Tehachapi Wind Energy Storage Project

Technology Performance Report #3

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Revision History

ID	Date	Summary of Changes	Revised By
v1	12/31/16	Changes and additions to TPR#2	SCE Team

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1 Executive Summary

This is the third and final Technology Performance Report (TPR) for the Tehachapi Wind Energy Storage Project (TSP). The TSP is jointly funded by the Department of Energy (DOE) (American Reinvestment and Recovery Act - ARRA) and Southern California Edison (SCE). The TSP is a demonstration of a Battery Energy Storage System (BESS) connected directly to the SCE sub-transmission grid. The facility is located approximately 100 miles northeast of Los Angeles, in Tehachapi, CA at the corner of Williamson Road and East Tehachapi Boulevard.

TPR #1 (issued 12/31/2014 with subsequent iterations) was primarily concerned with the description of events during construction, commissioning and characterization testing of the TSP facility. TPR #2 was concerned with the troubleshooting of various issues and the tuning of the custom designed facility as well as initial operations yielding first instances of project test data. This TPR #3 reports on the continuous operation of the facility and test data satisfying the project scope and Metrics and Benefits Reporting Plan (MBRP).

The main objective of the TSP is to evaluate the performance of utility scale lithium ion battery technology in improving grid performance and integrating intermittent generation, e.g., wind. The primary object is to use electrical energy storage to manage conventional energy flows in a time dependent function in order to address grid instability and capacity issues that result from the interconnection of highly variable generation resources.

The TSP was developed based on engineering studies and analysis of the transmission assets in the Tehachapi region, also referred to as the Antelope-Bailey area for transmission studies. In general, SCE evaluated the local transmission assets by completing power flow and dynamic stability simulation studies which looked at current conditions and contingency conditions at selected times in the future. Specifically, the objective of the study was to quantify the grid reliability and power quality issues and assess potential improvements on the grid at selected interconnection locations by the deployment of energy storage devices with four-quadrant control of real and reactive power.

The results of the studies identified scenarios that resulted in undesired effects on the Antelope-Bailey System. These scenarios revealed voltage problems due to lack of reactive power support and power flow capacity on two transmission lines in the region. Moreover, these scenarios led to wind farm generation curtailments to mitigate potential transmission problems. Thus, it was the objective of the study team to identify ways to alleviate the need to curtail wind farms in the Tehachapi region.

The analysis team identified an 8 MW (Megawatt), 4 hours (32 MWh – Megawatt-hr) Battery Energy Storage System (BESS) as an option to mitigate the reactive power problem and line overloading identified in the above scenarios. The immediate benefits of the BESS are contingency support (active and reactive power), voltage profile support, and improved fault ride-through capability.

The DOE awarded ARRA funding in early 2010 and project work began in October of that year. Installation and commissioning of the BESS was completed in July 2014. Initial design, specification and procurement of the BESS were disrupted by financial issues of the original BESS provider. Subsequently, a revised project plan was developed to select a new BESS

provider and continue with the project. Other than the discussion of Project History in section 3.1, this TPR addresses the project after transition to continuous operation and testing under the revised project plan.

The project is installed in the Monolith substation where it is connected to the 66 kV bus and will be tested under various load and wind power generation conditions. Specifically, tests will ascertain the capability and effectiveness of the BESS to support various grid operational uses.

The evaluation of the BESS is based on the premise that there are benefits which should accrue to SCE and to the overall electricity delivery system based on three general categories of operational uses: transmission, system and California Independent System Operator (CAISO) market:

- Transmission uses provide a means for evaluating the ability of the BESS to resolve capacity and stability issues on transmission systems, especially those with intermittent generation, e.g., wind.
- System uses provide for a means of meeting the system electricity needs with stored energy.
- The CAISO market uses look at the ability of the BESS to provide benefits to the grid in ways that meet specific needs of the system operator.

These three general categories of uses can be further detailed to arrive at 13 specific operational uses. A test plan consisting of eight tests was prepared for the project. The plan includes provisions to address all three of the benefits categories. Finally, the project includes provision for creating a baseline for the transmission system prior to the connection of the BESS. The following table indicates the relationship of tests and operational uses.

	Operational Use		Test							
			1	2	3	4	5	6	7	8
Transmission	Voltage support	1	X	X						
	Decreased losses	2			X					
	Diminished congestion	3			X					
	Increased system reliability	4				X				
	Deferred transmission investment	5			X		X			
	Optimized renewable-related transmission	6			X		X			
System	System capacity/resource adequacy	7				X		X		
	Renewable integration (firming & shaping)	8					X			
	Output shifting	9				X				
ISO Market	Frequency regulation	10						X		
	Spin/non-spin reserves	11							X	
	Deliver ramp rate	12						X	X	
	Energy price arbitrage	13								X

Table 1-1 Operational Use & Tests

It should be noted that since the initiation of this project, SCE has completed a large transmission investment in this area. These system upgrades may reduce the impact of the battery system with respect to the 13 operational uses. Nevertheless, SCE conducted experimentation to demonstrate the capabilities of the BESS to affect the identified operational uses. Demonstration

of the desired response of the device to grid conditions allowed us to extrapolate data, and apply lessons learned to other scenarios where a storage device may have a more significant impact.

The transmission system baseline effort was completed during the second half of 2014. Collection of baseline data for the project includes data from the region before and after the recent system upgrades. Some of the "pre-upgrades" data is useful for predicting and trending area loads and generation. For example, the timing of individual tests described later in this report were scheduled, based in part, on seasonal variations in wind generation.

Validation of the installed BESS at the component and system level involved a multi-phase commissioning process. A "Mini-System" was installed and tested at one of SCE's off site laboratories. The Mini-System consisted of all the functional components of the full system with a scaled down set of batteries (originally 30 kW, 116 kWh; the Mini-System was expanded to 60 kW, 232 kWh in December 2015. The Mini-System allowed for operational testing of system control schemes. A second element of commissioning involved end to end testing of the software, communications, and data collection components of the BESS again in a lab environment. This testing allowed SCE to verify data paths, proper communications, and ensure proper configuration of the associated communications hardware. The third phase of commissioning tested the BESS control strategy in a Real Time Digital Simulator (RTDS) environment. A spare BESS system controller was hardwired into the RTDS system at yet another SCE lab. This Hardware in the Loop (HWIL) allowed the project team to study the interaction of the control system with other grid systems prior to actual live system operations. The fourth and final phase of commissioning involved the component and full system testing of the complete system at the TSP facility. This final phase of commissioning was completed in June 2014.

Full scale System Acceptance Testing (SAT) of the BESS began in July 2014 following completion of system commissioning. The BESS was fully operational and grid connected for the SAT, and was exercised across the full range of system operating capabilities. As a natural progression and in order to better understand more detailed operating characteristics of the installed system, the next phase of evaluation consists of system Characterization Testing. A more detailed understanding of the BESS baseline performance allowed comparison during later stages of the M&V testing.

Preliminary Characterization Testing began at the end of 2014, further project testing continued in January 2015 through December 2016. This Final Technical Report TPR #3 reports on activities from inception of the project through the testing of the 13 operational use cases continuing until the end of 2016.

The following table identifies the five top lessons learned during each reporting period of the project. Additional lessons learned are found in Section 6.

Key Lessons Learned During TPR #1	
Topic	**Lesson Learned**
Site Considerations	• Build within existing substation to accelerate project schedule • Facility outside of substation would have potentially onerous permitting requirements • Location and proximity to existing infrastructure needs to be evaluated (above & underground utilities) • Noise was not a significant issue since the system was installed in a remote location, but in a populated area the noise level generated by the cooling system, transformer or power conversion unit may need to be considered • Grid protection settings evaluation needs to be performed early in the development • Typical construction considerations e.g. construction power, storage, access, staging, interim battery storage (climate control)
Fire Suppression System[1]	• Limited guidance found in fire codes and standards for lithium ion facilities. (SCE applied best practices and guidance from the BESS supplier and a professional consultant, along with actual destructive testing of the system in a lab setting.) • Permitting requirements may vary depending on the chosen location for future BESS installations. • Vendors should demonstrate the effectiveness of the proposed fire suppression system through detailed analysis and laboratory tests • Firefighting and post fire protocols need to be considered in the event of a fire.
Deployment of BESS equipment to site - importance of decisions that can impact the on-site commissioning/ testing with an active grid.	• Deployment of BESS components to the site should be carefully considered and made part of the commissioning planning. • The potential for commissioning a partial BESS with the power conversion systems (PCS) while connected to the grid should be considered. The advantage of this approach is the potential for earlier project completion since PCS and grid integration testing can occur while the remainder of the battery continues in production. The result is an incremental commissioning with a potential earlier project completion date.
Testing using the Mini-System	• Mini−System testing provides excellent opportunities to test out both hardware and software in advance of full−scale deployment. • Tests in a controlled environment required less coordination with grid operations and reduced impact to grid reliability while working out system control issues.
TSP CAISO interconnection of the Battery Energy Storage	• CAISO Interconnection Request (IR) required significant lead time to allow for processing in Queue Cluster (typically 18 months). • Consider the schedule time required for environmental impact studies for the acquired property.

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[1] Battery over-charge, over-discharge, or manufacturing defect leading to internal short-circuit can lead to thermal runaway, a rapid uncontrolled increase in temperature leading to catastrophic failure.

System (BESS)	• Limited time to submit an IR. • Required Positive Sequence Load Flow Model (PSLF) to be submitted as part of the IR process. • Significant costs associated with system upgrades, required up front Security Deposits to stay in the Queue. • Interconnection agreement stipulated operating restrictions/limitations on BESS due to system topology and/or reliability requirements.
Topic	**Key Lessons Learned During TPR #2**
Resolution of startup issues involving a new system.	• This BESS system is an early custom designed solution based on evolving commercial maturity and formative technology. Hence, significant time and effort was required to allow for start-up issues and system troubleshooting during commissioning and initial operations.
Industry/manufacturer maturity/experience with battery/power conversion subsystem integration, and overall system integration	• Battery energy storage systems are still an emerging technology, and different system integrators and subsystem manufacturers with varying levels of experience offer products that are at different points along the technology maturity and adoption curves. While many manufacturers are very capable of making specific BESS subsystems or major components, these same manufacturers frequently lack the integration experience to deliver complete systems with the high levels of reliability expected in utility applications. A limited number of manufacturers, typically with more years of system design, deployment, and operational experience with a particular battery chemistry, are capable of delivering relatively reliable utility-scale systems, but this may be an exception. • TSP is a research and development system, so a certain amount of failures, downtime, and lessons learned are acceptable and expected. However, for utilities wishing to deploy "production" battery energy storage systems that are relied on for meeting grid reliability and/or market needs, the manufacturer's product offerings should be closely scrutinized for design, integration, and deployment maturity and experience. This can be accomplished by considering the number of other, similar systems that have been deployed, as well as their time in operation and reliability.
Use of common components and easily serviceable designs instead of highly custom designs	• The PCS manufacturer discovered a design deficiency in the custom PCS medium voltage transformers specifically manufactured for this project, which resulted in a failure of one of the transformers and a protracted replacement. This design deficiency was due to not considering all of the possible operational modes of the system. The protracted replacement was due to lead-time associated with re-designing, manufacturing, and replacing the custom-built transformers, which were tightly integrated with the rest of the PCS. • This design was due to the limited space and performance specifications of the system. Future designs should place a greater emphasis on using more common component designs, such as standard transformer builds, that have proven reliability, well-understood operational characteristics, and short replacement lead times. This should increase overall system reliability and

	reduce down time in the event a component needs to be replaced.
System data historian integration with corporate data historian	• The system's local data historian only "streams" data to the corporate data historian via a dedicated gateway device. The system operator's technology integration team originally anticipated this path would have a high quality of service with little downtime, and the vast majority of system operational data would be captured by the corporate data historian. However, long-term issues with the gateway device resulted in multiple periods where the streaming data was interrupted and not recorded by the corporate historian, forcing system operators to use the local data historian as a primary data source. The local data historian's remote access methods and interface limited its ability to be easily used in this capacity, but ultimately provided the data necessary to perform the long-term analysis required by the project. • Future data historian architectures should continue to include a local data historian that is dedicated to the system and operates completely independently of the corporate data historian, so a backup data source always exists at the system itself. However, future architectures should also avoid streaming data from the local historian to the corporate historian, since any interruption to such stream will result in data loss on the corporate historian. Instead, a more robust data transfer method should be employed, which will continue to transfer and re-transfer data until the local and corporate historians both have the same, complete data set.
System architecture and segmentation for high reliability	• At various points in time, anywhere from 25 to 100 percent of the system was off line due to battery and PCS subsystem trips. At a high-level, TSP is divided into four relatively independently operating battery/PCS sections, which means that a trip in any one section usually results in the remaining three sections continuing to operate. While it is possible for individual racks within a section to trip off line and allow the rest of the section to continue operating, there were a number of trips that affected the entire section (i.e., 25 percent of the system at a time). • One such case was the failure of one of the four battery section controllers, which resulted in one of the four battery sections being off line for an extended period. This demonstrates the value of a segmented system architecture where the remainder of the system can continue operating while one part is off line. However, this also demonstrates the need for additional layers of isolation (ex., further subdivisions that would reduce the impact of a single trip/failure), and the need for redundant/failover components that have the potential to affect a large portion of the system (ex.: 25 percent) in the event of failure. • Future designs should include clear failure mode and effects analysis, and architectures that limit the effect of individual component failures and trips, to increase overall reliability.

Topic	Key Lessons Learned During TPR #3 Final Technical Report
Telemetry	• Accurate telemetry is paramount for the physical management of state of charge. If points are incorrectly scaled the market could assume the unit has no binding state of charge.
State of Charge	• State of Charge is finite. In a market that re-optimizes between day-ahead and real-time there needs to be an opportunity cost calculation in order to take into account the resource Day-ahead position relative to its potential Real-time re-dispatch.
GMS (Market) Interface	• TSP was SCE's first, as well as one of the state's first, battery systems to participate in the CAISO market as a non-generator resource (NGR). From the beginning of the project, the telemetry requirements (hardware, software, metering, data/control points, logic, and configuration) were unknown or ambiguous at best. The project team worked with SCE's market operations group to define and build as much of the point-to-point Generation Management System (GMS) interface as possible, but additional requirements and refinements were identified as the system was tested and entered the market. Some of these improvements were made by updating the SEC software in mid-2016. Additional improvements were identified as CAISO published draft business practice manuals (BPMs) for storage and corrected certain limitations with their control systems. Some of these newer improvements will be implemented after the conclusion of the M&V phase, as the system continues to operate on the market for the long term. • Due to the lack of existing batteries on the CAISO market, TSP had to solve many of the integration issues as they arose. However, as a direct result of TSP, SCE was able to deploy other battery systems, such as the Mira Loma 20 MW, 80 MWh BESS, in record time and with a greater understanding of the market interface requirements. CAISO has also been using deployments like TSP and Mira Loma to formalize the battery NGR connection process, which will make future deployments smoother and easier.
Communications Equipment	• On March 31, 2016, engineers lost the ability to remotely monitor or access the system's control interfaces. This was a concern, since without remote monitoring ability, the status of the system remained unknown. The only monitoring system that still worked was the security cameras, which confirmed the system was still intact, but its operational state was unknown. SCE IT personnel traced the issue to an unresponsive switch in the substation control building, through which all TSP traffic was passed (excluding the security cameras, which were part of a completely separate system). Once the issue was identified, the switch was replaced and the issue resolved. • Since all BESS installations are unmanned and usually not conveniently accessed (especially remote systems), future systems should consider using redundant hardware and communication paths, even if the backup has limited functionality. This will at least allow operators to continue to monitor

	the high level operation and health of the system.
Building HVAC	• On June 29, 2016, the battery building HVAC system experienced a complete failure. The building is served by two packaged rooftop units. For unknown reasons (possibly a power quality disturbance), both units experienced simultaneous failures. One unit had a bad compressor, and the other unit had a bad fan unit. These components prevented both units from operating. The battery system continued to operate throughout the HVAC outage, as the batteries increased in temperature but did not reach their upper temperature limits for normal operation. Also during this event, operators discovered that the HVAC alarm signal wasn't active. Operators discovered the HVAC failure during a scheduled trip to the site, and confirmed the start of the outage by trending battery temperature data. • In this case, having multiple HVAC units didn't prevent a total HVAC failure, but this is still a good design practice to prevent a single point of failure. Also, the HVAC alarm signal was tested during system commissioning, but the artificial alarm was created at the SEC rather than the HVAC control panel. In future system commissioning, the configuration and test of the alarm signal should be verified at the HVAC panel rather than the battery system's master controller or PLC.

Table 1-2 Key Lessons Learned To Date

2   Scope

2.1   Abstract

The TSP is located at SCE's Monolith Substation in Tehachapi, California. The 8 MW, 4 hours (32 MWh) BESS is housed in a 6,300 square foot facility and 2 x 4 MW/4.5 MVA smart inverters are on a concrete pad adjacent to the BESS facility. The project will evaluate the capabilities of the BESS to improve grid performance and assist in the integration of large-scale intermittent generation, e.g., wind. Project performance was measured by 13 specific operational uses: providing voltage support and grid stabilization, decreasing transmission losses, diminishing congestion, increasing system reliability, deferring transmission investment, optimizing renewable-related transmission, providing system capacity and resources adequacy, integrating renewable energy (smoothing), shifting wind generation output, frequency regulation, spin/non-spin replacement reserves, ramp management, and energy price arbitrage. Most of the operations either shift other generation resources to meet peak load and other electricity system needs with stored electricity, or resolve grid stability and capacity concerns that result from the interconnection of intermittent generation. SCE also demonstrated the ability of lithium ion battery storage to provide nearly instantaneous maximum capacity for supply-side ramp rate control to minimize the need for fossil fuel-powered back-up generation. The project began in October, 2010 and will continue through December, 2016.

2.2   Introduction to SCE

SCE is one of the nation's largest electric utilities, serving more than 14 million people in over 180 cities across central, coastal and southern California. SCE is based in Rosemead, California, and has been providing electric service in this region for more than 125 years. SCE, a subsidiary of Edison International, is an investor owned utility operating in the state of California, with a service territory of over 50,000 square miles and delivering 12.6 billion kWh of renewable energy in 2015.

SCE has over twenty years of experience in large-scale wind generation integration and in the development and testing of battery technologies for grid applications. As such, SCE brings to the project comprehensive experience in all relevant technological and operational areas.

The following table, lists statistics further describing the SCE service area.

Southern California Edison Service Territory	
Total number of customers:	
Residential	4,368,897
Commercial	557,957
Industrial	10,782
Peak load: MW	
Summer	23,055
Total MWh sales	
Residential	30,115,000
Commercial	42,127,000
Industrial	8,417,000

Table 2-1 Southern California Edison Company's Service Territory (2015)

2.3 Project Overview

The TSP is a demonstration project of a BESS connected directly to the sub-transmission grid. SCE is the project manager with overall responsibility for the project. Quanta Technology, LG Chem, ABB and the California Independent System Operator (CAISO) are project participants. Quanta Technology is an engineering and consulting firm specializing in providing technological solutions to utilities. LG Chem is the developer and manufacturer of the battery storage device, and ABB is providing the smart inverters used in this project. The CAISO is the independent system operator for the California transmission grid. Additionally, California State Polytechnic University, Pomona, provided analytical support through advanced numerical modeling using a Real Time Digital Simulator (RTDS).

The TSP was developed based on engineering studies and analysis of the transmission assets in the Tehachapi region, also referred to as the Antelope-Bailey area for transmission studies. In general, SCE evaluated the local transmission assets by completing power flow and dynamic stability simulation studies which looked at current conditions and contingency conditions at selected times in the future. Specifically, the objective of the study was to quantify the grid reliability and power quality issues and assess potential improvements on the grid at selected interconnection locations by the deployment of energy storage devices with four-quadrant inverter able to inject and absorb real and reactive power.

The analysis team identified an 8 MW, 4 hours (32 MWh) device as an option to demonstrate the ability of the BESS to mitigate the reactive power problem and line overloading. The analysis identified benefits from the application of an 8 MW BESS connected through a 20 MVA static synchronous compensator (STATCOM) to the grid. In the simulation studies, the BESS connected directly to the 66 kV transmission system adequately addressed the transmission problems in conjunction with the wind farms in the Antelope-Bailey area. Specifically, the analysis revealed three primary benefits of a BESS in the Tehachapi local area as follows:

1. **Contingency support** in terms of MW and MVAr; applying the BESS/STATCOM system to mitigate power system contingencies.
2. **Voltage profile support -** applying the BESS/STATCOM system results in improved voltage recovery of about 10-15%.
3. **Improved fault ride-through capability** for some of the Type 1 wind turbines in close vicinity of the proposed substation installation.

The results of possible applications of the BESS/STATCOM system between the wind farms and congested transmission lines in the Antelope-Bailey area were studied in detail. For hourly dispatch at one local wind farm, the battery contributes to minimizing the wind power variations and controls wind farm power output within a preset power range. For contingency support, the battery contributes to absorb energy (8 MW during four hours maximum) in order to avoid wind farm curtailments during the time the contingency is in effect in the Antelope-Bailey area. At project inception, significant curtailments were required due to transmission line congestion in the Antelope-Bailey region. Since then, SCE has made planned improvements in the system topology that mitigate much of the congestion in the area and alleviate much of the need for curtailment events. Nevertheless, TSP was operated and tested in a fashion that demonstrated the ability of storage to reduce congestion as originally planned.

The BESS is installed at the Monolith substation near Tehachapi, California and connected to the 66 kV bus. Tehachapi, California is one of the premier places in California for wind generation and one of the windiest places in the United States. SCE has entered into several long term contracts for new wind projects in the Tehachapi-Mohave area and has committed to investing in a significant amount of transmission infrastructure in the same area. This demonstration project is situated at an ideal location on the California grid, where existing and new wind projects and transmission infrastructure jointly help California meet its renewable energy targets. This project was designed to test a BESS under various grid and power generation conditions. Specifically, SCE anticipated evaluating the BESS capability and effectiveness to support 13 operational uses, described by the following.

Transmission Uses

1. Voltage support/grid stabilization: Energy storage used for transmission support improves Transmission and Distribution (T&D) system performance by compensating for electrical anomalies and disturbances such as voltage excursions, angular stability, and frequency stability. The result is a more stable system with improved performance (throughput).

2. Decreased transmission losses: Transmission losses are dependent on the current flow through transmission lines. By optimizing the magnitude and power factor angle of current flow on the transmission system under various system conditions, energy storage can reduce losses.

3. Diminished congestion: Storage could be used to avoid congestion-related costs and charges, especially if the charges become onerous due to significant transmission system congestion. Storage systems traditionally have been installed at locations that are electrically downstream from the congested portion of the transmission system. Energy would be stored when there is no transmission congestion, and it would be discharged (during peak demand

periods) to reduce transmission capacity requirements. In the TSP, storage is installed on the transmission system, at a location electrically upstream from the congestion. It will be charged when wind generation output is high to reduce congestion, and it will be discharged when wind generation output is lower to utilize available transmission capacity.

4. Increased system reliability by load shed deferral: In certain situations, load shedding (or addition) is needed to mitigate under-frequency (or over-frequency) conditions. Storage could be used to avoid load shedding by supplementing inadequate available generation and/or transmission capacity.

5. Deferred transmission investment: Consider a T&D system whose peak electric loading is approaching the system's load carrying capacity (design rating). In some cases, installing a small amount of energy storage downstream from the nearly overloaded T&D node (or upstream as in the TSP design) will defer the need for a T&D upgrade.

6. Optimized size and cost of renewable energy-related transmission: New transmission infrastructure built to fully integrate renewable energy into the grid must be planned and sized for maximum output of installed renewable generation, even though that output is variable and will usually be well below its maximum. Such sizing would lead to substantial under-utilization of transmission capability most of the time. If battery energy storage performs as anticipated, installing a small amount of storage upstream from new transmission infrastructure could effectively smooth the wind output and improve the effective utilization of new renewable energy-related transmission.

System Uses

7. **Provide system capacity/resource adequacy:** Depending on the circumstances in a given electric supply system, energy storage could be used to defer and/or reduce the need to buy new central station generation capacity and/or to "rent" capacity in the wholesale electricity marketplace. The BESS will be evaluated for its ability to qualify for Resource Adequacy (RA) under existing requirements. If regulatory statutes for storage are written during the demonstration period, the BESS will be evaluated for its capabilities to meet the new requirements.

8. Renewable energy integration (smoothing): As wind generation penetration increases, the electricity grid effects unique to wind generation will also increase. Storage could assist with orderly integration of wind generation (wind integration) by providing services that reduce the variability of wind generation. Short duration applications could include: reduce output volatility and improve power quality. Long duration applications could include: reduce output variability, transmission congestion relief, backup for unexpected wind generation shortfall, and reduce minimum load violations.

9. Wind generation output shifting: Many renewable generation resources produce a significant portion of electric energy when that energy has a low financial value (e.g., at night, on weekends, during holidays and off-peak times). Energy storage used in conjunction with renewable energy generation could be charged using low value energy from the renewable energy generation so that energy may be used to offset other purchases or sold when it is more valuable.

CAISO Market Uses

10. Frequency regulation: Some thermal/base-load generation used for regulation service is not especially well-suited to provide regulation, because the generation is not designed for operation at partial load or to provide variable output. Storage may be an attractive alternative to most generation-based load following for at least three reasons: 1) in general, storage has superior part-load efficiency, 2) efficient storage can be used to provide up to two times its rated capacity for regulation services, and 3) storage output can be varied rapidly (e.g., output can change from none/full to full/none within seconds rather than minutes).

11. Spin/non-spin replacement reserves: Generation resources used as reserve capacity must be online and operational (i.e., at part load). Unlike generation, in almost all circumstances, storage used for reserve capacity does not discharge at all – it just has to be ready and available to discharge if needed.

12. Deliver ramp rate: Storage is well-suited for providing load following services for several reasons. First, most types of storage can operate at partial output levels with relatively modest performance penalties. Second, most types of storage can respond very quickly (compared to most types of generation) when more or less output is needed for load following. Consider also that storage can be used effectively for both load following up (as load increases) and for load following down (as load decreases), either by discharging or charging.

13. Energy price arbitrage: This operational use may shift wind energy output (see Use Number 9) in response to a market signal from the CAISO.

These 13 operational uses formed the basis for SCE's evaluation of the BESS. In order to place the TSP in the context of other ARRA funded demonstration projects it is helpful to show the relationships between the 13 operational uses and the seventeen functions as defined by Sandia document *Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide* (SAND2010-0815, February 2010). The table below illustrates the relationships between the operational uses and the Sandia applications.

SCE Operational Uses	DOE Applications	Comments
Voltage Support/grid stabilization	Voltage Support	
Decreased transmission losses	Transmission Support	Decreased Transmission Losses are more accurately defined as storage benefits rather than uses or applications. "Avoided T&D Energy Losses" is included in the DOE Guide as an "Incidental Benefit (#19)". As such, applying storage for Transmission Support has an incidental benefit of decreasing transmission losses.
Diminished congestion	Transmission Congestion Relief	
Increased system reliability by load shed deferral	Transmission Support	Under-frequency Load Shedding Reduction (See Table 6 of DOE Guide) This reduces the number of mandatory load shed events to relieve congestion or line loading, thereby increasing the reliability of the regional system.
Deferred transmission investment	T&D Upgrade Deferral	
Optimized size and cost of renewable energy related transmission	T&D Upgrade Deferral	The intent is to increase the firm capacity rating of the affected transmission lines resulting from the operation of the BESS. Any incremental improvement in transmission line firm capacity ratings supports the deferral of capacity upgrade.
Provide system capacity/resource adequacy	Renewables Capacity Firming	
Renewable energy integration (smoothing)	Wind Generation Grid Integration, Short Duration	
Wind generation output shifting	Wind Generation Grid Integration, long Duration	
Frequency regulation	Area Regulation	
Spin/non-spin replacement reserves	Electric Supply Reserve Capacity	
Deliver ramp rate	Load Following	
Energy price arbitrage	Renewables Energy Time Shift	

Table 2-2 Relationship of 13 Uses to DOE Applications

2.4 Project Objectives

The main objective of the TSP was to evaluate the capability of utility scale lithium ion battery technology in improving grid performance and integrating intermittent generation, e.g., wind. The primary objective was to use electrical energy storage to manage conventional energy flows in a time dependent function in order to address grid instability and capacity issues that result from the interconnection of highly variable wind generation resources.

The evaluation of the BESS was based on the premise that there are benefits which should accrue to SCE and to the overall electricity delivery system based on three categories of operational uses: transmission, system and CAISO market. These operational uses are further

delineated into a total of 13 areas for the three categories mentioned above. The operational uses are summarized in the following table.

Summary of Operational Uses		
Transmission	System	CAISO Market
• Voltage support/grid stabilization • Decreased transmission losses • Diminished congestion • Increased system reliability by load shed deferral • Deferred transmission investment • Optimized size and cost of renewable energy-related transmission	• Provide system capacity /resource adequacy • Renewable energy integration (smoothing) • Wind generation output shifting	• Frequency regulation • Spin/non-spin replacement reserves • Deliver ramp rate • Energy price arbitrage

Table 2-3 SCE Operational Uses for the BESS

The transmission uses provide a means for evaluating the ability of the BESS to resolve capacity and stability issues on transmission systems, especially those with interconnected wind resources. System uses provide for a means of meeting the system electricity needs with stored energy. The CAISO market uses look at the ability of the BESS to provide benefits to the grid in ways that meet specific needs of the system operator. Some of these uses will address particular problems that existed on the Antelope-Bailey system at the time of the project's inception, and all will be broadly applicable to wind integration challenges in general.

2.5 Project Benefits

As described in the foregoing, SCE has identified 13 operational uses for the demonstration project to evaluate. These operational uses are aligned with the economic, reliability and environmental benefits that DOE has set for grid-scale energy storage projects and they help demonstrate the ability of lithium ion BESS to meet the public benefits goals set out by the DOE. Most of the 13 operational uses aim at shifting wind and conventional power across time to meet peak load and other electricity system needs with stored electricity, and at resolving grid instability and capacity issues that result from the interconnection of wind generation resources. More specifically, the transmission uses (1-4) provide a means for evaluating the ability of the BESS to resolve capacity and stability issues on transmission systems, especially those with wind resources interconnected.

Wind generation output shifting, (operational use 9), is aimed at meeting the electricity system needs with stored energy. The first three CAISO market uses (operational uses 10, 11 and 12) will help evaluate the ability of the BESS to provide benefits to the grid in ways that meet specific needs of the system operator. Some of these uses will address particular problems that exist on the Antelope-Bailey system, and all will be broadly applicable to wind integration problems in general. In addition, several of the operational uses SCE have identified (5-8, and

13) may be used to explore the practical business implications associated with evaluating grid-connected lithium ion BESS.

The California Independent System Operator (CAISO) administers a wholesale power market that can allow many types of resources to participate, including energy storage resources. These resources participate by bidding in their availability and operating characteristics into the market, which are then optimized and dispatched by the CAISO. In order to manage battery storage resources, the CAISO developed a specialized model template called the Non-Generator Resource (NGR) Resource Data Template (RDT) which has two types of configurations.

The base NGR model template is for resources that are configured in the CAISO's market to provide Energy, Regulation and Spin Products. These resources are configured much like a conventional gas-fired generator with two key differences: the ability to charge the resource through load bids, and the ability to define and bid a state of charge (SOC). A variant on this data template is the NGR - Regulation Energy Management (REM) RDT. These are for energy storage resources configured to provide Regulation only. The ability to bid a SOC remains, but there are no discrete load and generation bids, only regulation up and regulation down. Scheduling Coordinators (SC) managing the resource in the CAISO market must choose to configure the resource using one of the two data templates. The potential economic benefits of using either model must be balanced and with operational efficiency and reliability. The standard NGR model may have higher potential economic benefits due to its greater variety of products and flexibility in optimizing its capacity. However this flexibility can be more challenging to administer and tuning of the resource, in particular the communication protocols, becomes much more paramount and can increase the risk in not being able to meet schedules.

Frequency Regulation:
Tehachapi Storage Project was certified for frequency regulation on April 19th, 2016. The unit was rated for a regulation up range of -8.05 to 8.05 at a ramp rate of 50.84 MW/min and a regulation down range of 8.00 to -8.01 at a ramp rate of 50.56 MW/min.

Spin/Non Spin:
Tehachapi Storage Project was certified for Spin on June 1st, 2016. WECC Standard BAL-STD-002-0 - Operating Reserves requires that a resource have available energy to meet an operational need. SCE did not bid the resource for spinning reserve because it did not have the systems in place to reserve energy for a guaranteed dispatch during a Spin dispatch event.

Deliver Ramp Rate:
Load Following is not a product that is offered in CAISO's marketplace for a single resource. It is a product that is allowed for a metered subsystem. There is a new CAISO product called the Flexible Ramping Product. However, this new product is only available to resources that provide Energy (NGR Non REM) and the enhancement went live on 11/1/16.

Energy Price Arbitrage:

SCE operated the unit as an energy only resource from 4/21/16 to 5/3/16. Energy was bid using an opportunity cost methodology into the CAISO market and the resource was optimized by the CAISO for each market run.

The table below lists the benefits identified in the ARRA Guide as being potentially realized by Smart Grid Demonstrations. It also shows SCE's assessment of the TSP's ability to provide these benefits. Some of the listed economic benefits and all of the reliability benefits are not expected to be demonstrated directly by the TSP because it is connected to the transmission system and some of those benefits, as defined, are expected to be realized by the consumer. However, as noted in the remarks section, SCE plans to evaluate similar benefits at the wholesale (economic) and transmission (reliability) levels.

Benefit Category	Benefit	Provided by Project?	Remarks/Estimates
Economic	Arbitrage Revenue	YES	TSP will evaluate the ability to arbitrage at the wholesale level. Revenue generation may be simulated due to market restrictions.
	Capacity Revenue	YES	TSP will evaluate the ability to provide capacity at the wholesale level. Revenue generation may be simulated due to market restrictions.
	Ancillary Service Revenue	YES	TSP will evaluate the ability to provide ancillary services at the wholesale level. Revenue generation may be simulated due to market restrictions.
	Optimized Generator Operation	YES	TSP will evaluate the ability of storage to support this benefit.
	Deferred Generation Capacity Investments	YES	TSP will evaluate the ability of storage to support this benefit.
	Reduced Ancillary Service Cost	NO	
	Reduced Congestion Cost	YES	TSP will evaluate the ability of storage to support this benefit.
	Deferred Transmission Capacity Investments	YES	TSP will evaluate the ability of storage to support this benefit.
	Reduced Electricity Losses	YES	TSP will evaluate the ability of storage to support this benefit.
	Reduced Electricity Cost (Consumer)	NO	
	Reduced Sustained Outages (Consumer)	NO	
Reliability	Reduced Momentary Outages (Consumer)	NO	
	Reduced Sags and Swells	YES	TSP will evaluate the ability to reduce Sags and Swells at the transmission and distribution level
Environmental	Reduced carbon dioxide emissions	YES	TSP will evaluate the ability of storage to support this benefit.
	Reduced SO_X, NO_X, and PM-2.5 Emissions	YES	TSP will evaluate the ability of storage to support this benefit.

Table 2-4 Benefits Potentially Realized By Stationary Electric Storage Demonstrations

2.6 Build & Impact Metrics

In accordance with the MBRP, SCE reports Build and Impact Metrics.

- Build Metrics track how the project money is spent, including spending on hardware and software, and associated programs. These reports are issued separately every 3 months.
- Impact metrics measure how, and to what extent, the storage system affects grid operations and performance.

This TPR is written specifically to address Impact Metrics. The TPR addresses how the BESS affects the transmission system performance and how well the storage system itself performs under each of the operational uses discussed previously.

In addition to Build and Impact Metrics, key BESS performance parameters are addressed as part of the TSP system evaluation. These include system availability, maintenance procedures and costs; energy charged and discharged, capacity degradation over time, and ramp rate capabilities. During the entire test period, data was collected and metrics assessments were conducted to evaluate the performance of the system. As will be discussed later in this report, to some degree the assessment was compromised by not unexpected non-recurring issues relating to design and operations of a new system.

2.7 Project Plan

The DOE awarded ARRA funding in early 2010 and project work began in October of that year. Initial design, specification and procurement of the BESS were disrupted by financial issues of the original BESS provider. Subsequently, a revised project plan was developed to select a new BESS provider and continue with the project. This TPR#3 addresses the project after transition to the revised project plan.

Key asset deployment milestones, as identified in SCE's Project Management Plan, are included in the table below. Baseline data was gathered and analyzed prior to asset deployment, and post-deployment data was gathered and analyzed in accordance with the project's Metrics and Benefits Reporting Plan (MBRP) and DOE reporting frequencies (i.e. Build Metrics reported quarterly and Impact Metrics reported with each TPR). Please refer to Section 5 of this report for more information regarding Baseline Data, including proposed timelines, data sources, and analysis methods.

	Tasks	Milestone	Completion Date
Phase I- Definition and NEPA Compliance	Task 1.1 – Update Project Management Plan	Submission of PMP to DOE	8/8/2013
	Task 1.2 – National Environmental Policy Act Compliance	Completion of NEPA Compliance (categorical exclusion)	11/4/2010
	Task 1.3 – Develop Interoperability and Cyber Security Plan	Completion of I&CS Plan for every phase of engineering life cycle of the project	11/4/2010
	Task 1.4 – Develop Metrics and Benefits Reporting Plan	Completion of Metrics and Benefits Reporting Plan	1/6/2011
	Task 1.5 – Finalize Energy Storage System Manufacturing Plan	Completion of BESS Manufacturing Plan	11/4/2011
	Task 1.6 – Finalize Plan for Baseline Measurements	Finalization of Baseline Data Measurement Plan	4/4/2011
Phase II – Final Design, Construction, and Baselining	Task 2.1 – Battery and Inverter Systems Development, Manufacture, Assembly, and Installation	Completion of Acceptance Testing for Battery System	5/15/2014
	Task 2.2 – Siting, Construction and Substation and Grid Preparation	Construction and Installation of Equipment	5/15/2014
	Task 2.3 – Baselining	Installation and connection of baselining equipment, beginning to accumulate and prep data	6/29/2011
Phase III – Operations, Measurement and Testing	Task 3.1 – System Operations and Testing	Operation of energy storage system over 24 months to test operations use applications and effects (includes system characterization tests)	12/31/2016
	Task 3.2 – Communications, Interoperability and Cybersecurity	No associated milestone	N/A
	Task 3.3 – Study, Measurement, Validation and Valuation	Complete analysis of data and submission of final report	3/31/2017

Table 2-5 SCE TSP Milestone Log

2.8 Report Organization

This report presents the results of project work performed by the TSP project team from inception of the project through continuation of project plan testing in December, 2016. This report is the third and final TPR report. In the aggregate, the TPRs will report test results and operational experience with the TSP over the entire project period through December 2016.

Section 4 presents the methodology and approach used by the project to assess and evaluate performance of the BESS as part of the Measurement and Validation (M&V) preparation phase. Section 5 presents the summary of the Measurement and Validation Test Plan and Baseline development. Section 6 identifies the M&V tests conducted, and the results observed. Section 7 presents the BESS performance parameters that were examined. In Section 8, the table of Impact Metrics is presented and other pertinent data. In Section 9, the Appendices contain test data forms and miscellaneous information associated with supporting the test results.

3 Technical Approach - Battery Energy Storage System

3.1 Project History

Project definition for TSP was completed in October 2010, preliminary design work was initiated in December, and the DOE authorized SCE to start work on all tasks in January 2011. The I&CS Plan and the MBRP were submitted and approval for the documents occurred in November, 2010 and May 2011 respectively. In parallel, SCE initiated an Interconnection Request with the CAISO in May, 2011 making allowances for market participation during the M&V period.

The site selected for the BESS was within the perimeter of an existing sub-transmission substation. The location was chosen based on an earlier study which examined suitable locations for installation of grid scale energy storage. The Antelope Bailey system was determined to be a viable candidate based on grid conditions at that time, and the likelihood that a storage device of the size under consideration could have a measureable impact on grid performance. Monolith substation was chosen as the BESS site because it was within the Antelope Bailey system, there was sufficient space to build a facility, and SCE owned the property which allowed for an immediate start to facility construction.

SCE partnered with A123 at project inception and contracts were issued between A123 and SCE in February, 2011. A123 chose DynaPower as the supplier for the PCS. Design work continued through 2011, and a critical design review with A123 was conducted in January, 2012. Contracts for civil/structural and electrical construction along with a release for procurement of construction materials were issued in January. Due to concerns with A123 performance following Q1 financial results disclosure, SCE began a risk evaluation/mitigation process. In October, 2012 A123 filed for Chapter 11 protection, and the company was later acquired through auction in January of 2013. In March of 2013, SCE entered into a new contract with LG Chem Ltd replacing A123 as the battery manufacturer and prime contractor for TSP. An element of the selection process stipulated that the capability for conducting testing as outlined in the MBRP would be a requirement. As such, no substantive modifications to the MBRP were required due to the replacement of BESS vendor.

Based on original plans, the BESS facility (structure and interconnection infrastructure) was substantially complete at the time of the change to LG Chem. As a result, LG Chem designed their system to fit within the existing physical confines of the BESS facility. A design review with LG Chem. occurred in June, 2013, and battery deliveries began in late July. The LG Chem system matched original design requirements of an 8 MW, 32 MWh lithium ion battery system utilizing a bi-directional four quadrant smart inverter. The batteries and controls systems fit within the existing facility, and interconnection facilities including switchgear, step up transformer, and communications/controls hardware from the previous design were accommodated by the LG Chem system design. Installation and commissioning of the BESS was completed in July 2014. Characterization Testing began in 2014 and completed in early 2015. Individual project tests in accordance with the MBRP began in June 2015, following characterization testing, and continued through December 2016.

3.2 Basic Facility Description

The TSP project facilities are located inside the fence of the existing and active SCE Monolith substation located in Tehachapi, CA, approximately 100 miles north east of Los Angeles. The coordinates of the Monolith substation are: 35° 07' 24" N, 118° 22' 48" W.

Figure 3-1 Monolith Substation and BESS Facility

The TSP BESS is composed of two major parts, the power conversion system and the battery. Figure 3-2 shows the design of the BESS and how the AC, DC, and Control sections are configured. The AC section is composed of two 4 MW bi-directional inverters and each inverter is composed of two 2 MW bi-directional inverter lineups. The DC section is mainly composed of battery racks. There are four battery sections and each battery section has 151 battery racks that are connected to one 2 MW bi-directional inverter lineup. A battery rack has 18 battery modules connected in series with one Rack Battery Management System (BMS). All battery racks are connected in parallel. Each 2 MW string is controlled by a Section controller which is connected to a Power Conversion System (PCS) Master controller, which is in turn connected to the Master Controller. In addition to the two major systems described in the foregoing, the project also includes a variety of data acquisition and data storage systems to monitor, record and store operational and system data.
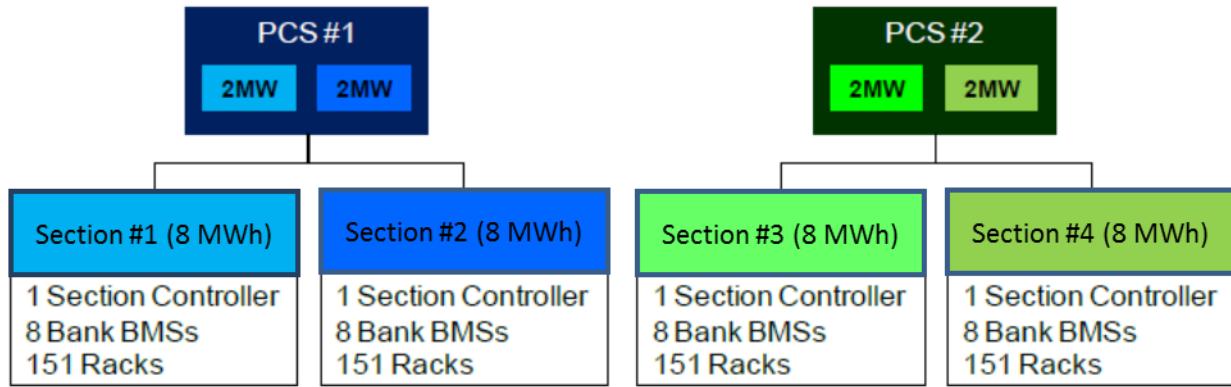
Figure 3-2 System Overview

BESS Configuration	
System Specifications	
Nameplate Power Rating, AC	8 MW, Continuous
Nameplate Energy Rating, AC	32 MWh @ 8 MW AC output
Nameplate Reactive Power Rating	±4 MVAr at full 8 MW charge or discharge
Nameplate Apparent Power Rating	9 MVA
Aux Power	<100kVA

Table 3-1 BESS System Configuration & Specification

The BESS system was designed for the specific project location. Operating conditions are as follows.

Location:	Tehachapi, California
Maximum Temperature:	45℃
Max. Average Temperature:	30℃ (24 hours)
Minimum Temperature:	-20℃
Humidity:	100%
Altitude:	1210 m.a.s.l. (meters above sea level)
Maximum Wind Speed:	100 mph
Seismic Rating:	Designed to UBC Zone 4 (0.4 g seismic acceleration)

Table 3-2 Operating Conditions

3.3 Battery Design and Layout

The BESS voltage output is 12 kV, and a 12 kV to 66 kV transformer steps voltage to the final 66 kV bus interconnection. Between 17 and 20 Racks make up one Battery Bank and 8 Banks

comprise one Battery Section. Each Battery Section is composed of 151 Battery Racks and the Sections are connecting to 2 MW PCS lineup respectively. The BESS is composed of four Battery Sections (2 M X 4 = 8 MW).

The general approach was to install the battery racks inside the 6,300 square foot facility and to locate the PCS outside using 40 foot long containers. The total system is divided into 4 sections. Each of 4 sections consists of 1 PCS lineup and 151 battery racks. The battery racks are composed of 19" wide rack-mounted battery modules with front-mounted power and communications cables. The layout of the battery racks was performed by taking into account the facility floor plan provided by SCE, the position of doors, the location of the control room, and aisle way access for maintenance and service. The BESS major components and battery rack layout is illustrated below.
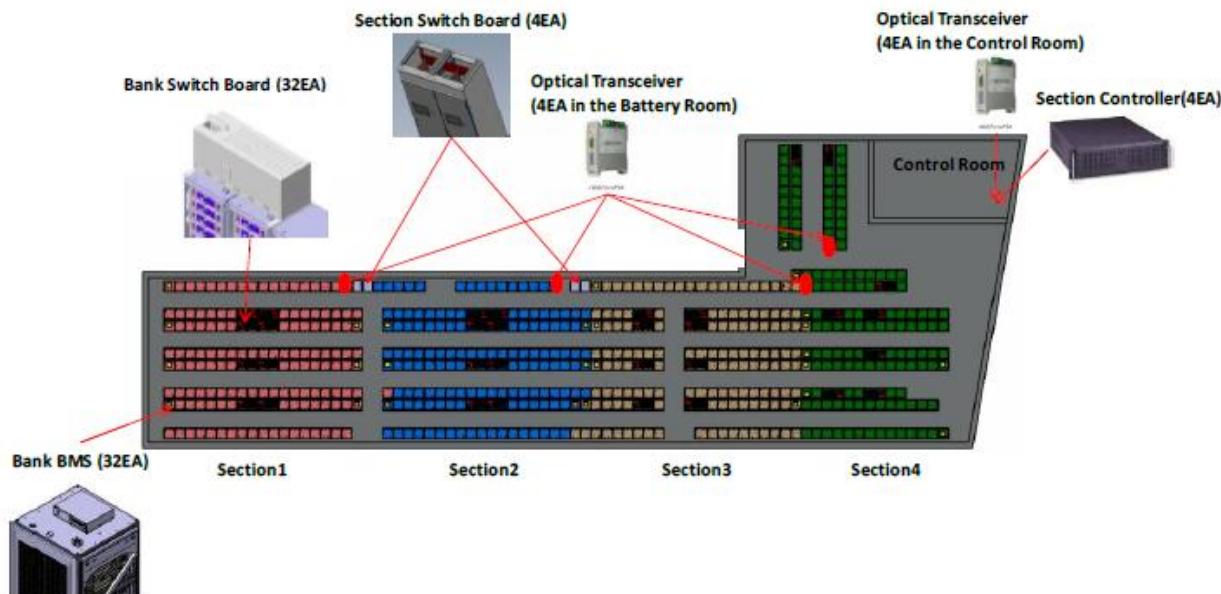
Figure 3-3 Battery Rack Layout

Battery Specifications	
Battery Configuration	4 Sections (Total 604 Racks)
Section	151 Racks per Section
Rack	18 Modules
Module	56 Cells
DC Voltage Range [Vdc]per Rack	760 –1050
Total Energy [MWh]	32
Recommended Operating Temperature	20℃ ±5℃

Table 3-3 Battery Specification

3.4 Power Conversion System Design

The PCS for the project is composed of two (2) outdoor PCS enclosures made from 40 foot CAISO containers. Each unit is rated for 4 MW/4.5 MVA capacity designed for connection to a 12.47 kV grid network. Each PCS unit is configured to connect to two 2 MW LG Chem battery strings based on a charge-discharge DC voltage range of 750 to 1050 Vdc.

The novel CAISO container approach makes use of a standard PCS technical solution and proven equipment, in a special packaging scheme to yield reduced initial system cost, reduced shipping costs and reduced installation and commissioning costs. The packaging concept consists of taking a new ("one way" class A) standard 40 foot CAISO sea container and having it modified to meet the requirements of the PCS system. The containers are modified by adding equipment access doors and man doors, air intake louvers or vents, exhaust fans, internal barriers, partitions and panels, lighting and power distribution, supports and brackets and so on as needed so that it is the ideal enclosure for the application.

The DC battery connections are made inside the enclosure at the incoming DC circuit breaker cabinets – one for each 2 MW inverter lineup. The DC power is then bussed to the individual inverter lineups where it is converted to a regulated AC voltage. The AC output from the inverter modules in each lineup is connected to a common AC bus and then to the low voltage AC circuit breaker where it is available as the AC coupling voltage. The line side of the AC breaker is connected to one of two secondary windings of the main step-up transformer. Each inverter lineup is connected to a separate secondary winding on the transformer which allows the two inverter lineups to be controlled separately. This transformer steps up the AC coupling voltage to the required output voltage. The external AC power connections are made through a gland plate at the bottom of the enclosure. The external DC battery connections are through bottom gland plates below the circuit breaker cabinet on one side of the enclosure.

Each inverter lineup is protected by an AC low voltage circuit breaker and one or two DC circuit breaker switches are integrated into a standard breaker cabinet. There is generally one circuit breaker cabinet for each inverter lineup. Typically it is located in the middle of the inverter.

A 15 kV primary disconnect and grounding switch is included with each PCS enclosure to assist in making repairs and routine maintenance easier and safer. The integrated disconnect/ground switch is inside a weather proof enclosure that is mounted inside the 40 foot container enclosure around the primary lead stub ups near the step-up transformer inside. The primary leads are connected from the transformer terminals to the load side of the switch.

PCS Specification	The following electrical ratings are for one PCS 4 MW enclosure.
Number of Inverter Lineups:	2
Nominal Power:	2 x 2000 kW (charge/discharge power)
Nominal Apparent Power:	2 x 2250 kVA (inductive / capacitive)
DC Battery Voltage:	750 Vdc (discharged) to 1050 Vdc (charged)
AC Coupling Voltage:	480 Vac, 3-phase, 60 Hz
Connection Voltage:	12,470 Vac, ±10 %
Frequency:	60 Hz
Total Harmonic Distortion:	< 3% at rated power
Efficiency:	96% at rated power output
Overload Capability:	120%, 10 min/150 %, 30s/200%, 2s
Auxiliary Power:	40 kVA

Table 3-4 PCS Specification

3.5 BESS Auxiliary Systems

3.5.1 Auxiliary Power System

The BESS requires auxiliary power to operate a number of the ancillary BESS systems (Fire suppression, HVAC, etc.), and facility utility functions (lighting and 120 V power outlets). PCS and Battery Sections will use 480 V 3 phase and 120 V single phase. The total power consumption of the system will be less than 150 kVA.

3.5.2 HVAC System

The BESS includes a Heating Ventilation and Air Conditioning (HVAC) system for thermal management. The HVAC system is composed of two rooftop heat pumps. The interface for the HVAC system is via a controller manufactured by Trend and configured as described below:

- The set point temperature is manually set at the control panel.
- The fans in both HVAC units run constantly.
- On a weekly, alternating basis, one unit is designated as the primary unit and the other unit becomes the secondary.
- In the event of a HVAC unit failure, a red "Fail" light will illuminate at the HVAC Control Panel and BESS will not be allowed to be operated.

3.5.3 Fire Suppression System

The BESS includes a fire suppression system to mitigate effects in the event of a fire. The BESS facility is equipped with an FM 200 clean agent fire suppression system. This is the sole fire suppression system for this facility. The facility has an NFPA 72 compliant fire alarm system installed, which will activate the release of the FM 200 system by cross zoned smoke detection. During system design and deployment, codes and standards for fire suppression for lithium ion battery storage facilities were not well defined. SCE commissioned an outside professional consultant to evaluate fire suppression design, and to provide recommendations

for modifications as deemed necessary. In addition, LG Chem conducted destructive testing to demonstrate the efficacy of the fire suppression system for their specific applications.

The system is a pressurized gas system delivered via overhead piping and ceiling mounted open discharge nozzles, designed for total flooding of the fire area with a pre-established concentration by volume of the extinguishing media. This is a commonly available clean agent system which suppresses fires by a combination of chemical and physical mechanisms that still maintains breathable oxygen levels. The system is to be released by cross zoned smoke detection devices as part of the facility's fire alarm system.

3.6   TSP Data Acquisition System

A one-line schematic of the Data Acquisition System (DAS) is provided in the Figure 3-4 below. Energy Management System (EMS) SCADA historical data is available for the transmission system and for the wind farms. The EMS SCADA data will be used in conjuction with data collected during the year prior to BESS operation to establish baseline information. Power Quality Meters (PQM) data will also be available locally at the BESS, and at remote adjacent substations (Cal-Cement, and Goldtown). In addition, a Phasor Measurement Unit (PMU) with digital fault recorder data will be available at Monolith. These PMU/PQMs and the EMS SCADA system will capture the transmission system data needed to demonstrate the ability of the BESS to perform the 13 operational uses and to assess the value of the BESS's benefit.

The project has defined eight tests that will be conducted during the demonstration period. Data obtained from these eight tests will be used in different combinations to demonstrate the BESS's ability to perform the 13 operational use cases. Transmission data to be captured during these tests includes:

- 66 kV substation bus voltage
- Transmission line load profiles and transmission losses
- Wind generation profiles
- Wind curtailment events
- CAISO congestion – magnitudes and costs
- CAISO frequency response requirements and the response provided by the BESS over time
- CAISO spin/non-spin reserve requirements and the response provided by the BESS over time
- CAISO generation reserve requirements and the response provided by the BESS over time
- CAISO energy price signals and the charge and discharge patterns of the BESS
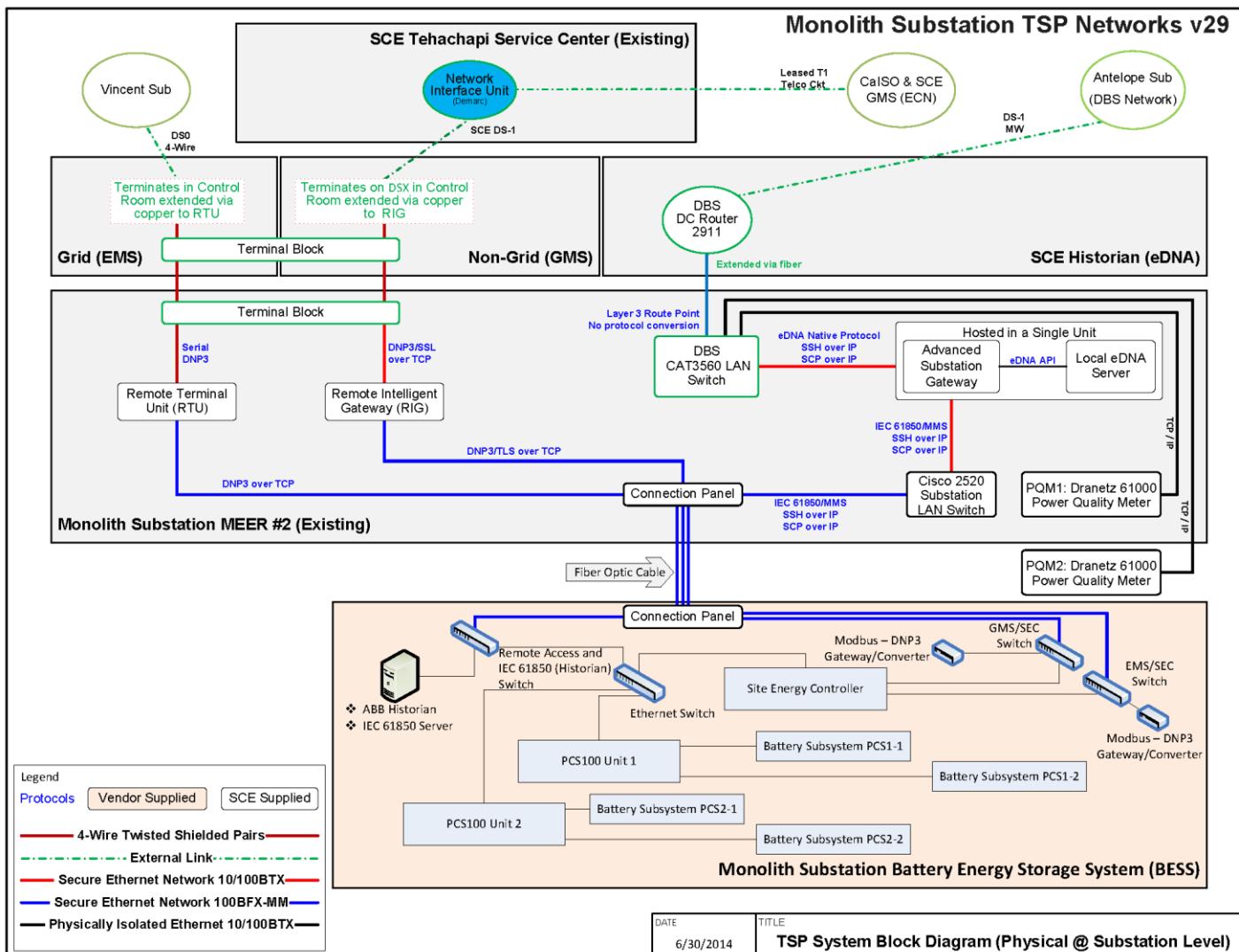
Figure 3-4 Data Acquisition System

4 Measurement and Validation Strategy

4.1 Methodology and Approach

The TSP BESS was installed on the sub-transmission system at the Monolith substation 66 kV bus. The BESS system data collected was used to help SCE quantify the TSP's potential effects on transmission capacity and load requirements and thereby allowed SCE to evaluate the ability of the BESS to reduce congestion and improve the integration of wind generation into the grid. The project team analyzed the data that was archived continuously from the Supervisory Control and Data Acquisition (SCADA) historian database as its primary source, while using data sources from event-driven substation recording devices to supplement the analysis. Formal testing began in January 2015 and continued through December 2016.

An M&V Test Plan was developed to evaluate the effectiveness of the BESS in the Monolith substation in accordance with the MBRP. The testing protocol of eight (8) tests was developed to align with the operational use cases. The test plan specifies the data to be collected, how frequently, and what observations are critical for the analysis. The test plan and operational uses will be discussed in subsequent sections of this report.

The overall approach to M&V was to evaluate the instantaneous and steady-state or trending measurement data over a specified time period set aside for specific system tests. Using post-processing, the data was analyzed by system engineers to verify the system response as expected or observed from the simulations. It was expected that this approach will produce "big data" that will be subject to data mining techniques.

Data mining techniques were used to manage the big data to identify specific conditions that support the operational uses discussed as part of the research objectives. Since the wind generation is basically unchanged and local customer loads are relatively the same, these conditions are more than likely to occur again. Data mining techniques looks at the statistical probability of historic wind generation patterns and "predicts" when, how often and where the project team should analyze the test year data. Those prescribed periods are then identified and the BESS response is observed. The project team then determines, based on the data and observations, that the BESS response is appropriate, and whether or not it can scale up to a larger system. This approach relies on engineering experience and judgment to prove or disprove the hypothesis that a larger BESS, if in a specific location, can provide significant and measureable benefits to the surrounding system.

SCE captured data from its SCADA historian database (eDNA) which records 4-second instantaneous measurements; and a Phasor Measurement Unit (PMU) in the Monolith substation captured event data at a rate of 30 samples per second. In addition the PMU at Monolith Substation is a Digital Fault Recorder (DFR)/PMU device able not only to record RMS voltages and currents but also sinusoidal waveforms able to capture high frequency transient data.

All of the above sources provide physical data inputs to the engineering analysis which becomes the basis for the impact metrics. The project team had at its disposal a RTDS (a

parallel processor computer used to simulate the power system in real time) to simulate system performance in cases where it was physically impractical to conduct field tests in an operational substation. Additionally, when an expected event didn't occur under normal operating conditions (such as a fault, line trip, or contingency) this "test condition" was simulated and analyzed on the RTDS. More information on the use of RTDS is found in the appendices.

During 2015, the Cal State Polytechnic University Pomona team focused on Modeling & Performance studies, Data Reduction & Analysis, and discussed some R & D Projects with faculty and students. The Pomona team subsequently designed, developed and tested some different examples of the system. The team reviewed test results and built a small prototype system which was documented as a comprehensive tutorial that would be beneficial for anyone that is either new to the RTDS or for use as a refresher course.

In addition to the RTDS, SCE utilized General Electric Positive Sequence Load Flow (PSLF) steady-state and dynamic modeling to observe system conditions in a simulation environment for the same reasons the RTDS was used. PSLF is a standard tool utilized by operation engineers and transmission planners on which system performance is evaluated under various contingencies. It was early PSLF studies which identified the current location of the BESS for its potential benefits to the adjacent wind farms due to transmission contingencies. More information on the use of PSLF is found in the appendices.

Some system conditions were expected under normal operating conditions such as high wind generation and a low local load which produce a large amount of export energy from the region. Based on past experience, these periods are predictable and are anticipated. Although these conditions historically have produced stress on the system, it does not demonstrate the type of stress caused by a system event such as a fault or by wind gusts causing unusually high wind ramp rates. Therefore, the approach is to capture data for both types of scenarios. SCADA data is the primary source for steady-state or trend data, while the PMU and DFR will be the primary source for transient type event.

Project TPRs also provide information about wind generation availability, variability, and capacity. Working with the CAISO, SCE evaluated the ability of the BESS smart inverter to follow operator and market signals to provide ancillary services and arbitrage market prices. To that end, some non-EMS data was observed and analyzed for its relation to BESS performance.

The ability of the BESS to respond to CAISO market signals or its ability to follow a prescribed schedule as a result of being awarded for an acceptable bid into the market was examined. The intent of the first year of operation was to let the SCE Trading and Market Operations Group simulate market awards and dispatches to the BESS control system. The Trading and Market Operations Group observed the operation of the BESS to respond to CAISO signals via the RIG and made an assessment whether the BESS would pass CAISO requirements as a market resource.

During year 2 of the BESS field test, the SCE Trading and Market Operations Group took the lessons learned from initial operations and actually bid the BESS into the CAISO market with real financial implications and exposure. This activity was conducted under the close scrutiny of the project team while monitoring the BESS performance and benefits under real market conditions. In summary, the ability of the BESS to bid into the market was examined into two parts. Part 1 was a simulation of market dispatch signals and AGC signals that represent flat schedules and varied AGC signals. Part 2 was an actual market based demonstration that had Bids, Awards, and Dispatches from the ISO systems as if it was a wholesale market resource. This included all the groups in SCE's Energy Procurement & Management (EP&M) from market planning to settlements.

During the final phase of testing, the BESS was added as a commercial resource and participated in the CAISO wholesale market. During this phase of market participation, the system was operated in to maximize the opportunities for learning, as opposed to an optimization strategy for market revenue.

Additionally, key performance factors for BESS applications such as energy capacity degradation, round trip efficiency, and thermal performance are reported.

4.2 Operational Uses

As referenced previously, SCE identified operational uses to be evaluated as part of the TSP. Each of the 13 use cases and the associated evaluation methodology are summarized below. Modeling and/or simulation may be used in some instances to scale results to better understand potential and other impacts of the BESS.

4.2.1 Transmission Uses

4.2.1.1 Voltage Support/Grid Stabilization

Steady state and dynamic voltage regulation testing will be conducted locally (Monolith 66 kV bus voltage profile). This will provide data for real and reactive power (power factor), and storage system dispatch metrics. Existing EMS SCADA data collection systems, along with PMU/Digital Fault Recorder (DFR)/Power Quality Monitor (PQM) devices will be used to collect and archive event data. PSLF and the RTDS will be used for simulation and validation.

4.2.1.2 Decreased Transmission Losses

Transmission losses for the affected system under study will be evaluated by monitoring real-time transmission line loading. Existing EMS SCADA data collection systems, along with PMU/DFR/PQM devices will be used to collect and archive field data. The RTDS will be used for simulation and validation.

4.2.1.3 Diminished Congestion

Effectiveness of the BESS to diminish congestion will be measured by the reduction of transmission line loading wind generation curtailment and/or the frequency of wind

curtailment events. This will be provided through system operator control of on-peak charging and off-peak discharging of the BESS. Existing EMS SCADA data collection systems along with PMU/DFR/PQM devices will be used to collect and archive data. The RTDS will be used for simulation and validation.

4.2.1.4 Increased System Reliability by Load Shed Deferral

Effectiveness of the BESS to increase system reliability through load shed deferral will be measured by the reduction of load shedding events and increased power flow into the area. This will be provided through system operator control of the storage system; charging during high wind and discharging during low wind. Existing EMS SCADA data collection systems along with PMU/DFR/PQM devices will be used to collect and archive data. The RTDS will be used for simulation and validation.

