entrainment.
- Maintenance of the hydraulic cross section by providing permanent ground and groundwater support, which prevents rock falls, ground loss, structural instability, erosion or scour.

4.2.2 Operating and Maintenance Requirements

4.2.2.1.1 Tunnels and Shafts

- Dry access to the upper reservoir I/O, power shaft, and headrace tunnel is accomplished by draining the Upper Reservoir.
- Service gates in the lower reservoir I/O provide isolation from the Slab Creek Reservoir to permit dewatering of the water conveyance system below tailwater via the station unwatering sump.
- A personnel access hatch is provided in the lower reservoir gate structure on the powerhouse side of the service gates.
- The vertical shaft is accessed via lowering a personnel basket by mobile crane.
- The penstocks and draft tube may also be accessed via penstock manway and draft tube manway located in the powerhouse basement.

4.2.2.1.2 Slab Creek I/O

- Vehicle access to the I/O will be provided by the Chute Camp and Boat Ramp Access Roads.
- Parking will be provided adjacent to the I/O for commercial vehicles. Provisions for trailers will not be provided.
- The top of the gated I/O structure will be at elevation 1,875 feet, approximately the same elevation as the adjacent parking area.
- A vertical access shaft will be located within the vertical gate structure to provide personnel access to the unwatered tailrace tunnel.

4.2.2.2 Design Occupancy

- Water conveyance tunnels and shaft shall not be designed for continuous occupancy.

4.2.2.3 Leakage

- Allowable leakage rates to be developed during final functional design.
- Leakage into the tunnels shall only be allowable in the dewatered condition. Allowable leakage rate into the tunnels (infiltration) shall be developed during final functional design
- To prevent groundwater/water transmission, a minimum of three grout curtains shall be provided at the high pressure interface of all tunnel plugs, steel-like conduits, and the Upper Reservoir I/O and shaft.

4.2.3 Geometry

- The final tunnel and shaft cross sections shall be circular, horseshoe, or modified horseshoe shaped.
- Tunnel intersections shall be maintained at a minimum angle of 30 degrees.
- All tunnels shall be fully lined with concrete or steel linings.

4.2.4 Structural Design

Water conveyance tunnels shall be lined with concrete for the full length except where steel lining is required.

Concrete design shall consider all loads, including the following at a minimum and with the load factors presented in Table 4-4:

- Self-weight
- Rock Loads
    - Vertical and horizontal ground loads including wedge loading unless permanent rock dowel support is provided
- Hydrostatic operational
    - Maximum internal pressure, minus the minimum external water pressure under normal operating conditions
- Hydrostatic transient
    - Maximum transient internal pressure minus the minimum external water pressure
- Hydrostatic external
    - Maximum groundwater pressure acting on an empty tunnel
- Contact grouting pressure

The effects of net internal hydrostatic loads on the concrete lining may be reduced or eliminated by considering interaction between the lining and the surrounding rocks in accordance with EM 1110-2-2901.

External water loads shall be taken at the maximum and minimum observed piezometer readings, which may vary along the alignment of the tunnels. For inspection conditions, the design external groundwater pressure shall be taken as 100% of the maximum hydrostatic head unless pressure relief holes are incorporated. If pressure relief holes are incorporated, a maximum reduction of 50% of the hydrostatic head may be taken. Pressure relief hole length, arrangement, and spacing shall be determined using numerical modeling and shall consider reduced operational efficiency due to plugging or clogging over time. Minimum spacing along the length of the tunnel shall be 35 feet.

Ground support, such as rock dowels, shall be double corrosion protected if it considered to be functional for the design life of the lining.

Table 4-4. Minimum Load Factors for Concrete Lining Design

Load Case	Self/ Dead	Rock Load	Operational Hydrostatic	Hydrostatic Transient	Hydrostatic External	Grouting
L1	1.2	1.6	1.2	-	-	-
L2	1.2	1.2	-	1.2	-	-
L3	1.2	1.6	-	-	1.2	-
L4	1.2	1.2	-	-	1.2	1.6

4.2.5 Contact Grouting of Cast-in-Place Concrete Linings, Steel Linings, and Penstocks

Contact grouting shall be performed uniformly and throughout the locations for installed cast-in-place lining.

4.2.6 Component Requirements

4.2.6.1 Headrace Tunnel

4.2.6.1.1 Minimum Rock Cover Criteria for Unlined High-pressure Headrace Tunnel

Adequate confinement shall be confirmed with a minimum stress of 0.55 times the vertical stress and using the factors of safety noted in Table 4-5.

Table 4-5. Summary of Confinement Evaluation Criteria

Minimum Static Factor of Safety	1.25
Minimum Transient Factor of Safety	1.10

4.2.6.2 Manifold and Penstocks

The manifold structure will be concrete lined.

Concrete design for the manifolds shall be in accordance with the loading scenarios described under Section 4.2.4.

The use of pressure relief holes shall not be allowed.

Refer to Section 4.2.5 for contact grouting requirements.

4.2.6.2.1 Penstocks

The penstock tunnels shall be steel lined for a minimum of 250 feet or a distance equal to 25% of the operating static pressure head, whichever is greater. Steel lining length and penstock angle shall also take into account the bedding foliation angle and preferential seepage paths towards the powerhouse complex in order to meet groundwater inflow restrictions. The steel-to-concrete transition shall include a triple array of pressure grouted radial holes a minimum of 50 feet long.

4.2.6.2.1.1 Penstock Design

Penstock design shall consider all design loads, including the following at a minimum:

- Self-weight
- Hydrostatic operational
  - Maximum internal pressure, minus the minimum external water pressure under normal operating conditions
- Hydrostatic transient
  - Maximum transient internal pressure minus the minimum external water pressure
- Hydrostatic external
  - Maximum groundwater pressure acting on an empty penstock
- Contact grouting pressure

The effects of net internal hydrostatic loads on the concrete lining may be reduced or eliminated by considering interaction between the lining and the surrounding rocks in accordance with EM 1110-2-2901.

External water loads shall be taken at the maximum and minimum observed piezometer readings, which may vary along the alignment of the tunnels. The use of pressure relief holes shall not be allowed.

Rock dowel support shall be designed to handle the permanent ground loads and shall be double corrosion protected.

- Rock loads
  - Vertical and horizontal ground loads including wedge loading unless permanent rock dowel support is provided.
  - Rock loads shall be factored in accordance with Section 4.2.4.

4.2.6.3 Surge Chambers

A surge chamber is not permitted.

4.2.6.4 Unit Draft Tube Tunnels and Gates

The required extent of the steel lining from the end of the draft tube shall be determined during Final Functional Design. Steel design shall be in accordance with the loading scenarios described under Section 4.2.6.1.

Rock dowel support shall be designed to handle the permanent ground loads and shall be double corrosion protected.

4.2.6.5 Tailrace Tunnel

Concrete design for the tailrace tunnel shall be in accordance with the loading scenarios described under Section 4.2.4.

The design external ground water pressure shall be taken as 100% of the external water pressure. Pressure relief holes may be incorporated but, a maximum reduction of 50% of the external water pressure may be taken. Pressure relief hole length, arrangement, and spacing shall be determined using numerical modeling and shall consider reduced operational efficiency due to plugging or clogging over time. Minimum spacing along the length of the tunnel shall be 50 feet.

Refer to Section 4.2.5 for contact grouting requirements.

Ground support, such as rock dowels, shall be considered temporary unless corrosion protection is provided equivalent to the design life of the lining.

4.2.6.6 Tunnel Plugs

Access tunnels utilized for construction shall be appropriately isolated from the water conveyance tunnels with a watertight wedge-shaped concrete plug. Plugs shall be designed to support ground loads and shall hydraulically isolate select components of the facility. The plugs should be located in sound rock, carefully blasted, with damaged rock scaled and removed in the location of the final plug to facilitate keeping the plug as short as possible and at the highest quality to limit leakage.

The plug length shall be a minimum of 4% of the operating water head acting on the plug and have the following factors of safety:

- Minimum shear failure factor of safety under static operating pressure = 3.
- Minimum shear failure factor of safety under transient pressure = 3.
- Maximum hydraulic gradient in accordance with Lang (1999) Table 2. Grouting shall not be considered for the hydraulic gradient.

- The leakage through the plug shall not exceed 25 gpm where the operating pressure exceeds 125 psi, and shall not exceed 15 gpm where the operating pressure is less than 125 psi.
- The leakage through the steel bulkhead shall not exceed 0.5 gpm.

The following are the maximum design loads and their load factors for the plug design:

- Internal pressure: Load factor = 1.2
- Short-term internal pressure (125%): Load factor = 1.0
- Coefficient of friction concrete on rock: Lang (1999) Table 2

An 8-foot by 8-foot equipment access hatch is required at a minimum of one low-pressure plug location into the tailrace. A 3-foot circular personnel access shall be provided at a minimum of one high-pressure plug location into the headrace.

4.2.6.7 Pressure Grouting at Tunnel Plugs and Steel Lining Transitions

- Pressure grouting of the rock mass surrounding permanent plugs or terminus of steel penstock lining shall be conducted to reduce the hydraulic conductivity of the rock mass due to disturbance during excavation.
- Pressure grouting shall be performed after the structures are placed and after contact grouting of the structures is fully completed.
- Pressure grouting shall be performed within general conformance with USACE EM 1110-2-3506, Grouting Technology, and described procedures for ring curtain grouting techniques.
- Pressure grouting shall be performed fully around each structure (360 degrees), with the array extending up to a maximum one diameter beyond the excavation limits.
- Pressure grouting holes shall extend either half the length of the plug or two diameters longitudinally along the length of the steel lining, where the structure is placed in radially fanned holes.

4.2.7 Slab Creek Inlet/Outlet (I/O) Structure

4.2.7.1 Functional Design Requirements

The Slab Creek I/O provides the hydraulic connection between Slab Creek Reservoir and the tailrace tunnel. The I/O shall:

- Divert the full range of pump/turbine flow without formation of surface vortices, air entrainment, or moving sediment larger than a 2-millimeter grain size.
- Minimal surface expression of flow or discharge shall be visible in front of the I/O when the reservoir is at the normal minimum water surface during the pump or generate mode.

- Divert the full range of flow between El. 1,815 feet and El. 1,850 feet with an approach velocity less than 2 feet per second measured 12 inches in front of the trash rack during maximum pumping flow.
- Prevent rocks and debris from entering the tail tunnel with a trash rack.
- Ensure sufficient air is supplied and discharged during all modes of tailrace tunnel draining and filling. Air speeds shall be subsonic and not entrain airborne material.
- Manually isolate the tailrace tunnel from Slab Creek Reservoir with at least one slide gate.

The vertical gate structure shall be constructed with a bypass line and two valves to permit controlled filling of the tailrace tunnel. The headgates are not designed to be lowered into place under flow; therefore, pressure equalization across the gate shall need to occur prior to raising and lowering of the gate. A lifting beam shall be provided with the headgates.

4.2.7.2 Operating and Maintenance Requirements

4.2.7.2.1 Access

- Vehicle access to the I/O shall be provided by the Chute Camp and Boat Ramp Access Roads.
- Parking shall be provided adjacent to the I/O for commercial vehicles. Provisions for trailers shall not be provided.

4.2.7.2.2 Design Occupancy

- This structure shall not be designed for continuous occupancy. Condition assessment and maintenance will follow the permit-required confined space regulations.

4.2.7.2.3 Service Gate

- The I/O shall include at least one vertical gate (bulkhead) capable of sealing and isolating the tailrace tunnel from Slab Creek Reservoir.
- The service gates shall be lowered and raised by a mobile crane.
- The gate(s) shall be stored within the I/O at least one-half tunnel diameter above the tunnel crown.

4.2.7.3 Public Safety Precautions

- The area between the I/O structure and the reservoir shall be backfilled to maintain the shoreline profile.
- Fixed barriers shall prevent access from the outboard edge of the I/O structure to the water surface in order to prevent jumping and diving into the water.

4.2.7.4 Recreation Access

Details of recreation access in the area of the Slab Creek Reservoir I/O have yet to be finalized.

4.2.8 Material Properties

Concrete requirements and steel properties are provided in Table 4-2 and Table 4-3, respectively.

Table 4-2. Concrete Requirements

Location	Min. Compressive Strength	Min. Thickness	Min. % Reinforcement	Min. % Pozzolan
Headrace	5,000 psi	12 inches	TBD	TBD
Power Shaft	5,000 psi	16 inches	TBD	TBD
Manifolds	5,000 psi	12 inches	TBD	TBD
Penstock	5,000 psi	12 inches	TBD	TBD
Tailrace	5,000 psi	12 inches	N/A	TBD
Plugs	4,000 psi	N/A	N/A	30%

Table 4-3. Steel Properties

Location	Min Yield Stress	Min. Thickness	TBD	TBD
Penstock	50 ksi	1.5 inches	TBD	TBD
Draft tube extension	50 ksi	1.5 inches	TBD	TBD

Rock dowels shall have a minimum yield strength of 60 ksi and be cement grouted.

4.3 Underground Powerhouse Complex

The powerhouse complex shall include the main access tunnel, powerhouse, low-voltage bus tunnels, transformer gallery, and high-voltage utility shaft. Listed below are brief descriptions of each. It should be noted that, depending on the future geologic subsurface exploration result, an upstream drainage tunnel may be recommended to intercept seepage and relieve hydrostatic pressure imposed on the upstream powerhouse wall and steel-lined penstock sections (during tunnel unwatering).

4.3.1 Powerhouse

The powerhouse substructure, which encases and supports the pump-generating units, shall be constructed of reinforced concrete with floors and passages provided to accommodate all balance of plant (BOP) and ancillary equipment, cabling, piping, and support facilities. In addition to space for normal operation and maintenance, there shall be sufficient space available to accommodate construction as well as the complete disassembly of a single unit.

A suspended/or self-supporting ceiling shall be included to shield the machine hall floor from any minor rock spalls or water inflows, and allow access to the rock in the roof of the cavern for monitoring and maintenance, if required.

In addition, powerhouse location and dimensions shall satisfy the following:

- The underground powerhouse dimensions shall be based on the physical unit dimensions and required submergence to prevent water column separation in the scroll case, runner, draft tube, and water conveyance.
- The powerhouse location shall satisfy the minimum stress criteria.
- The PFD powerhouse location and orientation shall be dictated by results of the geotechnical investigation program. These requirements will be incorporated as part of the Final Functional Design.
- For the purpose of isolating a single unit post-tunnel filling, isolation valves and draft tube gates shall be located upstream and downstream of each unit, respectively.

4.3.1.1 Control Room

The control room shall be located on the machine hall floor, and shall include the following equipment and facilities:

- Operator console
- Relief operator console
- Voice and radio consoles
- SCADA access
- Data system access
- Wi-Fi system access
- Storage requirements

- Security (access control, CCTV) annunciation and control
- Fire alarm system annunciation and control

4.3.1.2 Powerhouse Public Access Area

Areas where public access will be provided shall be barricaded to prevent unauthorized entrants from entering nonpublic areas. Barricades shall prevent visual obstruction beyond the barricade. ADA requirements will be developed with the Owner during Final Functional Design.

4.3.2 Low Voltage Bus Tunnels

Three low voltage bus tunnels between the generator and generator step-up transformer shall be sized to contain all equipment and provide access to maintain all equipment in compliance with safe working distances. Each tunnel shall contain a suspended roof to protect the power electronics from loose rock fragments and seepage emanating from the crown.

4.3.3 Transformer/Draft Tube Gate Gallery

The transformer/draft tube gate gallery transformer shall be sized to contain all equipment and provide access to maintain all equipment in compliance with safe working distances. A suspended ceiling is required to protect the gallery from minor roof spalls and water inflows. The gallery invert shall be concrete lined. A rail system shall allow removal of the transformers for maintenance and/or repair. Pits shall provide access to the bonneted draft tube gates.

4.3.4 Unit Draft Tube Tunnels and Gates

The unit draft tube tunnels shall connect the pump-turbine draft tubes with the tailrace tunnel. The bifurcations shall be formed by the intersection of conical sections to minimize hydraulic losses in both pump and generate modes.

The unit draft tube tunnels shall be steel lined between the end of the steel draft tube and the draft tube gate, and concrete lined for the remaining tunnel section extending to the concrete-lined tailrace tunnel. The draft tube gates shall be hydraulically operated from the control room and locally from the transformer gallery.

4.3.5 Operating and Maintenance Requirements

4.3.5.1 Access

Access shall be provided to haul in, haul out, load, and unload the largest pieces of equipment that will be transported to or from the powerhouse complex during and after construction to support future outages.

4.3.5.2 Design Occupancy

The powerhouse complex shall be designed for continuous occupancy.

4.3.5.3 Climate Controls

The powerhouse temperature shall be controlled to the approximately 72°F to 78°F range, for the electrical equipment protection and personnel comfort. The relative humidity should be in the 35% to 40% range. Because of some concentrated heat loads within the powerhouse, the temperature in some spots of the powerhouse will be higher than this average design temperature.

4.3.5.4 Watertightness

To be developed in Final Functional Design.

4.3.5.5 Groundwater Control

- A drip canopy water collection system shall be implemented in the caverns and bus tunnels. The canopy shall provide a 5-foot minimum clear space at the sidewall for inspection and future maintenance. The drip canopy shall have collection gutters on both ends that drain to collection pipe(s). The drip canopy shall be watertight. All areas exhibiting leakage shall be sealed.
- The canopy shall be designed for a live load of 200 psf for maintenance of the canopy and inspection of the roof support.
- A hanging pedestrian gangway shall be provided for inspection above the drip canopy, with access from the machine hall level.
- Drain holes shall be drilled to intercept seeps.
- Maximum allowable total inflows into the cavern will be determined during Final Functional Design.
- Vertical shielding shall be used in locations where seeps exceed 5 gpm.
- Collected groundwater shall be directed to the powerhouse sump locations.

4.3.6 Geologic

- Orientation and shape:
  - Powerhouse and transformer caverns’ longitudinal axis shall be aligned perpendicular to bedding/foliation +/- 15 degrees. The angle deviation shall be evaluated during the secondary investigation phase.
  - Pillar width (powerhouse cavern to transformer cavern edge) shall be designed to limit the extent of yield zones in the pillar. No yielding shall be permissible in the central XX% of the pillar. (Details of this criteria will be developed during the final functional design.
- Support Requirements:
  - Ground support system shall be designed to control convergence such that rock mass does not deteriorate over the life of the project.
  - Bolts shall be double corrosion protected.

4.3.7 Mechanical Equipment and Systems

4.3.7.1 General

- A P&ID reference drawing shall be provided for all piping systems in the powerhouse.
- All piping in the powerhouse shall be identified by external pipe identification tags. Piping identification shall conform to ANSI/ASME A13.1.
- All mechanical equipment shall be equipped with secure mechanisms for lock-out during maintenance.
- Nomenclature for equipment to be developed in Final Functional Design.

4.3.7.2 Pump-turbine Equipment

4.3.7.2.1 Pump-turbine

4.3.7.2.1.1 Functional Requirements

a. The powerhouse shall be equipped with three or more pump-turbines, each mechanically coupled to an asynchronous motor-generator.

b. The following operating modes shall be integrated into the design:

   - Pump operation to turbine operation
   - Turbine operation to pump operation
   - Condensing mode operation in both pump and turbine modes

c. The following system interfaces shall be integrated into the design:

Table 4-4. Pump-Turbine Equipment System Interfaces

System Title
Cavern for the units, main building
Main inlet valve (spherical valve)
Cranes in cavern for the units and hoisting equipment
Motor-generator
Cooling water system
Seal water Injection system
Depressing air system
Station service air system
Governor hydraulic system
Turbine guide-bearing lubricating oil system
Auxiliary power supply
Control system
Protection system
Cables (low voltage / sensor / fiber optics)

d. The following operating criteria shall be integrated into the design:

Table 4-5. Pump-turbine Equipment Functional Design Criteria

Data	Value
Machine data	
• Number of units	3
• Type of pump-turbine	Francis
• Shaft orientation	vertical
• Rotation direction for turbine mode operation (view from above motor-generator)	counterclockwise
• Nominal electrical power output of one pump-turbine (turbine operation)	133.33 MW
• Nominal electrical power consumption of one pump-turbine (pump mode operation), expected	158 MW
• Grid frequency	60 Hz
• Nominal speed pump-turbine	514.28

Data	Value
• Range of speed variation of the pump-turbine (maximum prospective range of speed variation)	min. between -6.5% and +6.5%
Runaway speed	≤ 750 min^{-1}
Maximum overspeed and smaller than runaway speed	≤ 750 min^{-1}
Runner diameter, maximum	≤ 3,500 mm
Runner setting level (center line spiral case) satisfying the water column separation criteria for transient loading condition of 2 simultaneous unit trips followed by the third unit trip	1,531.0 ft asl
Minimum pressure below runner at worst case transient conditions	14.5 psig
Maximum pressure for all parts related to the upstream pressure (design pressure)	1.5 max static head
Test pressure for all parts related to the upstream pressure	1.5 design pressure

e. The pump-turbine design shall be integrated with the turbine inlet isolation valve, water conveyance system, and inlet/outlets design requirements.

f. The pump-turbine and its auxiliary equipment shall be designed, manufactured, installed, and field tested to meet the performance and cavitation guarantees of the DBE contract.

g. The pump-turbine hydraulic design shall be model tested per IEC 60193 in a qualified hydraulic test loop. The model test shall include an Owner witness test and acceptance of the hydraulic design.

h. The pump-turbine shall be provided with calculated prototype performance charts and tables derived from model testing including efficiency versus discharge, efficiency versus power, discharge versus needle opening, and power output versus discharge.

i. All machine components shall be designed to prevent vibration at or near their natural frequency for the entire normal operating range of head and discharge. Machine components shall be designed for a 25-year useful life before major overhaul and be free from excessive stress, fatigue, or vibration-induced permanent deformations or cracking for all normal condition and design basis conditions and events, except for specific wear components, to be agreed to by the Owner. The typical operating year shall incur a minimum of 1,000 and a maximum of 2,000 starts/stops or mode changes per year.

j. The pump-turbine will be installed with a vertical shaft; the guide bearing shall be arranged in the head cover.

k. The combined thrust and guide bearing of the motor-generator shall be arranged in the lower bracket, with the upper guide bearing in the upper bracket.

l. The pump-turbine runner shall be provided with access, equipment, and tools for removal and replacement of the runner from below the spiral case and stay ring. To achieve this requires that the access passage, equipment, and tools supplied also permit rapid removal and reinstallation of sections of the draft tube liner, discharge ring, and bottom ring.

m. All pump-turbine components subject to particle erosion or cavitation erosion shall be manufactured of martensitic stainless steel. These components shall include but are not necessarily limited to the runners, exposed portions of discharge rings, wicket gates, and facing plates. All components exposed to erosion in and adjacent to the water passage of the pump-turbine shall be easily removable and replaceable.

n. Pump-turbine guide bearings shall be of the “pivoting-shoe,” Babbitt-lined, oil-lubricated type The bearing sump shall be equipped to effectively contain the oil through all steady state and transient operating conditions including full runaway without loss of oil. The bearing shall be equipped with any necessary water cooling system.

o. Pump-turbine shall be equipped a hydrostatic type, main shaft seal designed for filtered water lubrication to isolate the wheel pit from the headcover/runner crown space. The design of the shaft seal shall take into account back-pressure conditions resulting from worn runner seals. The filtered water system shall be included.

p. The upper runner seal leakage shall be carried to the draft tube either by a system of stainless steel balancing piping from the headcover/runner crown space to the draft tube. This system and the other pump-turbine components affected must be designed to handle safely, the back-pressure generated in the headcover/runner crown space when the runner seals are worn to their “admissible limit.”

q. A pump-turbine pit drainage system shall be provided and shall effectively and safely evacuate leakage from the main shaft seal in a “worn state” and from the wicket gate bushings with their seals in a worn state. If pumps or eductors are necessary for this system, they shall be provided with full redundancy.

r. The wicket gate linkage and bushings shall be self-lubricated. The self-lubricated bearing bushing and bearing material shall have a bronze shell with lubrication included either interstitially or in the form of small pucks that will provide adequate lubrication for small amounts of rotation.

s. The mating surfaces of all self-lubricating bushings and bearings shall be of stainless steel or of a similar corrosion- and erosion-resistant alternative material recommended by Contractor and accepted in writing by Owner.

t. All bushings exposed to the water passage shall be equipped with “Lip” or “Polypack” type seals to prevent ingress of foreign particles. “O-ring” seals shall not be accepted in this service.

u. Access shall be provided to all major turbine components for inspections and maintenance. This shall include smaller components subject to wear.

v. Cavitation erosion damage on the runner and all other turbine parts shall in no case exceed that permitted by IEC 60609 for the guarantee reference period. However, it is Owner’s goal to have “cavitation free” performance.

w. The generating units shall be erected in accordance with the requirements of the latest edition of the CEATI Guide for Erection Tolerances and Shaft System Alignment, Parts I and II, for Francis turbine units.

x. The runner shall be designed to withstand the operating stresses over the life of the plant without cracking.

y. The castings for Francis runners shall be inspected and upgraded in accordance with _TBD________.

z. Prototype turbine efficiency tests shall be conducted on one pump-turbine in accordance with IEC 60041 as agreed to by Owner.

aa. Tolerances, surface finish and verification of runner geometry shall be in accordance with IEC 60193.

bb. The runner shall be static balanced according to ISO 1940/1, grade 6.3 or better.

cc. A complete record of the results of homology and balancing checks of each and every runner shall be submitted to Owner for acceptance before the runner is released for shipment.

4.3.7.2.1.2 Maintenance and Access Requirements

a. Access shall be provided to all pump-turbine components for inspection, maintenance, and ultimate overhaul or replacement.

b. For runner removal from below the spiral case and stay ring, the handling equipment shall also facilitate the removal and reinstallation of the draft tube liner sections and the discharge ring and bottom ring where necessary for runner access.

4.3.7.2.1.3 Control and Monitoring Requirements

a. The pump-turbine shall be supplied with templates used at the factory and drawings to enable determination of deformation or damage to the hydraulic profiles of the runner and guide vanes, during routine maintenance inspections. Such documentation will also serve during repairs and rebuilding of worn components.

b. Instrumentation shall be provided for monitoring of:

- Spiral case inlet pressure
- Machine vibration monitoring
- Flow by Winter-Kennedy taps
- Cooling water flow to the pump-turbine guide bearing when applicable
- Filtered water flow to the shaft seal when applicable
- Bearing metal temperature
- Bearing oil temperature
- Wicket gate position
- Shafting system vibrations
- Other parameters recommended by Contractor and accepted by Owner in writing

c. The pump-turbine shall be field performance tested to IEC 60041 standard.

4.3.7.2.1.4 Codes and Standards

a. To be developed in Final Functional Design

4.3.7.2.2 Pump-turbine Spiral Case

4.3.7.2.2.1 Functional Design Requirements

a. The spiral case and stay ring and all related components shall be capable of safely withstanding all combinations of hydraulic and mechanical forces, such as hydraulic transients, unit runaway, and sudden motor-generator short-circuiting.

b. The following operating modes shall be integrated into the design: See pump-turbine.

c. The spiral case and stay ring must be capable of safely withstanding all construction and handling forces with no permanent deformation or damage.

d. Dewatering of the pump-turbine runner for start-up of the pump or during condenser operation (if applicable) will be achieved by compressed air.

e. The spiral case and stay ring shall be equipped with stainless steel piezometer taps and stainless steel piping to a point outside of the concrete unit block to enable flow monitoring through differential pressure (Winter-Kennedy taps).

f. .The spiral case shall be provided with piezometer taps and piping to a point outside the concrete unit block in accordance with IEC 60193 for monitoring, control, and efficiency testing.

g. The embedded portions of the pump-turbine wheel pit liner and scroll case/distributor shall be designed to inhibit corrosion damage, which could affect operation of the unit over the life of the plant. Surfaces in contact with the embedment concrete shall be clean and left unpainted.

4.3.7.2.2.2 Maintenance and Access Requirements

a. Access to the spiral cases shall be provided by a manhole designed to satisfy the requirements of the ASME Boiler and Pressure Vessel Code, Section VIII. The clear opening of the manhole shall be at least 30 inches in diameter and the hatch shall be hinged.

b. Access to the pump-turbine shall be provided through a removable draft tube section. The access shall be configured such that the pump-turbine runner can be removed from the spiral case and draft tube, and placed on a maintenance cart on the basement floor.

c. Access between the machine hall deck and basement shall be provided to permit the pump-turbine runner to be moved from the basement to the machine hall.

d. The pump-turbine shall be capable of being dewatered through a corrosion-resistant manual drain valve provided with embedded stainless steel piping that leads to the lower part of the draft tube.

4.3.7.2.2.3 Control and Monitoring Requirements

a. To be developed in Final Functional Design

4.3.7.2.2.4 Codes and Standards

a. ASME Boiler and Pressure Vessel Code, Section VIII.

4.3.7.2.3 Governor and Governor Hydraulic System

4.3.7.2.3.1 Functional Design Requirements

a. A dedicated digital electronic speed governor shall be provided for each unit to fulfill all control and protection functions and to provide the necessary parameter indication and alarm functions.

b. The governor shall be capable of meeting the pump mode runout criteria for Upper Reservoir water level control and shall be capable of regulating speed to NERC requirements. The governor shall be capable of responding to system frequency changes and to operator or controller introduced load changes and to maintain stability.

c. All outputs from the governor that lead to trips shall be hardwired to the protection I/O panels rather than provided though the communications link.

d. Each unit shall be equipped with a secondary overspeed detection device able to provide a signal that will shut down the unit regardless of governor setting.

e. Governors shall comply with Section 4 of IEEE Standard 125, IEEE Recommended Practice for Preparation of Equipment Specifications for Speed Governing of Hydraulic Turbines Intended to Drive Electric Generators.

f. There shall be a dedicated governor hydraulic system consisting of an HPU and control cabinet for each pump-turbine.

g. The design pressure for the hydraulic system shall be approximately 1,500 psig or as required by Owner.

h. The high operating pressure shall allow for a minimum volume of hydraulic fluid as well as smaller hydraulic components and a higher capacity. The system shall be designed to minimize locations for potential leakage. The HPU shall use drilled manifolds to the maximum extent possible

i. The system shall provide for at least three full cycles of the servomotors in case of pump failure or loss of power.

j. The pumps shall maintain system pressure or run continuously during periods of high demand. Pump redundancies shall be provided for maximum safety and system reliability.

k. The following components shall be integrated into the design:

- Unit/speed governor control panel with human-machine interface (HMI) screen and programmable logic controllers (PLCs)

- Hydraulic fluid sump
- Multiple positive displacement pumps
- Pump suction strainers
- Filters
- Proportional control valves
- Directional control valves
- Hydraulic valve manifold
- Nitrogen pressurized accumulators for stored energy
- Heaters
- HPU instrumentation

l. The governor HPU shall be located as close as possible to the pump-turbine wheel pit and servomotors to minimize the run of high-pressure hydraulic piping and system oil volume. Welded stainless steel piping is required.

m. Flanges shall be used only where necessary to facilitate piping disassembly for maintenance and shall be stainless steel and of the SAE Code 61, O-ring, four-bolt type.

n. The control cabinet that interfaces with the HPU shall provide local control and operating status for the HPU. This will include such information as what pumps are running, system pressure, and high-filter differential pressure alarms. The control cabinet shall also provide local indication and control of pump-turbine speed, wicket gate position, spherical valve position, penstock pressure, pump prime indication, and runner tip pressure.

o. The design shall be integrated with the following: See pump-turbine.

p. The following operating modes shall be integrated into the design: See pump-turbine.

4.3.7.2.3.2 Maintenance and Access Requirements

a. Access shall be provided to all governor components for maintenance, repairs, and replacement.

4.3.7.2.3.3 Control and Monitoring Requirements

a. Monitoring for leakage of hydraulic fluid shall be provided.

b. Monitoring of governor oil pressure and oil levels shall be provided and incorporated into the plant data system.

c. Control of the governor shall primarily be through the plant control system. Secondary local controls in close proximity to the pump-turbine wheel pit shall be provided.

d. Remote monitoring of the Governor HMI screen shall be made available in the control room, independent of the main plant HMI.