4.2.1.5 Deferred Transmission Investment

The suitability of the BESS to allow for deferred transmission investment will be evaluated as part of the TSP. Transmission load profile and storage system dispatch data will be collected to determine transmission line loading, transmission losses, congestion, and congestion costs. Comparison of this data against current transmission plans will provide a means to support deferral of transmission investment. Existing EMS SCADA data collection systems along with PMU/DFR/PQM devices will be used to collect and archive data. The RTDS will be used for simulation and validation. It should be noted that since the initiation of this project, SCE has completed a large transmission investment in this area, which may reduce the ability to evaluate this usage.

4.2.1.6 Optimized Size and Cost of Renewable Energy-Related Transmission

The ability to reduce cost and optimize size of renewable energy related transmission will be measured by comparing the projected differences in the required transmission line capacity. Wind generation profiles and storage dispatch data will be used to draw these comparisons.

4.2.2   System Uses

4.2.2.1 Provide System Capacity/Resource Adequacy

System capacity and resource adequacy will be evaluated based on the required generation reserves relative to total wind generation injecting power into the Monolith substation. Pre and post installation values will be compared to determine the effect of the BESS.

4.2.2.2 Renewable Energy Integration (Smoothing)

Power output and voltage fluctuations before and after BESS installation will be compared to determine the effect of the BESS. Existing EMS SCADA data collection systems along with PMU/DFR/PQM devices will be used to collect and archive data. The RTDS will be used for simulation and validation.

4.2.2.3 Wind Generation Output Shifting

Our objective is to determine the BESS's ability to shift wind generation output from lower cost off-peak times to higher cost, on-peak times. The battery will be charged at night and discharged during the day. The cost difference between energy during discharge and charge cycles will be evaluated to determine the benefits.

4.2.3 CAISO Market Uses

4.2.3.1 Frequency Regulation

Our objective is to determine if the BESS can provide frequency regulation as directed by CAISO Automated Generation Control (AGC) signal. The results will demonstrate the system's ability to follow schedule.

4.2.3.2 Spin/non-Spin Replacement Reserves

The objective is to determine if the BESS can supply power in non-spinning and spinning situations as directed by the CAISO automated dispatch system (ADS) signal. The evaluation will determine the quantity and financial value of displaced operating reserves.

4.2.3.3 Deliver Ramp Rate

The output from the BESS controller will be monitored to verify the ability to follow CAISO signals. The accuracy will be expressed in terms of the percentage deviation from schedule.

4.2.3.4 Energy Price Arbitrage

The cost difference between energy during discharge and charge cycles at both peak and off-peak hours will be evaluated. The output from the BESS controller will be monitored to verify the ability to follow CAISO market signals.

4.3 Baseline Development

4.3.1 Overview

Baseline development was completed during the second half of 2014. Collection of baseline data for the project includes data from the region before and after the recent system upgrades. Establishing a baseline set of conditions of the system prior to BESS connection, and providing monthly status updates and periodic update reports as to trends and findings, are important aspects of the original plan for this project. Baseline report data and information were used in Technical Performance, Impact Metrics, and Final Reports defined by the MBRP. The Baseline Data Analysis & pre-M&V modeling is specifically tailored to support the requirements of the TSP Test Plan. For reasons set forth below, the approach for developing and using a baseline was revised, due to changes in the transmission system in the Tehachapi area.

4.3.2 The Role of a Baseline in Measurement and Validation for the TSP Performance Evaluation

A baseline is a set of measured values before a test is conducted, against which comparable values collected during the test are to be compared to verify that changes in system response to the test can be validly attributed to the TSP and not to changes in other conditions. Therefore, the purpose of a baseline is to set a standard of system response to events if the TSP were not in service. Such events are of four types:

1. **Spontaneous events**. Examples include faults, unintended line trips, load changes, and excursions in wind speed affecting generation.
2. **Operational actions**. These are intentional changes affecting other system elements for reasons unrelated to the operation or testing of the TSP. Examples include changed generation dispatch, voltage targets, line or capacitor status, transformer taps.
3. **System response tests**. These involve intentional changes to other system elements to which the TSP is to respond which will be followed by a reversal to bring the system back to its prior condition. The actions performed are similar to type 2 above but the intent is to test the TSP.
4. **Local tests**. These involve intentional changes in the set points or dispatch of the TSP itself, to be followed by a reversal to bring the system and the TSP back to their prior condition.

Events of the first and second types occur routinely during the operation of a power system. The intentional changes in the third type of event can be applied during either baseline or test conditions. Events of the fourth type are not meaningful unless the TSP is in service.

4.3.3 Requirements for a Valid Baseline

A baseline is valid if and only if system conditions have not been changed in a way that will affect the values recorded. The data collected in years 2010-2011 for the Tehachapi area includes some variables, such as local load and wind generation, which are expected to follow similar patterns in the future, because the installed equipment and the climactic conditions are not known to have experienced material change. However the installation of new 230/66 kV transformers at Windhub, the separation of the Antelope – Bailey area into two parts, and the reconfiguration of the 66 kV lines in the Tehachapi area to radially feed into Windhub (together referred to as the Eastern Kern Wind Resource Area - EKWRA Project) mean that the data collected is not a valid baseline for such quantities as congestion and voltage.

4.3.4 Alternatives to Use of Historical Data as a Baseline

Not all of the tests to be performed would depend on a baseline even if one were available. Several tests to demonstrate the response of the system to a signal from the CAISO to the

TSP cannot be compared to a baseline, as if there were no TSP there would be nothing to send the signal to.

One type of baseline which can be applied is to utilize the TSP for only a portion of a test and compare responses during the two periods. Some tests are designed to be conducted during special conditions such as a certain combination of wind generation and load, it is beneficial to compare the system response with and without TSP for a portion of the test since it can fully utilizing the limited occurrence of the required condition.

Due to the EKWRA project strength the system in the area, it is possible that the impact of BESS is not as significant as in the initial engineering studies and analysis of the transmission assets in the Tehachapi region. As needed, it is beneficial to form the baseline by simulating the effect of a test using PSLF and to compare the simulated response to that observed in the field.

4.4   Data Collection and Analysis

Energy Management System (EMS) SCADA historical data was available to the project for the transmission system and for the wind farms. EMS SCADA data in conjuction with data collected during the year prior to BESS operation, was used to establish baseline information. This baseline data was also used to determine optimum periods for specific tests. The EMS SCADA will capture transmission system data needed to demonstrate the ability of the BESS to perform the 13 operational uses and to assess the value of the BESS's benefit. SCE has defined eight tests that were conducted during the demonstration period. Data obtained from these eight tests were used in different combinations to demonstrate the BESS's ability to perform against the 13 operational use cases.

Briefly, the eight tests were designed to measure the BESS's ability to respond to the following system needs or signals:

1) Provide steady state voltage regulation at the local Monolith 66 kV bus
2) Provide steady state voltage regulation at the local Monolith 66 kV bus while performing any other tests
3) Charge during periods of high wind and discharge during low wind under SCE system operator control
4) Charge during off-peak periods and discharge during on-peak periods under SCE system operator control
5) Charge and discharge seconds-to-minutes as needed to smooth intermittent generation in response to a real-time signal
6) Respond to CAISO control signals to provide frequency response
7) Respond to CAISO control signals to provide spin/non-spin reserves
8) Follow a CAISO market signal for energy price

SCE expected that each of the above tests will be conducted independently. In addition, some of the tests were conducted concurrently in various combinations (stacking) to develop an

understanding of an operator's ability to deploy the BESS for multiple operational uses simultaneously. The ability to respond to multiple uses will be an important factor in determining the cost effecetivness of the battery system. The table below shows which tests are expected to provide data for each of the operational uses.

Operational Use		Test							
		1	2	3	4	5	6	7	8
Transmission	1	X	X						
	2			X					
	3			X					
	4			X					
	5			X		X			
	6			X		X			
System	7				X				
	8					X			
	9				X				
CAISO Market	10						X		
	11							X	
	12						X	X	
	13								X

Table 4-1 System Test and Operational Use Matrix

4.4.1 Steady State Data Collection

The principal source for system steady state data is the EMS SCADA data historian which records 4 second instantaneous values continuously. This data, which is time stamped, is archived for the duration of the project in a separate server for this data called eDNA. eDNA is the corporate depository of practically all electrical measurements providing ample data to support analyses of the battery system's effect on the grid system as a whole.

Transmission data captured during these tests includes:

- Wind generation
- 66 kV substation bus voltages at Monolith and Windhub
- Loading on the following transmission lines
  - Monolith – Breeze 66 kV line 1 and 2
  - Monolith – Cummings 66 kV line
  - Monolith – Loraine 66 kV line
  - Monolith – Cal Cement 66 kV line
  - Monolith – MidWind 66 kV line
  - Monolith – ArbWind 66 kV line

In addition to the physical data, non-EMS data such as information provided by CAISO were captured during these tests include:

- Frequency response requirements and the response provided by the BESS over time
- Spin/non-spin reserve requirements and the response provided by the BESS over time
- Generation reserve requirements and the response provided by the BESS over time
- Energy price signals and the charge and discharge patterns of the BESS

This data was archived in the Generation Management System (GMS) market system.

BESS data measurements collected in the Data Acquisition System (DAS) are shown in the table below:

DAS		GMS
Operational Mode	Battery System SOC	MW Availability
Import Energy Signal	(State of Charge)	Market Awards
Export Energy Signal	Response Time	Mode of Control
Power Input (MW)	Number of Cycles	Outage Information
Power Output (MW)	Harmonics	GMS/CAISO control
Voltage	Hourly Electricity Price	signals
Reactive Power	Energy (MWh)	
(MVAr)	Frequency	
Power Factor	Current (A)	

Table 4-2 BESS Data Collection

4.4.2   Transient Event Data Collection

In the event that a system fault or disturbance impacts the Monolith substation and adjacent substations, the EMS data collection would be inadequate to record the data due to its short duration of the event. Typically system disturbance duration is less than a second; therefore, an EMS 4 second scan could not see this event in its entirety.

These types of events cause chain reaction of events such as low voltage on substation busses and lines, tripping early versions of installed wind generation, and if severe enough, tripping of customer loads. Specialized equipment such as PMU and DFR and local PQM devices were used to record data at high sampling rates as required, capturing event data with sufficient detail for post event analyses by project system engineers. The PMU captured voltage and phase angle at 30 samples per second. The DFR sampling rate was 30 samples per second providing even more detail at the substation bus. This data was captured in data files available to the project team for more extensive examination.

5 Measurement and Validation Test Plan Summary

5.1 Baseline Data Analysis

Two years (2010 through 2011) of data was collected and analyzed to guide the project team for the optimum times to implement specific tests. For example, system engineers recalled that problems in the system exacerbated during times of high wind generation and low local load. The baseline data provided insight as described below on the seasonality and time of day sensitivity for the voltage tests. This data included:

EMS Data:
  i. Monolith Substation 66 kV bus voltage
  ii. Monolith Capacitor Bank Status
  iii. Monolith substation real power profiles
  iv. Line load profiles on seven 66 kV transmission lines of interest :
  - Monolith – Sub Tran Lines BO-HA-LO-WB (Monolith – Loraine line)
  - Monolith – Sub Tran Lines BREEZE1
  - Monolith – Sub Tran Lines BREEZE2
  - Monolith – Sub Tran Lines CAL-GOL-WIN (Monolith – MidWind line)
  - Monolith – Sub Tran Lines CAL-ROS-WIN (Monolith – ArbWind line)
  - Monolith – Sub Tran Lines CAL-WINDP (Monolith – Cal Cement line)
  - Monolith – Sub Tran Lines CUMMINGS
  v. Area wind farm generation profiles.

Non EMS Data:
  vi. Area wind farm curtailments requiring compensation
  vii. System disturbance
  viii. CAISO locational marginal pricing

Statistical methodologies were used to analyze two-year's data. The collected load data was normalized to the peak value observed, termed a "load factor". The normalized data was summarized for time periods distinguished by:

- Calendar month
- Period within the day: six four hour periods, period 1 beginning at midnight and ending at 4:00 AM, period 2 beginning at 4:00 AM and ending at 8:00 AM, etc.

Wind generation data was normalized and summarized for the same periods. The resulting metric is referred to as a capacity factor. Detailed analyses are presented in the Appendices.

5.2 M&V Analysis Assumptions

The Test Plan assumed the BESS would always be operated within the specifications given by the manufacturer, and with safety constraints determined by SCE. The BESS would be taken off-line in any circumstance that places additional stress on the system, or when it may

interfere with system operations or grid reliability. When bidding into the CAISO market, the BESS would be operated and scheduled in accordance with established procedures like any other CAISO resource. It was expected that lessons learned in early testing will inform future tests, particularly as they relate to market participation. As such, financial constraints and expectations during year 1 of operation would be appropriately measured.

When applicable the project ran numerical model simulations of the each test. System variables (voltages, currents, power flows) predicted by simulation models were made available to grid operations.

5.3 Mini-System

Contractual requirements for substantial acceptance included manufacturer delivery of a Mini-System for testing, evaluation, and acceptance by SCE. The Mini-System replicated all major hardware, software, and firmware components present in the full system, including the batteries, BMS, PCS modules, PCS controls, Site Energy Controller (SEC) controls, and communication paths within and between these components. This enabled SCE to test the overall design, quality, safety, and reliability of the system's final integration prior to commissioning or energizing the full system. This approach had the advantage of avoiding significant limitations to performing the same tests on the full system, including the difficulty in working out software/firmware bugs with the manufacturer outside of a controlled laboratory environment, the need to exchange significant power and energy at will, the remote location of the site, the availability of laboratory facilities, equipment, and personnel, and the ability to perform tests that would be hazardous or potentially detrimental to the full system.

The original Mini-System was delivered and installed at the SCE Pomona facility in October 2013 as a 30 kW, 116 kWh system comprised of two racks, one bank, and one battery section. This original build was extremely useful in supporting full system startup and commissioning, but only had one battery section and one PCS inverter lineup. This limited the ability of engineers to test the multi-inverter lineup/battery section operation of the system in the laboratory, such as inter-section balancing controls, multi-PCS operation, and symmetrical/unsymmetrical operation of the inverter lineups. Therefore, the Mini-System was expanded in December 2015 to include twice the number of each component, resulting in a system with two PCS controllers, inverter lineups, and battery sections, as shown below. This expansion even more closely resembled the full system, and will allow engineers to study the long-term effects of operating multiple, independent battery sections in parallel.

Mini-System characteristics include the following:

Original Build (October 2013)	Expansion (December 2015)
• 77 sq. ft. footprint • 30 kW • 116 kWh • 1 mini Power Conversion System cabinet • 1 Section • 1 Bank • 2 Racks • 36 Modules • 2,016 Cells	• 154 sq. ft. footprint • 60 kW • 232 kWh • 2 mini Power Conversion System cabinets • 2 Sections • 2 Banks • 4 racks • 72 modules • 4,032 Cells

A Mini-System test plan was developed by SCE energy storage engineers, and was divided into two phases. The first phase focused on the safety and expected behavior of the batteries and BMS during interruptions to various communication paths during system startup and operation. The first phase also consisted of intentionally changing the BMS's warning and fault thresholds to confirm the system was capable of recognizing operation outside of these limits, and its ability to take appropriate action to reach a stable, safe condition without manual intervention. SCE required successful completion of the first phase before allowing the manufacturer to finish commissioning or energize the full system. The second phase of testing consisted of performing system acceptance tests on the Mini-System to confirm overall correct operation of the SEC control algorithms, test modes, and system response prior to performing the same tests on the full system. This had the added advantage of being able to refine and make improvements to the system acceptance test plan itself prior to final, official performance on the full system.

5.4 System Acceptance Test Plan

Similar to the Mini-System, contractual requirements for substantial acceptance called for the full system to pass a series of system acceptance tests as defined in the System Acceptance Test Plan jointly developed by SCE, the manufacturer, and the PCS/SEC/controls subcontractor. The test plan included five tests to verify compliance with the contractually specified performance parameters, as well as seven tests to confirm the proper operation of the SEC control algorithms that would be used throughout the M&V period. The individual system acceptance tests were:

- Performance and Capabilities
  1. Real/reactive power dispatch accuracy
  2. Sustained full real/reactive power dispatch capability
  3. Real power discharge capacity and duration
  4. Real/reactive power ramp rate
  5. Automatic battery section balancing
- SEC Control Algorithms
  1. Test 1: Steady State Voltage Regulation

2. Test 3: Charge During High Line Load/Discharge During Low Line Load
3. Test 4: Charge Off-peak/Discharge On-peak
4. Test 5: Charge and Discharge as Needed for Grid Purposes
5. EMS–GMS Transition
6. EMS and GMS Communication Fault Handling
7. Manual and CAISO Power Dispatch

5.5 Characterization Test Plan

The System Acceptance Tests performed in July 2014 (see Section 6) included a capacity test that measured the dischargeable energy of the system. However, this test did not measure round trip efficiency, nor did it operate the system under realistic, frequent cycling profiles. The purpose of the system Characterization Test Plan is to characterize the behavior and performance of the system during frequent full charge/discharge cycles at 8 and 4 MW. Power, energy, efficiency, and temperature data from the battery system, PCS, and PCC will be analyzed.

5.5.1 Charge/Discharge Duration Test

During the System Acceptance Tests, the system took four hours (+/- one minute) to discharge from 98% SOC to 2.5% SOC (the full operating range) at 8 MW (see Section 6 and Appendix I). From this, the TSP team concluded that the system will take no more than eight hours to discharge over the same range at 4 MW. However, the System Acceptance Tests did not demonstrate the amount of time the system takes to charge from 2.5% SOC to 98% SOC, at either 8 or 4 MW. The purpose of the Charge/Discharge Duration Test is to determine the current charge and discharge durations of the system at 8 and 4 MW, in order to optimize the SEC Test 4[2] On/Off Peak schedules for the Cycle Tests below.

1. Using Fully Discharge BESS, the system will discharge at 8 MW to a full discharge.
2. After a minimal rest period (less than 15 minutes) with Fully Discharge BESS still on, using Fully Charge BESS, the system will charge at 8 MW to a full charge.
3. After a minimal rest period (less than 15 minutes) with Fully Charge BESS still on, using Fully Discharge BESS, the system will discharge at 8 MW to a full discharge.
4. After an optional rest period, using SOC Control, the system will charge to approximately 30 % SOC.
5. Steps 1 through 4 will be repeated at least once, and no more than once per day.
6. Steps 1 through 5 will be repeated at 4 MW.

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[2] SEC Test 4 refers to a specific BESS operating mode that includes a schedule function.

5.5.2   8 MW Cycle Test

The purpose of the 8 MW Cycle Test is to characterize the behavior and performance of the system during frequent full charge/discharge cycles at 8 MW, with a daily rest at 30 % SOC. Prior to starting the test, the SEC Test 4 On/Off Peak schedules should be optimized using the results of the Charge/Discharge Duration Test. The schedules include two continuous charge/discharge cycles over the entire SOC operating range (2.5–98 % SOC), as well as a rest period at 30 % SOC. This rest period fills the gap between the end of a day's two full-range charge/discharge cycles and the start of the next day's cycles. This gap is not long enough to include a third complete cycle, and the SEC Test 4 scheduler is not capable of creating a rolling schedule that spans multiple days.

1. Using SCE Test 4 and the On/Off Peak schedules below, the system will charge/discharge at 8 MW for at least one week.

	Day of week		Time		
Sequence/Description	Start	Stop	Start	Stop	Duration (h:mm)
1. Full discharge from ~30 % SOC	Su	Sa	0000	0130	1:30
3. Full discharge	Su	Sa	0600	1015	4:15
5. Full discharge	Su	Sa	1445	1900	4:15

Table 5-1 SEC Test 4 on Peak Schedule

	Days		Times		
Sequence/Description	Start	Stop	Start	Stop	Duration (h:mm)
2. Full charge	Su	Sa	0130	0600	4:30
4. Full charge	Su	Sa	1015	1445	4:30
6. Partial charge to ~30 % SOC	Su	Sa	1900	2015	1:15

Table 5-2 SEC Test 4 off Peak Schedule

5.5.3   4 MW Cycle Test

The purpose of the 4 MW Cycle Test is to characterize the behavior and performance of the system during frequent full charge/discharge cycles at 4 MW, with a daily rest at approximately 30 % SOC. Prior to starting the test, the SEC Test 4 On/Off Peak schedules should be optimized using the results of the Charge/Discharge Duration Test. The schedules include one continuous charge/discharge cycle over the entire SOC operating range (2.5–98 % SOC), as well as a rest period at 30 % SOC. This rest period fills the gap between the end of a day's full-range charge/discharge cycle and the start of the next day's cycle. This gap is not long enough to include a second complete cycle, and the SEC Test 4 scheduler is not capable of creating a rolling schedule that spans multiple days.

1. Using SEC Test 4 and the On/Off Peak schedules below, the system will charge/discharge at 4 MW for at least two weeks.

	Day of week		Time		
Sequence/Description	Start	Stop	Start	Stop	Duration (h:mm)
1. Full discharge from ~30 % SOC	Su	Sa	0000	0245	2:45
3. Full discharge	Su	Sa	1115	1930	8:15

Table 5-3 SEC Test 4 on Peak Schedule

	Days		Times		
Sequence/Description	Start	Stop	Start	Stop	Duration (h:mm)
2. Full charge	Su	Sa	0245	1115	8:30
4. Partial charge to ~30 % SOC	Su	Sa	1930	2200	2:30

Table 5-4 SEC Test 4 off Peak Schedule

5.5.4   8 MW Cycle Test without Approximately 30 % SOC Rest

The purpose of the 8 MW Cycle Test without Approximately 30 % SOC Rest is to characterize the behavior and performance of the system during continuous full charge/discharge cycles at 8 MW, without a daily rest at approximately 30 % SOC. Prior to starting the test, the SEC

On/Off Peak schedules should be optimized using the results of the Charge/Discharge Duration Test.

The SEC On/Off Peak schedules define up to four unique on/off peak periods, resulting in only 1.5 days of continuous full charge/discharge cycles at 8 MW. Due to this limitation, the SEC On/Off Peak schedule must be updated at least once every 1.5 days to maintain continuous full charge/discharge cycles at 8 MW for any test duration greater than 1.5 days. Furthermore, the SEC On/Off Peak schedule must be updated without interrupting the continuous full charge/discharge cycles. This is achieved by updating the SEC On/Off Peak schedules during the brief period of time between the end of a full discharge and the beginning of a full charge, when the system is still trying to discharge, but is limited to zero active power discharge, due to all four battery section current discharge limits equaling zero (i.e., just before the end of an SEC on peak period).

1. Using Test 4 and continuous SEC On/Off Peak schedules, the system shall continuously and fully charge/discharge at 8 MW for at least one week.

5.6 TSP Market Telemetry Testing

The objective of Market Telemetry testing was to assess the ability of the resource to follow automated dispatch instructions in a simulated environment. The first round of testing involved building hourly schedules and feeding those into the Schedule Follow Mode (SFM) of the control software. System performance was then assessed as the resource responded to those hourly changes.

SFM is a base configuration that is used when the control system loses communication with the primary dispatch signal. It is not normally a primary mode of operation. The SFM logic uses the market hourly block structure protocol. That protocol starts the next hour's ramp 10 minutes prior to the flow hour and completes 10 minutes after the start of the flow hour. It then holds that scheduled value until the next hourly interval and repeats.

Automated Generation Control (AGC) simulation testing was then performed using a randomized setpoint program to simulate four second CAISO Energy Management System (EMS) requests. AGC control mode is used to provide regulation ancillary services. The system was expected to follow all set points and achieve MW values as instructed within the safety permissives of the BESS control system. The tests were designed to dispatch the BESS system at various levels and durations for the entire day acting as a typical market resource following and four second AGC setpoint instructions, simulating regulation ancillary services.

5.7 Test 1 Provide Steady State Voltage Regulation at the Local Monolith 66 kV Bus

Overview: This test will examine the BESS' ability, in a reactive power control mode, to respond with ±4 MVAr of nominal capability to maintain AC voltage on the 66 kV Monolith substation bus within steady-state (± 5%) range.

Primary Method of Performing Test	Operate passively in background, absorbing or supplying reactive power as required to hold voltage set-point
Expectations for this test not expected for all tests	Correlate reactive power output with voltage response at 66 kV bus
Preconditions for this test not required for all tests	Coordinate schedule with operational sequence for capacitor banks
Simulation	Real Time Digital Simulation with Hardware in the Loop (RTDS) 1. Representing voltage, generation and load values before test. 2. With BESS at changed voltage setpoint. 3. With capacitor switched off, BESS off 4. With capacitor off, BESS at maximum MVAr injection.

Timing of test	▪ High and low expected wind generation
	     ○ High wind months are May and June.
	     ○ Low wind months are from September through February
	     ○ March, April, September and October vary from year to year.
	 ▪ High and low expected local load

Duration of test	At a minimum, until bus voltage has stabilized at the command value. A minimum of one hour is suggested to demonstrate the ability to sustain the scheduled MVAr flow
Data to be collected	▪ 66 kV Monolith bus voltage profile ▪ Storage dispatch (BESS reactive power output)
Relevant DOE Metrics	▪ Reactive power at BESS 66 kV connection ▪ Storage Dispatch
Operational Uses	Voltage support/grid stabilization
Expected Results and Benefits	Monolith bus voltage expected to respond with up to 5% change in value in response to BESS discharging. The percentage change will depend on the system topology and wind generation level.

Test Results	Tests began in 2015 and results to be reported in the final Technology Performance Report.

Table 5-5 Test 1 Plan Procedure

Test Data	Source	Units	Sample Rate
Monolith 66 kV bus voltage	eDNA	kV/kVAr	4 seconds
BESS State of Charge (SOC)	eDNA	%	Better than 5 minutes
Voltage Response Curves	PMU/PQM	kV	30 samples per second

Table 5-6 Test 1 Source of Test Data

5.8 Test 2 Steady State Voltage Regulation Under Any Mode

Overview: Similar to Test 1, the BESS will be operated in a reactive power control mode to test its ability to automatically maintain AC voltage on the 66 kV Monolith substation bus within steady state (+/-) 5%) range. However, the test examines BESS' ability to control voltage as a voltage compensation device while obeying real power dispatch commands instead of as a dedicated voltage compensator in Test 1.

Primary Method of Performing Test	Operate passively in background, absorbing or supplying reactive power as required to hold voltage set-point
Expectations for this test not expected for all tests	Correlate reactive power output with voltage response at 66 kV bus
Preconditions for this test not required for	Coordinate schedule with operational sequence

all tests	for capacitor banks
Simulation	Real Time Digital Simulation with Hardware in the Loop (RTDS) 1. Representing voltage, generation and load values before test. 2. With BESS at changed voltage setpoint. 3. With capacitor switched off, BESS off 4. With capacitor off, BESS at maximum MVAr injection.

Timing of test	■ High and low expected wind generation
	    ○ High wind months are May and June.
	    ○ Low wind months are from September through February
	    ○ March, April, September and October vary from year to year.
	 ■ High and low expected local load
	 ■ Real power BESS modes: charging, discharging, and inactive

Duration of test	At a minimum, until bus voltage has stabilized at the command value. A minimum of **one hour** is suggested to demonstrate the ability to sustain the scheduled MVAr flow
Data to be collected	■ 66 kV Monolith bus voltage profile ■ Storage dispatch (BESS real and reactive power output)
Relevant DOE Metrics	■ Real and reactive power at BESS 66 kV connection ■ Storage Dispatch
Operational Uses	Voltage support/grid stabilization
Expected Results and Benefits	Monolith bus voltage fluctuation will be reduced greatly in response to BESS voltage support and the number of switching operations for the substation shunt capacitors will be greatly reduced (reduce the maintenance requirements).
Test Results	Tests began in 2015 and results to be reported in the final Technology Performance Report.

Table 5-7 Test 2 Plan Procedure

Test Data	Source	Units	Sample Rate
Monolith 66 kV bus voltage	eDNA	kV/kVAr	4 seconds
BESS State of Charge (SOC)	eDNA	%	Better than 5 minutes
Voltage Response Curves	PMU/PQM	kV	30 samples per second

Table 5-8 Test 2 Source of Test Data

5.9 Test 3 Charge During Periods of High Loading for the Export Lines And Discharge During Low Loading Periods Under SCE System Operator Control

Overview: This test is primarily designed to demonstrate the BESS operation to mitigate line congestion by charging during periods of high line loading and discharging during periods of low line loading.

Primary Method for testing high/low load operation	Operational control center operates the BESS in appropriate configured mode for a specified duration
Expectations for this test not expected for all tests	▪ Mitigate high line loading utilizing full capacity of the BESS.
Preconditions for this test not required for all tests	▪ BESS is fully discharged (for charging) or charged (for discharging) at start of tests of steady state operation. ▪ Coordination with Grid Operations Center about line outage conditions.
Simulation	Real Time Digital Simulation with Hardware in the Loop (RTDS) 1. Representing voltage, generation and load values before test. 2. With BESS at changed MW setpoint, dispatched against generation external to Tehachapi area.

Timing of test	▪ High expected wind generation for charging
	   o High wind months are May and June.
	▪ Low expected wind generation for discharging
	   o Low wind months are from September

	through February ■ The test should be repeated under high and low expected load conditions.
Duration of test	For steady state tests, a four hour period is required to fully charge or discharge at maximum rate. Consideration should be given to charging/discharging at a lower rate for a longer time to demonstrate this capability

Data to be collected	■ Transmission loads on the following 66 kV lines.
	    ○ Monolith – Breeze line 1 & 2
	    ○ Monolith – Cummings line
	    ○ Monolith – Loraine line
	    ○ Monolith – Cal Cement line
	    ○ Monolith – MidWind line
	    ○ Monolith – ArbWind line
	■ Wind generation profile
	■ Wind generation curtailment requiring compensation
	■ CAISO price data
	■ Storage dispatch

Relevant DOE Metrics	■ Transmission line load ■ Transmission losses ■ Congestion and congestion cost ■ Storage dispatch
Operational Uses	■ Decreased transmission losses ■ Diminished congestion ■ Increased system reliability by load shed deferral ■ Deferred transmission investment ■ Optimized size and cost of renewable energy-related transmission
Expected Results and Benefits	Lines flow expected to respond with 5-25% change in line flow values in response to BESS (dis)charging. The percentage depends on the system topology wind generation and load level during the discharge period.
Test Results	Tests began in 2015 and results to be reported in the final Technology Performance Report.

Table 5-9 Test 3 Plan Procedure

Test Data	Source	Units	Sample Rate
Circuit breaker loads	eDNA	MWh/MVAr	4 seconds
BESS State of Charge (SOC)	eDNA	%	5 minutes
Wind Farm Generation	eDNA	MWh	4 seconds

Table 5-10 Test 3 Source of Test Data

5.10 Test 4 Charge During Off-Peak Periods & Discharge During On-Peak Periods Under SCE System Operator Control

Overview: This test will store off-peak energy for use during on-peak periods to increase the amount of available wind energy used and reduce the use of energy produced by other generating sources.

Primary Method for testing high/low load operation	Operational control center dispatches operates the BESS at an appropriate configured mode for a specified level and duration
Expectations for this test not expected for all tests	▪ Time shift wind generation output from off-peak to on-peak utilizing full capacity of the BESS
Preconditions for this test not required for all tests	▪ BESS is fully discharged at start of test.
Simulation	Real Time Digital Simulation with Hardware in the Loop (RTDS) 1. Representing voltage, generation and load values before test. 2. With BESS at changed MW setpoint, dispatched against generation external to Tehachapi area.
Timing of test	▪ Off-peak periods at night & mornings ▪ On-peak during late-day and early evening ▪ Summer months
Data to be collected	▪ Transmission loads on the following lines. 　o Monolith – Breeze lines 1 & 2 　o Monolith – Cummings line 　o Monolith – Loraine line 　o Monolith – Cal Cement line to Monolith – MidWind line 　o Monolith – ArbWind line

	▪ Wind generation profile
	▪ Wind generation curtailment requiring compensation
	▪ Storage dispatch
Relevant DOE Metrics	▪ Congestion and congestion cost
	▪ Storage dispatch
Operational Uses	▪ Provide system capacity/resource adequacy
	▪ Wind generation output shifting
Expected Results and Benefits	BESS charge and discharge according to schedule shifting up to 100% of the battery energy from off-peak to on-peak
Test Results	Tests began in 2015 and results to be reported in the final Technology Performance Report.

Table 5-11 Test 4 Plan Procedure and Results

Test Data	Source	Units	Sample Rate
BESS Energy	eDNA	MWh	4 seconds
BESS State of Charge (SOC)	eDNA	%	5 minutes
Wind Farm Generation	eDNA	MWh	4 seconds

Table 5-12 Test 4 Source of Test Data

5.11 Test 5 Charge & Discharge Seconds-To-Minutes As Needed To Firm & Shape Intermittent Generation in Response to a Real-Time Signal

Overview: This test will demonstrate the BESS' ability to firm and shape the power, respond to system signals and reduce the system requirements to integrate variable energy sources from the grid.

Primary Method for test	Operational control center dispatches operates the BESS at an appropriate configured mode for a specified level and duration
Expectations for this test not expected for all tests	▪ Intermittent generation output is firmed and shaped, both in ramp up and ramp down conditions
Preconditions for this test not required for all tests	▪ Approximately 50% SOC at start of test
	▪ Set BESS in AGC/Dispatch mode

	▪ Validate market awards and schedules
Simulation	N/A
Timing of test	N/A

Data to be collected	▪ Transmission loads on the following lines
	   o Monolith – Breeze lines 1 & 2
	   o Monolith – Cummings line
	   o Monolith – Loraine line
	   o Monolith – Cal Cement line
	   o Monolith – MidWind line
	   o Monolith – ArbWind line
	▪ Wind generation
	▪ Storage dispatch

Relevant DOE Metrics	▪ Transmission line load ▪ Transmission losses ▪ Congestion and congestion cost ▪ Storage dispatch
Operational Uses	▪ Deferred transmission investment ▪ Optimized size and cost of renewable energy-related transmission ▪ Renewable energy integration (Firming and Shaping)
Expected Results and Benefits	BESS charge and discharge according to wind farm generation mitigating intermittency
Test Results	Tests began in 2015 and results to be reported in the final Technology Performance Report.

Table 5-13 Test 5 Plan Procedure and Results

Test Data	Source	Units	Sample Rate
BESS Energy	eDNA	MWh	4 seconds
BESS State of Charge (SOC)	eDNA	%	5 minutes
Wind Farm Generation	eDNA	MWh	4 seconds

Table 5-14 Test 5 Source of Test Data

5.12 Test 6 Respond To CAISO Control Signals to Provide Frequency Response

Overview: This test will demonstrate the BESS' ability to follow CAISO's control signal for Area Control Error (ACE) via the RIG (Remote Intelligent Gateway).

Primary Method for test	The Generation Management System (GMS) schedules a predetermined schedule for BESS to follow CAISO market signal via the RIG
Expectations for this test not expected for all tests	▪ BESS awarded market AGC for testing hours ▪ BESS follows CAISO AGC signals in real time
Preconditions for this test not required for all tests	▪ Connection to CAISO via RIG module ▪ BESS has been certified to provide Ancillary Services – regulation and/or spinning reserve – to CAISO ▪ BESS has been Bid and Awarded regulation ▪ BESS is capable of receiving a MW dispatch notification – for dispatch signal case ▪ Approximately 50% State of Charge at start of test
Simulation	N/A
Timing of test	Based on market award
Data to be collected	▪ CAISO operations signal for system frequency response (set point) ▪ Frequency response requirement ▪ Storage dispatch ▪ Control Mode ▪ Control Permissive ▪ High and Low range regulation values ▪ Energy schedule
Relevant DOE Metrics	▪ System Frequency ▪ Storage dispatch
Operational Uses	▪ Frequency regulation ▪ Deliver ramp rate
Expected Results and Benefits	BESS charge and discharge according to market signals within acceptable CAISO performance guidelines
Test Results	Tests began in 2015 and results to be reported in the final Technology Performance Report.

Table 5-15 Test 6 Plan Procedure and Results

Test Data	Source	Units	Sample Rate
BESS Energy	eDNA	MWh	4 seconds
BESS State of Charge	eDNA	%	5 minutes

(SOC)			
Wind Farm Generation	eDNA	MWh	4 seconds
CAISO LMP	GMS	$/MWh	hourly

Table 5-16 Test 6 Source of Test Data

5.13 Test 7 Respond To CAISO Market Awards to Provide Energy Non-Spin Reserves

Overview: This test will demonstrate the BESS' ability to respond to CAISO's market awards to provide Energy and spinning (5 minute response) and non-spinning (10 minute response) reserves. This will provide further support of improved dependability of wind resources for resource adequacy considerations

Primary Method for test	GMS schedules a predetermined schedule for BESS to follow simulated CAISO market signal via the RIG
Alternate Method for test	N/A
Expectations for this test not expected for all tests	▪ BESS awarded Energy and spin/non spin services
Preconditions for this test not required for all tests	▪ Connection to CAISO via RIG module. ▪ BESS has been certified to provide Ancillary Services – regulation and/or spinning reserve. ▪ BESS is capable of receiving a MW set point signal. ▪ BESS is capable of receiving energy dispatch "Go To" signals ▪ BESS is fully charged
Simulation	N/A
Timing of test	Based on market award
Data to be collected	▪ CAISO operations awards for spin and non-spin reserves ▪ CAISO "Go To" dispatch (ADS) ▪ GMS schedules ▪ CAISO Ancillary Services prices ▪ Spinning and non-spinning reserves requirements ▪ Storage dispatch
Relevant DOE Metrics	▪ Ancillary Services cost

	▪ Storage dispatch
Operational Uses	▪ Spin/non-spin Replacement reserves
	▪ Deliver ramp rate
Expected Results and Benefits	BESS charge and discharge according to market signals within acceptable CAISO performance guidelines
Test Results	Tests began in 2015 and results to be reported in the final Technology Performance Report.

Table 5-17 Test 7 Plan Procedure and Results

Test Data	Source	Units	Sample Rate
BESS Energy	eDNA	MWh	4 seconds
BESS State of Charge (SOC)	eDNA	%	5 minutes
Wind Farm Generation	eDNA	MWh	4 seconds
CAISO LMP	GMS	$/MWh	hourly

Table 5-18 Test 7 Source of Test Data

5.14 Test 8 Follow A CAISO Market Signal for Energy Price

Overview: This test will demonstrate the BESS' ability to respond to CAISO market signals for energy price to charge during periods of low price and discharge during periods of higher price.

Primary Method for testing high/low load operation	Bid into CAISO to buy (for charging) or sell (for discharging) during periods of high and low expected wind, respectively
Expectations for this test not expected for all tests	▪ Time shift wind generation output from off-peak to on-peak utilizing full capacity of the BESS
Preconditions for this test not required for all tests	▪ BESS is fully discharged at start of test.
Simulation	N/A
Timing of test	▪ Off-peak periods at night & mornings ▪ On-peak periods during late-day and early evening ▪ Summer months
Data to be collected	▪ CAISO Price data ▪ CAISO energy market dispatches ▪ SCE GMS MW signals ▪ Storage dispatch events with timing ▪ BESS parameters

	o Status
	o State of Charge (%)
	o Energy Available
	o Charge/discharge rate (MW/MVAr
Relevant DOE Metrics	▪ Congestion and congestion cost ▪ Storage dispatch
Operational Uses	▪ Provide system capacity/resource adequacy ▪ Wind generation output shifting
Expected Results and Benefits	BESS charge and discharge according to market signals within acceptable CAISO performance guidelines
Test Results	Tests began in 2015 and results to be reported in the final Technology Performance Report.

Table 5-19 Test 8 Plan Procedure and Results

Test Data	Source	Units	Sample Rate
BESS Energy	eDNA	MWh	4 seconds
BESS State of Charge (SOC)	eDNA	%	5 minutes
Wind Farm Generation	eDNA	MWh	4 seconds
CAISO LMP	GMS	$/MWh	hourly

Table 5-20 Test 8 Source of Test Data

5.15 Detailed Test Plans

Detailed Test Plans have been prepared for the project. The plans for the eight M&V tests are found in the Appendices.

6   Measurement and Validation Test Results and Conclusions

6.1   Status & Timing of Tests

Prior to onsite project commissioning activities, Mini-System testing was performed at SCE lab facilities. In parallel, Hardware-In-The-Loop RTDS Testing using an actual PCS controller was conducted. SCE engineers reached a level of confidence in the system through RTDS and Mini-System Testing and onsite commissioning activities were initiated to verify function and integration of system components. Subsequent to project commissioning and trial demonstration use of the BESS, System Acceptance Testing was performed in July 2014 to demonstrate that the system met all design specification and criteria. Finally, a Characterization Test Period was initiated in December 2014 to determine key characteristics of the total system. Characterization testing concluded in early 2015. Results of this characterization testing were reported in the initial TPR #1. The TSP project began initial operations and resolved various startup issues. Although multiple operating issues took some time to resolve, the project subsequently began operations of tests 1 through 8 and was able to obtain limited test results during the period of TPR #2. In 2016, the system realized higher levels of reliability and availability compared to 2015, and was able to operate in each of the test modes. Notably, the system was certified by the California Independent System Operator and began routine market operations, providing energy and ancillary services in competition with other resources. However, various system subcomponents continued to experience trips or failures, which meant that system was rarely in a stable state with full nominal power and energy availability.

6.2   Mini-System Test Results

The Mini-System was delivered and installed at SCE's energy storage laboratories in October 2013. Engineers then operated the system to gain familiarity and experience with the actual hardware, software, and firmware build, especially the integration of the various subsystem components. This experience was then used to develop the Mini-System test plan described in Section 5. Finally, the Mini-System test plan was used to start methodical Mini-System testing in November 2013.

Originally, SCE anticipated performing two or three rounds of Mini-System phase 1 testing: one to discover any software/firmware bugs, safety concerns, or suboptimal behavior, and another round or two to verify the issues were corrected by the manufacturer. However, actual phase 1 testing consisted of a total of 11 initial rounds over nine months in support of full system startup and commissioning, from November 2013 through August 2014. Each round of testing, excluding the final round, generated a BMS, PCS, and/or SEC software/firmware update to correct any issues that had been identified. Each round also consisted of a complete repeat of all Phase 1 test components, since the software/firmware updates frequently resulted in new issues or other discoveries, such as areas for improving system behavior and stability. Phase 2 testing occurred concurrently with Phase 1 in mid-2014, took approximately one month, and also included updates to the SEC firmware to refine system control logic. Furthermore, phase 2 testing allowed all parties to refine the system acceptance test plan prior to performance on the full system.

Issues identified included:

- Potential overcharging and over-discharging the battery due to incorrect BMS safety limits
- Incorrect aggregation/summarization of battery data based on the actual number of battery racks online, resulting in incorrect real-time capability/capacity limits being provided to the PCS
- Inability to recognize or take appropriate action for certain battery warnings or faults
- Failure to perform an automatic maintenance charge at low SOC, allowing the battery to self-discharge below the operating range of the PCS. This required manual, external charging of the batteries in order to restore the system to operation (this particular situation would have been extremely problematic for the full system, since there is no way to manually, externally charge all 604 racks).
- Incorrect redundant communication paths being used for inter-component communication
- Lack of recognition or appropriate response when certain communication paths were interrupted

While Mini-System testing took longer than originally anticipated, it did not significantly delay the completion of full system commissioning, since some final construction activities were still taking place at the site. Furthermore, the Mini-System testing proved invaluable to SCE, the manufacturer, and the PCS/SEC/controls subcontractor in identifying and correcting a number of issues prior to completing commissioning, energizing, or trying to perform system acceptance tests on the full system. All parties agreed that the Mini-System testing substantially reduced the number of issues that would have otherwise surfaced on the full system and caused significant delays and larger-scale problems.

Once the Mini-System passed all critical phase 1 and 2 tests, SCE allowed the manufacturer to energize the full system and exchange power to complete commissioning in early July 2014. During this time, SCE engineers continued the final rounds of Mini-System testing in preparation for system acceptance testing.

Since August 2014, SCE engineers and the manufacturer identified additional software bugs and operational issues through the operation of the full system. These prompted the development of software updates and three additional rounds of phase 1 Mini-System testing, which were completed between June and December 2015. Similar to the initial 11 rounds of phase 1 testing, these software updates were tested on the Mini-System prior to being installed on the full system.

When not performing phase 1 testing of software updates, the Mini-System was operated on a continual basis using the Test 4 schedule functionality to create two complete charge/discharge cycles per day. This cycling had the effect of creating more cycles and associated degradation on the Mini-System's two racks compared to the full system. In addition to the dc data collected by the Mini-System's BMS, engineers used AC data collection equipment on the PCS to measure changes in overall 480 Vac-AC round trip efficiency and capacity. This data was periodically collected and analyzed to track gradual changes over time.

In December 2015, the Mini-System was expanded to a total of two lineups and four battery racks. This upgrade added a second PCS, a second bank, and two additional racks, in order to simulate the multiple lineups operating in parallel in the full system. From January 7, 2016 to present, the expanded Mini-System continued the Test 4 cycling with both lineups and all four racks. During this period, PCS lineup 1 saw a total of 664 cycles and lineup 3 completed 641 cycles. The overall degradation of both lineups combined was 14.7 kWh or roughly 7.3 % from Q1 to Q4. Lineup 1 saw a degradation of 7.44 kWh or 7.77 % whereas lineup 3 saw a degradation of 7.44 kWh or 7.04 % from Q1 to Q4 of 2016.

6.3   System Acceptance Test Results

Full system acceptance testing (SAT) was performed in mid-July 2014 per the system acceptance test plan jointly developed by SCE, the manufacturer, and the PCS/control subcontractor. SAT was successfully completed on-schedule over the course of 10 workdays, due in no small part to the extensive Mini-System testing. The full system passed all SAT tests. However, a few issues surfaced including a rack BMS hardware failure, two PCS transformer cooling fan failures, and a PCS trip due to a false positive smoke detector signal.

Originally, there were concerns with the system not being able to meet the contractually required energy discharge capacity of 32 MWh at 12 kV AC. This concern was developed from the manufacturer's estimates for battery capacity degradation from the date of manufacture, as site construction, commissioning, and Mini-System testing activities were delaying the operation of the full system. However, during the last stages of commissioning involving power exchange, the manufacturer determined that actual battery degradation was not as high as originally estimated, and was actually able to reduce the system's SOC operating range from 1–100 % to 2.5–98 %. This resulted in exactly 32 MWh discharged over four hours at 12 kV AC. Table 6-1 shows the results from the system acceptance test plan for BESS capacity.

Test Plan for BESS Capacity		Cycle 1	Cycle 2	Cycle 3	Minimum	Average	Maximum	Max. % diff
Energy (MWh)	Nominal		32.00					
	Actual	31.95	32.04	32.08	31.95	32.03	32.08	0.41
	% error	0.14	0.12	0.27	0.12	0.18	0.27	
Power (MW)	Nominal		8.00					
	Actual	7.99	8.00	7.97	7.97	7.99	8.00	0.32
	% error	0.15	0.04	0.35	0.04	0.18	0.35	
Power Factor	Nominal		1.00					
	Actual	1.00	1.00	1.00	1.00	1.00	1.00	0.15
	% error	0.15	0.00	0.07	0.00	0.07	0.15	
Duration (h:mm)	Nominal		4:00					
	Actual	3:59	4:00	4:01	3:59	4:00	4:01	0:61
	% error	0.17	0.03	0.44	0.03	0.21	0.44	
SOC (%)	Nominal Start		98.00					
	Actual Start	98.70	96.78	96.85	96.70	96.78	96.85	0.15
	Nominal Range		95.50					
	Actual Range	93.40	93.38	93.35	93.38	93.44	93.55	0.19
	Nominal Stop		2.50					
	Actual Stop	3.30	3.40	3.30	3.30	3.33	3.40	2.99

Table 6-1 Results from System Acceptance Test Plan for BESS Capacity

The system acceptance test report, including results from all tests, is included in Appendix H.

6.4 Characterization Test Results

Characterization Testing was conducted in two separate periods: one in December 2014, and another from late April to early June 2015. The first period was preliminarily reported in the first TPR, but was subsequently interrupted by the battery section 1 trip and PCS 1 480 V – 12 kV transformer failure and replacement. Therefore, the first period of characterization testing was not completed as originally planned, and prompted the second period of testing. The second period of testing included a repeat of all characterization tests already completed, since one of the purposes of the characterization testing was to generate a complete performance snapshot of the system at a single point in time.

The preliminary results of the first period of testing from the first TPR are still reported below, while the results from the second period of performance testing are reported later.

6.4.1 First Period Test Results – December 2014

The Characterization Test was started in December 2014, and continued into January 2015.

The two 8 MW cycles from the Charge/Discharge Duration Test were completed on December 12 and December 14, respectively. As described in Section 5, the purpose of these cycles was

to determine the amount of time it takes the system to fully charge and discharge, in order optimize the charge/discharge schedules for the later cycle tests. Results from the two 8 MW cycles are shown in Table 6-2.

Segment	Cycle 1 (clock time, hh:mm)	Cycle 2 (clock time, hh:mm)	Max. Duration (duration, hh:mm)
Start full discharge from ~30 % SOC time	08:07	07:17	
Stop full discharge from ~30 % SOC time	09:12	08:19	
Full discharge from ~30 % SOC duration	**01:05**	**01:02**	**01:05**
Start full charge time	09:18	08:28	
Stop full charge time	13:44	12:56	
Full charge duration	**04:26**	**04:28**	**04:28**
Start full discharge time	13:47	12:57	
Stop full discharge time	17:43	16:54	
Full discharge duration	**03:56**	**03:57**	**03:57**
Start partial charge to ~30 % SOC time	17:57	16:55	
Stop partial charge to ~30 % SOC time	19:06	18:04	
Partial charge to ~30 % SOC duration	**01:09**	**01:09**	**01:09**

Table 6-2. Characterization Test, Charge/Discharge Duration Test 8 MW Cycle Results

From this, the system took a maximum of 4 hours 28 minutes to charge at 8 MW over the full SOC operating range (2.5–98 % SOC), and took a maximum of 3 hours 57 minutes to discharge immediately after finishing the charge. Maximum durations for charging/discharging at 8 MW between 2.5 and 30 % SOC are also shown. Using the results from Table 6-2, the SEC Test 4[3] On/Off Peak schedules for the 8 MW Cycle Test were optimized as shown in Table 6-3 and Table 6-4.

	Day of week		Time	
Sequence/Description	Start	Stop	Start	Stop

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[3] SEC Test 4 refers to a specific BESS operating mode that includes a schedule function.

Sequence/Description				
1. Full discharge from ~30 % SOC	Su	Su	0000	0115
3. Full discharge	Su	Su	0553	1000
5. Full discharge	Su	Su	1438	1845

Table 6-3. Optimized SEC Test 4 on Peak Schedule for 8 MW Cycle Test

	Day of week		Time	
Sequence/Description	Start	Stop	Start	Stop
1. Full discharge from ~30 % SOC	Su	Su	0115	0553
3. Full discharge	Su	Su	1000	1438
5. Full discharge	Su	Su	1845	2004

Table 6-4. Optimized SEC Test 4 off Peak Schedule for 8 MW Cycle Test

The 8 MW Cycle Test was started on December 16. The cycling was paused on December 18 due to substation relay testing that required the BESS be taken off line. Cycling resumed on December 19. Figure 6-16 shows a profile of the cycling between December 18 and December 22 as measured at 66 kV, where positive values indicate charging and negative values indicate discharging.
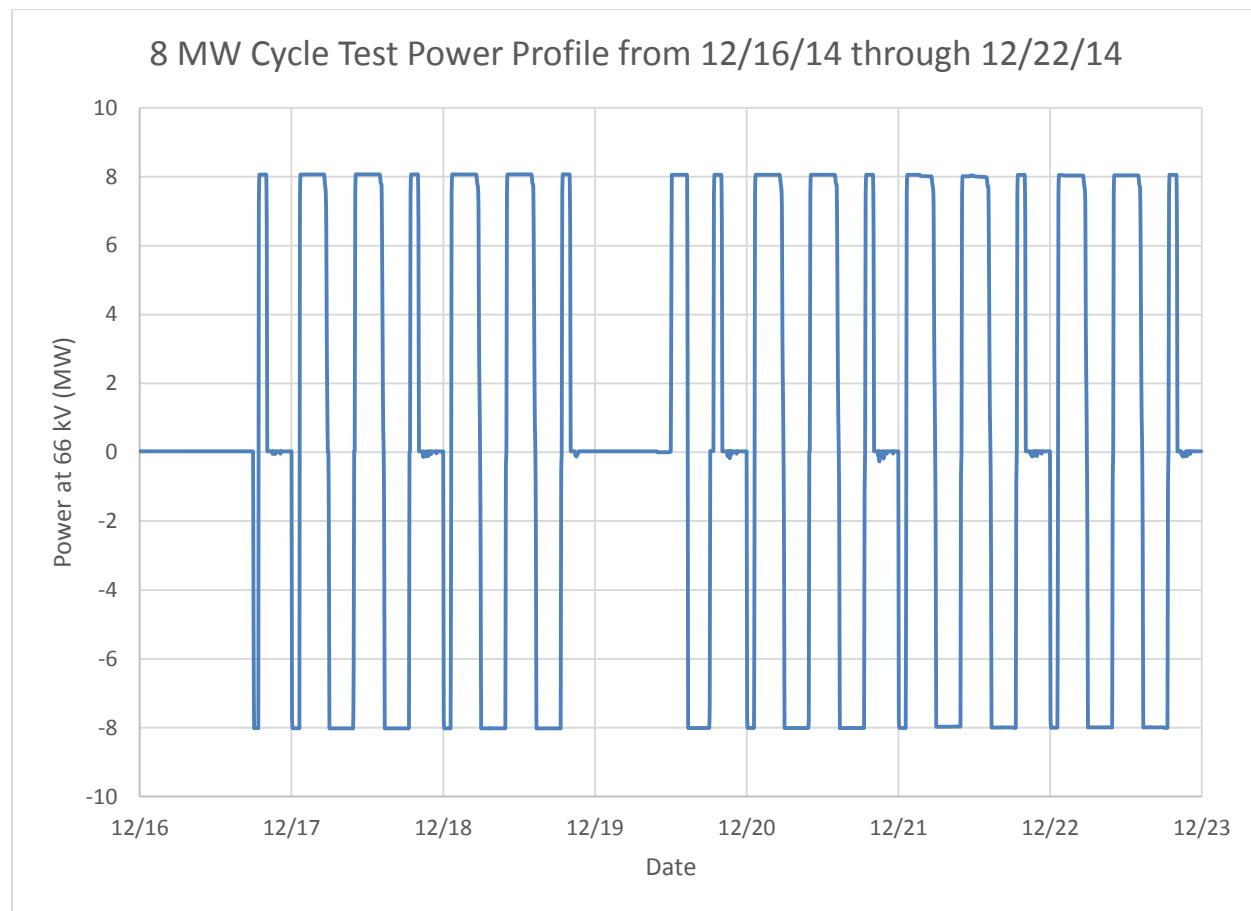
Figure 6-1 8 MW Cycle Test Power Profile from 12/16/14 through 12/22/14

The system performed a total of 10 cycles over this period, with a partial charge to 30 % SOC at the end of each day, and an interruption on December 19 for the substation relay testing. However, only five of these cycles were included in the analysis (the second cycle of day), since the first cycle of each day did not reach a full discharge stop condition (2.5 % SOC) after discharging from the 30 % SOC starting point. This occurred despite the two 8 MW cycles from the Charge/Discharge Duration tests, which were used to optimize the schedule. The schedule will need to be adjusted for future characterization testing to ensure the system reaches a full discharge stop condition.

The five complete cycles used in this analysis indicate an average round trip AC efficiency of 90.6 % as measured at 66 kV, excluding auxiliary loads for the battery facility and PCS containers. These cycles also had an average charge energy of 34,932 kWh and discharge energy of 31,638 kWh, excluding auxiliary loads. Auxiliary loads are also being measured, but preliminary data was not analyzed for this TPR. Table 6-5 shows the charge/discharge energy and round trip efficiency for each of the 10 cycles, but only cycles 2, 4, 6, 8, and 10 (the second cycle of each day) were used to calculate the averages.

Cycle	Charge Energy (kWh)	Discharge Energy (kWh)	Round Trip Efficiency (%)
1	33,548	31,265	93.2
2	34,998	31,633	90.4
3	34,954	31,436	89.9
4	34,981	31,678	90.6
5	35,159	31,570	89.8
6	34,990	31,678	90.5
7	35,097	31,499	89.7
8	34,766	31,606	90.9
9	35,115	31,579	89.9
10	34,927	31,597	90.5
Average of Cycle 2, 4, 6, 8, and 10	**34,932**	**31,638**	**90.6**

Table 6-5 Charge/Discharge Energy and Round Trip Efficiency (not including auxiliary loads)

Note: Auxiliary loads for the battery facility and PCS containers are not included in the data above.

6.4.2   Second Period Test Results – April to June 2015

During the second period of characterization testing the following results were observed.

6.4.2.1 State of Charge (SOC) profile for the BESS
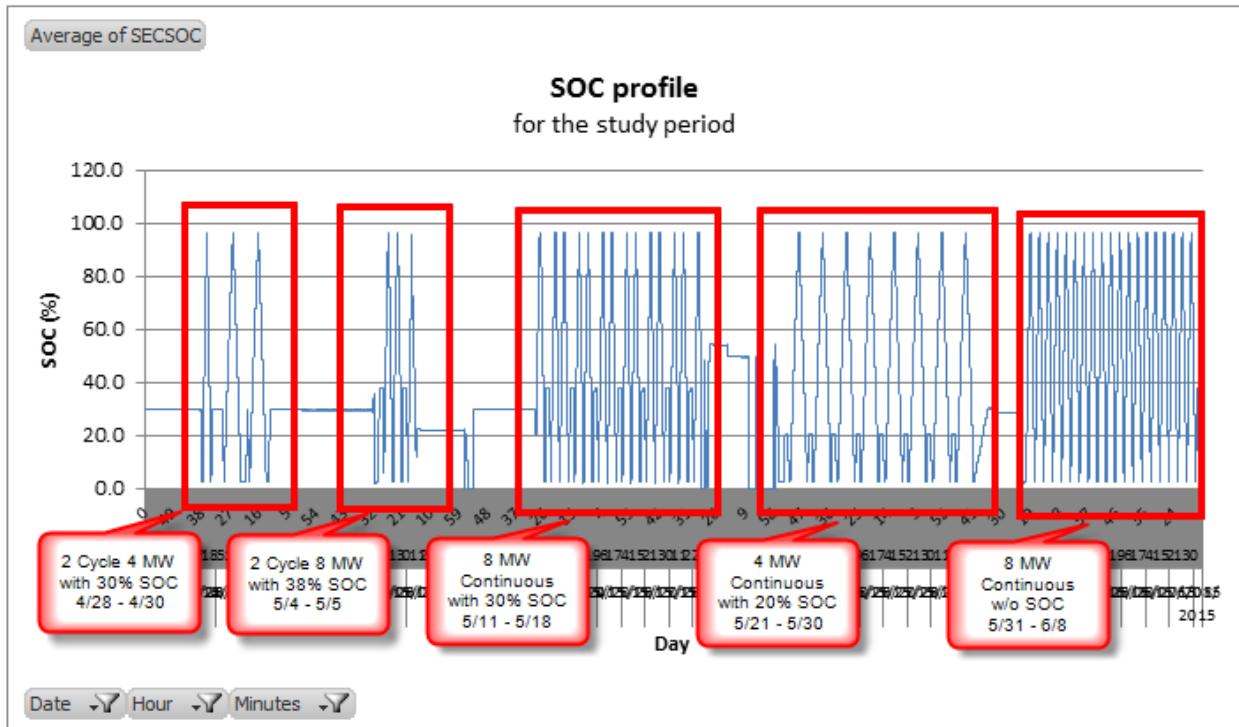
Figure 6-2 - SOC Profile for the Reporting Period

Several system characterization tests were performed to evaluate the battery efficiency under different charging/discharging modes:

- 2-Cycle 4 MW with ~30% SOC rest
- 2-Cycle 8 MW with ~30% SOC rest
- 8 MW continuous cycle with ~30% SOC rest
- 4 MW continuous cycle with ~30% SOC rest
- 8 MW continuous cycle with no rest

This data was then used to calculate the round trip efficiency of the system under these operating modes using two different calculations:

- Excluding the battery building and PCS auxiliary energy
- Including the battery building and PCS auxiliary energy

Unless explicitly mentioned, all efficiency calculations exclude the impact of the battery building and PCS auxiliary energy.

The results are tabulated in the sections that follow at several different measuring points (MPs) as identified below. Each MP is recorded in the system data historian, but is measured by a different, un-calibrated instrument. For example, PCC_CC1 and PCC_CC2 are measured by two separate, un-calibrated power meters installed in the two PCS containers. These meters are

primarily intended to provide control system feedback for the PCS, rather than measurement data. Similarly, the inverter lineup and battery section MPs are provided by the respective components' internal feedback circuitry. Furthermore, the overall PCC efficiency at 12 kV is a calculated average of PCC_CC1 and PCC_CC2, so either CC1 or CC2 may have an efficiency greater than the overall PCC at 12 kV. This data is provided for reference only, and in some cases, the efficiencies at each MP may not correlate well with upstream/downstream efficiencies.

In addition to these MPs, the project team installed four calibrated power quality monitors (PQMs). One of these is installed at 66 kV and measures total system voltage and current (and all associated derived measurements), the results of which are also included in the sections below. The other three PQMs measure the battery building auxiliary power, PCS 1 auxiliary power, and PCS 2 auxiliary power, all at 480 V. These three PQMs allow for calculating overall system efficiency with and without auxiliary loads taken into consideration. Therefore, the 66 kV efficiency data presented below, including and excluding auxiliary loads, is based on calibrated instrumentation and reflects an accurate measurement of overall efficiency for the respective operating profile. Operation under other conditions, such as different profiles with longer rest periods and lower charge/discharge rates will significantly affect overall efficiency.
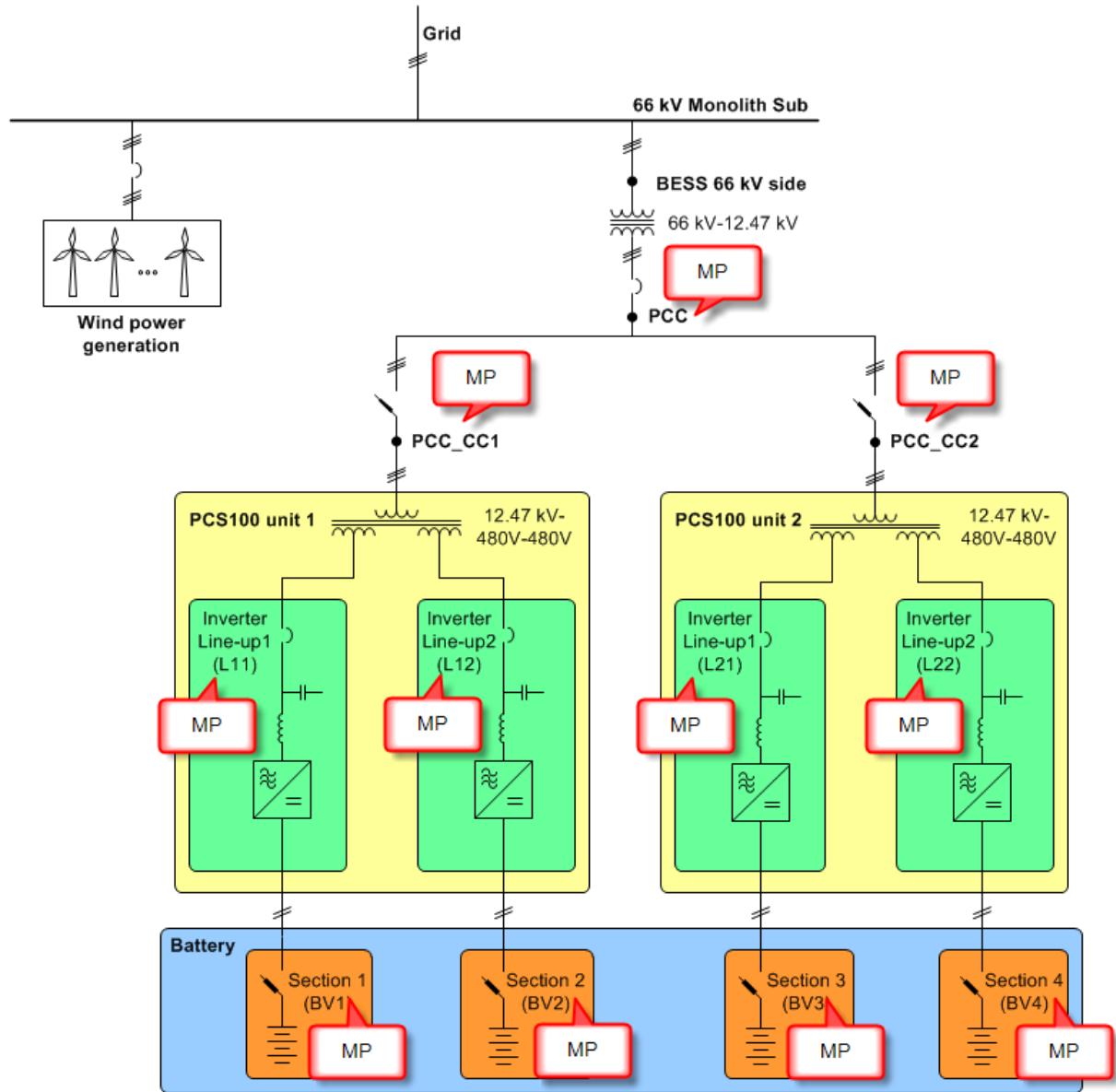
Figure 6-3- The BESS System, Major Components and Measuring Points (MP)

6.4.2.2 2-cycle 4-MW test with ~30% SOC rest results summary

Measuring point	Round trip efficiency		
	Cycle 1	Cycle 2	Average
PCC	0.91	0.91	0.91
PCC_CC1	0.91	0.90	0.91
PCC_CC2	0.90	0.91	0.90
Battery Section 1 (BV1)	0.98	0.98	0.98
Battery Section 2 (BV2)	0.98	0.98	0.98
Battery Section 3 (BV3)	0.96	0.96	0.96
Battery Section 4 (BV4)	0.97	0.97	0.97
PCS100_1 Inverter Lineup 1 (L11)	0.98	0.99	0.99
PCS100_1 Inverter Lineup 2 (L12)	0.97	0.97	0.97
PCS100_2 Inverter Lineup 1 (L21)	0.98	0.98	0.98
PCS100_2 Inverter Lineup 2 (L22)	0.99	0.99	0.99

Table 6-6 - BESS round trip efficiency based on local historian data for 2-cycle 4-MW test with ~30% SOC rest

Bldg. and PCS auxiliary energy included	Round trip efficiency		
	Cycle 1	Cycle 2	Average
NO	0.91	0.91	0.91
YES	0.89	0.89	0.89

Table 6-7 - BESS efficiency at 66 kV based on PQM data for 2-cycle 4-MW test with ~30% SOC rest
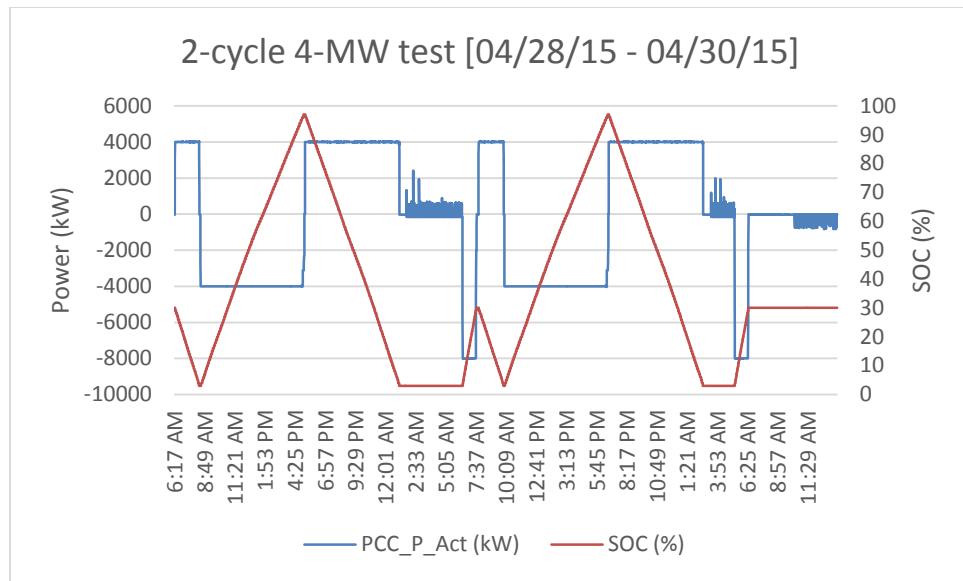
Figure 6-4- Actual Power at PCC (kW) and BESS SOC (%) for 2-cycle 4-MW Test with ~30% SOC Rest
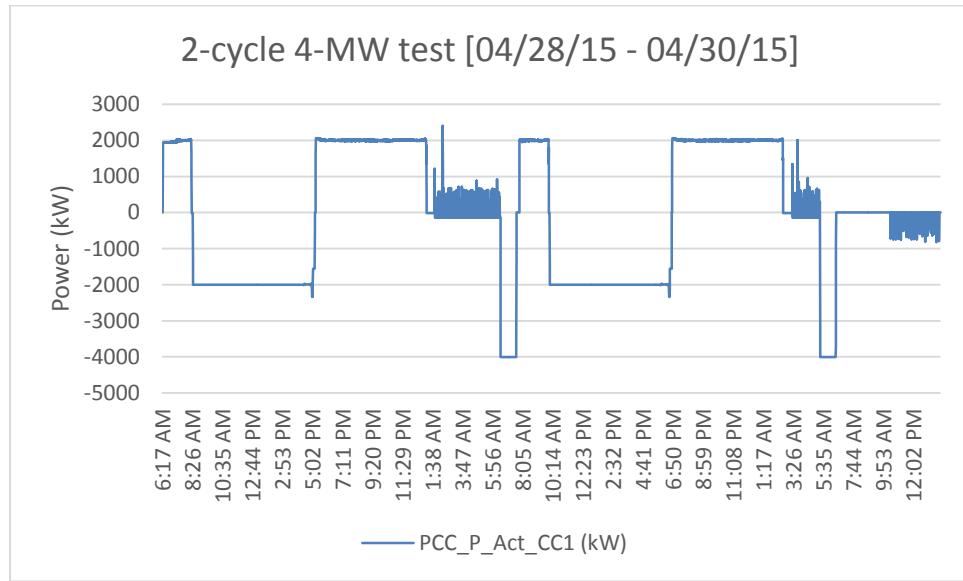
Figure 6-5- Actual Power at PCC_CC1 for 2-cycle 4-MW Test with ~30% SOC Rest
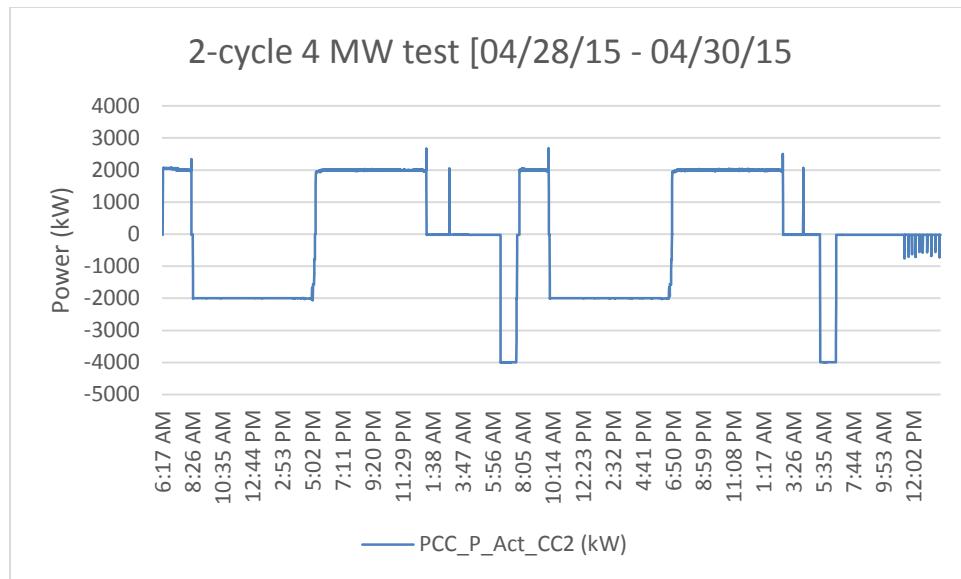
Figure 6-6- Actual Power at PCC_CC2 for 2-cycle 4-MW Test with ~30% SOC Rest
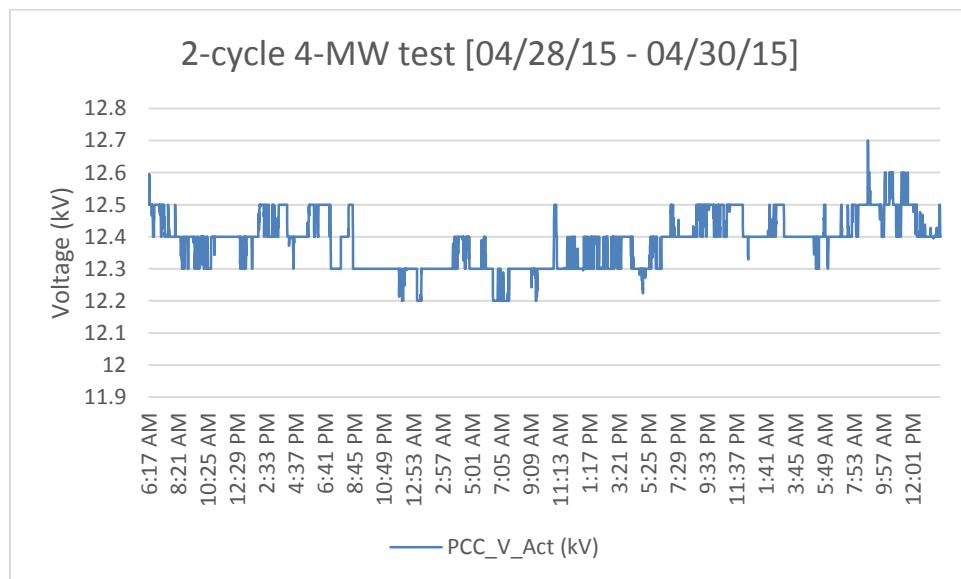
Figure 6-7- Voltage at PCC for 2-cycle 4-MW Test with ~30% SOC Rest
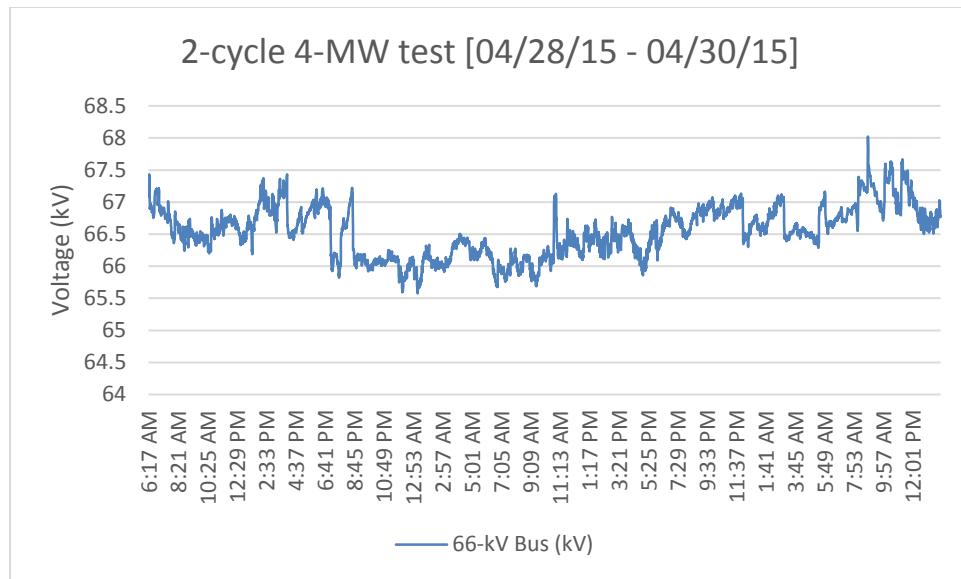
Figure 6-8- Voltage at 66 kV for 2-cycle 4-MW Test with ~30% SOC Rest

6.4.2.3 2-cycle 8-MW test with ~30% SOC rest results

Measuring point	Round trip efficiency		
	Cycle 1	Cycle 2	Average
PCC	0.93	0.91	0.92
PCC_CC1	0.93	0.91	0.92
PCC_CC2	0.93	0.91	0.92
Battery Section 1 (BV1)	0.99	0.98	0.99
Battery Section 2 (BV2)	0.99	0.98	0.99
Battery Section 3 (BV3)	0.99	0.97	0.98
Battery Section 4 (BV4)	0.99	0.97	0.98
PCS100_1 Inverter Lineup 1 (L11)	0.98	0.98	0.98
PCS100_1 Inverter Lineup 2 (L12)	0.98	0.98	0.98
PCS100_2 Inverter Lineup 1 (L21)	0.98	0.98	0.98
PCS100_2 Inverter Lineup 2 (L22)	0.98	0.98	0.98

Table 6-8 - BESS round trip efficiency based on local historian data for 2-cycle 8-MW test with ~30% SOC rest

Bldg. and PCS auxiliary energy included	Round trip efficiency		
	Cycle 1	Cycle 2	Average
NO	0.91	0.90	0.91
YES	0.90	0.89	0.90

Table 6-9 - BESS efficiency at 66 kV based on PQM data for 2-cycle 8-MW test with ~30% SOC rest
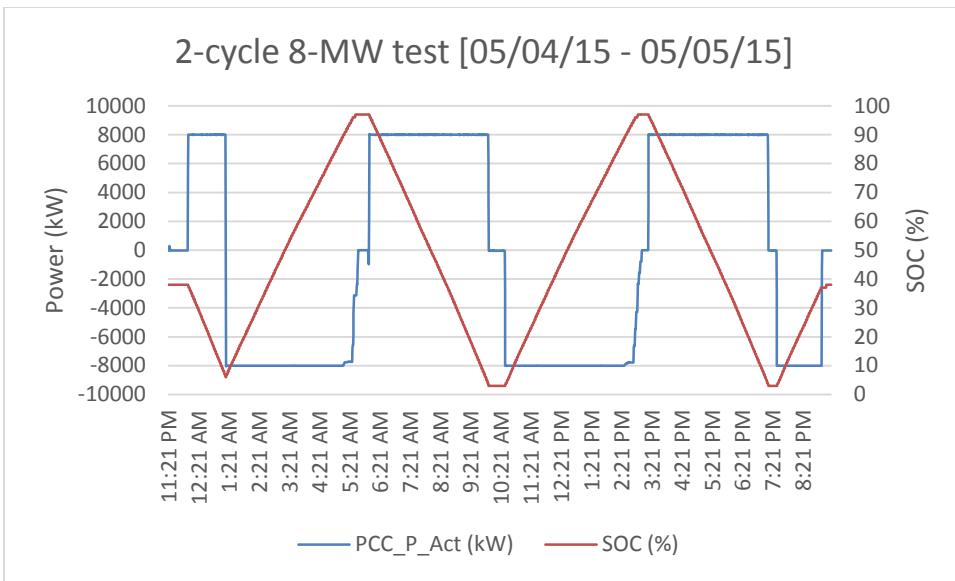
Figure 6-9- Actual Power at PCC (kW) and BESS SOC (%) for 2-cycle 8-MW Test with ~30% SOC Rest
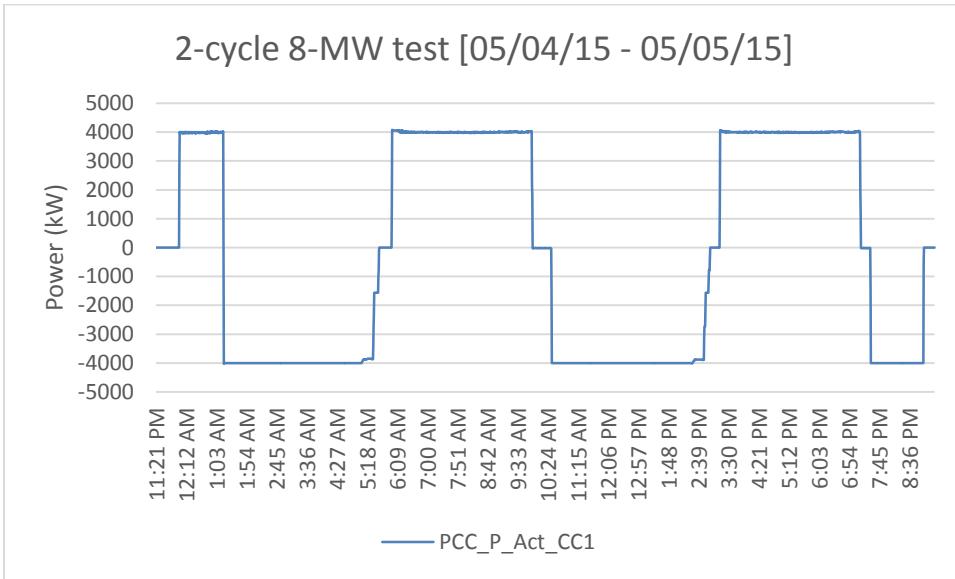
Figure 6-10- Actual Power at PCC_CC1 for 2-cycle 8-MW Test with ~30% SOC Rest
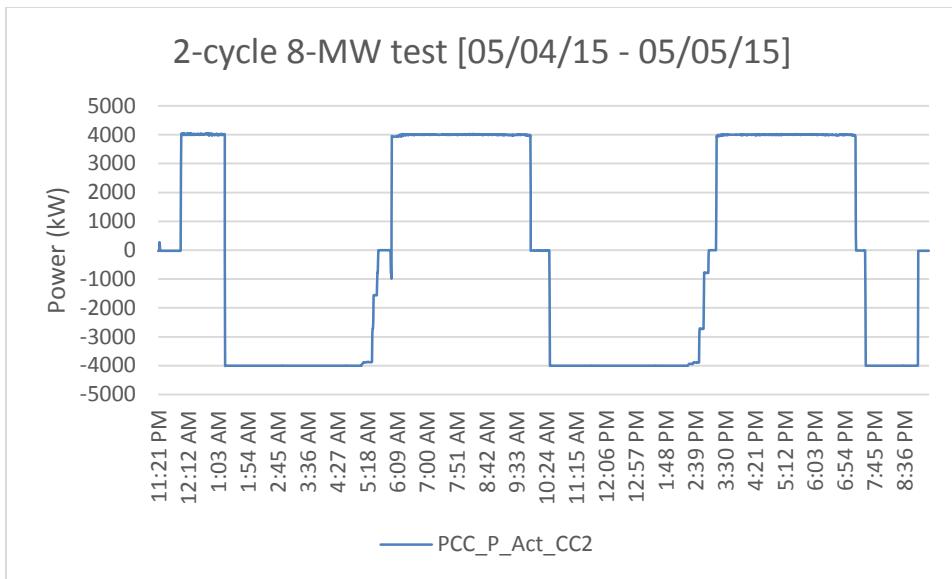
Figure 6-11- Actual Power at PCC_CC2 for 2-cycle 8-MW Test with ~30% SOC Rest
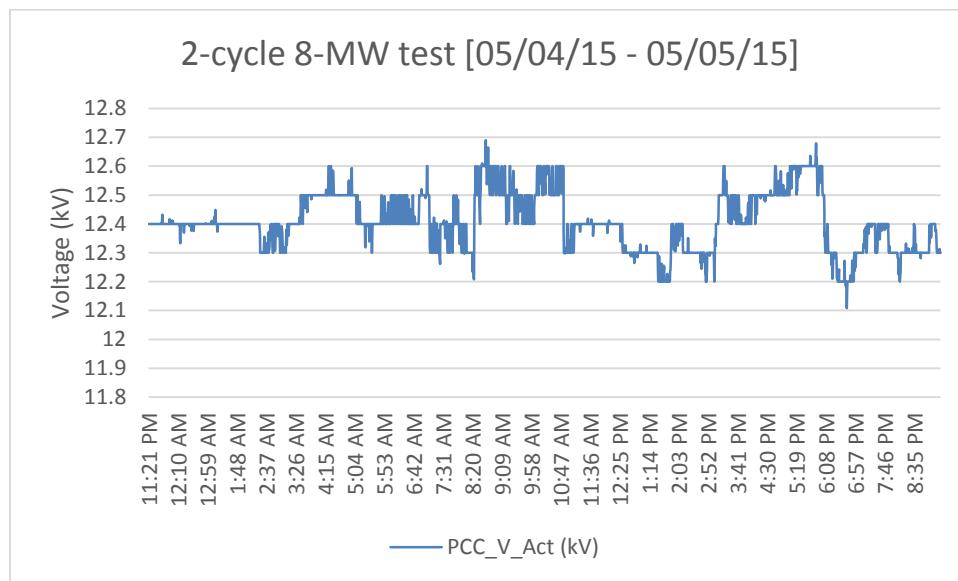
Figure 6-12- Voltage at PCC for 2-cycle 8-MW Test with ~30% SOC Rest
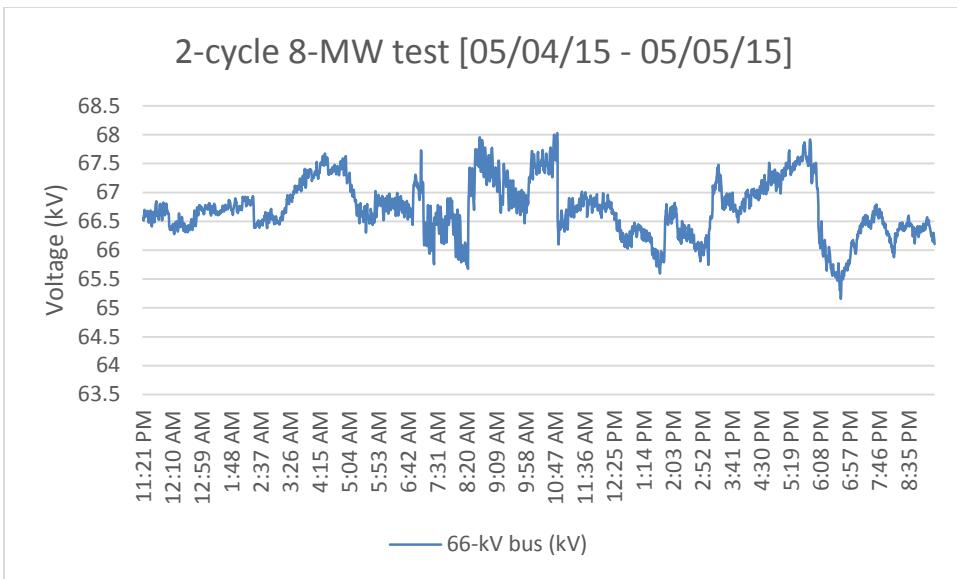
Figure 6-13- Voltage at 66-kV for 2-cycle 8-MW Test with ~30% SOC Rest

6.4.2.4 8-MW continuous cycle test with 30% SOC rest

Round-trip efficiency							
Measuring point	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Ave.
PCC	0.91	0.91	0.91	0.91	0.91	0.91	0.91
PCC_CC1	0.91	0.91	0.91	0.91	0.91	0.91	0.91
PCC_CC2	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Battery (BV1)	0.93	0.91	0.91	0.93	0.91	0.97	0.93
Battery (BV2)	0.92	0.89	0.89	0.93	0.90	0.97	0.92
Battery (BV3)	0.92	0.90	0.90	0.93	0.90	0.97	0.92
Battery (BV4)	0.93	0.90	0.90	0.93	0.90	0.97	0.92
Inverter (L11)	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Inverter (L12)	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Inverter (L21)	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Inverter (L22)	0.98	0.98	0.98	0.98	0.98	0.98	0.98

Table 6-10 - BESS round trip efficiency based on local historian data for 8-MW continuous cycle test with 30% SOC rest

Round-trip efficiency							
Bldg. and PCS aux. energy included	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Ave.
NO	0.89	0.89	0.91	0.92	0.92	0.92	0.91
YES	0.88	0.88	0.90	0.91	0.91	0.91	0.90

Table 6-11 - BESS efficiency at 66 kV based on PQM data for 8-MW continuous cycle test with 30% SOC rest
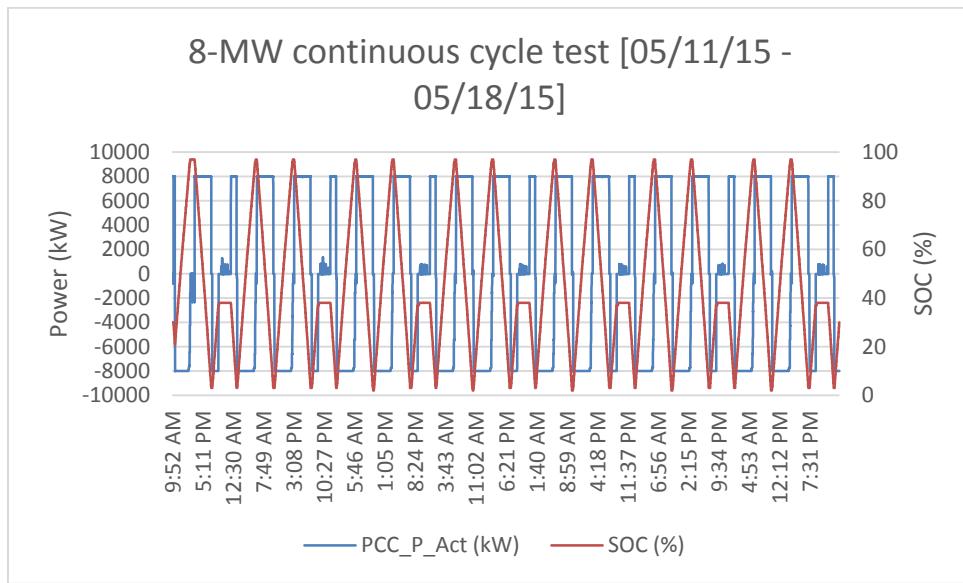
Figure 6-14- Actual Power at PCC (kW) and BESS SOC (%) for 8-MW Continuous Cycle Test with 30% SOC Rest
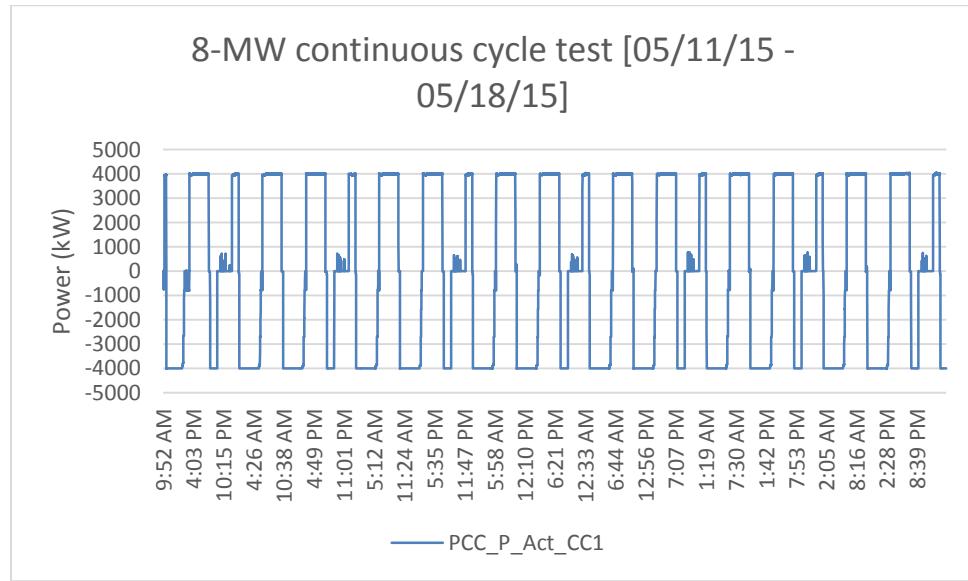
Figure 6-15- Actual Power at PCC_CC1 for 8-MW Continuous Cycle Test with 30% SOC Rest
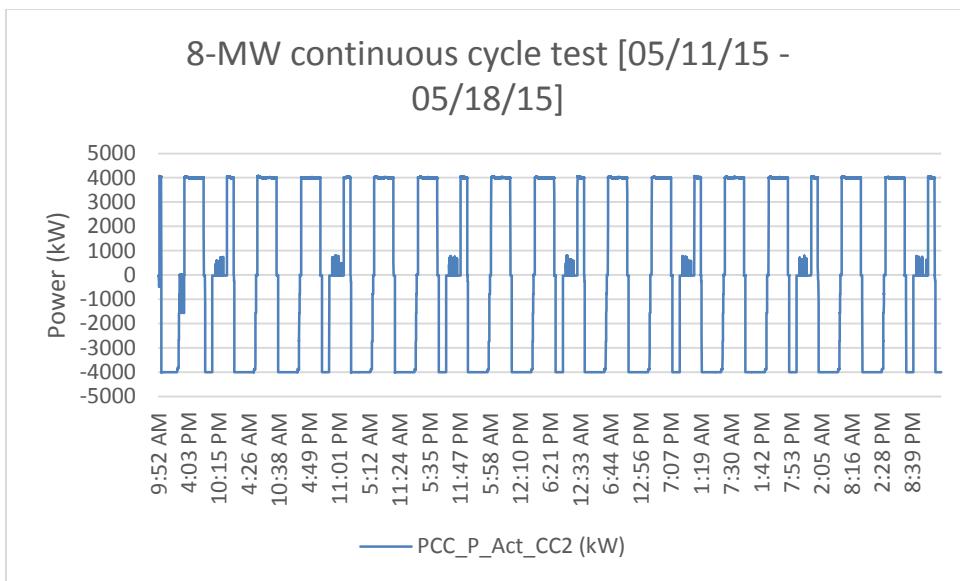
Figure 6-16- Actual Power at PCC_CC2 for 8-MW Continuous Cycle Test with 30% SOC Rest
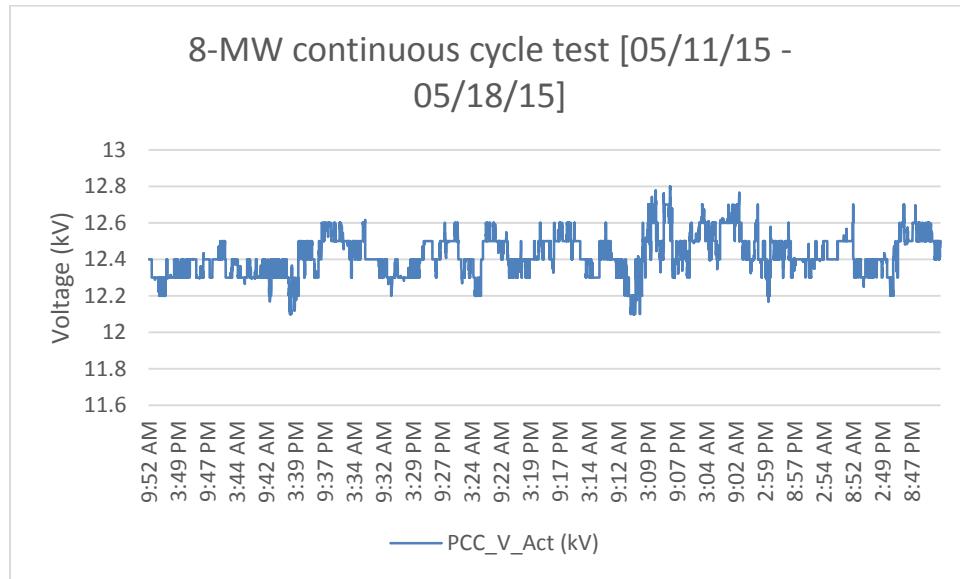
Figure 6-17- Voltage at PCC for 8-MW Continuous Cycle Test with 30% SOC Rest
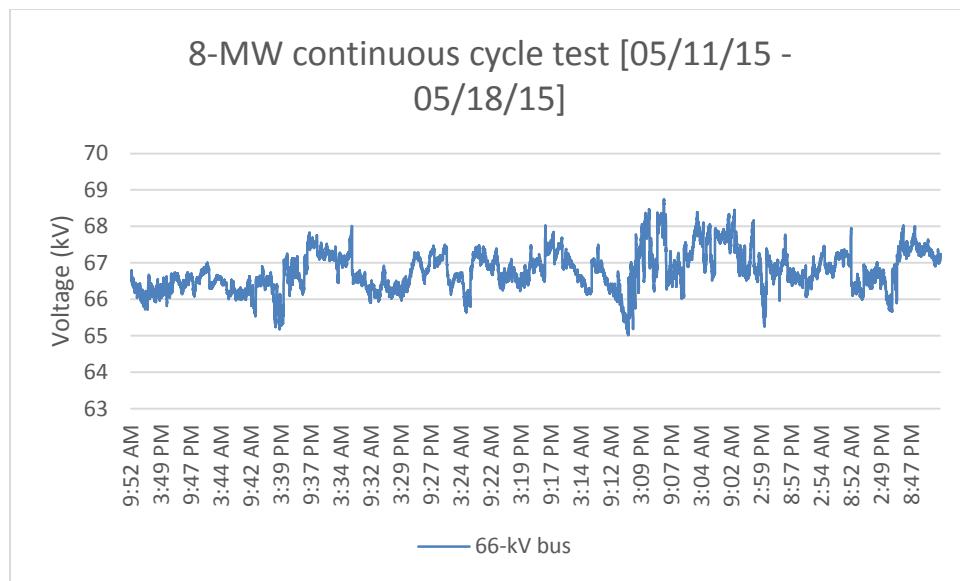
Figure 6-18- Voltage at 66-kV for 8-MW Continuous Cycle Test with 30% SOC Rest
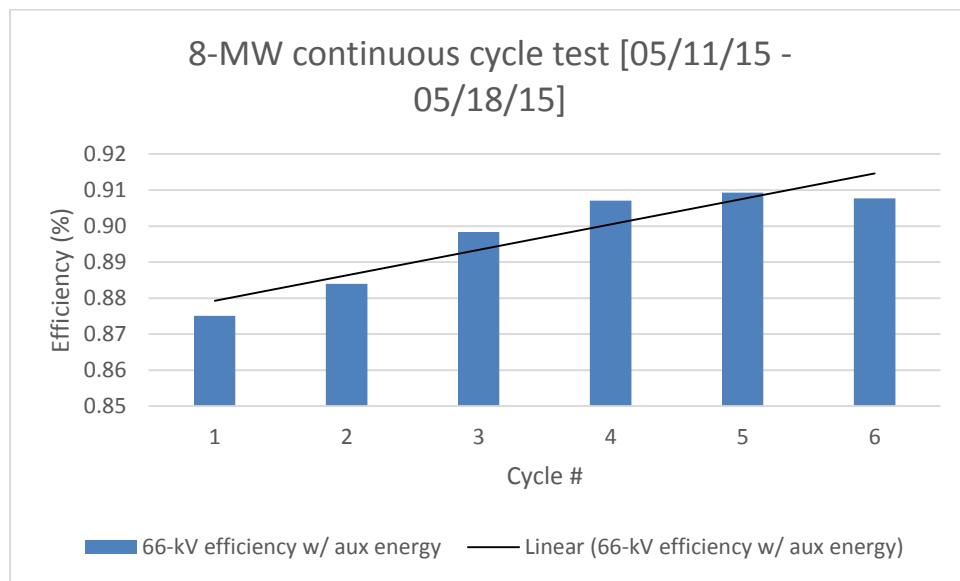
Figure 6-19- Calculated Efficiency for the Six Test Cycles During the 8-MW Continuous Cycle Test with 30% SOC Rest

6.4.2.5 4-MW continuous cycle test with ~30% SOC rest

Measuring point	Round-trip efficiency								
	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	avg
PCC	0.91	0.93	0.92	0.92	0.92	0.92	0.91	0.92	0.92
PCC_CC1	0.91	0.93	0.92	0.92	0.92	0.92	0.91	0.91	0.91
PCC_CC2	0.91	0.93	0.92	0.92	0.92	0.92	0.91	0.92	0.92
Battery (BV1)	0.96	0.96	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Battery (BV2)	0.98	0.97	0.98	0.97	0.97	0.97	0.97	0.97	0.97
Battery (BV3)	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Battery (BV4)	0.98	0.97	0.98	0.97	0.97	0.98	0.97	0.97	0.98
Inverter (L11)	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Inverter (L12)	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Inverter (L21)	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Inverter (L22)	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

Table 6-12 - BESS round trip efficiency based on local historian data for 4-MW continuous cycle test with ~30% SOC rest

Bldg. and PCS aux. energy included	Round-trip efficiency								
	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	avg
NO	0.90	0.91	0.90	0.99	0.90	0.90	0.90	0.90	0.90
YES	0.88	0.89	0.88	0.88	0.89	0.88	0.88	0.89	0.89

Table 6-13 - BESS efficiency at 66 kV side based on PQM data for 4-MW continuous cycle test with ~30% SOC rest
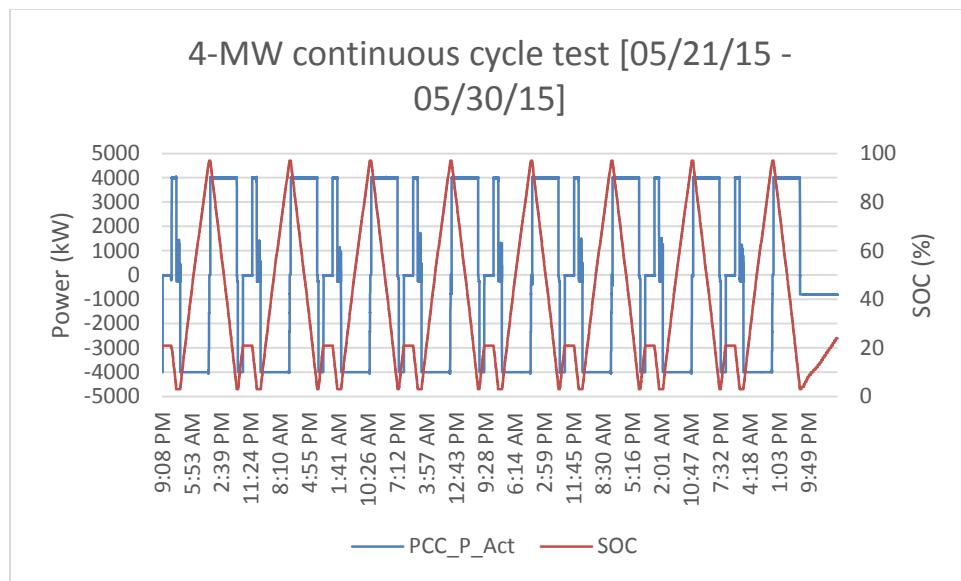
Figure 6-20- Actual Power at PCC (kW) and BESS SOC (%) for 4-MW Continuous Cycle Test with ~30% SOC Rest
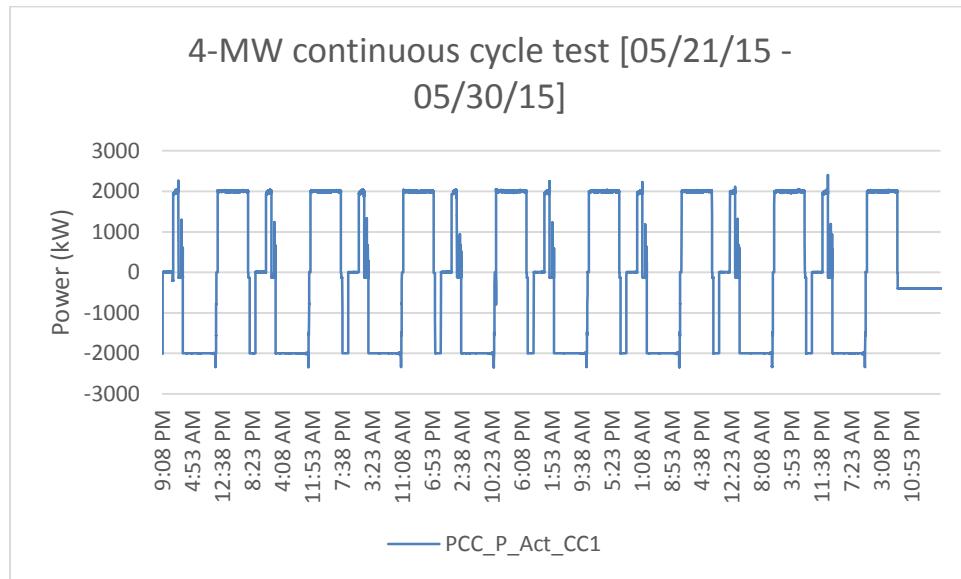
Figure 6-21- Actual Power at PCC_CC1 for 4-MW Continuous Cycle Test with ~30% SOC Rest
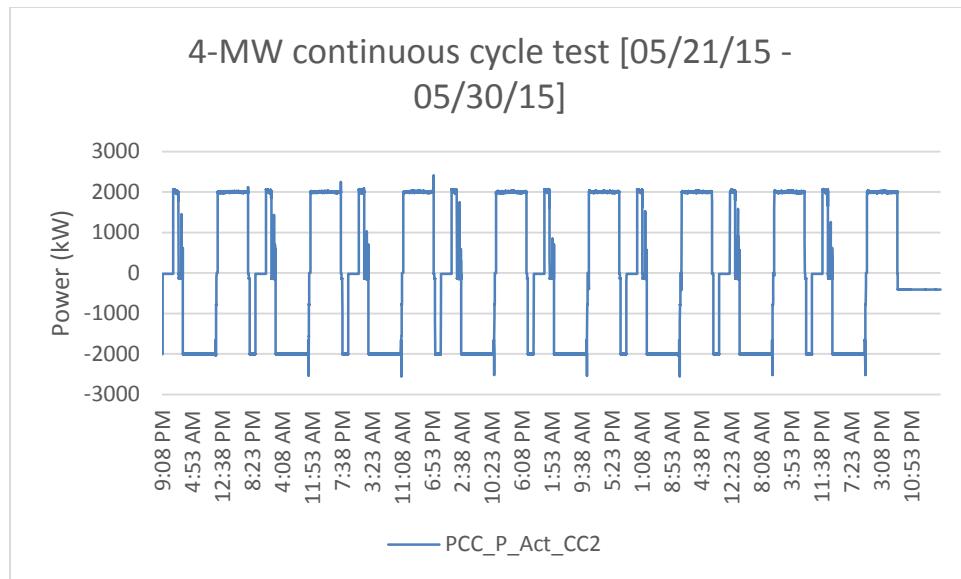
Figure 6-22- Actual Power at PCC_CC2 for 4-MW Continuous Cycle Test with ~30% SOC Rest
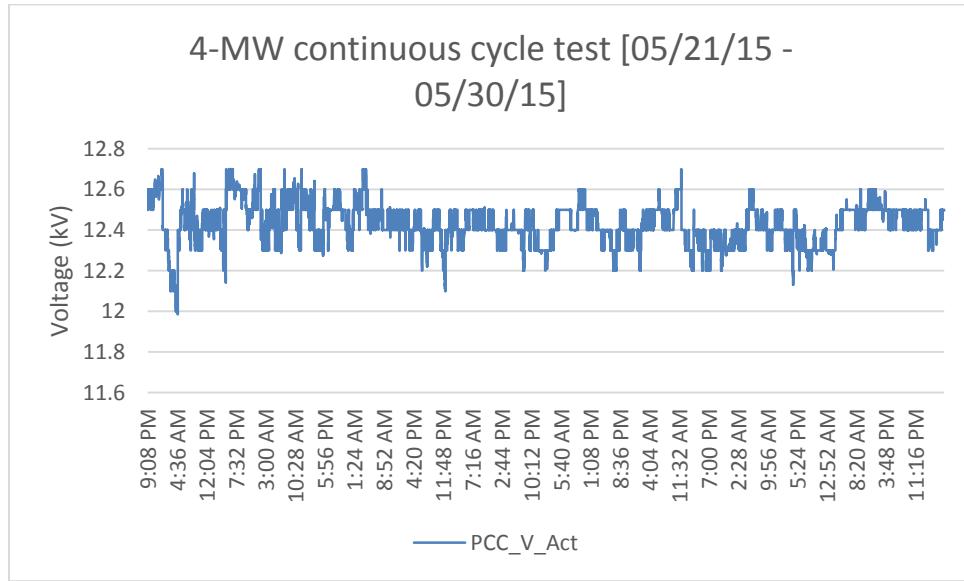
Figure 6-23- Voltage at PCC for 4-MW Continuous Cycle Test with ~30% SOC Rest
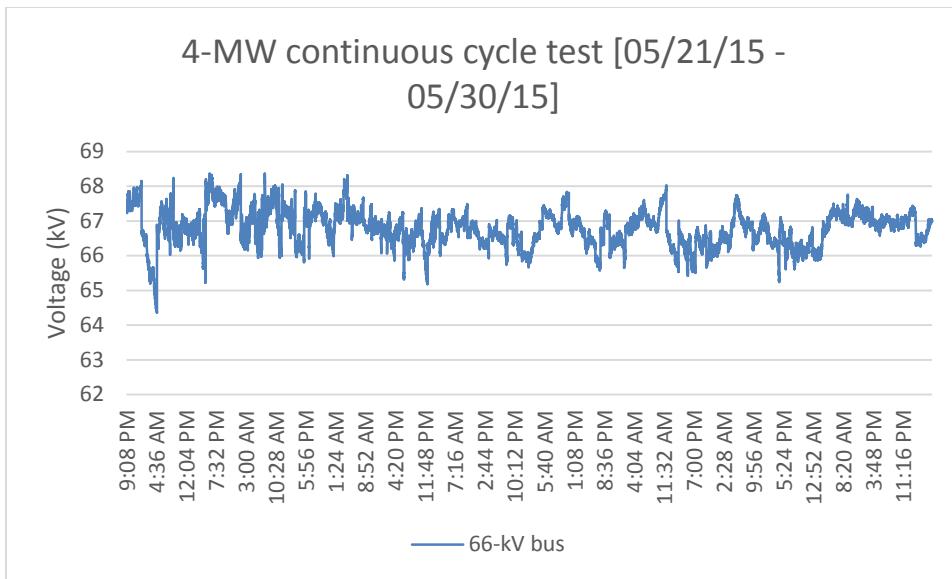
Figure 6-24- Voltage at 66-kV for 4-MW Continuous Cycle Test with ~30% SOC Rest
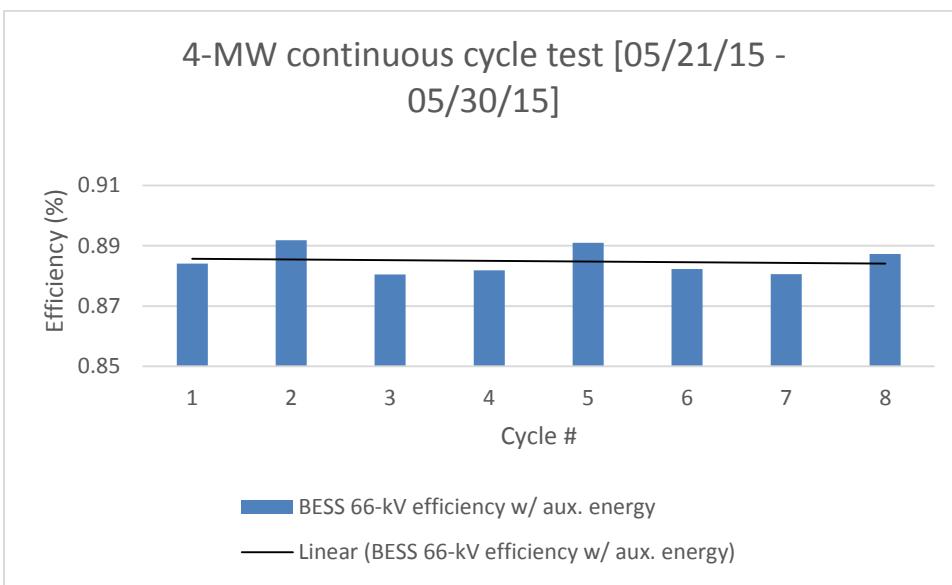
Figure 6-25- Calculated Efficiency for the Eight Test Cycles During the 4-MW Continuous Cycle Test with ~30% SOC Rest

6.4.2.6 8-MW continuous cycle test w/o rest

MP	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11	Cycle 12	Cycle 13	Cycle 14	Cycle 15	Cycle 16	Cycle 17	Cycle 18	Cycle 19	Ave.
Round-trip efficiency																				
PCC	0.91	0.92	0.91	0.90	0.91	0.91	0.91	0.91	0.93	0.91	0.92	0.92	0.90	0.91	0.89	0.92	0.92	0.90	0.91	0.91
PCC1	0.91	0.92	0.91	0.91	0.91	0.91	0.91	0.91	0.93	0.91	0.92	0.92	0.90	0.91	0.89	0.92	0.92	0.90	0.91	0.91
PCC2	0.91	0.92	0.91	0.90	0.91	0.91	0.91	0.91	0.93	0.91	0.92	0.92	0.90	0.91	0.89	0.91	0.91	0.90	0.91	0.91
BV1	0.96	0.97	0.97	0.97	0.97	0.93	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
BV2	0.98	0.98	0.97	0.98	0.97	0.93	0.98	0.98	0.97	0.97	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.97	0.97	0.97
BV3	0.97	0.97	0.97	0.97	0.97	0.93	0.97	0.97	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.97	0.98	0.97	0.97	0.97
BV4	0.99	0.98	0.98	0.98	0.97	0.94	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.97	0.98	0.98
L11	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
L12	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
L21	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
L22	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98

Table 6-14 - BESS round trip efficiency based on local historian data for 8-MW continuous cycle test w/o rest

Bldg. and PCS aux energy included	Round-trip efficiency																			
	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11	Cycle 12	Cycle 13	Cycle 14	Cycle 15	Cycle 16	Cycle 17	Cycle 18	Cycle 19	Ave.
NO	0.87	0.90	0.90	0.90	0.90	0.88	0.90	0.90	0.89	0.90	0.88	0.88	0.89	0.88	0.88	0.88	0.88	0.90	N/A	0.89
YES	0.86	0.88	0.89	0.89	0.88	0.87	0.89	0.88	0.87	0.88	0.87	0.87	0.87	0.87	0.86	0.86	0.87	0.88	N/A	0.87

Table 6-15 - BESS efficiency at 66 kV based on PQM data for 8-MW continuous cycle test w/o rest
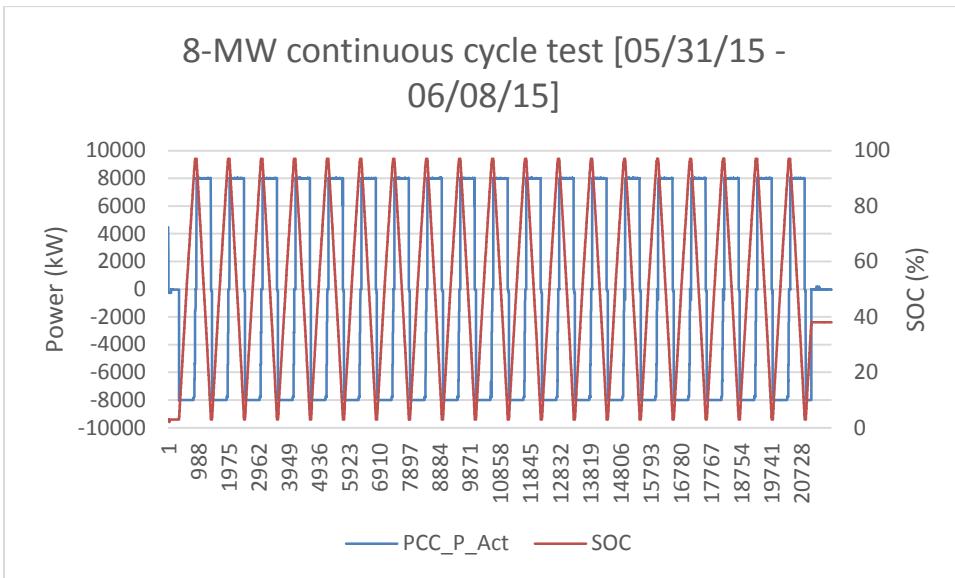
Figure 6-26- Actual Power at PCC (kW) and BESS SOC (%) for 8-MW Continuous Cycle Test w/o Rest
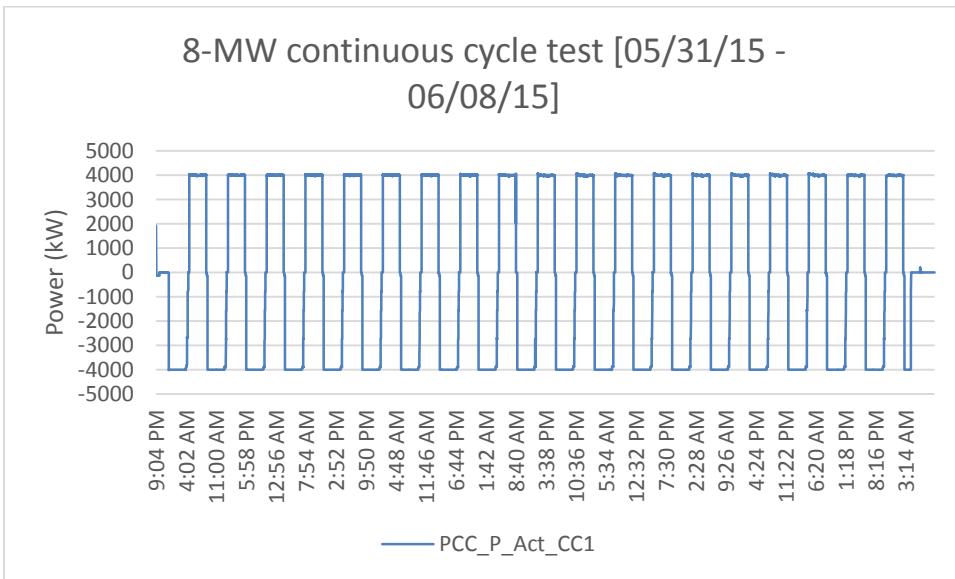
Figure 6-27- Actual Power at PCC_CC1 for 8-MW Continuous Cycle Test w/o Rest
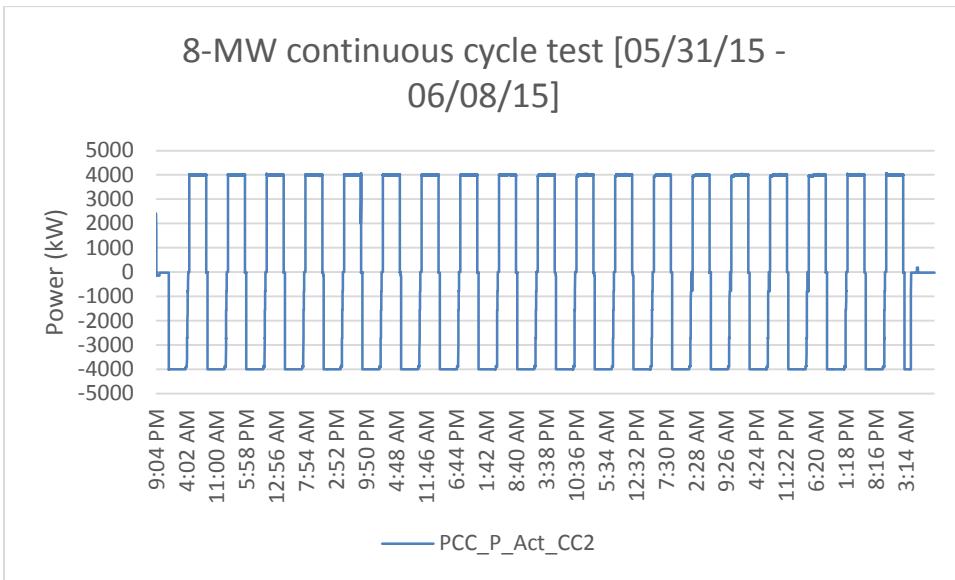
Figure 6-28- Actual Power at PCC_CC2 for 8-MW Continuous Cycle Test w/o Rest
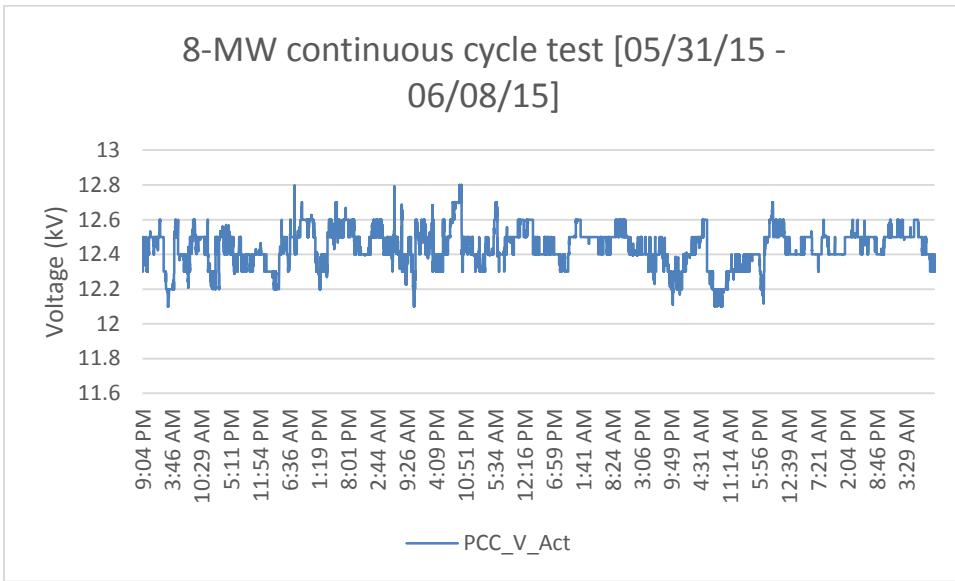
Figure 6-29- Voltage at PCC for 8-MW Continuous Cycle Test w/o Rest
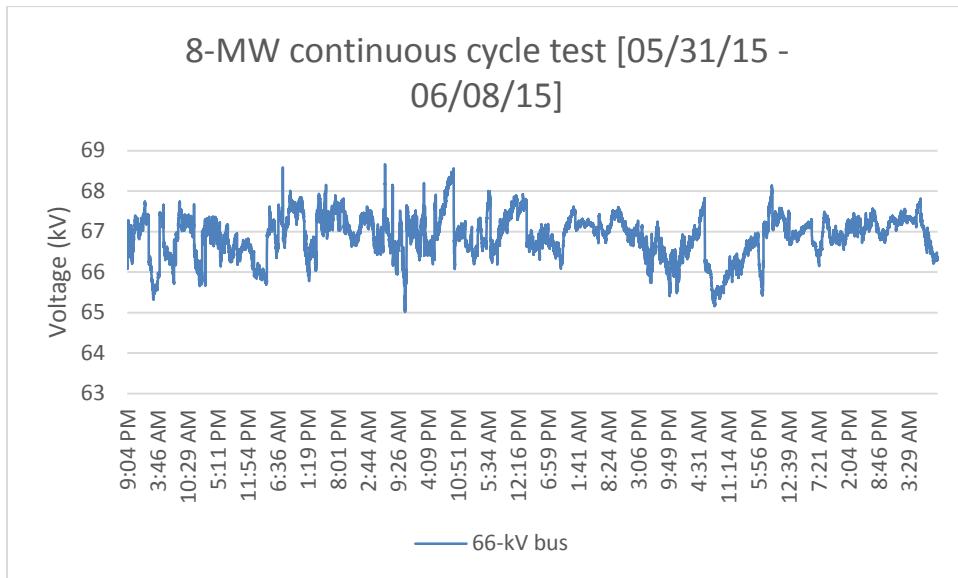
Figure 6-30- Voltage at 66-kV for 8-MW Continuous Cycle Test w/o Rest
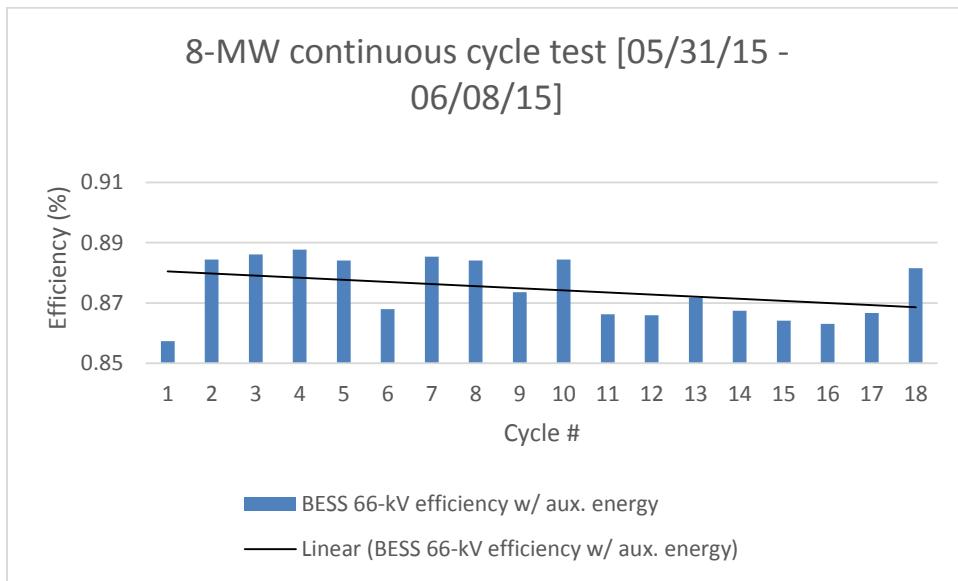
Figure 6-31- Calculated Efficiency for the 20 Test Cycles During the 8-MW Continuous Cycle Test w/o Rest

6.5 TSP Market Telemetry Testing

During this first round of testing the system was completely automated and no Operator actions were required. Observation of the system response to signals was done using the graphical Human Machine Interface (HMI) display for an instantaneous look and after the fact using archived data as necessary. TSP performed as expected following hourly schedules and randomized setpoints.

6.5.1 TSP Market Test Schedule (HE1-HE8)

DateTime	HE1	HE2	HE3	HE4	HE5	HE6	HE7	HE8
9/4/2015	2	-2	3	-3	4	-4	5	-5
9/5/2015	3	3	3	3	-3	-3	-3	-3
9/6/2015	3	3	3	3	-3	-3	-3	-3
9/7/2015	3	3	3	3	-3	-3	-3	-3
9/8/2015	3	3	3	3	-3	-3	-3	-3
9/9/2015	6.5	6.5	6.5	6.5	-6.5	-6.5	-6.5	-6.5
9/10/2015	1	1	1	1	1	1	1	1
9/11/2015	2	2	2	2	4	4	4	4
9/12/2015	3	3	3	3	3	3	3	3
9/13/2015	3	3	3	3	3	3	3	3
9/14/2015	3	3	3	3	3	3	3	3
9/15/2015	-2	-2	-2	-2	-2	-2	-2	4
9/16/2015	-2	-2	-2	-2	-2	-2	-2	7
9/17/2015	-3.5	-3.5	-3.5	-3.5	-3.5	7.5	7.5	7.5
9/18/2015	-3.5	-3.5	-3.5	-3.5	-3.5	7.5	7.5	7.5
9/19/2015	6.5	6.5	6.5	6.5	-6.5	-6.5	-6.5	-6.5
9/20/2015	6.5	6.5	6.5	6.5	-6.5	-6.5	-6.5	-6.5
9/21/2015	6.5	6.5	6.5	6.5	-6.5	-6.5	-6.5	-6.5
9/22/2015	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	4.25	4.25
9/23/2015	-6	-6	-6	-6	2	-2	3	AGC SIM
9/24/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/25/2015	1	1	1	1	1	1	1	1
9/26/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/27/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/28/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/29/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/30/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
10/1/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
10/2/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM

DateTime								
10/3/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
10/4/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
10/5/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM

6.5.2   TSP Market Test Schedule (HE9-HE16)

DateTime	HE9	HE10	HE11	HE12	HE13	HE14	HE15	HE16
9/4/2015	6	-6	8	-8	2	2	-2	-2
9/5/2015	4	4	4	4	-4	-4	-4	-4
9/6/2015	4	4	4	4	-4	-4	-4	-4
9/7/2015	4	4	4	4	-4	-4	-4	-4
9/8/2015	4	4	4	4	-4	-4	-4	-4
9/9/2015	1	2	3	4	5	-7	-6	-5
9/10/2015	2	2	2	2	3	3	3	-7
9/11/2015	-5	-5	-5	-5	-5	6	6	6
9/12/2015	-3	-3	-3	-3	-3	-3	-3	-3
9/13/2015	-3	-3	-3	-3	-3	-3	-3	-3
9/14/2015	-3	-3	-3	-3	-3	-3	-3	-3
9/15/2015	4	4	0	-5	-5	-5	-5	-5
9/16/2015	7	7	-7	-7	-7	1.994	2	2
9/17/2015	-7	-7	-7	3.25	3.25	3.25	3.25	-3.25
9/18/2015	-7	-7	-7	3.25	3.25	3.25	3.25	-3.25
9/19/2015	1	2	3	4	5	-7	-6	-5
9/20/2015	1	2	3	4	5	-7	-6	-5
9/21/2015	1	2	3	4	5	-7	-6	-5
9/22/2015	4.25	4.25	-5.6	-5.6	-5.6	-5.6	-5.6	2.5
9/23/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/24/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/25/2015	1	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/26/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/27/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/28/2015	4	7	7	1	1	AGC SIM	AGC SIM	AGC SIM
9/29/2015	AGC	AGC	AGC	AGC	AGC	7	7	7

	SIM	SIM	SIM	SIM	SIM			
9/30/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
10/1/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
10/2/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
10/3/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
10/4/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
10/5/2015	AGC SIM	Null	Null	Null	Null	Null	Null	Null

6.5.3 TSP Market Test Schedule (HE17-HE24)

DateTime	HE17	HE18	HE19	HE20	HE21	HE22	HE23	HE24
9/4/2015	3	3	-3	-3	4	4	-4	-4
9/5/2015	7	7	7	7	-7	-7	-7	-7
9/6/2015	7	7	7	7	-7	-7	-7	-7
9/7/2015	7	7	7	7	-7	-7	-7	-7
9/8/2015	7	7	7	7	-7	-7	-7	-7
9/9/2015	-4	0	8	8	8	-8	-8	-8
9/10/2015	-7	-7	-5	3	-3	3	-3	3
9/11/2015	6	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5
9/12/2015	3	3	3	3	3	3	3	3
9/13/2015	3	3	3	3	3	3	3	3
9/14/2015	3	3	3	3	3	3	3	3
9/15/2015	2.5	3.5	4.5	5.5	6.5	1	1	1
9/16/2015	2	2	2	2	2	-3	-3	-3
9/17/2015	-3.25	-3.25	-3.25	4.5	4.6	4.2	4.3	-4.5
9/18/2015	-3.25	-3.25	-3.25	4.5	4.6	4.2	4.3	-4.5
9/19/2015	-4	-3	8	8	8	-8	-8	-8
9/20/2015	-4	-3	8	8	8	-8	-8	-8
9/21/2015	-4	-3	8	8	8	-8	-8	-8
9/22/2015	3.5	4.5	5.5	6.5	1	1	1	1
9/23/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/24/2015	1	1	1	1	1	1	1	1
9/25/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM

9/26/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/27/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/28/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/29/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
9/30/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
10/1/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
10/2/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
10/3/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
10/4/2015	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM	AGC SIM
10/5/2015	Null	Null	Null	Null	Null	Null	Null	Null

6.5.4   TSP Market Testing Log

9/3/15 – Made changes to software configuration and tested values with ABB, DC Systems, GMS. Changes were verified and testing was completed and passed. Started testing HE13 following values from test plan. Flat hourly schedules with varying MW values and hourly duration.

9/4/15 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration.

9/5 – 9/7 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration. Schedule was repeated in auto mode through the Holiday weekend.

9/8 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration. Updated today and tomorrow schedules per test plan.

9/9 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration. Updated today and tomorrow schedules per test plan.

9/10 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration. Updated today and tomorrow schedules per test plan.

9/11 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration. Updated today and tomorrow schedules per test plan.

9/12 – 9/14 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration. Schedule was repeated in auto mode through the weekend.