4.3.7.2.3.4 Codes and Standards

a. IEEE 125. IEEE Recommended Practice for Preparation of Equipment Specifications.

4.3.7.3 Water Conveyance Isolation

4.3.7.3.1 Pump-turbine Inlet Valves (TIV) and Hydraulic System

4.3.7.3.1.1 Functional Design Requirements

a. Each unit shall have an independent pump-turbine inlet valve (TIV) for emergency unit shutdown in the event of loss of control of the pump-turbine by the governor and for maintenance isolation of the pump-turbine and its auxiliary equipment.

b. The TIV shall be of a spherical-type inlet valve and be designed to enable certification as a single point of isolation for permit-required confined space entry. The TIV seals shall be drop-tight when closed to avoid seal and seat erosion. There shall be an upstream maintenance seal and a downstream seal for normal closing. Positive electrical and visual indication of whether seal is open or closed shall be provided. The sealing surfaces shall be manufactured from a combination of corrosion-resistant metal surfaces (e.g., stainless steel, bronze). Counterweights shall be provided to enable valve closure upon failure of the TIV hydraulic cylinder pressure supply.

c. The following components shall be integrated into the design:

- Spherical valve body
- Spherical valve rotor with trunnions
- Upstream and downstream rotor seals
- Rotor lever arm and counterweights
- Valve hydraulic cylinder actuator, double acting
- Hydraulic power unit and stored energy accumulators
- Control panel
- Penstock expansion coupling
- Bypass piping, isolation valves, and pressure reducing valve

d. The design shall be integrated with the following:

- Penstock pressure for seal actuation
- Spherical valve hydraulic power unit
- Pump-turbine
- Penstock
- Drainage and dewatering
- Draft tube gates
- Cranes in cavern for the units and hoisting equipment
- Monitoring instrumentation
- Governor and unit control
- Auxiliary AC power
- Auxiliary DC power
- Cables (low voltage / sensor / fiber optics)

e. The valve pressure boundary shall be designed for maximum static head plus a 30% allowance for anticipated pressure transients. The valve will be hydrostatic tested at 150% of the design pressure.

f. The TIV shall be shop pressure tested to prove its design, its integrity, and the performance of the seals.

g. In the case of a spherical valve incorporating an upstream maintenance seal to satisfy the single point of isolation requirement, when the TIV is closed for maintenance of the pump-turbine, both the upstream maintenance seal and the downstream service seal shall be closed and the body of the TIV shall be drained to atmosphere between the two seals. The upstream maintenance seal shall have provisions for positively, mechanically locking it in the closed position for the rare circumstances when the downstream service seal of the TIV is being replaced. Similarly, the drain valve for the valve body between the seals shall be large enough to ensure there is no pressure buildup between the seals when the upstream seal is closed. This TIV body drain valve shall also be provided with the means of positively locking it in the open position.

h. The TIV shall have corrosion and erosion resistant sealing surfaces (including seal rings, seat rings, and the chambers or surfaces on the TIV body and plug in which they are mounted). All components in the control system shall be manufactured also using corrosion resistant materials. If the TIV seals function by penstock pressure, the water circuits shall use clean filtered water. Filter systems shall have full redundancy and automatic switching with alarms when the backup system is actuated. Filter systems shall provide safe isolation (block and bleed) of filters to allow for changing while the plant is running.

i. The TIV shall be operated by a double-acting hydraulic cylinder actuated by a high-pressure hydraulic fluid.

j. The TIV shall be capable of closing without external power (for both normal and emergency closure) using counterweights.

k. The closing of the TIV shall be rate limited to positively avoid excessively rapid closure and excessive pressure transients in the Penstock. The limiter shall be a passive device integrated into the valve or its operating servomotor. Opening and closing times will be adjustable using valves in the hydraulic circuit.

l. The TIV shall be equipped with an automatic bypass system for filling the spiral case and for equalizing the upstream and downstream pressures before opening the TIV. The bypass line shall have an automatic power operated bypass valve along with manual upstream guard valves and dismantling flanges to facilitate maintenance and replacement.

m. The TIV shall be capable of closing under the most severe maximum flow and pressure conditions (i.e., maximum turbine output, or turbine runaway speed as the design may dictate).

n. The TIV shall be capable of closing independent of any other plant system when tripped locally by the operator.

o. The TIV shall show no degradation of performance and reliability over the design life because of operating and environmental conditions excluding eventual particle erosion of the normal downstream service seal and its seat.

p. The valve and controls shall be designed to enable emergency closure under uncontrolled high hydraulic pressure unit (HPU) pressure.

4.3.7.3.1.2 Maintenance and Access Requirements

a. The TIV shall include a dismantling piece to allow clearance for the installation and removal of the valve.

b. Infrastructure to perform a leakage test on both the downstream normal service seal and on the upstream maintenance seal shall be provided prior to opening a manhole or removing the dismantling section.

c. Access shall be provided to enable installation and removal of the valve without structural modifications to the powerhouse.

d. All isolation points shall be designed to allow reasonably easy access for maintenance and lock-out; this includes but is not limited to the bypass valve.

e. The TIV body shall be equipped with a corrosion resistant, manual lockable drain valve at the bottom piped to the turbine runner pit and an air vent valve at the top to allow trapped air to escape. The discharge from both shall be arranged to protect plant personnel from injury.

f. The TIV shall be equipped with polished stainless steel trunnion sleeves and self-lubricating bushings which have a service life of at least 20 years. The bushings shall be protected by "lip type" or "Polypack" type seals to prevent the ingress of water-borne contamination in the bushing and by multielement chevron seals for pressure containment.

4.3.7.3.1.3 Control and Monitoring Requirements

a. The TIV shall have valve rotor and seal position sensors.

b. The TIV controls shall be integrated in the generating unit controls such that the unit closes each time it is stopped for more than a predetermined period, which is to be established by Owner in consultation with Contractor.

c. The TIV shall be lockable in full-open and full-closed positions for maintenance and generating unit isolation.

d. The TIV shall be programmed to close with application of only the downstream service seal each time the pump-turbine is stopped or direction of rotation is reversed.

e. Remote open functionality shall be provided with operation from the control room and capability for operation from Owner's remote control facility.

f. Operation shall be linked to plant control system to enable emergency close as part of the automatic control system (e.g., sustained overspeed).

4.3.7.3.1.4 Codes and Standards

a. The pressure containing components of the pump-turbine inlet valve shall be designed in accordance with approved industry-accepted design requirements.

4.3.7.3.2 Draft Tube Gates

4.3.7.3.2.1 Functional Requirements

a. Draft tube gates shall be installed in each of the draft tube tunnels to isolate the pump-turbine draft tube from the tail tunnel if other units are in operation so that maintenance work may be performed. The draft tube gates shall only be closed for maintenance purposes.

b. The following operating modes shall be integrated into the design:

- Maintenance of the pump-turbine and draft tube.

c. The draft tube gates shall be of the bonneted gate type, oriented to operate vertically, with the gate being completely retracted from the flow path and physically locked when in the open position.

d. The assemblies shall be of welded steel construction, reinforced on the outside by means of ribs or structural shapes, and provided with means for secure embedment in the surrounding concrete.

e. Each draft tube gate shall also include a bypass line and vent line for refilling the draft tube after dewatering.

f. The following interfaces shall be integrated into the design:

- Hydraulic power unit
- Pump-turbine
- Spherical valve
- Draft tube
- Monitoring instrumentation
- Unit controls
- Auxiliary AC power
- Auxiliary DC power
- Cables (low voltage / sensor / fiber optics)

4.3.7.3.2.2 Maintenance and Access Requirements

a. Access shall be provided to all draft tube gate components for inspection, maintenance, and ultimate overhaul or replacement.

b. Access to the hydraulic operating system and gate bonnet shall be provided from the transformer gallery.

4.3.7.3.2.3 Control and Monitoring Requirements

a. The gates shall be able to close underbalanced water pressure conditions (no flow).

b. The draft tube gates shall be operated by hydraulic cylinders and equipped with locking devices that shall secure the gate in the open position and prevent flutter and vibration due to flow.

c. Each draft tube gate shall be installed with a redundant means of indicating gate open, gate closed, and locks engaged.

d. The gate operating system shall be designed and sized to open and/or close in no less than 5 minutes, and no more than 15 minutes.

e. The gate operating system shall be interlocked with the generating unit controls to prevent inadvertent closure during pump-turbine operation.

4.3.7.3.2.4 Codes and Standards

a. To be developed in Final Functional Design.

4.3.7.4 Motor-generator Equipment

4.3.7.4.1 Motor-generator Adjustable Speed

4.3.7.4.1.1 Functional Requirements

a. The powerhouse shall be equipped with three or more asynchronous motor-generators, each mechanically coupled to a pump-turbine.

b. The following operating modes shall be integrated into the design:

- Pump mode: In Pump Mode, the unit will consume electrical energy from the grid and drive the pump-turbine.
- Generate mode: In generate mode, the unit will convert the mechanical torque from the turbine into electrical energy.
- Condensing mode: Active power and reactive power are generated or are consumed.

c. The double-fed induction machine (asynchronous machine [DFIM]) shall be considered for variable speed with reversal of rotation. With the AC excitation, the speed shall be varied both in pump mode and in turbine mode. By changing the rotor speed, with utilization of the kinetic energy stored in the rotating masses, the DFIM shall be capable of adjusting the active power dynamically to support frequency regulation and power. This shall apply to both the pumping and generate mode.

d. Adjustment of reactive power in the pump mode and generate mode shall be made via the AC excitation.

e. Fire protection shall be provided via combination inert gas and mist or deluge system.

f. The static and dynamic loads imposed by the rotating assembly of the vertical units shall be handled with a combined thrust and guide bearing within the lower bracket and a guide bearing within the upper bracket of the motor-generator.

g. The rotor shall be specifically designed for asynchronous technology.

h. A bearing lubrication system shall provide a cooled and filtered supply of oil to the bearings for the motor-generator.

i. The motor-generator design shall include the following components:

- Stator
- Rotor
- Line side terminals and neutral terminals
- Slip rings including cover
- Upper bracket with guide bearing
- Lower bracket with combined thrust and guide bearing
- Main shaft
- Cooling system with air to water heat exchangers
- Brakes / hydraulic jacks
- Sensors with complete cabling within the motor-generator pit to the terminal boxes outside the motor-generator pit
- Platforms, stairways, hatches, and railings
- Fire protection system

j. The following system interfaces shall be integrated into the design:

- Powerhouse civil
- Pump-turbine
- AC excitation
- Generator voltage equipment
- Powerhouse crane
- Cooling water system
- Low pressure air system
- Auxiliary power supply
- Control system (including process control and network)
- Protection systems
- Low voltage/ control / fiber-optic cables, cable trays, and earthing systems

k. The following operating criteria shall be integrated into the design:

Table 4-6. Motor-generator Equipment Functional Design Criteria

Criterion	Value
Rated power motor-generator unit	160 MVA
Rated power stator motor-generator	160 MVA
Rated power AC excitation (reference value)	≥ 10 MVA
Rated power factor cos phi Geno (related to 133 MW)	0.90
Rated power factor cos phi Motor (related to 133 MW)	0.95
Rated voltage (reference value)	16.5 or 18 kV
Rated Temperature Rise	60°C
Design Maximum Ambient Air	40°C
Range of automatic voltage regulator (AVR)	±10%

Criterion	Value
Rated frequency	60 Hz
Synchronous speed	514.28 rpm
Speed range (reference value)	minimum ±6.5%
Runaway speed (reference value)	≤ 750 rpm
Bearing arrangement	IM 8225
Type of construction	W 42
Cooling	ICW37 A71
Insulation class stator and rotor	F (IEC)
Heating of stator and rotor according insulation class	B (IEC)
Moment of inertia MR2 (reference value)	$\geq 11 \times 10^6$ lb-ft^2
Protection class	IP44
Maximum permissible temperatures during continuous operation in:	
• Slip rings	≤ 90°C
• Thrust bearing segments	≤ 75°C
• Guide bearing segments	≤ 65°C
Maximum cooling water inlet temperature	30.0°C

4.3.7.4.1.2 Control and Monitoring Requirements

a. Requirements to be developed in Final Functional Design.

4.3.7.4.1.3 Maintenance and Access Requirements

a. Access shall be provided to all motor-generator components for inspection, maintenance, and ultimate overhaul or replacement.
b. The overhead crane shall have sufficient capacity to remove the rotor assembly and shaft.

4.3.7.4.1.4 Codes and Standards

a. The motor-generators shall be designed and constructed in accordance with ANSI C50.12 or Owner-approved equivalent. The motor-generator shall be supplied with characteristic and capacity curves.

4.3.7.4.2 Motor-generator AC Excitation System

4.3.7.4.2.1 Functional Design Requirements

a. The powerhouse shall be equipped with an AC converter for each unit that is electrically coupled to an asynchronous motor-generator. The converter shall be capable of adjusting the speed of the motor-generator both in motor and generate modes. The consumption or supply of reactive power of the DFIM will be adjusted via the AC excitation system.

b. The following operating modes shall be integrated into the design:

- Start-up of power unit in motor mode
- Variation of speed, regulation of frequency, both in motor mode and in generate mode
- Voltage regulation and regulation of reactive power both in motor mode and in generate mode
- Braking of unit during shutdown

c. The following operating criteria shall be integrated into the design:

Table 4-7. Motor-generator AC Excitation System Functional Design Criteria

Criterion	Value
Rated power converter (reference value)	>10 MVA
Cos phi	1
Range of output voltage (reference value)	3.3–6.6 kV
Range of output frequency (reference value)	0 ÷ 60 Hz
Range of automatic voltage regulator	± 10%
Range of frequency regulation	± 2%
Cooling system of semiconductors	closed circuit with pure water

d. The exciter shall be equipped with means to prevent dust from entering into and condensation from developing on the exciter components.

e. Metering accuracy of sensing PTs and CTs shall have a maximum allowable error of less than 1% rated voltage and current.

f. The following components shall be integrated into the design:

- Three-phase excitation transformer
- Converter
- Rectifier module
- DC-link
- Inverter module
- Control devices
- Harmonic filter (if required)
- Pure water in closed cooling water circuit
- Bus bars from excitation transformer to AC excitation system

- Bus bars from AC excitation to the brush holders at rotor of DFIM
- Fire protection system
- Short-circuit limiting reactor

g. The following system interfaces shall be integrated into the design:

- Powerhouse
- Motor-generator
- Cooling water system
- Generator voltage equipment
- Auxiliary power supply
- Control system
- Protection systems
- Low voltage / control / fiber-optic cables, cable trays, and grounding systems

4.3.7.4.2.2 Control and Monitoring Requirements

a. The excitation system shall include an HMI located at the exciter cubicle on the powerhouse main floor close to the unit providing for local manual control.

b. The excitation systems shall include monitoring of all excitation variables including cooling system status, rectifier temperature, AVR sensing armature and field voltage, stator current, field current, and excitation transformer temperature. These shall be integrated into the unit protection and control systems for alarms and fault response.

c. The exciter shall be equipped with over and under excitation limiters.

d. The primary power supply of the excitation transformer shall be fused and monitored for safety through a grounded shield between the primary and secondary sides.

4.3.7.4.2.3 Maintenance and Access Requirements

a. Requirements to be developed in Final Functional Design.

4.3.7.4.2.4 Codes and Standards

a. The design shall conform with IEEE/ANSI C57.12.01.

4.3.7.5 Cooling Systems

4.3.7.5.1 Low Pressure Service Water System (LPSW)

4.3.7.5.1.1 System Function

4.3.7.5.1.2 Functional Design Requirements

a. The powerhouse shall include a closed loop cooling water system to reduce corrosion problems from raw water and minimize heat transfer surface fouling. There shall be a closed loop system for component cooling water on the primary side that will reject heat through a single pass, main heat exchanger in a secondary side low pressure, raw water system. The low pressure service water (LPSW) system shall provide sufficient cooling water flow to remove the heat load of the powerhouse equipment through a single pass, shell and tube heat exchanger. The LPSW system will be on the tube side. Plant cooling water will be located on the shell side.

b. The following components shall be integrated into the design:

- Pumps with motors
- Strainers
- Heat exchanger
- Valves
- Instrumentation

c. The LPSW shall be equipped with two 100% capacity, horizontal, double-suction, split-case, centrifugal pumps per unit.

d. An automatic self-cleaning strainer with a separate manual bypass strainer shall be installed in the suction line running to each pump.

e. Service water flow shall be controlled by pneumatically operated control valves. Full port (i.e., ball-type) valves shall be utilized for isolation wherever possible.

f. The suction source for the LPSW system shall be a pipeline with an isolation valve that will be connected to the draft tube of each unit and then joined into a common distribution manifold located in the dewatering valve pit.

g. Suction lines shall be routed from this distribution manifold to each of the LPSW water pumps.

h. An alternate source of water shall be required to ensure low-pressure service water system operation if all units are dewatered. The service water system will discharge to the Lower Reservoir through a pipeline embedded in the tailrace tunnel. A second pipeline will be installed to serve as the intake for the alternate source as well as a redundant line for discharge to the Lower Reservoir if needed.

i. The LPSW pumps shall circulate raw water from the Lower Reservoir through strainers, valves, and a single pass heat exchanger to withdraw heat from the closed loop cooling water system.

- All surfaces of the heat exchanger exposed to raw water shall be manufactured from corrosion-resistant materials. The heat exchanger will be designed to facilitate cleaning of the heat transfer surfaces to ensure optimum heat transfer.The system piping, valves, fittings, and solenoids shall be rated for 150-pound service. The larger diameter piping will be constructed of flanged carbon steel. To preclude formation and clogging of any smaller diameter piping in the LPSW system, stainless steel will be used for all piping with an inner diameter less than or equal to approximately 4 inches. All embedded piping regardless of size shall be stainless steel.

j. All piping will be insulated with antisweat insulation.

k. The main heat exchanger will be designed with a generous heat transfer surface area and fouling factor. Corrosion-resistant materials shall be used for the heat transfer surfaces.

l. The design shall be integrated with the following:

- Cooling water system
- Motor-generator air coolers
- Flush/lube water for the station drainage and dewatering sump pump shaft bearings
- Water supply to the penstocks, draft tubes, and tailrace tunnels during filling and pressurization
- Fire protection system
- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

4.3.7.5.1.3 Control and Monitoring Requirements

a. Requirements to be developed Final Functional Design.

4.3.7.5.1.4 Maintenance and Access Requirements

a. A method of monitoring, draining, and refilling the LPSWS shall be provided.

b. All drains shall have a suitable diameter of not less than 10 inches.

c. All equipment (surface air coolers, heat exchangers, pumps, valves, etc.) shall be accessible for routine annual maintenance. All water circuit devices shall be provided individually with isolating valves and dismantling joints for maintenance.

d. Strainers shall be installed in parallel configuration with each strainer set having full capacity so that it can be backwashed and maintained without shutting down the cooling system.

e. Monitoring of the cooling system pressures, flows, and fluid levels for the system and for each subsystem shall be provided.

f. All heat exchangers shall be equipped with inlet and outlet temperature sensors on all streams with data available in the plant data and control system.

g. Control of flow shall avoid low pressure or air in surface air coolers and heat exchangers.

4.3.7.5.1.5 Codes and Standards

a. The pressure containing components of the cooling water system shall be designed in accordance with ASME B31.1.

4.3.7.5.2 Cooling Water System

4.3.7.5.2.1 Functional Design Requirements

a. The powerhouse shall include a closed loop cooling water system, treated with corrosion inhibitors, to provide cooling to the following equipment:

- Motor-generator thrust and guide (upper and lower) bearing oil coolers

- Motor-generator stator coolers
- Pump-turbine guide bearing oil cooler
- Pump-turbine runner seals when pump suction is depressed
- Powerhouse HVAC chiller condensers
- Depressing air compressors
- Station / instrument air compressors
- Pump-turbine shaft mechanical seals
- Main dewatering pump motor coolers

4.3.7.5.2.2 Major Components

a. The following components shall be integrated into the design:

   - Pumps with motors
   - Filters
   - Heat exchangers
   - Valves
   - Instrumentation
   - Chemical treatment system

b. The system shall be equipped with two 100% capacity, horizontal, double-suction, split-case, centrifugal pumps per unit.

c. An automatic self-cleaning strainer with a separate manual bypass strainer shall be installed in the suction line running to each pump.

d. Service water flow shall be controlled by pneumatically operated control valves. Full port (i.e., ball-type) valves shall be utilized for isolation wherever possible.

e. Cooling water system chemistry shall be controlled to minimize fouling of the various heat exchangers and increase cooling efficiency.

f. Cooling water makeup to the closed loop cooling water system shall be from the low pressure cooling water system.

g. The cooling water system shall provide sufficient cooling water flow to remove the heat load of the powerhouse equipment through a single pass, shell and tube heat exchanger. The LPSW system will be on the tube side. Plant cooling water will be located on the shell side. The raw water will be placed on the tube side to facilitate cleaning of any fouling that may occur on the heat transfer surfaces.

h. The system piping, valves, fittings, and solenoids shall be rated for 150-pound service. The larger diameter piping will be constructed of flanged carbon steel. To preclude formation and clogging of any smaller diameter piping in the cooling water system, stainless steel shall be used for all piping with an inner diameter less than or equal to approximately 4 inches. All embedded piping shall be stainless steel regardless of size.

i. All piping shall be insulated with antisweat insulation.

j. The design shall be integrated with the following systems:

- Motor-generator bearing lube oil
- Motor-generator cooling
- Pump-turbine bearing lube oil
- Pump-turbine cooling and lubrication
- HVAC
- Depressing air
- Station / instrument air
- AC excitation cooling system
- Generator step-up transformer coolers
- Monitoring instrumentation
- Station control system
- Auxiliary power supply
- Cables (low voltage / sensor / fiber optics)

4.3.7.5.2.3 Control and Monitoring Requirements

a. Requirements to be developed Final Functional Design.

4.3.7.5.2.4 Maintenance and Access Requirements

a. A method of monitoring, draining, and refilling the cooling water system shall be provided.

b. All equipment (surface air coolers, heat exchangers, pumps, valves etc.) shall be accessible for routine annual maintenance. All water circuit devices shall be provided individually with isolating valves and dismantling joints for maintenance.

c. Strainers shall be installed in parallel configuration, with each strainer set having full capacity so that it can be backwashed and maintained without shutting down the cooling system.

d. Monitoring of the cooling system pressures, flows, and fluid levels for the system and for each subsystem shall be provided.

e. All heat exchangers shall be equipped with inlet and outlet temperature sensors on all streams, with data available in the plant data and control system.

f. Control of flow shall avoid low pressure or air in surface air coolers and heat exchangers.

4.3.7.5.2.5 Codes and Standards

a. The pressure-containing components of the cooling water system shall be designed in accordance with ASME B31.1.

4.3.7.5.3 Powerhouse Chilled Water System

4.3.7.5.3.1 Functional Design Requirements

a. The powerhouse shall include a chilled water system to provide cold water for cooling purpose to all air handling units distributed throughout the powerhouse. The system shall be a closed loop system.

b. The following components shall be integrated into the design:

- Chillers
- Pumps
- Chemical treatment system
- Valves

c. The closed loop chilled water system shall consist of mechanical chillers and recirculating pumps supplying chilled water to the air cooling coils of the powerhouse air handling units and the cooling coil of the control room air handling unit.

d. A chemical treatment skid shall be installed so that the chemistry of the water in the system can be controlled to minimize corrosion of the air handling unit heat exchangers.

e. Chiller design redundancy shall be provided so that if one of the chillers is undergoing maintenance, there will be minimum chiller capacity still available to maintain a degree of air conditioning in the powerhouse and full-capacity air conditioning in the control room.

f. Backup pumps shall be provided for the chiller system.

g. The design shall be integrated with the following systems:

- Powerhouse ventilation system
- Cooling water system
- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

4.3.7.5.3.2 Control and Monitoring Requirements

a. Requirements to be developed in Final Functional Design.

4.3.7.5.3.3 Maintenance and Access Requirements

a. A method of monitoring, draining, and refilling the chilled water system shall be provided.

b. All equipment shall be accessible for routine annual maintenance. All water circuit devices shall be provided individually with isolating valves and dismantling joints for maintenance.

c. Strainers shall be installed in parallel configuration with each strainer set having full capacity so that it can be backwashed and maintained without shutting down the chiller system.

d. Monitoring of the chiller system pressures, flows, and fluid levels for the system and for each subsystem shall be provided.

e. All heat exchangers shall be equipped with inlet and outlet temperature sensors on all streams with data available in the plant data and control system.

f. Control of flow shall avoid low pressure or air in surface air coolers and heat exchangers.

4.3.7.5.3.4 Codes and Standards

a. The pressure-containing components of the chilled water system shall be designed in accordance with ASME B31.1.

4.3.7.6 Compressed Air Systems

4.3.7.6.1 Tailwater Depressing Air

4.3.7.6.1.1 Functional Design Requirements

a. Each pump-turbine shall include a tailwater depressing air system to depress the water column in the draft tube away from the pump-turbine runner. The tailwater depressing air system may serve as an alternate source of compressed air for both station and instrument air should the station air compressors fail. Self-contained pressure regulating valves shall be used to reduce pressure automatically to the appropriate level, if necessary.

b. The following components shall be integrated into the design:

- Air compressors with motors
- Air receivers
- Valves
- Draft tube level instrumentation
- Monitoring instrumentation

c. Fully redundant, multistage, reciprocating-type air compressors shall be provided, with air receivers of sufficient capacity located on the basement floor.

d. Piping between the air receivers and the pump-turbine shall be provided to admit air to the area of the pump-turbine inside of the closed wicket gates.

e. Sufficient compressor and air receiver capacity shall be provided for three tailwater depressions (change from generate mode to pump mode for all three units) without recharging the air receivers.

f. Sufficient volume of compressed air shall be provided to manage any in-leakage of water past the wicket gate end and vertical seals.

g. The tailwater depressing air system shall be designed for the maximum tailwater static pressure plus 20%, or approximately 300 psig.

h. Depressing air system components shall be located within the powerhouse with consideration of noise generation and space requirements for the large tanks and compressors as well as the length of piping runs.

i. Water level instrumentation located at the pump-turbine draft tube man-door shall determine the point at which the water level has been depressed sufficiently and the introduction of compressed air may be discontinued. The piping and components shall be stainless steel.

j. The water level (e.g., during pump priming) shall be raised by venting the compressed air from the pump-turbine head cover to the powerhouse sump. Air release velocity shall be subsonic and less than _TBD_ feet per second.

k. The design shall be integrated with the following systems:

  - Station air system
  - Cooling water system
  - Pump-turbine
  - Monitoring instrumentation
  - Station control system
- Auxiliary AC power
- Cables (low vltage / sensor / fiber optics)

4.3.7.6.1.2 Control and Monitoring Requirements

a. Requirements to be developed Final Functional Design.

4.3.7.6.1.3 Maintenance and Access Requirements

a. A method of monitoring and draining condensate shall be provided.

b. All equipment shall be accessible for routine annual maintenance. All air circuit devices shall be provided individually with isolating valves and dismantling joints for maintenance.

c. Each pump-turbine's tailwater dressing air system shall include valving to isolate that system from the other units' system in accordance with the permit required confined space requirements for maintenance work on the pump-turbine.

d. Monitoring of the tailwater dressing air system pressures for the system and for each sub-system shall be provided with data available in the plant data and control system.

4.3.7.6.1.4 Codes and Standards

a. The pressure containing components of the cooling water system shall be designed in accordance with ASME B31.1.

4.3.7.6.2 Station / Instrument Air

4.3.7.6.2.1 Functional Design Requirements

a. The powerhouse shall include a centralized station compressed air handling system to provide a sufficient pressure and capacity to charge and operate all air-operated components of the generating units simultaneously if the generating units are so equipped. The system shall also provide compressed service air during various duties including pneumatic tools and equipment, the pump-turbine inflatable maintenance seal, motor-generator brakes, pneumatic valve operators and dampers, and sewage ejectors.

b. All receivers shall have the air outlet on the top and a condensate drain on the bottom.

c. Station service air shall include regulated compressed air outlets available next to each unit on each powerhouse floor, near the door to the draft tube, in the service bay, near the TIVs, and in the workshop.

d. The compressed station service air system shall include an air receiver to reduce the cycling of the compressors.

e. Tailwater depressing air shall be provided by the tailwater depressing air system.

f. The following components shall be integrated into the design:

   - Air compressors with motors
   - Air receivers
   - Valves
   - Air dryers
   - Monitoring instrumentation

g. Rotary screw-type compressors for station service and instrument quality compressed air shall be provided throughout the powerhouse.

h. Station air shall be dried and filtered to produce instrument quality air.

i. Separate air receivers shall be provided to store the compressed air for use upon demand.

j. Station air shall be processed upon demand, and supplied from the station air receiver to each floor elevation by separate headers, which are interconnected to form a closed loop.

k. Air drops shall be located next to equipment requiring compressed air for maintenance. Drain traps shall be provided to remove any moisture accumulated in the lines.

l. Instrument quality air shall be processed downstream of the dedicated instrument air receiver by one of two 100% capacity contaminant removal packages consisting of a refrigerated air dryer, particulate filter, and coalescing filter to each floor elevation by separate headers.

m. Sufficient volume of compressed air shall be provided to deliver required air pressure and flow volume to all locations with TBD__% of air stations working simultaneously.

n. The station air system shall be designed for 175 psig.

o. 100% redundant compressors and instrument quality air treatment packages shall be provided.

p. The design shall be integrated with the following systems

   - Depressing air system
   - Cooling water system
   - Pump-turbine
   - Motor-generator
   - Monitoring instrumentation
   - Station control system
   - Auxiliary AC power
   - Cables (low voltage / sensor / fiber optics)

4.3.7.6.2.2 Control and Monitoring Requirements

a. Requirements to be developed Final Functional Design.

4.3.7.6.2.3 Maintenance and Access Requirements

a. The compressors and air receivers shall be located within the reach of the auxiliary hook of the powerhouse crane.

b. The compressors shall be equipped with operating-hour meters.

c. Compressors shall be capable of being isolated and maintained or replaced one at a time without affecting the operation of the plant.

d. A method of monitoring and draining condensate shall be provided.

e. All equipment shall be accessible for routine annual maintenance. All air circuit devices shall be provided individually with isolating valves and dismantling joints for maintenance.

4.3.7.6.2.4 Codes and Standards

a. The pressure-containing components of the cooling water system shall be designed in accordance with ASME B31.1.

4.3.7.7 Station Drainage, Unwatering, and Power Tunnel Filling Systems

4.3.7.7.1 Station Drainage System

4.3.7.7.2 System Function

4.3.7.7.2.1 Functional Design Requirements

a. The powerhouse shall include a station drainage system to collect all drainage from the powerhouse into one sump. Any oil will be separated with an oil skimmer. The accumulated drainage will then be pumped to a waste treatment holding pond on site.

b. The following components shall be integrated into the design:

- Pumps with motors
- Valves
- Instrumentation

c. The station drainage sump shall be equipped with two 100% capacity sump pumps. These pumps will be required to pump all leakage flow coming into the sump from the powerhouse up to the waste treatment facility located near the entrance of the access portal. The station drainage sump shall also include oil detection and removal equipment. Any oil captured will be stored in a container for proper disposal.

d. The design pressure for the station drainage system will be 175 psig.

e. Vertical turbine-type sump pumps shall be provided to meet the high total discharge head requirement. The pumps shall be sized so that the discharge rate may be increased by changing impeller diameter if the inflow to the station drainage sump is higher than expected. The pump suction shall be protected by a corrosion-resistant strainer with a large surface area. The pumps shall have corrosion resistant impellers, wearing rings, and shaft.

f. The design shall be integrated with the following systems:

- HVAC
- Low pressure service water system
- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

4.3.7.7.2.2 Control and Monitoring Requirements

a. Requirements to be developed Final Functional Design.

4.3.7.7.2.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance. All water circuit devices shall be provided individually with isolating valves and dismantling joints for maintenance.

4.3.7.7.2.4 Codes and Standards

a. The pressure containing components of the cooling water system shall be designed in accordance with ASME B31.1.

4.3.7.7.3 Unwatering System

4.3.7.7.3.1 Functional Design Requirements

a. The powerhouse shall include an unwatering system to facilitate dewatering the pump-turbine and draft tube from the spherical valve to the draft tube gate to allow access to these areas while the power tunnel and tailrace tunnels are still watered up. The system shall also be configured to facilitate the dewatering of the entire water conveyance system if necessary.

b. The following components shall be integrated into the design:

- Pumps with motors
- Valves
- Instrumentation

c. The dewatering sump shall be provided with three pumps: two 100% capacity main dewatering pumps and a dewatering holding pump.

d. The design pressure for the station drainage system shall be 175 psig.

e. Vertical turbine-type sump pumps shall be provided to meet the high total discharge head requirement. The pump motors for the main dewatering pumps will likely be in the 350 kW to 400 kW range.

f. Discharge from the system shall be plumbed to the Lower Reservoir via the draft tube and tail tunnel.

g. The dewatering sump shall be designed to be a pressurized sump. Water admitted to the sump shall be throttled by valves until the sump is pressurized. After full pressure is reached, the valves shall be opened fully. The dewatering sump shall be manually isolated from the nonpressurized station drainage sump.

h. The design shall be integrated with the following systems

- Pump-turbine
- Spherical valve
- Draft tube
- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

4.3.7.7.3.2 Control and Monitoring Requirements

a. Requirements to be developed Final Functional Design.

4.3.7.7.3.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.7.7.3.4 Codes and Standards

a. The pressure-containing components of the cooling water system shall be designed in accordance with ASME B31.1.

4.3.7.7.4 Power Tunnel Filling System

4.3.7.7.4.1 Functional Design Requirements

a. The powerhouse shall include a power tunnel filling system designed to fill the power tunnel and power shaft to prime the pump-turbines. The pumps will fill up to the Upper Reservoir I/O. Once to that level, the pump-turbines will be used to fill the Upper Reservoir.

b. The following components shall be integrated into the design:

- Pumps with motors
- Strainers
- Valves

- Instrumentation

c. The system shall be equipped with two multistage, horizontal 50-percent-capacity pumps to meet high total discharge head requirement. They shall be sized so that the fill rate in the power tunnel vertical shaft is controlled to 50 vertical feet per hour.

d. The discharge rate shall be controlled using control valves to produce a constant vertical filling rate in the power shaft. The motors for the pumps shall be 350 kW each, minimum.

e. The design pressure for the pumping system shall be <u>TBD</u> psig, minimum.

f. Intake to the system shall be between the draft tube gates and the Slab Creek inlet/outlet structure. Intake piping shall be stainless steel.

g. Discharge from the system shall be between the turbine isolation valve and the Upper Reservoir I/O.

h. The design shall be integrated with the following systems:

- Cooling water system
- Monitoring instrumentation
- Station control system
- Auxiliary AC power

4.3.7.7.4.2 Control and Monitoring Requirements

a. Requirements to be developed Final Functional Design.

4.3.7.7.4.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.7.7.4.4 Codes and Standards

a. The pressure containing components of the cooling water system shall be designed in accordance with ASME B31.1.

4.3.7.8 Cranes and Hoists

4.3.7.8.1 Powerhouse Crane

4.3.7.8.1.1 Functional Design Requirements

a. The powerhouse shall include double overhead bridge cranes in the main powerhouse cavern to facilitate construction, and maintenance of the major equipment once the facility is operational.

b. The two cranes of this system shall be designed for a combined lift and transport of the heaviest components, such as the motor-generator rotor and pump-turbine inlet isolation valve. All load equalizing beams and appliances shall be provided. The two cranes may be used individually in order to accelerate the erection of the units.

c. Each crane main hook shall provide coverage of the machine hall area and access to the generating units, runners, pump-turbine spherical valves, erection bays, any access hatches to heavy equipment at lower levels in the powerhouse, and the area immediately in front of the powerhouse access tunnel.

d. The powerhouse crane shall be radio as well as cab controlled, double girder, bridge type, with two main hoists, each mounted on a separate trolley and designed for precision control of lifts.

e. Each crane shall have an auxiliary hook for lighter loads and maintenance with a minimum 25 ton capacity. It shall have a hook travel rate at least three times that of the main hook, or at a speed that is acceptable to the Owner, and shall be capable of reaching the lowest equipment level in the powerhouse.

f. Both the main and auxiliary hooks shall be equipped with a mechanism to prevent two blocking.

g. All crane hooks shall be equipped with self-closing latches.

h. Certified rigging shall be provided to lift all generating equipment and ancillary components. Specialty rigging may be shared among valley facilities as long as the loads are compatible with the rigging certification.

i. Sufficient vertical capacity shall be provided to lift the motor-generator rotor and shaft or pump-turbine runner and shaft clear from the unit encasement and place them on donnage on the machine hall deck.

j. The following components shall be integrated into the design:

- Double bridge–type crane with multiple trollies / hooks
- Crane remote controls

k. Crane service classification in accordance with CMAA shall be Class A.

l. The design shall be integrated with the following systems:

- Pump-turbine
- P-T Inlet Isolation valve
- Motor-generator
- Station control system
- CCTV
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

4.3.7.8.1.2 Control and Monitoring Requirements

a. Both main and auxiliary crane hooks shall be controllable from the main floor of the powerhouse by radio control.

b. The crane shall be equipped with overload protection.

c. The crane control shall be compatible with all unit-related installation and removal procedures including speed, braking, and capacity.

d. Local disconnect shall be located on the floor that the equipment operates on.

4.3.7.8.1.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.7.8.1.4 Codes and Standards

a. Applicable crane safety codes to be determined in Final Functional Design.

4.3.8 Electrical Equipment and Systems

Listed below are the principal functional design characteristics for the electrical equipment and systems.

4.3.8.1 Motor-generator Voltage Equipment

4.3.8.1.1 Motor-generator Circuit Breakers

4.3.8.1.1.1 Functional Design Requirements

a. Motor-generator circuit breakers shall be provided to allow isolation of the motor-generator in the event of a fault or abnormal condition. The 16.5 kV (or 18 kV) circuit breaker shall provide for the unit to be paralleled with the system at a medium voltage level instead of being synchronized directly into the transmission system. Medium voltage generator circuit breakers are designed for heavy duty use, while 230 kV switchyard circuit breakers are designed for lower cycling MTBFs proportional to open/close cycles.

b. The following components shall be integrated into the design:

   - Grounding switch
   - Current transformers
   - Potential transformers
   - Isolated phase bus (IPB)

c. Breakers shall be designed to withstand many operations without requiring inspections. Current transformers and potential transformers shall be installed in the breaker bushings.

d. Breakers shall be opened/closed automatically through the distributed control system (DCS) with every startup and shutdown.

e. Provisions for remotely racking the breaker in and out shall be provided.

f. The breakers shall consist of three poles in single-phase enclosures mounted on a common skid with operating mechanisms, supervisory equipment, and control equipment.

g. A disconnector module shall be included on the line side of the breaker for series isolation. Surge arrester, earthing switch, current transformers, and potential transformers shall be mounted in this module as well.

h. The design shall be integrated with the following systems:

   - Protective relay boards

- Auxiliary AC power
- Auxiliary DC power
- Excitation system
- Reversing switch
- Motor-generator
- Isolated phase bus duct

4.3.8.1.1.2 Control and Monitoring Requirements

a. The unit circuit breaker shall be supplied with both local and remote control. Local controls shall be mounted in the breaker control cabinet on the breaker skid.

b. The breaker status shall be monitored by the DCS, and auxiliary contacts shall be used to provide the status of the protective relays, excitation, and governor system.

4.3.8.1.1.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.8.1.1.4 Codes and Standards

a. IEEE C37.06, AC High-Voltage Circuit Breakers.

4.3.8.1.2 Phase Reversing Switch

4.3.8.1.2.1 Functional Design Requirements

a. A phase reversing switch shall be provided for each unit that will be integrated into the supplied circuit breaker skid. The phase reversing switch shall be a buildout of disconnector modules. The switch shall be motorized and used for switching between pump mode and generate mode. The switch shall have five poles. B-phase and C-phase poles shall be switched when changing modes of operation.

b. The following components shall be integrated into the design:

   - Reversing switch
   - Isolated phase bus (IPB)

c. The switch shall be motorized and its position status shall be monitored by the DCS and protection relays.

d. IPB going from generator breaker terminals shall be routed to one side of the reversing switch, and the other side of the reversing switch shall have the IPB going towards the main generator step-up transformer.

e. The enclosure for the reversing switch shall have viewable windows so that the physical position of the switch can be seen at all times.

f. The switch shall be provided with three positions, defined as: (1) generate mode; (2) dead position (neither generating nor pumping); (3) pump mode. Phase B and Phase C shall switch when alternating from generate to pump mode. The correct position of the switch shall be a start required by the DCS for the unit to initiate the automatic start sequence for either the generate or pump mode.

g. The design shall be integrated with the following systems:

- Protective relay boards
- Auxiliary DC power
- Plant control system
- Generator circuit breaker
- Isolated phase bus duct
- Cables (low voltage / sensor / fiber optics)

4.3.8.1.2.2 Control and Monitoring Requirements

a. The phase reversing switch status contacts shall be inputs to the DCS.

b. Interlocks shall be designed into the control logic, preventing closure into the live system when conditions exist that could cause damage to the equipment.

4.3.8.1.2.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.8.1.2.4 Codes and Standards

a. IEEE C37.06, AC High-Voltage Circuit Breakers.

4.3.8.1.3 Isolated Phase Bus (IPB)

4.3.8.1.3.1 Functional Design Requirements

a. An IPB shall be provided for each unit to connect the generator terminals to the main generator step-up transformer. The five-pole phase reversing switch, motor-generator circuit breaker, and disconnector module shall be mounted in the bus. Surge protection, potential transformers, the AC excitation system, and station service transformers shall be tapped from the bus. Metering and relaying current transformers shall be installed around each phase of the bus as well.

b. The following components shall be integrated into the design:

- Current transformers
- Disconnector module
- Phase reversing switch

c. The IPB shall be routed from the generator terminals to the motor-generator breaker, continue from the motor-generator breaker to the phase reversing switch, and then continue to the main transformer low side terminals.

d. The bus shall be rated for 18 kV, 5,000 Å, and shall be self-cooled.

e. The IPB shall be seismically supported and routed from the generator terminals to the main transformer low side terminals.

f. Taps shall be provided from the main bus for powering the AC excitation system, station service transformer, and potential transformers.

g. Grounding provisions shall be provided on the IPB enclosure to keep safe touch potentials during fault conditions.

h. Two-hour rated fire stops shall be provided at all penetrations of walls and floors.

i. A watertight enclosure shall be provided.

j. The design shall be integrated with the following systems:

- Motor-generator
- Generator step-up transformer
- Station service transformer
- Motor-generator circuit breaker
- Phase reversal switch
- Potential transformer
- Monitoring instrumentation
- Protective relay board
- Relaying and metering
- Cables (low voltage / sensor / fiber optics)

4.3.8.1.3.2 Control and Monitoring Requirements

a. Requirements to be developed Final Functional Design.

4.3.8.1.3.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.8.1.3.4 Codes and Standards

a. Requirements to be developed Final Functional Design.

4.3.8.2 Protection Systems

4.3.8.2.1 Instrumentation

4.3.8.2.1.1 Functional Design Requirements

a. All instruments shall be provided necessary to monitor process conditions, providing feedback for control, operations monitoring of process conditions, and generating of alarms and trip signals through control logic.

b. Instruments specified shall be of the latest state-of-the-art technology and methods.

c. The instrumentation and control equipment/systems and materials and their installation shall be designed in accordance with applicable codes and industry standards.

d. Instruments and valves shall be precalibrated, tagged, and preprogrammed by the supplier when applicable. All instruments, control valves, switches, and process control logic shall be shown on the piping and instrument diagrams (P&IDs) in sufficient detail to describe each instrument loop, its function, connection, and components.

e. Electronic smart digital transmitters and controllers shall be specified for proportional output of 4 to 20 mÅ DC with a 24 VDC power supply. Transmitters requiring an external power supply shall be connected to 115 VAC or 24 VDC.

f. The following components shall be integrated into the design:

- Pressure instruments: Air system, oil accumulators, transformer tank level, penstock pressure, cooling water
- Temperature instruments: Generator bearings, cooling water, powerhouse fans, generator windings
- Level instruments: Oil accumulators, oil reservoirs, sump system, unwatering system, upper and lower reservoir level
- Flow instruments: Cooling water system, penstock
- Control valves: Cooling water, service water, oil systems, air systems
- Air system: Tailwater depression system, oil accumulators, air compressor

g. Pressure gauges shall be installed at locations where only local indication is required. Gauges shall have white faces with black markings.

h. Pressure transmitters shall be installed on several systems including the air compressor system, the oil accumulator, large transformers, and the penstock.

i. The instrument signal shall be integrated with the applicable monitoring and control process. Temperatures of cooling water, generator bearings, and the powerhouse shall be monitored and used to control different elements in the powerhouse.

j. Pressure switches shall be provided where it is determined that only discrete pressure indication is required for monitoring and control.

k. Temperature instruments shall be specified and scaled with temperature units in degrees Fahrenheit except for electrical machinery RTDs and transformer winding temperatures, which are in degrees Celsius.

l. RTDs shall be dual, three- or four-wire 100-ohm platinum or 10-ohm copper. The element shall be spring-loaded, mounted in a thermowell, and connected to a cast iron head assembly.

m. Thermocouples, unless otherwise noted, shall be spring loaded, dual element, Type K ungrounded.

n. Level measurement shall be provided for by the following types of measuring devices: conductivity, ultrasonic, displacement, differential pressure, level switches.

o. Reflex-glass or magnetic-level gauges shall be used. Level indication for corrosive service (if required) shall use devices other than reflex-glass gauges. Level gauges for high-pressure service shall have suitable personnel protection. Gauge glasses used in conjunction with level instruments shall cover a range that includes the highest and lowest trip/alarm set points. Oil and water level alarms/trips shall be monitored for various systems.

p. Process flow measuring devices shall include: orifice plate, annubar, vortex, magnetic flowmeter, positive displacement, turbine meter, flow switches, ultrasonic.

q. Concentric-type orifice plates shall be used as the primary elements for flow measurement. In general, 316 stainless steel orifice plates shall be provided. For clean fluids, the square edge orifice shall be used. Penstock excess flow and cooling water flow shall be monitored and used to control valves.

r. Differential pressure flow transmitters shall be supplied with three-valve manifolds for use with orifice plate flowmeters.

s. Ultrasonic flowmeters shall be used to provide penstock flow measurement.

t. Control valves in throttling service shall be the globe-body, cage-type with body materials, pressure rating, and valve trim suitable for the service involved. Each control modulating valve shall be specified on the data sheet and shall be sized per the manufacturer’s method based on the ISA-S75.01 sizing equations.

u. All actuators, positioners, solenoid valves, limit switches, etc., shall be mounted on the valve by the vendor. On/off valves shall be full-port, line size, and selected to produce minimum pressure drop. Limit switches shall be provided where it is necessary to know the valve position.

v. Instruments shall be mounted throughout the powerhouse at locations appropriate for the systems being monitored or controlled. Identified instruments shall be connected to the DCS system for display of flow level, temperature, and pressure. Relay contacts from the instruments shall be used for controlling different functions of respective systems. For unsafe conditions, trip shall be initiated to shut down the system after alarm condition set points are exceeded.

w. Tubing used to connect instruments to the process line shall be seamless 316 stainless steel for primary instruments and sampling systems. Instrument tubing fittings shall be the compression type. One manufacturer shall be selected for use, and fittings shall be standardized as much as practical throughout the plant.

x. Field-mounted instruments shall be of a design suitable for the area in which they are located. They shall be mounted in areas accessible for maintenance and relatively free of vibration and shall not block walkways or prevent maintenance of other equipment.

y. The design shall be integrated with the following systems being fully instrumented:

- Monitoring instrumentation
- HVAC
- Compressed air system
- Lube oil system
- Cooling water system
- Tailwater depression system
- Motor-generator and pump-turbine bearings
- Station drainage sump system

- Unwatering system
- Fire protection system
- Penstock monitoring
- Governor hydraulic power unit
- Auxiliary AC power
- Auxiliary DC power
- Plant control system
- Upper and Lower Reservoirs

4.3.8.2.1.2 Control and Monitoring Requirements

a. Alarms and trips shall be displayed on the human-machine interface (HMI) in the control room when abnormal conditions have been detected. Alarms shall be prioritized with three alarm levels.

4.3.8.2.1.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.8.2.1.4 Codes and Standards

a. Requirements to be developed Final Functional Design.

4.3.8.2.2 Relaying and Metering

4.3.8.2.2.1 Functional Design Requirements

a. The protective relaying system shall be provided to initiate clearing of electrical faults and abnormal conditions that could be detrimental to the plant equipment or create hazardous situations for personnel.

b. Metering shall be provided to inform operators about the condition and status of plant equipment.

c. The following components shall be integrated into the design:
   - Current transformers
   - Potential transformers
   - Motor-generator multifunction relays
   - Main GSU transformer multifunction relays
   - Station service transformer multifunction relays
   - Multifunction meters.

d. Protective relays shall be provided that are microprocessor-based and will provide metering, event recording, and oscillography. Plant protective relays shall communicate with plant-operating computers, and be accessible to SMUD's protection engineers through an SEL-3530 communication relay or an approved equivalent. The minimum requirements for relay protection zones are shown in drawing E-SC-403.

e. Redundant generator and main step-up transformer multifunction relays shall provide the following functions, as a minimum, for the motor-generator, main step-up transformer, and associated equipment:

- Motor-generator differential (87G), which protects the machine itself
- Motor-generator neutral ground (both a ground overvoltage relay [59N], which protects approximately 95% of the motor-generator winding, and a 180 Hz undervoltage relay [27TN], which protects the machine from faults near the neutral ground, are recommended)
- Motor-generator voltage restrained overcurrent (51VR) or distance (21) relaying to provide backup protection for faults on the system side of the motor-generator circuit breaker
- Motor-generator loss of field (40) to protect for damage due to loss of excitation
- Motor-generator negative sequence (46) to protect the motor-generator rotor from overheating because of unbalanced phase currents
- Motor-generator undervoltage (27) to protect the stator winding from damage because of an undervoltage condition
- Motor-generator underfrequency (81U) to protect the machine during pumping from an underfrequency condition
- Motor-generator phase imbalance (60) to detect blown fuses, which could cause misoperation of relays or the voltage regulator
- Motor-generator sync check (25) to prevent synchronizing out of phase
- Motor-generator breaker failure (50BF), which causes upstream breakers to trip on the failure of a motor-generator breaker because of a fault detected by the protective relaying
- Motor-generator out-of-step (78), which separates the unit from the system for a loss of synchronism
- Motor-generator volts/hertz (24) to protect the machine and transformer cores from overheating because of overexcitation
- Transformer differential (87T), which overlaps the motor-generator differential and includes the system side of the motor-generator breaker in its zone of protection
- Transformer high side overcurrent (50/51T)

f. The following relays are recommended for the balance of the 18 kV main power systems:

- Station service transformer overcurrent (SEL-501 or equivalent)
- 18kV bus undervoltage (27B)
- Generator step-up transformer differential (SEL-387E, GE-T60 or equivalent)
- Generator step-up transformer fault pressure relays (63, provided by transformer manufacturer)
- Generator step-up transformer liquid detector relays (70L)
- Generator step-up transformer winding temperature (Qualitrol ITM or equivalent)
- Generator step-up transformer gas temperature (Qualitrol ITM or equivalent)
- Generator step-up transformer gas pressure relays

- Auto synchronizer (25A – Basler BE1-25A or equivalent)
- Synchronizer check (25 – Basler BE1-25 or equivalent)

g. The following relays are recommended for the 480 V systems:

- Overcurrent trip devices with long time, short time, and ground fault current functions for all main and feeders on the 480 V load centers (switchgear)
- Time delay and instantaneous trip functions for motor control center feeder breakers
- Instantaneous magnetic trip breakers with overload protection for motor control center combination starters

h. Multifunction digital revenue metering shall be provided as needed to supplement the metering provided by the protective relays. As a minimum, the following metering functions are recommended for the station:

- Motor-generator A, B, and C phase current
- Motor-generator power factor
- Motor-generator frequency
- Motor-generator megawatts
- Motor-generator megavars
- Motor-generator voltage
- Station 230 kV voltage
- Station 230 kV megawatts
- Station 230 kV megavars
- Station 230 kV frequency
- Station service transformer low-side volts
- Station service transformer low-side amps
- Gross revenue metering of each motor-generator unit

i. Synchroscope, single-phase voltage meters and single-phase frequency meters shall also be provided to allow for manual synchronizing when needed.

j. The gross revenue metering shall provide the sum of the motor-generator and variable speed power electronics (VSPE) circuits and shall not include the power consumed by the auxiliary station service transformers and other auxiliary loads. The metering shall meet the SMUD revenue quality metering requirements and standards.

k. Operation of the breakers and other plant controls/equipment necessary to clear the faults or respond to detrimental conditions shall be accomplished by using multicontact lockout relays.

l. The lockout relays shall be initiated by station-protective relays or plant controls.

m. Current transformer class and sizes shall be determined based on full load currents, burden, and saturation curves.

n. Relay class current transformers shall be used for protective relays, and metering class current transformers shall be used for metering.

o. Potential transformers shall be used for voltage signals utilized in metering, protection, and synchronizing the unit to the grid.

p. The design shall be integrated with the following systems”

- Motor-generator circuit breaker
- Line breaker
- Isophase bus
- Protective relay boards
- Plant control system
- Auxiliary AC power
- Auxiliary DC power
- AC Excitation system
- Governor control system

4.3.8.2.2.2 Control and Monitoring Requirements

a. All trips and alarms from protective relays and lockout relays shall be recorded in the DCS and displayed on the control room HMI screens.

b. Metering information shall be available to the operator on the monitor in the control room and also locally at the protective relay boards where manual synchronizing could be done.

4.3.8.2.2.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.8.2.2.4 Codes and Standards

Requirements to be developed in Final Functional Design.

4.3.8.2.3 Protective Relay Boards

4.3.8.2.3.1 Functional Design Requirements

a. Each unit shall include a protective relaying system to detect faulted conditions within the electric power system and to remove equipment from service as soon as possible. Each unit shall have a set of protective relays mounted on a relay board located near the unit, and the unit control panel. All alarms/trips from these relays shall be communicated to the control room and displayed on the monitors.

b. The following components shall be integrated into the design:

   - Protection relays
   - Control switches
   - Indicating lights
   - Stand-alone panel

c. Panels shall be stand-alone, 19-inch rack style with terminal blocks mounted behind the panel and isolated from sources of vibration.

d. Panels shall include microprocessor relays for motor-generator protection and transformer protection, control switches for manually adjusting voltage and speed, indicating lights, breaker control switches, synch scope, voltage meters, frequency meters, auxiliary relays, auto synchronizing relays, and synch check relays.

e. The design shall be integrated with the following systems

- Relaying and metering
- AC excitation system
- Governor control system

4.3.8.2.3.2 Control and Monitoring Requirements

a. Requirements to be developed in Final Functional Design.

4.3.8.2.3.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.8.2.3.4 Codes and Standards

a. Requirements to be developed in Final Functional Design.

4.3.8.3 Auxiliary Power

The AC auxiliary power system shall supply AC power to station loads. AC loads will be 4160 V, 480 V, and 120/240 V, which shall be provided by the station service transformers and low voltage auxiliary transformers. All of the transformers shall be either SF6 type or dry type. Loads shall be both single-phase and three-phase loads. A conceptual single line of the auxiliary power system is shown on the drawing E-SC-401.

4.3.8.3.1 AC Auxiliary Power System

4.3.8.3.1.1 Functional Design Requirements

a. The powerhouse shall include an AC auxiliary power system to supply AC power to station loads. AC loads shall be 480 V, and 120/240 V, which shall be provided by the station service transformer and low voltage dry-type auxiliary transformers. Loads shall be both single-phase and three-phase.

b. The following components shall be integrated into the design:

- 16.5 kV (or 18 kV) / 480V station service transformers
- 4160 V/480 V station service transformers
- 480 V 120/240 auxiliary transformers
- Low voltage panels
- Motor control centers

- Emergency standby generator (located at utility shaft building)
- Upper Reservoir loads

c. Station service transformer shall be provided that is sized to meet the station load or 5 MVA minimum.

d. The station service transformer shall be connected with a plant 480-V motor control center supplying powerhouse motor loads.

e. Dry-type distribution transformers shall be used to step down voltage from 480 V to 120/240 V to feed powerhouse low voltage loads.

f. AC power shall be directly from the grid, so the tap for the station service transformer shall be between the generator breaker and low side of the main generator step-up transformer. This will keep the station service transformer energized all the time as long as the grid is available. The station service transformer shall feed the motor control center from which all station loads will be fed. A step-down transformer for 120/240 VAC shall be used for lighting loads and other small single-phase loads needed throughout the powerhouse.

g. An emergency standby generator shall be provided for use when the grid is not available to keep the lights, life safety systems, and other critical systems operational.

h. The design shall be integrated with the following systems:

- Megavar bus and GSU transformer
- Alternate station service feed (if available)
- Emergency standby generator
- Cables (low voltage / sensor / fiber optics)

4.3.8.3.1.2 Control and Monitoring Requirements

a. Requirements to be developed in Final Functional Design.

4.3.8.3.1.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.8.3.1.4 Codes and Standards

a. Requirements to be developed in Final Functional Design.

4.3.8.3.2 DC Auxiliary Power System

4.3.8.3.2.1 Functional Design Requirements

a. The powerhouse shall include a DC auxiliary power system consisting of batteries, chargers, and a distribution panel. Batteries shall be either lead acid or gel type and rated for a nominal 125 VDC. A battery charger shall be used to keep the battery voltage at correct levels.

b. The following components shall be integrated into the design:

- Battery bank
- Battery charger
- Emergency standby generator (ESG)
- DC distribution panel
- Uninterrupted power source (UPS)

c. The system shall provide DC control power to the plant's control system, protection relays, and emergency lighting, and an uninterrupted power source of AC power to vital plant equipment systems and services.

d. The DC source shall supply power to the following lighting fixtures: To be developed.

e. The ESG source shall supply power to the following lighting fixtures: To be developed.

f. The battery charger shall be sized to carry all DC loads as long as AC power is available. Upon loss of AC power, the battery bank shall provide power to the protection relays and critical equipment.

g. The ESG shall feed the UPS through an automatic transfer switch (ATS), which will switch to the ESG feeder when sensing low voltage on the permanent power side. An undervoltage relay shall be used to monitor low DC volts, and this relay shall trip the unit when there is low voltage detected. The setting of undervoltage shall be such that there will still be enough amps in the battery bank to trip the unit safely.

h. Batteries shall be installed in a separate room with adequate ventilation. The battery bank rank shall meet seismic requirements and be installed in accordance with ANSI Z 358.1. An eye wash station shall be provided in the battery room.

i. The DC distribution panel shall be mounted outside the battery room.

j. The battery bank amp-hour rating shall be designed to carry all critical electrical loads for a minimum of 8 hours.

k. The DC distribution panel shall be sized based on the DC load requirements or 300 amp-hour minimum.

l. The design shall be integrated with the following systems:

- Megavar bus and GSU transformer
- Alternate station service feed (if available)
- Emergency standby generator
- Cables (low voltage / sensor / fiber optics)

4.3.8.3.2.2 Control and Monitoring Requirements

a. Battery charger failure, UPS failure, and battery undervoltage alarms shall be displayed on the monitor in the control room.

4.3.8.3.2.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.8.3.2.4 Codes and Standards

a. Requirements to be developed in Final Functional Design.

4.3.8.4 Plant Computer Control

4.3.8.4.1 Plant Computer Control System

4.3.8.4.1.1 Functional Design Requirements

a. The powerhouse shall include a distributed control system (DCS), which shall provide unit control, balance of plant control, alarm monitoring, diagnostic troubleshooting, and data logging.

b. The following components shall be integrated into the design:

- Touch screen monitors
- Engineering workstations
- Operator workstations
- Printers
- Keyboards

c. The system shall include touch screen monitors in a climate-controlled control room for operators to observe plant processes, equipment alarms, and status. Engineering workstations shall provide capability to modify control sequencing, change control settings, manage alarms, and program status. All alarms shall be recorded in the DCS system and time stamped. The units shall be capable of being started and stopped from DCS operator workstations located in the control room.

d. Control functions shall be provided that will be executed by microcomputers (or other intelligent field devices located throughout the plant) such as protective relays, transmitters, flowmeters, and valve actuators.

e. All computers shall be linked via a high-speed redundant Ethernet communication system. Control of processes such as turbine governor, motor-generator excitation system, circuit breaker switching, and motor control shall be accomplished using computers close to those processes. Control shall be accomplished from the climate-controlled control room, which shall be centrally located in the powerhouse.

f. DCS shall be provided with sequence of event recording capability, analog inputs, analog outputs, digital inputs, and digital outputs to control various instruments in the powerhouse.

g. The design shall be integrated with the following systems:

- Cooling water system
- Sump pump system

- Unwatering system
- Fire pump system
- Governor hydraulic system
- Instrumentation
- Relaying and metering
- Excitation system
- Motor control center

4.3.8.4.1.2 Control and Monitoring Requirements

a. Requirements to be developed in Final Functional Design.

4.3.8.4.1.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine maintenance, troubleshooting, and servicing.

4.3.8.4.1.4 Codes and Standards

a. Requirements to be developed in Final Functional Design.

4.3.8.4.2 Emergency Standby Generator (ESG) System

4.3.8.4.2.1 Functional Design Requirements

a. A propane-fueled, engine-driven electric generator shall be provided for emergency power. This generator shall automatically start when grid power is not available.

b. The following components shall be integrated into the design:

   - Automatic transfer switch
   - Propane-fueled, engine-driven electric generator

c. The ESG capacity shall be designed to provide electrical service for critical systems or 750 kVA and 480 V, minimum. Critical systems include: sump pumps, emergency lighting, ventilation fans, fire protection equipment, and the DC system battery chargers.

d. The generator fuel tank size shall be sufficient to run the ESG under full load for at least 36 hours. Access to the fuel tank shall be provided for easily refueling. Fire suppression shall be provided in accordance with Owner's fire suppression policy.

e. The ESG shall be connected to a 480 V switchgear group via a transfer switch, which shall also be located at the surface. Only critical loads shall be powered by the standby generator.

f. The ESG shall be located on the surface at the top of shaft building above the utility shaft.

g. The design shall be integrated with the following systems:

   - Motor control center

4.3.8.4.2.2 Control and Monitoring Requirements

a. Requirements to be developed in Final Functional Design.

4.3.8.4.2.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.8.4.2.4 Codes and Standards

a. Requirements to be developed in Final Functional Design.

4.3.8.5 Communications

4.3.8.5.1 Telephone, Paging, and Security Systems

4.3.8.5.1.1 Functional Design Requirements

a. The powerhouse shall include a main communication switching termination and isolation equipment in a communications room, consisting of all site communication switching equipment, and phone line extensions. The telephone system shall connect into the plant paging system, which shall consist of dedicated handsets, speakers, amplifiers, and associated wiring.

b. The telephone system capacity shall be:

- Thirty extensions for voice, fax, and data communication
- A T-1 line for use by SMUD information systems
- A T-1 line for use by the transmission provided for communication and control of plant generation data

c. The following components shall be integrated into the design:

- Isolation equipment
- Punch-out boards for termination
- Fiber optic
- Telephone
- Card readers
- Cameras

d. A plant communications system shall be provided that consists of a telephone system and a public address paging system.

e. Card readers shall be provided to limit access to the powerhouse control room, communications room, and other secured areas. Card readers shall be connected with the DCS or RTU, and this information shall be communicated to the SMUD headquarters via SCADA.

f. Phones and cameras shall be installed at the portal entrance and switchyard building, and the operator shall be able to see who is entering/exiting the powerhouse using this camera. A security system with zoom, tilt, and pan surveillance cameras shall be provided, and located at the powerhouse access tunnel portal, at the switchyard, and at other specified locations.

g. Access through the powerhouse access tunnel portal shall be controlled from a card reader at the gate outside of the portal, and from the control room. An intercom system shall be provided from the main gate to the control room. Automatic opening and closing of the gate shall be provided for vehicles exiting the powerhouse.

h. The design shall be integrated with the following systems

- Plant control system
- DCS / SCADA

4.3.8.5.1.2 Control and Monitoring Requirements

a. Requirements to be developed in Final Functional Design.