9/14 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration. Updated today and tomorrow schedules per test plan.

9/14 – 9/15 – Noted inverters #1 & #2 are off due to work conducted on PCS – Energy schedules were not changed causing system to be limited to load or charge limits set by the BESS. Hour Ending 1100 was changed from 4 mw to 0 mw to allow system to stay at existing charge and reach BESS limitations. Once inverters were returned to service system was able to follow schedules as expected.

9/16 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration. Updated today and tomorrow schedules per test plan. At 1:10 PM testing of the internal AGC program was started with -8 to +8 MW limits and 8 MW delta change. 1:45 PM moved delta change to 1 MW. 2:00 PM internal AGC program stopped. 2:05 PM connected with CAISO to perform AGC testing with their EMS system as a pre-test to prove data quality, ability to follow ISO AGC 4 second set point changes, ISO EMS tuning. 3:00 PM Stopped ISO pre-testing activities system acted as expected ISO was able to pre-tune their system. Started following flat test energy schedule at for HE 3.

9/17 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration. Updated today and tomorrow schedules per test plan.

9/18 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration. Updated today and tomorrow schedules per test plan.

9/19 – 9/20 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration. Schedule was repeated in auto mode through the weekend.

9/21 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration. Updated today and tomorrow schedules per test plan.

9/22 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration. Updated today and tomorrow schedules per test plan.

9/23 – TSP performing as expected, following test plan schedule. Flat hourly schedules with varying MW values and hourly duration. System was set to AGC mode at 1535 with the following parameters Delta Change 4MW, High Limit 6.9MW, Low Limit -8MW. Starting SOC 15.52MW.

9/24 – Updated client provide by GMS vendor with non-related TSP updates at 1129. AGC test script is not server based, but client based, resulting in stopping the AGC testing. Re-established TSP AGC test at 1420 with the following parameters: Delta of 4 MW, High Limit of 6.9 MW, & Low Limit of -8 MW. SOC 29.10 when restarted. Determined to go from AGC mode to Flat hourly schedule mode due to SOC at 30.07 MW. TSP in Flat hourly schedule

mode at 1555 with +1 MW for hour ending 1700-2400 & hour ending 0100-0900 for tomorrow 9/25. The discharge should place SOC at 12 MW to 13 MW.

9/25 – Placed TSP in AGC test mode at 0855. High Limit of 6.9 MW, Low Limit of -8 MW, & Delta set to 5.0 MW. Starting SOC 13.58 MW.

9/26-27 – TSP in AGC test mode. High Limit of 6.9 MW, Low Limit of -8 MW, & Delta set to 5.0 MW.

9/28 – Determined to go from AGC mode to Flat hourly schedule mode due to SOC at 31.07 MW. TSP in Flat hourly schedule mode at 0830 with +4, +7, +7, +1, +1 MW for hour ending 0900-1400. Moved to AGC HE 15 with the following changes. High Limit of 9.13 MW, Low Limit of -8 MW, & Delta set to 7.0 MW, SOC 8.73.

9/29 – TSP in AGC test mode. Changed rate of set point changes to 15 seconds and Delta to 7.5 MW @ 0814. High Limit of 6.9 MW, Low Limit of -8 MW, Delta set to 7.5 MW, SOC 19.4 MW. Moved low limit @ 1404 to -5 to see if the charging time would be less. Moved high limit to 7.5MW.

9/30 – TSP in AGC test mode. AGC program stayed in generation mode more as expected after limit changes. Changed High Limit @ 0730 to 3.0 MW, Low Limit of -7 MW, Delta set to 7.5 MW, SOC .90 MW to bring SOC closer to 50%. Adjusted to flat schedules 7.0 MW HE14-16. Returned TSP to AGC @ 1545. High limit 7.0 MW, Low limit -7.0 MW, Delta 6.0 MW, SOC 17.46 MW.

10/1 – TSP in AGC test mode. Adjusted low limit to generate more @ 0810 High Limit of 7.0 MW, Low Limit of -3MW, & Delta set to 7.0 MW, SOC 30.19MW. At 1510 the AGC function was disabled. Re-established AGC @ 1538 with 7.5 MW HL, -3.0 MW for LL, & 7.0 MW for Delta.

10/2-4 – TSP in AGC test mode. Limits remained the same from 10/1 and the unit was allowed to respond to signals that were in the ranges of the control system.

10/5 – TSP in AGC test mode. Moved GMS to control to Off status @ 0845 with an SOC of .97. System handed over to grid test team.

6.6 M&V Results to Date

In addition to analyzing the results of the second period of Characterization Testing and Telemetry Testing described above, the project team built and tested models for analyzing results from each of the eight core test modes and thirteen operational uses. These models were validated using a combination of actual battery system and grid operational data, as well as extensive simulated data to fill in gaps where actual data was not available (due to the core tests not being run when these models were developed in mid-2015). The models were useful in analyzing the large volume of actual test data for the final report, while the validations of the models have already been useful in confirming expected model output and determining appropriate set points for the core test modes.

Concurrent with development and testing of the models in mid-2015, SCE briefly operated the system in each of the first five core test modes (those related to Transmission and System operational uses) from June 8 to July 24,2015, to collect short data sets for each mode and verify system operation. These short core tests were analyzed using the models, and were used in establishing set point adjustments for the longer-term core test periods in 2016.

Test data used for evaluation during this reporting period. The system was operated in the test modes shown in the following table.

Test	Description	Start Date	Stop Date
1	Provide steady state voltage regulation at the local Monolith 66 kV bus	1/25/16	2/16/16
2	Provide steady state voltage regulation at the local Monolith 66 kV bus while concurrently operating test 3, 4, or 5	6/8/15	7/25/15
3	Charge during periods of high light loading and discharge during periods of low line loading under SCE system operator control	3/8/16	3/24/16
4	Charge during off-peak periods and discharge during on-peak periods under SCE system operator control	2/16/16	3/8/16
5	Charge and discharge seconds-to-minutes as needed to firm and shape intermittent generation in response to a real-time signal	6/10/16	6/27/16

Table 6-16 Test modes and time period of the tests

6.6.1   Use Case 1 – Voltage Support

6.6.1.1   Test 1- Voltage Support

Energy storage used for transmission support improves Transmission and Distribution (T&D) system performance by compensating for electrical anomalies and disturbances such as voltage excursions, angular stability, and frequency stability. The battery energy storage system (BESS) can regulate line voltage at the point of common coupling (PCC) or compensate load reactive power by producing the desired amplitude and phase of inverter output voltage. The BESS can be installed to support electricity networks with a poor power factor and poor voltage regulation, and it can be helpful for voltage stability.

During Test 1, the battery injects and absorbs reactive power to regulate line voltage. The time frame for this test is 1/25/2016, 11:17:00 AM to 2/16/2016, 3:48:00 PM.

The measurements used in this study are:

-   Voltages of each phase of the BESS at the 66 kV connection to the substation.
-   Reactive Power exchange of the BESS

The actual settings for Test 1 can be written as follows:
V Control set point (target voltage): 66.75 kV
Tolerance: 1.12 %

These settings resulted in the following trigger thresholds:
Upper: 67.12 kV [66.75 + ((66.75 * 0.0112) / 2)]
Lower: 66.38 kV [66.75 - ((66.75 * 0.0112) / 2)]

It should be noted that the actual 66 kV bus voltages at the substation were extremely stable. Therefore, these settings were chosen with the objective of triggering and demonstrating the Test 1 algorithm for the purposes of the test.

The actual Monolith BESS 66 kV Connection Meter voltage and reactive power data are used for this analysis.

Data	Source	Sample Rate
AVrmsAvg[Volts] BVrmsAvg[Volts] CVrmsAvg[Volts] TOTQFnd(kVAR)Avg[kVAR]	Monolith BESS 66 kV Connection Meter	5 minutes

Table 6-17 - Use Case 1 – Data Used – Test 1

Using the above measurements, the variations of voltages and reactive power support of the BESS at Monolith is depicted below illustrating the effect of Q variations on voltage seen at the BESS. Positive Q shows inductive reactive power, and negative Q shows capacitive reactive power. As can be seen, the BESS generates/ absorbs reactive power to maintain the line voltage. It is observed that the BESS generates reactive power when the line voltage decreases, and the BESS absorbs reactive power when the voltage increases. The BESS is a voltage source converter (VSC)-based device. The reactive power at the terminals of the BESS depends on the amplitude of the voltage source. For example, if the terminal voltage of the BESS is higher than the AC voltage at the point of connection, the BESS generates reactive current, and when the amplitude of the voltage source is lower than the AC voltage, it absorbs reactive power. The response time of a BESS is shorter than that of conventional reactive power compensators like capacitor banks and static VAR compensator (SVC), mainly due to the fast switching times provided by the IGBTs of the voltage source converter.
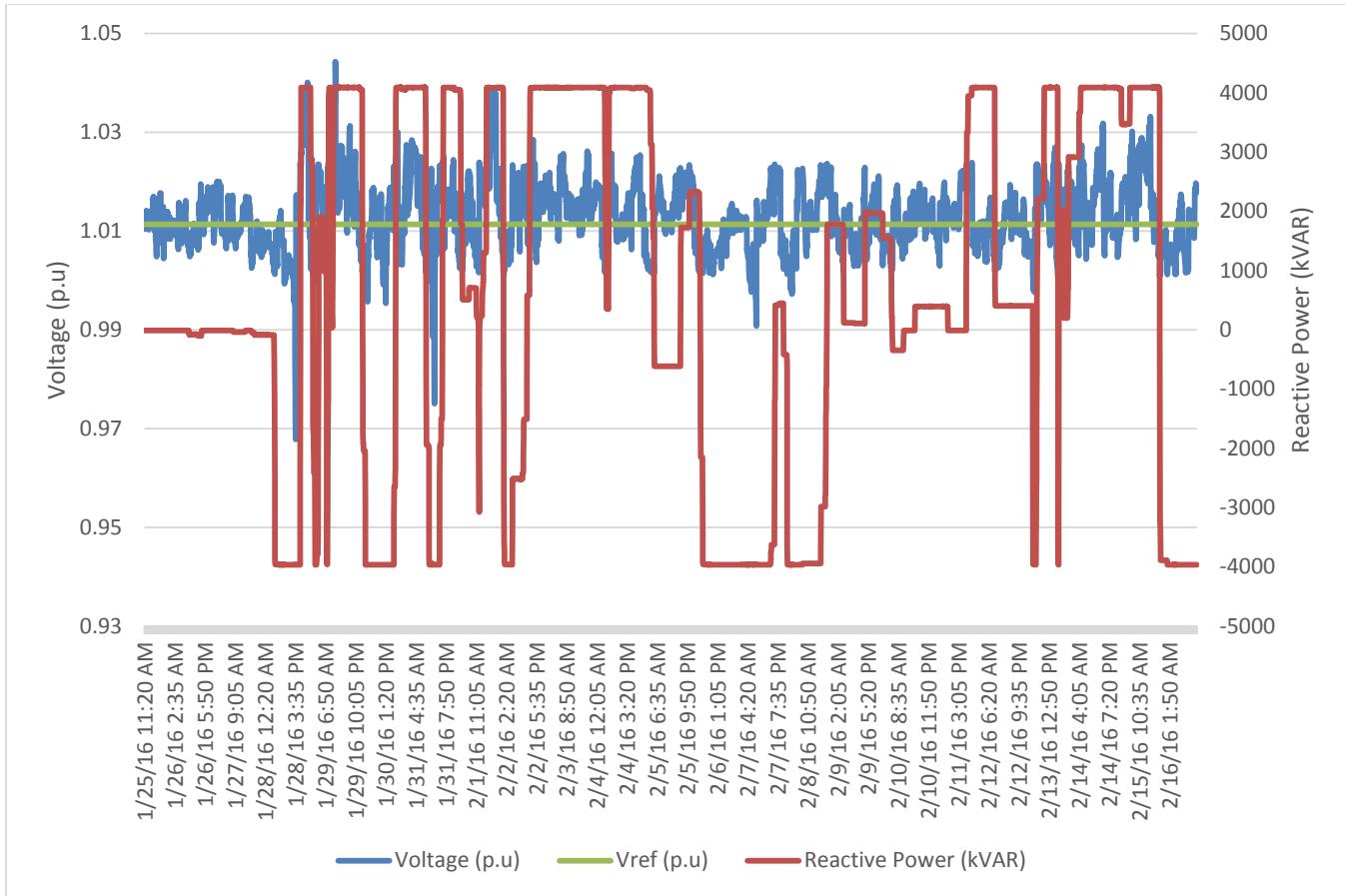
Figure 6-32- BESS Voltage and Reactive Power in Test 1 Time Frame

It can be noted that the BESS generates reactive power when the line voltage decreases, and the BESS absorbs reactive power when the voltage increases. So, BESS can be used to regulate line voltage, and it can be used to supplement capacitor switching schedules.

The total reactive power energy for the study period is:

$$E_{reactive} = \sum |Q_{BESS}| . \Delta t = 1346 \ (MVAR.h)$$

Where Δt is the interval between two sampling moment, which in this case is equal to 5 minutes.

From the total reactive power energy, 843 (MVAR.h) is the inductive reactive power energy, and 503 (MVAR.h) is the capacitive reactive power energy.

Total reactive power energy (MVAR. h)	1346
Total inductive reactive power energy (MVAR. h)	843
Total capacitive reactive power energy (MVAR. h)	506

Table 6-18 – Total Reactive Power Energy

6.6.1.2 Test 2- Voltage Support

During Test 2, the battery injects and absorbs reactive power to regulate line voltage, and it provides steady state voltage regulation and dynamic voltage support at the local Monolith 66 kV bus while operating under test 1, and also, performing real power injection/absorption required under test 3, 4 and 5 modes.

The time frame for this test is 06/08/2015, 8:37:00 AM to 06/15/2015, 10:28:00 AM & 06/15/2015, 2:55:00 PM to 06/23/2015, 10:00:00 AM & 07/01/2015, 11:17:00 AM to 07/06/2015, 10:20:00 AM & 07/10/2015, 4:38:00 PM to 07/15/2015, 6:20:00 APM & 07/22/2015, 9:30:00 PM to 07/24/2015, 8:21:00 AM per the following table:

Test	Start Date	Stop Date
Test 1	06/08/2015	06/15/2015
Test 4 with voltage regulation on	06/15/2015	06/23/2015
Test 5 with voltage regulation on	07/01/2015	07/06/2015
Test 3 with voltage regulation on	07/10/2015	07/15/2015
Test 3 with voltage regulation on	07/22/2015	07/24/2015

Table 6-19 – Test 2 Time Frame

The measurements used in this study are:

- Voltages of each phase of the BESS at the 66 kV connection to the substation.
- Reactive Power exchange of the BESS
- Active Power exchange of the BESS

The actual Monolith BESS 66 kV Connection Meter voltage and reactive power data are used for this analysis.

Data	Source	Sample Rate
AVrmsAvg[Volts] BVrmsAvg[Volts] CVrmsAvg[Volts] TOTQFnd(kVAR)Avg[kVAR]	Monolith BESS 66 kV Connection Meter	5 minutes

Table 6-20 - Use Case 1 – Data Used – Test 2

Using the above measurements, the variations of voltages and reactive power support of the BESS at Monolith is depicted below illustrating the effect of Q variations on voltage seen at the BESS. Positive Q shows inductive reactive power, and negative Q shows capacitive reactive power. As can be seen, the BESS generates/ absorbs reactive power to maintain the line voltage. It is observed that the BESS generates reactive power when the line voltage decreases, and the BESS absorbs reactive power when the voltage increases.
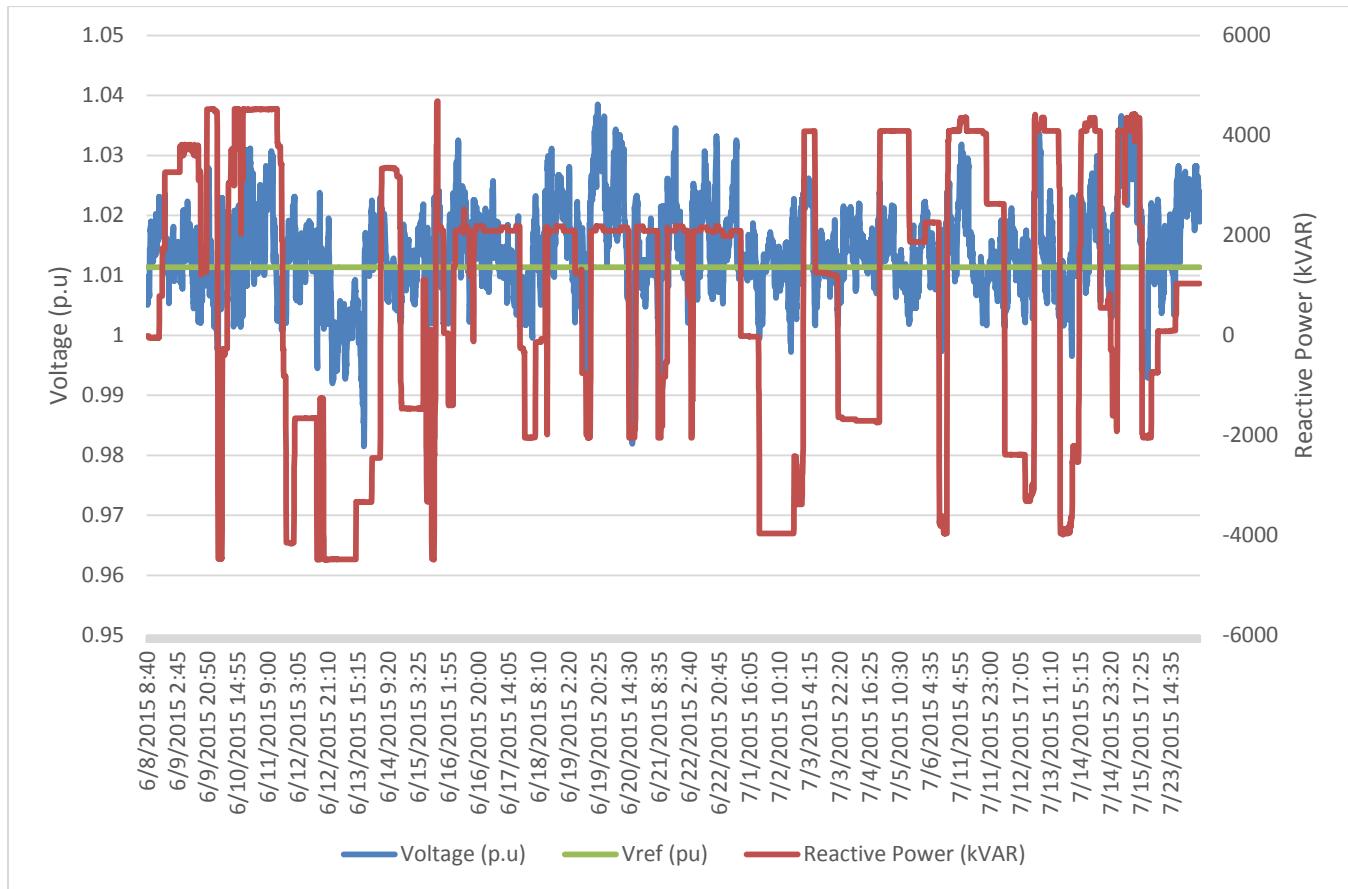
Figure 6-33- BESS Voltage and Reactive Power in Test 2 Time Frame
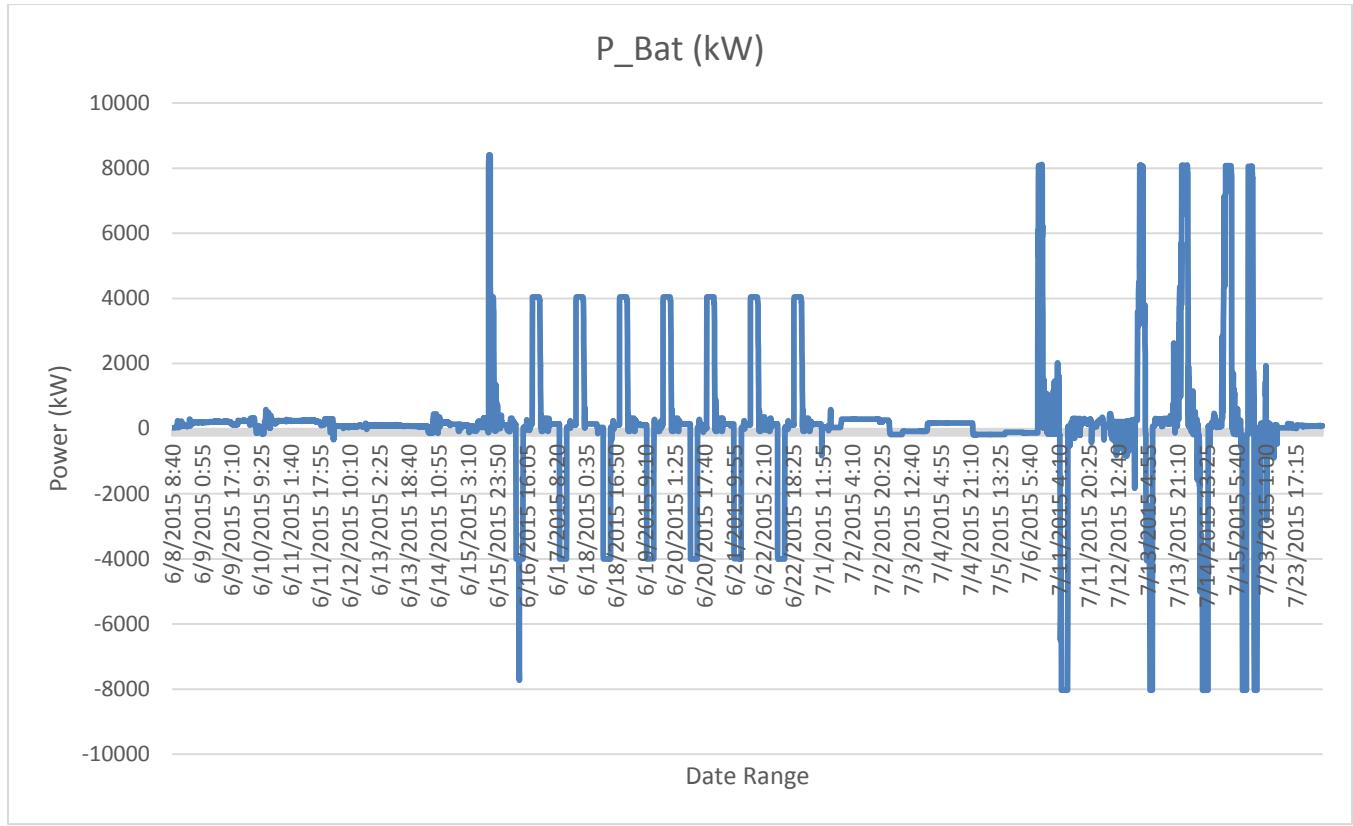
Figure 6-34- BESS Active Power Flow in Test 2 Time Frame

It can be noted that the BESS generates reactive power when the line voltage decreases, and the BESS absorbs reactive power when the voltage increases. So, the BESS can be used to regulate line voltage, and it can be used to supplement capacitor switching schedules.

The total reactive power energy for the study period is:

$$E_{reactive} = \sum |Q_{BESS}|.\,\Delta t = 1600 \; (MVAR.h)$$

Where Δt is the interval between two sampling moment, which in this case is equal to 5 minutes.

From the total reactive power energy, 1060 (MVAR.h) is the inductive reactive power energy, and 540 (MVAR.h) is the capacitive reactive power energy.

Total reactive power energy (MVAR. h)	1600
Total inductive reactive power energy (MVAR. h)	1060
Total capacitive reactive power energy (MVAR. h)	540

Table 6-21 – Total reactive power energy

After the first five core tests, the system was operated in each of the remaining three core tests modes (those related to Market operational uses) from September 3 to October 5, 2015, again to collect short data sets for each test mode and verify system operation. These are described in the Market Participation section below, and were also used to establish longer-term market testing scheduled for two periods in late 2015 and 2016.

6.6.2   Use Case 2 – Decreased losses

Transmission losses are dependent on the current flow through transmission lines. By reducing the current flow on the transmission system under peak conditions, the BESS can reduce losses. The analysis is performed using the system configuration information provided, i.e. two lines running between Monolith and Wind Hub.

During Test 3, the battery is charged to reduce the current flow in the lines connected to Monolith. The time frame for this test is 3/8/2016, 4:10:00 PM to 3/11/2016, 9:40:00 AM, and 3/21/2016, 11:55 AM to 3/24/2016 8:55 AM.

The measurements used in this study are:

- BESS SOC
- Wind generation at Monolith
- Current in Line 1
- Current in Line 2
- Currents of each phase from the BESS.
- Power exchange of the BESS

The actual data on battery voltage and reactive power are used for this analysis.

Data	Source	Sample Rate
SEC_AC800M.GRIDGGIO1.RelativeLin (Line 1, gold) SEC_AC800M.GRIDGGIO1.Relative_1 (Line 2, red) SEC_AC800M.GRIDGGIO1.TotalRealWi SEC_AC800M.SECGGIO1.SECSOC	Historian Data	5 minutes

Table 6-22 - Use Case 2 – Data Used

Using the above measurements, the variations of SOC and Wind generation at Monolith in the study time frame are depicted below. In order to assess the performance of BESS to reduce losses, the specified period shown in the figure is considered. In this period, the BESS is charging and then being discharged, so the BESS efficiency is also considered. At the specified period, the wind power is increasing, and the battery is also charged to reduce the current flow through transmission lines.

During Test 3 period, the battery is charged under high line load, and it is discharged under low line load, and the actual settings for Test 3 can be written as follows (Appendix-A shows entire settings for test 3)
P_Charge_SetPoint=8000
P_Discharge_SetPoint=8000
T_Lim=90
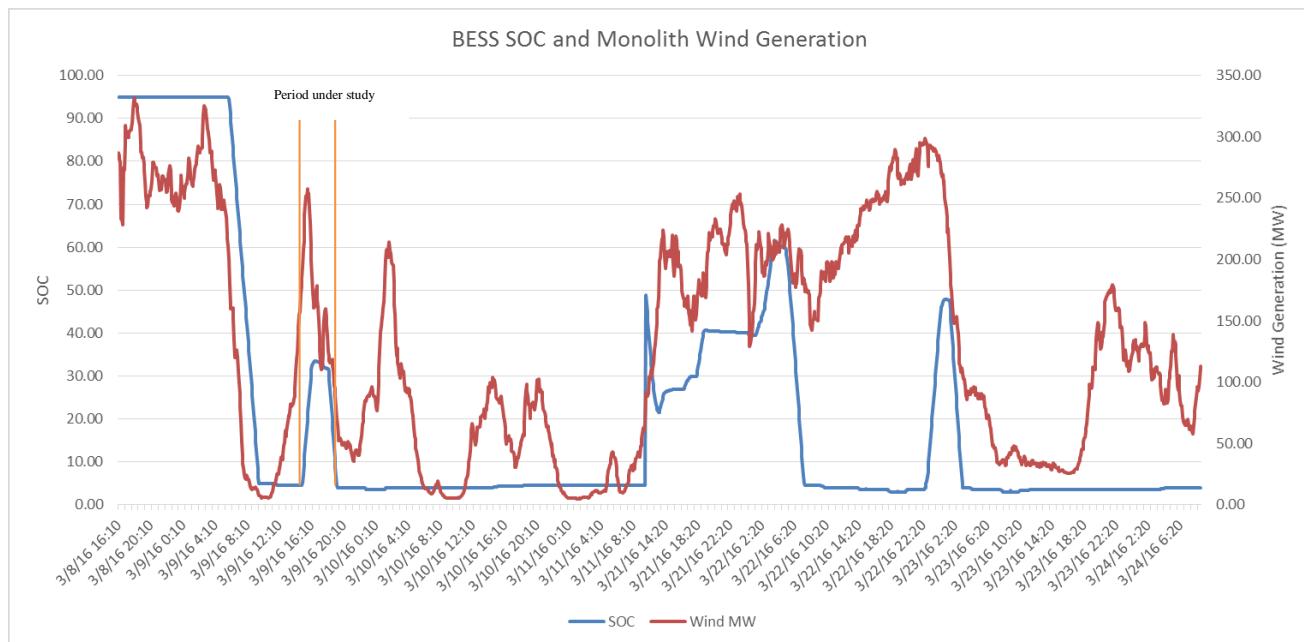
Figure 6-35- BESS SOC and Monolith Wind Generation in Test 3 Time Frame

The average daily current profile for the resultant summated values is depicted below, along with the average wind power generation profile
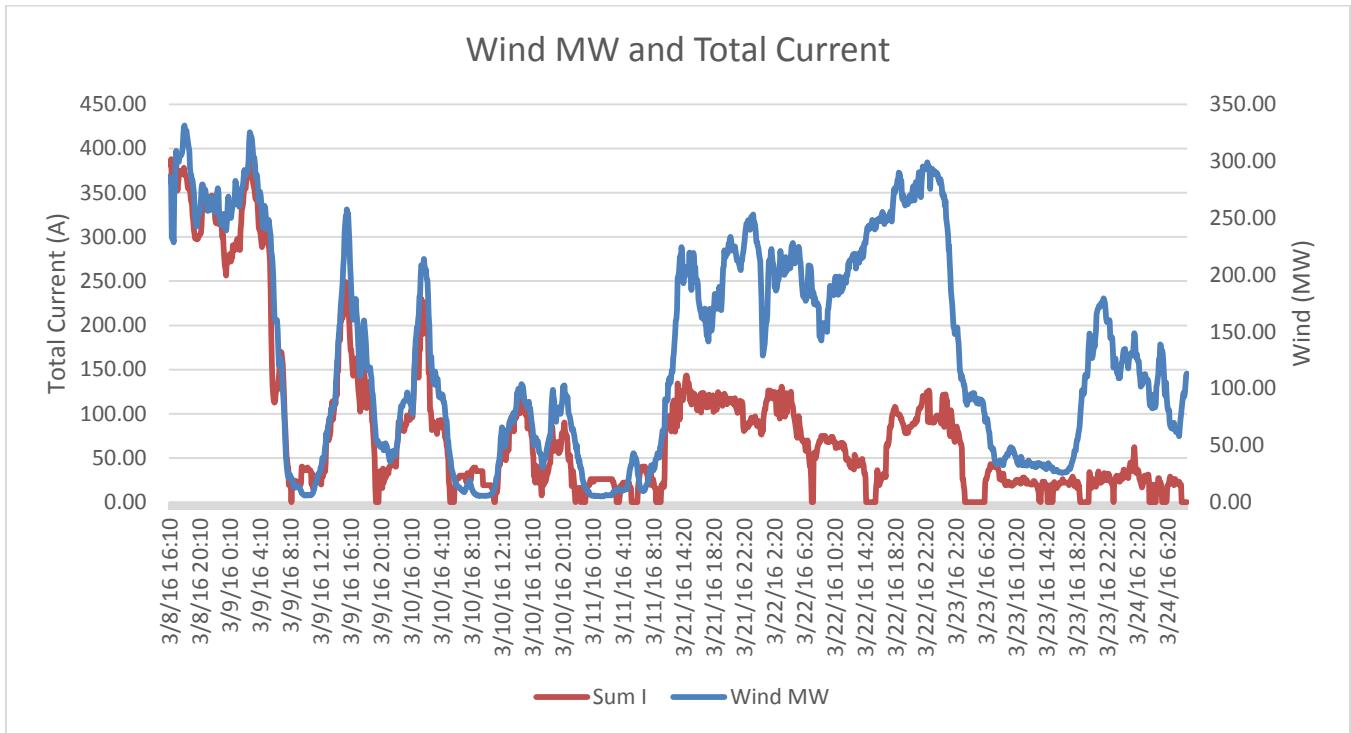
Figure 6-36- Average Total Current Profile

The line impedances calculated from actual system specifications are shown below.

		section	from	to	Impedance (Ohms)		
					R	X	|Z|
Path #	1 (Gold)	1	Monolith	Tap 88	0.99	5.28	5.37
		2	Tap 88	Wind Hub	0.07	0.54	0.54
		Total			1.06	5.82	5.91
	2 (Red)	1	Monolith	Tap 75	1.86	4.26	4.65
		2	Tap 75	Tap 74	0.53	2.82	2.87
		3	Tap 74	Wind Hub	0.52	2.77	2.81
		Total			2.91	9.85	10.27

Table 6-23 - Line Impedances from Monolith to Wind

Therefore, the value of active line loss at each sampling time in the study period are calculated as:

$$P_{loss} = 1.06I_{line1}^2 + 2.91I_{line2}^2$$

And hence the total energy loss for the study period is:

$$E_{loss} = \sum P_{loss}\Delta t$$

Where Δt is the interval between two sampling moments, which in this case is equal to 5 minutes.

Now if the BESS was not operating, the BESS current would have been added to the line currents and have increased the losses. Therefore, the BESS current is divided between line 1 and line 2 in proportion to their current flow at each sample. Considering the updated values of line currents, the similar procedure is followed to calculate the value of E_{loss} in the study period in this situation.

The results of both cases are compared below. As seen in this table, the BESS has succeeded to reduce the value of E_{loss} by 29.31%. Also note that the total duration of study is 6 hours and 25 minutes, and the BESS has not been fully charged, which denotes that full usage of BESS capacity over a longer time frame may have resulted in even higher performance in decreasing losses.

Start Time	End Time	Duration	E_{loss} with BESS	E_{loss} without BESS	% decrease
3/9/2016 2:00:00 PM	3/9/2016 7:25:00 PM	325 minutes	0.123 MWh	0.174 MWh	29.31

Table 6-24 - Comparison of $\boldsymbol{E_{loss}}$ in the Study Period with and without BESS Operation

6.6.3 Use Case 3 – Diminished Congestion

Storage can be used to avoid congestion-related costs and charges. It can be charged when wind generation output is high to reduce congestion, and be discharged when wind generation output is lower to utilize available transmission capacity.

Data	Source	Sample Rate
LMP_CONG_PRC (for node WINDHUB_2_NO32)	OASIS	1 hour
SEC_AC800M.GRIDGGIO1.TotalRealWi	Historian Data	5 minutes
TOTP(kW)Avg[kW]	Monolith BESS 66 kV Connection Meter	5 minutes

Table 6-25 - Use Case 3 – Data Used

During Test 3, the battery is charged to reduce congestion cost. The time frame for this test is 3/8/2016, 4:10:00 PM to 3/11/2016, 9:40:00 AM, and 3/21/2016, 11:55 AM to 3/24/2016 8:55 AM.

The measurements used in this study are:

- Wind generation at Monolith
- Power exchange of the BESS
- Locational Marginal Congestion Price (LMP)

The congestion price component of the Locational Marginal Prices (LMP) is used to indicate when congestion conditions exist.

The average of congestion price, the wind power, and the battery active power are depicted below. A drop in the LMP Congestion price below zero indicates the presence of congestion. It is interesting to note that the wind power generation curve is also at its lowest during this time frame, which theoretically restricts the benefit of using wind power for diminishing congestion (as opposed to say, PV). However, since the BESS' size is small compared to available wind generation at any time during the day, this is not considered further.

In order to assess the performance of BESS to diminish congestion, the specified periods shown in the figure are considered. In these periods, the BESS is charging and helps diminish congestion.
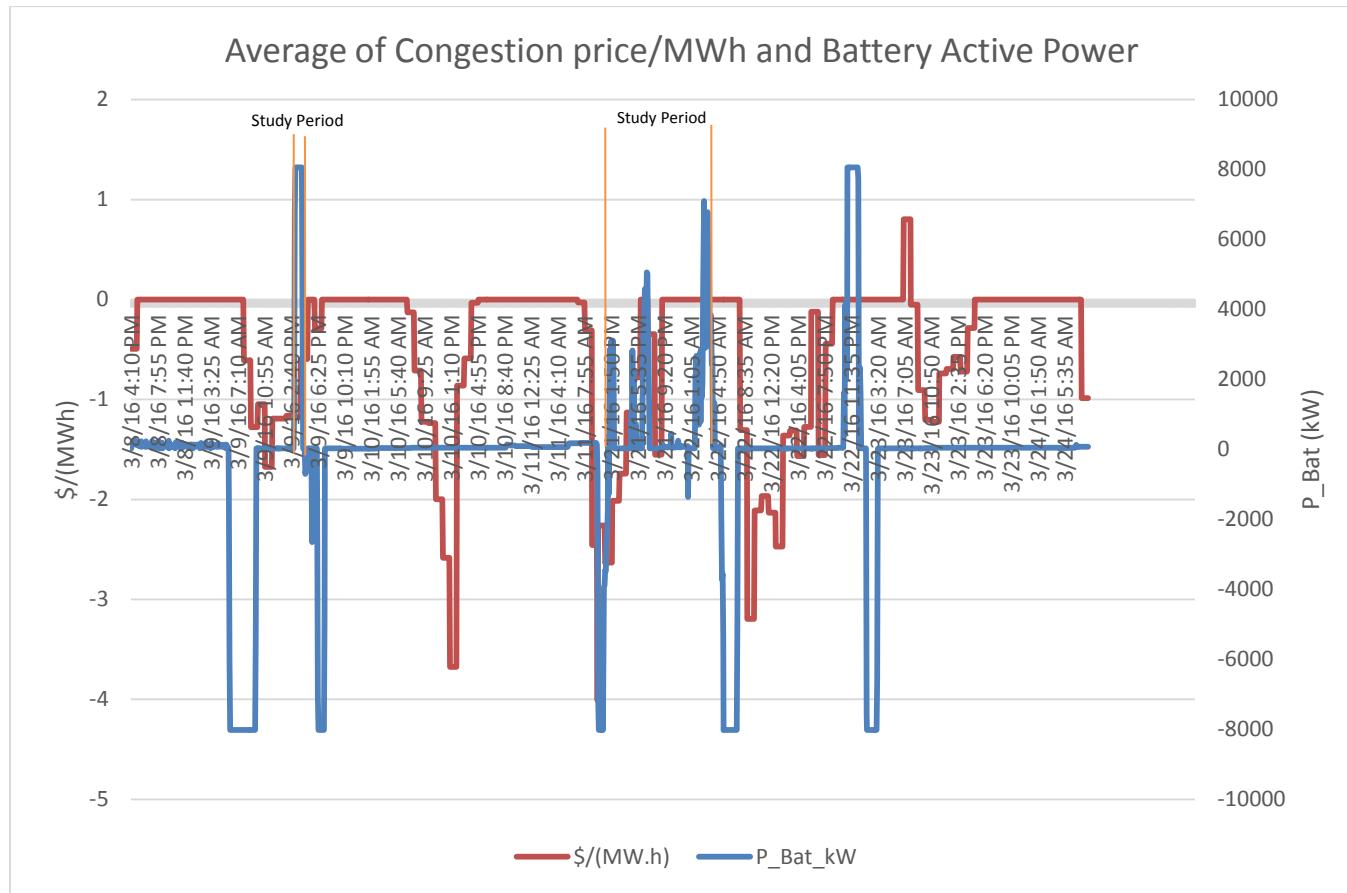
Figure 6-37- Congestion Price and Battery Active Power
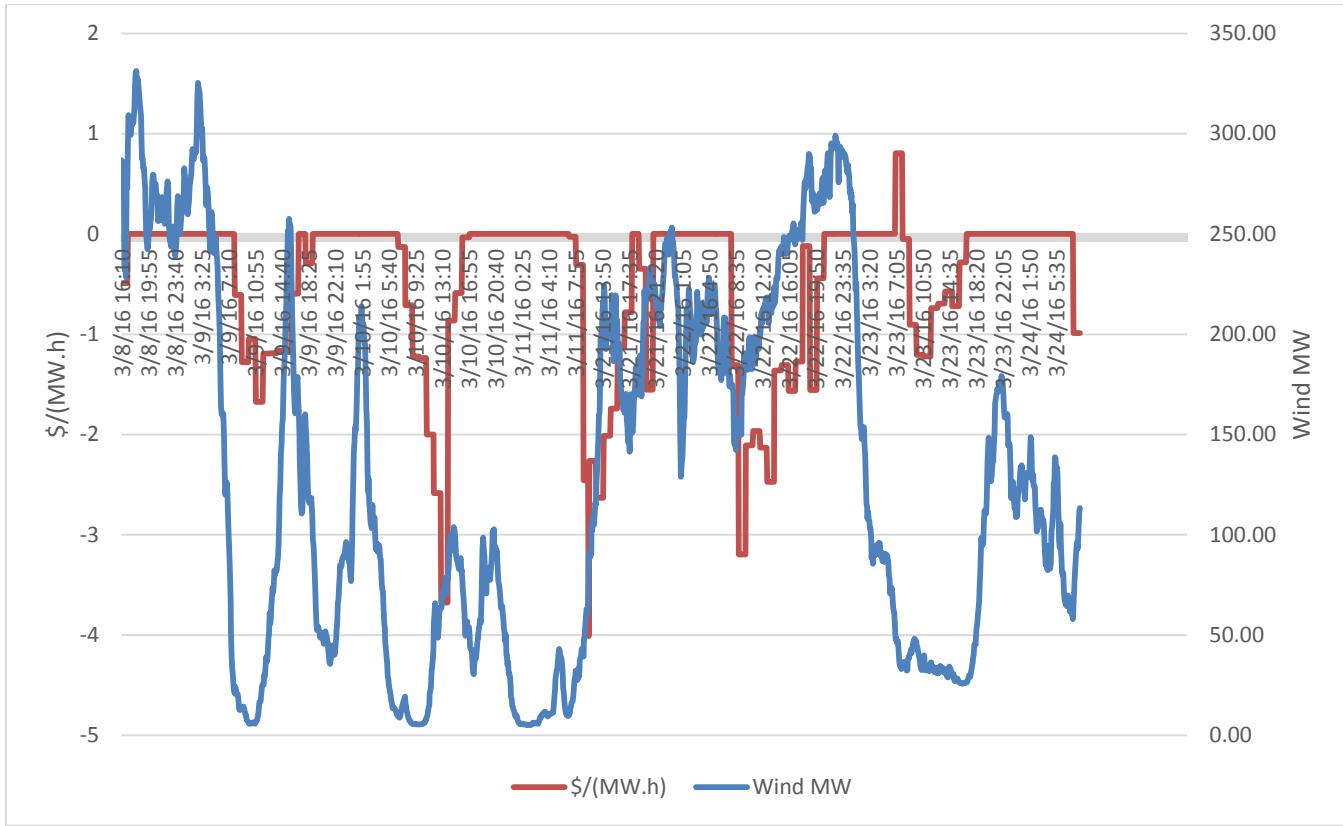
Figure 6-38- Congestion Price and Wind Power

The purpose of this test case study is to evaluate the impact of battery to reduce congestion. The battery is being charged, and as a result the power flow through transmission lines is reduced when the congestion is high.

When the battery power is multiplied by the hourly Congestion price/MW at the optimal charging periods and the LMP congestion price is below zero, the total savings realized is $16.62 for the reporting period. The following formula is used to find the total savings:

$$Total\ Saving = \text{Locational Marginal Price } (\frac{\$}{\text{MWh}}) \times \sum_{P_{Battery}>0} P_{Battery}\Delta t$$

6.6.4   Use Case 4 – Increased Reliability

At this juncture, it does not appear feasible to quantify the benefits obtained for the BESS for either this use case, or that for use case #7 (System capacity / resource adequacy) which has similar restrictions on calculating benefits. Consequently, the analysis is limited to the concept description below.

There are different standards for evaluating RA and therefore reliability. The 1-in-10 standard usually interpreted as 0.1 loss of load events per year (0.1 LOLE) is widely adopted across North

America. However, CAISO only adopts a minimum of 15% Reserve Margin (RM) standard as the criteria for evaluating RA. This guideline is according to the long-term RA framework established by California Public Utility Commission (CPUC) in 2004 (D.04-01-050). In that docket, the decision was made to adopt a 15% to 17% Planning Reserve Margin (PRM) and each LSE was directed and made responsible to acquire sufficient reserve capacity to meet its customer loads. CAISO has since carried out LOLE studies, but those studies have not impacted the decision made in 2004 to maintain 15% RM. Moreover, an operating reserve margin of 3% or higher is required before firm load shedding takes place.

Demand response (DR) programs are one of the critical ways system operators provide RA and improve system reliability. DR can reduce summer peak demands and provide grid operators with additional system flexibility during periods of limited supply. It can be utilized to reduce end-user loads in response to a high price, a financial incentive, an environmental condition or a reliability issue. Demand response can also provide economic day-ahead and real-time energy and ancillary service.

The SCE BESS can help with the CAISO DR program. BESS DR can be defined as either a load-reduction resource or as a supply-side resource:

1- BESS deployed as supply-side resource in DR program

$$RM \% = \left[\frac{Gen(MW) + BESS(MW)}{Load\ (MW)} - 1 \right] * 100$$

2- BESS deployed as load-reduction resource in DR program

$$RM \% = \left[\frac{Gen(MW)}{Load(MW) - BESS(MW)} - 1 \right] * 100$$

During Test 4, the battery is tested for reliability analysis. The time frame for this test is 2/16/2016, 4:10 PM to 2/26/2016, 8:55 AM, 2/29/2016, 10:21 AM to 3/2/2016, 6:53 AM, and 3/3/2016, 5:20 PM to 3/8/2016 3:41 PM.

The measurements used in this study are:

- Wind generation at Monolith
- Power exchange of the BESS

Data	Source	Sample Rate
Actual Operating Reserves Price	OASIS	1 hour
SEC_AC800M.GRIDGGIO1.TotalRealWi	Historian Data	5 minutes
TOTP(kW)Avg[kW]	Monolith BESS 66 kV Connection Meter	5 minutes

Table 6-26 - Use Case 3 – Data Used

The battery reserve margin active power and the actual operating reserves price are shown below. In response to proper control signal and depending on battery SOC, the BESS can stop charging and start discharging its energy at specified power levels. Although RM (Reserve Margin) percentage will be somewhat different depending on what definition is adopted for BESS, it is evident from above that RM always improves with deployment of BESS in discharge mode. Therefore, as both planning and operating RM are increased, it can be further concluded that system reliability improves with deployment of BESS in discharge mode. Moreover, it should be noted that the SCE BESS is only 8MW/32MWh, which is very small compared to the size of Antelope-Bailey system. It is anticipated that by scaling up the BESS, or aggregating multiple units, the RA and reliability improvement benefits will be more pronounced.
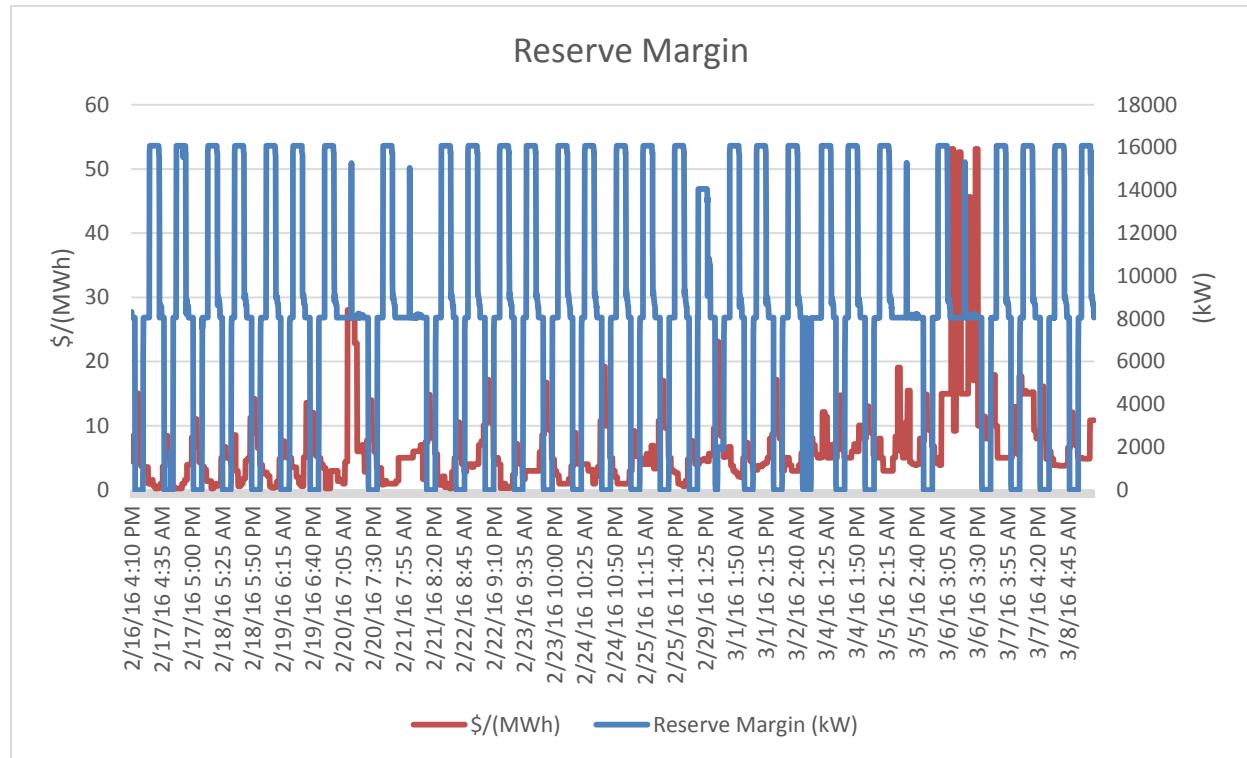
Figure 6-39- Actual Operating Reserves Price and Reserve Margin
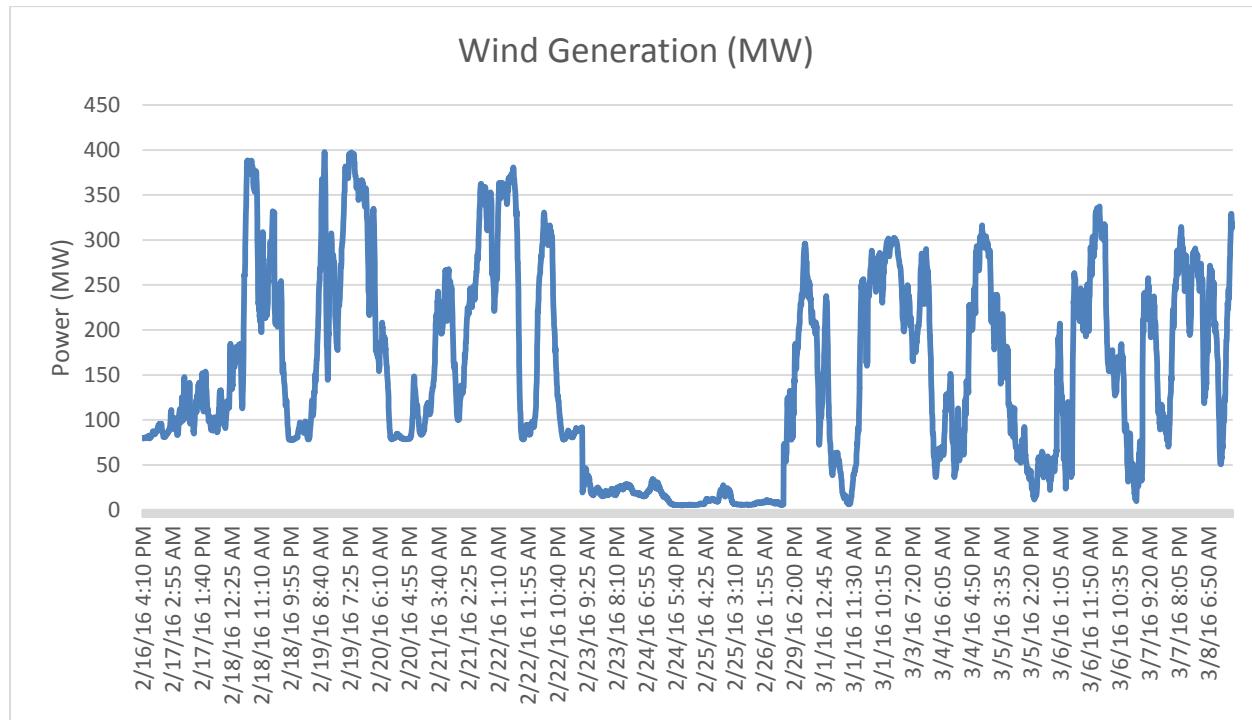
Figure 6-40- Wind Generation
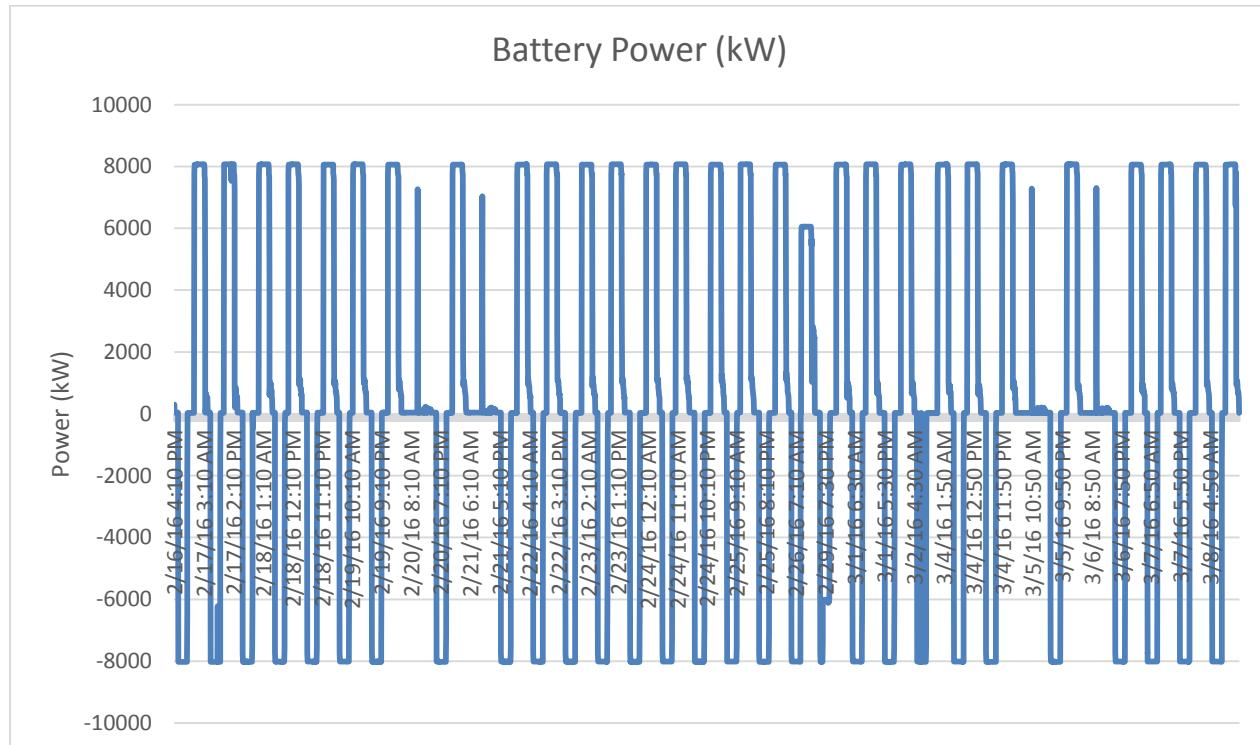
Figure 6-41- Battery Active Power

The total Reserve Margin (RM) Energy realized is 3289 MWh for the reporting period. The following formula is used to find the total RM energy in this case

$$Total\ RM\ Energy = \sum P_{RM}\Delta t$$

When the battery reserve power is multiplied by the hourly operating reserve price/MW, the total potential savings realized is $16,946 for the reporting period. The following formula is used to find the total savings in this case

$$Total\ Saving = A \times Operating\ Reserves\ Price\ (\frac{\$}{MWh}) \times \sum P_{RM}\Delta t$$

Where Δt is the interval between two sampling moment, which in this case is equal to 5 minutes. Also, *A* can be written as follows:

$$A = \begin{cases} 1, & x = \dfrac{SOC \times Battery\ Size}{P_{RM}\Delta t} \geq 1 \\ x, & x = \dfrac{SOC \times Battery\ Size}{P_{RM}\Delta t} < 1 \end{cases}$$

References:

[1] http://www.ferc.gov/legal/staff-reports/2014/02-07-14-consultant-report.pdf

[2] http://www.caiso.com/Documents/2014SummerAssessment.pdf

[3] http://docs.cpuc.ca.gov/PUBLISHED/FINAL_DECISION/33625-03.htm#P191_20252

6.6.5   Use Case 5 – Deferred Transmission Investment

Wind generation to be transmitted from Monolith substation to the Wind Hub could be limited by the 66 kV tie-lines transmission capacities. The BESS can be used to store the excess wind generation and defer investment in additional transmission capacity.

Data	Source	Sample Rate
LMP_CONG_PRC (for node WINDHUB_2_NO32)	OASIS	1 hour

Table 6-27 - Use Case 5 – Data Used

During Test 3, the battery is charged to reduce congestion cost. The time frame for this test is 3/8/2016, 4:10 PM to 3/11/2016, 9:40 AM, and 3/21/2016, 11:55 AM to 3/24/2016 8:55 AM.

Use Case #3 is used as the basis for this calculation. The average daily savings realized by congestion avoidance are calculated and then extrapolated for a 30 year period as illustrated below.

Results from Use Case #3		Extrapolated savings in years (Cumulative)	
Start of reporting period (1st)	3/8/16 4:10 PM	1	$1,082.64
End of reporting period (1st)	3/11/16 9:40 AM	5	$5,413.18
Start of reporting period (2nd)	3/21/16 11:55 AM	10	$10,826.35
End of reporting period (2nd)	3/24/16 8:55 AM	15	$16,239.53
Study period (in minute)	8070	20	$21,652.70
Savings realized	$16.62	25	$27,065.88
Average Savings/day	$2.97	30	$32,479.05
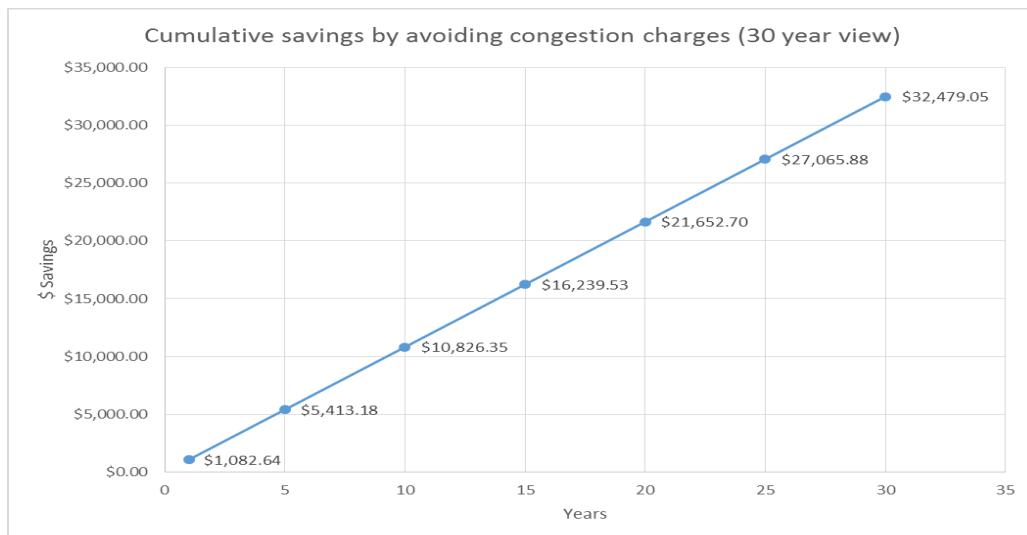
Figure 6-42- Cumulative Savings by Avoiding Congestion Charges (30 year view)

The 30 year time horizon used above is the same as that typically used when making transmission investment calculations – so by utilizing the BESS to avoid congestion charges, $32,479 savings will be realized.

6.6.6 Use Case 6 – Optimized Renewable Transmission

New transmission infrastructure built to fully integrate renewable energy into the grid must be planned and sized for maximum output of installed renewable generation, even though that output is variable and will usually be well below its maximum. Such sizing would lead to substantial under-utilization of transmission capability most of the time. The BESS can be used to store the excess wind generation and defer investment in additional transmission capacity. The analysis is similar to that for Use Case 5, except that the time horizon utilized is much shorter (1

year, as opposed to 30 years) and the metric is energy deferred to improve the effective utilization of renewable energy-related transmission.

Data	Source	Sample Rate
LMP_CONG_PRC (for node WINDHUB_2_NO32)	OASIS	1 hour

Table 6-28 - Use Case 6 – Data used

During Test 3, the battery is charged to reduce congestion cost. The time frame for this test is 3/8/2016, 4:10 PM to 3/11/2016, 9:40 AM, and 3/21/2016, 11:55 AM to 3/24/2016 8:55 AM.

Use Case #3 is used as the basis for this calculation. The average daily energy shifted by congestion avoidance are calculated and then extrapolated for a 12 month period as illustrated below.

Over a 12 month period of time, the BESS has the potential to shift 927 MWh that would otherwise require investment in transmission capacity.

Results from Use Case #3		Extrapolated savings in months (Cumulative)	
Start of reporting period (1st)	3/8/16 4:10 PM	1	77.25
End of reporting period (1st)	3/11/16 9:40 AM	2	154.5
Start of reporting period (2nd)	3/21/16 11:55 AM	3	231.75
End of reporting period (2nd)	3/24/16 8:55 AM	4	309
Study period (in minute)	8070	6	463.5
Total energy transferred (MWh)	14.43	9	695.25
Average MWh/day	2.57	12	927
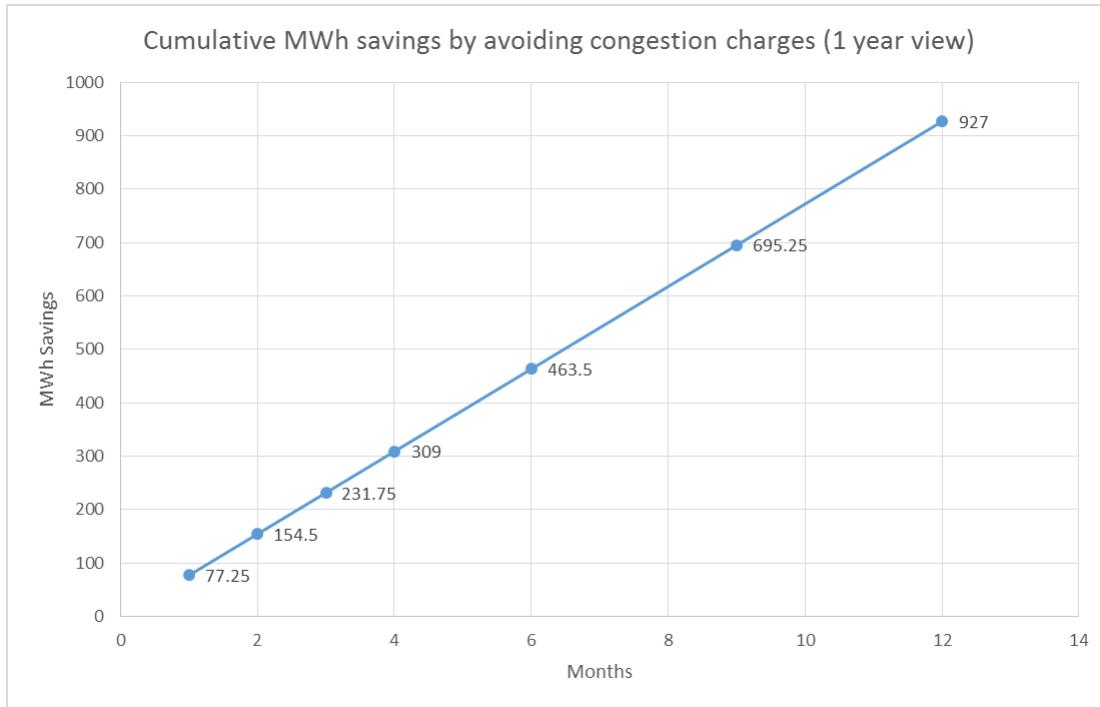
Figure 6-43- Cumulative Energy Savings by Avoiding Congestion Charges (1 year view)

6.6.7   Use Case 7 – System Capacity / Resource Adequacy

This use case aims to measure the ability of the BESS to improve the resource adequacy of the generated wind power.

Test 4 is used for this analysis. The time frame for this test is 2/16/2016, 4:10 PM to 2/26/2016, 8:55 AM, 2/29/2016, 10:21 AM to 3/2/2016, 6:53 AM, and 3/3/2016, 5:20 PM to 3/8/2016 3:41 PM.

The actual data on line loading and wind power generation was used as input to the model.