4.3.8.5.1.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.8.5.1.4 Codes and Standards

a. Requirements to be developed in Final Functional Design.

4.3.9 Station Services

4.3.9.1 Heating, Ventilation, and Air Conditioning Systems

4.3.9.1.1 Powerhouse Smoke/Fume Control and Removal System

4.3.9.1.1.1 Functional Design Requirements

a. The powerhouse shall include a smoke/fume control and removal system to maintain a safe underground work environment at all times.

b. The following components shall be integrated into the design:

- Exhaust fans and motors
- Filters
- Ductwork

c. Separate zoned exhaust systems shall be provided for the machine hall, transformer cavern, and each of the lower floors of the powerhouse.

d. An independently operated and controlled exhaust system shall be provided for each zone.

e. The exhaust ducts shall be isolated from each other, from floor to floor, by means of smoke/fire isolation dampers. Low-capacity smoke removal fans shall discharge smoke/air to the smoke discharge header located in the utility shaft, from which the smoke shall eventually be discharged outside.

f. The machine hall shall be provided with large ductwork exhaust routed from the crown above the crane to the inlet of the high-capacity smoke removal fans and discharged to the discharge header located in the Utility Shaft, from which the smoke shall eventually be discharged outside.

g. Multiple exhaust fans shall be provided along the exhaust header to facilitate effective removal of smoke and fumes from the underground powerhouse complex.

h. This system shall be responsible for battery room exhaust, welding fume exhaust (pump-turbine work), restroom/shower room exhausting, refrigerant escape from chillers, and other miscellaneous fumes.

i. Makeup air shall be provided by drawing air in through the powerhouse access tunnel portal fans into the underground powerhouse environment.

j. All exhaust smoke/fumes shall be discharged into the utility shaft and exhausted to the atmosphere through fans in the top of shaft building.

k. The system shall be designed to meet all applicable safety requirements and ventilation system standards.

l. Smoke/fume exhaust shall not be required for water conveyance tunnels and shaft.

m. The design shall be integrated with the following systems:

- Fire detection system
- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)
- DCS / SCADA

4.3.9.1.1.2 Control and Monitoring Requirements

a. Requirements to be developed in Final Functional Design.

4.3.9.1.1.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.9.1.1.4 Codes and Standards

a. Requirements to be developed in Final Functional Design.

4.3.9.1.2 Powerhouse Ventilation System

4.3.9.1.2.1 Functional Design Requirements

a. The powerhouse shall include a ventilation system to maintain a comfortable and reliable underground work environment at all times. The system shall control temperature and humidity within the design range.

b. Design temperature range shall be: 72°F to 78°F. Design relative humidity range shall be: 35% to 40%. The design ranges shall consider equipment manufacturers' recommendations for ambient environment controls for reliable operations.

c. The following components shall be integrated into the design:

- Large air handling units
- Duct and dampers
- Duct heaters (backup)
- Filters

d. The powerhouse air conditioning system shall be designed to be a zoned system for the machine hall, low voltage bus caverns, transformer cavern, and each of the lower floors of the powerhouse. The design shall be compatible with and independent from the smoke/fume removal system.

e. The powerhouse air conditioning shall consist of large air handling units located within the powerhouse. Supply air ducting shall be provided to every floor from the units as well as return air ducting from every floor back to the unit.

f. Capacity for fresh air makeup of no less than 15% by flow shall be provided.

g. The cooling medium for the air shall be chilled water from the powerhouse chilled water system. The heating medium for the air shall be internal plant equipment heat to the return air system. Electrical supply duct heaters shall serve as a backup when plant equipment is shut down, or if additional heat is required.

h. The powerhouse floors shall be isolated from each other for smoke and fire protection purposes, as described below.

i. An independently operated system shall be provided with controls for each zone.

j. The ventilation ducts shall be isolated from each other, from floor to floor, by means of isolation dampers.

k. Multiple supply fans shall be provided to facilitate effective distribution throughout the underground powerhouse complex.

l. Provide makeup air by drawing air in through the Powerhouse Access Tunnel Portal fans into the underground powerhouse environment.

m. The system shall be designed to meet all applicable safety requirements and ventilation system standards.

n. The design shall be integrated with the following systems

- Powerhouse chilled water system
- Fire detection system
- Monitoring instrumentation

- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)
- DCS / SCADA

4.3.9.1.2.2 Control and Monitoring Requirements

a. Requirements to be developed in Final Functional Design.

4.3.9.1.2.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.9.1.2.4 Codes and Standards

a. Requirements to be developed in Final Functional Design.

4.3.9.1.3 Stairwell Ventilation System

4.3.9.1.3.1 Functional Design Requirements

a. The powerhouse shall include a stairwell ventilation system to maintain a supply of fresh air under positive pressure to the stairwells between floors as well as the stairwell in the utility shaft. The stairwells shall provide for emergency egress from the underground powerhouse complex.

b. The following components shall be integrated into the design:

   - Air handling units
   - Ductwork
   - Duct and dampers
   - Duct heaters (backup)
   - Fans and motors
   - Filters
   - Instrumentation

c. The stairwell ventilation system shall be designed to be a zoned system with dedicated air handling units. The air handling units shall receive cold water from the powerhouse chilled water system.

d. Ductwork shall be provided to distribute conditioned air throughout the stairwells to ensure a source of positive-pressure clean, cool, fresh air at all times.

e. The utility shaft stairwell shall be provided with fresh air from the powerhouse ventilation system.

f. The design shall be integrated with the following systems:

   - Powerhouse chilled water system

- Fire detection system
- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)
- DCS / SCADA

4.3.9.1.3.2 Control and Monitoring Requirements

a. Requirements to be developed in Final Functional Design.

4.3.9.1.3.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.9.1.3.4 Codes and Standards

a. Requirements to be developed in Final Functional Design.

4.3.9.1.3.5 System Function

4.3.9.1.4 Main Access Tunnel and Transformer Cavern Ventilation System

4.3.9.1.4.1 Functional Design Requirements

a. The powerhouse shall include a powerhouse access tunnel and transformer cavern ventilation system to maintain a fresh air environment in those areas and remove smoke or fumes that could otherwise accumulate.

b. The following components shall be integrated into the design:

- Large ductwork
- Duct and dampers
- Fans and motors
- Filters
- Instrumentation

c. The powerhouse access tunnel and transformer cavern ventilation system shall be designed to draw fresh air through the powerhouse access tunnel portal with fans, through ducting, to the powerhouse and transformer cavern. The system shall be capable of sustaining an underground atmosphere meeting air quality and hygiene requirements.

d. Ductwork shall be provided to distribute fresh air to the transformer cavern.

e. The utility shaft stairwell shall be provided with fresh air from the powerhouse ventilation system.

f. The design shall be integrated with the following systems

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)
- DCS / SCADA

4.3.9.1.4.2 Control and Monitoring Requirements

a. Requirements to be developed.

4.3.9.1.4.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.9.1.4.4 Codes and Standards

a. Requirements to be developed in Final Functional Design.

4.3.9.1.5 Control Room Air Conditioning System

4.3.9.1.5.1 Functional Design Requirements

a. The powerhouse shall include a control room ventilation system to maintain a controlled environment for personnel and control electronics at all times. The system shall control temperature and humidity within the design range.

b. The following components shall be integrated into the design:

- Air handling units
- Air chilling unit
- Fans and motors
- Heaters
- Duct and dampers
- Duct heaters (backup)
- Filters
- Instrumentation
- DCS / SCADA

c. The control room air conditioning system shall have an air handling unit located in close proximity to the control room. Depending on the size of the unit, it may either be a standard manufacturer's split DX system air conditioning unit, or a shop-fabricated unit using chilled water from the powerhouse-chilled water system.

d. A dedicated fresh air intake shall be provided that draws fresh air from the powerhouse access tunnel before it enters the machine hall.

e. Exhaust air may be discharged to the machine hall.

f. Design temperature range shall be: 72°F to 78°F. Design relative humidity range shall be: 35% to 40%. The design ranges shall consider equipment manufacturers' recommendations for ambient environment controls for reliable operations. The system shall be designed to control the environment in the control room to a tolerance of +/-2°F for personnel comfort.

g. The design shall be compatible with and independent from the smoke/fume removal system.

h. The cooling medium for the air may be chilled water from the powerhouse chilled water system.

i. The system shall be designed to meet all applicable safety requirements and ventilation system standards.

j. The design shall be integrated with the following systems

- Powerhouse chilled water system
- Fire detection system
- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)
- DCS / SCADA

4.3.9.1.5.2 Control and Monitoring Requirements

a. Provide an independently monitored, operated and control for the control room.

4.3.9.1.5.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.9.1.5.4 Codes and Standards

a. Requirements to be developed in Final Functional Design.

4.3.9.2 Sanitary Systems

4.3.9.2.1 Wastewater Treatment Systems

4.3.9.2.1.1 Functional Design Requirements

a. The powerhouse shall include a wastewater treatment system to collect and treat the station drainage sump wastewater, transforming it to an effluent that meets all environmental standards and is suitable for discharge to the Lower Reservoir via the draft tube.

b. The following components shall be integrated into the design:

- Pumps with motors
- Valves

- Instrumentation
- Chemical treatment package
- Oil skimmer system
- Holding tanks
- Storage tank

c. The wastewater treatment system shall include a wastewater collection system, treatment system, and discharge system.

d. The collection system shall collect and transport wastewater to the primary settling basin and treatment system.

e. The treatment system shall treat waste streams transported to the first of two settling basins. The primary settling basin shall allow suspended solids to settle out; have oil removal capability; and provide chemical treatment of the wastewater if necessary. The primary settling basin shall also function as a holding tank and be isolated from the secondary settling basin as required for maintenance. Effluent, without solids, from the primary settling basin shall enter the secondary settling basis for treatment.

f. A wastewater treatment process shall be provided to treat effluent in the secondary basin to meet Regional Water Quality Control Board discharge requirements.

g. Pumps and piping shall be provided o route permitted discharges to the powerhouse sump.

h. The design shall be integrated with the following systems":

- Powerhouse chilled water system
- Fire detection system
- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)
- DCS / SCADA

4.3.9.2.1.2 Control and Monitoring Requirements

a. Water level indication in the primary settling basin and associated high water alarms shall be provided.

4.3.9.2.1.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.9.2.1.4 Codes and Standards

a. Requirements to be developed in Final Functional Design.

4.3.9.2.2 Sanitary Drains and Waste Treatment Systems

4.3.9.2.2.1 System Function

The sanitary waste system shall process and dispose of all sanitary waste generated on site. All sanitary waste shall be collected in holding tanks and then transferred to a treatment system.

4.3.9.2.2.2 Major Components

- Holding tanks
- Sewage ejectors
- Septic systems with drain fields

4.3.9.2.2.3 System Description

Sewage from various sources shall drain to sewage holding tanks. It shall then be transferred pneumatically by a series of ejectors to a sanitary waste collection truck for transport and disposal off-site.

4.3.9.2.2.4 System Interfaces

Mechanical

- None

Electrical

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)

4.3.9.2.2.5 Functional Design Criteria

The drain and vent lines shall be a combination of PVC and ductile iron. The design pressure for the discharge line from the sewage ejectors will be 100 psig. All valves shall be full port, ball valves. The sanitary drains and waste treatment systems shall be designed and installed in accordance with all required codes and standards.

4.3.9.2.3 Potable Water System

4.3.9.2.3.1 Functional Design Requirements

a. The powerhouse shall include a potable water system to treat and distribute potable water to water taps throughout the underground powerhouse complex for water consumption, sanitary facilities, and eye wash stations.

b. The following components shall be integrated into the design:

- Water conditioning equipments
- Pumps with motors
- Valves
- Instrumentation
- Chemical treatment package
- Storage tank

c. Drinking-quality water shall be provided that is supplied from the draft tube or groundwater wells, and treated, stored, and distributed on site. The design shall produce water that meets the water quality requirements for potable water supply.

d. A treated water holding tank shall be provided with 5,000 gallons capacity, minimum.

e. The design shall be integrated with the following systems:

- Monitoring instrumentation
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)
- DCS / SCADA

4.3.9.2.3.2 Control and Monitoring Requirements

a. Water level indication shall be provided in the treated water holding tank.

4.3.9.2.3.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.9.2.3.4 Codes and Standards

a. Requirements to be developed in Final Functional Design.

4.3.9.3 Generator Step-up Transformers

4.3.9.3.1 Functional Design Criteria

The generator step-up (GSU) transformers shall be SF6 type and shall be located in the powerhouse transformer cavern. They shall be connected to the iso-phase bus from the motor-generator and shall step-up the voltage up to connect to the 230 kV high voltage cables with pluggable connections. Cooling water shall be provided to the heat exchangers mounted on the transformer. CTs shall be located on the transformer bushing for protection relaying and metering. The transformer cavern shall have embedded rails for moving the transformers on wheels.

4.3.9.3.1.1 Optional GSU Configuration

An allowable optional GSU transformer configuration shall use mineral-oil-filled GSU transformers that shall be located at the utility shaft house or in the switchyard. Oil-filled GSU transformers shall not be allowed in the powerhouse cavern. In order for SMUD to approve this option, the DBE shall provide backup information with capital cost and life cycle cost net present value (NPV) calculations. The cost evaluations shall compare the main configuration and options configuration to show that there will be a capital cost savings and a life cycle cost savings.

4.3.9.3.2 System Description

The shall be one generator step-up (GSU) transformer for each motor-generator unit. The GSU transformers shall meet the requirements specified in SMUD Specification 001.

4.3.9.3.3 System Interfaces

The GSU transformer shall interface with the following equipment in the powerhouse:

- High voltage cables to switchyard
- Iso-phase bus to generator
- Embedded rail system for moving transformer in powerhouse
- Closed loop cooling water system
- Plant DCS system input
    - Derate motor-generators if cooling is lost to the transformer
    - Alarm plant evacuation if there is a rapid pressure drop in the transformer
- 480 V aux power system for SF6 blower power
- Relay protection system

4.3.9.3.4 High Voltage Breakers and Disconnects

A high-voltage 230 kV breaker, disconnect, and earthing switch may be required on the high side of the GSU transformer in the transformer cavern of the powerhouse. SMUD shall determine this requirement in the next phase of the functional design. This equipment may be integrated into the high side of the GSU transformer. This shall allow operators to disconnect the HV cables and GSU transformers for inspection, testing, and maintenance. For maintenance, the lock-out/tag-out process can be completed in the powerhouse without going to the switchyard to isolate the high voltage cables.

4.3.9.4 Fire Protection

4.3.9.4.1 Fire Protection System

4.3.9.4.1.1 Functional Design Requirements

a. The powerhouse shall include a fire detection system consistent with the Owner's fire prevention policy.

b. Fire protection systems shall meet the minimum recommended requirements of NFPA 851 - Recommended Practice for Fire Protection for Hydroelectric Generating Plants.

c. The following components shall be integrated into the design:

- Pumps and motors
- Strainers
- Filters
- Valves
- Preactivation equipment
- Sprinklers
- Misting system

d. A fire detection system shall be provided that shall receive inputs from various heat detectors, smoke detectors, and manual pull stations throughout all areas of the powerhouse complex.

e. A fire suppression system shall be provided that typically consists of either: (1) a deluge subsystem, which shall consist of deluge and sprinkler systems in oil storage areas as well as in the transformer gallery and motor-generator barrel area; or (2) a standpipe subsystem, which shall consist of two independent standpipes with hose reels to provide manual fire protection for all areas of the powerhouse, transformer gallery, and access tunnels.

f. Fire extinguisher stations shall be provided throughout the underground powerhouse complex in accordance with the California State Fire Marshall's requirements.

g. Fire suppression in the motor-generator barrel area may be handled by an inert gas / water mist system to minimize water damage.

h. The design shall be integrated with the following systems:

- Low pressure service water
- Fire detection
- Station control system
- Auxiliary AC power
- Cables (low voltage / sensor / fiber optics)
- DCS / SCADA

4.3.9.4.1.2 Control and Monitoring Requirements

a. Requirements to be developed in Final Functional Design.

4.3.9.4.1.3 Maintenance and Access Requirements

a. All equipment shall be accessible for routine annual maintenance.

4.3.9.4.1.4 Codes and Standards

a. Requirements to be developed in Final Functional Design.

4.4 Powerhouse Access Tunnel Portal and Tunnel

4.4.1 General

The powerhouse access tunnel (PHAT) shall provide secured vehicle access from the surface access road to the powerhouse for personnel, vehicles, and equipment. The portal structure and powerhouse access tunnel shall provide the following:

- The primary air supply to the occupied areas of the powerhouse complex
- Utility connections for emergency dewatering, station power, and security
- Ventilation fans and filter media
- Security monitoring systems necessary for Owner to supervise access to the facility

4.4.2 Operating and Maintenance Requirements

4.4.2.1 Access

- Vehicular access to the PHAT portal shall be accessible during all conditions up to the probable maximum flood event for Slab Creek Reservoir and Dam.
- The PHAT portal structure invert elevation shall be at the probable maximum flood elevation for Slab Creek Reservoir.
- Parking shall be provided adjacent to the portal for four owner vehicles.
- The PHAT shall be sized to accommodate two 10-foot lanes of traffic, a utility corridor, a drainage ditch, and 6-inch minimum curbs.
- The PHAT shall be sized to accommodate the largest pieces of equipment, which will be transported into or out of the powerhouse complex including accommodating the transport vehicle.

4.4.2.2 Design Occupancy

- The PHAT shall be designed for continuous occupancy.
- The PHAT shall have a concrete invert slab.

4.4.2.3 Utilities/Space

- The PHAT shall contain a powerhouse unwatering discharge line. Size shall be determined based on maximum calculated water inflow into tunnels and cavern and unwatering in the event of flooding.
- The PHAT shall be sloped to one side to direct water into a drainage channel. Channel size shall be determined by maximum calculated water inflow into the PHAT.
- Temporary utilities may be hung along the PHAT sidewalls during construction.
- The PHAT access door shall be louvered to allow for natural ventilation up the utility shaft.

- The PHAT portal shall provide space for a settling basin to be used prior to discharging tunnel and powerhouse drainage water to Iowa Creek. Size shall be determined based on maximum allowable water inflow into tunnels and cavern, as well as the capacity needed to pump out the cavern complex in the event of flooding.
- The PHAT portal area shall be a maximum of 0.75 acre for construction and final configuration.

4.4.2.4 Equipment Clearances

- Cable trays, conduits, and all other utilities shall be secured to the tunnel lining.
- Powerhouse unwatering line shall be protected from vehicle impacts.

4.4.3 Security

- Portal access shall be secured with a locked steel door with a roll-up inset door for smaller vehicle access.
- A chain-link fence shall separate the final portal area from Slab Creek Reservoir Road. A gate opening shall be provided for truck access.

4.4.4 Safety Precautions

- The PHAT Portal shall have shielded lighting.
- The PHAT portal turn-under may require supplemental support for weathered rock zones including possible concrete lining.
- The PHAT shall be illuminated.

4.4.5 Geometry

- Provide required clearances for traffic, maximum load size and utilities as described herein.
- Minimum curve radius of 300 feet
- Maximum slope of 10%

4.4.6 Minimum Support Requirements:

- Range of ground support shall be reflective of the anticipated rock quality throughout the alignment.
- PHAT portal cuts shall be pattern bolted with shotcrete as necessary to provide 2-inch cover over bolt hardware.
- Powerhouse access tunnel shall be fully shotcrete-lined.
- Rock dowels that are considered part of the permanent support shall be double corrosion protected.

4.4.7 Water Inflows

- Maximum point source inflow shall be xx (to be determined during Final Functional Design).
- Maximum total inflow shall be less than xx (to be determined during Final Functional Design).

4.5 Utility Shaft and Utility Shaft Building

4.5.1 General

The utility shaft shall provide the connection between the powerhouse and the utility shaft building and shall furnish the following:

- Exhaust air flow from the underground structure to the surface
- Emergency egress stairway
- Conveyance of the high-voltage conductors
- Conveyance of telecommunications and emergency backup power conductors

The utility shaft building shall incorporate the requirements for the primary air exhaust from the occupied areas of the powerhouse complex. The building shall also contain critical communications and backup power systems. The building shall be provided with secured entry for personnel and equipment.

4.5.2 Operating and Maintenance Requirements

4.5.2.1 Access

- A removable hatch shall provide access to the Utility Shaft beneath the building.
- A fence shall control access around the building.
- Appropriate signage shall be placed advising the public of the hazards present in the structure.
- Parking shall be provided adjacent to the building for two commercial vehicles.

4.5.2.2 Design Occupancy

- The Utility Shaft and Utility Shaft Building shall be designed for continuous occupancy.

4.5.2.3 Location

- The utility shaft shall be located adjacent to and connected with either the powerhouse cavern or transformer cavern at the machine hall/transformer deck elevation.

4.5.3 Public Safety Precautions

- The utility shaft and utility shaft building shall be secured to prevent public access.
- Appropriate signage shall be placed advising the public of the hazards present in the structure.

4.5.4 Design/Minimum Ground Support Requirements

- Rock bolts combined with shotcrete support (as necessary) shall be used to support the shaft where ground conditions are suited to this support approach.

- Rock dowels/bolts and accessories shall be double corrosion protected and shall provide for the required design life.
- For soil to severely weathered rock, a shaft lining system shall be provided to adequately handle earth pressures and control groundwater inflow

4.5.5 Water Inflows

- Maximum point source inflow shall be xx (to be determined during Final Functional Design).
- Maximum total inflow shall be less than xx (to be determined during Final Functional Design).

4.6 Upper Reservoir and Dam

4.6.1 General

4.6.1.1 Terminology and Abbreviations

Following are key terminology and abbreviations for the Upper Reservoir:

- IDF: Inflow design flood
- MRWS: Maximum reservoir water surface elevation during IDF
- MOWS: Maximum reservoir operating water surface at spillway crest
- MNWS: Maximum normal operating water surface elevation
- LWS: Minimum normal operating water surface elevation
- LLO: Low-level outlet for emergency release

4.6.1.2 Regulatory Oversight

In addition to being part of the overall IHPSD facilities under the federal regulatory oversight of FERC, the Upper Reservoir and Dam is a jurisdictional dam and subject to regulatory oversight by the State of California Department of Water Resources, Division of Safety of Dams (DSOD). Key regulatory considerations include the following:

- The Upper Reservoir and Dam shall be designed to be operated safely and in compliance with all FERC and DSOD design, construction, monitoring, and operating criteria and requirements.
- The FERC Board of Consultants shall provide oversight of design and construction.
- The Upper Reservoir and Dam shall be integrated into SMUD's existing Owner's Dam Safety Program to ensure that the reservoir is operated and the dam maintained to preserve public safety and prevent a dam failure.

4.6.2 Hydrologic, Seismic, and Environmental Criteria

4.6.2.1 Hazard Classification

- Damage potential classification per DSOD guidelines shall determine total class weight (TCW).
- DSOD TCW: TBD (based on dam breach/flood routing studies in progress).
- FERC hazard classification: TBD (based on dam breach/flood routing studies in progress).

4.6.2.2 Inflow Design Flood (IDF)

- IDF shall be governed by the greater of uncontrolled pumped operational inflows or the hydrologic probable maximum flood (PMF).
- Peak IDF of 4,608 cfs (operational IDF governs, see below).
- Reference: Draft Upper Reservoir Emergency Spillway Hydraulics Study Memorandum, Jacobs Associates and GEI, June 2015.

4.6.2.2.1 Hydrologic IDF

- PMP based on Upper American River Project Probable Maximum Flood Study, GEI, February 2011.
- General (72-hour) storm over an 86.4 acre drainage area (only slightly larger than 71-acre reservoir).
- Total 72-hour precipitation of 38.44 inches, with maximum 1-hour intensity of 2.4 inches per hour and 1.2 inches per 15-minute time step.
- Total PMF inflow volume of 277 acre-feet (conservative estimate assuming 100% runoff).
- Peak PMF inflow of 420 cfs (conservative estimate based on precipitation of 1.2 inches over 15 minutes assuming 100% runoff) and no routing.

4.6.2.2.2 Operational IDF

- 4,608 cfs (accidental maximum uncontrolled pumping rate).

4.6.2.3 Freeboard

4.6.2.3.1 Operational

- Emergency spillway crest set 2 feet above maximum normal operating water surface (MNWS).
- Purpose is to prevent incidental discharges through the emergency spillway due to overpumping above MNWS (provides approximately 20 minutes of storage at maximum pumping rate before spilling).
- Also minimizes incidental discharges from waves generated by sustained winds up to 40 mph when reservoir is at MNWS.

4.6.2.3.2 Total (Flood and Residual)

- DSOD minimums:
  - Residual freeboard above IDF water surface (MRWS): Not less than 1.5 feet.
  - Total freeboard (above spillway crest) for new off-stream reservoirs with minimal drainage area shall be subject to case-by-case review based on site seismicity, project configuration, and design features.
- Other references: USBR DDS13-6-Freeboard; Draft Upper Reservoir Emergency Spillway Hydraulics Study Memorandum, Jacobs Associates and GEI, June 2015; USBR DS13-6 Freeboard; and USACE Shore Protection Manual.
- Minimum dam crest elevation: Maximum reservoir water surface (MRWS) during IDF + 3 feet; also satisfies:
  - MRWS + wave runup and setup based on mean wind speed;
  - MRWS + 1.5 feet DSOD residual freeboard;

  - Maximum normal operating water surface (MNWS) + wave runup and setup for design maximum wind speed; and
  - DSOD total freeboard above spillway crest as per initial communications between DSOD and Owner's Engineer.
- MRWS during IDF from over pumping: El. 3,082 feet (7 feet above spillway crest) per flood routing calculations (see Section 4.6.3 Hydraulic Design, below).
- Mean wind speed: 15 mph (see Section 4.6.2.5 Environmental, below).
- Design maximum wind speed: 75 mph (see Section 4.6.2.5 Environmental below).
- Wave runup and setup (75 mph design maximum wind speed): 3.5 feet (preliminary calculation package).
- Wave runup and setup (15 mph mean wind speed): 0.7 foot (preliminary calculation package).

4.6.2.4 Seismicity

- Based on seismicity studies for UARP (Hamilton and Harlan, 2006). Summarized in Draft Upper Reservoir Conceptual Design Report, June 2015.
- Controlling earthquake: Maximum Credible Earthquake (MCE) M 6.0 event within the Sierra Foothills Domain, at a distance of 10 kilometers (6.2 mi) from dam site.
- Estimated PGA: 0.16 g (50th percentile ground motion) and 0.29 g (84th percentile ground motion) as referenced in the June 2015 Draft Conceptual Design Report.
- The seismic sources shall be reviewed and confirmed in consultation with DSOD during design geotechnical studies.
- The peak ground accelerations (PGAs) shall be refined in consultation with DSOD and using recently updated Next Generation Attenuation Relationships during design geotechnical studies.

4.6.2.5 Environmental (Climate)

- Reference: Western Regional Climate Center, http://www.wrcc.dri.edu (Placerville IFG), for precipitation and temperature; other parameters as noted.
- Average annual precipitation: 39 inches.
- Average snowfall: 10 inches.
- Highest monthly average high temperature (July): 91°F.
- Record maximum temperature: 109°F.
- Lowest monthly average low temperature (January): 38°F.
- Record low temperature: 11°F.
- 100-year, 24-hour storm precipitation for site drainage design: 7 inches (County of El Dorado Drainage Manual).
- Design mean wind speed (1 minute): 15 mph (National Climate Data Center [Fairfield/Travis AFB]).
- Design maximum wind speed (gust): 75 mph (National Climate Data Center [Fairfield/Travis AFB]).
- Ice thickness: to be developed in Final Functional Design.
- Frost depth: to be developed in Final Functional Design.

- Average annual solar radiation: 2,000 kWh/m^2 per year (http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/atlas/).
- Average annual UV exposure: to be developed in Final Functional Design.

4.6.3 Hydraulic Design

4.6.3.1 Emergency Spillway

- Design shall be governed by the greater of maximum pumped operational inflows or hydrologic IDF.
- Reference: Draft Upper Reservoir Emergency Spillway Hydraulics Study Memorandum, Jacobs Associates and GEI, June 2015.
- Operational IDF (overpumping) of 4,608 cfs; hydrologic IDF of 420 cfs; operational IDF governs.
- Minimum design capacity: 4,608 cfs (assume no routing under sustained over pumping).
- Anticipated use: Emergency only from uncontrolled overpumping; 2 feet operating freeboard provided to prevent incidental discharge from waves or control system failure (20 minutes storage before discharge).
- Location/type: Cut through rock on reservoir perimeter with reinforced concrete control section and channel lining, discharging to hillside and existing gully drainage to Slab Creek Reservoir.
- Control section: Broad crested weir.
- Geometry: Concrete-lined trapezoidal weir and channel; 10H:1 side slopes on weir for trafficability (Dam Crest Road).
- Hydraulic analysis and rating curve (refer to Draft Upper Reservoir Emergency Spillway Hydraulics Study Memorandum, Jacobs Associates and GEI, June 2015).
- Outlet erosion: Must be controlled to prevent backcutting damage to spillway structure or dam.

4.6.3.2 Emergency Low Level Outlet (LLO)

- Design shall be governed by DSOD requirement for dams >5,000 acre-foot capacity of lowering reservoir storage depth by 10% in 7 days and full contents in 90 days.
- Other reference: USBR Design of Small Dams.
- Required 7-day drain-down volume: 980 acre-feet (14-foot drain-down depth from MOWS).
- Required 7-day average drain-down capacity: 71 cfs.
- Anticipated use: Emergency only under full-open conditions (no throttling), with annual exercise of gates/valves; not for maintenance drain-down or other regular use.
- LLO configuration: Pressurized flow through conduit with upstream sluice gate and downstream energy dissipation for discharge to drainage gully below toe of dam. Include downstream guard valves in series to minimize downstream release volume during annual gate exercise.
- Design capacity and rating curve for preliminary design with 24-inch conduit: Maximum capacity is approximately 75 cfs at MNWS elevation (refer to hydraulic analysis calculation package).
- Energy dissipation: Submerged baffled outlet pipe discharging to established drainage/gully in rock.

4.6.3.3 Inlet/Outlet (I/O) Structure

- Located in sump excavated into the floor of the Upper Reservoir.
- Hydraulic design shall be governed by overall IHPSD pump/storage operating requirements.
- Reinforced concrete apron over the sump bottom and side slopes shall be provided as part of I/O structure to protect the excavated surface from erosion and seepage; reservoir lining system shall seal to the edge of the apron.

4.6.4 Geotechnical Design: General

4.6.4.1 Design Geotechnical Investigations

- Geologic mapping, surface geophysics, subsurface explorations, and laboratory testing to be performed in accordance with Subsurface Investigation Plan included as Appendix A of Draft Upper Reservoir Conceptual Design Report, Jacobs Associates and GEI, June 2015.
- Supplemental investigations may be required depending on findings of initially planned investigations.

4.6.4.2 Cut and Fill Slopes

- Presumptive maximum cut and embankment slopes shall be 2H:1V or flatter, with the following exceptions:
    - Cuts in rock may be steeper where justified by site-specific geologic study or by low cut height in rock (less than approximately 20 feet). Unless justified by site-specific study, cut slope shall not be steeper than 1H:1V.
    - Flatter where necessary because of site drainage or global stability issues, maintenance, or landscape/revegetation needs.

4.6.4.3 Hillside Stability

- Upper Reservoir Dam shall be set back from top of the American River Canyon to minimize impacts on stability of natural canyon slope.
- Canyon slope stability shall be evaluated based on findings from subsurface investigations. Potential need for drainage or other stability improvements, and possible need for instrumentation and monitoring, to be determined as part of Final Functional Design.

4.6.4.4 Foundations

- Miscellaneous structures: Mat or shallow spread foundations bearing on bedrock or compacted embankment shall be designed for maximum allowable bearing pressure of 4,000 psf unless special design recommendation provided based on site geotechnical investigations.
- Retaining walls and other structures: Per future site geotechnical investigations.