Data	Source	Sample Rate
SEC_AC800M.GRIDGGIO1.TotalRealWi	Historian Data	5 minutes
TOTP(kW)Avg[kW]	Monolith BESS 66 kV Connection Meter	5 minutes

Table 6-29 - Use Case 2 – Data Used

Wind generation at Monolith substation and the battery active power are depicted below.
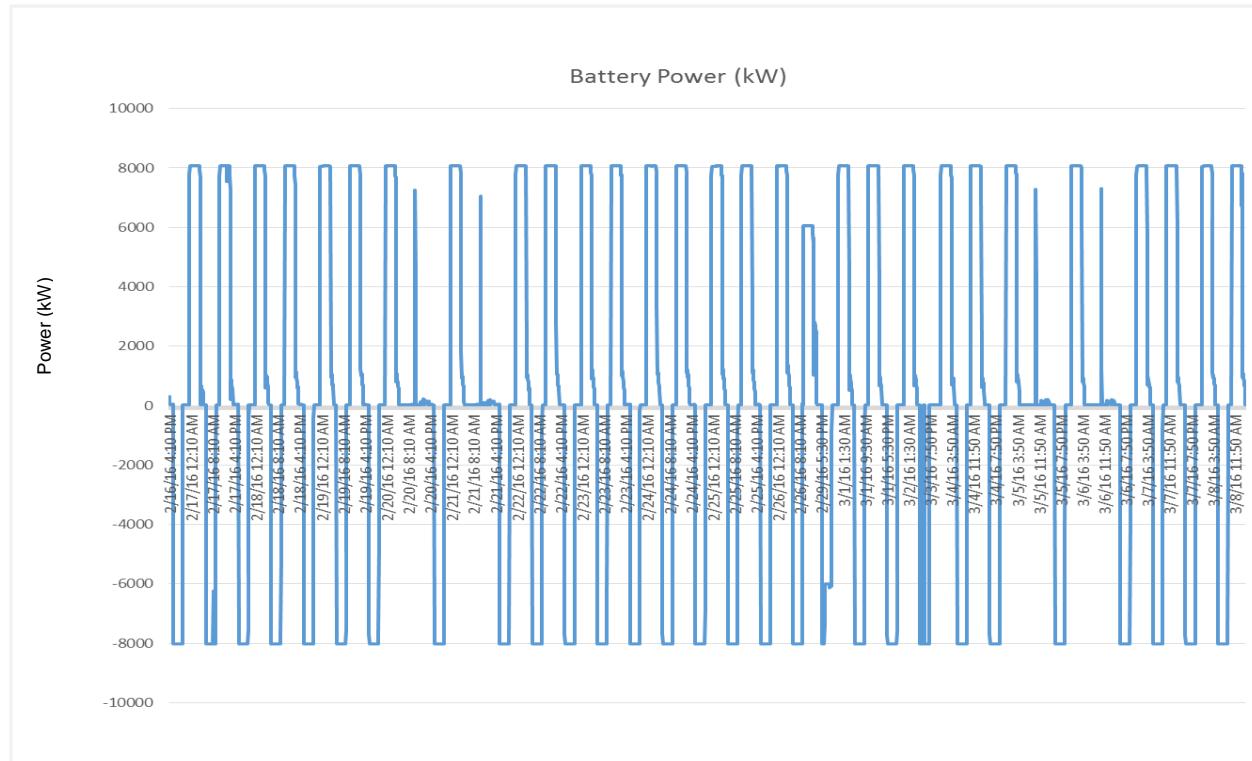
Figure 6-44- Battery Active Power
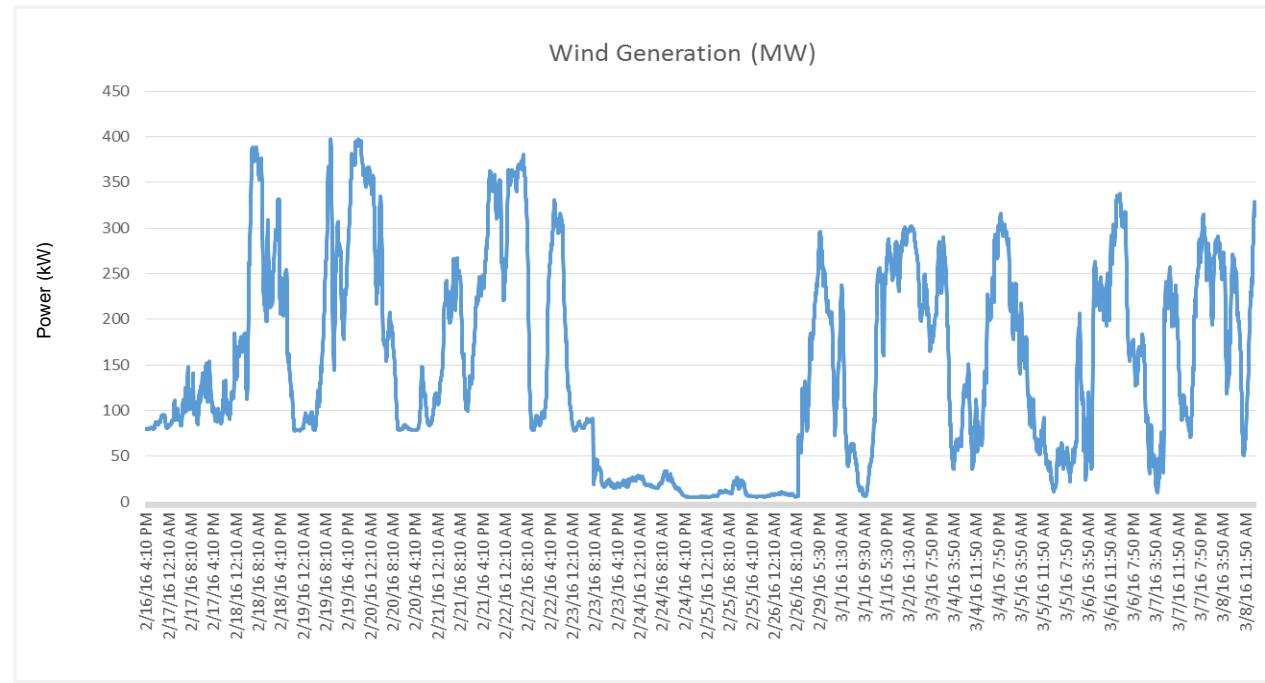
Figure 6-45- Wind Generation at Monolith

Using the BESS, the minimum value of wind generation can be improved if the BESS is discharged during minimum output hours; hence the BESS can improve the resource adequacy value of Wind Hub by charging during peak generation and discharging during minimum output hours.

To better demonstrate the theoretical impact of the BESS on improving the Monolith power output, the below figure shows the power output with and without BESS. The resultant power output of Monolith substation is overlaid on the charts assuming the BESS is charged during the peak power output, and discharged during the minimum power output.
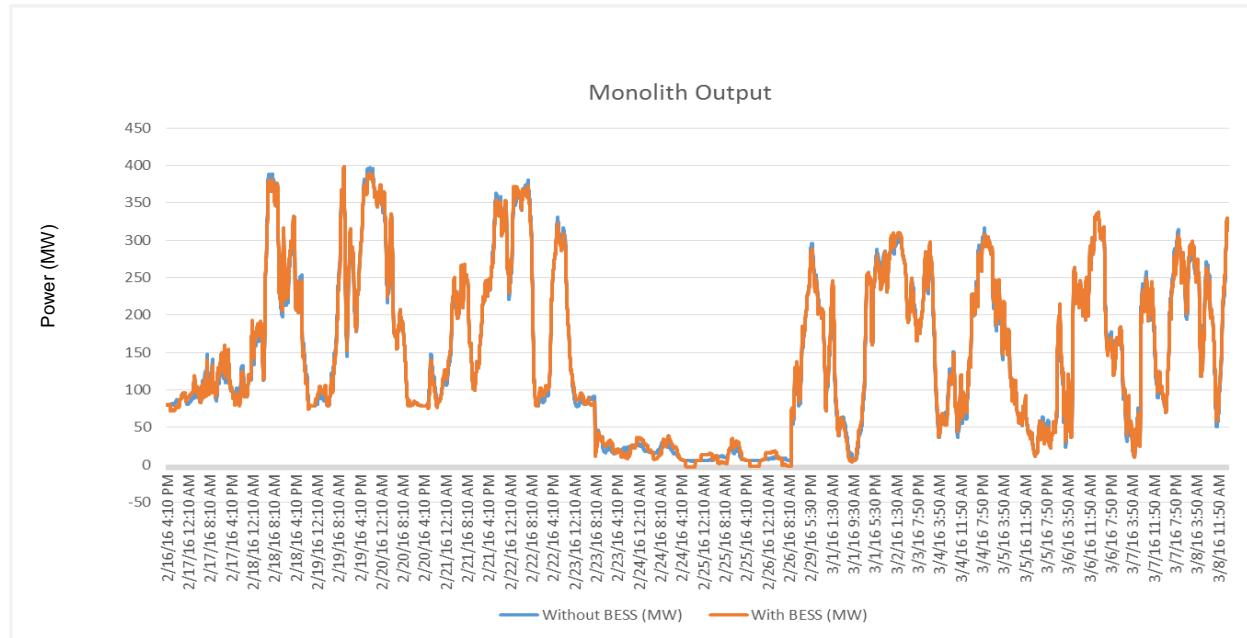
Figure 6-46- Wind Generation with and without BESS Support at Monolith

The increase in minimum power value after the impact of the BESS is added represents the improvement in resource adequacy as demonstrated below:
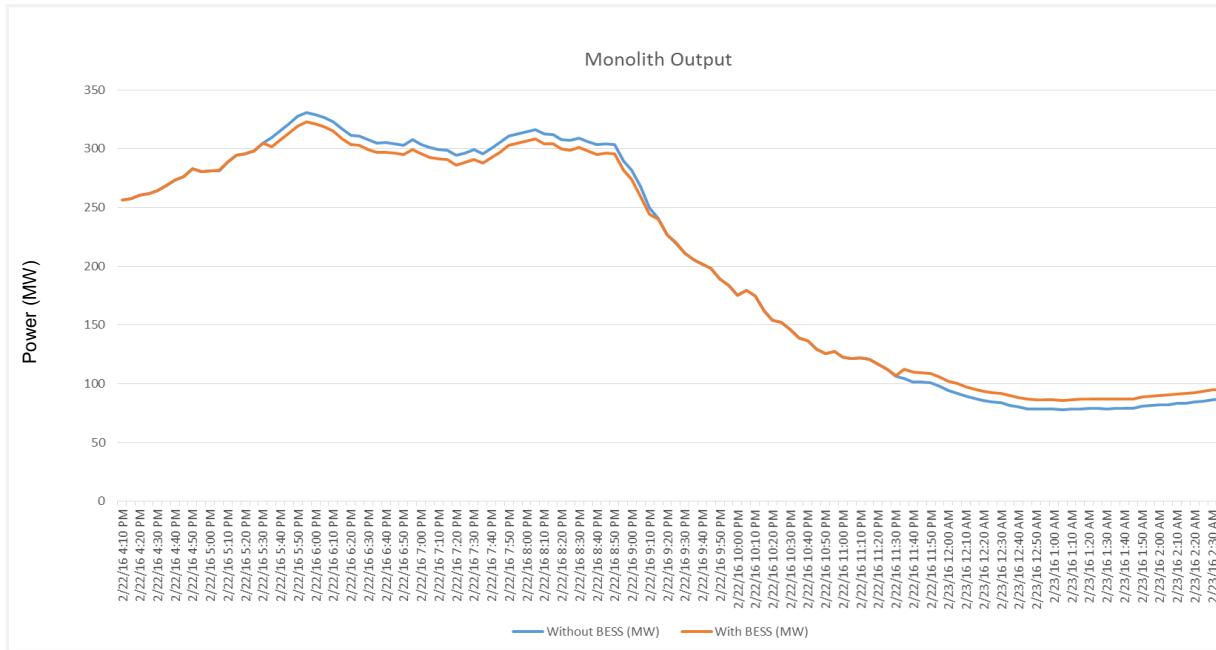
Figure 6-47- Wind Generation with and without BESS Support at Monolith (2/22/2016-2/23/2016)

As shown, the BESS has improved the power output profile and increased the minimum power generation from Monolith substation that can be factored in during planning studies.

6.6.8   Use Case 8 – Renewable Integration (firming and shaping)

This use case evaluates the benefit of the BESS in reducing sudden wind generation variations and providing a smoother wind generation profile.

During Test 5, the battery is charged and discharged seconds-to-minutes as needed to firm and shape intermittent generation in response to a real-time signal. The time frame for this test is 6/10/2016, 4:17:00 PM to 6/27/2016, 9:00:00 AM.
The measurements used in this study are:

- BESS SOC
- Wind generation at Monolith
- Power exchange of the BESS

The actual settings for Test 5 can be written as follows:

Wind Coef: 1 (no scaling applied to wind generation signal)
Allowable Wind Ramp +: 17
Allowable Wind Ramp -: 17
The actual data on wind power and battery state of charge (SOC) are used for this analysis.

Data	Source	Sample Rate
SEC_AC800M.PCCGGIO1.PCCPAct SEC_AC800M.GRIDGGIO1.TotalRealWi SEC_AC800M.SECGGIO1.SECSOC	Historian Data	30 seconds

Table 6-30 - Use Case 8 – Data Used

The figure below shows the wind power generation and battery SOC for Test 5 period. As can be seen, wind generation has a variable profile, with different ramp rates. In this use case, the BESS is used to improve the ramp rate of power delivered to wind hub.
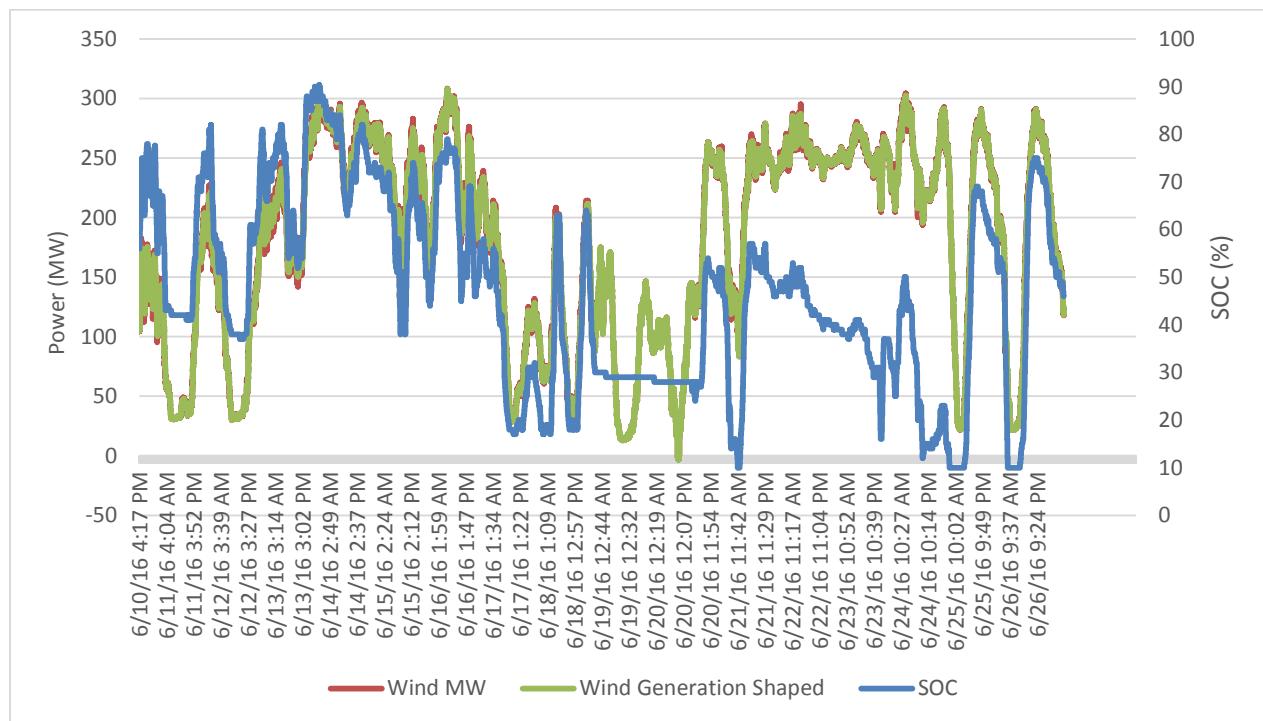
Figure 6-48- Wind Generation, Wind Generation Shaped, and Battery SOC

The figure below shows the state of the charge (SOC) of the battery, wind generation as well as the power output shaped by BESS. As can be seen in the figure, the battery has improved the ramp rate value to a degree. However, in some instances, the battery has reached its maximum SOC before the ramp rate improvement is complete.

This use case shows the benefits provided by the BESS with regards to ramp rate control – with the larger BESS size providing greater control capabilities.
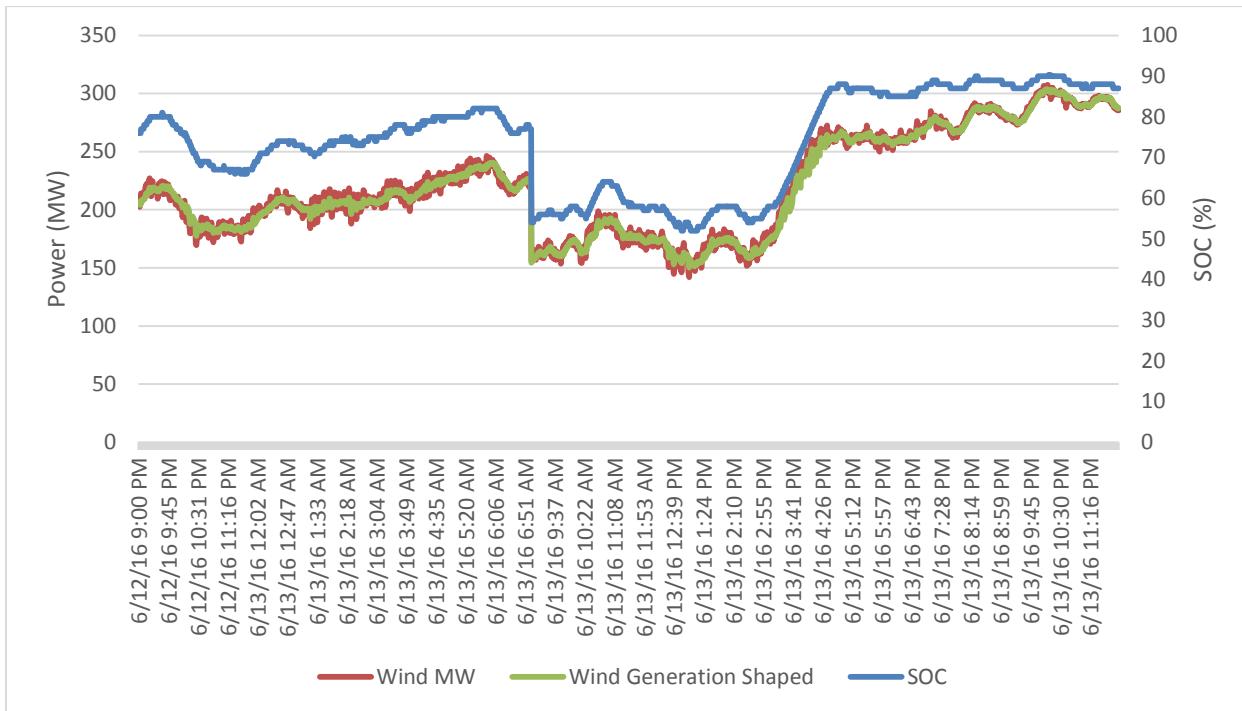
Figure 6-49- Wind Generation, Wind Generation Shaped, and Battery SOC (6/12/2016-6/13/2016)

6.6.9 Use Case 9 – Output Shifting

Local wind generation resources often produce a significant portion of electric energy when that energy has a low financial value (e.g., at night, on weekends, during holidays off-peak times). Energy storage used in conjunction with renewable energy generation could be charged using low value energy from the renewable energy generation so that energy may be used to offset other purchases or sold when it is more valuable. Our objective is to determine the BESS's ability to shift wind generation output from lower cost off-peak times to higher cost, on-peak times. The cost difference between energy during discharge and charge cycles will be evaluated to determine the benefits.

Data	Source	Sample Rate
LMP_PRC (for node	OASIS	1 hour

WINDHUB_2_NO32)		
SEC_AC800M.GRIDGGIO1.TotalRealWi	Historian Data	5 minutes
TOTP(kW)Avg[kW]	Monolith BESS 66 kV Connection Meter	5 minutes

Table 6-31 - Use Case 9 – Data Used

Test 4 is used for this analysis. The time frame for this test is 2/16/2016, 4:10 PM to 2/26/2016, 8:55 AM, 2/29/2016, 10:21 AM to 3/2/2016, 6:53 AM, and 3/3/2016, 5:20 PM to 3/8/2016 3:41 PM.

The average LMP_PRC price profile for the reporting period is illustrated below, along with the battery power profile. As can be seen, the battery is discharged when the LMP price is high, and it is charged when the LPM value is low.
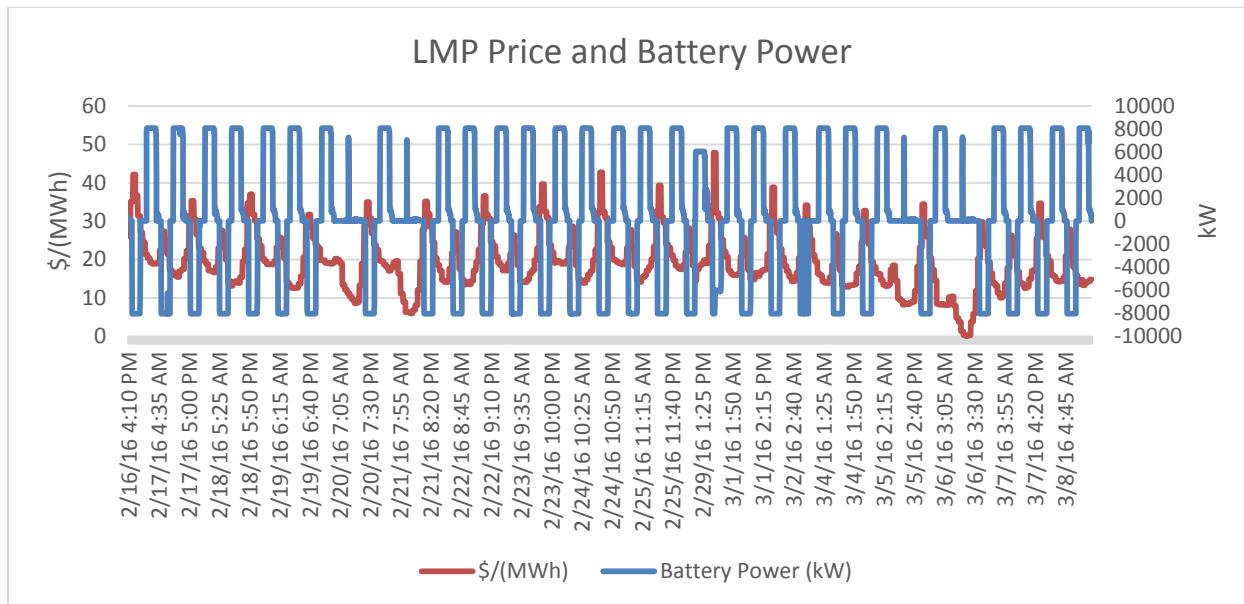
Figure 6-50- Average LMP_PRC Price Profile and Battery Power

The purpose of the algorithm is to evaluate the impact of shifting energy from a period of higher production to one of lower production.

The total charging and discharging savings for the reporting period can be calculated as follows:

$$Total\ Charging\ Saving\ (MWh) = \sum \left| P_{charging} \right| \Delta t$$

$$Total\ Discharging\ Saving\ (MWh) = \sum \left| P_{discharging} \right| \Delta t$$

$$Total\ Charging\ Saving\ (\$) = Locational\ Marginal\ Price\ (\frac{\$}{MWh}) \times \sum \left| P_{charging} \right| \Delta t$$

$$Total\ Discharging\ Saving\ (\$) = Locational\ Marginal\ Price\ (\frac{\$}{MWh}) \times \sum \left| P_{discharging} \right| \Delta t$$

$$Total\ Saving\ (\$) = Total\ Discharging\ Saving - Total\ Charging\ Saving$$

The total charging and discharging savings can be summarized in the below table.

Total charging purchased energy (MWh)	950.94
Total discharging selling energy (MWh)	836.74
Total charging purchased price ($)	$15,153.36
Total discharging selling price ($)	$23,005.11
Total savings ($)	**$7,851.75**

Table 6-32 – Total Charging and Discharging Savings

Test 3 Settings

Version 1 — 2016-03-08

Setting	Value	Notes
P_Charge_SetPoint	8000	
P_Discharge_SetPoint	8000	
T_Lim	90	
I_Line1_Lim1	175	First set of limits for
I_Line1_Lim1_Lower	100	T < T_Lim
I_Line1_Lim2	165	Second set of limits
I_Line1_Lim2_Lower	90	for T > T_Lim
I_Limits_Deadband	25	
I_Limit_Lower_Deadband	25	
I_Line1_Act_Coef	1	
I_Line2_Act_Coef	0	
I_Calc_Lim1	350	
I_Calc_Lim1_Lower	0	
I_Calc_Lim2	350	Weighted sum of
I_Calc_Lim2_Lower	0	I_Line1 and I_Line2

Version 2 — 2016-03-21

Setting	Value	Notes
P_Charge_SetPoint	8000	
P_Discharge_SetPoint	8000	
T_Lim	90	
I_Line1_Lim1	125	First set of limits for
I_Line1_Lim1_Lower	90	T < T_Lim
I_Line1_Lim2	115	Second set of limits
I_Line1_Lim2_Lower	80	for T > T_Lim
I_Limits_Deadband	10	
I_Limit_Lower_Deadband	10	
I_Line1_Act_Coef	1	
I_Line2_Act_Coef	0	
I_Calc_Lim1	350	
I_Calc_Lim1_Lower	0	
I_Calc_Lim2	350	Weighted sum of
I_Calc_Lim2_Lower	0	I_Line1 and I_Line2

Version 3 — 2016-03-21

Setting	Value	Notes
P_Charge_SetPoint	8000	
P_Discharge_SetPoint	8000	
T_Lim	90	
I_Line1_Lim1	150	First set of limits for
I_Line1_Lim1_Lower	100	T < T_Lim
I_Line1_Lim2	140	Second set of limits
I_Line1_Lim2_Lower	90	for T > T_Lim
I_Limits_Deadband	25	
I_Limit_Lower_Deadband	25	
I_Line1_Act_Coef	1	
I_Line2_Act_Coef	0	
I_Calc_Lim1	350	
I_Calc_Lim1_Lower	0	
I_Calc_Lim2	350	Weighted sum of
I_Calc_Lim2_Lower	0	I_Line1 and I_Line2

Version 4 — 2016-03-21

Setting	Value	Notes
P_Charge_SetPoint	8000	
P_Discharge_SetPoint	8000	
T_Lim	90	
I_Line1_Lim1	125	First set of limits for
I_Line1_Lim1_Lower	75	T < T_Lim
I_Line1_Lim2	115	Second set of limits
I_Line1_Lim2_Lower	65	for T > T_Lim
I_Limits_Deadband	25	
I_Limit_Lower_Deadband	25	
I_Line1_Act_Coef	1	
I_Line2_Act_Coef	0	
I_Calc_Lim1	350	
I_Calc_Lim1_Lower	0	
I_Calc_Lim2	350	Weighted sum of
I_Calc_Lim2_Lower	0	I_Line1 and I_Line2

Setting	Value	Notes
P_Charge_SetPoint	8000	
P_Discharge_SetPoint	8000	
T_Lim	90	
I_Line1_Lim1	125	First set of limits for
I_Line1_Lim1_Lower	75	T < T_Lim
I_Line1_Lim2	115	Second set of limits
I_Line1_Lim2_Lower	65	for T > T_Lim
I_Limits_Deadband	40	
I_Limit_Lower_Deadband	40	
I_Line1_Act_Coef	1	
I_Line2_Act_Coef	0	
I_Calc_Lim1	350	
I_Calc_Lim1_Lower	0	
I_Calc_Lim2	350	Weighted sum of
I_Calc_Lim2_Lower	0	I_Line1 and I_Line2

Market Participation

Market participation depends on technical performance, particularly the ability to cycle repeatedly, and this requires careful attention to the BESS state of charge. Prior to starting the Market Participation testing, the system had a state of charge operating range from 2.5–98 % SOC. While this was designed to be the system's normal operating range, and was used for system acceptance and system characterization testing, there were a number of events where individual racks tripped off line due to over/under SOC faults. These faults resulted from inter-rack imbalances within each of the four battery sections while the system was at its SOC operational extremes (fully charged or discharged). These faults were especially common when the system was fully discharged and lingered at low SOC for an extended period of time. This allowed some racks to self-discharge to an SOC below the rest of the battery section, triggering a rack under SOC fault and taking that rack off line.

In an effort to increase the BESS' overall reliability and availability by preventing rack over/under SOC faults, engineers decided to reduce the state of charge operating range from the original 2.5–98 % SOC, to 5–95 % SOC. Project management decided this change was appropriate, since market participation placed a higher emphasis on availability and reliability than energy storage capacity, and project engineers would have less control over the system during this type of operation.

The testing of TSP in the first round (9/3/15 – 10/5/15) was to build daily forward schedules at hourly levels and then allow those schedules to roll into the Schedule Follow Mode (SFM) of control and to observe the system as it reacts to those hourly changes. The SFM logic uses the market hourly block structure protocol. That protocol starts the next hour's ramp at 10 minutes prior to the flow hour and completes at 10 minutes after the start of the flow hour and then holds that schedule value until the next interval and repeats.

The system was expected to follow all set points and achieve MW values as instructed within the safety permissives of the BESS control system. These tests flexed the BESS system at various levels and durations for the entire day while acting as a typical market resource following dispatches. The data was used to validate the reaction of the BESS system and correlate that use to a life cycle performance conclusion.

During this first round of testing the system was completely automated and no operations actions are required. Observation of the system response to signals is done by the graphical display for an "at the moment" look and after the fact using data as necessary.

The results of these tests were as expected and the BESS system followed the signals up to the limits set by the BESS control system.

6.6.10 Use Case 10 – Energy & Regulation

The chart below summarizes TSP's awards and its response to CAISO real-time 4-sec AGC (automatic generation control) signals on trade date 05/13/2016. On this trade date, the unit was bid and awarded for both Energy and Regulation services.

Unit performance is represented in the chart on a 5 minute interval basis for trade date 05/13/2016. On the primary axis, we can see the addition of the battery's regulation capacity awards (denoted by the shaded blue area for Regulation Up and Purple for Regulation Down) along with energy awards (green shaded area). The battery's CAISO instructions and battery's meter output are line graphs on primary axis and stat of charge (SOC) on the secondary axis.
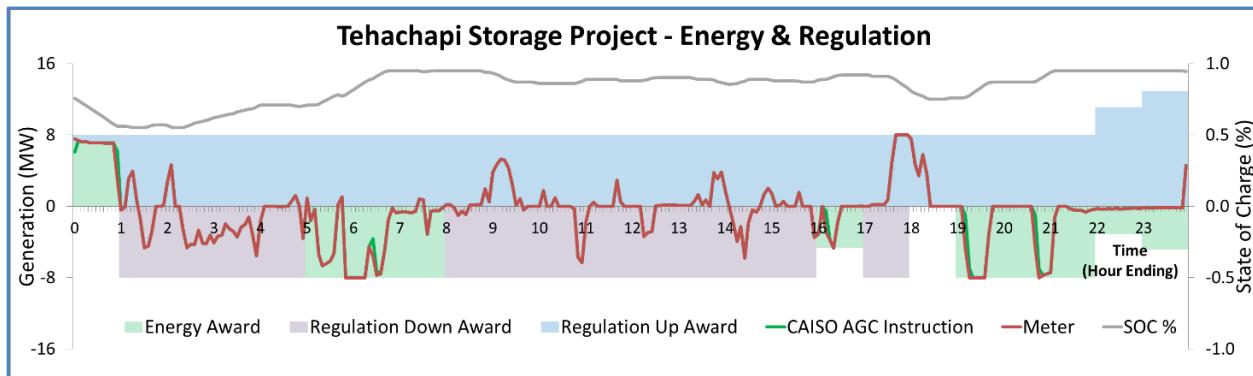
Figure 6-51 Energy & Regulation

A snapshot of the one hour period from 1AM to 2AM is represented in the chart below for 4-second interval dispatch and performance.

The following is a chart depicting Regulation mileage performance accuracy (per CAISO) for the project.
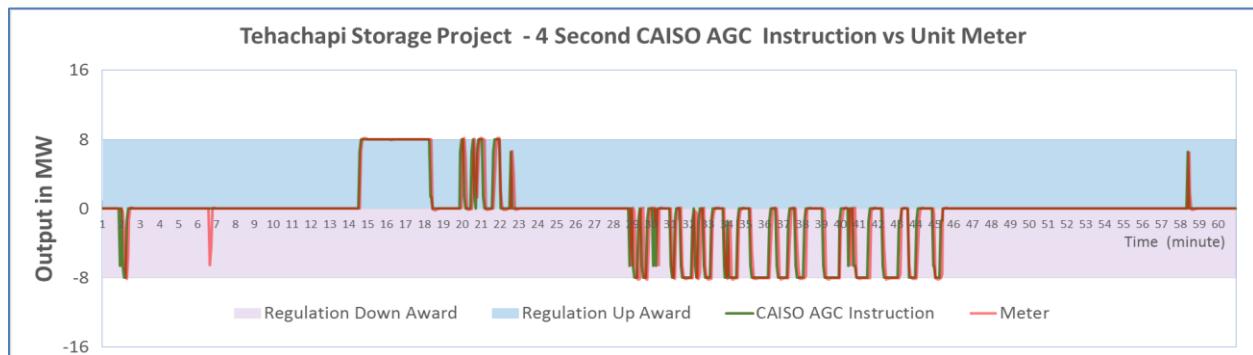
Figure 6-52 4 Second CAISO AGC Instruction vs Unit Meter
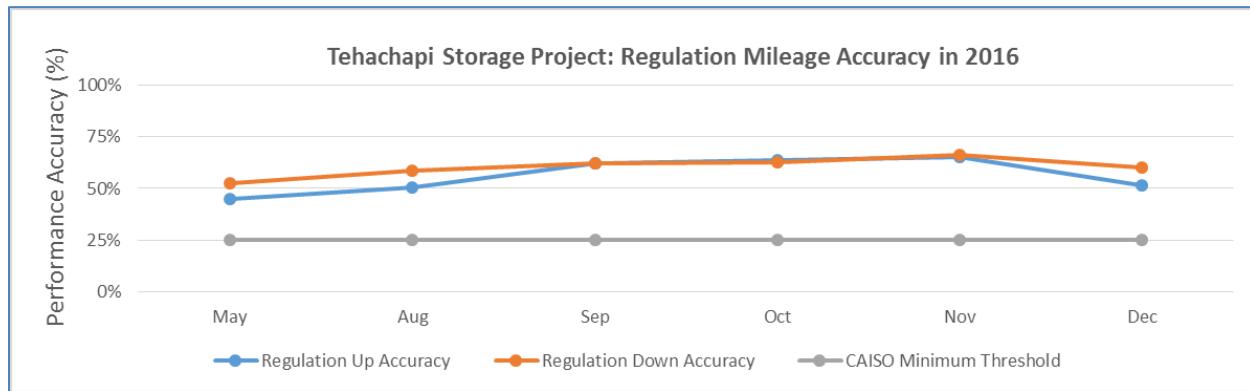
Figure 6-53 Regulation Mileage Accuracy in 2016

Test Result:

a) The battery was able to follow CAISO's 4-sec AGC instructions fairly accurately.
b) In the months of May, and Aug through Dec of 2016, regulation accuracy averaged 56% on Regulation up and 60% on regulation down using the CAISO's accuracy metric. June and July 2016 are omitted as the unit was unavailable in the market for other off-market testing. Overall performance of the battery for regulation service is much higher than CAISO's minimum performance threshold of 25% and in line with CAISO system wide limited energy storage resource average of 61% in 2015.

6.6.11 Use Case 11 – Spin Test

On 6/1/2016, TSP conducted a spin test with CAISO operators. The test duration was approximately 10 minutes, TSP was able respond to the CAISO's instructions to provide Spin. Due to the short duration of the test, there is insufficient data to demonstrate the unit's ability to provide spin.

6.6.12 Use Case 12 &13 – Energy Only (No Ancillary Services)

The Tehachapi Storage project (TSP) battery unit started bidding & operating in to the CAISO wholesale energy markets on 4/21/2016. The chart below summarizes TSP's awards and its response to CAISO real-time 5-min instructions on trade date 04/27/2016. On this trade date, the unit was bid and awarded for Energy only.

On the primary Y-axis, we can see the battery's energy awards (denoted by the shaded green area – positive awards are for discharging and negative for charging), CAISO 5 min instruction (denoted by the green line) and the battery's meter output (denoted by the red line).

One system limitation is the resources state of charge (SOC). On the second horizontal axis, the battery's SOC is represented by the grey line.
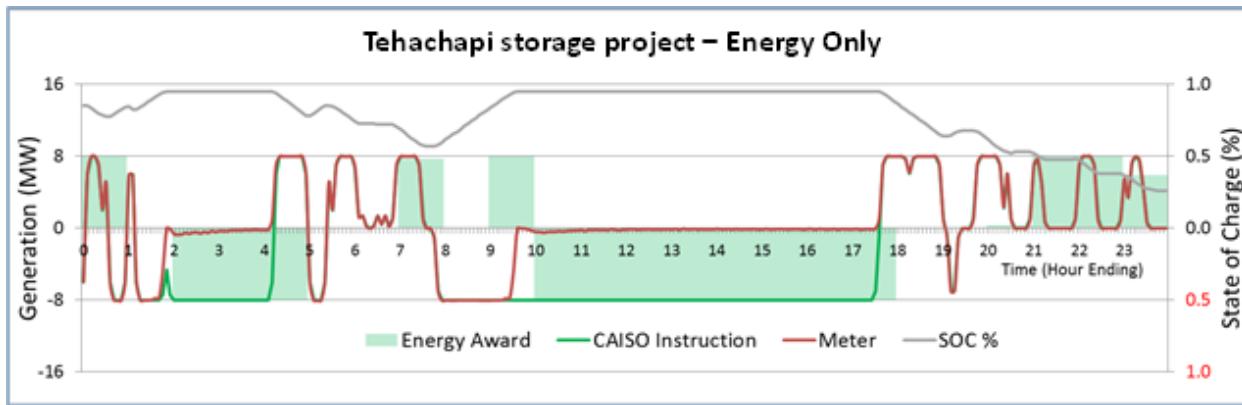
Figure 6-54 Energy Only

Test Result:

a) The Battery was able to follow CAISO 5 Min instruction accurately and was able to respond to CAISO instructions to charge or discharge with the exception for the SOC issue described below.

b) SOC Issue: The system configuration limits the battery to 95% capacity. Once the project reaches "full", the battery cannot draw/hold additional energy in storage, however, as we see from the graph, CAISO system did not recognize the charge status on this day and continues to instruct the battery to draw load even though it is full. We identified this issue with CAISO instructions on numerous days and provided the feedback to CAISO.

6.6.13 Additional Market Participation Evaluation

Over the 2016 testing period SCE tested the resource using the two CAISO-defined configurations. The resource was tested while providing an Energy Only, Regulation Only, and a combination of Energy and Regulation. Testing of the resource occurred in all CAISO markets: Day Ahead Market (DAM), Fifteen Minute Market (FMM), and Real Time Market (RTM).

6.6.13.1 Energy Only using the NGR Non-REM Model

In the initial phases of market testing, the unit was only certified by CAISO to provide Energy. When a resource is not encumbered by a DAM regulation schedule the resource can respond to a change in dispatch from providing generation to consuming load. This allows the unit to be re-dispatched in subsequent markets, such as FMM and RTM. SCE used an opportunity cost based methodology to determine generation and load bids for the resource.

On April 28th 2016 (graph below), the resource was awarded 8 MW in HE 22 through the DAM and was re-dispatched in FMM and RTM. As the unit went through the different market timelines it became economic for the resource to sell its DAM award for the last six RTM intervals (7-12) and in the last three RTM intervals (10 - 12) the resource even began to consume load. This flexibility improves the economic potential of the resource.
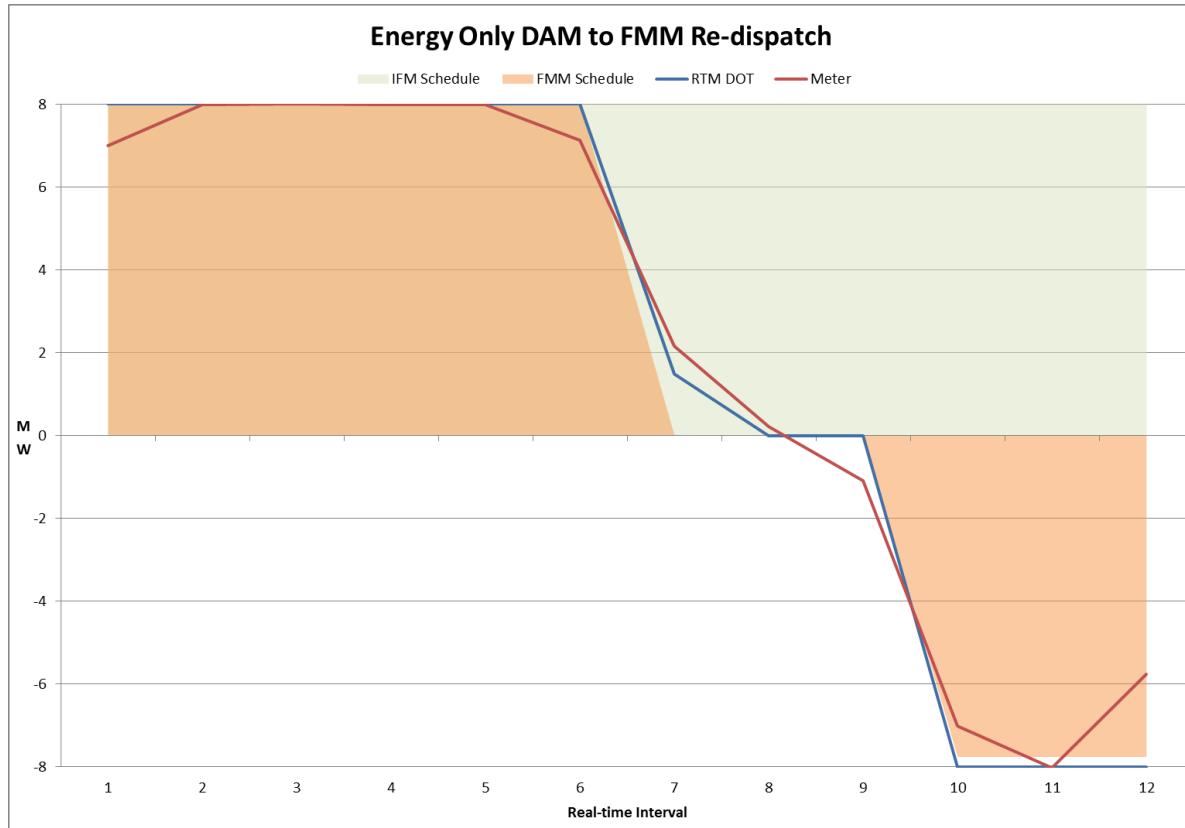
Figure 6-55 Energy Only DAM to FMM Re-dispatch

6.6.13.2 Regulation Only Using the NGR-REM Model

When a resource is designated as a Regulation Energy Management (NGR-REM) resource it is not certified by CAISO to provide energy, only Regulation. In the graph below the resource is fully awarded on 10/1/16 for HE 3 by the DAM. The resource is providing both regulation up and regulation down during all 4 of the 15 minute intervals for HE 3.
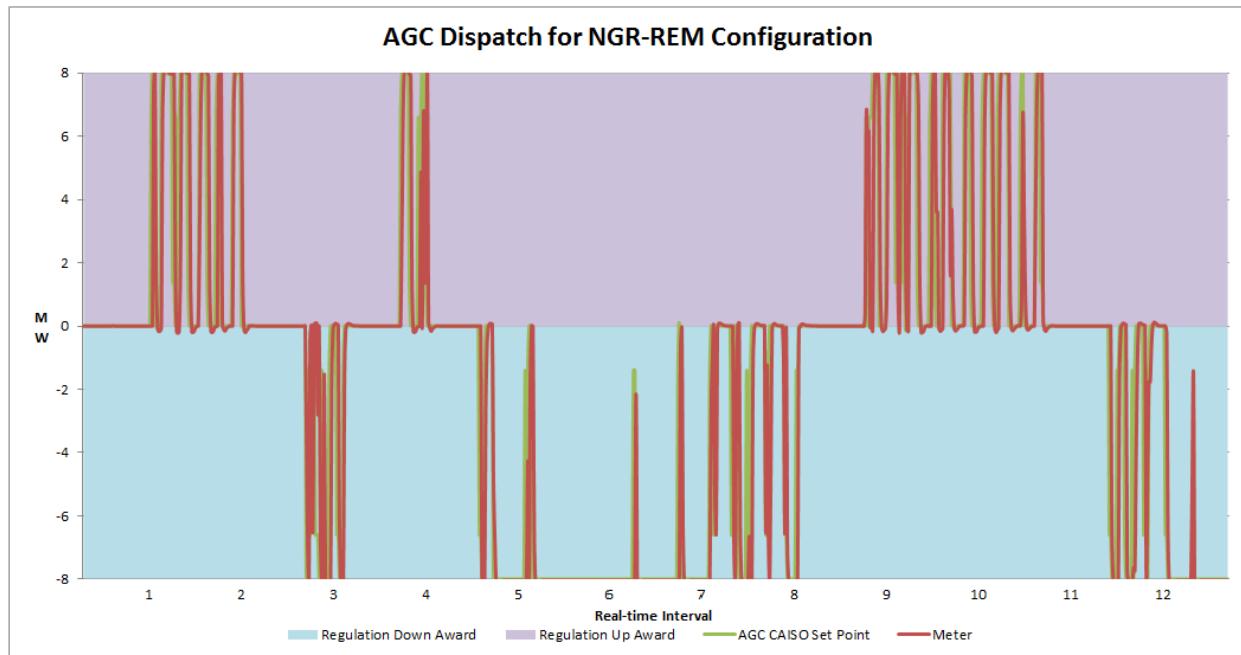
Figure 6-56 AGC Dispatch NGR-REM Configuration

6.6.13.3 Energy and Regulation using the NGR Non-REM Model

One of the main benefits of a NGR Non-REM resource is the ability to offer twice as much regulation capacity as its generating capacity. On December 23rd, 2016 in the 2nd 15 minute interval of HE 3 TSP was able to provide 15.97 MWs of Regulation Up, nearly twice as much as its 7.99 MW rated capacity. During this time CAISO Automated Generation Control (AGC) ramped the resource from -7.99 to 7.98 MW switching between charging and generation without any issues and using the full regulation range of the resource.
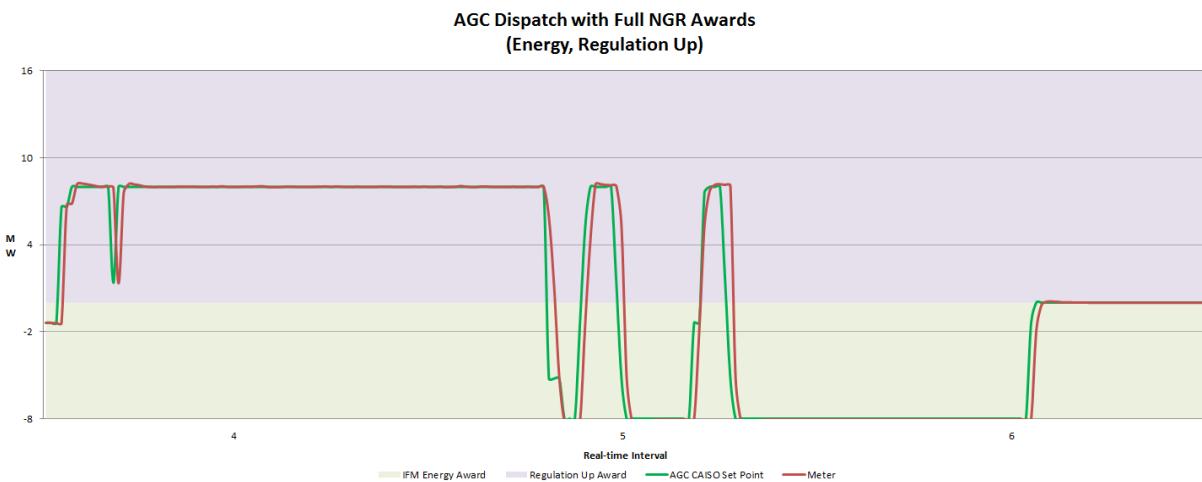
Figure 6-57 AGC Dispatch with Full NGR Awards

6.6.14 Operator Log and Incident Reports

An important factor in developing and implementing a BESS strategy is that the system performance is reliable. The system experienced various events such as trips, alarms, and failures throughout the M&V period. Major events and lessons learned are discussed in section 6.7 and 6.8. While typical non-recurring issues relating to design and operations of a new system startup can be expected, the TSP continued to experience various types of problems throughout the M&V period. Earlier issues were more frequent and sometimes more extreme, affecting a large portion if not all of the system. While events continued to occur toward the end of the M&V period, the system reached a higher level of availability and predictability, where failures were less frequent and less impactful to the operation of the entire system. Ironically, in December 2016, the very last month of operation during the M&V period, the problematic battery section controllers were replaced with new hardware and the system had a relatively trouble-free period of operation on the market, so much so that system operators were reluctant to shut down the BESS at the close of 2016 as SCE and LG Chem negotiated a new service contract for post-M&V operation.

Appendix J contains a comprehensive list of the issues and events that had an impact on system availability. The start time, stop time, duration, and description are provided for each event, in addition to any parts that were replaced. The system's overall nominal power and energy availability during each event is also provided. For example, if the entire system was off line during an event, then the power and energy available is reported as zero. However, if part of the system remained online and available, the power and energy are reduced accordingly from their nominal values of 8 MW and 32 MWh. The descriptions and replacement parts columns used the following abbreviations:

- P#: PCS container # $(1 - 2)$
- L#: PCS lineup # $(1 - 4;$ L1–L2 are in P1, L3–L4 are in P2)
- M#: PCS module # $(1 - 30)$
- BSC#: Battery section controller # $(1 - 4)$
- S#: Battery section # $(1 - 4)$
- B#: Battery bank # $(1 - 8)$
- R#: Battery rack # $(1 - 20)$
- M#: Battery module # $(1 - 18)$

The same abbreviation is used for a PCS module and a battery module. The type of module depends on the context. If the M# follows a P# or L#, then it's a PCS module. If the M# follows an R#, then it's a battery module.

The figure below provides a representation of the percent availability of the system over the duration of the project from August 01, 2014 through December 31, 2016. This is based on the system's approximate availability during each event. Generally speaking, events where only a few racks were off line did not have a noticeable impact on the system's power availability, and had a small to negligible impact on the system's energy availability, due to the total number of racks and redundancy of the system's architecture. However, events where an entire battery bank, battery section, or PCS lineup were off line, did have a noticeable impact in both power and energy capacity compared to nominal values.
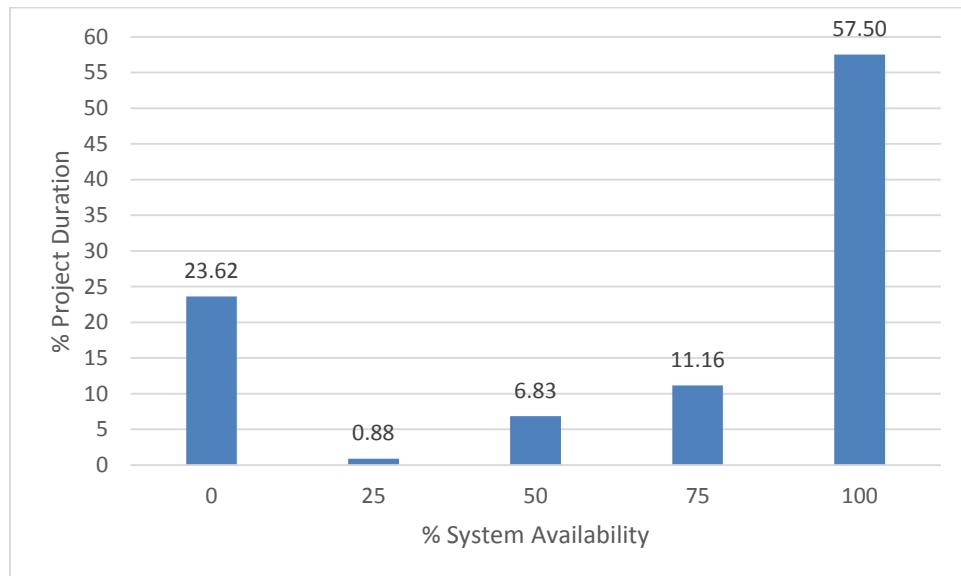
Figure 6-58- The Percentage of the System Available Versus the Total Time of the Project

6.7   Lessons Learned – Design through Commissioning

Over the course of the design, deployment, testing and commissioning periods, the team accumulated a series of insights that may be useful to the project stakeholders and to the utility industry more broadly. This section provides a summary of these lessons for those phases of the project. The first TPR included lessons from the inception of the project in 2010 through the initial Characterization Testing ending in late 2014 as indicated in the following.

6.7.1 Commercial

Item/Event	Lessons Learned
Lessons learned tracking	• Track lessons learned from the beginning, like a diary or journal. • Set up template for all parties in the beginning so that all lessons can be compiled consistently.
New project with some elements that require development	• Prepare scope of work accordingly for subcontractors.
Regular communications	• Identify communications needs as project progresses and arrange regular communications.
Broad range of stakeholders as project progresses	• Engage stakeholders, continue developing new relationships as project progresses.
Lack of templates for some reporting items	• Work together to develop templates if needed. • Be prepared to work in gray areas initially.
Handling unexpected delays and outages	• Include contingency time in advance to account for potential delays and outages. • Keep team informed about timing and plan.
Completing and navigating complex processes (grid connection)	• Request/map out flowchart in advance to clearly identify steps and gaps. Plan out resources and timing to successfully complete processes.

6.7.2 Construction

Item/Event	Lessons Learned
Complex project with several subcontractor tiers. Onsite presence needed for shipments, unannounced visitors, on-the-spot decision making	• Perform project management and site management onsite. • People expect the prime contractor to be onsite.

Roof leaks and door gaps	• Perform leak checks of roof prior to equipment installation. • Inspect and seal doors prior to equipment installation.
Presence of insects and rodents	• Seal up doors. • Install traps. • Install sonic repellers.
No loading dock, no storage space	• Made scheduling a priority: deliveries, tasks, crew sizes, and trash disposal
Site security issues, break-ins	• Set up security procedures, track keys issued. • Perform daily check of all doors from outside prior to leaving site.
Relatively remote location, no mailing address	• Allocate resources and time for setting up basic infrastructure. • Plan to spend more time on receiving shipments, directing drivers to the site.
Unique aspects of site (location, access, weather, rodents, etc.)	• Plan for every project site being different and unique. • Take site aspects into account during pre-bid job walks. • Check weather daily and plan schedule accordingly.
Uneven floor and rack leveling	• Develop shim hardware and shimming methods to handle site conditions.
TSP CAISO interconnection of the Battery Energy Storage System (BESS)	• CAISO Interconnection Request (IR) required significant lead time to allow for processing Queue Cluster (QC) 4 • Only 2 windows for submitting IR Oct or March • Required PSLF Model to be submitted as part of the IR process • Significant costs associated with System upgrades, required up front Security Deposits to stay in the QC • Interconnection stipulated restrictions/limitations on BESS due to system topology and/or reliability requirements

Installation of System HVAC	• HVAC was specified for original BESS supplier and later applied to LG Chem. This required adoption of existing system capabilities. In retrospect it would have been valuable to consider an HVAC system that had direct interface with the BESS controls. • HVAC system was a source of roof leaks
Site Considerations	• Built within existing substation to accelerate project • Facility outside of substation would have different permitting requirements • Location and proximity to existing infrastructure needs to be evaluated (above and underground utilities) • Noise was not a significant issue due to the location, but if in a populated area it may be • Grid Protection Settings evaluation needs to be performed early in the development • Typical construction considerations e.g. construction power, storage, access, staging, interim battery storage (climate control)
Site Civil works	• Battery facility foundation used very dense rebar matt, required consideration when anchoring racks • Site seismic requirements should be considered (PCS units and battery components) • Thermal design for structure (insulation, air handling equipment, modeling, etc.) • Weight considerations for installation, movement of materials
66 kV to 12 kV Transformer Connection	• Point of demarcation needs to be clearly identified • Inter-company Clearance Procedure Requirements • Roles & Responsibilities for "Customer" and Transmission/Distribution System Owner • Lock out tag out procedure • Auxiliary power provided from a separate bus for TSP.
Fire Suppression System	• Limited guidance from fire codes and standards for lithium ion facilities. • Fire marshal reviews could be an issue for other locations • Vendors should demonstrate the effectiveness of the proposed fire suppression system through detailed analysis and laboratory tests • In the event of a fire, firefighting and post fire protocols need to be considered

Deployment of BESS equipment to site - importance of decisions that can impact the on-site commissioning and integration testing with an active grid.	• Deployment of BESS components to the site should be carefully considered and made part of the commissioning planning. • The potential for commissioning a partial ESS with the power conversion systems (PCS) while connected to the grid should be considered. The advantage of this approach is the potential earlier project completion since PCS and grid integration testing can occur while the remainder of the battery continues in production. The result is an incremental commissioning with a potential earlier project completion date.

6.7.3   Technical

Item/Event	Lessons Learned
Equipment installation and assembly challenges	• Provide more extensive training in advance. • Include more photos in manuals, have demos, have post-training tests. • Develop products with ease of installation in mind.
Initial understanding of and questions about software interface, software functions and behavior	• Include onsite training visit and training manual to introduce software.
Managing scope and requests	• Discuss and review SOW more frequently. • Have a more detailed design review toward the beginning of the project.
Subscale testing using the Mini-System	• Subscale testing provides excellent opportunities to test out both hardware and software in advance of full-scale deployment.
Computer, network, and communications configurations	• Identify specific configurations with team. • Clarify scope and resources for each piece of equipment and software since each piece may have multiple scopes and

Item/Event	Lessons Learned
	owners.
File sharing and access	• Set up file portal at project start. • Make sure that central file portal can be accessed by all team members. • Need to factor in extra efforts for posting/sending files separately if IT security prevents all team members from accessing files.
DC-bus engineering required more engineering than estimated	• Utilize additional resources for this type of work.
Onboard step-up transformer requires additional resources than an external transformer. Creates additional costs and risks.	• Avoid this configuration if possible.
Lack of familiarity with IEC61850 Server solution caused challenges in defining hardware and assembly information.	• Improve internal communications and processes.
DC bank switchboards damaged due to unit not being protected properly during shipment.	• Verify proper packaging before shipment from vendor.
Personnel were frequently requested to site for unplanned visits, causing resource issues, and additional costs.	• Include plan for site support during sales process.

6.7.4 Information Technology

Item/Event	Lessons Learned

General Management System Interface.	• Ensure early engagement of IT team. • Clearly define roles and responsibilities for IT team.

6.7.5   Preliminary Testing

Item/Event	Lessons Learned
Defined SAT procedure in advance of full-scale testing vs. in-process procedure during Mini-System testing	• Collaborating and defining all test procedures in advance helps the actual testing process later on. • Conduct training on system in advance so that software and hardware interfaces are understood clearly to enable seamless SAT.
SAT – Testing time and schedule	• Allow sufficient time not only to perform the test, but also for changeover, setup, shutdown, data collection, and data analysis.
SAT – Onsite support is beneficial for answering questions, collaborating real-time, and performing repairs	• Provide onsite support for customer during SAT. • Include onsite support on several fronts, including technical, electrician, and laborers.
Unexpected additional tasks, outages, and changes to test sequences	• Make plan flexible and not completely serial. • Be flexible and adjust as needed.
Lengthy approval and confirmation processes	• Communicate expected process and timing in advance, identify if there are scheduling and resource limitations.

6.7.6 Training

Item/Event	Lessons Learned
Page turn meetings with training team	• Collaborating and reviewing materials page-by-page is very beneficial and productive.
Training logistics/meeting location	• Prepare for multiple training sessions at different locations due to different audiences. • Allow sufficient time for travel, security clearances, etc.
Role of training in processes (grid connection, operations)	• Engage all stakeholders in advance to determine when training is needed and which processes are affected.
Targeted training is needed for software operation, maintenance, safety, site details, etc.	• Expect that turnkey provider will need to provide training to different audiences.
Training material development and customization	• Expect materials development and customization due to range of audiences involved. • Do not assume that completely standard materials can be used.

6.8 Events and Lessons Learned – Operations

Over the course of the formal testing period (scheduled from January 2015 through December 2016) the team accumulated a number of insights. This TPR#3 Final Technical Report reports lessons learned derived from the implementation and operation of the Test Plan. The following describes the categories and timing of significant events.

Categories

- PCS (entire or partial) trip offs such as the transformer event, dirty filters, temp overloads, etc.
- Section trip offs
- Sub elements trip offs such as banks, racks, etc.
- Data Historian Gateway

Reporting Aspects

Description of the events is focused on the following three aspects:

- Is it a unique incident i.e. one time only? What is the likelihood of reoccurrence either on the same unit or another similar unit or systemic? This is assuming there are no external drivers such as an extreme ambient temp change or animal impacts, etc.
- Did the fix involve a design change or modification to the system or part(s)?
- What lessons learned can SCE derive from the incidents that speak to system reliability, operation and maintenance, etc.

6.8.1 PCS Medium Voltage (MV) Transformer Replacement (4 December 2014 – 22 April 2015)

While running EMS Test 4 on December 24, 2014, PCS inverter lineup 1 tripped unexpectedly. At the time of the trip, battery section 1 was at approximately four percent SOC, near the 2.5 percent minimum SOC for normal operation. All battery section 1 racks remained on line, as designed for this type of trip. The other three PCS inverter lineups and battery sections also remained on line. Upon discovering the trip, SCE attempted to remotely reset and restart inverter lineup 1, but was unable to bring the lineup back on line due to an "unexpected status" fault code from one of the dc circuit breakers. SCE was able to charge the other three battery sections to approximately 30 percent SOC and left them on line.

Recognizing battery section 1 was at a low SOC, and that the module battery management systems (MBMSs) built into each battery module had the potential to continue discharging the battery through standby losses, SCE disconnected the high-level battery section controller (BSC) from the bank battery management systems (BBMSs) in an attempt to shut down the MBMSs and preserve battery SOC. SCE was concerned that if battery SOC decreased to a low enough level, the battery bus voltage would be too low to operate the PCS inverter lineup and recharge the battery section. This scenario had the potential of requiring each battery module in each rack to be manually recharged in order to bring the voltage high enough to operate the PCS, which would be an extremely laborious and lengthy task given there are 151 racks and 2,718 battery modules in section 1.

However, the BBMS/MBMS software was not designed to turn off the MBMSs when the BBMSs were disconnected from the BSC, even if the corresponding racks were off line (all racks automatically go off line when the BSC is disconnected from the BBMS). The only way to turn off the MBMSs was to manually open the bank/rack auxiliary power circuit breakers, which could only be accomplished on-site. As a result, the MBMSs continued to consume energy from the batteries and lower the SOC. On January 2, 2015, per recommendation from LG Chem, SCE traveled to the site and manually opened the battery section 1 bank/rack auxiliary power circuit breakers to turn off the MBMSs and stop the further degradation in SOC.

On January 6, 2015, LG Chem traveled to the site to investigate the trip with remote support from ABB. LG Chem found one of the two dc circuit breakers in PCS inverter lineup 1 tripped, requiring a manual reset. As designed, this tripped circuit breaker was preventing the inverter lineup from being remotely reset or restarted (and was causing the aforementioned circuit breaker "unexpected status" fault code). On January 7, LG Chem used a circuit breaker checker tool from ABB in an effort to determine the cause of the trip, but the tool did not

provide any useful information. Also during the visit, LG Chem noted the voltage of battery section 1 had dropped below the default minimum for the PCS to operate.

After some additional analysis, ABB identified a plan to charge the batteries by resetting the dc circuit breaker, changing the 12 kV–480 V medium voltage (MV) transformer tap, and modifying the PCS software to temporarily allow the PCS to run at a lower voltage. On January 13, 2015, LG Chem and ABB changed the transformer tap and PCS software, and successfully charged battery section 1 to approximately 16 percent SOC. During this time, all other inverter lineups and battery sections were off line.

While continuing to charge battery section 1, fuses blew on two of the three phases in the fused disconnect switches on the substation 12 kV rack, between the PCS MV transformer for inverter lineups 1 and 2, and the 12 kV circuit breaker in the substation. Upon inspecting the PCS, ABB found the MV transformer for inverter lineups 1 and 2 had failed. The transformer showed signs of localized heating and arcing around the secondary coils.

Through further investigation, ABB determined the MV transformers in both PCS containers (one transformer for inverter lineups 1 and 2, and another transformer for inverter lineups 3 and 4) had a design deficiency that did not allow the transformers to operate with a large load on one inverter lineup and little to no load on the other inverter lineup. The transformers consisted of one primary coil and two secondary coils, where the secondary coils had axially stacked windings. Each of the two secondary coils was connected to one of the two inverter lineups. When both inverter lineups were operating with similar load, the transformer was "balanced" and operated normally. However, in the case of the failure, inverter lineup 1 was operated to charge the battery section, while inverter lineup 2 was off line. This created a large load on one of the secondary coils, with no load on the other secondary coil. In turn, this created a high flux area and localized overheating at the corner of the secondary winding, which eventually melted the insulation, shorted the coil, and caused the failure.

This series of events led to further investigations and the following actions:

- Inverter lineup dc circuit breaker: The dc circuit breaker was replaced. The original circuit breaker was returned to ABB Italy for analysis, but there were no conclusive findings as to why it tripped.

- BMS software: LG Chem developed a Protective Power Saving (PPS) mode for the rack battery management system (RBMS) software to automatically turn off the MBMSs when the rack voltage is low and the rack main contactor is open. This will prevent the MBMSs from further discharging the battery in a similar situation in the future.

- Remote e-stop: The system had an existing on-site e-stop circuit designed to quickly and safely stop the system in the event of a major failure or emergency. Upon activation, this circuit was designed to send a signal to trip the PCS containers, and to open the master bank/rack auxiliary power circuit breaker after a three second delay, thereby shutting down the BBMSs, RBMSs, and MBMSs, and opening the rack main contactors for all four battery sections. However, this circuit could only be activated via a physical pushbutton in the control room. Had this circuit been controllable remotely, SCE could have used it to remove power from the BMS (albeit for all four battery sections), which

would have immediately preserved the SOC without traveling to the site. At SCE's request, LG Chem and ABB added a second e-stop button outside the battery building, and added a remotely controllable software e-stop button to the SEC interface. This software button triggers the same circuit as the physical buttons, and can be used to remotely trip the system in the event of an emergency or similar situation in the future.