- Reference: NAVFAC DM 7.2, Foundation and Earth Structures, U.S. Department of the Navy, 1984.

4.6.5 Embankment Design

- Reference: Applicable chapters of USBR DS13 – Embankment Design, and other special references as noted below.

4.6.5.1 Zonation and Materials

- Embankment type: Compacted dirty rockfill dam, with upstream facing (liner system) that is integral with overall reservoir lining system. "Dirty" rockfill refers to material from excavation in weathered rock that breaks down significantly upon handling, placement, and compaction, resulting in a mixture of silt, sand, and gravel mixed with coarser particles. A suitably compacted fill of this material typically has high shear strength and low compressibility, but depending on its grain size distribution it may or may not be considered free-draining. The rock material from which dirty rockfill is obtained is also often referred to as "soft rock" or "weak rock."
- Dirty rockfill shall be obtained from reservoir excavation with minimal processing for "random embankment." Processing shall be limited to selective (depth-controlled) excavation, and oversize separation if needed.
- Strength, permeability, and other parameters shall be characterized as part of subsurface investigations, subject to field confirmation at start of construction with test fill.
- Specialized materials for filter, drain, and gravel surfacing shall be processed from on-site materials obtained from underground excavations in fresh rock, or imported if necessary. Properties shall be determined during Final Functional Design based on subsurface investigations and design requirements.
- Presumptive material properties, subject to refinement or confirmation by testing, are summarized in Table 4-8.

Table 4-8. Summary of Presumptive Material Properties

Material	Description*	Dry Unit Weight, pcf	Effective Friction, degrees (min./max.)	Apparent Cohesion, psf (min./max.)	Horizontal Permeability cm/sec (min./max.)	Other
Clean Rockfill	Coarse rock materials used as riprap or stabilization materials at the toe of slopes	120–130	40/50	0	1×10^{2} /N/A	
Random Dirty Rockfill	Well-graded mixtures of cobbles, gravel, sand, and silt	120–140	40/45	0	1×10^{-4} / 1×10^{-1}	
Gravel Drain Blanket	Crushed GP material based on USCS	120–135	40/45	0	1×10^{-1} / 1×10^{1}	
Sand and Gravel Bedding	SW, SP, or GW material / mixtures	120–135	35/40	0	1×10^{-4} / 1×10^{-3}	

Material	Description*	Dry Unit Weight, pcf	Effective Friction, degrees (min./max.)	Apparent Cohesion, psf (min./max.)	Horizontal Permeability cm/sec (min./max.)	Other
	based on USCS					
Filter Sand	Similar to ASTM C33 Fine Aggregate with less than 5% fines	100–110	35/40	0	1×10^{-3} / 1×10^{-2}	
Gravel Surfacing	Similar to Caltrans 3/4-inch Class 2 Aggregate Base	120–135	35/45	0	†	
Fine Grained Top Soil	ML or CL material based on USCS	95–110	25/35	100/250	†	
Coarse Grained Top Soil	SC/SM material based on USCS	110–130	30/35	100/150	†	

* Symbols GP, GM, SW, SP, ML, CL refer to soil symbols defined in the Unified Soil Classification System (USCS), ASTM D2487

† Property not needed,

4.6.5.2 Dam Embankment Geometry and Slope Protection

- Slopes: Flatter than typical rockfill designs because of expected grain size distribution from the available excavation materials from reservoir cut, and improved constructability and stability of upstream lining system under severe, repeated drawdown operations.
- Presumptive slopes: 2.5H:1V upstream and 2H:1V downstream; to be confirmed by detailed stability analysis pending completion of site-specific geotechnical investigations.
- Additional landscaping berm between Stations 38+00 and 57+00 and El. 2,965 and 3,065 feet with a 3H:1V / 2H:1V slope for visual screening of dam slope facing American River Canyon.
- Upstream slope protection: Exposed composite liner system.
- Downstream slope protection: Vegetated topsoil layer over slope or unvegetated, exposed rockfill.

4.6.5.3 Liner System

- General performance requirements:
    - Restrict reservoir seepage into dam and foundation (serve as dam/reservoir water barrier).
    - Accommodate large and rapid changes in water level and protect underlying embankment from saturation and subsequent possible drawdown slope failure.
    - Accommodate expected deformations and settlement due to static embankment consolidation and seismic displacements without cracking or tearing.
    - Protect upstream dam slope from wave erosion.
    - Perform reliably under expected site exposure conditions (wind, sun, temperature) for a service life of 25 years before replacement, with repairs during the first 10 years of service life covered under manufacturer/installer’s extended warranty.

  - Incorporate redundancy and monitoring to provide ductile (slow) failure mechanism of the liner system that allows for problem detection and repair before dam integrity is compromised.
  - Incorporate features to facilitate O&M inspection and repairs, and worker access/safety.
- References: USBR DS13-19 Geotextiles; USBR DS13-20 Geomembranes; USBR DS13-5 Protective Filters; and U.S. Society on Dams (USSD) Materials for Embankment Dams, January 2011, Section 5.0 Asphalt Concrete as the Water Barrier in Embankment Dams.
- Liner system continuous across reservoir, anchored at a depth of 5 feet (to be confirmed) below dam crest elevation; no plinth at upstream toe of dam, but with special connection details (embedded and/or batten strips) at connections to concrete structures including emergency spillway approach, apron around Upper Reservoir I/O, intake structure for emergency low-level outlet, and access ramp(s) into reservoir.
- Composite liner system includes exposed geomembrane upper liner (for leakage control) and asphaltic-concrete lower liner (for upper liner support and leakage control in event of damage to upper liner).
- Geotextile layer with piped outfall between upper and lower liner layer for leak detection and pressure control under upper liner (see specific criteria under Section 4.6.5.8, Seepage and Drainage, below).
- Graded bedding and drainage layers beneath asphalt-concrete lower liner for control of seepage through liner system, and prevention of piping into rockfill and foundation joints (see specific criteria under and Section 4.6.5.8, below).
- Design of geomembrane liner stability/anchorages needs to consider sliding stability under gravity for loads imposed by features placed on top of the liner (e.g., ballasting) and wind resistance for a 75 mph design wind speed. Typical factor of safety value for sliding stability and anchorage is 1.5.
- Detailed liner system design criteria and performance requirements to be determined during final design in collaboration with potential liner manufacturers; may include multiple liner materials (HDPE, PVC) under competitive bid alternatives.
- Design criteria shall also include color (for aesthetics or thermal performance), UV resistance, and texture (for access/safety or sliding stability) requirements in addition to primary physical performance requirements.

4.6.5.4 Foundation

4.6.5.4.1 Objective

- General: Firm and unyielding surface after removal of overburden soils and decomposed bedrock.
- Firm unyielding support for dam embankment and reservoir lining system, with little to no differential movement of overlying lining system between cuts and fills; may require gradual sloping of foundation excavations to reduce differential settlement of overlying embankment and potential liner deformation/cracking.

- Drainage of low areas and springs disclosed during construction (if any) to be provided to prevent potential uplift of reservoir lining system, with subdrainage flows separate from liner leakage collection flows.

4.6.5.4.2 Excavation and Preparation

- Reference: USBR DS13-3 Foundation Surface Treatment.
- Excavation depth to be determined after completion of subsurface investigations, with final adjustment or confirmation in field during construction.
- Excavated foundation surface will require specific DSOD approval in the field (per Division 3, California Water Code).
- Foundation treatment requirements to be determined after completion of subsurface investigations, with final adjustment or confirmation in field during construction. Foundation treatment is expected to include:
    - Removal/overexcavation of protruding hard points or ribs under liner in reservoir area;
    - Removal/overexcavation of soft/loose/decomposed materials;
    - Foundation surface cleanup prior to placement of fill; and
    - Backfilling of overexcavated areas with approved compacted fill.
- No slush grouting or dental concrete is expected.
- Blasting controls to prevent fracturing or loosening of final foundation surface.

4.6.5.4.3 Grouting

- None currently expected for seepage control beneath dam and reservoir because of reservoir lining system; absence of grouting to be confirmed following completion of site-specific geotechnical investigations.
- Grout curtain may be needed around the top 120 feet of the headrace shaft (depth to be confirmed/refined based on explorations), within the depth of variable rock weathering, to minimize radial seepage emanating from the headrace shaft into the formation; coordinate with underground work.

4.6.5.5 Static Stability

- Analysis of upstream and downstream slopes per USBR DS13-4 Static Stability Analysis.
- Minimum factors of safety per

- Table 4-9. Analyses to be performed after geotechnical design investigations and testing to confirm presumptive slopes included in Conceptual Design.

Table 4-9. Minimum Factors of Safety

Loading Condition	Shear Strength Parameters	Minimum Factor of Safety	Slope to Be Analyzed
End of Construction	Effective and Undrained	1.3	Upstream & Downstream
Steady-state Seepage (Normal Max. WS*) (MOWS or MNWS)	Effective	1.5	Downstream
Steady-state Seepage (Partial Pool – any elevation between LWS and MOWS)	Effective	1.5	Upstream
Rapid Drawdown (Normal Max. WS to Normal Min. WS) (MNWS to LWS)	Effective or Undrained	1.3	Upstream
Rapid Drawdown (Max. PMF Pool to Normal Max. WS) (MRWS to MOWS or MNWS)	Effective or Undrained	1.2	Upstream
Steady-state Seepage (Max. Pool during PMF) (MRWS)	Effective	1.2	Downstream

* WS = water surface.

- Presumptive slopes included in Conceptual Design based on constructability and conventional embankment dam practice assuming that a compacted dirty rockfill embankment has an effective friction angle of Φ' = 37 degrees or greater (refer to calculations for simplified infinite-slope slope stability analysis).

4.6.5.6 Static Deformation (Settlement)

- Reference: USBR DS13-9 Static Deformation Analysis.
- No significant foundation settlement expected (rock foundation).
- Presumptive postconstruction settlement value for compacted rockfill embankment estimated at less than 0.5% of embankment height.
- Confirmatory settlement analyses to be performed after completion of geotechnical design investigations and testing of materials for design of rockfill embankment.

4.6.5.7 Seismic Stability

- Preliminary Design:
  - The Makdisi and Seed approach (1978) shall be used to estimate horizontal deformations of the rockfill dam for the controlling earthquake magnitude event.
  - Vertical deformations of the dam crest shall be assumed to be 80% of the horizontal deformations estimated above.
- Presumptive seismic settlement for compacted rockfill embankment estimated at less than 0.5% of embankment height.
- Final Design: Guidance and procedures provided in USBR DS13-13 Seismic Design and Analysis shall be followed for seismic deformation analyses.

4.6.5.8 Seepage and Drainage

- References: USBR DS13-8 Seepage; USBR DS13-5 Protective Filters; USBR DS13-20 Geomembranes; and GRI White Paper 15, Survey of US State Regulations on Allowable Leakage Rates in Liquid Impoundments and Wastewater Ponds.

4.6.5.8.1 Foundation Underseepage

- Gravity underdrainage of topographic low areas beneath reservoir bottom and springs disclosed during construction shall be provided to prevent uplift of lining system when reservoir is drawn down.
- Foundation underseepage shall include groundwater flows, reservoir liner flows, and infiltration into unlined portions of the dam.
- Preliminary layout of the gravity underdrainage system shall include a gravel drainage layer that underlies the reservoir and is equipped with collection and conveyance pipes at a minimum 1% slope that have the capacity to convey a flow in excess of 1 cfs for discharge downstream of the reservoir.
- Drain and outfall design is expected to provide conveyance capacity for at least 10 times the estimated seepage rates.

4.6.5.8.2 Composite Liner System Leakage

- The conceptual reservoir liner system includes a geosynthetic liner (geomembrane with a bonded geotextile), an underlying asphalt-concrete layer, and a granular bedding layer, and is designed to function integrally as a composite, redundant barrier.
- The maximum allowable rate for the reservoir lining system shall be a contract compliance instantaneous maximum value of 25 gpm with reservoir level sustained at MNWS (to be confirmed or refined in final design). Leakage rates in excess of this amount shall require repairs under the warranty clause of the construction contract.
- After expiration of the warranty, the operational action level for reservoir lining system repairs shall be 1 cfs (to be confirmed or refined in final design).

4.6.5.8.3 Upper Liner (Geomembrane) Leakage Collection and Control

- The reservoir liner system, including the geosynthetic liner (geomembrane with a bonded geotextile) and underlying asphalt-concrete layer, is designed to function integrally as a composite barrier.
- Experience with leakage rates through defects in well-constructed geomembrane-lined impoundments indicates an expected leakage rate of about 200 to 500 gallons per acre per day (gpad), or about 10 to 25 gpm for the entire impoundment.
- For IHPSD, the geotextile bonded beneath the geomembrane shall convey flows from defects in the geosynthetic liner to a piped outfall system. The purpose of this conveyance system shall be an operational one, that is, to provide a means to remove water that collects between

geomembrane/geotextile and the asphalt-concrete layer and limit excess pressures behind the geomembrane.

- Evacuation of flow rates through defects in the geosynthetic liner shall be limited by the transmissivity of the underlying geotextile layer (geotextile assumed with a weight of 500 g/m^2).
- The estimated maximum permeability/flow rate of the geotextile layer is 1,800 gpad on side slopes, 50 gpad on the base, based on geotextile transmissivity (refer to calculations), averaging 1,100 gpad for the reservoir, or approximately 60 gpm.
- Outfall pipes shall convey flows through geomembrane defects that are collected by the geotextile to measurement weirs at the downstream toe of the dam. Piped outfalls shall be sealed through penetration of asphalt concrete portion layer of the composite barrier.
- The required discharge capacity for outfall pipes shall be at least 5 times the estimated maximum flow rate from the side slope geotextile layer, or approximately 300 gpm.

4.6.5.8.4 Lower Liner (Asphalt Concrete) Leakage Collection and Control

- The leakage estimate through the asphalt concrete assumes potential flaws in the overlying geomembrane that would allow full head on the asphaltic-concrete liner. Estimates of seepage in the asphalt-concrete liner consider two cases:
  - Expected leakage rate through asphalt concrete per recent California industry experience with a modern, well-constructed asphalt liner system is approximately 4–8 gpm (75–150 gpad). The value is based on a typical flow rate of 1 to 2 gpm through an asphalt liner system measured from a similar facility, adjusted for head values and lined area at IHPSD. (Reference: Design and Construction of the Asphalt Lining System at Devil Canyon Second Afterbay, presented in the publication *Non-soil Water Barriers for Embankment Dams*, USCOLD Lecture Series, April 1997.)
  - Assuming full head, the leakage through cracked asphaltic-concrete and underlying bedding zone is estimated to be approximately 1,500 gpad, based on the minimum bedding layer thickness stated below. This leakage rate assumes a crack, 0.5 inch wide and 18 inches long, at a frequency of 1 crack per acre (reference calculations).
- The design leakage rate through the asphalt-concrete liner shall be taken in total to be 1,500 gpad (10 times the normal expected leakage rate), that is, approximately 80 gpm, for a condition that assumes defects in the overlying composite system (geomembrane/geotextile leak detection layer) that transmits the full reservoir head over a damaged area of the asphalt-concrete liner.
- A gravel drainage layer shall be provided beneath the reservoir side slopes and bottom areas to collect leakage and convey it to a system of perforated collection pipes and measurement weirs at the downstream toe. The design of the gravel drainage layer and pipe collection system shall provide capacity to remove approximately 5 times the design leakage rate, or approximately 450 gpm (1 cfs) (refer to calculations).
- Minimum layer thickness requirements (normal to slope) for transmission of leakage, subject to constructability considerations:
  - Sand and gravel bedding: 24 inches;
  - Gravel drain blanket: 18 inches.

- Gradation requirements for filter compatibility shall meet requirements in USBR DS13-5, Protective Filters.

4.6.5.9 Crest and Other

4.6.5.9.1 Crest Width

- A 25-foot minimum crest width, assuming a 20-foot-wide aggregate-base or asphalt-concrete-paved access road with 2.5-foot-wide aggregate-base shoulders; wider if needed for installation of liner system.
- To be confirmed during final design after design-level installation discussions with liner suppliers/installers.

4.6.5.9.2 Camber

- To account for estimated static and seismic embankment settlement.
- Minimum presumptive value of 1% of embankment height measured at dam centerline (calculation package).
- Subject to adjustment based on final deformation analysis after completion of design geotechnical investigations and testing.

4.6.5.9.3 Ramp

- Ramp needed for future maintenance access into reservoir.
- Number: 1.
- Configuration: 28 feet wide, 10% vertical slope.
- Surfacing: Reinforced concrete with grooved surface for traction.
- Other: Integral part of reservoir lining system (ramp constructed on top of asphalt-concrete liner; water stops through concrete joints and perimeter battens or embeds to seal upper geomembrane liner at ramp edge; or alternatively concrete ramp constructed on top of continuous upper geomembrane liner).

4.6.5.9.4 Vegetation

- Vegetation shall be in conformance with overall IHPSD landscape and vegetation plan.
- Vegetation plan for downstream slope shall be coordinated with DSOD and FERC.
- Shallow-rooted, low-groundcover vegetation shall be planted on downstream slope of dam for erosion protection and view screening.
- Trees and woody vegetation shall be planted on landscaping fill on west-facing dam slope for view screening. Prior variance approval is required from DSOD and FERC for this nonconventional view screening measure. Trees shall not exceed 12 inches in diameter at breast height. Landscape fill shall be designed and the trees located such that tree roots will not penetrate the structural dam section.

4.6.6 Structural Design

4.6.6.1 General

- Appropriate consideration of dead and live loads resulting from the following loading conditions:
  - Normal reservoir pool (MOWS or MNWS)
  - Maximum reservoir pool (resulting from the routed IDF) (MRWS)
  - Ice (with normal [MNWS] and minimum [LWS] reservoir pool)
  - Buoyancy
  - Seismic (with normal reservoir pool [MNWS])
  - Wind, snow, soil, pedestrian, and vehicle

4.6.6.2 Stability Analysis

- Structural stability analyses to assess overturning, sliding and flotation stability, and foundation-bearing pressures for the following usual, unusual, and extreme load cases:
  - Load Case 1-A (Usual): Concrete dead loads, soil dead loads (lateral and vertical), wind loads, snow loads, pedestrian and vehicle loads.
  - Load Case 1-B (Usual): Load Case 1-A, water dead loads (vertical), hydrostatic loads at MNWS elevation.
  - Load Case 2-A (Unusual): Load Case 1-A, water dead loads (vertical), hydrostatic loads at MOWS or MNWS elevation, ice loads.
  - Load Case 2-B (Unusual): Load Case 1-A, water dead loads (vertical), hydrostatic loads at MOWS or MNWS elevation (during IDF).
  - Load Case 3 (Extreme): Load Case 1-A; water dead loads (vertical); hydrostatic loads at MOWS or MNWS elevation; seismic loads from structure, soil, and internal and external hydrostatic.
  - Additional load cases if determined appropriate during final design.
- Minimum required factors of safety for stability analyses shall be per Table 4-10,

Table 4-10. Minimum Required Factor of Safety

Loading Condition	Overturning	Sliding	Flotation	Foundation Bearing
Usual	3.0	3.0	1.5	2.0
Unusual	2.0	2.0	1.3	1.5
Extreme	1.0	1.0	N/A	1.1

4.6.6.3 Pipe Loading

- Longitudinal pipe thrust: All pipe joints welded or restrained.

- Circumferential strength: Design for internal pressure and external earth loads per industry design manuals:
  - Steel pipe: AWWA M11.
  - HDPE pipe: AWWA M55.
  - For concrete-encased LLO pipe and any other concrete-encased pipes beneath the dam, the pipe shall be designed to handle internal pressure, ignoring concrete encasement. Reinforced concrete encasement shall be designed to handle the external embankment load (Load Case 1-B, above) and the internal pressure equal to full reservoir head, acting separately and ignoring the contribution of the interior pipe.

4.6.6.4 Concrete Structures

- Reinforced concrete structures and structural elements shall be designed using the "strength design method" in accordance with the requirements of the current edition of American Concrete Institute's *Building Code Requirements for Structural Concrete* (ACI-318). For design of hydraulic structures, ACI-318 shall be supplemented by American Society of Civil Engineer's *Strength Design of Reinforced-Concrete Hydraulic Structures* (ASCE 1993).
- Unless specified otherwise in overall IHPSD design criteria, design criteria are as follows:
  - Design compressive strength: 4,000 psi.
  - Design density: 150 pcf.
  - Reinforcing bars: Grade 60 steel, uncoated.

4.6.6.5 Steel Structures

- Steel structures and structural elements shall be designed using the "allowable stress design method" in accordance with the requirements of the current edition of the American Institute of Steel Construction's (AISC) *Manual of Steel Construction*. Design will incorporate appropriate considerations and/or provisions for corrosion protection.
- Emergency LLO trash rack design:
  - Located where flow velocity through trash rack does not exceed 3 fps.
  - All members and anchor bolts shall be stainless steel.
  - Bar spacing shall be selected to retain debris of such size that could result in damage to the sluice gate or knife gate valves.
  - Trash rack shall be designed for safe operation with 50% clogging with reservoir at MNWS.
  - Given the infrequent and limited use anticipated for the emergency LLO, no raking or cleaning facilities shall be provided.

4.6.6.6 Pipe and Water Control Valves

- Pipes, water control gates, and water control valves shall be designed in accordance with applicable American Water Works Association (AWWA) standards and guidelines.
- Pipe, gate, and valve types shall be confirmed or determined in final design.

- Except for submerged upstream guard gate on emergency LLO, gate and valve actuators shall include direct electric actuators, with manual override/backup. Submerged LLO guard gate shall have hydraulic actuator with manual backup pump. Electronic control stations shall be in locked vaults located near each installation. Hydraulic lines shall be located in ductbank.
- Gates/valves shall include air vent pipes or a combination of air/vacuum release valves.
- Electric power for gate/valve actuators to be provided by SMUD as part of AC Auxiliary Power System.
- SCADA for position/flow indication: As described in overall IHPSD Plant Computer Control design criteria.

4.6.6.7 Corrosion Protection

- Exposed metal: Stainless steel or galvanized or painted finishes as required by overall IHPSD Corrosion Criteria (to be developed in Final Functional Design).
- Embedded items, hydraulic lines and cylinders: Stainless steel.
- SMUD requires consideration of cathodic protection on carbon steel piping, equipment unless otherwise approved.
- Buried metal and concrete: Protected from soil corrosion based on results of corrosion testing of soil during final design investigations.

4.6.7 Sediment and Erosion Control

- To be developed in Final Functional Design

4.6.8 Instrumentation and Monitoring

- Reference: FERC Engineering Guidelines. Chapter 14.
- Reservoir level:
  - Primary: Level monitoring as part of overall IHPSD instrumentation and controls, operated from SCADA system.
  - Secondary: Pressure transducer or bubbler tube installed at LLO intake structure with wire/tube embedded in ductbank for hydraulic lines and vent pipe.
  - Local/manual backups: (1) Staff gauge graduated in tenths of a foot installed at the spillway to determine water level down to MNWS; (2) embedded or grooved curb markings every 1 foot down the concrete access ramp for the full depth of the reservoir.
- Operational reservoir inflow/outflow: Refer to overall IHPSD SCADA system.
- Emergency LLO releases: V-notch weir with manual staff gauge built into discharge structure.
- Emergency spillway overflow: Weir structure on spillway chute connected to IHPSD SCADA system.
- Embankment phreatic surface: Open standpipe piezometers to monitor the phreatic surface within the dam; location and depth to be finalized after completion of final design geotechnical investigations and analysis, subject to confirmation in the field during construction.

- Embankment movement: Settlement monuments shall be located at 500-foot intervals along dam crest perimeter except along western dam reach, where the dam section is highest, and settlement monuments shall be located at approximately 250-foot intervals.
- Seepage: Weir boxes with V-notch weirs equipped with pressure transducers connected to SCADA and backup manual staff gauges on all liner leakage collection outfalls and foundation underdrain outfalls.
- Structure movement: Brass monuments at corner points or other key locations on structures, including emergency spillway crest, I/O structure and apron, LLO intake, and concrete access ramp. Because all of these structures shall be founded on rock, survey of these structure points shall be taken after construction to establish a baseline, but monitoring of these points shall not be included in the Dam Safety Monitoring Program unless there is a specific operational reason.
- Groundwater levels: Open pipe standpipe piezometers to monitor groundwater levels around the perimeter of the reservoir, with a particular focus on the slope of the American River Canyon. Refer to overall IHPSD Groundwater Monitoring Report.
- Weather station: Include if one is to be provided, or delete.
- Monitoring Plan: To be developed as part of final design, subject to DSOD and FERC approval. Plan to address following critical periods:
    - During construction;
    - First filling of reservoir;
    - First 2 years after construction;
    - Long-term monitoring; and
    - Significant events such as earthquakes, floods, and pumping overflows.

4.6.9 Construction Site Operations

4.6.9.1 Sequencing and Coordination with Other IHPSD Components

Sequencing items include but are not limited to the following:

- Early construction of switchyard / north parking area and disposal areas B and C using excess excavation (overburden and shallow rock). This shall provide approximately 7 acres on the north side of the reservoir and 10 acres on the south side of relatively flat areas for stockpiling/processing of materials and erection/use of temporary construction facilities such as aggregate stockpiles, crushing/screening plant, concrete batch plant, equipment, and material storage.
- Coordination of I/O shaft excavation with reservoir bottom excavation/fill operations.
- Completion of I/O structure before installation of reservoir lining system.
- Excavation of underground openings to generate tunnel muck for processing of granular bedding and drain materials.
- Completion of placement of granular bedding and drain layers prior to installation of reservoir liner system.
- Liner system needs shall be completed before testing of the units can proceed.
- Testing of the units shall be coordinated with first-fill testing of the reservoir.

4.6.9.2 Temporary Construction Water

- To be obtained by pumping from Slab Creek Reservoir.
- Contractor shall design, install, operate, and remove temporary facilities for delivery of water to work area; expected to include pumps, conveyance piping, valves and measurement devices, and temporary storage tanks up at the reservoir work site.
- Contractor shall pay for electricity for pumping (or provided by SMUD).
- SMUD shall secure permits for water use and provide water at no cost.

4.6.9.3 Diversion, Dewatering, Care of Water

- No major stream diversion is required for construction of the Upper Reservoir; however, precipitation runoff will collect in drainages, and seeps or springs may be exposed by excavations. Flows from runoff and springs shall need to be routed through or around the reservoir construction work areas using culverts, ditches, pumps, berms, and erosion/sediment protection features. This work shall need to be coordinated with the IHPSD SWPPP and work on other components of the IHPSD project.
- Preliminary water control/diversion requirements to be developed during final design as part of overall IHPSD site development plan for use in permitting; finalization of diversion details shall be performed by the construction contractor in compliance with project permits.
- Requirements for dewatering prior to and during construction shall be assessed once final design geotechnical investigations are performed.

4.6.9.4 Clearing Grubbing and Stripping

- Overall IHPSDP site clearing and grubbing requirements, including timber harvest, salvage, and off-site disposal requirements to be developed in Final Functional Design.
- Clearing and grubbing debris shall be disposed of - to be developed in Final Functional Design.
- Topsoil strippings shall be salvaged and stockpiled in designated on-site stockpile areas for reuse in landscaping berm, other downstream slope revegetation, and site restoration.

4.6.9.5 Material Handling and Processing

4.6.9.5.1 Required Excavation

- Minimum excavation limits shown on drawings.
- Excavation methods shall be determined by contractor, with methods to be coordinated with material processing to produce suitable materials needed for construction.
- Blasting allowed shall be subject to local ordinances, project permit conditions, and avoidance of damage to other parts of the work.

4.6.9.5.2 On-site Processing

- Tunnel muck from underground excavations and materials from required reservoir excavation shall be processed to develop suitable materials for construction, including various dam and roadway embankment and surfacing materials, and aggregate for Portland cement concrete and asphalt concrete. If necessary or at contractor's option, imported aggregate for concrete and asphalt may be provided subject to permit restrictions.
- Contractor shall selectively excavate and stockpile materials, and coordinate with material processing, as needed to balance cut-and-fill operations for various materials.
- Contractor shall obtain permits for material screening/processing facilities, and operate them in accordance with permit requirements.
- Contractor shall pay for electricity for processing facilities.

4.6.9.5.3 Stockpile and Staging Areas

- Disposal Areas B and C and north parking/staging area shall be utilized as primary stockpile and staging areas for Upper Reservoir construction.
- Reservoir bottom area is also available for stockpiling and staging prior to installation of reservoir lining system.
- Disposal Area A can be constructed in stages and used as stockpile and staging area. It is envisioned that Disposal Area A will be the last to be filled because of its placement, partially over the downstream slope of the dam, so it cannot be completed until late in the embankment construction process.

4.6.9.5.4 Disposal Areas for Excess Excavation or Unsuitable Material

- Materials from required excavation in excess of those required for construction of embankments or incorporation in other permanent facilities can be placed in any approved on-site disposal area.
- Wet, oversized, or otherwise unsuitable (noncontaminated) material shall be placed in any approved on-site disposal area.
- Trash, demolition debris, and contaminated materials shall be disposed of off-site in accordance with laws and regulations and overall IHPSD project requirements.

4.6.10 Construction Inspection and Testing

- Reference: FERC Engineering Guidelines, Chapter 7.
- Specific requirements and criteria to be developed during Final Functional Design.

4.6.11 Vehicle Access

- The dam crest, spillway crest, reservoir access ramp to I/O apron, and emergency LLO discharge structure shall be accessible by truck for O&M purposes.

- Refer to Section 4.7, Access Roads, for technical design criteria for reservoir perimeter access road including spillway crest crossing.
- Design-vehicle criteria, and criteria for the access ramp, I/O apron, and the LLO discharge structure to be developed during Final Functional Design.

4.6.12 Site Security and Safety

- The Upper Reservoir is considered hazardous because of the nature of reservoir operations and the slip hazard on the steep, lined reservoir slope. Reservoir shall require security fencing, signage, and operational controls to prevent unauthorized access.
- The Upper Reservoir O&M Manual shall be developed in partnership and with input from SMUD operational and safety staff, and shall address procedures and equipment for work adjacent to or inside the lined reservoir. Such plan shall be coordinated with overall IHPSD operations.
- Security and safety requirements for the Upper to be developed during Final Functional Design.as part of SMUD's overall security and safety plan for IHPSD facilities.

4.6.13 Maintenance

- Maintenance activities at the Upper Reservoir are expected to include, but not be limited to, the following:
  - Daily and periodic inspections as part of the Dam Safety Monitoring Program;
  - Snow removal to maintain access to the dam crest, LLO, and spillway;
  - Vegetation maintenance and control to prevent erosion as well as reduce tree-fall or fire hazard to facilities;
  - Grading and repair of access roads, drainage ditches, and slope erosion;
  - Repair of damaged gates, fencing, and signage;
  - Regular monitoring of leakage / seepage weirs;
  - Periodic readings of survey monuments and piezometers;
  - Annual exercise of emergency LLO gate and valves;
  - Periodic inspection of liner when reservoir is lowered;
  - Periodic cleaning of emergency LLO trash rack when reservoir is lowered; and
  - Repair of liner defects or damaged liner anchorage components.
- Upper Reservoir maintenance activities shall be coordinated with overall IHPSD operations.

4.6.14 Dam Safety Monitoring Program

- Reference: *FERC Engineering Guidelines*, Chapter 14 – Dam Safety and Performance Monitoring.
- To be developed during Final Functional Design.
- Shall be coordinated with/integrated into SMUD's existing Dam Safety Monitoring Program.

4.6.15 Emergency Action Plan

- Reference: *FERC Engineering Guidelines*, Chapter 6 – Emergency Action Plans.
- To be developed during Final Functional Design.
- Shall be coordinated with/integrated into SMUD EAP for UARP.

4.6.16 Basis and Limitations

Upper Reservoir and Dam Technical Design Criteria presented herein have been identified based on ongoing refinements to the previously developed Conceptual Designs for the Upper Reservoir presented in the following Iowa Hill Pumped-Storage Development (IHPSD) Reference Documents:

1. Draft Upper Reservoir Conceptual Design Report, dated June 2015
2. Preliminary Functional Design Drawings, dated June 2015

The technical design criteria identified herein are considered preliminary/incomplete at this time and are subject to further refinement because of several factors:

- At the time of this writing, site-specific geotechnical explorations and laboratory testing needed to fully define technical criteria have yet to be conducted; therefore, some criteria are currently undefined, or will be subject to refinement and/or confirmation after completion of the necessary geotechnical investigations.
- Criteria for specialty items such as the geomembrane or asphalt-concrete liner cannot be fully defined until the material manufacturers/installers and SMUD are more fully involved in the design development process.
- Criteria for some Upper Reservoir and Dam features will be defined in coordination with other components (e.g., Upper Reservoir I/O structure and power shaft), or will be determined as part of overall facility design requirements (e.g., fencing, security, and landscaping/vegetation).

To the extent practicable, criteria subject to further definition or confirmation are noted above.

4.7 Access Roads

4.7.1.1 General

Roadways shall have an all-weather surface consisting of a minimum of 8 inches of Class 2 Aggregate Base per SMUD's direction. The Contractor shall evaluate traffic loading and provide traffic surface suited to their planned use during construction.

4.7.2 Long Canyon Access Road

The following presents the guiding design criteria for the Long Canyon access and switchyard access.

- Length = 8,800 feet (+/- to existing Cable Point Road)
- Maximum grade = 16%
- Minimum total bench width = 18 feet
- Minimum travel width = 14 feet
- Metal beam guard rail (MBGR)
- Annual average daily traffic (AADT) (Construction) = 200
- AADT (Postconstruction) = 40
- Construction duration = 5 years
- Postconstruction design life = 50 years
- Finish surface = 8-inches of Class 2 Aggregate base (AB)
- Drainage improvements = 24-hour, 100-year stormfall event
- Design speed = 10 mph
- Fill slopes steeper than 2:1 will use mechanically stabilized earth (MSE) walls
- Cut slopes not to exceed 0.5(H):1(V)
- Public access after construction design vehicle = WB-62 (tractor wheelbase 19.5 feet, trailer wheelbase 40.5 feet); minimum inside turning radius = 30 feet
- Minimum travel width at switchbacks = 60 feet

4.7.2.1 Upper Reservoir Crest Road

The following presents the guiding design criteria for the Upper Reservoir Crest Road.

- Length = 6,950 feet (+/-)
- Reservoir crest travel only
- Minimum travel width = 14 feet
- Minimum shoulder width = 2 feet
- AADT (Construction) = 20
- AADT (Postconstruction) = 5
- Construction duration = 1 year
- Postconstruction design life = 50 years
- Finish surface = 8 inches of Class 2 Aggregate base (AB) or HMA
- Drainage improvements = 24-hour, 100-year stormfall event

- Design speed = 10 mph
- No public access
- Design vehicle = 3-axle truck

4.7.2.2 Minor Access Roads

The following presents the guiding design criteria for the minor access roads:

- Length = 850 feet (+/-)
- Maximum grade = 12%
- Minimum total bench width = 14 feet
- Minimum travel width = 12feet
- No traffic shoulders
- AADT (Postconstruction) = 2
- Postconstruction design life = 50 years
- Finish surface = Aggregate base (AB)
- Drainage improvements = 24-hour, 100-year stormfall event
- Design speed = 10 mph
- Fill slopes steeper than 2:1 will use MSE walls
- Cut slopes not to exceed 0.5(H):1(V)
- No public access
- Design vehicle = 3-axle dump truck
- Minimum inside turning radius = 30 feet

4.7.3 Lower Boat Ramp Road

The following presents the guiding design criteria for the Lower Boat Ramp Road:

- Length = 5,000 feet (+/- 3,600 feet + 1,400 feet)
- Maximum grade = 10%
- Minimum total bench width = 25 feet
- Minimum travel width = 18 feet
- AADT (Construction) = 100
- AADT (Postconstruction) = 10
- Construction duration = 5 years
- Postconstruction design life = 50 years
- Finish surface = 8 inches of Class 2 Aggregate base (AB)
- Drainage improvements = 24-hour, 100-year stormfall event
- Design speed = 10 mph
- Fill slopes steeper than 2:1 will use MSE wall
- Cut slopes not to exceed 0.5(H):1(V)
- Public access after construction
- Design Vehicle = 5-axle tractor/trailer

- Minimum inside turning radius = 30 feet

4.7.3.1 Gen-Tie Tower Access Trails

The following presents the guiding design criteria for the gen-tie access trails:

- Length = 6,000 feet (+/-)
- Maximum grade = 16%
- Minimum travel width = 12 feet
- No engineered travel surface
- Finish surface = Unsurfaced Trail
- Fill slopes steeper than 2:1 will use MSE wall
- Cut slopes not to exceed 0.5(H):1(V)
- No public access after construction
- Minimum inside turning radius = 50 feet (crane access)

4.7.3.2 Boat Launch at Slab Creek Reservoir near Dam

FERC license conditions require improving the road and boat launch area. The minimum improvements include:

- Provide needed improvements to road access from North Canyon Road (County Road 8014 and FS Road 11N96) to provide for public safety, such as widening, turnaround at boat launch, turnouts, and signs (no trailer access).
- Provide parking for a minimum of 10 vehicles within a reasonable distance of the boat launch.
- Improve boat launch and harden to extend to the minimum reservoir level and restrict trailer use.
- Provide one-unit vault restroom.
- Address needs for garbage collection.
- Provide resource protection measures at the boat launch and along the access road from North Canyon Road (FS Road 11N96).
- Provide directional sign at the intersection of County Road ELD-8014 and North Canyon Road.
- Provide information kiosk or signboard at the boat launch.

4.8 230KV Switchyard and HV Cable Trench

4.8.1 General

The preliminary project design presented herein, including the attached preliminary design drawings and specifications, are to be considered “Conceptual Design—For Reference Only.” The Design Build Enity (DBE) shall prepare final design documents for submission to and approval by SMUD. The DBE is solely responsible for preparing the final design, including final engineering calculations, detailed design drawings, and specifications. The DBE shall certify that the design complies with the applicable national, state, and local codes, standards, and specifications as referenced herein, as well as SMUD-specific standards identified herein. The DBE is responsible for providing professional certification of the design and for the stamping of the final design drawings by California Registered Professional Engineers.

4.8.2 Regulations and Codes

The following codes, standards, and specifications of United States organizations shall be consulted to establish a basis for quality and safety in facility design and operation. Systems and equipment shall be designed in accordance with the latest edition and addenda in effect at the date of contract execution, unless noted otherwise.

AA	The Aluminum Association
AASHTO	American Association of State Highway and Transportation Official
ACI	American Concrete Institute
ACMA	Air Moving and Conditioning Association
AISC	American Institute of Steel Construction
ANSI	American National Standards Institute
API	American Petroleum Institute
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASNT	American Society for Nondestructive Testing
ASTM	American Society for Testing and Materials (B-230, B-232, B-241, B-3, B-33, B-5, B-8)
AWS	American Welding Society
CBC	California Building Code
CRSI	Concrete Reinforcing Steel Institute
CSFCM	California State Fire Marshal Code
EEI-AEIC	Edison Electric Institute Publications
FAA	Federal Aviation Administration
FERC	Federal Energy Regulatory Commission
FM	Factory Mutual
GO 95	State of California General Order 95
GO 128	State of California General Order 128
ICEA	Insulated Cable Engineers Association (S-87-670, S-94-649, S94-682, S-95-658, T-31-610, T-32-545, T-34-664)

IEEE	Institute of Electrical and Electronics Engineers (48, 80, 81, 383, 386, 605, 693, 980)
IES	Illuminating Engineering Society of North America
ISA	Instrumentation, Systems and Automation Society
ISO	International Standards Organization
MBMA	Metal Building Manufacturers Association
NACE	National Association of Corrosion Engineers
NBS	National Bureau of Standards
NEC	National Electric Code
NEMA	National Electrical Manufacturers Association (SG-6, WC-7, WC-8)
NESC	National Electrical Safety Code
NETA	National Electrical Testing Association
NFPA	National Fire Protection Association (851)
OSHA	Occupational Safety and Health Administration and Cal/OSHA
PCA	Portland Cement Association
REA	Rural Electrification Administration (USDA)
SAE	Society of Automotive Engineers
SMUD	Sacramento Municipal Utility District
SSPC	Steel Structures Painting Council
UBC	Uniform Building Code
UFC	Uniform Fire Code
UL	Underwriters Laboratories (44, 467, 1072, 1581)
UMC	Uniform Mechanical Code
UPC	Uniform Plumbing Code

Design specifications and construction of the project shall also be in accordance with all applicable local, state, and federal laws including, but not limited to, those set forth below:

Americans with Disabilities Act
Comprehensive Environmental Response, Compensation, and Liability Act of 1980
Clean Air Act and Amendments
Environmental Protection Agency Regulations
Federal Aviation Administration Regulations
Federal Energy Regulatory Commission Regulations
Federal Power Act
Noise Control Act of 1972
Occupational Safety and Health Act
Occupational Safety and Health Standards
Resource Conservation and Recovery Act (RCRA)
Safe Drinking Water Act
Solid Waste Disposal Act
Toxic Substances Control Act

In the event that conflicts arise between the codes, standards of practice, specifications, or manufacturer recommendations described herein and the codes, laws, rules, decrees, regulations, standards, etc., of the locality where the equipment is to be installed, the more stringent code shall apply. Any conflict between the above-referenced codes or standards, or between the standards and these specifications involving fire protection, shall be, in writing, referred immediately to the SMUD Fire Group, who shall determine which standard or specification requirements shall govern. SMUD shall be the authority having jurisdiction over interpretation of the National Fire Protection Association (NFPA) standards. In the case of fire codes, NFPA 851 will generally be the governing fire code.

4.8.3 SMUD Standards

The following SMUD design standards and equipment standards shall be met for the IHPSP. Changes to these design criteria shall be approved by SMUD. The SMUD standards are attached in Appendix B.

2.14 – Switchyard Remote Control/Monitoring
C911 – Polyvinyl Chloride Electrical Conduit
C913 – Structural Concrete
C914 – Chain Link Fence
C917 – Electrical Grounding
CDS-C9Q-A001 – Precast Trenches
D008 – Loose Tube Single Mode Optical Fiber Cable
EDS-E9A-A001 – 600V Power and Control Cables
EDS-E9A-A004 – 230kV High Voltage CT/PT Revenue Metering Units
EDS-E9A-A005 – High Voltage Disconnect Switches
EDS-E9A-A006 – High Voltage Insulators
EDS-E9A-A010 – High Voltage Surge Arresters
EDS-E9A-A016 – Conductors – Stranded Bare, Rigid Bus and Connectors
ES-7 – Sizing Aluminum Bus
ES-9 – Electrical Clearances
FPLC-CR5 – Fire Alarm Standard (Appendix A)
FPLC-CR8 – Penetration Fire Stopping Standard
FPLC-OP6 – Vegetation Management
GS1001 – Equipment Wiring Requirements
SD2801 – Test Switches
SPEC-001 – 230-18KV, 175MVA, GSU Transformer (SF6)
SPEC-002 – HV Circuit Breakers 230kV
SPEC-003 – SMUD RTU Specification
SPEC-004 – SMUD Telecom Design Requirements
TD-0004 – Tubular Bus Rating

4.8.4 Civil Requirements

4.8.4.1 General

The IHPSP equipment yard and access roadways shall be designed and constructed within the easement boundaries established for the project. These layout drawings identify the approximate configuration for the new equipment and support facilities. It is the DBE's responsibility to design the equipment layout to accommodate the spaces required to service equipment as well as maintain and operate the switchyard.

Access aisles and clearance shall be provided for operation, maintenance, inspection, and equipment removal. Provisions shall be made for personnel walkways including, doors, stairs, landings, ladders, and other approved access/egress means. The site design configuration criteria include, but are not limited to, the following items:

- Breakers.
- Tapered steel galvanized structures.
- Control module.
- Microwave tower.
- Gen-tie transmission line towers and conductors.
- Personnel access/egress relating to security and life safety of operations and maintenance staff.
- Switchyard arrangement to facilitate the economic performance of maintenance activities with the appropriate use of cranes, forklifts, and other lifting devices.
- Protection of the cable trench from normal maintenance activities, including lifting and rigging equipment wheel loadings, etc.
- Adequate forklift access aisles, pull spaces, letdown areas, and laydown areas required to support equipment maintenance or replacement. Where forklift access is not practical because of space limitations, or where provisions for rigging equipment are provided, adequate clear space shall be provided above the equipment to ensure that foundation bolts or other devices do not obstruct removal.
- Equipment layout shall accommodate truck access to the circuit breakers to support periodic maintenance, and crane and rigging equipment access should the equipment need to be removed during the service life period.

4.8.4.2 Excavation

Excavation work shall consist of the removal of earth, sand, gravel, vegetation, organic matter, rock, boulders, and debris to the lines and grades necessary for construction.

Materials suitable for backfill shall be stockpiled at designated locations, approved by SMUD, using proper erosion protection methods. Disposition of any excess uncontaminated backfill material shall be the DBE's responsibility and shall be transported and disposed of at permitted areas off site.

The DBE shall provide dewatering of structural excavations when necessary to support construction activities. All dewatering activities shall be performed within limitations identified in the Environmental Impact Report (EIR).

The DBE shall identify appropriate sources of material and provide testing results to verify the material is suitable for the application.

4.8.4.3 Backfilling

Prior to backfill placement, the subgrade shall be tested to confirm that it is in accordance with minimum specifications. Backfilling shall be in accordance with the DBE's geotechnical report recommendations and project specifications. Soil in each layer shall be properly moistened and compacted to obtain its specified relative density. To verify compaction, representative field density and moisture-content tests shall be taken by the DBE during compaction.

Structural fill supporting foundations and other critical structures, as well as general site fill, shall be compacted in accordance with the criteria specified by the Geotechnical Investigation Report. In the event of a failing test, supplemental testing shall be performed to define the area that has been inadequately compacted. Material not meeting minimum specified compaction shall be reworked or replaced, at no additional costs to SMUD.

Based on the preliminary geotechnical investigation, the existing soil excavated during cut operations is suitable for fill embankments and nonstructural areas only because of apparent expansive properties, and is not suitable as structural material under equipment foundations. The DBE shall develop the requirements for structural fill based on directions from a registered professional geotechnical engineer licensed in the State of California. Soil imported for use on the project, including soil imported for structural fill, shall be tested to confirm it does not contain environmental contaminants, including metals and organic solvents. The DBE shall identify the required environmental testing in the Construction Quality Control (CQC) plan.

Reinforced concrete cover over buried conductors shall be designed by a California Registered Professional Engineer. The concrete cover shall extend at least 5 feet horizontally beyond the vertical projection of the buried cable in all directions.

4.8.4.4 Grading

All grading shall be performed under an approved grading permit. Graded areas shall be smooth, compacted, free from irregular surface changes, and sloped to drain. Final earth grades adjacent to equipment shall be sloped away from foundations as necessary to maintain proper drainage.

Prior to any further construction, all graded areas under roadways, foundations, or other supportive areas shall have a compacted subgrade consisting of at least the top 6 inches scarified and compacted to 95% relative density. Backfill for all embankments, nonsupportive areas, and unpaved areas shall be compacted to at least 90% in 6-inch maximum lifts, except for trench fill and fill beneath structures and roads, which shall be compacted to 95% relative density.

The DBE shall provide a geotechnical analysis and recommendations report supporting the design of any fill slope and cut slopes, steep slope protection measures, retaining walls, or other structural earthen support systems required to construct the equipment yard and access roadway. The geotechnical report shall be prepared by a California Registered Professional Geotechnical Engineer. Any geotechnical investigation requirements to prepare this analysis and report are the responsibility of the DBE.

4.8.4.5 Access Roads

The switchyard road design shall be in compliance with local requirements and, at a minimum, be designed for American Association of State Highway and Transportation Officials (AASHTO) HS20-44 loading. Access roads shall be asphalt and shall have a design life of 30 years.

The DBE shall submit a turning radius analysis with the design that illustrates the vehicle flow patterns on the access road, and equipment yard alignments shall support all required vehicle and crane access requirements for the project. The DBE shall determine thickness, reinforcement, and other design criteria for all surface treatments and paving to ensure areas with different load carrying capabilities (e.g., areas thickened/strengthened to support cranes), which will not be apparent after construction, shall have a different surface finish and are fully documented and communicated to operating personnel so that planning of maintenance activities precludes damage to plant paving.

Site road construction and use shall conform to the following:

- Operating speed of 10 miles per hour.
- Minimum paved/surfaced road width of 20 feet, with 5-foot-wide graded gravel shoulders and roadside drainage swales and culverts as required to freely drain stormwater from the site.
- Minimum radius of curvature shall be determined to accommodate access for all required vehicles, including maintenance trucks, equipment delivery trucks, and cranes, and the minimum required radius at the equipment yard entrance shall be determined to support the delivery of the equipment.
- AASHTO HS-20-44 loading conditions (minimum requirement).
- Maximum longitudinal slope of 10%.
- Maximum transverse gradient of 2%.

4.8.4.6 Fencing

The DBE shall supply a single, 8-foot-high galvanized chain link fence topped with three strands of barbed wire ringed with razor ribbon angled outward around the equipment yard boundary, with 24-foot-wide swinging gates and 4-foot-wide personnel gates as shown on drawing E-PL-409. All fencing shall comply with SMUD Standard C914 Chain Link Fence for a Transmission Substation. All fencing, gates, and metal shall be grounded as required in SMUD Standard C917 Electrical Grounding.

4.8.5 Structural Requirements

The CBC and any other applicable local building codes shall be incorporated into the design of electrical modules and structures. Steel nonbuilding structures shall be designed in accordance with CBC and design specifications for structural steel buildings published by the American Institute of Steel Construction (AISC) for Allowable Stress Design (ASD). The submittal of Load and Resistance Factor Design (LRFD) is not allowed. Reinforced concrete structures shall be designed in accordance with the CBC and design requirements for concrete buildings published by the American Concrete Institute (ACI) for factored design.

All other plant areas shall be designed and configured to meet California Department of Industrial Relations, Division of Industrial Occupational Health and Safety (Cal/OSHA) requirements contained in Part 1910 of the U.S. Code of Federal Regulations.

4.8.5.1 Equipment Foundations

The equipment foundations shall be designed in accordance with the manufacturer's recommendations, Institute of Electrical and Electronics Engineers (IEEE) 693, CBC, and the DBE's geotechnical report. All foundations shall be mat type or drilled pier type unless otherwise recommended by the DBE's geotechnical engineer. Both static and dynamic loading criteria set forth by the manufacturer shall be considered. All necessary anchors and embedments for this equipment shall be cast-in-place, unless otherwise preapproved by SMUD. Any foundation or anchor changes resulting from equipment changes shall be designed by a California Professional Engineer.

4.8.5.2 Loads and Load Combinations

Loads and load combinations shall be in conformance with the CBC and IEEE 693, Recommended Practice for Seismic Design of Substations.

4.8.5.2.1 Dead Loads

Dead loads shall consist of the weight of all permanent construction including, but not limited to, fixed equipment, framing, piping, floors, walls, roofs, partitions, stairs, ductwork, cable tray, and any other structures, contents of tanks, bins.

4.8.5.2.2 Live Load

Live load is the load superimposed by building use and occupancy and does not include wind load, snow load, earthquake load, or dead load. The minimum live load design basis shall be as follows:

Stairs:

- Uniform load, 100 pounds per square foot.
- Concentrated load, 1,000 pounds.

Ground floor (grade):

- 250 pounds per square foot, or equipment, storage, or laydown weight, whichever is greater.
- Equipment and piping (other than dead load):

Supports for equipment and members to which supports are attached shall, at a minimum, be designed for the following load cases:

- Normal operating loads of equipment (excess over dead load).
- Test loads of equipment and piping (excess over dead load). Supports for equipment and piping may be stressed to 1.2 times the allowable amount under hydrotest loads.
- Thermal force caused by thermal expansion of equipment and piping under all operating conditions.

4.8.5.2.3 Dynamic Loads

These loads shall be considered and applied in accordance with the manufacturer's specifications, criteria, or recommendations, and industry standards including IEEE 693. Rotating parts shall be considered as a vibrating mass.

4.8.5.2.4 Vehicle Loads

Underground piping, conduits, trenches, septic tanks, leach lines, sumps, and foundations accessible to truck traffic shall be designed for HS-20-44 truck wheel loads per the AASHTO Standard Specification for Highway Bridges.

4.8.5.2.5 Seismic Loads

All buildings, nonbuilding structures, and equipment shall be designed to withstand CBC-specified seismic loading requirements for this site. The DBE shall provide a memorandum to SMUD certifying the seismic design requirements are met.

The Importance Factor shall be in accordance with CBC for all buildings, nonbuilding structures, and equipment, unless noted otherwise. In addition, equipment anchorages and supports shall be designed to prevent overturning, displacement, and dislocation in accordance with CBC requirements. Piping, cable tray, and ductwork shall be installed in accordance with CBC to resist applicable dead, live, and seismic loads.

4.8.5.2.6 Wind Loads

- Wind pressures and shape factors shall be applied to all system components and exposed equipment in accordance with CBC.
- Allowances shall not be made for the effect of shielding by other structures.
- The overturning moment calculated from wind pressure shall not exceed two-thirds of the dead load resisting moment.
- The uplifting forces calculated from the wind pressure shall not exceed two-thirds of the resisting dead loads.

4.8.5.2.7 Other Loads

- Other expected loads (dynamic loads from operating equipment, system modulation, etc.) required to predict the response of structures shall be considered where appropriate.
- Proper load combinations shall be used for structural steel and reinforced concrete to comply with applicable codes and standards and with vendor requirements.

4.8.5.3 Structural Steel

Structural steel shall conform to ASTM A36, ASTM A572, or other materials as required and accepted by AISC, and shall be detailed and fabricated in accordance with the AISC Code of Standard Practice and the AISC Specification for Structural Steel Buildings. All steel design shall be based on the Allowable Stress Design.

High-strength bolts shall conform to ASTM A325 or ASTM A490. Other bolts shall conform to ASTM A307, Grade A. All bolts shall be resistant to rusting for a minimum of 30 years. Anchor bolts shall conform to ASTM A36, unless higher strength bolting materials are required by design. Anchor bolts shall be hot-dipped galvanized.

Welded structural members shall meet the requirements of American Welding Society (AWS) D 1.1. Slip critical bolt torque shall be accomplished by the "turn of the nut" method or by use of compression washers. A minimum of 10% of the bolts shall be checked by a calibrated torque wrench.

All outdoor structural steel shall be hot-dipped galvanized. Galvanizing shall be in accordance with requirements of ASTM A123, ASTM A153, and/or ASTM A653. Galvanized nuts and bolts shall conform to ASTM B695.

4.8.5.4 Steel Grating and Steel Grating Stair Treads

Steel to be used for grating and grating treads shall conform to either ASTM A36 or ASTM A572. Stair treads shall have nonslip abrasive nosing. The treads shall have end plates for attaching to stringers.

Grating shall be rectangular and consist of welded steel construction. Grating shall be hot-dipped galvanized after fabrication in accordance with ASTM A123. All grating ends shall be banded.

Floor or platform openings around the equipment necessitated by expansion and movement requirements shall be protected in accordance with OSHA standards, as applicable.

4.8.5.5 Structural Concrete

Concrete shall comply with ACI 301, ACI 318, and ASTM C94. Materials shall be handled and stored as recommended in ACI 304. Mixes shall be formulated to produce durable concrete of the required strength for the anticipated exposure conditions.

Admixtures may be added at the discretion of the DBE, provided that qualifying mix designs are made accordingly.

Where concrete is to be placed by pumping, special consideration shall be given to the concrete mix to provide workability, quality, and strength required for the pumping operation.

Calcium chloride or admixtures containing calcium chloride shall not be used.

Unless superseded by explicit requirements within this specification, concrete shall conform to SMUD Standard C913 Structural Concrete.

4.8.5.6 Reinforcing Steel

Concrete reinforcing shall be deformed bars of intermediate grade, billet steel conforming to ASTM A615, Grade 60. Welded wire fabric shall not be used as reinforcing.

4.8.5.7 Concrete Finishing

Concrete finishing shall be point and patch to cover honeycomb or other minor surface defects. Structural units with defects that expose structural reinforcing shall be replaced/repaired at the discretion of SMUD.

4.9 Electrical Requirements

4.9.1 Electrical Studies

Electrical studies shall be performed under the direction of a California Registered Professional Electrical Engineer. Electrical studies shall be provided for SMUD review and approval.

4.9.1.1 Short Circuit and Arc Flash Study

A computer model shall be developed to include the existing 230 kV transmission system equivalent fault contribution, gen-tie, switchyard, HV insulated cables, GSU transformers, powerhouse auxiliary systems, and motor-generators. The study shall provide phase-to-ground and 3-phase fault levels to establish switchyard equipment sizing, and shall be used to provide input to the ground grid study and relay protection and coordination. An arc flash study shall be provided to determine the level of incident energy exposure in servicing the equipment. The study shall provide warning labels in accordance with NFPA requirements. Arc flash labeling shall be installed on all equipment according to the IEEE 70E.

4.9.1.2 Load Flow Study

Employing the same model used for the short circuit study, the load flow study shall determine recommended tap selection for the main transformers to achieve the desired voltage levels at various node locations at the switchyard and throughout the system over the full range of motor-generator operation. The model also shall be used to verify compliance with the power factor requirements of the Contract.

4.9.1.3 Relay Setting and Coordination

SMUD will provide settings for all 230 kV bus protection, transformer protection, breaker failure protection, gen-tie line protection, SEL-2030 relay communication device, RTU, and telecommunication systems. The DBE shall be responsible for determining and setting all other devices such as, but not limited to, the auxiliary relays and timers in the control modules or switchyard, low voltage AC and DC systems, and annunciators. All settings shall be provided with detailed calculations with annotations and listed assumptions. All necessary annotated program listings shall be provided. All settings shall be submitted to SMUD for review and approval.

4.9.1.4 Battery Systems

The 48VDC and 125VDC battery systems shall be designed to operate the switchyard for an 8-hour duration after an AC power loss. The DBE shall perform battery loading calculations for the 48 VDC and 125 VDC battery systems.

4.9.1.5 Ground Grid Design

Ground grid design shall be performed under the direction of a California Registered Professional Electrical Engineer. Ground grid design calculations shall be provided for SMUD review and approval.

The swithyard grounding grid shall be designed to protect personnel and equipment during faults. The design calculations and soil resistivity data shall be furnished for SMUD review and approval. The ground grid shall be designed in accordance with IEEE 80 based on the following minimum requirements:

- Maximum ground fault clearing time: 0.50 sec.
- Maximum ground fault ground grid current: To be determined, based on result of short circuit study performed by DBE.
- Mesh spacing: Per IEEE 80 Calculations.
  Ground conductor size: Per IEEE 80 calculations, 250 kcmil (minimum).
- Number of Ground rods and size: Per IEEE 80 calculations, 3/4-inch x 10-foot rods.
- Grid size: Grid shall extend 5 feet beyond the fence.
- Grid burial: Minimum of 2 feet in soil.
- Soil resistivity test by DBE after the switchyard rough grading is complete. Testing to be conducted prior to installation of the switchyard ground grid:

4.9.1.6 Rigid Bus Design

a. Rigid bus design shall be performed under the direction of a California Registered Professional Electrical Engineer. Rigid bus design calculations shall be provided for SMUD review and approval. The bus design shall take into account the requirements of IEEE 693 and IEEE 1527.
b. Bus shall be aluminum alloy 6063-T6, Schedule 80 tubular bus.
c. Dead load deflection shall not exceed half the outer diameter of the tubular bus, and the fiber stress shall be limited to the elastic limit stress in accordance with IEEE 605.
d. Maximum deflection of the bus with dead load and wind load shall be limited to 0.5% of the distance between adjacent supports. Under this condition, the fiber stress shall be limited to the elastic limit stress in accordance with IEEE 605.
e. No permanent deformation shall occur to the tubular bus when subjected to short circuit forces with dead load and wind force. Bus bracing shall be based on the maximum short circuit current. After the short circuit, the bus shall return to its original shape.
f. Deflection with the dead load in combination with short circuit force plus wind load shall be limited to maintain phase spacing greater than metal-to-metal limits stated elsewhere in the specification. The fiber stress shall be limited to the minimum yield stress in accordance with IEEE 605.
g. Refer to Section 4.8.5 for structural design requirements.

4.9.1.7 Electrical Calculations

The DBE shall provide all necessary engineering and design calculations in support of the work. Electrical calculations shall be performed under the direction of a California Registered Professional Electrical Engineer. Electrical calculations shall be provided for SMUD review and approval.

Electrical calculations shall include, but are not limited to:

- Rigid bus deflection calculations

- Post insulator cantilever calculations
- Short circuit force calculations on bus and equipment
- Equipment and bus ampacity calculations
- Current transformer burden and saturation calculations
- SSVT loading calculations
- Insulation coordination and arrester sizing
- Grounding and lightning protection calculations
- Station low-voltage alternating current (AC) and direct current (DC) sizing calculations
- DC battery system sizing calculations (48VDC and 125VDC)

4.9.2 Electrical Equipment

4.9.2.1 18 kV:230 kV GSU Transformers

For detailed requirements about the generator step-up (GSU) transformers see Section 3.3.5.2.

4.9.2.2 230 kV Disconnect Switches

Disconnect switches shall be provided for isolation and maintenance purposes of the 230 kV systems. The 230 kV disconnect switch shall be of the 3-pole, group-operated, center break, vee type. Disconnect switches shall be manufactured, tested, and delivered per Technical Specification EDS-E9A-A005 High-Voltage Disconnect Switches.

4.9.2.3 230 kV Circuit Breakers

SF6 gas-charged circuit breakers shall be provided and installed. Circuit breakers shall be outdoor, dead tank, and rated for installation in a switchyard. Integral, bushing-mounted current transformers shall be fitted for relaying, control, and metering per drawing E-SC-402. Reference SMUD Technical Specification SPEC-002 High-Voltage Circuit Breaker for details for design, manufacturing, testing, and delivery requirements.

4.9.2.4 230 kV Station Service Voltage Transformers (SSVT)

230 kV station service voltage transformers (SSVT) shall be provided with the following characteristics:

System Voltage (Line-Line):	230 kV
Basic Insulation Level:	1,050 kV
Voltage Ratio:	132,790:120/240 V
Power Rating:	300 kVA

4.9.2.5 230 kV Potential Transformers (PT)

230 kV potential transformers (PT) shall be provided with the following characteristics:

System Voltage (Line-Line):	230 kV
Basic Insulation Level:	1,050 kV

Thermal Rating Factor:	2.0
Accuracy:	0.3% with ZZ Burden
Voltage Ratio:	138,000:115V/69 V
Thermal Rating:	3,000 VA

All potential transformers shall comply with the provisions of Reference Standard EDS-E9A-A004 Voltage (potential) Transformers.

4.9.2.6 Surge Protection

Surge protection shall be provided in the form of surge arrestors on the 230 kV system. Switchyard class arresters shall be provided with a maximum continuous operating voltage (MCOV) of 152 kV.

Arrester protective characteristics shall coordinate with the insulators, cable insulation, and transformer insulation to give satisfactory protection to the equipment per IEEE C62.11, IEEE 1313 and NEMA LA1. Each arrester for the 230 kV terminals shall have a surge counter to indicate operations and a leakage detector to indicate current leakage. The surge counter and current leakage detector shall be mounted so that they can be read easily from the ground. Arrestors and surge counters shall be appropriately insulated. The surge counter shall be by EMP Bowthorpe or the SMUD approved equal. Surge arresters shall be station class metal oxide varister (MOV) type.

All arresters shall be mounted so that the minimum clearances for bushings are obtained. All necessary mounting brackets, insulators, and hardware for the arresters shall be provided. Arresters shall be provided with full capacity copper connections between arresters and bushing terminals with provisions for expansion and contraction. Arresters shall be designed as a rigid equipment connection. The design shall be in accordance with IEEE 693, Annex D, Section D 4.0.

Arresters shall be furnished with NEMA standard connectors suitable for connection to the conductors and all required ground connections.