- MV transformer: ABB inspected the failed transformer, prepared a new design that allowed each inverter lineup to operate independently, manufactured two new transformers, and replaced the existing transformers on site. The new design featured secondary coils that were interleaved rather than axially stacked. The complete replacement project was a major undertaking, since the original and replacement transformers were a custom design that required noticeable lead time for materials, manufacturing, and transportation to the battery system. Furthermore, the transformers were located inside the PCS containers, between the inverter lineups and the 12 kV disconnect switch/control system bulkhead. Replacing the transformer in each PCS required first removing the 12 kV disconnect switch and all control system components, followed by the bulkhead, and finally the transformer. On top of this, the PCS containers were arranged end-to-end and in close proximity to the battery building and substation 12 kV rack, which meant that working clearances were very limited. Rather than lift the entire PCS containers to another location to replace the transformers, ABB and the riggers elected to build platforms to slide the original transformers out of the end of the PCS containers, lower them to the ground, and then use wood ramps to roll them to a location where they could be loaded on a truck. The process was reversed to install the new transformers. Once the transformers were replaced, each PCS container underwent recommissioning and testing with the rest of the system.

The lessons learned from this series of events include:

Item/Event	Lessons Learned
System Design	- When possible, use standard, proven designs and components to increase reliability and speed of replacement (sometimes, due to unique site constraints or operational requirements, customized components are still needed). - Design equipment so that all components can be easily accessed for service and replacement. - Place equipment so that all components can be easily accessed for service and replacement. - Perform design reviews in more detail to understand all operational scenarios and contingencies. - Keep in mind that even mature, non-battery components can cause issues; no component is routine. - Review remote access capabilities and limitations; plan operations and support accordingly.
Testing and Operations	Keep in mind that testing and support is a team effort and that team members from multiple departments are actively

	involved.
	• Factor in time needed for re-commissioning in the event that major components require replacement.
System Protection	• Incorporate power saving and shutdown modes in software to prevent energy consumption.

The replacement BESS vendor has acknowledged the lessons learned identified above and reports to SCE that it desires to implement many of the lessons learned from TSP into commercial projects that are providing support and ancillary services for the electric grid.

6.8.2   PCS Voltage Measurement Error (16 June 2015 – 23 June 2015 & 27 June 2016 – 30 June 2016)

In June 2015, PCS #2 tripped due to an over temperature fault. Upon resetting and restarting several hours later, system operators noticed the PCS was outputting more power than was commanded, and was driving the inverter lineups to their maximum allowable output. System operators then noticed the voltage measurement at the Point of Common Coupling was reporting 9.23 kV, when it should have been reporting around 12.47 kV. This was causing the power meter measuring the PCS' output to report 1345 kW, when it should have been reporting around 4000 kW. In turn, this was feeding back into the PCS control system and causing the inverters to output maximum allowable power in an attempt to reach the commanded power level of approximately 4000 kW. Operators shut down the PCS, followed by an ABB inspection that found a blown fuse for one of the power meter PTs. It is suspected that the fuse may have been mishandled during the replacement of the 480V/12kV transformers in April, and later blew under normal operation. The fuse was replaced and the PCS resumed normal operation.

Almost exactly one year after the fuse was replaced in PCS #2, PCS #1 exhibited identical behavior, which was traced to the same problem (blown fuse). The cause of the blown fuse remains undetermined, but replacing the fuse restored the system to operation.

Item/Event	Lessons Learned
System Design	• Include diagnostics and error messages that would help identify a blown fuse. • Incorporate additional logic for PCS control system to detect when feedback parameters are out of range and report errors so that corrective action can be taken.
Installation, Testing and Operations	• Incorporate stricter handling guides during repairs and post-repair inspections and recommissioning.

6.8.3 PCS Air Filter Replacement (20 July 2015 – 24 July 2015)

PCS #1 tripped due to a transformer high temperature fault. After visiting the TSP site and inspecting the system, it was determined that there were two issues involved: 1) clogged PCS air filters and 2) restricted air flow in the 480V/12kV transformer due to a piece of insulation from the manufacturing process. Around this timeframe, the BESS was taken off the transfer bus due to substation maintenance, which limited the ability to operate the system to diagnose this trip.

Originally, the manufacturer planned to replace the PCS air filters every two months, but due to periods of system inactivity related to the transformer replacements and other trips, the air filters were only replaced when visual inspection of the on-site analog pressure drop gauge indicated they were nearing replacement. However, as testing resumed in spring and early summer, system runtime and fan activity increased, which caused the air filters to become dirty more quickly. The time since the last visual inspection was too great, and the filters became too clogged to allow sufficient airflow into the PCS. It is also suspected that the nearby cement plant generates varying amounts of environmental dust which may have also clogged the air filters more quickly than usual.

In April 2016, SCE contracted LG and ABB to add a differential pressure transducer to the filter wall of both PCS containers. The reading from the transducer was added to the PCS controller and remote monitoring points list, so engineers and system operators can track changes in the pressure drop across the air filters. Since installing the transducers, the filter replacements have been frequent enough that the PCS hasn't tripped due to clogged filters or high internal temperatures, but the pressure drop can still be monitored for unusual clog conditions and provides more visibility into PCS status and operation.

Item/Event	Lessons Learned
System Design	• Include remote monitoring for maintenance items like air filters. The existing PCS containers have an analog gauge to measure pressure drop across the air filters. SCE ordered new functionality to remotely monitor this pressure drop and record it in the system's data historian. These upgrades are expected to be installed in early 2016.
Component Manufacturing	• Include more tests and inspections for components, like the transformers, after manufacturing.
Testing and Operations	• Factor in possible timeframes when equipment cannot be operated due to other operations or substation maintenance. • Be proactive with preventative maintenance, especially when there are periods of ramping up or ramping down testing and operations. • Make arrangements with local contractors for maintenance and support when possible. This helps provide options in case of limited availability, as well as resolving logistics

| | difficulties of having supplies delivered to/removed from an unmanned facility. |

6.8.4   Data Historian Gateway Replacement (16 December 2014 – 3 December 2015)

The system includes a local data historian consisting of an ABB embedded computer running companion data historian software. The local data historian is housed in the SEC cabinet in the control room, and records all normal system status and operational information reported by the SEC. The historian can be accessed locally or remotely by logging into the computer, and user-selected data points can be added to trend charts or exported via the built-in user interface.

The local data historian also "streams" all data points to a data historian gateway located nearby in the Monolith Substation equipment building. The gateway acts as a network interface between the local data historian and eDNA, the SCE company-wide data historian. This architecture was chosen by SCE's IT personnel to meet cybersecurity requirements while still making the data available and easily accessible alongside other company-wide data in eDNA. The gateway itself was specified, configured, and delivered by a third-party utility IT solutions provider. Originally, the project team planned to use eDNA for nearly all system status checks and performance analysis, while the local data historian acted as a lower-level, internal, backup data repository.

However, as the measurement and validation period commenced, project engineers began noticing instances where eDNA was not receiving data from the system, even though the local historian was still recording all data. IT personnel traced the problem to the gateway, which was losing communication with the corporate eDNA server. However, the third-party utility IT solutions provider responsible for the gateway was unable to determine the cause of the loss of communication. Their interim solution was to remotely reboot the gateway to restore communication, and since the gateway only "streamed" data from the local historian to eDNA, these instances resulted in gaps in the eDNA data that were not backfilled when communication was reestablished. Initially, the third-party suggested checking the fiber connection on the gateway, where SCE IT personnel found a possibly loose fiber connection. On 12/16/14, SCE moved the fiber connection to an adjacent spare port, after which the gateway seemed to operate normally.

From 1/13/14 to 4/21/15, the system was off line for the PCS medium voltage transformer replacements, and eDNA status checks were not performed. Once the system was available for operation on 4/22/15, project engineers again noticed that eDNA was not receiving data. SCE IT personnel and the third-party again found the gateway lost communication with the eDNA server. The gateway continued to lose communication as frequently as several times per week while the third-party investigated the problem. At its peak, the third-party undertook daily status checks to make sure data was being streamed to eDNA. Still, each interruption created a multi-hour gap in the eDNA data set, which made it difficult for project engineers to use this data for status checks or long-term performance analysis.

On 5/26/15, the third-party changed the gateway's configuration to use "buffered reporting" instead of "dataset polling". This appeared to greatly improve the performance of the gateway, since there were no interruptions to the data stream until 9/17/15. However, after 9/17, the

gateway again lost communication with the eDNA server as much as several times per week, and the third-party resumed daily status checks.

As a custom piece of IT hardware not present in other SCE installations, SCE IT personnel and project management decided to procure a spare gateway at the same time as the original, in case the original ever experienced a hardware failure. Since the third-party was unable to determine the cause of the reoccurring communication loss and each interruption was making the eDNA data set less complete and less useful, SCE and the third-party decided to replace the gateway on 12/3/15. The replacement gateway was mostly preconfigured by the third-party, so an SCE substation Testman was able to change out the hardware while IT personnel and the third-party remotely established communication. As of December 15, 2015, the replacement gateway has maintained communication with the eDNA server.

Due to the frequency and duration of each data gap in eDNA, project engineers resorted to using the local data historian as the source for all performance data. While the local historian is appropriate for quickly and easily creating trend charts with several points to analyze recent performance or events, it is not intended to be used for bulk data export or access by third-party database tools. Furthermore, since it is internal to the system, it is remotely accessible only through several remote desktop "jumps" or layers, which makes it more cumbersome and sluggish to work with. Also, it is incapable of displaying system performance data alongside the SCE company-wide grid data available in eDNA. Therefore, using the local historian for long-term performance analysis is not ideal, and project engineers still expect to use eDNA for nearly all analysis for the remainder of the project.

Item/Event	Lessons Learned
As a custom piece of IT hardware not present in other SCE installations, project management and IT personnel procured a spare, preconfigured data historian gateway at the same time as the original; the spare gateway was used to replace the original gateway due to suspected hardware failure.	• Having a spare for unique, custom hardware came in very handy. Also, since the replacement was already preconfigured, installation was relatively quick and easy.
Data historian gateway was a custom piece of IT hardware not present in other SCE installations; therefore, its reliability, durability, and	• Avoid the use of unique, custom hardware or designs (this may not be possible with special installations such as new battery systems with unique data requirements).

performance in a substation environment was unknown, and it was not subject to SCE's normal (and possibly more rigorous) design standards.	
On-site local data historian only "streams" data to corporate eDNA data historian (the intended method for getting status and performing analysis); any interruption in data stream results in gaps in corporate data historian, making status checks and analysis problematic or impossible with this data source; configuration issues and hardware failure in system's network gateway resulted in frequent, recurring interruptions to data stream and resulted in such problems	• On-site local data historian provided a backup data source for all system operational data, covering the gaps in the corporate data historian; without the local data historian, the project would have lost substantial amounts of system operational data; project engineers wound up using data solely from the local historian due to lack of continuous data in corporate historian; local data historians are very important and useful as a backup data source • Corporate/remote data historians should not rely on capturing a continuous "stream" of data from the local data historian; rather, the data should be transferred using a process that accounts for lost data and re-transfers such data until the local and remote historians have the same complete data set
On-site local data historian does not provide a method for quickly or easily exporting large amounts of data for analysis; when engineers had to rely on the local data historian to provide all system performance data over the entire operational period, data export became very	• Ensure data historian provides a way to export all data to a common file format, without limitations on the amount of data that can be exported at a single time • Even better, use an industry-standard database, such as SQL, rather than a manufacturer-proprietary data repository that is limited to using the manufacturer-provided GUI to view and export the data

Item/Event	
cumbersome and time consuming due to limitations with the data export procedure and amount of memory available on the local data historian embedded computer	

6.8.5   Battery Rack Fuse Replacement (24 September 2015 – 2 November 2015)

On September 3, one of the racks in battery section 2 tripped off line due to an under voltage fault. Upon further investigation, the manufacturer determined that one of the eighteen battery modules in the rack had failed and needed to be replaced. On September 24, after replacing the battery module, the manufacturer attempted to charge the rack using the PCS and battery section controller in manual mode. Manual mode is a special operating mode between the PCS and battery section controller that allows a technician to charge or discharge one or more racks while the rest of the battery section is off line, in order to match the rack voltage with the rest of the system. This is useful after a rack has been off line and no longer matches the rest of the battery section, or after maintenance or repair, as was the case here.

Like during normal operation, under manual mode, the PCS controller and battery section controller are designed to monitor the number of racks on line at any given point in time and limit the PCS charge/discharge power to avoid over charging/discharging the rack(s). However, in this case, the control system appears to have failed to properly limit the charge/discharge power, as the rack's battery protection unit (BPU) fuse blew while attempting to charge the rack to match the voltage of the rest of the battery section. This is the only time a rack fuse has blown, and indicates a failure of the control system and various levels of software/hardware safety features to properly limit the charge power and/or take the rack off line prior to the fuse blowing. The manufacturer replaced the fuse and successfully charged the rack using an external battery charger, but is unsure why the control system failed to limit the charge power for the one on-line rack.

Item/Event	Lessons Learned
The rack's only passive protective element prevented the rack from being charged at an unsustainable rate, after the control system failed to properly limit the charge power based on real-time system operating conditions.	• Passive protective elements that are simple and completely independent from the primary control system are critical in protecting devices from severe damage, especially in the event the primary control system and associated safety features fail to provide the intended levels of safety and protection. • Extensive system behavior and safety testing is important to ensuring control system hardware, software, and algorithms work properly under all possible operating modes and scenarios, and are capable of protecting the

	integrity of system components and the safety of personnel.

6.8.6   Battery Section Controller Replacement (26 October 2015 – 3 December 2015)

On October 26, battery section 4 tripped off line. SCE was unable to remotely access or even ping the corresponding battery section controller computer. The manufacturer traveled to the site and found the computer off. The other three battery section controller computers were running normally. Suspecting hardware failure, the manufacturer ran a hardware diagnostic test on the computer, but this test didn't indicate any problems. The manufacturer restored the battery section to operation and left the site.

On November 2, the same symptoms reoccurred. The manufacturer ordered and installed a new battery section controller computer on November 18 and restored the section to operation.

On November 18, SCE noticed the battery section controller #4 computer clock was behind all of the other clocks in the system. All system component clocks are normally synchronized to a GPS time source, which makes alarm reporting and trip diagnosis easier when comparing recorded events from different subsystems. The battery section controllers are responsible for recording low-level battery data in addition to high-level battery section events, so having a synchronized clock is similarly important. The manufacturer found the computer clock was not configured to properly synchronize with the GPS time source when it was installed on November 18, and made the necessary configuration change to correct and synchronize the time.

On November 27, SCE again found battery section 4 tripped, and was unable to remotely access the corresponding battery section controller computer. During a previously scheduled site visit to replace the data historian gateway, SCE found the section 4 computer frozen. After notifying the manufacturer and restarting the computer, the battery section was restored to operation. The manufacturer suspects the computer froze due to not installing a software patch on the battery section controller software when the new computer was installed on November 18.

Item/Event	Lessons Learned
Battery section controller computer failed	- Use of a hardened computer, industrial PLC, or parallel devices with redundancy or failover, may have prevented a similar singular control system hardware failure from affecting a large portion of the system. - Use redundant power supply
Computer clock unsynchronized; not configured properly during commissioning	Manufacturers should make use of complete commissioning procedures to ensure all configuration and startup aspects of a hardware/software installation/replacement are addressed before the system is returned to the client for operation.
Computer frozen, likely	Same as above.

due to battery section controller software patch not installed during commissioning	• Software issues discovered during testing and operation may be addressed by patches, and all appropriate patches should be included in commissioning procedures. When appropriate, patches should be replaced by subsequent software revisions/updates, and commissioning procedures should be updated.

6.8.7   Additional Lessons Learned During 2015

Further to the events and lessons described above, additional lessons learned during the TPR#2 period were identified:

Item/Event	Lessons Learned
SEC interface does not provide a way to schedule changes to system operating parameters, operating modes, or more complex on/off peak schedules for EMS Test 4; all such changes must be made manually in real-time	• Specify system controls be scriptable, employing use of flexible scheduling capabilities such as Cron expressions for setting up changes to operating schedules, modes, and parameters • Even better, specify system controls be scriptable, including logic (ex.: IF, THEN) based on system status points (ex.: SOC, operating mode, control input) for maximum flexibility and to avoid the limitations of a GUI with fixed choices
Various system interfaces use different conventions for reporting status and alarms, and in different locations, with no consolidation; different types of trips and alarms (ex.: battery, PCS) require checking multiple interfaces and recording different types of data presented in different formats; subsequent need to review operational logs and history is difficult	• All system operations, including mode and parameter changes, trips, alarms, should be aggregated, displayed, and archived in a single interface with uniform display format and synchronized times, so system operational history, changes, and trips can be easily recalled, reviewed, and diagnosed without having to piece together information for multiple different formats and locations.

due to a lack of standardized reporting	
System is temporarily connected to 66 kV transfer bus, resulting in need to take system off line any time there's a scheduled or unscheduled need for the transfer bus to support substation or grid operations	• This limitation was known when the system was interconnected, but will need to be removed if the system is permanently interconnected to the substation; the transfer bus is not intended to be a point of connection for any normal circuit or system.

6.8.8   Additional Lessons Learned During 2016

Item/Event	Lessons Learned
Telemetry	• Accurate telemetry is paramount for the physical management of state of charge. If points are incorrectly scaled the market will not have clear visibility to the state of charge of the resource..
State of Charge	• State of Charge is finite. In a market that re-optimizes between day-ahead and real-time there needs to be an opportunity cost calculation in order to take into account the resource Day-ahead position relative to its potential Real-time re-dispatch.
GMS (Market) Interface	• TSP was SCE's first, as well as one of the state's first, battery systems to participate in the CAISO market as a non-generator resource (NGR). From the beginning of the project, the telemetry requirements (hardware, software, metering, data/control points, logic, and configuration) were unknown or ambiguous at best. The project team worked with SCE's market operations group to define and build as much of the point-to-point Generation Management System (GMS) interface as possible, but additional requirements and refinements were identified as the system was tested and entered the market. Some of these improvements were made by updating the SEC software in mid-2016. Additional improvements were identified as CAISO published draft business practice manuals (BPMs) for storage and corrected certain

	limitations with their control systems. Some of these newer improvements will be implemented after the conclusion of the M&V phase, as the system continues to operate on the market for the long term. • Due to the lack of existing batteries on the CAISO market, TSP had to solve many of the integration issues as they arose. However, as a direct result of TSP, SCE was able to deploy other battery systems, such as the Mira Loma 20 MW, 80 MWh BESS, in record time and with a greater understanding of the market interface requirements. CAISO has also been using deployments like TSP and Mira Loma to formalize the battery NGR connection process, which will make future deployments smoother and easier.
Communications Equipment	• On March 31, 2016, engineers lost the ability to remotely monitor or access the system's control interfaces. This was a concern, since without remote monitoring ability, the status of the system remained unknown. The only monitoring system that still worked was the security cameras, which confirmed the system was still intact, but its operational state was unknown. SCE IT personnel traced the issue to an unresponsive switch in the substation control building, through which all TSP traffic was passed (excluding the security cameras, which were part of a completely separate system). Once the issue was identified, the switch was replaced and the issue resolved. • Since all BESS installations are unmanned and usually not conveniently accessed (especially remote systems), future systems should consider using redundant hardware and communication paths, even if the backup has limited functionality. This will at least allow operators to continue to monitor the high level operation and health of the system.
Building HVAC	• On June 29, 2016, the battery building HVAC system experienced a complete failure. The building is served by two packaged rooftop units. For unknown reasons (possibly a power quality disturbance), both units experienced simultaneous failures. One unit had a bad compressor, and the other unit had a bad fan unit. These components prevented both units from operating. The battery system continued to operate throughout the HVAC outage, as the batteries increased in temperature but did not reach their upper temperature limits for normal operation. Also during this event, operators discovered that the HVAC alarm signal wasn't active. Operators

	discovered the HVAC failure during a scheduled trip to the site, and confirmed the start of the outage by trending battery temperature data. • In this case, having multiple HVAC units didn't prevent a total HVAC failure, but this is still a good design practice to prevent a single point of failure. Also, the HVAC alarm signal was tested during system commissioning, but the artificial alarm was created at the SEC rather than the HVAC control panel. In future system commissioning, the configuration and test of the alarm signal should be verified at the HVAC panel rather than the battery system's master controller or PLC.

6.8.9   Hardware Replacements in 2015

In addition to the events described above, the system experienced a number of component hardware failures that are described below.

Item/Event	Lessons Learned

Module Issues
• Low cell voltage and voltage deviation between cells in the module
• Warnings/Faults occurred due to low/deviation voltage
	• Root cause: Cell defects due to metallic particle contamination inside cell
	• Corrective action: Replaced seven affected modules
	• Implement countermeasures for contamination control and detection method
	• Develop cell products specific to application
	  • High energy (peak shifting, renewable energy)
	  • High power (frequency regulation)

Battery Protection Unit (BPU) Issues • Current Sensor Wire Error message appeared during starting or restarting of the battery system	• Root cause: Intermittent connection between the sense lead connector and current sensor • Corrective action: Replaced 11 affected BPUs • Component Manufacturing: Include manufacturing enhancements, such as using assembly jigs • System Design: Test and evaluate components more strictly during the design and product development process; include diagnostic messages that are more descriptive • Product Design: Develop new versions of BPUs with improved internal structure, more robust parts, and secure connections; including

	improved connector housing and dual-channel current sensor
PCS 1 & 2 12kV/480V Transformer • Design flaw that doesn't allow unbalanced/single lineup operation when another lineup is down.	• Root cause: Design flaw that doesn't allow a single lineup operate when the other in the same PCS is offline. • Corrective action: Replaced both transformers to allow single lineup operation.
PCC Voltage Measurement Fuse Issue • PCC measurements found to be incorrect.	• Root cause: PCS 2 lineup 3 PCC voltage measurement had a blown fuse which caused incorrect values being sent to the PCS control system. • Corrective action: Replaced the blown fuse which allowed correct voltage measurements.
Battery Section Controller (BSC) Issue • Lineup trips offline due to a battery communication issue.	• Root cause: Battery section controller has failed and needs to be replaced. • Corrective action: Replaced battery section controller 4 to prevent battery communication trips.

6.8.10 Hardware Replacements in 2016

During operations in 2016, the system experienced a number of component hardware failures that are described below.

Item/Event	Lessons Learned
Master Controller Module Issue • Lineups trip due to "not running unexpectedly" error.	• Root cause: Master controller module failed and needs to be replaced • Corrective action: Replaced master controller module
Module Issues • Low cell voltage and voltage deviation between cells in the module • Warnings/Faults occurred due to	• Root cause: Cell defects due to metallic particle contamination inside cell • Corrective action: Replaced five affected modules • Implement countermeasures for contamination control and detection method

low/deviation voltage	• Develop cell products specific to application
	    • High energy (peak shifting, renewable energy)
	    • High power (frequency regulation)

Battery Protection Unit (BPU) Issues • Current Sensor Wire Error message appeared during starting or restarting of the battery system	• Root cause: Intermittent connection between the sense lead connector and current sensor • Corrective action: Replaced 5 affected BPUs • Component Manufacturing: Include manufacturing enhancements, such as using assembly jigs • System Design: Test and evaluate components more strictly during the design and product development process; include diagnostic messages that are more descriptive • Product Design: Develop new versions of BPUs with improved internal structure, more robust parts, and secure connections; including improved connector housing and dual-channel current sensor
PCC Voltage Measurement Fuse Issue • PCC measurements found to be incorrect.	• Root cause: PCS 1 PCC voltage measurement had a blown fuse which caused incorrect values being sent to the PCS control system. • Corrective action: Replaced the blown fuse which allowed correct voltage measurements.
Battery Section Controller (BSC) Issue • Lineup trips offline due to a battery communication issue.	• Root cause: Battery section controller has failed and needs to be replaced. • Corrective action: Replaced battery section controller 2 and 3 to prevent battery communication trips.
HVAC Issue • HVAC tripped due to compressor failure in unit 1 and a fan failure in unit 2.	• Root cause: HVAC unit 1 tripped due to a compressor failure and HVAC unit 2 tripped due to a condenser/fan issue leading to 90°F and above temperature in the battery room. • Corrective action: Replaced HVAC unit 1 compressor and HVAC unit 2 condenser/fan unit.

6.9 Conclusions

This Final Technical Report #3 presents the project-wide conclusions gleaned from implementation and operation of the Test Plan. The project has shifted in concept from two years of uninterrupted operation and data collection, to debugging and intermittent operation while accomplishing the scope of the Test Plan and accumulating significant operational BESS experience along the way.

Conclusions presented as part of TPR#2 are still valid today, including the following:

- Based on the BESS hardware and software available at the start of project construction and installation in 2013, BESS users should be mindful that for new product integration efforts, there should be project schedule time allocated specifically for testing and system refinements.

- This project has provided opportunities for learning and the lessons learned have enabled the manufacturer to make improvements and enhancements in the BESS hardware and software for subsequent projects.

- Sub-scale testing using the Mini-System as specified by SCE provided significant benefits for this project.

Measurement and Validation

Similar to the experience with smaller-scale BESSs deployed as part of the DOE/SCE co-funded Irvine Smart Grid Demonstration Project (ISGD, 2011–2015), the project team expected to have approximately two years of relatively uninterrupted operation and data collection. During this M&V period, the system would be thoroughly tested in each of its modes under a variety of alternative settings and scenarios. The collected data set would be extensively analyzed and the BESS dispatch optimized. In reality, ongoing system reliability issues created relatively short and limited test periods and associated data sets. This was especially true for the grid-support functions (Tests 1–5), where the system was prone to idling for periods of time until dispatched by the selected control algorithm. These idle periods, usually in combination with the battery system near its operating SOC extremes (full charge or discharge), were the most prone to system events such as trips or hardware failures. By comparison, when the system was operating in the market and being dispatched on a more frequent, if not continual, basis, trips and hardware failures were noticeably less common or less extreme.

Nevertheless, all of the system's control modes for grid support and market operation were tested and validated against the underlying algorithms. TSP was therefore not a story of proving whether a modern lithium-ion BESS can dispatch as programmed for different applications (which it obviously can), but rather, a practical experience in BESS operations and reliability under real-world conditions, at scale, outside of a laboratory.

The Future

In early 2016, SCE developed a proposal for TSP disposition following the conclusion of the DOE M&V period on December 31, 2016. The proposal was developed in accordance with the original California Public Utilities Commission (CPUC) decision allowing SCE to participate in the TSP. The original decision directed SCE to file a Tier III regulatory advice letter with the Commission, containing SCE's recommendations for the future use of the BESS after the DOE project ended.

SCE's proposal included three distinct options, including a financial analysis of TSP's forecasted operating expenses, revenues, and decommissioning costs under each option. The three options were:

1. 66 kV interconnection
2. 12 kV interconnection
3. Decommissioning

Under the 66 kV interconnection option, SCE would continue operating the BESS, but as a purely market resource (i.e., non-grid functions) providing energy and ancillary services to the CAISO market for up to 10 additional years. This would require moving the system from its temporary interconnection at the Monolith 66 kV transfer bus, to a permanent interconnection at a new (yet-to-be-constructed) position in the Monolith 66 kV rack. This new 66 kV position would require approximately eight years for the application, review, planning, design, construction, and interconnection processes at that voltage level. The BESS would continue operating under its temporary interconnection as the permanent interconnection process moved forward. Since the existing 66 kV rack had no open positions, and it already extended to the

substation property line, the substation would have to be expanded onto adjacent, non SCE-owned property. Obviously, such an undertaking would not be profitable or timely considering the age of the battery, and the financial analysis showed this. Therefore, SCE did not recommend proceeding with this option.

Under the 12 kV interconnection option, SCE would similarly continue operating the BESS as a purely market resource providing energy and ancillary services to the CAISO market for up to 10 additional years. However, this option would require moving the system from its temporary interconnection at the Monolith 66 kV transfer bus, to a permanent interconnection at an existing, open position in the Monolith 12 kV rack. This existing, open position would require approximately two years for the application, review, planning, design, construction, and interconnection processes at that voltage level, and would not require significant substation construction or expansion[4]. The BESS would continue operating under its temporary interconnection as the permanent interconnection processes moved forward. Once the system was interconnected at a position in the 12 kV rack, the existing temporary interconnection equipment, including 12 kV circuit breaker, 66-12 kV transformer, and switch rack, would be removed. The financial analysis indicated this option would result in a positive outcome, and SCE recommended proceeding with this option. SCE also recommended periodic reevaluation of the project's financial performance, especially the remaining funds in the balancing account. SCE committed to not use ratepayer funds to subsidize any aspect of the project's permanent interconnection or ongoing operation, and would therefore stop and decommission the system should the remaining funds in the balancing account drop to a level where only enough remained to support decommissioning. SCE also committed to continue using the system as a learning tool for optimizing the performance of BESSs in the CAISO market, and to continue to gain and share operational experience.

Whether the system is permanently interconnected at 66 kV or 12 kV, it will likely play a significant role in the development of a distribution Storage Management System (SMS), intended to help distribution system operators manage and mitigate the impact of BESS charging on already partially to heavily loaded circuits. Most recent BESSs interconnected to SCE's distribution system have been subject to a charge power limitation that varies by month and the daily on/off peak period. So far, these schedules are developed by SCE distribution engineers at the time of each interconnection, and are then implemented as a static table in the respective BESS's control system. The SMS will allow a centralized controller to change the charge power

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[4] Permanent interconnection at an open position in the Monolith 12 kV rack was not an option when TSP was constructed and commissioned. At the time, the region's sub-transmission system, including Monolith Substation, was subject to generation curtailments due to the amount of new renewable generation coming on line compared to the amount of transmission, sub-transmission, and distribution capacity available for such uses. Even though physical positions were available in the Monolith 12 kV rack, and the BESS's PCSs were specifically designed to interconnect at 12 kV, power system studies indicated the 12 kV rack did not have enough electrical capacity to interconnect TSP. At the same time, the Monolith 66 kV rack had available electrical capacity, but had no physical open positions. Therefore, TSP was temporarily interconnected to the Monolith 66 kV transfer bus for the purposes of the DOE M&V period. During the M&V period, SCE completed significant upgrades to the region's power grid for the express purpose of increasing the amount of generation interconnection capacity. By the end of the DOE M&V period, the Monolith 12 kV rack had both physical open positions and electrical capacity to interconnect TSP as originally intended.

limits of each BESS on a more dynamic basis, maximizing the BESS charge power capabilities while adjusting for real time circuit loading and conditions.

Under the decommissioning option, SCE would immediately stop operating the system and either begin decommissioning immediately, or mothball the system and decommission at a future date with the expectation that BESS decommissioning and recycling costs would be lower as the technology and processes mature. All decommissioning costs would be paid for with existing funds in the balancing account. Since the 12 kV interconnection option indicated a positive result and allowed for continued operation of the existing asset as a learning tool for various stakeholders, SCE did not recommend the decommissioning option.

SCE filed the Tier III advice letter with the Commission in early 2016, including the three options, corresponding financial analysis, and SCE's recommendation for continued operations at a permanent 12 kV interconnection. The advice letter proceeded through the normal regulatory process, including review before the commission and a public comment period. The CPUC's Office of Ratepayer Advocates (ORA) commented on SCE's proposal, and SCE's responded to the comments. In late 2016, the CPUC voted to approve SCE's proposal.

Concurrent with the Tier III advice letter filing, SCE started the interconnection process. Similar to SCE's other interconnected BESSs, SCE is both the distribution service provider (the "utility company") and the third party interconnection customer/generator. The TSP team must follow the same interconnection process as any other third party, including applications, reviews, payments, and timelines. Even at the 12 kV level, the process can take some time, which is why the team started the process and entered the interconnection queue prior to the Commissioning formally approving the Tier III advice letter. No significant interconnection payments or other expenditures were incurred prior to the Commission's approval, and the project was free to exit the process if the Commission had rejected SCE's recommendation for continued operation. The project team worked proactively to ensure the BESS could continue operations with minimal interruption, and the system is on track to be permanently interconnected at 12 kV by the late 2017 or early 2018 timeframe.

Significant Accomplishments, Impacts, and Learnings

Similar to how the groundbreaking EPRI/SCE 10 MW, 40 MWh, Chino Battery of the 1980s proved that utility-scale battery energy storage was possible with lead acid technology, TSP is a modern-day energy storage pioneer, achieving a number of significant accomplishments that have proven the viability of utility-scale energy storage using lithium-ion technology. These accomplishments include:

- **The largest lithium-ion BESS in North America, in terms of energy capacity (32 MWh), at the time of commissioning (2014).** TSP is still one of the largest lithium-ion systems in California, a state which has seen the procurement or construction of multiple 20 to 100 MW, 4-hour BESSs in the years since TSP.
- **The first BESS in California intentionally designed and operated as a dual-use asset, supporting utility transmission/distribution functions and operating in the competitive power market.** This dual-use strategy continues to be the focus of SCE and

other energy storage users in maximizing the value proposition of BESSs by supporting utility operations when called upon, and operating in the market the rest of the time.

- **The first known use of a "mini system" by an entity other than a BESS manufacturer or integrator, to ease full scale testing, commissioning, and ongoing operation.** SCE has since built two additional lab-based mini systems to evaluate and support BESS deployments and controls upgrades with other manufacturers' systems.

- **The first BESS integrated with SCE's system wide grid SCADA system (Energy Management System), providing high-level BESS visibility and control to grid operators.** EMS integration gives grid operators greater awareness of BESS status and impact, and allows them to dispatch the system to support grid operations when needed. Rather than acting as a standalone, separately-managed device, adding BESSs to power grid SCADA systems takes them one step closer to becoming part of a true distributed energy resource management system, necessary to achieving a smart grid capable of 50 percent or greater renewable energy integration.

- **The first BESS to be operated by SCE, and one of the first BESSs, to be interconnected, certified, and operated in the CAISO market.** TSP provided SCE and CAISO valuable experience with integrating a BESS into a market that had previously been filled with nearly all types of resources, other than batteries. TSP, combined with PG&E's San Bruno battery, paved the way for future BESSs to participate in the CAISO market. Continued operation of TSP and subsequent batteries has allowed third party interconnection customers, utilities, and CAISO to refine and better understand the process, requirements, limitations, and areas for improvement. Specifically, SCE used knowledge gained from TSP to interconnect two 10 MW, 40 MWh systems in record time in 2016, and to support the interconnection of additional systems coming on line in 2017 and beyond.

- **The first modern, large-scale, lithium-ion BESS installed in an SCE substation and connected to the regional transmission network.** The last large BESS to be installed in an SCE substation was in the 1980s, and no BESS had ever been connected at the 66 kV sub-transmission level. Installation and operation in a critical substation environment gave SCE greater confidence in installing the two aforementioned 10 MW, 40 MWh systems in 2016.

- **Design and operational experience has been used as a foundation for, and improved, subsequent SCE energy storage procurements.** With each round of procurements, SCE refines the BESS technical requirements and project scope of work that go into the request for proposal. The requirements originally developed for TSP, as well as all of the lessons learned, have been incorporated into the procurement documents. These documents are sent to industry, which then works to adapt and improve their offerings to meet the requirements. For example, other BESS manufacturers have had to enhance their control systems in order to make their offerings capable of dual-use applications and participating in the CAISO market.

- **Played a key part in funding the development and marketization of the first generation of two separate BESS manufacturers' long duration lithium-ion product offerings, which continue to be refined and deployed in systems worldwide.** TSP

spurred A123 Systems (later NEC Energy Solutions[5]) and LG Chem to develop their long duration BESS products from pre-market technology into an actual offering suitable for use by utilities and commercial customers. Prior to TSP, neither A123 Systems nor LG Chem had a commercial long duration product, and TSP was their first large scale deployment. SCE and many others have purchased NEC Energy Solutions and LG Chem long duration lithium-ion products in subsequent deployments in multiple countries, and both manufacturers can trace their present-day offerings back to TSP.

Closing

The significant financial, physical, and intellectual resources invested by project stakeholders such as DOE, SCE, LG Chem, ABB, A123 Systems, and others throughout the course of the project, from conceptualization through construction and M&V operation, will continue to provide tangible value beyond the end of the DOE project. TSP has already paid dividends in helping to define and refine the process for interconnecting batteries to the utility grid, integrate them in California's power market, and provide financial data to help value other proposed battery systems. While TSP system reliability and future CAISO market conditions (especially prices for ancillary services) will largely determine the extent of the project's future, TSP will live on for up to ten additional years as an active market participant in direct competition with other resources, continuing to build on its track record as one of the first and longest operating batteries in the California market.

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[5] A123 Systems declared bankruptcy shortly after starting to install their system at TSP. Their utility business was later spun off and purchased by NEC, which continues today as NEC Energy Solutions. Following A123's exit from TSP, DOE authorized SCE to partner with LG Chem and continue developing the project with LG Chem's offering.

7. Storage System Performance Parameters

The BESS performance parameters are specific to the energy storage systems itself. This means that in addition to measuring the impact of the BESS, this section reports how well the BESS operated under various conditions regardless of the impact it might have on the system or market. Specific performance parameters are described in the following tabulated summary. The table was populated from data that became available during M&V testing leading up to issue of this Final Technical Report #3.

STORAGE SYSTEM PERFORMANCE PARAMETERS: Technical		
Metric	Value	Definition
Scheduled maintenance down time[6]	11.33%	Ratio of the time that the energy storage system is down for scheduled maintenance divided by the total timeframe. Example: If the system was down for scheduled maintenance 50 hours out of 30 days (720 hours), then the "scheduled maintenance down time" would be 6.9% = (50/720*100).
Down time associated with State of Charge (SOC)[4]	N/A[7]	Ratio of time that the energy storage system has been charged/discharged to the limit and is unable to respond to a signal divided by the total timeframe minus scheduled maintenance down time. Example: If the energy storage system was at the SOC limit for 5 hours and the system was down for scheduled maintenance 50

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[6] Reliability testing to begin Jan 1, 2015

[7] This metric was not applicable to this project. When the system was operated as a market resource, SOC was already taken into account by CAISO when awarding dispatches, with the intent of avoiding a situation where the resource was being asked to charge/discharge but couldn't respond due to being fully charged or discharged. The only related limitations were concerning CAISO's control system, which originally couldn't handle BESSs with capacities greater than 32 MWh. Since TSP was always less than or equal to 32 MWh, this wasn't a limitation. Also, when the project was operated as a grid asset, voltage/reactive power modes were not dependent on SOC, and real power modes were expected to occasionally or regularly drive the system to a full charge or discharge. Since this system was not being used in a scenario where reaching a full charge or discharge was considered detrimental or unexpected (such as demand charge reduction, where reaching a full discharge could result in higher electric bills), the condition of being fully charged or discharged was considered normal, and was not considered down time. For example, Test 4 (charge off peak, discharge on peak) resulted in the system reaching a full charge or full discharge during a given on/off peak period, but this was expected, since the capacity of the BESS was small compared to the Test 4 power and schedule settings, which were in turn based on the amount of area generation and load. The system was not considered "down" when fully charged or discharged.

		hours out of 30 days (720 hours), then the "down time associated with SOC" would be 0.7% = (5/(720-50)*100) .
Unscheduled down time[4]	20.99%	Ratio of the unscheduled down time divided by the total timeframe minus scheduled maintenance down time. Example: If the system was down for 10 hours due to unscheduled incidents and down for 50 hours for scheduled maintenance out of 30 days (720 hours), then the "unscheduled down time" would be 1.5% = (10/(720-50)*100).
Plant availability**	79.01%	Ratio of the total timeframe minus scheduled maintenance down time minus down time associated with SOC minus unscheduled down time divided by the total timeframe minus scheduled maintenance down time. Example: If the system was down for 50 hours due to scheduled maintenance, 5 hours due to down time associated with SOC and another 10 hours for unscheduled down time out of 30 days (720 hours), then the "plant availability" would be 97.8% = ((720-50-5-10)/(720-50)*100).

*   To be reported at the start of operations.

** To be reported only at the end of operations.

STORAGE SYSTEM PERFORMANCE PARAMETERS: Technical		
Metric	Value	Definition
Number and duration of failure incidents	53 Incidents, 5204.66 Hrs	Date and time of the failure incidents including a description of the general cause and duration. To be tracked upon initiation of reliability testing starting Jan. 1, 2015 *Note: A summary list and details of each failure incident can be found in table 6-15.*
Energy dispatched on day-to-day and lifetime basis	<table><tr><td colspan="3">Energy Dispatched</td></tr><tr><td>Date</td><td>kWh</td><td>Cumulative kWh</td></tr><tr><td>August 1, 2014</td><td>196</td><td>196</td></tr><tr><td>August 2, 2014</td><td>196</td><td>392</td></tr><tr><td>August 3, 2014</td><td>196</td><td>588</td></tr><tr><td>August 4, 2014</td><td>196</td><td>784</td></tr><tr><td>August 5, 2014</td><td>0</td><td>784</td></tr><tr><td>August 6, 2014</td><td>0</td><td>784</td></tr><tr><td>August 7, 2014</td><td>0</td><td>784</td></tr><tr><td>August 8, 2014</td><td>196</td><td>980</td></tr><tr><td>August 9, 2014</td><td>196</td><td>1176</td></tr><tr><td>August 10, 2014</td><td>0</td><td>1176</td></tr><tr><td>August 11, 2014</td><td>196</td><td>1372</td></tr><tr><td>August 12, 2014</td><td>196.02</td><td>1568.02</td></tr><tr><td>August 13, 2014</td><td>0</td><td>1568.02</td></tr><tr><td>August 14, 2014</td><td>195.98</td><td>1764</td></tr><tr><td>August 15, 2014</td><td>0</td><td>1764</td></tr><tr><td>August 16, 2014</td><td>196.1</td><td>1960.1</td></tr><tr><td>August 17, 2014</td><td>196</td><td>2156.1</td></tr><tr><td>August 18, 2014</td><td>0</td><td>2156.1</td></tr><tr><td>August 19, 2014</td><td>0</td><td>2156.1</td></tr><tr><td>August 20, 2014</td><td>0</td><td>2156.1</td></tr><tr><td>August 21, 2014</td><td>0</td><td>2156.1</td></tr><tr><td>August 22, 2014</td><td>0</td><td>2156.1</td></tr><tr><td>August 23, 2014</td><td>0</td><td>2156.1</td></tr><tr><td>August 24, 2014</td><td>0</td><td>2156.1</td></tr></table>	Energy dispatched on day-to-day basis accumulated for entire project.

August 25, 2014	196	2352.1	
August 26, 2014	196	2548.1	
August 27, 2014	196	2744.1	
August 28, 2014	392.1	3136.2	
August 29, 2014	392	3528.2	
August 30, 2014	196	3724.2	
August 31, 2014	392.1	4116.3	
September 1, 2014	392	4508.3	
September 2, 2014	195.7	4704	
September 3, 2014	0	4704	
September 4, 2014	0	4704	
September 5, 2014	0	4704	
September 6, 2014	0	4704	
September 7, 2014	0	4704	
September 8, 2014	0	4704	
September 9, 2014	0	4704	
September 10, 2014	0	4704	
September 11, 2014	0	4704	
September 12, 2014	0	4704	
September 13, 2014	0	4704	
September 14, 2014	0	4704	
September 15, 2014	2941	7645	
September 16, 2014	11369	19014	
September 17, 2014	0	19014	
September 18, 2014	0	19014	
September 19, 2014	0	19014	
September 20, 2014	0	19014	
September 21, 2014	0	19014	
September 22, 2014	0	19014	
September 23, 2014	2156	21170	
September 24, 2014	2156	23326	
September 25, 2014	196	23522	
September 26, 2014	196	23718	
September 27, 2014	0	23718	
September 28, 2014	196	23914	
September 29, 2014	196	24110	
September 30, 2014	0	24110	
October 1, 2014	0	24110	
October 2, 2014	0	24110	
October 3, 2014	0	24110	
October 4, 2014	0	24110	
October 5, 2014	0	24110	
October 6, 2014	0	24110	

October 7, 2014	0	24110
October 8, 2014	0	24110
October 9, 2014	0	24110
October 10, 2014	0	24110
October 11, 2014	0	24110
October 12, 2014	0	24110
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October 15, 2014	0	24110
October 16, 2014	0	24110
October 17, 2014	0	24110
October 18, 2014	0	24110
October 19, 2014	0	24110
October 20, 2014	0	24110
October 21, 2014	0	24110
October 22, 2014	8233	32343
October 23, 2014	13133	45476
October 24, 2014	0	45476
October 25, 2014	0	45476
October 26, 2014	0	45476
October 27, 2014	0	45476
October 28, 2014	0	45476
October 29, 2014	196	45672
October 30, 2014	32343	78015
October 31, 2014	0	78015
November 1, 2014	0	78015
November 2, 2014	0	78015
November 3, 2014	0	78015
November 4, 2014	7645	85660
November 5, 2014	7841	93501
November 6, 2014	14897	108398
November 7, 2014	0	108398
November 8, 2014	0	108398
November 9, 2014	0	108398
November 10, 2014	0	108398
November 11, 2014	0	108398
November 12, 2014	0	108398
November 13, 2014	0	108398
November 14, 2014	0	108398
November 15, 2014	0	108398
November 16, 2014	0	108398
November 17, 2014	0	108398
November 18, 2014	0	108398

November 19, 2014	8233	116631	
November 20, 2014	48417	165048	
November 21, 2014	40379	205427	
November 22, 2014	8429	213856	
November 23, 2014	0	213856	
November 24, 2014	0	213856	
November 25, 2014	0	213856	
November 26, 2014	0	213856	
November 27, 2014	0	213856	
November 28, 2014	0	213856	
November 29, 2014	0	213856	
November 30, 2014	0	213856	
December 1, 2014	0	213856	
December 2, 2014	0	213856	
December 3, 2014	0	213856	
December 4, 2014	0	213856	
December 5, 2014	0	213856	
December 6, 2014	0	213856	
December 7, 2014	0	213856	
December 8, 2014	0	213856	
December 9, 2014	8429	222285	
December 10, 2014	40184	262469	
December 11, 2014	0	262469	
December 12, 2014	39792	302261	
December 13, 2014	0	302261	
December 14, 2014	0	302261	
December 15, 2014	0	302261	
December 16, 2014	6468	308729	
December 17, 2014	73311	382040	
December 18, 2014	72919	454959	
December 19, 2014	28227	483186	
December 20, 2014	72723	555909	
December 21, 2014	72723	628632	
December 22, 2014	72722	701354	
December 23, 2014	71939	773293	
December 24, 2014	33323	806616	
December 25, 2014	0	806616	
December 26, 2014	0	806616	
December 27, 2014	0	806616	
December 28, 2014	0	806616	
December 29, 2014	0	806616	
December 30, 2014	0	806616	
December 31, 2014	0	806616	

January 1, 2015	0	806616	
January 2, 2015	0	806616	
January 3, 2015	0	806616	
January 4, 2015	0	806616	
January 5, 2015	0	806616	
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January 19, 2015	0	806616	
January 20, 2015	0	806616	
January 21, 2015	0	806616	
January 22, 2015	0	806616	
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January 25, 2015	0	806616	
January 26, 2015	0	806616	
January 27, 2015	0	806616	
January 28, 2015	0	806616	
January 29, 2015	0	806616	
January 30, 2015	0	806616	
January 31, 2015	0	806616	
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February 3, 2015	0	806616	
February 4, 2015	0	806616	
February 5, 2015	0	806616	
February 6, 2015	0	806616	
February 7, 2015	0	806616	
February 8, 2015	0	806616	
February 9, 2015	0	806616	
February 10, 2015	0	806616	
February 11, 2015	0	806616	
February 12, 2015	0	806616	

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	February 16, 2015	0	806616
	February 17, 2015	0	806616
	February 18, 2015	0	806616
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	February 21, 2015	0	806616
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	February 23, 2015	0	806616
	February 24, 2015	0	806616
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	February 26, 2015	0	806616
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	March 11, 2015	0	806616
	March 12, 2015	0	806616
	March 13, 2015	0	806616
	March 14, 2015	0	806616
	March 15, 2015	0	806616
	March 16, 2015	0	806616
	March 17, 2015	0	806616
	March 18, 2015	0	806616
	March 19, 2015	0	806616
	March 20, 2015	0	806616
	March 21, 2015	0	806616
	March 22, 2015	0	806616
	March 23, 2015	0	806616
	March 24, 2015	0	806616
	March 25, 2015	0	806616
	March 26, 2015	0	806616
	March 27, 2015	0	806616

	March 28, 2015	0	806616	
	March 29, 2015	0	806616	
	March 30, 2015	0	806616	
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	April 3, 2015	0	806616	
	April 4, 2015	0	806616	
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	April 7, 2015	0	806616	
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	April 9, 2015	0	806616	
	April 10, 2015	0	806616	
	April 11, 2015	0	806616	
	April 12, 2015	0	806616	
	April 13, 2015	0	806616	
	April 14, 2015	588	807204	
	April 15, 2015	31755	838959	
	April 16, 2015	16074	855033	
	April 17, 2015	16269	871302	
	April 18, 2015	32147	903449	
	April 19, 2015	0	903449	
	April 20, 2015	196	903645	
	April 21, 2015	196	903841	
	April 22, 2015	3725	907566	
	April 23, 2015	392	907958	
	April 24, 2015	39987	947945	
	April 25, 2015	0	947945	
	April 26, 2015	0	947945	
	April 27, 2015	39988	987933	
	April 28, 2015	34891	1022824	
	April 29, 2015	34303	1057127	
	April 30, 2015	11173	1068300	
	May 1, 2015	0	1068300	
	May 2, 2015	0	1068300	
	May 3, 2015	0	1068300	
	May 4, 2015	10781	1079081	
	May 5, 2015	73507	1152588	
	May 6, 2015	31755	1184343	
	May 7, 2015	0	1184343	
	May 8, 2015	7057	1191400	
	May 9, 2015	0	1191400	

May 10, 2015	0	1191400	
May 11, 2015	34891	1226291	
May 12, 2015	74291	1300582	
May 13, 2015	74487	1375069	
May 14, 2015	74487	1449556	
May 15, 2015	74291	1523847	
May 16, 2015	74487	1598334	
May 17, 2015	74291	1672625	
May 18, 2015	35480	1708105	
May 19, 2015	1568	1709673	
May 20, 2015	0	1709673	
May 21, 2015	17641	1727314	
May 22, 2015	37244	1764558	
May 23, 2015	37244	1801802	
May 24, 2015	37047	1838849	
May 25, 2015	37244	1876093	
May 26, 2015	37243	1913336	
May 27, 2015	37244	1950580	
May 28, 2015	37047	1987627	
May 29, 2015	37244	2024871	
May 30, 2015	196	2025067	
May 31, 2015	8233	2033300	
June 1, 2015	72722	2106022	
June 2, 2015	85073	2191095	
June 3, 2015	95069	2286164	
June 4, 2015	72526	2358690	
June 5, 2015	84876	2443566	
June 6, 2015	94677	2538243	
June 7, 2015	72330	2610573	
June 8, 2015	21758	2632331	
June 9, 2015	196	2632527	
June 10, 2015	588	2633115	
June 11, 2015	196	2633311	
June 12, 2015	784	2634095	
June 13, 2015	784	2634879	
June 14, 2015	588	2635467	
June 15, 2015	392	2635859	
June 16, 2015	16465	2652324	
June 17, 2015	15682	2668006	
June 18, 2015	16270	2684276	
June 19, 2015	16073	2700349	
June 20, 2015	15878	2716227	
June 21, 2015	16073	2732300	

	June 22, 2015	15878	2748178
	June 23, 2015	7840	2756018
	June 24, 2015	0	2756018
	June 25, 2015	0	2756018
	June 26, 2015	0	2756018
	June 27, 2015	0	2756018
	June 28, 2015	0	2756018
	June 29, 2015	0	2756018
	June 30, 2015	30775	2786793
	July 1, 2015	196	2786989
	July 2, 2015	0	2786989
	July 3, 2015	2156	2789145
	July 4, 2015	393	2789538
	July 5, 2015	3724	2793262
	July 6, 2015	1372	2794634
	July 7, 2015	0	2794634
	July 8, 2015	0	2794634
	July 9, 2015	0	2794634
	July 10, 2015	196	2794830
	July 11, 2015	32343	2827173
	July 12, 2015	2156	2829329
	July 13, 2015	19994	2849323
	July 14, 2015	33323	2882646
	July 15, 2015	38616	2921262
	July 16, 2015	0	2921262
	July 17, 2015	0	2921262
	July 18, 2015	0	2921262
	July 19, 2015	0	2921262
	July 20, 2015	0	2921262
	July 21, 2015	0	2921262
	July 22, 2015	2156	2923418
	July 23, 2015	980	2924398
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	July 25, 2015	0	2924398
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	July 28, 2015	0	2924398
	July 29, 2015	0	2924398
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	August 1, 2015	0	2924398
	August 2, 2015	0	2924398
	August 3, 2015	0	2924398

Date		
August 4, 2015	0	2924398
August 5, 2015	0	2924398
August 6, 2015	0	2924398
August 7, 2015	0	2924398
August 8, 2015	0	2924398
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August 10, 2015	0	2924398
August 11, 2015	0	2924398
August 12, 2015	0	2924398
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August 17, 2015	0	2924398
August 18, 2015	0	2924398
August 19, 2015	0	2924398
August 20, 2015	0	2924398
August 21, 2015	0	2924398
August 22, 2015	0	2924398
August 23, 2015	0	2924398
August 24, 2015	1372	2925770
August 25, 2015	12742	2938512
August 26, 2015	35675	2974187
August 27, 2015	85072	3059259
August 28, 2015	60570	3119829
August 29, 2015	60570	3180399
August 30, 2015	0	3180399
August 31, 2015	11957	3192356
September 1, 2015	0	3192356
September 2, 2015	196	3192552
September 3, 2015	18622	3211174
September 4, 2015	39987	3251161
September 5, 2015	36264	3287425
September 6, 2015	49397	3336822
September 7, 2015	49592	3386414
September 8, 2015	49593	3436007
September 9, 2015	62530	3498537
September 10, 2015	31755	3530292
September 11, 2015	43712	3574004
September 12, 2015	43712	3617716
September 13, 2015	21170	3638886
September 14, 2015	14310	3653196
September 15, 2015	33911	3687107

September 16, 2015	27443	3714550	
September 17, 2015	50964	3765514	
September 18, 2015	50965	3816479	
September 19, 2015	48025	3864504	
September 20, 2015	56257	3920761	
September 21, 2015	49397	3970158	
September 22, 2015	38811	4008969	
September 23, 2015	34304	4043273	
September 24, 2015	27050	4070323	
September 25, 2015	27443	4097766	
September 26, 2015	36263	4134029	
September 27, 2015	36460	4170489	
September 28, 2015	58217	4228706	
September 29, 2015	58414	4287120	
September 30, 2015	43712	4330832	
October 1, 2015	53513	4384345	
October 2, 2015	18426	4402771	
October 3, 2015	18034	4420805	
October 4, 2015	17837	4438642	
October 5, 2015	6469	4445111	
October 6, 2015	12545	4457656	
October 7, 2015	60374	4518030	
October 8, 2015	44692	4562722	
October 9, 2015	0	4562722	
October 10, 2015	8821	4571543	
October 11, 2015	21366	4592909	
October 12, 2015	30383	4623292	
October 13, 2015	14309	4637601	
October 14, 2015	15094	4652695	
October 15, 2015	9605	4662300	
October 16, 2015	37635	4699935	
October 17, 2015	11762	4711697	
October 18, 2015	27246	4738943	
October 19, 2015	22542	4761485	
October 20, 2015	0	4761485	
October 21, 2015	22346	4783831	
October 22, 2015	29991	4813822	
October 23, 2015	38028	4851850	
October 24, 2015	23130	4874980	
October 25, 2015	35675	4910655	
October 26, 2015	0	4910655	
October 27, 2015	0	4910655	
October 28, 2015	0	4910655	

October 29, 2015	10389	4921044
October 30, 2015	18425	4939469
October 31, 2015	0	4939469
November 1, 2015	0	4939469
November 2, 2015	13918	4953387
November 3, 2015	0	4953387
November 4, 2015	0	4953387
November 5, 2015	22738	4976125
November 6, 2015	28814	5004939
November 7, 2015	22347	5027286
November 8, 2015	13329	5040615
November 9, 2015	0	5040615
November 10, 2015	0	5040615
November 11, 2015	0	5040615
November 12, 2015	0	5040615
November 13, 2015	0	5040615
November 14, 2015	0	5040615
November 15, 2015	0	5040615
November 16, 2015	0	5040615
November 17, 2015	0	5040615
November 18, 2015	3332	5043947
November 19, 2015	0	5043947
November 20, 2015	0	5043947
November 21, 2015	0	5043947
November 22, 2015	0	5043947
November 23, 2015	0	5043947
November 24, 2015	0	5043947
November 25, 2015	0	5043947
November 26, 2015	196	5044143
November 27, 2015	0	5044143
November 28, 2015	0	5044143
November 29, 2015	0	5044143
November 30, 2015	21954	5066097
December 1, 2015	34892	5100989
December 2, 2015	35087	5136076
December 3, 2015	34303	5170379
December 4, 2015	34891	5205270
December 5, 2015	35088	5240358
December 6, 2015	0	5240358
December 7, 2015	8821	5249179
December 8, 2015	37831	5287010
December 9, 2015	21562	5308572
December 10, 2015	34108	5342680

December 11, 2015	32931	5375611	
December 12, 2015	33127	5408738	
December 13, 2015	17249	5425987	
December 14, 2015	14898	5440885	
December 15, 2015	14701	5455586	
December 16, 2015	14898	5470484	
December 17, 2015	15485	5485969	
December 18, 2015	6077	5492046	
December 19, 2015	0	5492046	
December 20, 2015	0	5492046	
December 21, 2015	0	5492046	
December 22, 2015	0	5492046	
December 23, 2015	0	5492046	
December 24, 2015	0	5492046	
December 25, 2015	0	5492046	
December 26, 2015	0	5492046	
December 27, 2015	0	5492046	
December 28, 2015	0	5492046	
December 29, 2015	0	5492046	
December 30, 2015	0	5492046	
December 31, 2015	0	5492046	
January 1, 2016	0	5492046	
January 2, 2016	0	5492046	
January 3, 2016	0	5492046	
January 4, 2016	0	5492046	
January 5, 2016	0	5492046	
January 6, 2016	0	5492046	
January 7, 2016	0	5492046	
January 8, 2016	0	5492046	
January 9, 2016	0	5492046	
January 10, 2016	0	5492046	
January 11, 2016	0	5492046	
January 12, 2016	0	5492046	
January 13, 2016	26688	5518734	
January 14, 2016	30213	5548947	
January 15, 2016	1007	5549954	
January 16, 2016	0	5549954	
January 17, 2016	0	5549954	
January 18, 2016	0	5549954	
January 19, 2016	0	5549954	
January 20, 2016	13092	5563046	
January 21, 2016	34241	5597287	
January 22, 2016	0	5597287	

January 23, 2016	0	5597287
January 24, 2016	0	5597287
January 25, 2016	0	5597287
January 26, 2016	0	5597287
January 27, 2016	0	5597287
January 28, 2016	1007	5598294
January 29, 2016	504	5598798
January 30, 2016	504	5599302
January 31, 2016	503	5599805
February 1, 2016	504	5600309
February 2, 2016	503	5600812
February 3, 2016	504	5601316
February 4, 2016	0	5601316
February 5, 2016	0	5601316
February 6, 2016	1007	5602323
February 7, 2016	503	5602826
February 8, 2016	1008	5603834
February 9, 2016	503	5604337
February 10, 2016	0	5604337
February 11, 2016	504	5604841
February 12, 2016	0	5604841
February 13, 2016	503	5605344
February 14, 2016	0	5605344
February 15, 2016	504	5605848
February 16, 2016	27695	5633543
February 17, 2016	58412	5691955
February 18, 2016	58412	5750367
February 19, 2016	57908	5808275
February 20, 2016	29710	5837985
February 21, 2016	29205	5867190
February 22, 2016	58412	5925602
February 23, 2016	58412	5984014
February 24, 2016	58916	6042930
February 25, 2016	58411	6101341
February 26, 2016	28703	6130044
February 27, 2016	0	6130044
February 28, 2016	0	6130044
February 29, 2016	23667	6153711
March 1, 2016	58412	6212123
March 2, 2016	24674	6236797
March 3, 2016	18631	6255428
March 4, 2016	58915	6314343
March 5, 2016	29710	6344053

Date		
March 6, 2016	29709	6373762
March 7, 2016	58916	6432678
March 8, 2016	29206	6461884
March 9, 2016	38269	6500153
March 10, 2016	0	6500153
March 11, 2016	0	6500153
March 12, 2016	0	6500153
March 13, 2016	0	6500153
March 14, 2016	0	6500153
March 15, 2016	0	6500153
March 16, 2016	0	6500153
March 17, 2016	14100	6514253
March 18, 2016	9567	6523820
March 19, 2016	0	6523820
March 20, 2016	0	6523820
March 21, 2016	8561	6532381
March 22, 2016	17120	6549501
March 23, 2016	12589	6562090
March 24, 2016	0	6562090
March 25, 2016	0	6562090
March 26, 2016	0	6562090
March 27, 2016	0	6562090
March 28, 2016	0	6562090
March 29, 2016	0	6562090
March 30, 2016	0	6562090
March 31, 2016	0	6562090
April 1, 2016	0	6562090
April 2, 2016	0	6562090
April 3, 2016	0	6562090
April 4, 2016	14603	6576693
April 5, 2016	5036	6581729
April 6, 2016	2014	6583743
April 7, 2016	0	6583743
April 8, 2016	0	6583743
April 9, 2016	0	6583743
April 10, 2016	0	6583743
April 11, 2016	0	6583743
April 12, 2016	0	6583743
April 13, 2016	3021	6586764
April 14, 2016	5539	6592303
April 15, 2016	0	6592303
April 16, 2016	0	6592303
April 17, 2016	0	6592303

April 18, 2016	0	6592303	
April 19, 2016	2015	6594318	
April 20, 2016	0	6594318	
April 21, 2016	33234	6627552	
April 22, 2016	32227	6659779	
April 23, 2016	44816	6704595	
April 24, 2016	27192	6731787	
April 25, 2016	27192	6758979	
April 26, 2016	33234	6792213	
April 27, 2016	43809	6836022	
April 28, 2016	37766	6873788	
April 29, 2016	33234	6907022	
April 30, 2016	46831	6953853	
May 1, 2016	29206	6983059	
May 2, 2016	33738	7016797	
May 3, 2016	34744	7051541	
May 4, 2016	23667	7075208	
May 5, 2016	16618	7091826	
May 6, 2016	33738	7125564	
May 7, 2016	39277	7164841	
May 8, 2016	26185	7191026	
May 9, 2016	14099	7205125	
May 10, 2016	41292	7246417	
May 11, 2016	27695	7274112	
May 12, 2016	15610	7289722	
May 13, 2016	20645	7310367	
May 14, 2016	30213	7340580	
May 15, 2016	31724	7372304	
May 16, 2016	25177	7397481	
May 17, 2016	29710	7427191	
May 18, 2016	31724	7458915	
May 19, 2016	25681	7484596	
May 20, 2016	44313	7528909	
May 21, 2016	41794	7570703	
May 22, 2016	26689	7597392	
May 23, 2016	58915	7656307	
May 24, 2016	41292	7697599	
May 25, 2016	40787	7738386	
May 26, 2016	31724	7770110	
May 27, 2016	34241	7804351	
May 28, 2016	33235	7837586	
May 29, 2016	34745	7872331	
May 30, 2016	28198	7900529	

May 31, 2016	43809	7944338	
June 1, 2016	25681	7970019	
June 2, 2016	27695	7997714	
June 3, 2016	0	7997714	
June 4, 2016	0	7997714	
June 5, 2016	0	7997714	
June 6, 2016	0	7997714	
June 7, 2016	0	7997714	
June 8, 2016	12085	8009799	
June 9, 2016	0	8009799	
June 10, 2016	17625	8027424	
June 11, 2016	25681	8053105	
June 12, 2016	27192	8080297	
June 13, 2016	38773	8119070	
June 14, 2016	30717	8149787	
June 15, 2016	44816	8194603	
June 16, 2016	36256	8230859	
June 17, 2016	25178	8256037	
June 18, 2016	32731	8288768	
June 19, 2016	0	8288768	
June 20, 2016	4532	8293300	
June 21, 2016	29206	8322506	
June 22, 2016	20142	8342648	
June 23, 2016	14603	8357251	
June 24, 2016	28702	8385953	
June 25, 2016	12589	8398542	
June 26, 2016	25178	8423720	
June 27, 2016	12589	8436309	
June 28, 2016	0	8436309	
June 29, 2016	0	8436309	
June 30, 2016	0	8436309	
July 1, 2016	0	8436309	
July 2, 2016	17120	8453429	
July 3, 2016	0	8453429	
July 4, 2016	0	8453429	
July 5, 2016	0	8453429	
July 6, 2016	0	8453429	
July 7, 2016	0	8453429	
July 8, 2016	0	8453429	
July 9, 2016	0	8453429	
July 10, 2016	0	8453429	
July 11, 2016	1007	8454436	
July 12, 2016	0	8454436	

	July 13, 2016	0	8454436	
	July 14, 2016	0	8454436	
	July 15, 2016	0	8454436	
	July 16, 2016	0	8454436	
	July 17, 2016	0	8454436	
	July 18, 2016	0	8454436	
	July 19, 2016	0	8454436	
	July 20, 2016	504	8454940	
	July 21, 2016	0	8454940	
	July 22, 2016	0	8454940	
	July 23, 2016	0	8454940	
	July 24, 2016	503	8455443	
	July 25, 2016	0	8455443	
	July 26, 2016	0	8455443	
	July 27, 2016	4532	8459975	
	July 28, 2016	1511	8461486	
	July 29, 2016	0	8461486	
	July 30, 2016	0	8461486	
	July 31, 2016	0	8461486	
	August 1, 2016	7553	8469039	
	August 2, 2016	0	8469039	
	August 3, 2016	2014	8471053	
	August 4, 2016	0	8471053	
	August 5, 2016	0	8471053	
	August 6, 2016	0	8471053	
	August 7, 2016	0	8471053	
	August 8, 2016	0	8471053	
	August 9, 2016	15107	8486160	
	August 10, 2016	33738	8519898	
	August 11, 2016	31724	8551622	
	August 12, 2016	32227	8583849	
	August 13, 2016	31724	8615573	
	August 14, 2016	29206	8644779	
	August 15, 2016	27191	8671970	
	August 16, 2016	43809	8715779	
	August 17, 2016	43305	8759084	
	August 18, 2016	37766	8796850	
	August 19, 2016	29710	8826560	
	August 20, 2016	30717	8857277	
	August 21, 2016	33234	8890511	
	August 22, 2016	10575	8901086	
	August 23, 2016	4028	8905114	
	August 24, 2016	1511	8906625	

August 25, 2016	25178	8931803	
August 26, 2016	15106	8946909	
August 27, 2016	17624	8964533	
August 28, 2016	11078	8975611	
August 29, 2016	7050	8982661	
August 30, 2016	2014	8984675	
August 31, 2016	27696	9012371	
September 1, 2016	40284	9052655	
September 2, 2016	29709	9082364	
September 3, 2016	24171	9106535	
September 4, 2016	26688	9133223	
September 5, 2016	18631	9151854	
September 6, 2016	51866	9203720	
September 7, 2016	25681	9229401	
September 8, 2016	37263	9266664	
September 9, 2016	45823	9312487	
September 10, 2016	49852	9362339	
September 11, 2016	34745	9397084	
September 12, 2016	29709	9426793	
September 13, 2016	30213	9457006	
September 14, 2016	30213	9487219	
September 15, 2016	29710	9516929	
September 16, 2016	10071	9527000	
September 17, 2016	21149	9548149	
September 18, 2016	18631	9566780	
September 19, 2016	20646	9587426	
September 20, 2016	20646	9608072	
September 21, 2016	22659	9630731	
September 22, 2016	28703	9659434	
September 23, 2016	27191	9686625	
September 24, 2016	24171	9710796	
September 25, 2016	29709	9740505	
September 26, 2016	24171	9764676	
September 27, 2016	24674	9789350	
September 28, 2016	36759	9826109	
September 29, 2016	52873	9878982	
September 30, 2016	43809	9922791	
October 1, 2016	31220	9954011	
October 2, 2016	30213	9984224	
October 3, 2016	25681	10009905	
October 4, 2016	23163	10033068	
October 5, 2016	21149	10054217	
October 6, 2016	21149	10075366	

October 7, 2016	22660	10098026
October 8, 2016	15107	10113133
October 9, 2016	13596	10126729
October 10, 2016	15610	10142339
October 11, 2016	21149	10163488
October 12, 2016	28702	10192190
October 13, 2016	27695	10219885
October 14, 2016	23667	10243552
October 15, 2016	23667	10267219
October 16, 2016	4029	10271248
October 17, 2016	0	10271248
October 18, 2016	8056	10279304
October 19, 2016	26689	10305993
October 20, 2016	0	10305993
October 21, 2016	0	10305993
October 22, 2016	0	10305993
October 23, 2016	0	10305993
October 24, 2016	14099	10320092
October 25, 2016	30717	10350809
October 26, 2016	23163	10373972
October 27, 2016	30213	10404185
October 28, 2016	17625	10421810
October 29, 2016	0	10421810
October 30, 2016	0	10421810
October 31, 2016	0	10421810
November 1, 2016	0	10421810
November 2, 2016	6042	10427852
November 3, 2016	14603	10442455
November 4, 2016	29206	10471661
November 5, 2016	42802	10514463
November 6, 2016	45823	10560286
November 7, 2016	26688	10586974
November 8, 2016	21149	10608123
November 9, 2016	22157	10630280
November 10, 2016	15106	10645386
November 11, 2016	12589	10657975
November 12, 2016	16617	10674592
November 13, 2016	34241	10708833
November 14, 2016	23667	10732500
November 15, 2016	30213	10762713
November 16, 2016	42298	10805011
November 17, 2016	9567	10814578
November 18, 2016	0	10814578

	November 19, 2016	0	10814578
	November 20, 2016	0	10814578
	November 21, 2016	10071	10824649
	November 22, 2016	0	10824649
	November 23, 2016	0	10824649
	November 24, 2016	0	10824649
	November 25, 2016	0	10824649
	November 26, 2016	0	10824649
	November 27, 2016	0	10824649
	November 28, 2016	0	10824649
	November 29, 2016	0	10824649
	November 30, 2016	0	10824649
	December 1, 2016	0	10824649
	December 2, 2016	0	10824649
	December 3, 2016	0	10824649
	December 4, 2016	0	10824649
	December 5, 2016	0	10824649
	December 6, 2016	4029	10828678
	December 7, 2016	9567	10838245
	December 8, 2016	25178	10863423
	December 9, 2016	25681	10889104
	December 10, 2016	23163	10912267
	December 11, 2016	34241	10946508
	December 12, 2016	15611	10962119
	December 13, 2016	21652	10983771
	December 14, 2016	27192	11010963
	December 15, 2016	39277	11050240
	December 16, 2016	46831	11097071
	December 17, 2016	27695	11124766
	December 18, 2016	30213	11154979
	December 19, 2016	24674	11179653
	December 20, 2016	36256	11215909
	December 21, 2016	27191	11243100
	December 22, 2016	16114	11259214
	December 23, 2016	25177	11284391
	December 24, 2016	34745	11319136
	December 25, 2016	21653	11340789
	December 26, 2016	16114	11356903
	December 27, 2016	27695	11384598
	December 28, 2016	18631	11403229
	December 29, 2016	17121	11420350
	December 30, 2016	18128	11438478
	December 31, 2016	0	11438478

Round-trip efficiency (RTE)	82.03%[8]	Ratio of total energy storage system output (discharge) divided by total energy input (charge) as measured at the interconnection point. Example: If the total output was 5,000 kWh, but the total energy input was 6,500 kWh, then the "round-trip efficiency" would be 76.9% = (5,000/6,500*100). Note: supplemental loads and losses (e.g., cooling, heating, pumps, DC/AC and AC/DC conversions, control power, etc.) consumed the 1,500 kWh.

STORAGE SYSTEM PERFORMANCE PARAMETERS: Technical		
Metric	Value	Definition
Ability to follow Automatic Generation Control (AGC) signal (load following only) and Area Control Error (ACE) signal (regulation only)	Refer to section 6.6.10 for results of AGC load following evaluation	Ratio of the kWh provided by the energy storage system divided by the kWh required by the AGC at each 4 second interval. Example: If the AGC or ACE signal requires discharge of 100 kWh but the energy storage system only provides 80 kWh during that 4 second interval, the ability to follow the AGC or ACE signal would be 80% = (80 kWh/100 kWh *100) *Note: This is a summary number and the details of each of these incidents will be tracked and available.*
Capacity degradation	7.72%[9]	Ratio of energy capacity at the end of the time period divided by the capacity at the beginning. Example: If the total energy storage system capacity at

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[8] The round trip efficiency was calculated using total energy consumed and dispatched between August 1, 2014 and December 31, 2016.

[9] Due to limited amounts of capacity tests, the capacity degradation was calculated using system commissioning data from July 14-16, 2014 and capacity test data from September 15-17, 2016 to calculate the overall system degradation. This data was taken at the 66kV level.

		the end of the project had a capacity of 4,000 kWh and at the start of the project was 5,000 kWh, then the "capacity degradation" would be 20% = ((5,000-4,000)/5,000*100). Note: for battery systems, this measurement is taken on the device DC bus. Otherwise it is at the interconnection point.

STORAGE SYSTEM PERFORMANCE PARAMETERS: Technical		
Metric	Value	Definition
Ramp rate (charge/discharge)	The system ramp rate was user adjustable via the SEC from 0 to 8000 kW/sec in increments of 1 kW/sec. Since there were no interconnection ramp rate restrictions, the ramp rate was always set to 8000 kW/sec (other than during system acceptance testing). As long as the PCS lineup was online, it was capable of meeting the ramp rate. However, the data acquisition equipment was not capable of high speed data acquisition, so a graph is not provided.	The change in power charged and discharged over time to meet the variations in power requirements. Graphically (with resolution of 100 milliseconds) demonstrate the energy storage system's sustainable maximum ramp rate (kW/sec). List the number of times that the energy storage system did not meet the requested ramp rate on a daily basis. Example Details: August 29, 2010, 15:34.28, Maximum Discharge 0kW to 1,000kW achieved in 4 seconds for a discharge ramp rate of 250 kW/s.

STORAGE SYSTEM PERFORMANCE PARAMETERS: Economic		
Metric	Value	Definition
Engineering and design costs	$1.48M	The cost associated with engineering and design for the demonstration project implementation.
Capital cost (i.e., equipment capital and installation)*	$25.7M	Total installed first cost of fielded system, breaking out major categories including equipment (i.e., major equipment components, related support equipment, and initial spare parts) and costs associated with shipping, site preparations, installation, and commissioning.
Capital cost*	$803/kWh & $3,213/kW	Total installed first cost of fielded system, normalized by energy storage capacity and peak power output.
End of life disposal cost**	** TBD at end of operation	The system will continue to operate after the study period and costs will be evaluated at that time.
End of life value of plant and equipment**	** TBD at end of operation	The system will continue to operate after the study period and costs will be evaluated at that time.
Operating cost (activity based, non-fuel, by application plus monitoring)	N/A	Operating costs were inconsistent due to abnormal repair/downtime and are not representative for normal conditions.
Maintenance cost (by cost category)	N/A	Operating costs were inconsistent due to abnormal repair/downtime and are not representative for normal conditions.

*   To be reported at the start of operations.

** To be reported only at the end of operations.

STORAGE SYSTEM PERFORMANCE PARAMETERS: Environmental Health & Safety		
Metric	Value	Definition
Operating temperature	20°C	Degrees Fahrenheit at which the energy system normally operates.
Flammability	Under normal operating conditions, issues are	Material flammability ignition

	not anticipated. As with any electrical equipment, avoid exposing to open flames or corrosives	temperature and ignition energy.
Material toxicity	Lithium ion batteries are designed and manufactured to be routinely used for a variety of applications, including mobile electronics, electric vehicles, and electrical energy storage for electric grid applications.	Qualitative discussion on materials toxicity.
Recyclability	The system will remain in operation beyond the ARRA program evaluation term. As such, recyclability is to be evaluated at that time, based on technologies available at that time. As a starting point, when considering recycling, the estimated amount of metals in the battery is about 40-55% by weight.	Percent of the material from the energy storage system expected to be recyclable at the end of life. Example: If there are four tons of lead that can be recyclable from the original five tons installed, then the lead "recyclability" would be 80% = (4/5*100).
Other	N/A	List and describe any other EH&S issues.

Table 7-1 Storage System Performance Parameters

*   To be reported at the start of operations.

** To be reported only at the end of operations.

8.   Impact Metrics

Metric	Remarks	Value		Data Analysis
		Project	System[10]	
IMPACT METRICS: Electric Transmission Systems				
Metrics Related Primarily to Economic Benefits				
Congestion		MW	MW	Information will be estimated or modeled based on CAISO system records of MW dispatched to relieve a transmission constraint and the associated cost.
Congestion Cost	Not evaluated in this study due to reconfiguration of surrounding grid topology.	$	$	
Transmission Line or Equipment Overload Incidents	Not evaluated in this study due to reconfiguration of surrounding grid topology.	0	0	Data will come from the Transmission Management System (legacy EMS) and from PMUs when available.
Transmission Line load	Not evaluated in this study due to reconfiguration of surrounding grid topology.	N/A	N/A	
		N/A	N/A	
Deferred Transmission Capacity Investments	Project area transmission capacity investments are not anticipated at this time.	0	0	Semi-annual variance analysis of transmission capital investment plan
Transmission losses	See M&V Use Case 2 – Decreased losses	%	%	EMS load information, transmission planning model analysis.
Transmission power factor	System was not operated to change transmission PF	N/A	N/A	
Metrics Related Primarily to Environmental Benefits				
CO_2 Emissions	Direct measurement and evaluation for offset of CO_2 emissions were not available, and therefore not a focus of the evaluation	N/A	N/A	Emissions impacts will be calculated based on other metrics and results; including transmission losses, congestion and integration of wind generation resources.
Pollutant Emissions (SOx, NOx, PM-2.5)	Direct measurement and evaluation for offset of emissions were not available, and therefore not a focus of the evaluation	N/A	N/A	

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[10] This project only includes one single system, therefore "System" values are identical to "Project" values.

Table 8-1 Impact Metrics Electric Transmission Systems

Impacts Metrics Storage Systems

IMPACT METRICS: Storage Systems				
Metric	**Remarks**	**Value**		**Data Analysis**
		Project	**System**	
Metrics Related Primarily to Economic Benefits				
Annual Storage Dispatch	July 1 thru Dec. 31 2014	1,014,027 kWh[11]	1,014,027 kWh[11]	Data is from PCC and auxiliary service meters.
Annual Storage Dispatch	Jan. 1 thru Dec. 30 2015	4,693,048 kWh[11]	4,693,048 kWh[11]	Data is from PCC and auxiliary service meters.
Annual Storage Dispatch	Jan. 1 thru Dec. 31 2016	5,656,499 kWh[11]	5,656,499 kWh[11]	Data is from PCC and auxiliary service meters.
Average Energy Storage Efficiency	Excluding Aux. Loads	82.03%[12]	82.03%[12]	Information will be calculated based on data from the storage system PCS.
Average Energy Storage Efficiency	Including Aux. Loads	78.22%[12]	78.22%[12]	Information will be calculated based on data from the storage system PCS.
Ancillary Services Price	Operating reserves and frequency regulation	N/A	N/A	Information will be estimated or modeled based on CAISO system records of ancillary services prices.

Table 8-2 Impact Metrics Storage Systems

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[11] Discharged AC energy (one-way only) as measured at 66 kV point of common coupling

[12] The round trip efficiency was calculated using total energy consumed and dispatched between July 7, 2014 and December 31, 2016.

ESTIMATES FOR IMPACT METRICS: Transmission			
Metric	**Remarks**	**Baseline Estimate**	**Baseline Estimation Method**
Metrics Related Primarily to Economic Benefits			
Congestion			Three years of available CAISO system records of ancillary service prices, MW dispatched to relieve a transmission constraint and the associated cost will be modeled for projection.
Congestion Cost	Economic benefits related to congestion costs were not evaluated in the market analyses for this project.	N/A	
Transmission Line or Equipment Overload Incidents	0	0	Three years of EMS and available PMU data will be modeled for projection. Load and wind generation forecasts and transmission plans will be factored in.
Transmission Line load	Analyses results included in section 6.6 of this report	N/A	
Deferred Transmission Capacity Investments	Area transmission capacity investments are not anticipated at this time.	N/A	Current transmission plans and capital expenditure forecasts through the project period.
Transmission losses	N/A due to grid reconfiguraton	N/A	Three years of EMS and available PMU data will be modeled for projection. Load and wind generation forecasts and transmission plans will be factored in
Transmission power factor	N/A due to grid reconfiguraton	N/A	
Metrics Related Primarily to Environmental Benefits			
CO_2 Emissions	N/A	N/A	Modeled using three years of data for line losses, impacts of congestion on generation mix and curtailed load and wind generation from above.
Pollutant Emissions (SOx, NOx, PM-2.5)	N/A	N/A	

Table 8-3 Impact Metrics: Transmission Systems Baseline

Impact Metrics: Storage Systems Baseline

BASELINE ESTIMATES FOR IMPACT METRICS: Storage Systems			
Metric	**Remarks**	**Baseline Estimate - 6 Month Forecast**	**Baseline Estimation Method**
Metrics Related Primarily to Economic Benefits			
Annual Storage Dispatch	Economic analyese contained in Section 6.	0	The baseline would be zero storage dispatch in the area as there is no other available facility.
Average Energy Storage Efficiency	Economic analyese contained in Section 6.	0	
Ancillary Services Price	No market testing planned in the next 6 month window. Initially focused on Transmission tests	N/A	Three years of available CAISO system records of ancillary service prices.

Table 8-4 Baseline Estimates for Impact Metrics: Storage Systems

9. Appendices

9.1 Appendix A: Detailed Test Plans

9.1.1 Test 1 Provide Steady State Voltage Regulation At The Local Monolith 66 kV Bus

Overview:

This test will examine the BESS' ability, in a reactive power control mode, to respond with ±4 MVAr of nominal capability to maintain AC voltage on the 66 kV Monolith substation bus within steady-state (± 5%) range. This test aims to demonstrate the BESS' ability to control voltage as a dedicated voltage compensator.

Primary Method of Performing Tests:

According to the previously conducted PSS/E simulations, the system in the Tehachapi area already has good voltage support. In order to demonstrate the capability of BESS providing voltage regulation support, the BESS' voltage set point will be carefully selected so that voltage regulation activities, either reactive power injection or absorption, will more likely be triggered. With a proper voltage set point, this test can be applied at any time.

The BESS Site Energy Controller (SEC) regulates voltage to within +/-5%[13] of the set point. The +/- 5% dead-band will be adjustable in an upcoming software revision. If the voltage set point is 66 kV, then BESS voltage support capability will be in effect only when the Monolith bus voltage falls outside of 66 kV ±5% (i.e., [62.7 kV, 69.3 kV]), which may be a less likely event in the current system. However, if the voltage set point is 62.86 kV, then BESS voltage support capability will be in effect when the Monolith bus voltage is higher than 66 kV (set point voltage +5%), which is more likely to happen. In the first phase of the test, a sweeping test is proposed to evaluate BESS' voltage sensitivity in current system and to identify the best selection for voltage set point. The series of voltage set points to be tested are shown in Table 9-1.

Voltage Set Point - 5%	Voltage Set Point	Voltage Set Point + 5%
59.72 kV	62.86 kV	**66.00 kV**
60.29 kV	63.46 kV	66.63 kV
60.88 kV	64.08 kV	67.28 kV
61.47 kV	64.71 kV	67.95 kV
62.08 kV	65.35 kV	68.62 kV

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[13] ABB, "Tehachapi Wind Energy Storage Project Control and Interface Concept"

62.70 kV	66.00 kV	69.30 kV
63.34 kV	66.67 kV	70.00 kV
63.98 kV	67.35 kV	70.72 kV
64.64 kV	68.04 kV	71.44 kV
65.31 kV	68.75 kV	72.19 kV
66.00 kV	69.47 kV	72.94 kV

Table 9-1 Voltage Set Point Sweeping Test

As local voltage profile is very healthy, the BESS voltage support capability will very likely be triggered when the range boundary of +/-5% of the set point is around 66 kV. The series of voltage set points are selected using the system nominal voltage (66 kV) as the *boundary* reference, instead of the *base* reference, so that +5% of the lowest voltage set point is 66 kV and -5% of the highest voltage set point is 66 kV. For example, the highest voltage set point is selected to ensure its -5% is 66 kV (i.e., 66 kV/(1-0.05) =69.47 kV), which is different from the +5% of 66 kV (i.e., 66 kV * (1+0.05) = 69.3 kV). This selection of voltage set points is only one of the possible approaches.

Even though +5% of some higher voltage set points in the table are higher than +5% of the system nominal voltage, it is expected that the BESS voltage support only functions at the low end of the range. Similarly, even though -5% of some lower voltage set points in the table are lower than -5% of the system nominal voltage, it is expected that the BESS voltage support only functions at the high end of the range. As a result, no system voltage violation is expected to occur with BESS' steady state voltage regulation in effect.

The sequence of test scenarios is designed to alternate the reactive power injection and reactive power absorption. These test scenarios can be conducted with or without stops. The data collected from the sweeping test will be analyzed to determine the best voltage set point(s) for reactive power injection and/or absorption. The selected voltage set point(s) will then be applied in the second phase of the test.

During both phases of the test, operational control center sets the BESS in voltage regulation mode and then configure the BESS parameters as described in Table 9-2. The BESS will operate passively in background, absorbing or supplying reactive power as required to hold the voltage set point. Full power rating (up to 4MVAr) will be made available to provide voltage regulation in the test. Real power will only be exchanged to maintain battery state of charge.

Given the healthy local voltage profile, there is no particular preference on the time of day for conducting the test. Each test case will last, at a minimum, until bus voltage has stabilized at the command value. A duration of one hour is suggested to demonstrate BESS' ability to sustain the scheduled MVAr flow. It is ideal that capacitor banks will remain the same status during all the

series of voltage set points in the test. However, if keeping the capacitor banks fixed may cause potential adverse impact to the system, the status of capacitor banks will remain the same during the test for the same voltage set point.

Data to be collected:

- Voltage profile at 66 kV Monolith substation bus
- Monolith substation capacitor bank status
- BESS parameters
  - Status
  - Voltage Set Point
  - State of Charge (%)[14]
  - Charge/Discharge rate (MW/MVAr)

Step #	Who Does It?	Action	Additional Notes
	Which participant, either primary or secondary is responsible for the activity in this step?	Describe the actions that take place in this step in active, present tense.	Additional description of statement about the step to help support description. Comments about data collection requirements, special equipment features, unusual challenges, etc.
1	SCE EMS	Place BESS in Voltage Regulation mode (Test 1).	
2	Advanced Energy Storage	In BESS Human Machine Interface (HMI): • Set the "Maintain SOC Allowed for T1&T4" as ON.	The BESS will begin the test at approximately 50% SOC. Currently, the system dead-band for V Control is fixed at +/- 2.5% of the set-point; and the ramp rate is 100 kVAr/s. Both settings will be variable in the future (e.g., 0.5-5% for dead-band, 4–4000 kVAr/s for ramp rate).
3	Advanced Energy Storage	Set the "V Control Set Point" at 66 kV in BESS HMI	
4	Grid	Operate BESS in the configured	

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[14] State of Charge (SOC) information is mainly for the reference during data analysis. For example, if the collected test data shows the BESS charge/discharge rate change at certain time, this SOC information can help capture if the change is because the BESS is close to be fully charged/discharged or due to other reasons. This information can further help determine necessary data exclusion for analysis.

		Operations	mode for an hour	
5	Advanced Energy Storage	Set the "V Control Set Point" at 65.35 kV in BESS HMI	65.35 kV + 1% ≈ 66 kV 65.35 kV ±5% ≈ [62.08 kV,68.62 kV]	
6	Grid Operations	Operate BESS in the configured mode for an hour		
7	Advanced Energy Storage	Set the "V Control Set Point" at 66.67 kV in BESS HMI	66.67 kV - 1% ≈ 66 kV 66.67 kV ±5% ≈ [63.34 kV,70.00 kV]	
8	Grid Operations	Operate BESS in the configured mode for an hour		
9	Advanced Energy Storage	Set the "V Control Set Point" at 64.71 kV in BESS HMI	64.71 kV + 2% ≈ 66 kV 64.71 kV ±5% ≈ [61.47 kV,67.95 kV]	
10	Grid Operations	Operate BESS in the configured mode for an hour		
11	Advanced Energy Storage	Set the "V Control Set Point" at 67.35 kV in BESS HMI	67.35 kV - 2% ≈ 66 kV 67.35 kV ±5% ≈ [63.98 kV,70.72 kV]	
12	Grid Operations	Operate BESS in the configured mode for an hour		
13	Advanced Energy Storage	Set the "V Control Set Point" at 64.08 kV in BESS HMI	64.08 kV + 3% ≈ 66 kV 64.08 kV ±5% ≈ [60.88 kV,67.28 kV]	
14	Grid Operations	Operate BESS in the configured mode for an hour		
15	Advanced Energy Storage	Set the "V Control Set Point" at 68.04 kV in BESS HMI	68.04 kV - 3% ≈ 66 kV 68.04 kV ±5% ≈ [64.64 kV,71.44 kV]	
16	Grid Operations	Operate BESS in the configured mode for an hour		
17	Advanced Energy Storage	Set the "V Control Set Point" at 63.46 kV in BESS HMI	63.46 kV + 4% ≈ 66 kV 63.46 kV ±5% ≈ [60.29 kV,66.63 kV]	
18	Grid Operations	Operate BESS in the configured mode for an hour		
19	Advanced Energy Storage	Set the "V Control Set Point" at 68.75 kV in BESS HMI	68.75 kV - 4% ≈ 66 kV 68.75 kV ±5% ≈ [65.31 kV,72.19 kV]	
20	Grid Operations	Operate BESS in the configured mode for an hour		
21	Advanced Energy Storage	Set the "V Control Set Point" at 62.86 kV in BESS HMI	62.86 kV + 5% ≈ 66 kV 62.86 kV ±5% ≈ [59.72 kV,66.00 kV]	
22	Grid Operations	Operate BESS in the configured mode for an hour		

23	Advanced Energy Storage	Set the "V Control Set Point" at 69.47 kV in BESS HMI	69.47 kV - 5% ≈ 66 kV 69.47 kV ±5% ≈ [66.00 kV,72.94 kV]
24	Grid Operations	Operate BESS in the configured mode for an hour	
25	Grid Operations	First test phase complete, return BESS to the prior operating mode.	
26	Quanta Technology	Data analysis to determine the best voltage set point(s) for final test as well as the desired test duration.	
27	Advanced Energy Storage	In BESS HMI, set the "V Control Set Point" at the value(s) from the data analysis	The final voltage set point(s) are to be determined. There may have multiple set points.
28	Grid Operations	Operate BESS in each configured voltage set point.	The test duration is to be determined from the data analysis.
29	Grid Operations	Second test phase complete, return BESS to the prior operating mode.	
30	Grid Operations	Test complete	

Table 9-2 Test 1 Steps - Provide steady state voltage regulation at local Monolith 66 kV bus

9.1.2   Test 2 Steady State Voltage Regulation Under Any Mode

Overview:

Similar to Test 1, BESS will be operated in a reactive power control mode to test its ability to automatically maintain AC voltage on the 66 kV Monolith substation bus within steady-state (± 5%) range.   However, the test examines BESS' ability to control voltage as a voltage compensation device while obeying real power dispatch commands instead of as a dedicated voltage compensator in Test 1. Therefore, this test should be conducted in conjunction with other tests (i.e., Test 3, Test 4, and Test 5) and should be repeated under varied real power BESS modes: charging, discharging, and inactive.

Primary Method of Performing Test:

The general methodology of performing Test 2 is to enable the voltage set point while repeating Test 3/4/5. The voltage set point(s) adopted in this test is based on the findings of the first phase of Test 1 which aims to evaluate the best voltage set point(s) that are likely to trigger BESS's voltage support capability.

As this test will be conducted in conjunction with Test 3/4/5, it is recommended to perform this test after Test 3/4/5 have been conducted and data analyses have provided insight of how and how much the BESS affects the system parameters evaluated in each test. With this information

from well-developed tests 1/3/4/5, this test can concentrate on demonstrating the capability of BESS in providing dynamic voltage support at local Monolith 66 kV bus.

Data to be collected (in addition to the data collected for Test 3/4/5):

- Voltage profile at 66 kV Monolith substation bus
- Monolith substation capacitor bank status
- BESS parameters
    - Status
    - Voltage Set Point
    - State of Charge (%)
    - Charge/Discharge rate (MW/MVAr)

Step #	Who Does It?	Action	Additional Notes
	Which participant, either primary or secondary is responsible for the activity in this step?	Describe the actions that take place in this step in active, present tense.	Additional description of statement about the step to help support description. Comments about data collection requirements, special equipment features, unusual challenges, etc.
1	Advanced Energy Storage	In BESS HMI : Turn on "V Ctrl Selected for T3, T4 or T5"	The BESS will begin the test at approximately 50% SOC.
2	Advanced Energy Storage	Set the "V Control Set Point" at the value(s) from the data analysis in BESS HMI	The final voltage set point(s) are to be determined. There may be multiple set points.
3	SCE EMS / Grid Operations	Conduct Test 3/4/5	
4	Grid Operations	Test Complete	

Table 9-3 Test 2 Steps – Steady State Voltage Regulation under Any Mode

9.1.3   Test 3 Charge During Periods Of High Line Loading And Discharge During Low Line Loading Under SCE System Operator Control

Overview:

Test 3 was primarily designed to demonstrate BESS operation to mitigate congestion (Operational Use 3). Prior to the EKWRA project, two 66 kV lines between Cal Cement and Antelope substations and one 66 kV line between Goldtown and Antelope experienced congestion when high wind generation output exceeded available transmission capacity. If the

pre-EKWRA configuration had remained in place, this test would have demonstrated Operational Use 3 by charging during periods of high line loading and discharging during periods of low line loading. Reduced line loads in the high load period would correspond to reduced transmission congestion while also reducing curtailment of wind generation requiring compensation. Reduction in line loading will also reduce transmission losses (Operational Use 2).

The economic benefit would be determined by estimating the value of wind generation that did not have to be curtailed. Over time, wind generation curtailments would justify investment in additional transmission facilities (Operational Use 5). BESS can be operated to delay delivery of peaks of renewable output, holding delivery to a level which requires a smaller transmission investment (Operational Use 6). In addition to monetary savings, emissions will be reduced by the amount of extra wind generation output made available for use and by the reduction of out-of-merit generation required for congestion relief.

The EKWRA reconfiguration has essentially eliminated congestion in the Tehachapi area, so BESS can be operated to demonstrate that it can reduce line flows between Monolith and major load centers and/or wind generations. The reduction in line flows can be used to estimate reduction in line losses.

In some instances it may be possible to operate BESS in such a way as to avoid or reduce automatic load shedding during extreme contingencies (Operational Use 4). Automatic load shedding occurs when an isolated portion of an interconnected system, typically by multiple transmission outages, has an excess of load over generation, which causes kinetic energy to be pulled out of the rotating electrical machines, slowing their speed of rotation and causing frequency to decline. Discharging BESS can reduce the amount of energy withdrawn from the rotating machines, slow the rate of frequency decline and hopefully, allow frequency to stabilize at a higher level, with less dropping of load. Demonstrating the rapid ramping capabilities of BESS will verify the feasibility of it being used to avoid load shedding or generator tripping when system disturbances perturb frequency from the nominal 60 Hz level. However, the Tehachapi area has an excess of installed generation over load, so very few credible contingencies will result in an "island" with an excess of load over generation and cause under-frequency load shedding.

Primary Method of Performing Test:

This test can be applied at any line loading level. To be beneficial, the wind generation upstream of Monolith will be sufficiently above the 8 MW capability of the BESS so the resulting load is still positive, otherwise the BESS charging rate will be reduced from its maximum rate. SCE anticipates that at low loading levels it will achieve no more reduction in line flows, and possibly less if the flow actually reverses during the charging cycle.

The BESS SEC utilizes an algorithm[15] to compare the line loading of two selected transmission lines with the pre-defined range and then dispatch BESS to inject or absorb real power

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[15] ABB, "Tehachapi Wind Energy Storage Project Control and Interface Concept"

accordingly. The two selected transmission lines that carry the wind power to Windhub through Monolith substation are

- Monolith –TAP88-Windhub 66 kV line
- Monolith –TAP78- TAP79-Windhub 66 kV line

Given the system configuration change due to EKWRA project, it is recommended to conduct an initial test and examine the collected data for parameter tuning. During the initial test, the BESS is set in Test 3 mode and then Advanced Energy Storage personnel configure the BESS parameters as described in Table 9-4. The parameter configuration is designed to enable the BESS dispatch (both charge and discharge) occur frequently during the initial test phase. Even though the selected lines have limited seasonal variations in loading, the best month for conducting the initial test is October when the line loading fluctuation is good for triggering BESS dispatch.

The initial test with BESS dispatched in its maximum rate will last a week. Another week of monitoring without the BESS in place is required to collect baseline measurement. The purpose of conducting tests on alternative weeks is to maximize the possibility of pairing similar scenarios with or without BESS in service.

Data analyses will be conducted to evaluate the necessity to change the lines to be monitored or to lower the BESS charge/discharge rate given the combination of the cycle of load condition, the variation of wind generation during the test period.

One aspect of the test is to demonstrate BESS' rapid ramping capabilities to avoid load shedding or generator tripping when system disturbances perturb frequency from the nominal 60 Hz level. Given the excess of installed generation over load in the Tehachapi area, the under-frequency load shedding event is unlikely to occur. As an alternative, the test will monitor the frequency variation to assess the potential of BESS to avoid load shedding when in an excess of load over generation scenario.

During the test, the maximum BESS ramping rate is configured. During the data analysis, various BESS scenarios that are similar to being dispatched to arrest frequency decline and prevent load shedding will be examined: from neutral to maximum discharge and from charge to maximum discharge.

Data to be collected:

- Transmission loads on the following 66 kV lines.
    - Monolith – Breeze lines 1 & 2
    - Monolith – Cummings line
    - Monolith – Loraine line
    - Monolith – Cal Cement line
    - Monolith – MidWind line
    - Monolith – ArbWind line
- Frequency at Monolith substation (PMU data)

- Monolith transformer 1 and 2 load
- Tehachapi wind generation profile for each wind plant (MW/MVAr)
- Storage dispatch event with its timing
- BESS parameters
  - Status
  - State of Charge (%)
  - Energy Available
  - Charging/discharging rate (MW/MVAr)

Step #	Who Does It?	Action	Additional Notes
	Which participant, either primary or secondary is responsible for the activity in this step?	Describe the actions that take place in this step in active, present tense.	Additional description of statement about the step to help support description. Comments about data collection requirements, special equipment features, unusual challenges, etc.
1	Advanced Energy Storage	In BESS HMI, configure "Test 3 Set Points" SP parameters as: • $I\_Calc\_Lim1 = 91$ • $I\_Calc\_Lim1\_Lower = 79$ • $I\_Calc\_Lim2 = 91$ • $I\_Calc\_Lim2\_Lower = 79$ • $I\_Limit\_Lower\_Deadband = 2$ • $I\_Limits\_Deadband = 2$ • $I\_Line1\_Lim1 = 70$ • $I\_Line1\_Lim1\_Lower = 60$ • $I\_Line1\_Lim2 = 70$ • $I\_Line1\_Lim2\_Lower = 60$ • $T\_Lim = 70$[16]	The BESS will begin the test at approximately 50% SOC. The parameters "SOC Max (%)", "SOC Min (%)", "SOC (%)" will remain at default values. The parameters "P Ramp + [kW/sec]", "P Ramp – [kW/sec]", "P Charge [kW]", and "P Discharge [kW]" remain at default values to enable charge/discharge BESS at the maximum rate. The parameters are based on the selection

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[16] The algorithm used in SEC adopts two sets of current limit when for different temperatures. During the initial test, two sets of current limit are set as the same therefore the T_Lim can be arbitrarily selected. The average temperature for October is used (http://en.wikipedia.org/wiki/Tehachapi,_California)

			of Monolith – Sub Tran Lines BREEZE1/Monolith – Sub Tran Lines BREEZE2 as Line 1 and Line 2. If BESS SEC has other designated lines for monitoring, the parameters will be re-selected.[17]
2	Grid Operations	Operate BESS in the configured mode for one week.	
3	Grid Operations	Idle BESS.	Ensure a moderate SOC (e.g., 30%) of the BESS before being idled
4	Grid Operations	Monitor the same system parameters for one week.	
5	Grid Operations	First test phase complete	
6	Quanta Technology	Data analysis to evaluate the impact of BESS and to determine a more suitable set of parameters for the test.	
7	Advanced Energy Storage	In BESS HMI, configure "Test 3 Set Points" SP parameters based on data analysis	
8	Grid Operations	Operate BESS in the configured mode for one week.	
9	Grid Operations	Disable BESS	
10	Grid Operations	Monitor the same system parameters for one week.	
11	Grid Operations	Repeat steps 7 to 11 as necessary.	
12	Grid Operations	Test complete	

Table 9-4 Test 3 Steps - Charge during High Line Load/Discharge during Low Line Load

9.1.4   Test 4 Charge During Off-Peak Periods And Discharge During On-Peak Periods Under SCE System Operator Control

Overview:

The output of wind resources is variable and dependent on wind availability. Output is generally higher during off-peak periods than when load is at its peak. Storing off-peak energy for use

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[17] ABB, "Tehachapi Wind Energy Storage Project Control and Interface Concept" indicates that Line 1 is Lancaster 1B and Line 2 is Cal Cement 1B. It is believed to be the pre-EKWRA configuration. The document doesn't specify the new Line1 and new Line 2.

during on-peak periods will increase the amount of available wind energy used and reduce the use of energy produced by other generating sources. This test will also demonstrate the ability of the BESS to firm and shape wind output to better follow its generation schedule. Benefit will be determined by estimating the difference in energy prices between off-peak charge and on-peak discharge. There might be additional value in reduced transmission losses and reduced emissions.

Primary Method of Performing Test:

The historical load data analysis, as presented in Appendix B, shows that the average load at Monolith is typically within the 8 MW capability of the BESS. A larger load difference between on-peak period and off-peak load can fully utilize the BESS and potentially show more of its impact. The average load is the highest from July to September and the load difference between on-peak period and off-peak period is the largest in July and August. In addition, the average wind generation, as presented in Appendix A, peaks in May and June while April, July and August have relatively large wind generation. The best time to conduct this test is from July to August when the load variation between on-peak and off-peak periods are the largest while the wind generation is also relatively large. September is also a good time since the load variation is relatively large. Even though the typical average wind generation in September can be significantly smaller than July and August, the wind output is still sufficient to supply the battery charging need during the off-peak period.

The BESS is set Test 4 mode and then Advanced Energy Storage personnel configures the BESS parameters and dispatch schedule as described in Table 9-5 on alternative days. The purpose of conducting tests on alternative days is to maximize the possibility of pairing similar scenarios with or without BESS in service, given that EKWRA project changes system configuration and historically collected data are of limited usage for the M&V purpose. The test will last a few weeks to ensure a sufficient amount of data to be collected for both weekdays and weekends.

As shown in the four-hour segment based load data analysis (Appendix B), the off-peak period is between 0:00 and 4:00, while the load between 4:00 and 8:00 is also light; the on-peak period is between 12:00 and 16:00, while the load between 16:00 and 20:00 is also heavy. On the scheduled days when the BESS is dispatched, the BESS is charged at its maximum rate starting from 0:00 until fully charged (a six-hour period is designated as off-peak period in the test to allow for certain variation in charging) and is discharged at its maximum rate from 12:00 until fully discharged (a six-hour period is designated as on-peak period in the test to allow for certain variation in discharging).

Data to be collected:

- Transmission loads on the following lines.
  - Monolith – Breeze lines 1 & 2
  - Monolith – Cummings line
  - Monolith – Loraine line
  - Monolith – Cal Cement line
  - Monolith – MidWind line

- o Monolith – ArbWind line
- Monolith transformer 1 and 2 load
- Tehachapi wind generation profile for each wind plant (MW/MVAr)
- Storage dispatch event with its timing
- BESS parameters
  - o Status
  - o State of Charge (%)
  - o Energy Available
  - o Charge/discharge rate (MW/MVAr)
- CAISO price data

Step #	Who Does It?	Action	Additional Notes
	Which participant, either primary or secondary is responsible for the activity in this step?	Describe the actions that take place in this step in active, present tense.	Additional description of statement about the step to help support description. Comments about data collection requirements, special equipment features, unusual challenges, etc.
1	SCE EMS	Place BESS in EMS Test 4 mode.	
2	Advanced Energy Storage	In BESS HMI setting: • Set the "Maintain SOC Allowed for T1&T4" as ON. • Set the "Fully Charge BESS" and "Fully Discharge BESS" as ON.	The parameters such as "SOC Max (%)", "SOC Min (%)", "P Charge [kW]", and "P Discharge [kW]" remain at default values to enable fully charge/discharge BESS at the maximum rate.
3	Advanced Energy Storage	Set the BESS Off-Peak Period Schedule as 	Day of Week		Time	
Start	Stop	Start	Stop
Monday	Monday	0000	0600
Wednesday	Wednesday	0000	0600
Friday	Friday	0000	0600
Saturday	Saturday	0000	0600 | Set the BESS On-Peak Period Schedule as | Day of Week		Time			BESS will be fully charged/discharged in four hours under the maximum rate. The on/off peak duration in this test is set as six hours to ensure the battery to be fully charged/discharged in case wind generation fluctuates significantly or other variations occur.

		Start	Stop	Start	Stop	
		Monday	Monday	1200	1800	
		Wednesday	Wednesday	1200	1800	
		Friday	Friday	1200	1800	
		Saturday	Saturday	1200	1800	
4	Grid Operations	Operate BESS in the configured mode for 4 weeks.				The test period can start on any Monday, Wednesday, or Friday, but will last for a period that contains at least 4 weekends (both Saturday and Sunday).
5	Grid Operations	Test complete				

Table 9-5 Test 4 Steps – Charge Off-Peak/Discharge On-Peak

9.1.5 Test 5 Charge And Discharge Seconds-To-Minutes As Needed To Firm And Shape Intermittent Generation In Response To A Real-Time Signal

Overview:

Intermittent resources are by their nature variable, and with their substantial growth, managing the fluctuation will become more costly to the system. The test will demonstrate the BESS' ability to firm and shape the power output, respond to system signals and reduce the system requirements to integrate variable energy resources into the grid. This can reduce required reserves and may reduce the GHG footprint to serve load. This will also improve the utilization of available and planned transmission and may support the deferral of transmission investment. Benefit will be determined as the reduction in required reserves, reduction in output fluctuation, improved transmission utilization, reduced transmission losses and possibly reduced transmission congestion.

Primary Method of Performing Test:

EMS monitors aggregated output of wind farms and compares to a pre-set target, then dispatches BESS (charge/discharge) proportionate real power ramps in the opposite direction of wind power change to minimize the difference and to smooth the wind generators' output.

The wind-park generation information is captured in SCADA and mapped back as an input to the SEC. As this test can be applied at any season, it is recommended to use the average wind speed

during previous days as the parameter P_WT_Act_Coef[18] for the test periods. Depending on the test period, this value may vary.

Once the scaling factor is determined, the BESS is set in Test 5 mode and then Advanced Energy Storage personnel configures the BESS parameters as described in Table 9-6. The test with BESS enabled/disabled will be conducted on alternative weeks to increase the possibility of pairing similar scenarios with or without BESS in service.

Data to be collected for all tests:

- Total wind generation profile in Tehachapi (MW/MVAr)
  - P_WT_Act
- Storage dispatch event with its timing
- BESS parameters
  - Status
  - State of Charge (%)
  - Energy Available
  - Charge/discharge rate (MW/MVAr)
- Transmission loads on the following 66 kV lines
  - Monolith – Breeze lines 1 & 2
  - Monolith – Cummings line
  - Monolith – Loraine line
  - Monolith – Cal Cement line
  - Monolith – MidWind line
  - Monolith – ArbWind line

Step #	Who Does It?	Action	Additional Notes
	Which participant, either primary or secondary is responsible for the activity in this step?	Describe the actions that take place in this step in active, present tense.	Additional description of statement about the step to help support description. Comments about data collection requirements, special equipment features, unusual challenges, etc.
1	SCE EMS	Place BESS in EMS Test 5 mode	
2	Advanced Energy Storage	In BESS HMI setting: • Set the "P Ramp + [kW/sec]" and "P Ramp – [kW/sec]" to enable dispatch BESS at the maximum rate.	The BESS will begin the test at approximately 50% SOC.

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[18] ABB, "Tehachapi Wind Energy Storage Project Control and Interface Concept" indicates that P_WT_Act_Coef is one set point for test.

3	Quanta Technology	Calculate "P_WT_Act_Coef" for the chosen test period.	P_WT_Act_Coef is a parameter to be configured in the system.
4	Grid Operations	Operate BESS in the configured mode for one week.	
5	Grid Operations	Idle BESS.	Ensure a moderate SOC (e.g., 30%) of the BESS before being idled
6	Grid Operations	Monitor the same system parameters for one week.	
7	Quanta Technology	Evaluate the data collected to determine if longer test period is needed or test parameters will be changed.	
8	Grid Operations	Repeat step 2 – 6 as needed.	
9	Grid Operations	Test complete	

Table 9-6 Test 5 Steps – Charge and discharge seconds-to-minutes as needed to firm and shape intermittent generation in response to a real-time signal

9.1.6   Test 6 Respond to CAISO Control Signals to Provide Frequency Response

Overview:

This test will demonstrate the BESS' ability to follow CAISO's control signal for Area Control Error (ACE) via the RIG (Remote Intelligent Gateway) module to maintain system frequency and improve resource adequacy.

Primary Method of Performing Test:

In this test, the BESS will be placed in Grid Function mode and its control will be transferred to CAISO EMS.

The SCE scheduling coordinator first bids the BESS into Energy and Ancillary Services market to provide frequency regulation. CAISO market system selects bids in bid stack based on market optimization calculations and sends instructions to the CAISO EMS. After CAISO EMS determines the ACE, which represents the difference between Net Scheduled Interchange and Net Actual Interchange within a control area on the power grid taking frequency bias into account, the AGC MW signal is sent to the BESS. The BESS then follows the MW signal and operates within the regulation band to automatically respond to the AGC signal to absorb or inject real power.

At the start of the test, the BESS's state of charge will be approximately 50%. During the test, the remaining BESS power level and duration will be monitored for necessary intervention.

This test can be conducted at any time. However, there are some prerequisites for the test:

- BESS has the connection to CAISO via RIG module;
- BESS has been certified to provide Ancillary Services to CAISO;
- BESS has been bid and awarded frequency regulation;
- BESS is capable of receiving a MW dispatch notification.

Depending on CAISO's regulation requirements, the test can be conducted (i.e., the BESS is placed in the frequency regulation market) throughout the entire or partial award period. The test will be conducted 2 to 3 times.

Data to be collected:

- CAISO AGC MW signal with its timing
- Storage dispatch event with its timing
- BESS parameters
  - Status
  - State of Charge (%)
  - Energy Available
  - Charge/discharge rate (MW/MVAr)
- Frequency at Monolith substation (PMU data)

Step #	Who Does It?	Action	Additional Notes
	Which participant, either primary or secondary is responsible for the activity in this step?	Describe the actions that take place in this step in active, present tense.	Additional description of statement about the step to help support description. Comments about data collection requirements, special equipment features, unusual challenges, etc.
1	Grid Operations	In EMS Test Screen, turn off test modes and turn on Grid Functions.	
2	SCE GMS	Place BESS in appropriate mode allowing CAISO control.	Transfer control to CAISO EMS.
3	SCE Scheduling Coordinator	Bid into Energy and Ancillary Services market to provide frequency regulation services.	
4	CAISO EMS	Send AGC MW signal to the BESS.	
5	BESS	Automatically respond to AGC signal and absorb or inject real power.	Approximately 50% State of Charge at start of test
6	SCE GMS	Monitor dispatch instructions and BESS power level and duration remained.	Intervene as necessary, e.g., toggle BESS from AGC/Dispatch mode
7	SCE GMS	Reassume control when award period ends	
8	Grid Operations	Turn off Grid Functions and return BESS to prior mode. Test complete	

Table 9-7 Test 6 Steps – Respond to CAISO control signals to provide frequency response

9.1.7 Test 7 Respond to CAISO market awards to provide Energy and spin/non-spin reserves

Overview:

This test will demonstrate the BESS' ability to respond to CAISO's market awards to provide energy and spinning (5 minute response) or non-spinning (10 minute response) reserves. This will provide further support of improved dependability of wind resources for resource adequacy considerations.

Primary Method of Performing Test:

The SCE scheduling coordinator will first bid the BESS into Energy and Ancillary Services market to provide spinning and non-spinning reserves. CAISO market system will select bids in bid stack based on market optimization calculations and award the spinning or non-spinning reserve service through CAISO Automated Dispatch System (ADS). SCE Grid Operations first places the BESS in Grid Function mode, and then GMS monitors the market dispatch signals and controls BESS to inject real power.

When the test starts, the BESS will be fully charged. During the test, the remaining BESS power level and duration will be monitored by SCE GMS for necessary intervention.

This test can be conducted at any time. However, there are some prerequisites for the test:

- BESS has the connection to CAISO via RIG module
- BESS has been certified to provide Ancillary Services to CAISO
- BESS has been bid and awarded regulation
- BESS is capable of receiving energy dispatch "Go To" signals
- BESS is capable of receiving a MW set point signal.

Depending on CAISO's regulation requirements, the test can be conducted (i.e., the BESS is placed in the spinning/non-spinning market) for a certain period of time until the BESS is selected to provide resources as spinning or non-spinning reserves. However, the award may not always happen during a test period. The alternative method for the test is described below.

Alternative method of performing test:

As the spinning/non-spinning reserves may not be requested frequently, in order to demonstrate the BESS's ability to respond to the CAISO market awards, a simulation approach can be deployed as an alternative testing method.

In this simulation approach, historical CAISO dispatch signal is first examined to extract one or several dispatch events. SCE GMS then apply the extracted dispatch signals as if it occurred in real time. The BESS parameters will be monitored to demonstrate its ability to respond to CAISO market signals.

With the simulation approach, the test prerequisites listed above are not required. Instead, the BESS is toggled in GMS manual mode in order to receive the simulated CAISO dispatch signal.

Data to be collected:

- CAISO ADS dispatch events with timing
- Storage dispatch events with timing
- BESS parameters
  - Status
  - State of Charge (%)
  - Energy Available
  - Charge/discharge rate (MW/MVAr)

Step #	Who Does It?	Action	Additional Notes
	Which participant, either primary or secondary is responsible for the activity in this step?	Describe the actions that take place in this step in active, present tense.	Additional description of statement about the step to help support description. Comments about data collection requirements, special equipment features, unusual challenges, etc.
1	Grid Operations	In EMS Test Screen, turn off test modes and turn on Grid Functions.	
2	SCE GMS	Place BESS in appropriate mode allowing CAISO control.	
3	SCE Scheduling Coordinator	Bid into Energy and Ancillary Services market to provide spinning/non-spinning reserves.	
4	SCE GMS	Monitor CAISO ADS's dispatch signal or follow extracted CAISO ADS dispatch signal and dispatch BESS accordingly.	
5	BESS	Follow dispatch signal to inject real power.	Fully charged at start of test
6	SCE GMS	Monitor dispatch instructions and BESS power level and duration remained.	Intervene as necessary, e.g., toggle BESS from AGC/Dispatch mode
7	SCE GMS	Reassume control when award period ends.	
8	Grid Operations	Turn off Grid Functions and return BESS to prior mode. Test complete.	

Table 9-8 Test 7 Steps – Respond to CAISO market awards to provide Energy and spin/non-spin reserves

9.1.8   Test 8 Follow A CAISO Market Signal For Energy Price

Overview:

This test will demonstrate the BESS' ability to respond to CAISO energy price signals to charge during periods of low price and discharge during periods of high price. This test is generally a demonstration of the BESS' ability to perform Test 4 (i.e., charge off-peak and discharge on-peak) automatically in response to a signal instead of under system operator control.

Primary Method of Performing Tests:

The BESS will be registered and certified to provide energy in the CAISO market and have the connection to CAISO via RIG module. This test will utilize operators' ability to monitor market as a whole and dispatch the BESS operation according to the energy price. Therefore, the BESS is placed in Grid Function mode.

CAISO market system publishes Real-Time Dispatch (RTD) Locational Marginal Pricing (LMP) information. Generation operations center operators monitor LMP prices and dispatch signals, and generates base points, following market prices, in SCE GMS to issue the dispatch instructions to the BESS. The BESS then follows the generated MW signals to absorb or inject real power.

At the start of the test, the BESS's state of charge will be approximately 50%. During the test, the remaining BESS power level and duration will be monitored by SCE GMS for necessary intervention.

This test can be conducted at any time, and will be conducted 2 to 3 times for data analysis purpose.

Data to be collected:

- CAISO price data
- CAISO energy market dispatches
- SCE GMS MW signals
- Storage dispatch events with timing
- BESS parameters
    - Status
    - State of Charge (%)
    - Energy Available
    - Charge/discharge rate (MW/MVAr)

Step #	Who Does It?	Action	Additional Notes
	Which participant, either primary or secondary is	Describe the actions that take place in this step in active, present tense.	Additional description of statement about the step to help support description.

	responsible for the activity in this step?		Comments about data collection requirements, special equipment features, unusual challenges, etc.
1	Grid Operations	In EMS Test Screen, turn off test mode and turn on Grid Functions.	
2	SCE GMS	Place BESS in appropriate mode allowing CAISO control.	
3	Generation operations center operators	Monitor RTD-LMP prices and dispatch signals; generate base points in SCE GMS.	
4	SCE GMS	Issue the dispatch instructions.	
5	BESS	Absorb or inject real power in response to operator action.	Approximately 50% State of Charge at start of test
6	SCE GMS	Monitor dispatch instructions and BESS power level and duration remained.	Intervene as necessary, e.g., toggle BESS from AGC/Dispatch mode
7	Grid Operations	Turn off Grid Functions and return BESS to prior mode. Test complete.	

Table 9-9 Test 8 Steps – Follow a CAISO market signal for energy price

9.2   Appendix B: Analysis of Wind Generation Data

Aggregate generation data for 12 Tehachapi area wind farms has been recorded by the eDNA system for the period from 2010 to 2011.

- Arbwind *
- Canwind *
- Dutchwind *
- Flowind1
- Flowind2
- Midwind *
- Morwind (Gust)
- Morwind (Pinwheel)
- Northwind *
- Oakwind
- Southwind
- Zondwind *

The data for the six wind farms indicated with an asterisk above is essentially complete, and is used as a proxy for the total wind generation. A practical level of granularity is obtained by dividing the aggregate generation observations by calendar month and by six four-hour periods, which are designated by the beginning hour in military time, beginning at midnight, as shown in the Table 9-10.

Month	# Days	Period 1 0000 - 0400	Period 2 0400 - 0800	Period 3 0800 - 1200	Period 4 1200 - 1600	Period 5 1600 - 2000	Period 6 2000 - 2400
2010							
January	31	108	108	124	111	108	100
February	28	196	182	136	148	197	199
March	31	325	274	284	327	342	354
April	30	369	312	261	325	424	431
May	31	508	427	376	448	551	575
June	30	577	497	389	431	582	595
July	31	447	349	189	225	390	466
August	31	379	269	146	206	366	408
September	30	252	189	137	167	266	290
October	31	202	187	150	206	247	224
November	30	153	182	207	223	196	172
December	31	250	255	216	225	247	235
2011							
January	31	150	145	131	153	184	170
February	28	209	198	160	188	195	187
March	31	399	363	344	360	388	411
April	30	498	481	430	469	532	541
May	31	462	418	392	464	506	486
June	30	524	463	325	374	522	555
July	31	371	253	131	157	321	391
August	31	387	301	159	198	398	454
September	30	182	129	67	93	188	208
October	31	180	148	153	188	223	214
November	30	244	242	238	271	266	242
December	31	121	130	100	134	163	127

Table 9-10 Wind Farm Aggregate Generation in GWH by Calendar Month and Period

For each period in a given month, a capacity factor is obtained by dividing the total generation in MWh by the sum of individual peak generations of wind farms during the entire study period, then dividing by the number of hours in the calendar month. Generally, a capacity factor is the ratio of its actual output over a period of time, to its potential output if it were possible for it to operate at full nameplate capacity indefinitely[19]. The presented calculation uses peak generation instead of nameplate capacity. It is felt that the peak observed generation for each wind farm is a more credible measure of its capacity than its CAISO listed capacity, because wear and tear

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[19] http://en.wikipedia.org/wiki/Capacity_factor

during their service lives has left some wind turbines in a degraded state and they are unlikely to attain their original MW outputs. No adjustment is made for individual turbine outages due to mechanical causes.

Table 9-11 to Table 9-14 show the capacity factors calculated by the above methodology, as well as the capacity factors for the entire month (disregarding diurnal variations) and for the daily period (disregarding monthly variations) for different periods.

Month	Period 1 0000 - 0400	Period 2 0400 - 0800	Period 3 0800 - 1200	Period 4 1200 - 1600	Period 5 1600 - 2000	Period 6 2000 - 2400	*All Hours*
January	0.117	0.117	0.134	0.120	0.116	0.108	*0.119*
February	0.235	0.217	0.163	0.177	0.235	0.238	*0.211*
March	0.354	0.296	0.307	0.353	0.369	0.383	*0.344*
April	0.412	0.349	0.292	0.363	0.473	0.481	*0.395*
May	0.549	0.461	0.406	0.485	0.595	0.622	*0.520*
June	0.644	0.554	0.435	0.481	0.649	0.664	*0.571*
July	0.483	0.378	0.204	0.243	0.422	0.504	*0.372*
August	0.409	0.291	0.158	0.222	0.395	0.440	*0.319*
September	0.282	0.211	0.153	0.187	0.297	0.324	*0.242*
October	0.218	0.202	0.162	0.222	0.267	0.242	*0.219*
November	0.170	0.203	0.231	0.249	0.219	0.192	*0.211*
December	0.270	0.276	0.234	0.243	0.267	0.254	*0.257*
All Months	*0.345*	*0.296*	*0.240*	*0.279*	*0.359*	*0.371*	*0.315*

Table 9-11 Wind Farm Capacity Factors - 2010

Month	Period 1 0000 - 0400	Period 2 0400 - 0800	Period 3 0800 - 1200	Period 4 1200 - 1600	Period 5 1600 - 2000	Period 6 2000 - 2400	*All Hours*
January	0.157	0.151	0.136	0.160	0.192	0.177	*0.162*
February	0.242	0.229	0.185	0.217	0.226	0.217	*0.219*
March	0.420	0.379	0.359	0.375	0.405	0.429	*0.395*
April	0.538	0.519	0.464	0.506	0.574	0.584	*0.531*
May	0.482	0.437	0.409	0.484	0.528	0.507	*0.475*
June	0.565	0.499	0.351	0.403	0.563	0.598	*0.497*
July	0.387	0.265	0.137	0.164	0.335	0.408	*0.283*
August	0.404	0.314	0.166	0.206	0.416	0.474	*0.330*
September	0.197	0.139	0.073	0.100	0.203	0.224	*0.156*
October	0.188	0.155	0.160	0.196	0.233	0.223	*0.193*
November	0.261	0.261	0.257	0.292	0.288	0.261	*0.270*
December	0.127	0.136	0.105	0.140	0.171	0.133	*0.135*
All Months	*0.331*	*0.290*	*0.234*	*0.270*	*0.344*	*0.353*	*0.304*

Table 9-12 Wind Farm Capacity Factors - 2011

Month	Period 1 0000 - 0400	Period 2 0400 - 0800	Period 3 0800 - 1200	Period 4 1200 - 1600	Period 5 1600 - 2000	Period 6 2000 - 2400	*All Hours*
January	0.137	0.134	0.135	0.140	0.154	0.143	*0.141*
February	0.238	0.223	0.174	0.197	0.230	0.228	*0.215*
March	0.387	0.338	0.333	0.364	0.387	0.406	*0.369*
April	0.475	0.434	0.378	0.434	0.523	0.533	*0.463*
May	0.516	0.449	0.408	0.484	0.562	0.565	*0.497*
June	0.604	0.527	0.393	0.442	0.606	0.631	*0.534*
July	0.435	0.321	0.170	0.203	0.378	0.456	*0.327*
August	0.407	0.303	0.162	0.214	0.406	0.457	*0.325*
September	0.239	0.175	0.113	0.143	0.250	0.274	*0.199*
October	0.203	0.178	0.161	0.209	0.250	0.233	*0.206*
November	0.216	0.232	0.244	0.271	0.253	0.227	*0.240*
December	0.198	0.206	0.169	0.191	0.219	0.193	*0.196*
All Months	*0.338*	*0.293*	*0.237*	*0.275*	*0.352*	*0.362*	*0.309*

Table 9-13 Wind Farm Capacity Factors – 2010 and 2011

Values are shown graphically in Figure 9-1.
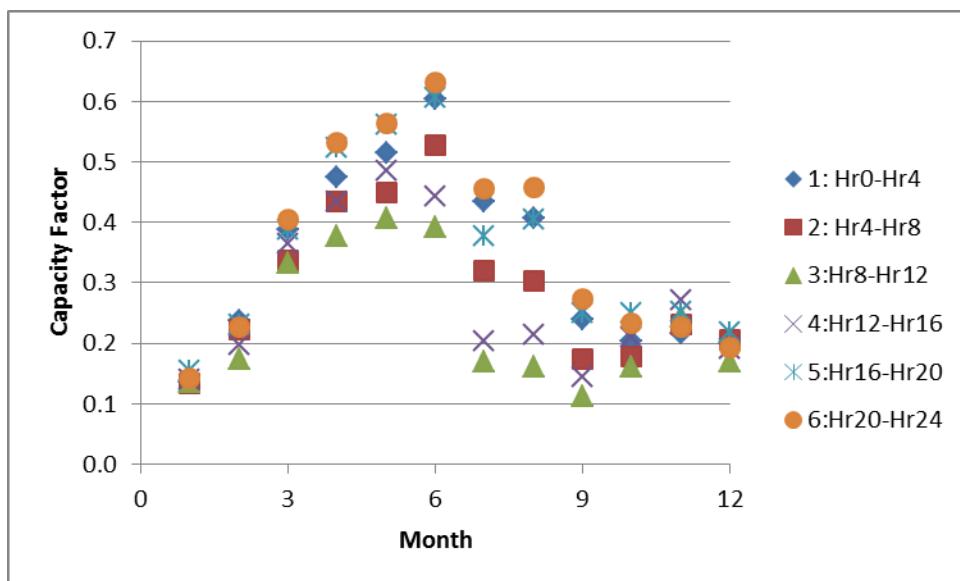
Figure 9-1 Wind Farm Capacity Factors – 2010 and 2011

Considerable variation in wind generation is observed within a given calendar month. Some corresponds to different periods within the day, while some is due to random factors. The average capacity factors and the standard deviations are shown in Table 9-14.

Month	2010		2011	
	Average	Standard Deviation	Average	Standard Deviation
January	0.119	0.199	0.162	0.205
February	0.211	0.257	0.219	0.244
March	0.344	0.310	0.395	0.304
April	0.395	0.313	0.531	0.276
May	0.520	0.312	0.475	0.283
June	0.571	0.269	0.497	0.275
July	0.372	0.261	0.283	0.225
August	0.319	0.254	0.330	0.237
September	0.242	0.277	0.156	0.188
October	0.219	0.278	0.193	0.262
November	0.211	0.232	0.270	0.279
December	0.257	0.284	0.135	0.191

Table 9-14 Wind Farm Capacity Factor -- Monthly Summary Statistics

As can be seen, the standard deviation is relatively constant from month to month but the average peaks in May and June and is lowest from September thru February for 2010. In 2011, the standard deviation is relatively constant from month to month but the average peaks in April, May and June and is lowest from September thru February.

9.3 Appendix C: Tehachapi Area Load Analysis

Test 4 will charge the BESS during periods of light load and discharge it during periods of high load. The following analysis identified the seasons and times of day when peak and light load occurred. Considering data availability, load on Monolith transformers 1 and 2 is used as a proxy for total load.

A few instances are noted where the total Monolith transformer power flow is negative, i.e., power flows from the 12 kV bus to the 66 kV bus. These generally occur in nighttime hours when wind generation (as analyzed in Appendix B) is high. It is plausible to assume that small wind farms and/or "distributed" wind generators, at the premises of residential or commercial customers, more than offset local load on these occasions.

Month	# Days	Period 1 0000 - 0400	Period 2 0400 - 0800	Period 3 0800 - 1200	Period 4 1200 - 1600	Period 5 1600 - 2000	Period 6 2000 - 2400
January	31	41.5	50.3	57.3	55.5	67.1	58.2
February	28	31.7	41.5	49.3	46.2	55.4	45.5
March	31	28.4	40.8	46.3	40.4	47.2	43.7
April	30	24.9	36.5	45.1	39.0	35.5	36.8
May	31	18.3	28.9	39.9	34.4	28.3	31.5
June	30	14.7	22.4	37.6	41.5	35.1	31.5
July	31	31.7	39.0	62.4	76.7	72.7	55.8
August	31	33.5	41.6	61.4	73.0	67.9	53.9
September	30	32.0	39.8	54.3	61.8	59.6	49.9
October	31	34.4	43.3	54.5	52.0	54.6	49.9
November	30	35.5	42.0	47.9	45.6	58.0	50.1
December	31	34.3	42.2	51.8	49.3	63.8	53.6

Table 9-15 Total 2010 GWh by Month and Period

Month	# Days	Period 1 0000 - 0400	Period 2 0400 - 0800	Period 3 0800 - 1200	Period 4 1200 - 1600	Period 5 1600 - 2000	Period 6 2000 - 2400
January	31	40.6	48.7	54.5	50.6	62.6	54.7
February	28	34.2	42.8	49.1	46.0	54.6	48.3
March	31	27.8	40.0	47.7	43.7	47.2	42.6
April	30	20.2	27.6	36.8	32.2	32.0	33.1
May	31	21.8	31.3	40.5	36.6	33.1	36.1
June	30	20.4	27.5	44.5	47.5	42.2	37.0
July	31	34.6	41.8	64.3	76.9	72.2	58.0
August	31	34.3	41.9	65.5	79.1	74.0	57.6
September	30	40.5	49.0	63.6	73.7	72.8	61.5
October	31	38.4	48.5	56.2	55.7	59.0	54.2
November	30	34.1	43.4	49.5	45.0	60.2	51.0
December	31	49.5	57.8	63.0	58.8	74.6	67.0

Table 9-16 Total 2011 GWh by Month and Period

The average load during each period as a fraction of the above peak value is as shown in Table 9-17.