4.9.2.7 Grounding Grid

Switchyard ground grid shall be constructed from bare copper grounding conductor and copper-clad steel ground rods. Lightning protection equipment shall be connected to the grounding grid per the DBE design.

4.9.2.8 Insulators

Suspension insulators for 230 kV application shall be of the high-strength fiberglass reinforced resin (RFP) body type with silicon rubber polymer weather sheds and appropriate termination hardware, as manufactured by Hubbell, Ohio Brass Hi-Lite type or equal. The 230 kV suspension insulators shall have SML mechanical rating of 25,000 pounds, leakage distance of 212 inches or greater, and 60 cycle flashover voltage of 810 kV (dry) and 750 kV (wet).

Switchyard post insulators shall be high strength porcelain with ANSI 70 light gray color. The 230 kV post insulators shall be rated 245 kV, 900 kV BIL. Refer to SMUD Technical Specification EDS-E9A-

A006 High Voltage Insulators. The DBE shall install corona rings on 230 kV polymer insulators, and other equipment as necessary.

4.9.2.9 Strain Bus

The 230 kV strain bus, strain insulators and all necessary hardware for conductor dead end and structure connection shall be designed by the DBE in accordance with SMUD Technical Specification EDS-E9A-A016 Conductors—Stranded Bare, Rigid Bus and Connectors and submitted to SMUD review and approval.

4.9.2.10 Rigid Bus

a. Rigid bus design shall conform to SMUD Design Guidelines ES-7 SMUD Sizing Aluminum Bus and ES-9 SMUD Electrical Clearances and SMUD Technical Specification EDS-E9A-A016 Conductors—Stranded Bare, Rigid Bus and Connectors.
b. Rigid bus shall be seamless, Schedule 80 tube made of 6063-T6 aluminum alloy fabricated per ASTM B241.
c. All connections, fittings, and termination pads shall be welded type except at bus supports where a slip fitting shall be utilized.
d. Bolted type connectors for connecting and splicing the aluminum bus shall not be used. The rigid bus splice shall be made by use of internal tube type bus couplers. Certified welders shall perform all bus welding.
e. A damping conductor shall be furnished in all horizontal bus.
f. All aluminum connections shall use 316 stainless steel bolts, flat washers, and lock washers.
g. All aluminum jumper terminals shall use Alcoa full-circumference compression type or approved equal. These jumpers shall be connected to the aluminum pads welded to the bus. Bolted type connectors shall not be used.
h. Expansion joints shall be supplied for installation in the rigid bus as required.
i. Strand hardware including bus tubing end bells shall be provided.

4.9.2.11 Yard Lighting

Switchyard light shall be with LED light fixtures to produce a general yard lighting level of 10 foot-candles with a task lighting level of 30 foot-candles at the 230 kV circuit breaker and the 230 kV disconnect switches. An ISO-foot-candle lighting plan shall be provided to verify lighting levels. Fixtures shall be mounted to steel structures, observing necessary clearances and locate fixtures so they can be serviced without de-energizing the 230 kV conductors or equipment.

4.9.2.12 Conduit

a. DBE shall supply and install electrical conduit and accessories required for embedded and exposed conduit systems. Conduit accessories shall include the following: conduit fittings; conduit connectors; outlet boxes; outlet bodies; standard pipe tees for conduit drains (as required); pull boxes; junction boxes; locknuts; bondnuts; bushings; materials for sealing joints and for coating external surfaces of conduit; materials for sealing and connecting the ends of conduits terminating at outdoor boxes, panelboards, and cabinets; hanger supports; bracket supports and clamps; and all other devices required to complete the electrical conduit system.

b. All rigid galvanized steel (RGS) and polyvinyl chloride (PVC) conduit shall be Schedule 40, unless otherwise specified.
c. RGS shall conform to ANSI C80.1, and all fittings shall be threaded. PVC shall conform to SMUD Standard Specification C911 Polyvinyl Chloride Electrical Conduit.
d. Wiring between the cable trench and field devices shall be in PVC conduit Schedule 40 directly buried. Conduit stub ups above ground shall be galvanized steel. Minimum underground conduit size shall be 2-inch nominal diameter.
e. Conduit under roadways and truck traffic shall be concrete encased.
f. DBE shall provide detailed drawings for underground installation. Minimum separation maintained between the outside surfaces of conduit shall be 2 inches. The concrete encasement surrounding the structure of the conduit shall be 3 inches. Red iron oxide shall be sprinkled on top of wet concrete after installation to color the concrete red.
g. Aboveground conduit shall be RGS conduit. Conduit shall be adequately sized, enabling the installation of the cables per the National Electrical Code (NEC) requirement.
h. Junction boxes shall be sized per NEC. Outdoor junction boxes shall be rated National Electrical Manufacturers Association (NEMA) 3R or 4X. For indoor installation, boxes shall be NEMA 1.

4.9.2.13 Controls Cable Trench

A precast concrete cable trench shall be provided for routing of low voltage power, control, metering, alarm, status, and telecom wiring throughout the switchyard. For cable trench requirements, refer to SMUD Technical Specification CDS-C9Q-A001 - Precast Trenches. Cable trenches shall be rated for AASHTO HS20-44 loading.

4.9.2.14 High Voltage Cable Trench

A precast concrete cable trench shall be provided for routing the high voltage cables, 4160 V cables, and telecommunications cables from the Switchyard to the Utility Shaft Building. For the conceptual layout and elevation views of the HV cable trench see drawing E-PL-407.

Each set of three (3) high voltage cables from each motor-generators shall be separated by concrete dividers in the cable trenches. Each cable trench compartment shall have separate removable concrete covers rated for AASHTO HS20-44 loading. Cable trenches outside secure fenced areas shall have tramper resistant bolted covers to prevent vandalism. For additional cable trench requirements, refer to SMUD Technical Specification CDS-C9Q-A001 - Precast Trenches.

Additional cable trench compartments and/or dividers shall be provided for each voltage level and cable type (e.g. 120VAC, 4,160VAC, fiberoptic cables, analog signal cables, etc.).

Proper drainage shall be provided in the cable trenches to drain water that collects in the trench without requiring mechanical pumping.

4.9.2.15 High Voltage Cables

The high voltage cables connecting the GSU transformers to the Switchyard shall be solid dielectric insulated cables properly rated for the system design. The cables shall be mounted in the cable trenches on trays, brackets, or other means to prevent chaffing of the cable insulation and or sliding of the cable due to trench slope, thermal expansion, and fault conditions. Mounting systems shall be approved by SMUD and the cable manufacturer.

Cable splices shall be designed by the cable manufacturer specifically for the selected cable. The cable manufacturer shall provide hands on training for the cable splicing process. The DBE electricians performing the splice work are required to attend the training and SMUD has the option to send a representative.

A spare set of three (3) conductors shall be provided between the GSU transformers and the Switchyard. The spare cables shall be segregated in a dedicated cable trench compartment. The spare cables shall have extra length at each end of the cable to be able to connect with any of the GSU transformers and any of the switchyard termination points above ground. The spare cable ends shall be capped and all intermediate splices sealed for long term layup and storage of the cables.

4.9.2.16 Terminal Blocks

a. All terminal blocks shall be Underwriters Laboratory (UL)-listed type GE EB or approved equal, and shall be rated 600 V, 30 A, suitable for #14 through #10 AWG stranded copper conductors or 600 V, 50 A, for #8 AWG stranded copper conductors.
b. Terminal blocks for current transformer secondary circuits shall be of the short-circuiting type.
c. Terminal blocks shall have marking strips, terminal screws, and divider strips.
d. A minimum of 15% spare terminals shall be supplied, excluding current transformer terminal blocks where spare terminals are not required.
e. Terminal blocks shall be arranged on each side of each panel with terminal block facing parallel to the panel surface.
f. Terminal blocks shall be grouped as to service (e.g., current transformer leads, lighting, control, interconnecting wiring, etc.) and the “grouped” blocks shall be located in approximately the same location in each panel.
g. Each terminal on every terminal block or device shall be properly identified with wire numbering matching the DBE’s interconnection drawings.
h. All raceway equipment and bulk materials shall be UL listed and installed per NEC requirements.
i. Terminal blocks shall comply with SMUD Standard GS1001.

4.10 Switchyard Control Module

The switchyard control module shall be manufactured, assembled, tested, and delivered according to this specification. The prefabricated metal control module shall house all racks, cable trays, AC and DC panels, fire alarm system, lights, auxiliary, telecommunication, supervisory, and protection and control equipment, as well as equipment to be supplied by others and designated to be installed in the building.

The completed control module shall be suitable for shipment to the site. The completely furnished building and all equipment shall be erected at the factory, and tested and inspected by SMUD before shipment. All parts and materials required for field assembly shall be supplied identified and shipped with the building. The physical drawing E-PL-411 depicts the minimum dimensions for the control module.

4.10.1 Service Conditions

The control module shall perform satisfactorily when installed outdoors. The control module shall be suitable for installation in a 50°C maximum temperature, -5°C minimum temperature, and at an elevation of 4,000 feet.

4.10.2 Control Module Structural Requirements

4.10.2.1 Module Base

The control module base shall be all welded construction of ASTM A36 structural steel members, sized and arranged for proper strength and durability, and shall be able to withstand the stress and loads that will result when lifting the completed factory fabricated control module. The base structural members shall not interfere with or obstruct the areas designated for routing of power cables or control wiring.

a. Deflection during lifting shall not exceed 0.34 inch per 10 feet. Base shall be designed for mounting on piers.
b. The control module manufacturer and DBE shall coordinate to provide pier loading, dimensional data, and anchor details to SMUD for its review and approval.
c. The base shall have removable lifting/jacking devices to facilitate handling and installation. The normal lifting for transportation and installation shall be by means of a crane making a single point lift using suitable rigging.
d. The manufacturer shall provide all materials and instructions for setting up and anchoring the building to the concrete piers to the DBE. All anchoring hardware is to be specified and installed by the DBE.

4.10.2.2 Seismic

The control module shall be designed and constructed in accordance with Chapter 16, Division III of the latest edition of the California Building Code. A structural analysis report shall be prepared by a Professional Engineer registered in the State of California.

4.10.2.3 Floor

The control module floor shall be a minimum of 1/4-inch steel plate welded to the perimeter members and to the cross members of the base. The floor loading shall be rated not less than 100 pounds per square foot distributed load, or a 1,300-pound load concentrated in a 2-1/2 square foot area located anywhere in the control module.

4.10.2.4 Frame

The entire control module shall be framed with 3-inch square ASTM A500 structural grade steel tubing to provide moment resisting welded connections at base to walls, side walls to end walls, and walls to roof, so as to minimize overall deflection, twisting, and elastic instability during lifting and transporting.

All wall openings, such as doors, windows, etc., shall be similarly framed with 3-inch square steel tubing. All frame connections shall be welded.

4.10.2.5 Walls

a. The inside height from floor to ceiling shall be a minimum of 128 inches. The exterior and interior walls shall be 16-gauge paint quality galvanized steel, and shall consist of formed vertical panels. The nominal thickness of the wall, including the required frame structure, shall be 3 inches.
b. The walls shall be designed to withstand wind loading per California Building Code.
c. Interior walls, supporting panels, and structural spans shall be designed so that interior loads of 400 pounds per linear foot of wall length may be attached to the wall without compromising the design wind loads.
d. The walls shall be provided with a lining, 3/4-inch plywood or approved equal, to enable equipment to be attached on the interior using wood screw fasteners.
e. Should damaged exterior wall panels need to be replaced, the tubular frame design shall facilitate replacement without disrupting the integrity of the roof and adjoining wall panels or adjacent walls.
f. Clearances inside the building shall meet NEC standards. Vertical clearance from the top of the highest cable tray to the lowest roof beam shall be 18 inches. A horizontal distance of 36 inches minimum is required between equipment requiring rear maintenance access and grounded structure.
g. All openings, penetrations, and cable trench entrances shall be sealed to prevent access into the building by rodents, animals, insects, etc.

4.10.2.6 Roof and Ceiling

a. The exterior roof shall be constructed of 16-gauge paint quality galvanized steel panels. The roof design load shall be rated 20 psf. The roof shall have a gable roof with a 2-degree pitch and shall be designed to support interior or exterior loads of 100 pounds per linear foot of truss length without compromising the roof design load.
b. Roof trusses shall consist of formed 10-gauge steel sections. Trusses shall be sloped to provide a 2-degree pitch and have a 1-1/2-inch upper and lower horizontal flange for attachment of equipment.
c. The ceiling shall consist of formed 16-gauge paint quality galvanized steel panels attached to the trusses. The ceiling assembly shall be designed to retain the insulation and to provide a smooth ceiling surface.
d. Two screened, louvered ventilation openings shall be provided, one at each end of the control module roof structure, to prevent condensation in the attic space.

4.10.3 Doors

a. The control module shall have one exterior double door measuring 36 wide by 96 inches high (or large enough to remove the largest installed piece of equipment, whichever is larger) and all other exterior doors each measuring 36 by 80 inches.
b. All doors shall open outward and have a minimum swing of 105 degrees.
c. Interior and exterior doors shall be 18 gauge, double wall steel construction with R-15 thermal insulation, reinforced for closure and rim exit type panic hardware and hinge preps for three 4 x 4 hinges per door. Doors shall have a fire rating of 1-1/2 hour class B.
d. Each interior and exterior door shall have a low profile rim exit device Russwin #ED-8200, a knob outside trim with cylinder lock, and a heavy-duty reversible door closure with hold/open feature Yale #154/AL. The locks shall be keyed alike and the DBE shall coordinate the locks and keys to allow SMUD standard access keys to be utilized.
e. Each interior and exterior door shall have a magnetic intrusion switch installed on it and wired to the location where SMUD will install an intrusion alarm, except restroom door.
f. A drip shield shall be provided above each exterior door.

4.10.4 Weatherproofing

All control module joints shall be designed to minimize the loss of conditioned or pressurized air and to prevent entry of rain, sleet, snow, or moisture.

All wall seams and areas where metal-to-metal contact is made shall be liberally caulked with butyl rubber caulking. All roof seams shall be sealed with ethylene propylene copolymer tape to ensure water resistance.

4.10.5 Module Blockouts

All field wiring shall enter the control module through the interconnection terminal cabinet (ITC). Coordinate location of ITC and blockouts with incoming yard cable trench. Special wall penetrations can conduit boots shall be provided for the microwave tower cables into the communication room.

4.10.6 Insulation

a. Insulation providing R-13 minimum value shall be provided in the walls and floor.
b. Insulation providing R-30 minimum value shall be provided in the ceiling.
c. Insulation shall be semirigid glass fiber type, UL flame-spread classification of 25 or less.
d. Polyfill type of material is prohibited from being used anywhere in the structure, including inside walls and doors.

4.10.7 Paint

a. Steel Structures Paint Council standards shall be followed in all preparation and application of coatings. The interior wall and ceiling panels shall be thoroughly cleaned, prepped, and finished with Sherwin-Williams heavy-duty White epoxy B62WZ101 and B60VZ70 (hardener) series or approved equals. Apply a tack coat to the surface and allow it to flash-off before a second coat of 3.0–6.0 DFT is applied.

b. The exterior wall and roof panels shall be thoroughly cleaned, and coated with 1 mil of Sherwin-Williams Kem Aqua wash primer E61G520 and finished with a minimum of 2.5–3.0 mils Sherwin-Williams acrylic polyurethane Acrolon 218 HS B65 Series or approved equals.
c. The base exterior shall be sandblasted smooth, free from scale and rust, and coated with 1.0–3.0 mils of Sherwin-Williams white recoat able epoxy #B67A5 and B675V5 (hardener) and top-coated with Sherwin-Williams acrylic polyurethane Acrolon 281 HS B65 Series 2.5–3.0 mils DFT to match the exterior or approved equals. The bottom of the base shall be coated with corrosion-resistant black mastic for protection against the environment.
d. The floor shall be thoroughly cleaned, primed with recoatable epoxy primer, Sherwin-Williams #B67A5 Gray and #B67V5 (hardener) with a final coat of Sherwin-Williams Corothane I Aliphatic Gray #B65A16.

4.10.8 Fire Extinguishers

Fire extinguishers shall be provided at each door and shall be 20 pound type ABC.

4.10.9 Wiring

a. All control module lighting and power wiring shall be single conductor, stranded copper, with THHN/THWN 600V insulation with a minimum size of No. 12 AWG. All lighting and power wiring shall be installed in the 8 inch x 8 inch wall wire way, EMT conduit, or other approved raceway in accordance with the National Electric Code.
b. Wire terminations shall be made using insulated sleeve ring tongue type lugs, Burndy YAV-10 or equivalent.

4.10.10 Grounding

a. Four NEMA Std (2-hole) grounding pads shall be provided on the enclosure base at each corner for attachment to the station ground grid with 250 kcmil copper cable.
b. A 1/4 inch x 3 inch ground bus bar shall be routed along the interior walls and shall connect to interconnect to the grounding pads.
c. No. 6 solid bare soft copper shall be installed as a grounding conductor in all wire ways and cable ladders within the module. This grounding conductor shall be solidly bonded to each section of wire way and cable ladder. The grounding conductor in the cable ladder shall be laid on top of the ladder rungs. The grounding conductor for the wire way shall be installed inside the wire way. Connect this ground conductor where installed in ladders along the walls to the aboveground bus bar.
d. The ground bars at the bottom of all rack panels shall be interconnected to their adjacent panel ground bars at both sides with No. 6 solid bare soft copper. At every other rack panel, the ground bar shall be connected with No. 6 solid bare soft copper to the No. 6 solid bare soft copper run in the cable tray.
e. All electrical equipment, raceways, boxes, cabinets, and devices shall be effectively grounded in accordance with NEC.

f. Grounded conductors, even though they have not been shown on the drawings, shall be installed in all raceway according to NEC.
g. Ground cable shall be copper conductor, either bare or with green-colored covering or identification in accordance with NEC.

4.10.11 Ceiling Mount Cable Trays

a. The ceiling mount cable trays shall be B-Line Series M14 aluminum Ventilated Trough type cable tray with a width of 24 inches. (Refer to drawing E-PL-411 for location of cable trays.) The elevation of the cable trays shall be coordinated with the installed equipment. All cable trays shall be grounded.
b. Install 2-inch stabilizer tubes between trays and between trays and wall at points.
c. At all locations where cable tray is above relay racks, the method of tray support shall be with "L" brackets attached to the upper part of the side rail. No part of the support shall extend below the bottom of the side rail.
d. At all locations where the cable tray system elbows down to the wire way, the last 3-foot section of tray shall be reversed so that the rungs are closest to the wall.
e. Cable tray design loading (including the tray), at a minimum, will support 50 pounds per foot and will conform to Section 4.8.5.2.5 for seismic loads. In addition, the tray system will be capable of temporarily supporting a 200-pount static load.
f. Per NEMA VE-1, all "Cable Tray Systems will be made corrosion-resistant material." Acceptable tray materials include aluminum, stainless steel, or hot-dipped galvanized steel.
g. The DBE shall use the manufacturer's standard connectors, hangers, clamps, etc., in the construction of the cable tray system. The cable tray system will be completely grounded. Cable tray fittings will be as provided by the cable tray manufacturer.
h. All rough edges will be ground smooth, and all damaged or nicked galvanized surfaces will be coated with zinc-rich paint.

4.10.12 Wall Wire Way

A Circle AW 8 inch x 8 inch screw cover wire way shall be provided around the control module perimeter as shown in the drawings. At all locations where the cable tray system elbows down to the wire way, 4 inch x 18 inch openings (with edges protected with plastic molding) in the top of the wire way shall be provided. See Section 4.10.10 for wire way grounding. This wire way shall contain all control module facilities wiring.

4.10.13 HVAC

a. HVAC design and installation shall comply with CBC and Title 24.
b. A central heating, ventilating, and air conditioning (HVAC) unit shall be supplied to condition the switchyard control module.
c. Control room HVAC equipment shall be sized and provided by the DBE. This HVAC equipment size shall be based on maintaining an interior temperature range of 60 to 80°F in the control room with both control room central units in operation, taking into consideration the heat load of present and future equipment and the site conditions. In addition to the heating from the equipment supplied in this contract, allow for heating from 1 kw load of the equipment to be

installed by SMUD in the vacant racks supplied. If one control room central unit is out of service, the remaining unit shall maintain the control room interior temperature in a range of from 45 to 95°F.

d. HVAC equipment shall consist of self-contained wall mount units, complete with supply and return grilles, lockable circuit breaker or disconnect switch, manual thermostat, barometric fresh air damper, and a 1-inch disposable air filter. The HVAC units shall be powered through the 240 VAC panelboard in the control module.
e. The following controls shall be supplied: high-pressure controls, low-pressure control, low ambient control, compressor anticycle relay, and alarm relay. Condenser and evaporator coils shall be phenol coated. Units shall be installed as recommend by manufacturer.
f. The HVAC shall be interconnected with the fire control panel and shall shut down if smoke is detected.
g. The HVAC units shall provide failure alarms which will be wired to the RTU.

4.10.14 Panelboards (AC and DC)

a. Panelboards shall be of dead front construction, surface mounted.
b. The below-numbered panelboards shall be supplied per the following. All panelboards shall be provided with main and branch circuit breakers. Branch circuit breakers shall be supplied with 20% spares.
    1. 120/208 VAC single phase station panel
    2. 125 VDC station panel
    3. 48 VDC station supply panel
c. Cabinet and Interior:
    1. Panelboards shall include complete assemblies with enclosures.
    2. The panelboard bus assembly shall be enclosed in a steel cabinet. The rigidity and gauge of steel shall be as specified in UL Standard 50 for cabinets. The size of the wiring gutters shall be in accordance with UL Standard 67 for Panelboards. The box shall be fabricated from galvanized steel or equivalent rust resistant steel and shall be painted with ANSI light gray baked-on enamel.
    3. Fronts shall include doors and have cylinder tumbler-type locks with catches and spring-loaded stainless steel door pulls. All panelboard locks shall be keyed alike. Doors shall be mounted with semiconcealed hinges. A circuit directory frame and card with a clear plastic covering shall be provided on the inside of the door. All interiors shall be completely factory assembled. The design of the interior should permit replacement of circuit breakers without disturbing adjacent units and without machine drilling or tapping. All bolts used to connect current-carrying parts together shall be case-hardened, thread-forming type, and be accessible for tightening from the front of the panel. An individual circuit number shall be provided next to each breaker. Incoming cable lugs shall be grouped at one end to separate them from the load side cables. Neutral bussing shall have a lug for each outgoing branch requiring a neutral connection. For easy wiring and shortest cable run possible, load side neutral connection lugs may be split with each side taking 50% of load neutral connections.
d. Bussing Assembly:
    1. Bus bars and breaker branch bus shall be of 98% conductivity copper. Panelboard bus structure and main breaker of main lugs shall have current ratings as shown on the plans or as

indicated in panel schedule. Such ratings shall be established by heat rise tests in accordance with UL Standard 67. Single-phase, three-wire panelboard bussing shall be such that any two adjacent single pole breakers are connected to opposite polarities in such a manner that two pole breakers can be installed in any location. All current carrying parts of the bus assembly shall be plated.

2. Terminals shall be UL listed, suitable for the copper conductors specified.

e. Circuit Breakers:
   1. Circuit breakers shall be molded-case, thermal-magnetic, bolt-on type. Voltage and continuous current ratings shall be as shown on the plans or as indicated in panel schedule. Circuit-breakers shall have a trip-free, toggle-type operating mechanism with quick-make, quick-break action and positive handle indication. Handles shall have “ON”, “OFF”, and “TRIPPED” positions.
   2. Molded case circuit breakers shall be UL listed. Interrupting rating shall be 10,000 RMS symmetrical amperes for the 240/120 VAC systems and 5,000 amperes for DC systems.
   3. Provisions for future breakers “space” shall be located at the bottom of the panel and be fully bussed complete with all mounting hardware less the breaker.
   4. Circuit breakers in DC panelboards shall include a bell alarm output contact that closes when the breaker trips because of overload condition. All bell alarm contacts shall be wired in parallel to form a common alarm condition, which shall terminate on a terminal board.

f. Tests:
   1. Panelboard tests shall be as those listed below.
   2. The accuracy of the calibration of all instruments to be utilized during the tests shall be ascertained and recorded at the beginning of the tests.
   3. Certified test results of previously built similar units will be accepted in lieu of actual tests.
   4. The tests shall include, but not be limited to, the following: Factory tests per NEMA PB-2 and UL-891.

Panelboards shall be installed level and plumb and shall utilize all provided mounting holes. Conduits shall be connected and all wiring shall be pulled before any panelboard internal hardware is mounted. Wiring shall by symmetrically arranged in the gutters with all unnecessary conductor lengths eliminated. The panelboard shall be covered prior to the installation of its faceplate. This will protect the unit from contamination and damage until the permanent cover is installed. In addition, all panelboards shall contain a complete typed directory detailing the exact location of all loads served from each associated circuit.

4.10.15 Fire Alarm

The fire alarm system shall be procured, installed, and tested in accordance with Design Guideline FPLC-CR5 Fire Alarm Standard. All fire detection design shall be approved and stamped by a California Registered Fire Protection Engineer. A high-temperature switch shall be provided to indicate module high temperature to the fire alarm system. A hydrogen detector shall be installed in the battery room. HVAC shall be shut down when smoke is detected.

4.10.16 Lighting

a. Indoor lighting shall be provided using 120 VAC LED fixtures. A three-way switch shall be mounted at each access door to switch the indoor lights on and off. Lighting level of the inside the module shall be 50 foot-candles minimum.
b. Interior emergency lights shall be provided above each door by means of a wall mounted self-contained continuously charging battery-powered unit with two lamps. Minimum battery power shall be for 1.5 hours. The emergency lighting fixtures shall include an illuminated EXIT sign. The exit sign shall be LED type. The exit fixture shall be Lithonia Type LHQM or approved equal.
c. Front door LED lighting and one Class A ground fault circuit interpreter (GFCI) dual receptacle with cover shall be provided at the outside of each door.
d. The module exterior lighting switches shall be located at the module entrances. Exterior module lighting shall be wired to a weatherproof exterior switch located near the door.
e. Yard lighting shall be controlled by three-way switches located at each entrance adjacent to the interior lighting switches. Refer to Section 4.9.2.11 Yard Lighting.
f. Outdoor yard general and task lighting shall be 240 V. The control module interior and exterior lighting shall be 120 V.

4.10.17 Receptacles

Convenience receptacles, 125 V, 20A, 3-wire, grounded duplex type, are to be located every 10 feet within the module. One outdoor-type receptacle shall be located at each door on the exterior. Each receptacle circuit shall be protected by a GFI.

4.10.18 Protective Relays and Control Panels

a. The control and relay panels shall be fabricated, components installed, and all internal panel wiring performed by a contractor specializing in the manufacture, assembly, and wiring of rack-mounted type protective relay and control panels. Panel construction shall conform to SMUD's panel construction and protective relay standards. All control and relay panel field wiring shall be factory-wired from the installed control and relay panels to terminal blocks in the control module interface terminal cabinet for field wiring interconnect.
b. All external connections to any control panel, unless prefabricated, shall be terminated on screw-type terminal blocks. All panels shall be mounted level and plumb and shall meet all NEC requirements. In addition, unless otherwise noted, all junction and terminal boxes shall possess gasketed screwed covers. Where necessary to provide rigidity, heavier steel plate or stiffening members shall be used.
c. The DBE shall provide relays as shown on the one-line diagram drawing E-SC-402. Electroswitch is an approved vendor for lockout relays and breaker control switch. Control switches shall have green and red LED lights. Lockout relays shall have a nameplate with LEDs for trip coil monitoring, a contact for supervisory control and data acquisition (SCADA) indication of trip coil failure, and existing trip signal. All indicating lights shall be LED type. Loss of DC power monitor relays shall be type EMAX-RAW-1 and shall be provided for each DC circuit. A common alarm contact (open to alarm) shall be provided and connected to the remote terminal unit (RTU).

d. DBE shall provide relay protection and control scheme description for approval by SMUD prior to generating elementary and schematic diagrams.
e. All switchyard status points, alarms, and monitoring shall be wired to relay input/output (I/O) ports. Relay must have enough I/O inputs and outputs to accomplish the above. All relays shall be capable of communicating with the RTU panel.
f. Control and relay panels shall be vertical, rack-mounted, freestanding panels. Panels shall be designed for top entry. Panels shall be painted light gray on the outside and white on the inside. Ground bus shall be provided in the bottom of each panel.
g. Protective relays, meters, terminal blocks, lockout, control, and test switches shall be arranged as shown on the SMUD approved drawings.

4.10.19 Relay Rack Panels (19-Inch)

The relay racks shall be Type A 19-inch rack panels constructed and installed as specified here and shown on attached drawings. All 19-inch rack panels shall be Newton Instrument Company brushed aluminum, 7.5 feet high. These base panels shall be installed in the control module as shown on drawing E-PL-411. The DBE shall obtain SMUD approval prior to modifying the standard panel layout provided by SMUD for relay and control panels.

4.10.20 Security

See Section 4.12.14. The security panel shall be installed the relay control room with a remote panel to deactivate the security system in the communication room.

4.10.21 RTU Panel

The RTU panel shall be provided with the following components:

a. 48 VDC Fuse Panel: 10POS A and 10 POS B sides, GMT Fuse; Manufacturer: Hendy; Part Number: 20HPGMTO5BNR2
b. Switch/Serial Server Access Concentration with RS232/RS485 Ports, LC SM Fiber Ports, Ethernet Ports, 48 VDC; Manufacturer: Garrettcom; Part Number: Dynastar 1500
c. 48 VDC Dual Power Supply; Manufacturer: n/a ; Part Number: APS-06741-11
d. DC-DC Converter, 48 VDC; Manufacturer: Wilmore; Part Number Wilmore 1502-48-48-8-M
e. 8 Slot Shelf for media converter with dual 48 VDC power supply; Manufacturer: Transition Network or Equal; Part Number: CPSMC0810-100/CPSMP-190

4.10.22 Interface Termination Cabinet

The interface termination cabinet (ITC) shall be freestanding with removable floor plates for access to the cable trench and open top for cable exit to control module tray. ITC shall be provided with a full-length access door and wire ways for cable routing. Terminal blocks shall comply with Section 4.9.2.16 for control wiring. Current transformer terminal blocks shall be of the shorting type specified in Section 4.9.2.16. Power terminal blocks for conductors larger than #8 AWG through 500kcmil (copper or aluminum) shall be Cooper Bussmann Magnum Series 160 and 165, or equal, 600 volt rated, with marker strip and terminal safety covers. The opening from the cable trench to the ITC shall be sealed after cables are installed to prevent animals and pests from getting into the control modules and into the cable trench. Refer to Section 4.9.2.16 (Terminal Blocks).

4.10.23 Metering

The metering panel shall be provided in the switchyard control module with the following components, one meter for each motor-generator.

- Revenue Meter: Socket Type; Manufacturer: Jemstar; Part Number: JS-0956030-03; Quantity: 3
- Meter A-Base Adapter, Manufacturer: Jemstar; Part Number: 6002-656; Quantity: 3
- Retaining Ring; Manufacturer: Jemstar; Part Number: 0631-392; Quantity: 3
- 10 Pole Test Switch; Manufacturer: AV0-States; Part Number: C3-210-N; Quantity: 2
- 10 Pole Test Switch; Manufacturer: AV0-States; Part Number: C3-210-H; Quantity: 3
- 8 Pole Test Switch; Manufacturer: AV0-States; Part Number: C3-209-CT; Quantity: 2
- 4 Pole Test Switch; Manufacturer: AV0-States; Part Number: C3-204-E; Quantity: 1
- 4 Pole Test Switch; Manufacturer: AV0-States; Part Number: C3-203-P; Quantity: 3
- Ground Bus Plate; Manufacturer: C&C; Part Number: Fabricate; Quantity: 2
- Terminal Bock, 12 Point; Manufacturer: Marathon; Part Number: 1512STD; Quantity: 10

4.10.24 RTU

The SMUD OMS Main RTU and associated DynaStar 1500 industrial frame router shall be engineered and installed to ensure proper operation and reliable communication as shown on Drawings E-SC-404 through E-SC-405. Telecommunication for remote monitoring and control shall be via the fiberoptic and microwave tower SCADA systems.

4.10.24.1 Switchyard Monitoring System

A switchyard control and monitoring system shall be provided capable of primary control and monitoring of equipment status. The system architecture shall include a LAN with required equipment and cables for integrated communication and monitoring of the following devices:

- Switchyard 230 kV equipment.
- Protective relays.
- Metering.
- The station RTU shall be provided and shall incorporate the following capabilities in addition to those specified in SMUD RTU Specification:
    - Communication on the IHPSP LAN.
    - Monitoring and control of 125 VDC discrete I/O with capacity designed to accommodate all necessary hardwired, discrete I/O points plus 20% spares.
    - Analog I/O at 0-1 mA-DC with capacity designed to accommodate all necessary hardwired analog I/O points plus 30% spares.
    - Monitoring station systems and auxiliary equipment through I/O.
    - Control and operation of switchyard equipment through I/O.

The system shall support remote monitoring, communications, and control from the SMUD SCADA system.

4.10.25 SCADA Communications

SCADA telemetry, control, and indication shall extend to all circuit breakers and auxiliary systems as required for a complete and properly operable switchyard with proper integration to control module facilities. SCADA communication shall be via the RTU.

4.10.26 Microwave Tower (Slate Mountain)

The existing microwave tower at Slate Mountain does not have additional room to add another microwave dish transmitter receiver. DBE shall reconfigure the equipment on the existing tower with SMUD's approval or construct a new microwave tower to support the new equipment required to communicate with the IHPSP. See Section 4.12.8 for additional details.

DBE shall install new microwave communication equipment in the Slate Mountain Communication Center and coordinate with SMUD the design, procurement, construction, and commissioning.

4.10.27 Testing and Inspection

a. At the option of SMUD, SMUD or its authorized representative shall witness all tests required herein, and no equipment shall be shipped until SMUD or its authorized representative has released it. The DBE shall notify SMUD at least four weeks in advance of the date of the tests so that arrangements can be made to be present at the tests and shall submit a detailed test plan/schedule at this time.
b. The DBE is responsible to coordinate the date of final acceptance tests with SMUD representative to witness the tests.
c. The DBE shall not commence the testing without final approval of all test procedures, test forms, and drawings by SMUD. Violation of these requirements may result in re-testing at the DBE's expense.
d. The DBE shall provide access to its facilities to SMUD's approved inspector and shall provide requested data for source inspection and checking the requirements of this specification.
e. The DBE shall notify SMUD of any unusual event or damage occurring during the fabrication of the control module and of all tests that does not meet the specified acceptance values. SMUD reserves the right to inspect such damages or test failures. Corrective measures to rectify such damages or failures shall be subject to acceptance by SMUD.
f. After the control module is fabricated, the electrical equipment is installed, and before shipping, the DBE will perform a wet spray test.
g. A test procedure document shall be prepared by the DBE with appropriate test sheets, forms and testing schedule and submitted to SMUD at least four weeks prior to the commencement of factory testing.
h. All wiring shall be verified including insulation resistance and continuity testing of all wiring.
i. Module auxiliary equipment, systems, and components shall be tested and demonstrated.
    - AC Distribution equipment
    - DC Distribution equipment

- Interior Lighting
- Exterior Lighting
- Fire Detection System
- HVAC System

j. All wiring shall be verified and tested point-to-point. Continuity and insulation resistance testing of wiring shall be performed. All potential and current circuits shall be verified for phasing and proper wiring at terminal blocks, shorting blocks, test switches, and devices. Inject 5 ampere secondary current through each current transformer circuit and verify proper indication of primary current values at meters and relays. Inject 120 VAC secondary voltage at each potential circuit and verify proper indication of primary voltage values at meters and relays. Using secondary voltage and current inputs, verify proper registration of all primary quantities at meters and relays. Provide calibration of all meters at 0%, 25%, 50%, 75%, and 100% of secondary current input for all meter registered values. Provide programming of approved settings for all protective relays. Provide setting output files with fully annotated descriptions of settings. Verify pickup values, timing, etc., by secondary current and voltage injection at all protective relays. Test functionality and correct operation of lockout relays and control switches. Verify outputs correctly initiate controlled devices.

k. The RTU input/output I/O wiring shall be wire-checked and tested point-to-point. Perform continuity and insulation resistance testing of wiring. RTU discrete inputs shall be verified by actuation from the initiating device. Analog inputs shall be calibrated at 0%, 25%, 50%, 75%, and 100% of input scaling range. Discrete outputs shall be verified by forcing. Proper actuation of the receiving device shall also be verified.

l. The communication backboard and related DynaStar 1500, and DynaStar 2000, and SEL 3530 communication equipment located in the RTU, and control and relay panels, respectively, shall be tested per the direction of SMUD's Telecommunication Department.

m. All devices programmed by the manufacturer—including but not limited to the RTU, protective devices and meters, and automation devices—shall be factory-tested by the manufacturer. Verify internal I/O mapping, scaling and engineering units, ranges and offsets, communication between devices, logical functions, timers and setpoints, and proper annotation of functionality.

n. Manufacturer shall factory-test all equipment that is to be connected with a networking or communications cable for proper network discovery and IP addressing.

o. The fire detection panel shall be tested as directed by SMUD's Fire Protection Group. The functionality of all input devices, alarm outputs, and communication interface devices and wiring shall be verified. Interlocks between the system and HVAC components shall be tested.

4.11 230KV Generation Tie (Gen-Tie)

4.11.1 General Description

Following is a description of the generation tie (gen-tie) transmission line. The gen-tie will have three transmission circuits that will connect the existing SMUD transmission lines to the Iowa Hill switchyard. The three (3) gen-tie circuits will be routed on two mono-pole tower transmission lines constructed of hot dipped galvanized steel that is tinted brown. One of the towers lines will have two (2) circuits (6 conductors), and the second tower line will have one (1) circuit (3 conductors). There will be no spare arms required on the second tower line. The gen-tie lines will connect the Iowa Hill switchyard to the existing SMUD transmission lines, Camino-Iowa Hill, Iowa Hill-Whiterock, and Iowa Hill-Lake. The distance of the gen-tie line is approximately 1.8 miles. SMUD will be extending the Iowa Hill-Lake circuit from Lake Substation to support the additional capacity requirements of the IHPSP. SMUD will upgrade the existing transmission system and constructing the new Iowa Hill-Lake circuit. SMUD will design and construct the gen-tie transmission line from the point of connection with the existing transmission lines to the Tower “B” as shown on drawing E-PL-408. The DBE contractor will need to extend the gen-tie to the final location of the IHPSP switchyard. The gen-tie extension shall include towers, foundations, conductors, insulators, optical ground wire, and dead end structures.

4.11.2 Regulations and Codes

The following codes, standards, and specifications of United States organizations shall be consulted to establish a basis for quality and safety in facility design and operation. Systems and equipment shall be designed in accordance with the latest edition and addenda in effect at the date of Contract execution, unless noted otherwise.

AA	The Aluminum Association
AASHTO	American Association of State Highway and Transportation Official
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASNT	American Society for Nondestructive Testing
ASTM	American Society for Testing and Materials
	ASTM A-36 Standard Specification for Carbon Structural Steel
	ASTM A-123 Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
	ASTM A-143 Standard Practice for Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement
	ASTM A-153 Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
	ASTM A-363 Standard Specification for Zinc-Coated (Galvanized) Steel Overhead Ground Wire
	ASTM A-385 Standard Practice for Providing High-Quality Zinc Coatings (Hot-Dip)

ASTM A-500 Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes

ASTM A-501 Standard Specification for Hot-Formed Welded and Seamless Carbon Steel Structural Tubing

ASTM A-563 Standard Specification for Carbons and Alloy Steel Nuts

ASTM A-572 Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel

ASTM A-588 Standard Specification for High-Strength Low-Alloy Structural Steel, up to 50 ksi [345 MPa] Minimum Yield Point, with Atmospheric Corrosion Resistance - AASHTO No.: M 222

ASTM A-633 Standard Specification for Normalized High-Strength Low-Alloy Structural Steel Plates

ASTM A-847 Standard Specification for Cold-Formed Welded and Seamless High-Strength, Low-Alloy Structural Tubing with Improved Atmospheric Corrosion Resistance

ASTM B-108 Standard Specification for Aluminum-Alloy Permanent Mold Castings

ASTM A-992 Standard Specification for Structural Steel Shapes

ASTM B-211 Standard Specification for Aluminum and Aluminum- Alloy

ASTM B-232 Standard Specification for Concentric-Lay-Stranded Aluminum Conductors, Coated-Steel Reinforced (ACSR)

ASTM B-308 Standard Specification for Aluminum-Alloy 6061-T6 Standard Structural Profiles

ASTM B-317 Standard Specification for Aluminum-Alloy Extruded Bar, Rod, Tube, Pipe, and Structural Profiles for Electrical Purposes (Bus Conductor)

ASTM B-429 Standard Specification for Aluminum-Alloy Extruded Structural Pipe and Tube

ASTM B-695 Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel

AWS	American Welding Society – D1.1 Steel
CPUC	California Public Utility Commission GO-95 - Rules For Overhead Electric Line Construction
CBC	California Building Code
CRSI	Concrete Reinforcing Steel Institute
EEI-AEIC	Edison Electric Institute Publications
FAA	Federal Aviation Administration
FERC	Federal Energy Regulatory Commission
IEEE	Institute of Electrical and Electronics Engineers (48, 383, 693, 1138) IEEE 738 – Standard for Calculating the Current-Temperature of Bare Overhead Conductors
ISO	International Standards Organization
NACE	National Association of Corrosion Engineers
NBS	National Bureau of Standards
NEMA	National Electrical Manufacturers Association
NESC	National Electrical Safety Code

NETA	National Electrical Testing Association
NFPA	National Fire Protection Association
	NFPA 70 - NEC/National Electrical Code
	NFPA 70E - Standard for Electrical Safety in the Workplace
OSHA	Occupational Safety and Health Administration and Cal/OSHA
PCA	Portland Cement Association
REA	Rural Electrification Administration (USDA)
SMUD	Sacramento Municipal Utility District
	SMUD Standard TD6405 – Overhead Transmission Conductor Ampacity
UL	Underwriters Laboratories

Design specifications and construction of the project shall also be in accordance with all applicable local, state, and federal laws, including, but not limited to, those set forth below:

Comprehensive Environmental Response, Compensation, and Liability Act of 1980
Clean Air Act and Amendments
Environmental Protection Agency Regulations
Federal Aviation Administration Regulations
Federal Energy Regulatory Commission Regulations
Federal Power Act
Noise Control Act of 1972
Occupational Safety and Health Act
Occupational Safety and Health Standards
Resource Conservation and Recovery Act (RCRA)
Safe Drinking Water Act
Solid Waste Disposal Act
Toxic Substances Control Act

In the event that conflicts arise between the codes, standards of practice, specifications, or manufacturer recommendations described herein and the codes, laws, rules, decrees, regulations, standards, etc., of the locality where the equipment is to be installed, the more stringent code shall apply.

4.11.3 Design Requirements

4.11.3.1 Gen-Tie Electrical Design Requirements

- Tower Type: Monopole, Steel, Hot Dipped Galvanized - Brown Tinted
- Conductor Type: 3M 795kcmil "Condor" ACCR/TW
- Shielding Wire: Optical Grounding Wire (Alcoa Fujikura Ltd. DNO-3599 – 72 fiber)
- Insulators: Nominal Voltage: 230kV; BIL: 1050kV; Insulator model and manufacturer shall match the insulators on the SMUD constructed portion of the gen-tie unless otherwise approved by SMUD.
- The gen-tie transmission lines shall be modeled in PLS-CADD™ and the final as-built native electronic files shall be provided to SMUD.

4.11.3.2 Steel Structure Design Requirements

- Tapered tubular, tubular, channel, or angle steel shapes shall be used.
- Dimensions and materials shall be selected to provide structural strength, maintain electrical clearances, and to suit equipment provided.
- All field connections shall be bolted unless otherwise noted herein.
- Base plates and anchor bolts shall be designed for concrete having 28-day compressive strength equal to 4,000 pounds per square inch in accordance with the ACI 318.
- All structure(s) shall include a provision for static wires located at the top of each tower and approximately 10 feet above the highest end of the conductor on the structure.
- Detail in accordance with AISC Structural Steel Detailing Manual.
- Equipment selected shall be designed to successfully withstand, without damage while in operation, sustained winds as shown on the attached General Design Requirements 013600, Light Ice Loading conditions as defined in NESC Std. C2 and RUS Bulletin 1724E-300.

4.11.3.2.1 Materials

- Structural steel for dead-end structures: ASTM A-36, A-572, A-992, A- 500 Grade B, A-501, A-618, and A-847.
- Base plates for dead-end structures: ASTM A-36, A-572, A-588
- Anchor bolt material: ASTM F1554, GRADE 36 with A-194 Grade 2H nuts. All anchor bolts shall be fully galvanized.
- All high-strength bolts shall conform to ASTM Type 1 with ASTM A- 563, Grade DH, or ASTM A-194, Grade 2H nuts. High-strength bolts for bearing type connections and shall have one plain hardened washer under the turned element (nut or bolt head). The use of interference body bolts shall not be permitted. Bolts and nut threads shall be lubricated. Bolts and nuts shall be mechanically galvanized in accordance with ASTM B-695. Mechanically galvanized nuts and bolts shall conform to the nut rotation test requirements of ASTM A-325. Bolts, nuts and washers shall be marked by the manufacturer, to show the manufacturer's name, type, grade, etc., as required by A-325, and F-436, respectively.

4.11.3.2.2 Fabrication

- Steel fabrication shall conform to the requirements of the latest revision of the AISC "Specification for the Design, Fabrication and Erection of Structural Steel for Buildings".
- Holes in base plates may be drilled. The roughness of oxygen-cut surfaces shall not be greater than that defined by AWS D1.1

4.11.3.2.3 Welding

- All welding shall be performed by welders qualified in accordance with AWS D1.1.
- Structures shall be fabricated in accordance with the latest edition of AWS D1.1.

4.11.3.2.4 Grounding Pads

- All structures shall include provision for the connection of a 250 kcmil copper ground wire pigtails to each structure leg.

- One ground connection shall be approximately 18 inches above each base plate.
- On tubular steel structures the grounding connection shall be a perpendicular welded tab drilled for NEMA 2 hole pad spacing. On non-tubular structures the ground pad shall be a stainless steel pad welded to the structure and drilled through the structure with NEMA 2 hole pad spacing.
- Additional ground cable supports shall be furnished as required.
- A ground connection shall be provided at each static wire dead-end at both the top and bottom of each leg that has an overhead ground wire attached.
- Ground connections shall be arranged such that all hardware is accessible for re-tightening after the structure is erected.

4.11.3.2.5 Drilling

- All holes required for equipment mounting and grounding shall be shop drilled before galvanizing.
- Field drilling shall not be permitted without the written permission by SMUD.

4.11.3.2.6 Galvanizing

- Remove slag, spatter and all foreign substances from welded areas after fabrication and before initiation of the galvanizing process.
- After fabrication and before assembly, galvanize all structural shapes, plates, bars, and strips in accordance with the latest revisions of ASTM A123, using the hot dip process. All bolts and nuts shall be mechanically galvanized to a minimum coating thickness equal to or exceeding Class 50. All tubular sections shall be hot dip galvanized.
- Safeguard against embrittlement by following the recommended practices of ASTM A-143.
- SMUD retains the right to inspect galvanized components prior to packaging for shipment. Any components not meeting or exceeding applicable ASTM specifications will be rejected and replaced with a component conforming to specifications, at no expense to the Purchaser.

4.11.3.2.7 Hardware

- All hardware shall be corrosion resistant.
- Nonferrous hardware shall be silicon bronze or stainless steel as applicable for connecting aluminum to aluminum or copper to galvanized steel.
- All ferrous hardware shall be hot dip galvanized per ASTM B464.

4.12 Telecommunications

4.12.1 General

This section provides the functional design criteria for Telecommunications Network Infrastructure for the Iowa Hill Pumped-Storage Project. These systems provide communications for SCADA (System Control and Data Acquisition), protective relaying, voice and data communications, and video surveillance and site security.

4.12.2 Regulations, Codes, and Standards

The SMUD Telecommunications design standards and equipment standards are provided in SPEC-003 – SMUD RTU Specifications and SPEC-004 – SMUD Telecommunications Specifications, which are included in Appendix B.

4.12.3 Equipment Space Requirements and Clearances

The Powerhouse control room and switchyard control module will have rows assigned for telecommunication racks and/or cabinets. The following clearances will be provided for equipment and cross-connect fields in the telecommunication equipment space:

- A minimum of 36 inches of clear working space in the front and rear of equipment cabinets, racks, and backboards.
- A 10-inch depth off the wall for wall-mounted equipment and panels.
- A minimum 36-inch aisle between each row of racks.
- A minimum aisle clearance of 36 inches is required at one end of each row of racks for an exit access.

The telecommunications rooms shall not be located near electrical power supply transformers, elevators, pump motors, generators, radio transmitters, radar transmitters, induction heating devices, or other potential sources of electromagnetic interference. Piping and plumbing unrelated to telecommunications (other than what is required to support the room such as chilled water supply/return) shall not be routed through the telecommunications rack row.

4.12.4 Telecommunication Cables

Inter-Building Backbone Cable will be used to connect buildings together, in order to concentrate and distribute aggregated signals to and from a central hub location. At a minimum, 100 pairs of copper cable will be installed from Switchyard Control Module to the Powerhouse Cavern. A High Voltage Protection (HVP) unit will be installed in the Switchyard Communication Room, and be connected to any OSP twisted-pair copper cable leaving the switchyard yard. A minimum of two OPGW fiber cables on the gen-tie towers will be installed to the switchyard yard dead-end structures and then the fibers shall be continued into the switchyard communications room. Between the Switchyard Communication Room and the Powerhouse Cavern a minimum of a 72 strand singlemode fiber cable will be installed.

Intra-Building Backbone Cable will be used to primarily carry signals between communications rooms and the edge to core communication electronics equipment. Multi-pair copper cable may be used to concentrate alarm and building control signals distributed throughout a building. Typically, Intra-Building Backbone Cables consists of multipair cable, high strand count optical fiber cable, and coaxial trunk cables.

Intra-building backbone cable shall be used primarily to carry signals between the communications rooms and the edge to core communication electronics equipment. Multipair copper cable may be used to concentrate alarm and building control signals distributed throughout a building. Typically, Intra-building backbone cables consists of multipair cable, high strand count optical fiber cable, and coaxial trunk cables.

4.12.5 Cable Management System

Horizontal and vertical wire managers are essential for proper installation of cable and equipment. The vertical and horizontal wire management systems shall accommodate patch cords for a fully loaded patch panel rack and allow for an additional 20% growth.

4.12.6 Inside Plant Pathways

The telecommunications pathways shall be located away from sources of electromagnetic interference (EMI), including:

- Electrical power cables and transformers
- Radio frequency (RF) sources
- Motors and generators
- Induction heaters
- Arc welders
- Photocopy equipment

4.12.7 Outside Plant Pathways & Structures

Inter-Building Communication Duct Banks are communication infrastructure pathways that carry communication cables between buildings. The raceways will be constructed of contiguous segments of schedule 40 PVC, 80 PVC, RGS conduit, or dedicated cable trays.

4.12.8 Microwave Radio Tower

Two (2) new microwave towers will be required for this project. One tower will be located within the new Iowa Hill Switchyard. The second tower will be located at Slate Mountain where there an existing SMUD microwave tower which does not have enough room for an additional microwave transmitter/receiver. The microwave radio tower heights will be determined as required to provide a microwave path between Iowa Hill Switchyard and Slate Mountain. The radio tower, foundation and grounding will be designed in accordance with EIA/TIA 222G including ½-inch radial ice on the tower and all attachments. The tower will be less than 198-feet, including lighting rod and all attachments so FCC lighting is not required. The tower will be a 3 or 4 leg lattice type structure, designed to last 30-years. The tower shall be hot dipped galvanized with brown tinted color.

The towers will include an inside work platform and a single, inside climbing ladder. The climbing ladder will extend to the ground or to a platform one step above ground. The safety cable or rail will be positioned so that personnel can clip into the safety device from the ground or platform. The climbing ladder will extend from the base of the tower to the top handrail of the top platform.

4.12.9 Microwave Radio System

The microwave radio system shall provide 99.995% availability. The system shall be a hot-standby radio system to SMUD's Slate Mountain telecommunications center. The microwave radio system consists of an antenna system, radios, and channel banks.

4.12.10 Telecommunications: 48V DC Power System

A DC Power system will supply power to telecommunications equipment and hardware exclusively. The system shall consist of the following: DC power board (includes rectifier/battery-charging equipment, primary distribution panel), equipment cabinet/rack, 48V DC battery, battery rack, battery disconnect, cable, wire, connectors, alarm interface, software, battery monitoring equipment, and other associated equipment and appurtenances.

4.12.11 Wireless LAN Service

SMUD IT Network Services has established Cisco model 3602i (indoor) and 1552E (for outdoor) wireless access points as the standard for wireless networks throughout SMUD facilities.

Site Survey software planning tools may be employed in order to develop a predictive survey of new building structures that are not yet constructed using the goals listed above.

4.12.12 Satellite TV/MATV and Off the Air Television

In the powerhouse operations room, viewing TV programming is part of daily operations. The TV programming consists of local broadcast channels like KCRA (NBC), KXTV (CBS), FOX, etc., and many news and information channels like CNN and Weather Channel. The powerhouse communications room shall have a dedicated master antenna television system (MATV) distribution system, which shall consist of a satellite TV receiver, switchers, and RG-6 and RG-11 coaxial cables. An off-the-air television system shall also be provided.

4.12.13 In-Building Distributed Antenna System

The In-building RF distributed antenna system (IBDAS) is a multioperator, multiservice system based on combining a number of services (e.g. voice and data) and distributing them to each remote location through a common antenna infrastructure. SMUD buildings are required to support radio communications from (1) the local public safety entities (Sacramento Metro Fire, Police, etc.) as per state and local codes; (2) SMUD's 900 MHz radio system (for voice and data services); and (3) cellular voice/data service (from AT&T, Verizon, and Sprint). The IBDAS system shall conform with all FCC, OSHA, state/local codes, NFPA 72 standards, UL listings, and shall be NEMA 4x certified. The system shall distribute RF coverage at levels described herein in the following minimum areas of the building(s) and as listed in

Table 4-11.

Table 4-11. RF Coverage Levels

Requirement	Functional Areas
Floor areas	Corridors, lobbies, concourse, interstitial spaces, penthouses, restrooms / bathrooms, elevator lobbies & shafts, mechanical rooms; electrical rooms, telecommunications rooms, conference rooms, class rooms, reception areas
External Building lobbies and floor area(s)	Bridges, tunnels and Building links, public spaces (e.g., courtyards, patios)
General use spaces	Break Room, staff, public, multipurpose rooms, etc.
Excluded Areas	NO AREAS ARE EXCLUDED

4.12.14 Security

The design shall be based on current industry standards for high resolution IP video surveillance systems, video recording systems, card access control systems and associated intrusion alarm systems for buildings, open spaces and perimeter alarm systems. Additional Standards to be followed are those pertaining to security and access control systems from organizations such as BICSI and ASIS.

All cabling shall be installed in conduit to provide protection against tampering and unauthorized access to security systems. All security components, power supplies, controllers, relays, interfaces, etc., shall be installed in secured lockable enclosures with key access, complete with tamper-proof hardware. All security cabinets shall be installed with tamper contacts to alert security personnel.

Conduits penetrating through rated walls and slabs between floors, and through roofs shall be sealed with fire-resistant materials.

The design shall include connectivity by multistrand fiber optic backbone optical feeds for all system connections. Security and access control that are Ethernet-based shall reside on a dedicated Ethernet network and not share hardware, IP addressing, or VLAN schemes with any other network and shall be dedicated to security infrastructure between buildings.

4.12.14.1 Security Infrastructure

The site shall incorporate multiple modes of site and building security, which shall involve card access, intrusion protection, and closed circuit surveillance systems. These systems shall communicate with SMUD’s current systems in use at its main campus; however the site shall be a standalone facility, able to operate without outside connections to servers, databases, NVRs, etc.

4.12.14.1.1 Access Control

The site shall utilize a system comprising control software and hardware, complete with database programming, controllers, power supplies, card readers, door controls, door strikes, electronic locksets and associated hardware.

An access control and monitoring system (ACAMS) is required and shall be designated to coordinate with existing systems that are in place at SMUD HQ Campus and other facilities. This will provide SMUD with one system to administer and maintain.

Intercom system integration shall be included to give the operator the flexibility to program intercom functions directly from the graphical interface. In this manner, calls can be opened, closed and redirected using a single intercom station dialog box.

Other included options shall be threat level support, allowing operators to adjust security functions based on previously configured threat level parameters. In the event of an elevated security threat, modifications can be made to reader acceptance levels (from card only, to card plus PIN, to card plus PIN plus biometrics), and CCTV cameras and guard tours can be changed to reflect heightened security requirements.

The access control system shall communicate over a dedicated Ethernet network, separate from in-house data networks and shall be solely dedicated to access control. The network shall utilize fiber optic cabling provided under the telecommunications contractor. Provisions shall need to be coordinated with telecommunications to connect all networked attached devices with horizontal CAT-6 cabling.

Entry turnstiles shall be provided at all employee entrances to the powerhouse control room. The entry turnstiles shall be high-quality, high-security type, interface with the card access control system, provide for reader assemblies to be mounted to the turnstile assemblies, and interface as required with the access control and CCTV systems.

Card readers will be provided at main exterior doors in the Switchyard Control Module, Utility Shaft Building, and Powerhouse.

4.12.14.1.2 Intrusion Protection

Intrusion protection into the site and buildings shall be accomplished through interfaces with the access control system. Devices such as motion sensors, door position contacts, perimeter fence alarms, perimeter motion sensors shall be connected to monitoring points within the access control system and programmed to general local and remote alarms to security personnel.

In-building devices shall consist of passive infrared (PIR) motion sensors and door position contacts, each with their own unique point of connection. All active devices shall be powered from secured low voltage power supplies collocated in the equipment rooms and or ancillary rooms within buildings.

Exterior perimeter and boundary protection shall be accomplished with the use of a perimeter cable detection system and associated controls and interfaces. Additionally, fencing areas that may be block wall, wrought iron or systems not prone to disturbance or vibration shall be protected with overlapping perimeter protection zones of microwave intrusion link type.

4.12.14.1.3 Closed Circuit Surveillance

The site shall include closed circuit camera television surveillance systems (CCTVs). Each camera shall record to a network video recorder (NVR). Camera systems shall be installed to monitor perimeter, exterior, and interior activity, as well as employee parking areas, SMUD vehicle parking areas, and interior and exterior storage areas. At designated rooms/areas with more than one door, all entries/exits shall receive camera coverage.

The CCTV systems shall provide coverage of the entire site through a network of exterior building, pole or PV canopy mounted units. Outdoor cameras shall be color, fixed or pan-tilt-zoom as application requires. All exterior cameras shall include fans and heaters for adverse weather as found in the region.

NVRs are required and are designated to coordinate with existing systems that are in place at the SMUD HQ Campus central monitoring station. This shall provide SMUD with one system to administer and maintain.

Exterior camera coverage will include:

- Switchyard Yard Perimeter Fence Line
- Switchyard Yard Entry and Exit Gates
- Switchyard Control Building Main Door Entrance
- Powerhouse Building Main Door Entrance
- Utility Shaft Building Door Entrances

Interior cameras coverage shall include:

- Powerhouse control room main door entrance
- Elevator cabin
- Transformer cavern
- Generator hall

5 General References

US Army Corps of Engineers. 1997. EM 1110-2-2901. Tunnels and Shafts in Rock. May 30, 1997.

Bechtel. 1972. Sacramento Municipal Utility District, Iowa Hill Pumped Storage Project, Preliminary Study, February, 1972.

Brekke. 1968.

Carlton Engineering, Inc. 2011. Geotechnical Investigation Plan, September 2011.

Carlton Engineering, Inc. 2012. Investigation Plan, Plan Alternatives Memorandum, April 2012.

CH2M Hill, Inc. 2008. Visual Resources Technical Report, Addendum No. 1, January 2008.

CH2M Hill Inc. 2008. Transportation Route Technical Report, January 2008.

CH2M Hill and Devine Tarbell & Associates, Inc. 2005. Socioeconomic Assessment of Construction and Operations Technical Report, January 2005.

CH2M Hill and Devine Tarbell & Associates, Inc. 2005. Auditory Assessment of Construction and Operations Technical Report, January 2005.

CH2M Hill and Devine Tarbell & Associates, Inc. 2005. Draft Transportation Management Plan, June 2005.

Devine Tarbell & Associates, Inc. and Martha Goodavish Planning & Design. 2005. Land Use Technical Report, February 2005.

Jacobs Associates. 2014. Interim Underground Design Feasibility Report, July 9, 2014.

Jacobs Associates and AMEC. 2014. Interim Geologic/Geotechnical Data Report, July 2014.

Jacobs Associates and AMEC. 2014. Geologic Mapping and Bedrock Structural Analysis, August 2014.

Lang, B. 1999. Permanent Sealing of Tunnels to Retain Tailings or Acid Rock Drainage. Mine, Water & Environment, 1999 IMWA Congress, Sevilla, Spain.

Makdisi, F.I., and H.B. Seed. 1978. “Simplified Procedure for Estimating Dam and EMBANKMENT earthquake-induced Deformations.” ASCE Journal of the Geotechnical Engineering Division 104, 849–867.

MWH. 2003. Preliminary Project Cost Assessment, February 11, 2003.

MWH. 2004. Phase 2 Subsurface Exploration, Geotechnical Investigation Technical Report, August 2004.

MWH. 2005. Draft Conceptual Erosion and Sedimentation Control Plan, June 2005.

MWH. 2005. Draft Revegetation Plan, June 2005.

MWH. 2005. Preliminary Supporting Design Report ("MWH PDR"), February 2005.

MWH. 2010. Sacramento Municipal Utility District Upper American River Project (FERC No. 2101), Iowa Hill Pumped Storage Development, Engineering Refinement and Opinion of Probable Construction Cost Report, December 2010, Draft Revision 1.

MWH Geotechnical. 2010. Engineering Refinement and OPCC Report, December 2010.

Post-tensioning Institute. 2004. *Recommendations for Prestressed Rock and Soil Anchors*.

SMUD. 2003. Initial Information Package ("IIP"), Revision 1, July 17, 2003.

SMUD. 2003. Project Description, November 2003.

SMUD. 2007. Relicensing Settlement Agreement for the Upper American River Project and Chili Bar Hydroelectric Project, January 2007.

SMUD. 2008. Final Environmental Impact Statement ("FEIS"), for the Upper American River and Chili Bar Hydroelectric Projects, March 14, 2008.

SMUD. 2008. Final CEQA Supplemental Analysis to the FERC/USFS Final Environmental Impact Statement for Hydropower License and Analysis of Iowa Hill Joint Advisory Committee Comments, August 22, 2008.

SMUD, Consumes Power Plant Distributed Control System Requirements

SMUD RFP NO. 130121.GV DOCUMENTS:

- Department of Energy, Statement of Project Objectives, issued March 2012
- Preliminary Schedule Iowa Hill
- Administration General, Public Comments, as of August 8, 2007
- Fire Protection, Public Comments, as of August 8, 2007
- Noise, Public Comments, as of August 9, 2007
- Socioeconomic, Public Comments, as of August 23, 2007
- Transportation, Public Comments, as of June 14, 2007
- Visual, Public Comments, as of August 8, 2007
- Lower Slab Creek Powerhouse, Geotechnical Engineering Study, dated March 20, 2012, by Carlton Engineering, Inc.
- Fire Plan for Special Use Permits, Placerville Ranger District, El Dorado National Forest, dated April 01, 2006
- California Public Resources Code References, California Forest and Fire Laws

- Reference Drawings
    - Plan View, Sheet 1
    - Waterway Profile, Sheet 2
    - Overpumping Spillway, Sheet 3
    - Plan El 1662, Sheet 4
    - Plan El 1662, Sheet 5
    - Section A-A, Sheet 6
    - Section B-B, Sheet 7