Month	Period 1 0000 - 0400	Period 2 0400 - 0800	Period 3 0800 - 1200	Period 4 1200 - 1600	Period 5 1600 - 2000	Period 6 2000 - 2400
January	0.326	0.394	0.445	0.422	0.516	0.449
February	0.290	0.371	0.434	0.406	0.485	0.413
March	0.225	0.321	0.374	0.335	0.376	0.343
April	0.185	0.264	0.337	0.293	0.278	0.287
May	0.160	0.239	0.320	0.283	0.244	0.269
June	0.144	0.205	0.338	0.366	0.318	0.281
July	0.264	0.322	0.504	0.611	0.577	0.453
August	0.270	0.332	0.505	0.605	0.565	0.444
September	0.298	0.365	0.485	0.557	0.544	0.458
October	0.290	0.365	0.440	0.429	0.452	0.414
November	0.284	0.351	0.400	0.373	0.486	0.416
December	0.333	0.398	0.457	0.430	0.551	0.480

Table 9-17 Average Tehachapi Load as a Fraction of 2010-2011 Peak

The average monthly loads during the 2010-2011 monitoring period are shown in Figure 9-2.
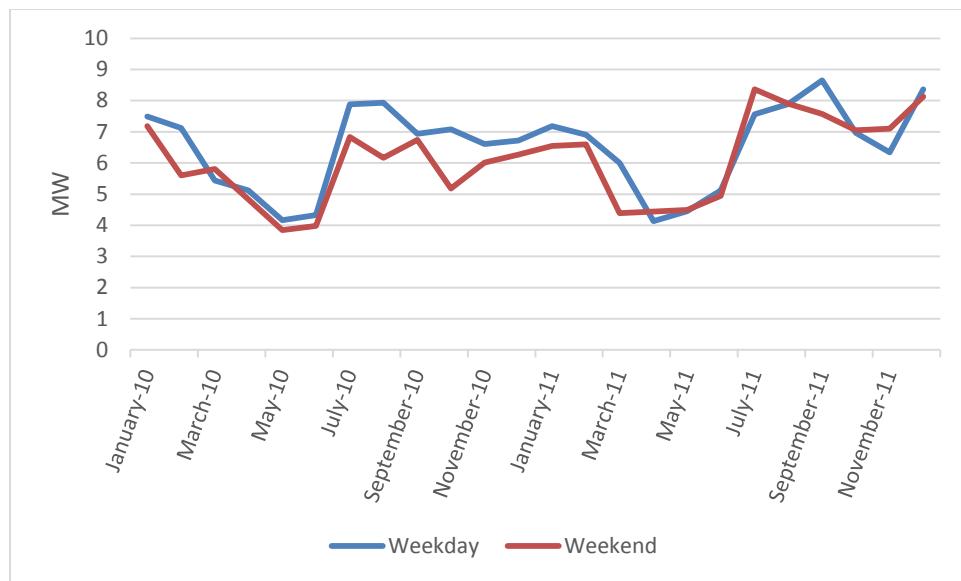
Figure 9-2 Monthly Average Loads at Monolith Substation

As was done in analyzing wind generation in Appendix B, average load is computed for six four-hour periods, beginning at midnight, as shown in Figure 9-3.
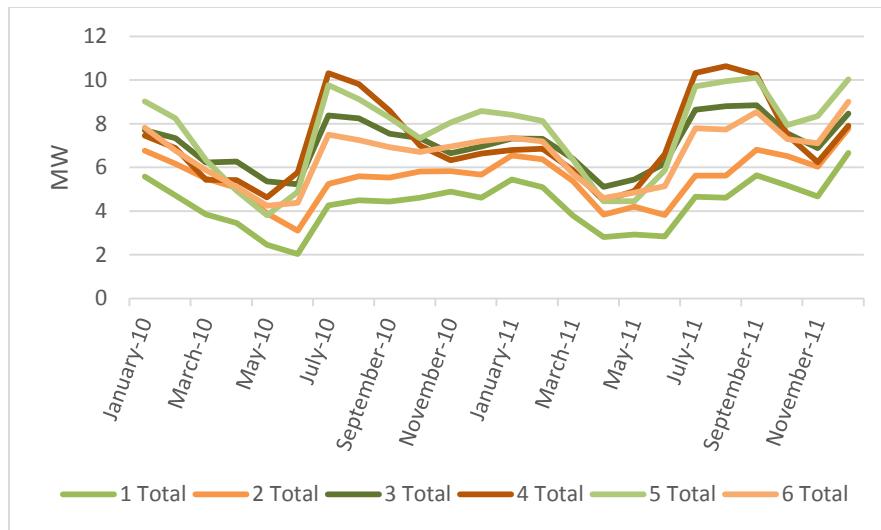

Figure 9-3 Monolith Average Load by Period

The principal observations about load variation are as follows:

- Load is the highest from July to September, with a secondary peak in December and January, and lower from February to June.
- Period 1 loads are the lowest, periods 4 and 5 loads are the highest.
- The load difference between peak period and light period is the largest for July and August and the lowest in March and April.
- The high load periods show more seasonal variation than do the low load periods.
- There is a variation of 3 ½ to 4 MW between the highest and lowest periods at any season of the year.
- Most of the year, the average load at Monolith is within the 8 MW capability of the BESS.

9.4 Appendix D: Line Loading Analysis

Test 3 will charge/discharge the BESS based on line loading. The following analysis examines the 2013 loading of seven sub-transmission lines that are connected with Monolith substation and studies their distributions in order to determine the parameters needed for the test.

The seven sub-transmission lines are listed below. The line names are from the eDNA system. In some cases, the names used in this plan differ, and the names used in this plan are listed as well, for cross reference.[20]

- Monolith – Sub Tran Lines BO-HA-LO-WB (Monolith – Loraine line)
- Monolith – Sub Tran Lines BREEZE1
- Monolith – Sub Tran Lines BREEZE2
- Monolith – Sub Tran Lines CAL-GOL-WIN (Monolith – MidWind line)
- Monolith – Sub Tran Lines CAL-ROS-WIN (Monolith – ArbWind line)
- Monolith – Sub Tran Lines CAL-WINDP (Monolith – Cal Cement line)
- Monolith – Sub Tran Lines CUMMINGS

Figure 9-4 to Figure 9-10 present the histogram of loading of seven sub transmission lines connected with Monolith substation.
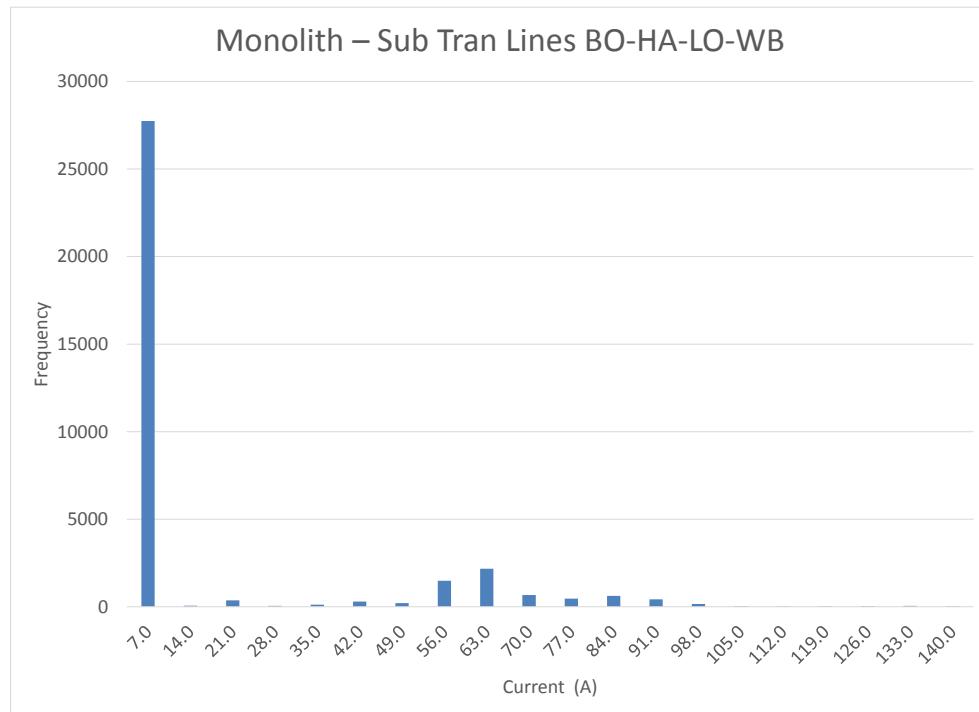
Figure 9-4 Distribution of Monolith – Sub Tran Lines BO-HA-LO-WB 2013 Loading

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[20] This matching is based on current information available to Quanta Technology, some information are uncertain, the final matching needs confirmation from SCE
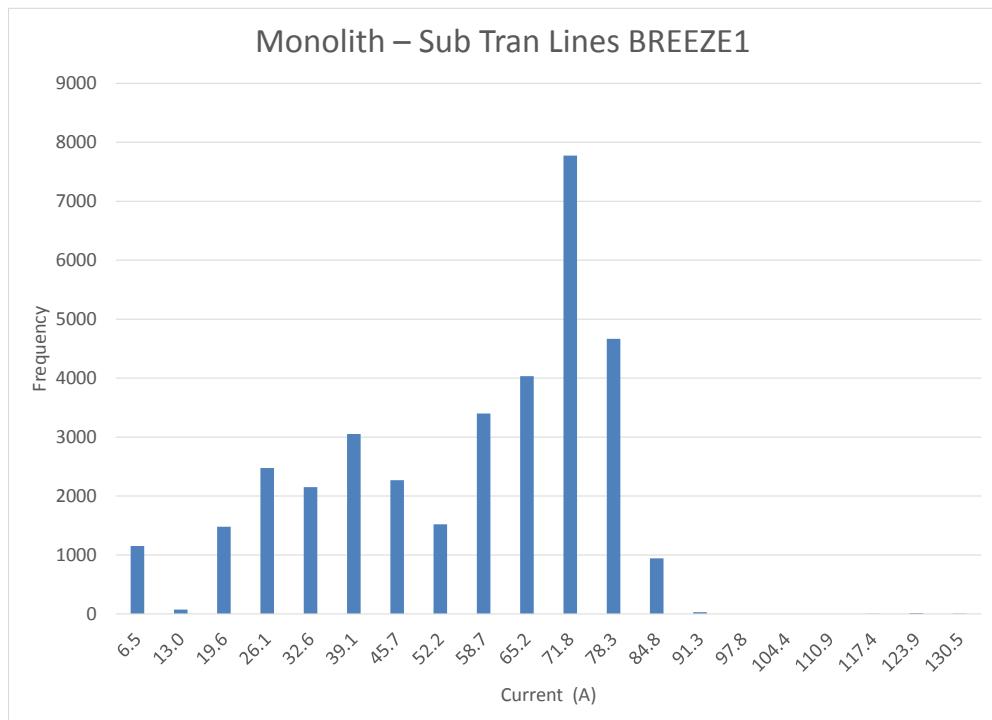
Figure 9-5 Distribution of Monolith – Sub Tran Lines BREEZE1 2013 Loading
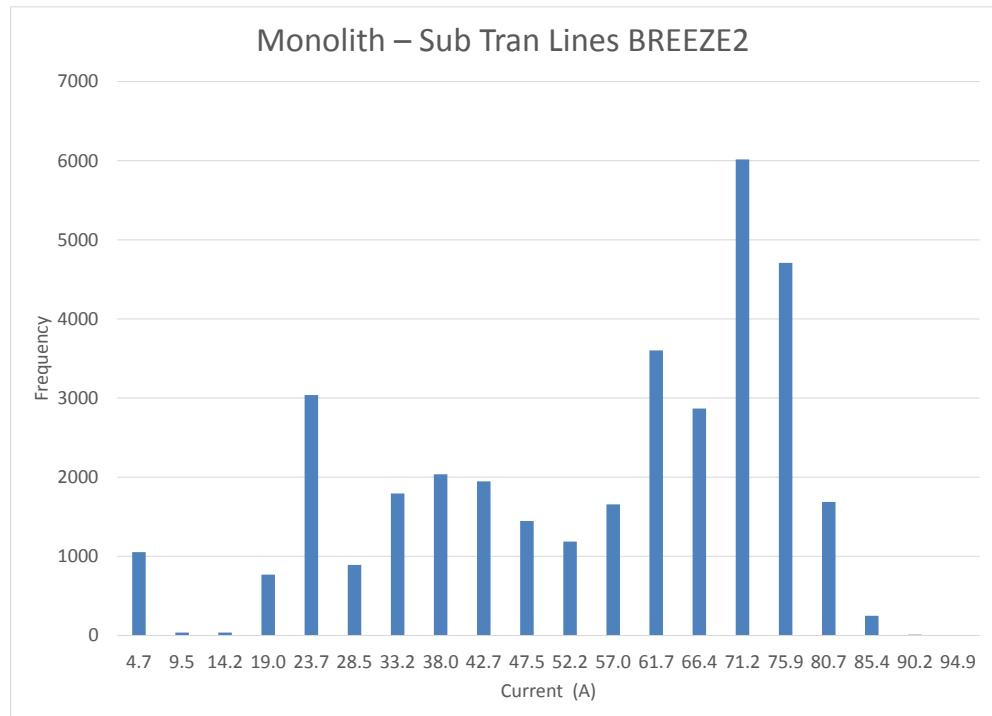
Figure 9-6 Distribution of Monolith – Sub Tran Lines BREEZE2 2013 Loading
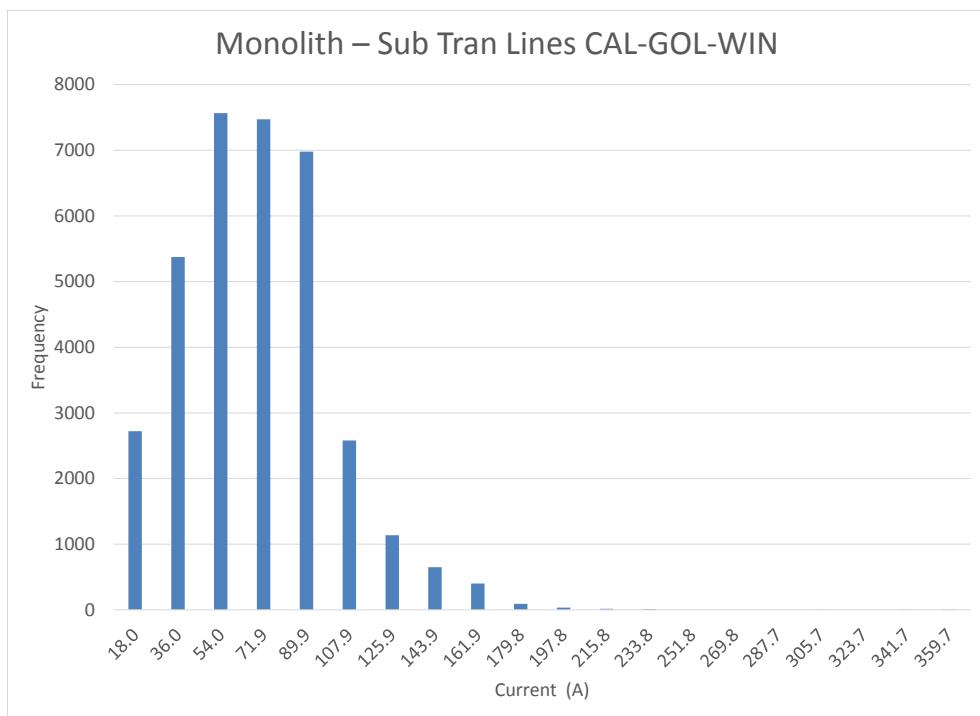
Figure 9-7 Distribution of Monolith – Sub Tran Lines CAL-GOL-WIN 2013 Loading
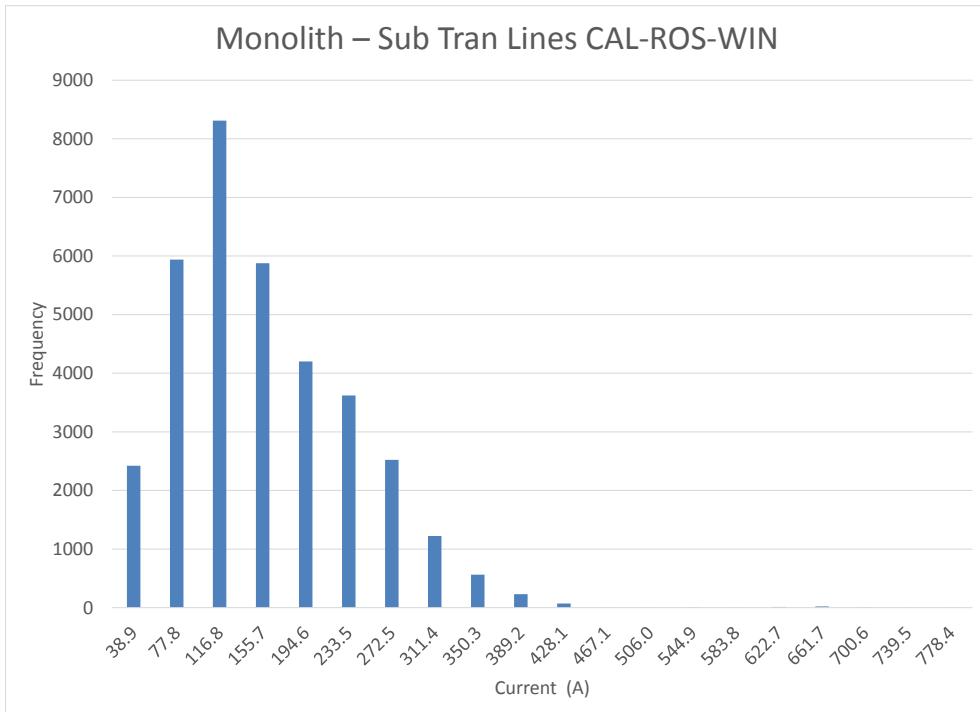
Figure 9-8 Distribution of Monolith – Sub Tran Lines CAL-ROS-WIN 2013 Loading
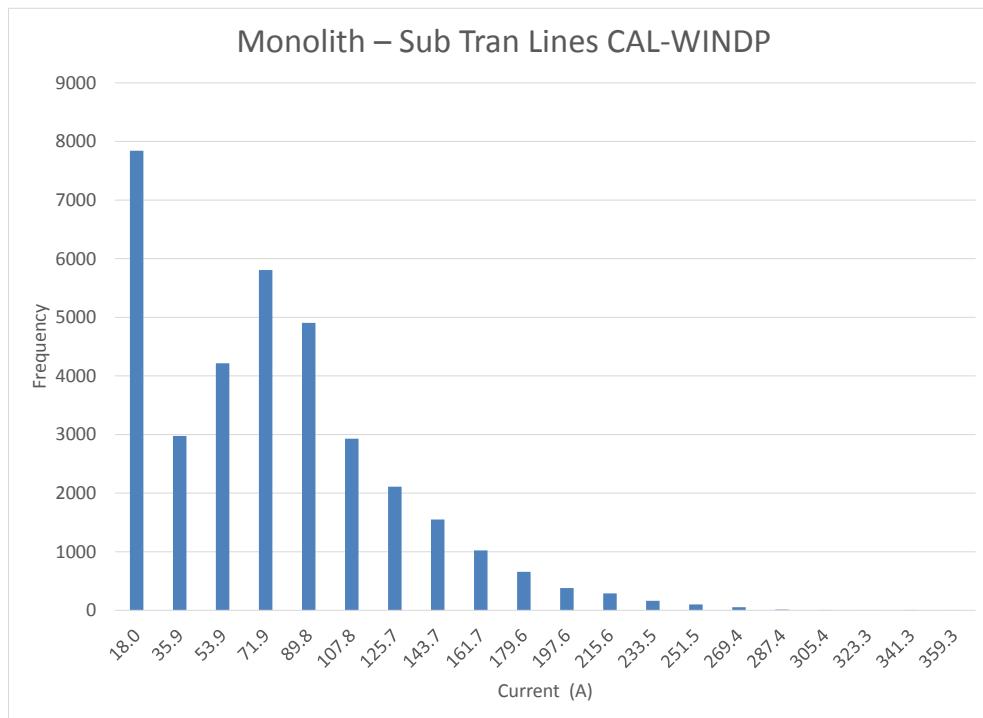
Figure 9-9 Distribution of Monolith – Sub Tran Lines CAL-WINDP 2013 Loading
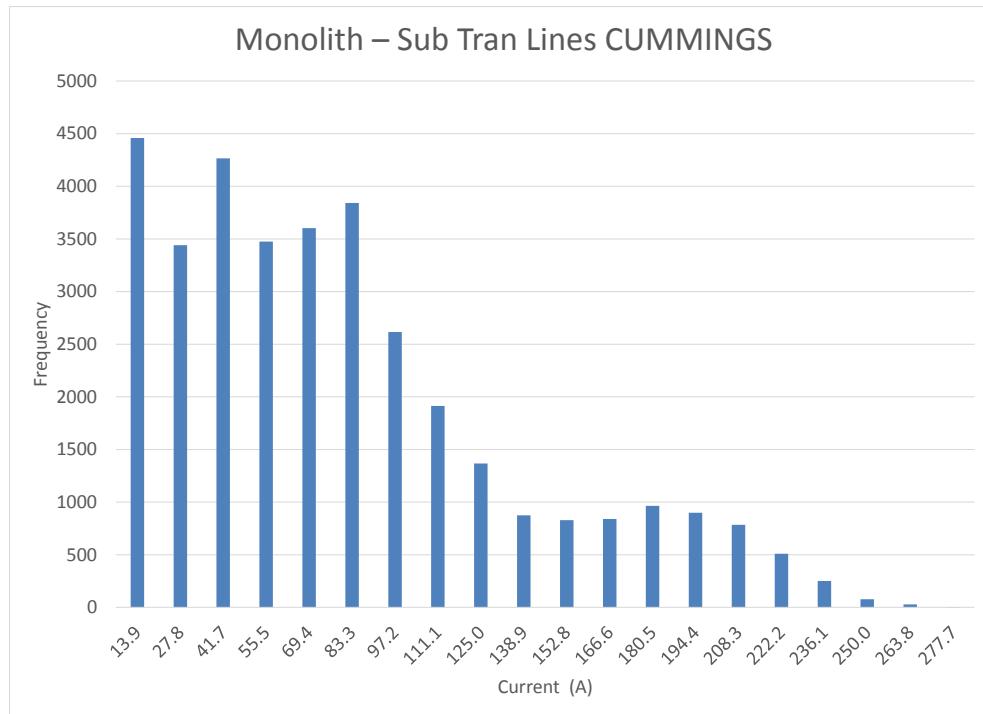
Figure 9-10 Distribution of Monolith – Sub Tran Lines CUMMINGS 2013 Loading

Among these seven lines, Monolith – Sub Tran Lines BO-HA-LO-WB has the smallest load, Monolith – Sub Tran Lines CAL-ROS-WIN has the largest load.

Electric system loads often vary by season, with some loads higher during one season and lower in others. Figure 9-11 to Figure 9-17 represent the 2013 load of the seven sub transmission lines. These plots show the temporal information as well as the variation of the loading over time. As exhibited in figure 9-17, the loading on Monolith – Sub Tran Lines CUMMINGS shows a clear seasonality – peaking in the spring and fall with lower loading during the winter and summer months. Other loads are relatively consistent over time as seen in figure 9-12 and 9-13 representing the loadings on Monolith – Sub Tran Lines BREEZE 1 and Monolith – Sub Tran Lines BREEZE 2. On these feeders the load is consistent all year except for the first quarter of the year. On the other hand, loading on Monolith – Sub Tran Lines BO-HA-LO-WB, Figure 9-11, presents large variation that are more of random nature with no relationship to seasonal fluctuation.
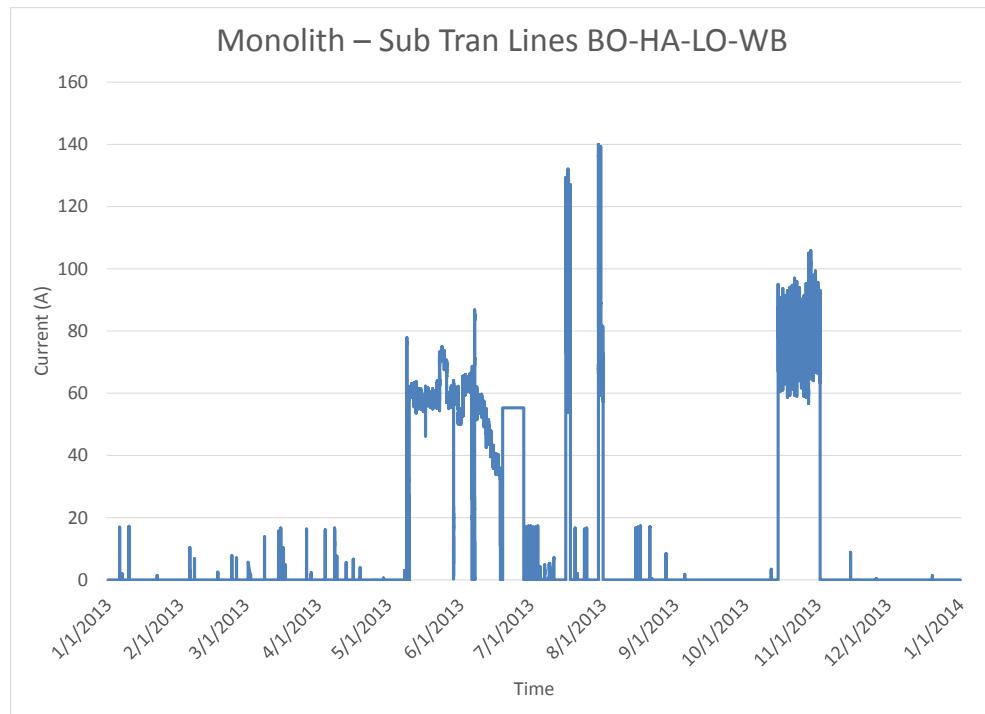
Figure 9-11 Monolith – Sub Tran Lines BO-HA-LO-WB 2013 Loading
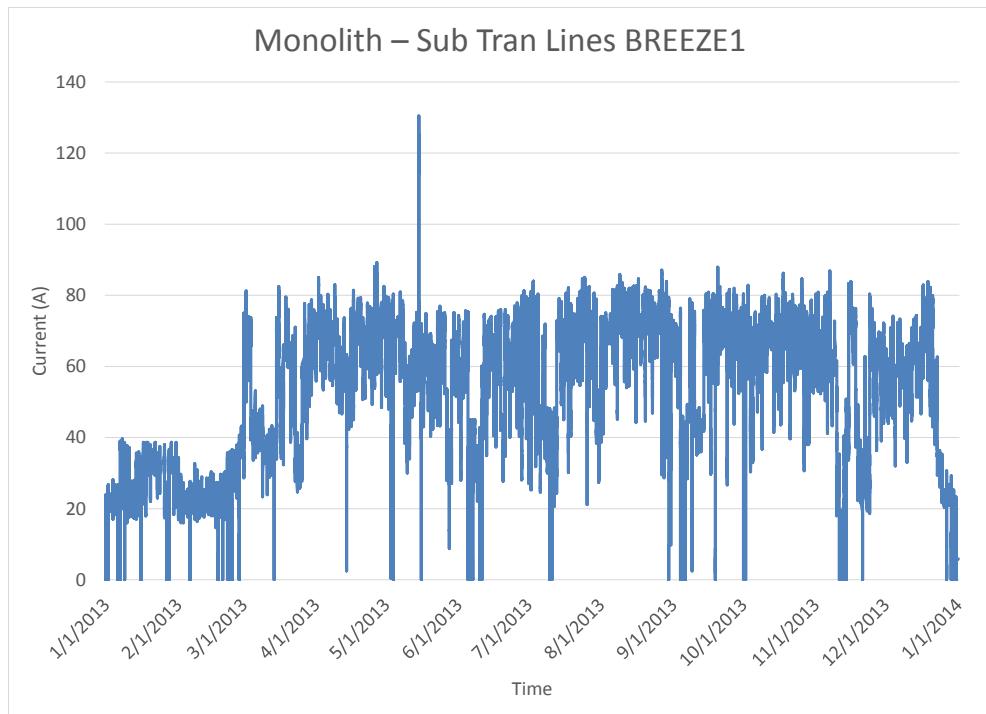
**Figure 9-12** Monolith – Sub Tran Lines BREEZE1 2013 Loading
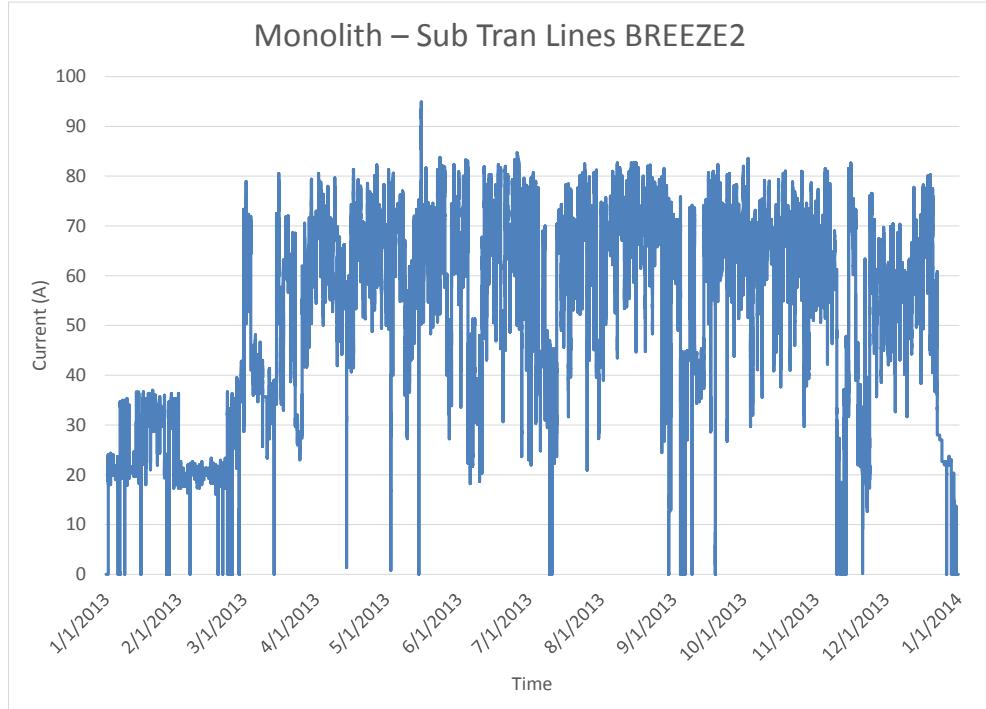
Figure 9-13 Monolith – Sub Tran Lines BREEZE2 2013 Loading
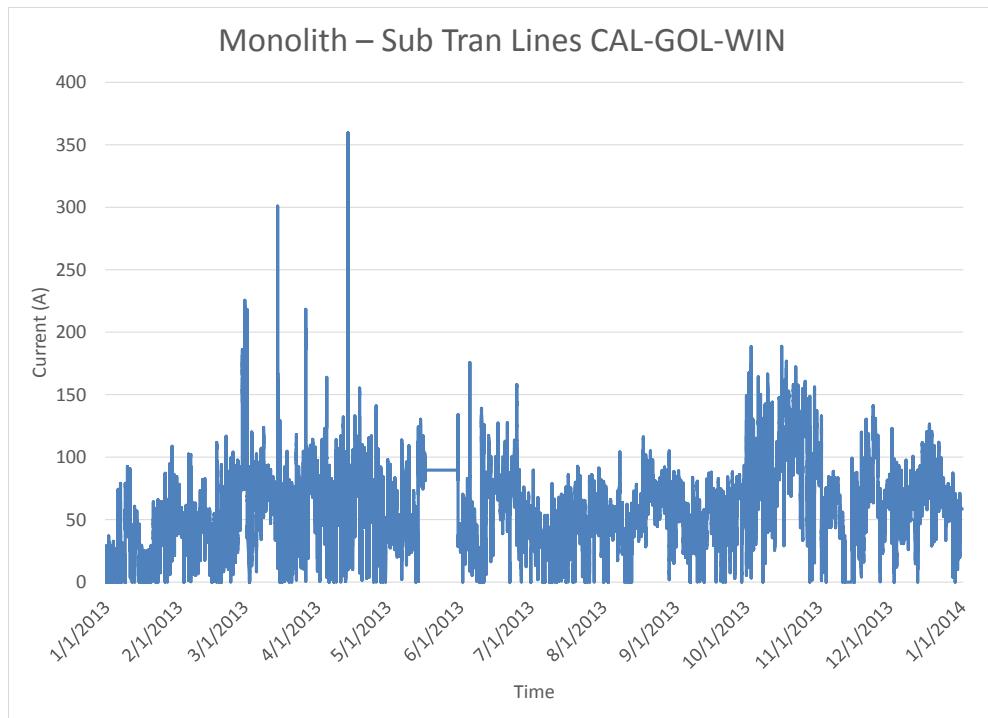
Figure 9-14 Monolith – Sub Tran Lines CAL-GOL-WIN 2013 Loading
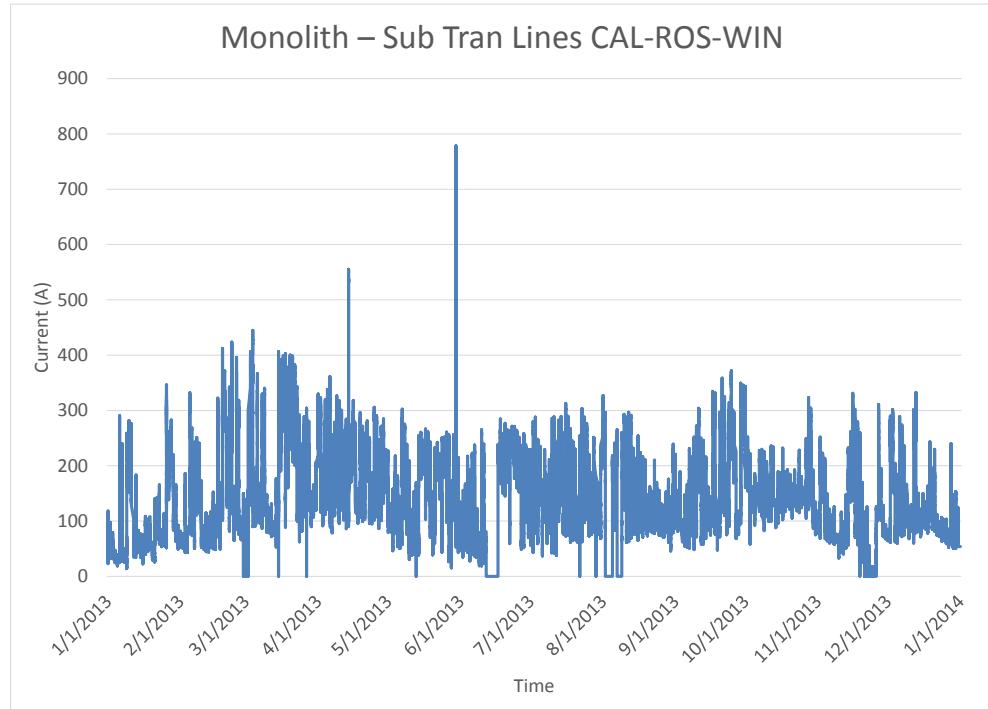
Figure 9-15 Monolith – Sub Tran Lines CAL-ROS-WIN 2013 Loading
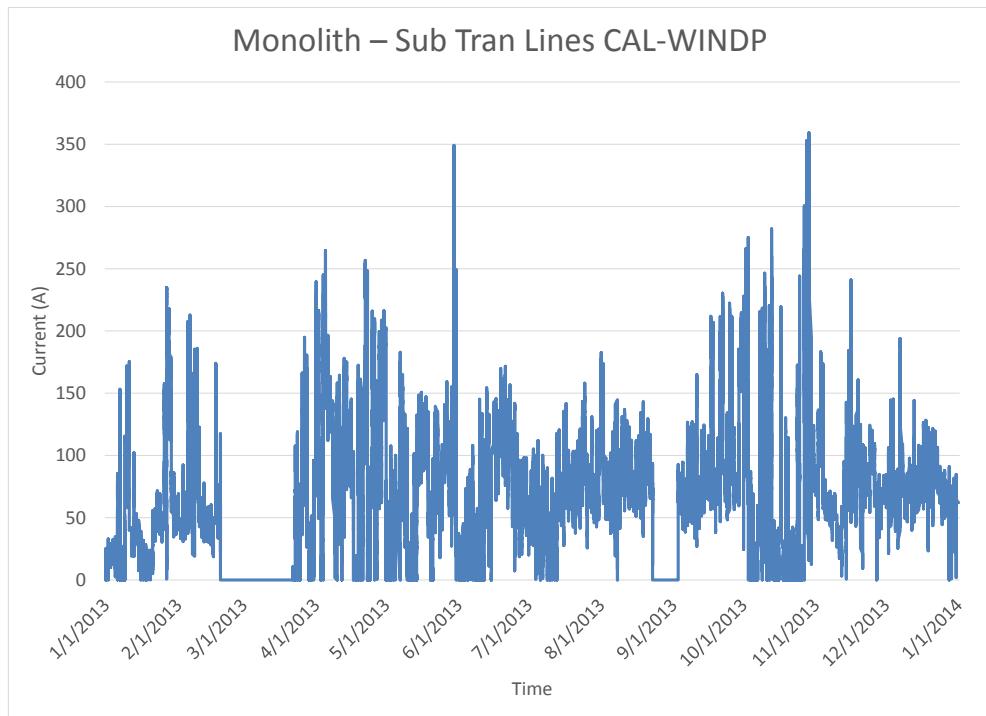
**Figure 9-16** Monolith – Sub Tran Lines CAL-WINDP 2013 Loading
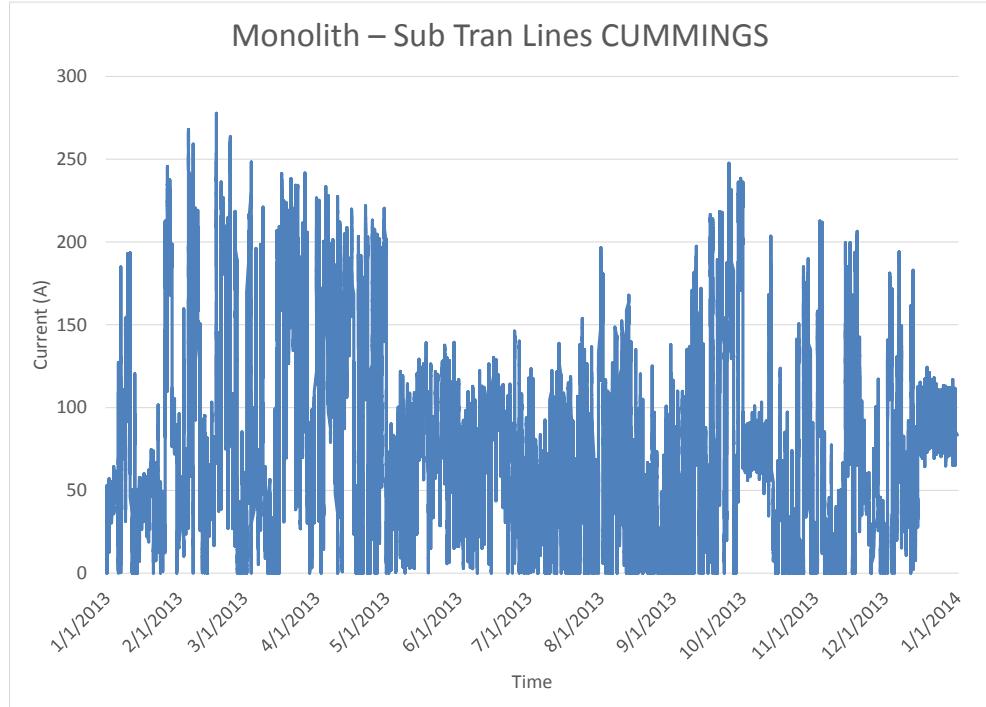
Figure 9-17 Monolith – Sub Tran Lines CUMMINGS 2013 Loading

9.5 Appendix E: Schedule of TPR/Impact Metrics Reporting

Report	Due Date
TPR/Impact Metrics #1	12/31/14
TPR/Impact Metrics #2	12/31/15
Final Technical Report/Impact Metrics #3	03/31/17

9.6 Appendix F: Static and Dynamic Analysis for TSP Project Using GE-PSLF Software

Sizing and Location Selection of the Battery Storage

The studies performed in Tehachapi area are based on two software tools: General Electric - Positive Sequence Load Flow (PSLF) and Power System Computer-Aided Design (PSCAD). The PSLF model is a WECC system wide network database used for bulk power system analysis. The 2009 High summer WECC base case was used for the steady-state contingency analysis and dynamic simulations to size the battery and select its location in the Antelope-Bailey system.

The area wind generation static and dynamic characteristics were added to the base case based on data collected from SCE EMS system. Wind generation was modeled as Type 1 wind farms, i.e., using shunt capacitors to support the wind farm. Different power cases with different dispatch for the wind generation were created to assess the system operating condition with and without the battery.

Static contingency analysis using load flow was then performed for the Tehachapi area on the cases prepared for the study (i.e. different area load/wind generation mix). Two critical contingencies were identified during the analysis. One of the identified contingencies was a major concern for SCE, SCE already had a RAS system for this contingency by area wind energy generation curtailment.

A dynamic analysis was then conducted using PSLF dynamic module to assess the critical contingencies and size the battery to mitigate this contingencies without wind generation curtailment. A three phase fault is simulated at time equal to 1 second and cleared after 4 cycles by disconnecting one of the critical lines. Figure 18a and b show the output power and the terminal voltage behavior of different wind farms in the system before and after the critical contingency without the energy storage. It's clear that the system is unstable and within an un-damped oscillatory state.

The size and location of the storage are selected based on the solution to contingency problems mentioned above. The BESS size was selected to be 8 MW up to 4 hours and the STATCOM should be capable of providing 20 MVAr up to 4 seconds in order to mitigate the aforementioned problems. Figure 19 shows the system frequency before and after the critical contingency without the energy storage. The abnormal frequency excursions are the result of system instability. Figure 20 shows the system frequency with the energy storage installed in the system. The figure shows that the system is stable after the contingency and the oscillations are damped. Figure 21 shows the voltage profile and the power output of a number of wind farms before and after the critical contingency with energy storage and reactive power support. As can be seen in the figure, the wind farms maintain their pre contingency power output without any oscillatory behavior.

The PSLF analysis showed that the installation of the energy storage with a STATCOM function will provide the best support at the Cal-Cement 66 kV station; however, due to the physical space available, the Cal-Cement Substation was ruled out and Monolith Substation was identified by the PSLF steady state and dynamic analysis.
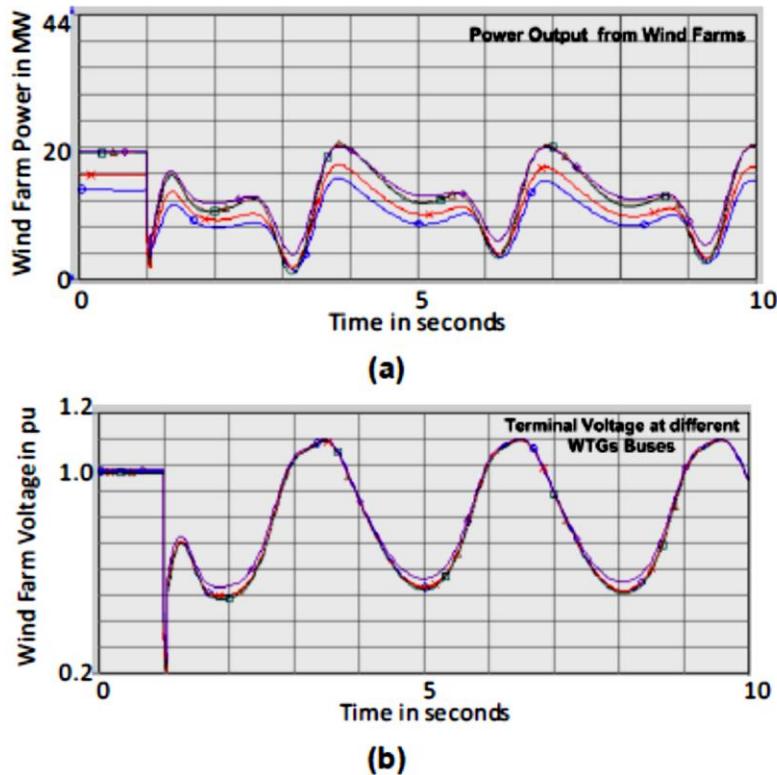
Figure 9-18 Power output (a) and voltage profile (b) at different wind generation buses before and after the contingency without the energy storage (the contingency is initiated at 1 sec).
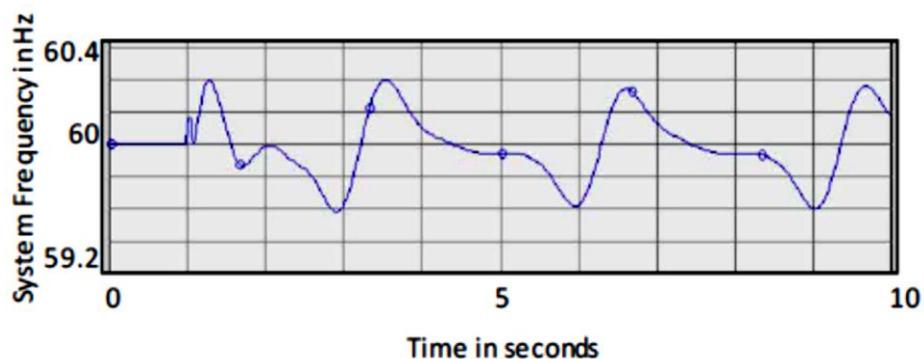
Figure 9-19 System frequency without the energy storage before and after the contingency
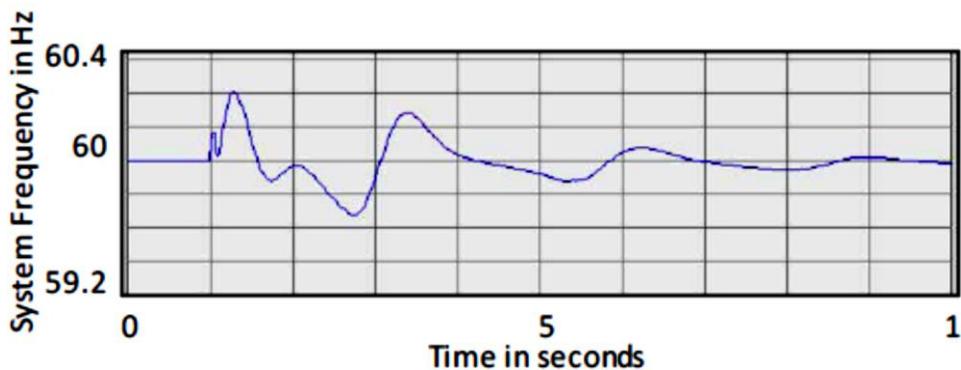
Figure 9-20 System frequency with the energy storage during the contingency
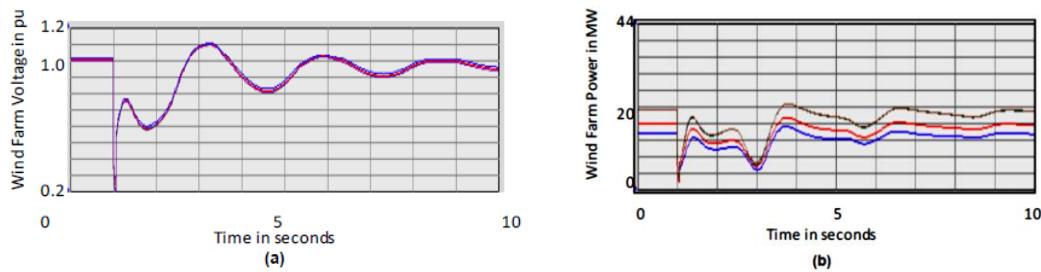
Figure 9-21 Voltage profile (a) and the wind farms output power (b) before and after the Contingency with energy storage (the contingency is initiated at 1 sec)

Use of PSLF in Measurement and Verification

Dynamic and static simulations will be conducted using PSLF to validate some system responses. The following are some beneficial capabilities of the BESS – STATCOM that may be evaluated with PSLF modeling:

- Provides system voltage support by injecting or absorbing real and reactive power after a disturbance or system contingency.
- Provides voltage support and improves the voltage recovery after a transient by 10-15%. (The percentage value depends on the fault type and location.)
- Provides wind generators terminal voltage (Type1-induction generators) support by providing VAR support to ride through low voltage excursions during remote faults.
- Provides regulation ancillary services.
- Provides black-start functionality.
- Provides additional spinning reserves.
- Can be used for energy price arbitrage.
- Reduces the need for curtailments of wind farms.
- Enhances system frequency regulation.

9.7 Appendix G: Analysis for TSP Project Using RTDS

Dynamic Voltage Support Testing

A real time digital simulator (RTDS) was used to test the dynamic voltage support function (also described as 'voltage clamp' in ABB nomenclature) of the PCS. The voltage support function was requested to test the ability of the TSP system to autonomously stop following a P & Q setpoint, and begin injecting reactive power to boost system voltage when the 66 kV bus voltage at Monolith Substation drops below a defined setpoint. When the voltage recovers, the PCS curtails the reactive power and resumes following the P and Q setpoint.

What is RTDS and how is it being used to test dynamic voltage support

A RTDS system is a hardware platform for running an electro-magnetic transients program (EMTP) in real time. One of the differences between EMTP and other power system simulation tools, is that EMTP calculates the instantaneous voltages at all of the nodes (or busses) and the currents between all of the nodes (or busses) at every simulation time step. Typical real time EMTP simulations build the waveform by calculating all of the instantaneous voltage and currents every 50 microseconds, which is about one degree on a single 60 hertz cycle.

In order to test external equipment, the RTDS has several different types of input/output cards that can be used to bring signals into or send out of the EMTP simulation. In this application, the simulated voltage and currents in the PCS and at Monolith substation are scaled down to a low voltage (+/-10V) analog signal and connected directly to the PCS 100's analog to digital converter via several D-subminiature connections in the front of the device. Similarly, the firing pulses that the PCS would send to the insulated-gate bipolar transistors (IGBT) are sampled by the RTDS via a low voltage digital input card.

For many applications, such as testing microprocessor based protective relays, a time step of 50 microseconds is sufficient, however converter systems such as the PCS 100 send out firing pulses that are only a few microseconds in duration. Additionally, converter controller systems typically have very fast control loops that may become unstable if the delay between time steps is too long.

To solve this problem, the RTDS has the capability to run part of a model with a much smaller time step (about 2.5 microseconds) and interface the small time step model with the large time step model. The interface between the small and large time step models is done with a special interface transformer model that decouples the two solutions. The decoupling does introduce some error (added series inductance and shunt reactance) but still captures overall system behavior. However, the interface transformer has a feature to scale up the output of a single PSC 100 unit to represent the power injected by both PCS container units (8 MVA).

The ABB PCS 100 lab unit was first run in an open loop mode for initial input signal calibration, verifying the polarity of current transformers and voltage transformers in the model match what the controller expects, and system phase rotation.

Next, the ABB PSC 100 lab unit was placed in a closed loop mode with an ideal voltage source. In this mode SCE verified the PSC 100 lab unit could run in all four quadrants (inject and absorb real and reactive power).

Lastly, the ABB PSC 100 was integrated into the Windhub 66 kV sub-transmission network model and subjected to system disturbances.
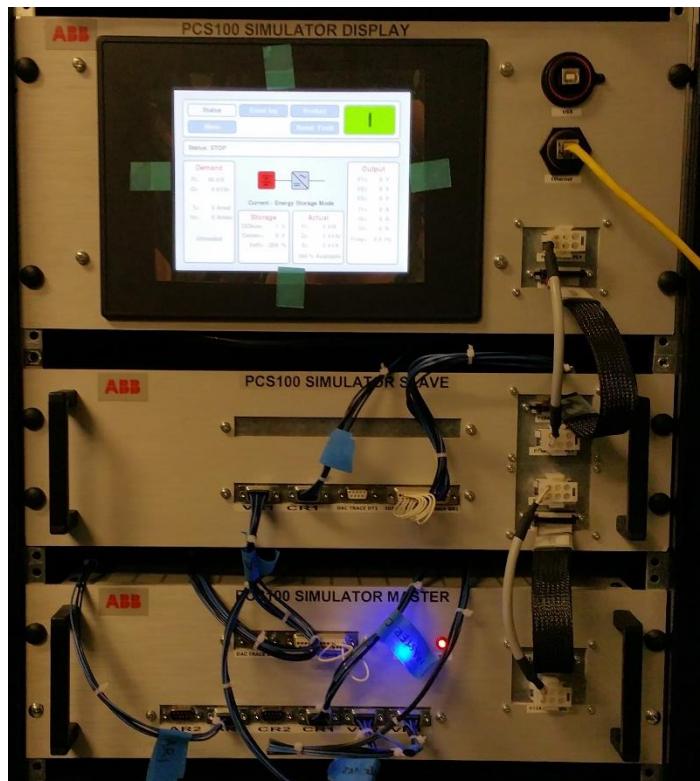
Figure 9-22 ABB PSC 100 Lab Controller

What Was Tested

The wind generation in Windhub system is made up of type 1 and type 2 wind generators, which draw a significant amount of reactive power during system events that depress the system voltage. SCE simulated faults and the resulting line clearing on several transmission lines in the

Windhub system and verified the response of the PCS 100 unit. This type of testing is important to verify correct operation of the system, but also there is no guarantee of a system event while the PCS is configured to operate in with the dynamic voltage support mode enabled.

Results for a Three Phase Fault on a Sub-Transmission Line near TSP
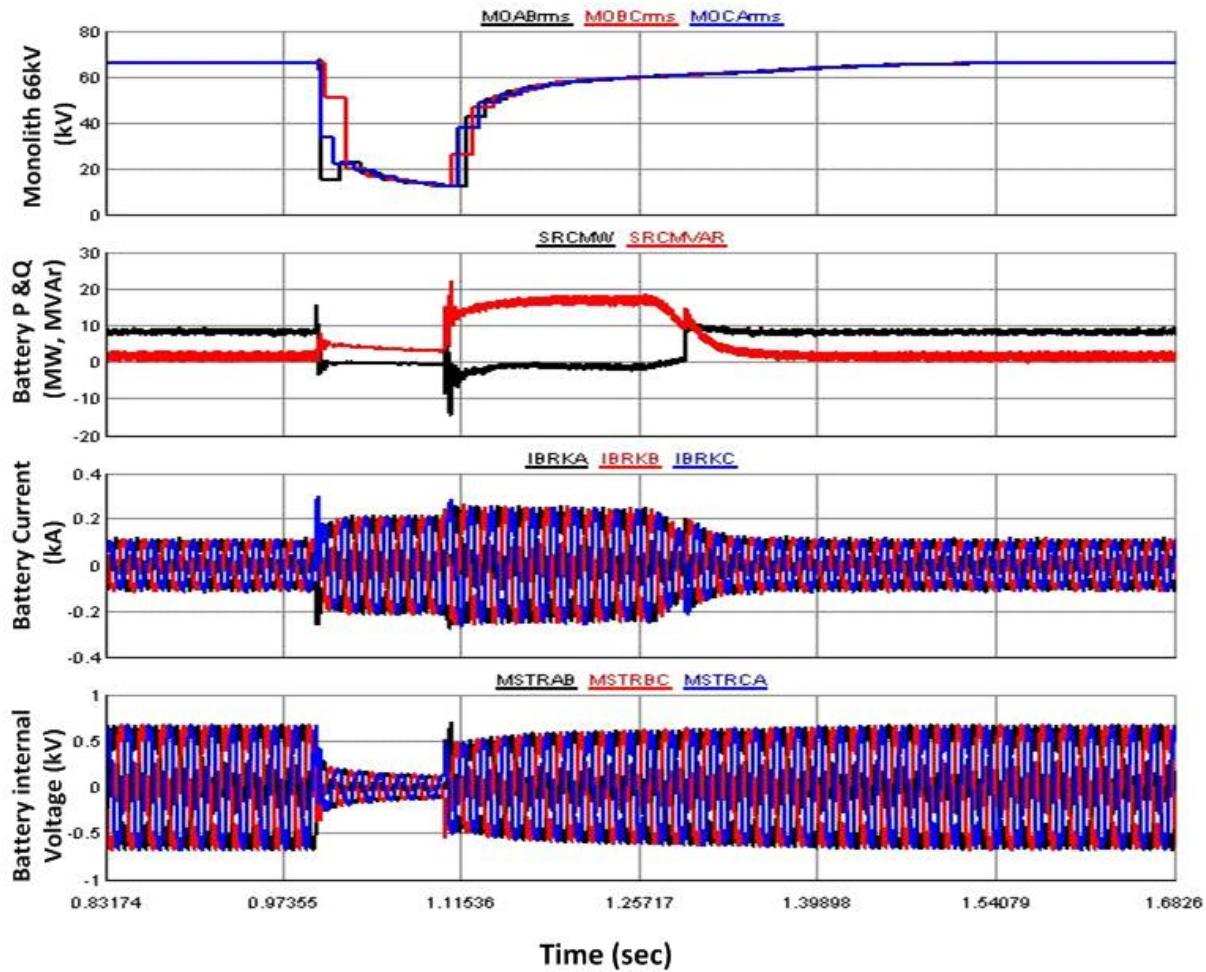
Figure 9-23 Bus Voltage, Power, and Interconnection Current and Voltage

The first graph shows the RMS voltage at the 66 kV bus the TSP is connected to, the second graph shows the real and reactive power output of the TSP, and the third and fourth graphs show the current and voltage at the TSP interconnection point.

It can be seen that during the period when the voltage is depressed due to a six cycle fault and the reactive power draw from the wind machines, the PCS switches into a reactive power injection mode to help the voltage recover. Once the voltage has returned to normal, the reactive power curtails and the PCS returns to the previous normal operation.

9.8   Appendix H: System Acceptance Test Results

Tehachapi Wind Energy Storage Project
System Acceptance Test Report
Project Report No. TC-13-269-TR01
Revision No. 00
Final Report, July 2014

Electric Vehicle Technical Center
An ISO 9001 Registered Facility
Prepared by:
Grant Davis, PE
Advanced Energy Storage
Southern California Edison

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Introduction

The Tehachapi Wind Energy Storage Project (TSP) is a 32 MWh, 9 MVA (8 MW, 4 MVAr) battery energy storage system (BESS) located at Monolith Substation in the Tehachapi Wind Resource Area, near Tehachapi, CA. The project is jointly funded by Southern California Edison (SCE) and the United States Department of Energy (DOE), and was awarded through the American Recovery and Reinvestment Act (ARRA).

SCE contracted with LG Chem to design, construct, and maintain the system for a two-year measurement and validation (M&V) period. During the M&V period, BESS and transmission system data will be collected to analyze the project's effect on the regional transmission network, as well as gain experience and knowledge about the operation of a large BESS.

The BESS is composed of a 6,300 square foot facility housing 604 lithium ion battery racks, which are divided into four separate 8 MWh battery sections. The battery sections are connected to two 4.5 MVA (4 MW, 2 MVAr) power conversion system (PCS) containers located adjacent to the battery facility. The PCS containers feed a 12.47/66 kV transformer, which is connected directly to the region's transmission network via the substation's 66 kV transfer bus. LG Chem was responsible for delivering the batteries and battery management system (BMS), while ABB was subcontracted by LG Chem to deliver the PCS containers and associated controls.

SCE, LG Chem, and ABB jointly developed "Contract Data Requirements List (CDRL) 19, System Acceptance Test Plan", which defined 12 separate tests to assess the system's operational readiness in meeting the project's contractual requirements for substantial acceptance. Once system commissioning was complete, CDRL 19 was used by LG Chem, ABB, and SCE to perform System Acceptance Testing (SAT). SAT occurred from July 7 through 11, 2014, and from July 14 through 18, 2014.

This document describes the results and analysis from SAT.

Procedure and Instrumentation

"CDRL 19, System Acceptance Test Plan (version AN)" describes the specific instrumentation, monitoring points, prerequisites, control settings, and procedures for all 12 tests. Reference CDRL 19 for details.

Depending on the test, electrical measurements were taken at the two 12.47 kV and/or one 66 kV monitoring points. The two 12.47 kV monitoring points (voltage and current) were each located in one of the PCS containers, on the high side of the 480/12.47 kV transformer. The one 66 kV monitoring point (voltage only) was located on the substation's 66 kV transfer bus. All three monitoring points reported measurements to the PCS control software via the BESS' communication network. For the purposes of SAT, an OPC data logger application was used to record data points available in the PCS control software, including measurements from the power meters, control points/statuses from the PCS, and data from the battery system. In addition, all normally available/recorded data points were captured in SCE's networked data historian. Table 9-18 shows the instruments and their corresponding accuracy, while Table 9-19 shows the cumulative accuracy (all accuracies are expressed as a percentage of the measured value).

Point	Description	Make	Model	Accuracy	Notes
66 kV	Power meter	Janitza	UMG604	Voltage: 0.2 % Current (L): 0.2 % Current (N): 0.6 % Power: 0.4 % Energy: 0.5 %	Does not include accuracy of external transducers
66 kV	PT	GE	JVT-350	0.3 % @ 69 kV	
12.47 kV	Power meter	Janitza	UMG604	Voltage: 0.2 % Current (L): 0.2 % Current (N): 0.6 % Power: 0.4 % Energy: 0.5 %	Does not include accuracy of external transducers
12.47 kV	CT	GE	120-401	0.3 % @ 400 A, 0.6 % @ 40 A	Assuming burden of 0.1 A or less
12.47 kV	PT	ABB	VIZ-11	0.3 % @ 690-- 13800 V	Assuming burden of 200 VA (Z burden) or less

Table 9-18 Instruments and Accuracies

Point	Description
66 kV	Voltage: 0.5 %
12.47 kV	Voltage: 0.5 % Current (L): 0.5 % Current (N): 0.9 % Power: 1.0 % Energy: 1.1 %

Table 9-19 Cumulative Accuracy

Results and Analysis

CDRL 19 Section 6, Test Plan for BESS Power Accuracy

The purpose of this test was to verify the output accuracy of the BESS at several real and reactive power set points.
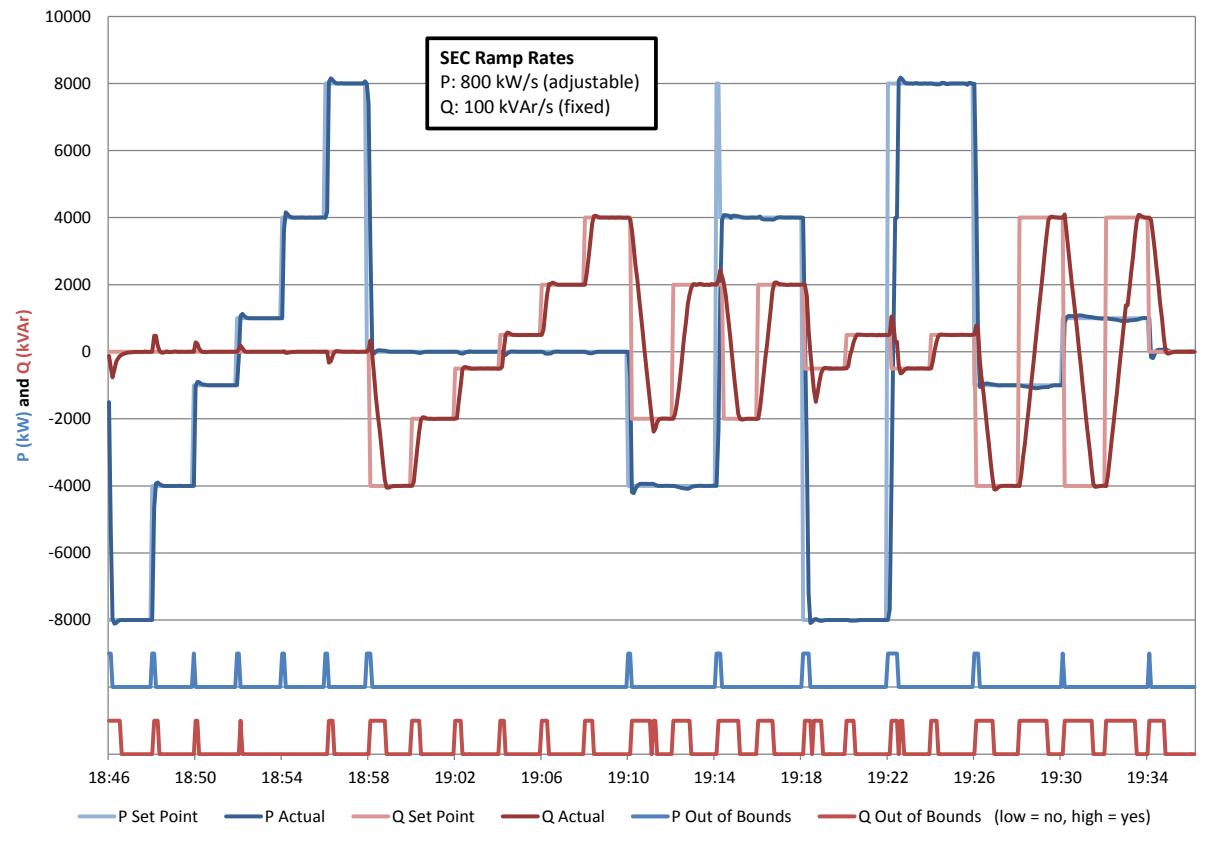
Figure 9-24. CDRL 19 Section 6, Test Plan for BESS Power Accuracy

In Figure 9-24 above, the light blue line is the real power set point, while the dark blue line is the real power actually measured. The separate blue high/low line at the bottom of the plot area shows when the measured real power was not within the expected accuracy (+/- 240 kW) of the set point. The only times at which the real power was not within +/- 240 kW of the set point were during transition periods caused by changes in the real power set point. For this test, the BESS' real power ramp rate was set at 800 kW/s. Therefore, when the real power set point was changed, the BESS followed the real power ramp rate and created a transition period where the measured real power was not within +/- 240 kW of the set point. This is the expected behavior.

Similarly, the light red line is the reactive power set point, while the dark red line is the reactive power actually measured. The separate red high/low line at the bottom of the plot area shows when the measured reactive power was not within the expected accuracy (+/- 120 kW) of the set point. The only times at which the reactive power was not within +/- 120 kW of the set point were during transition periods caused by changes in the reactive or real power set points. For this test, the BESS' reactive power ramp rate was fixed at 100 kVAr/s. Therefore, when the reactive power set point was changed, the BESS followed the reactive power ramp rate and created a transition period where the measured reactive power was not within +/- 120 kW of the set point. This is most evident in the last few reactive power set point changes near the right of the plot area, where the set point was changed from one extreme to another. This created a long transition

period as the BESS changed from +4 MVAr to -4MVAr at 100 kVAr/s, and is the expected behavior. However, the reactive power was not within +/- 120 kW of the set point during most changes in the real power set point as well. For example, a change in only the real power set point usually caused the reactive power to be more than +/- 120 kW from the reactive power set point. This was due to the inherent nature of the PCS components, where changes in real power output also created changes in the overall reactance of the system at the measurement point. In all cases, the reactive power returned to within +/- 120 kW of the set point after the transition period, and is acceptable behavior.

The BESS passed this test.

CDRL 19 Section 7, Test Plan for BESS Reactive Power Tests

The purpose of this test was to verify the BESS could deliver different combinations of full real and/or reactive (+/- 4 MVAr and/or +/-8 MW) power capacity for at least one hour blocks of time.
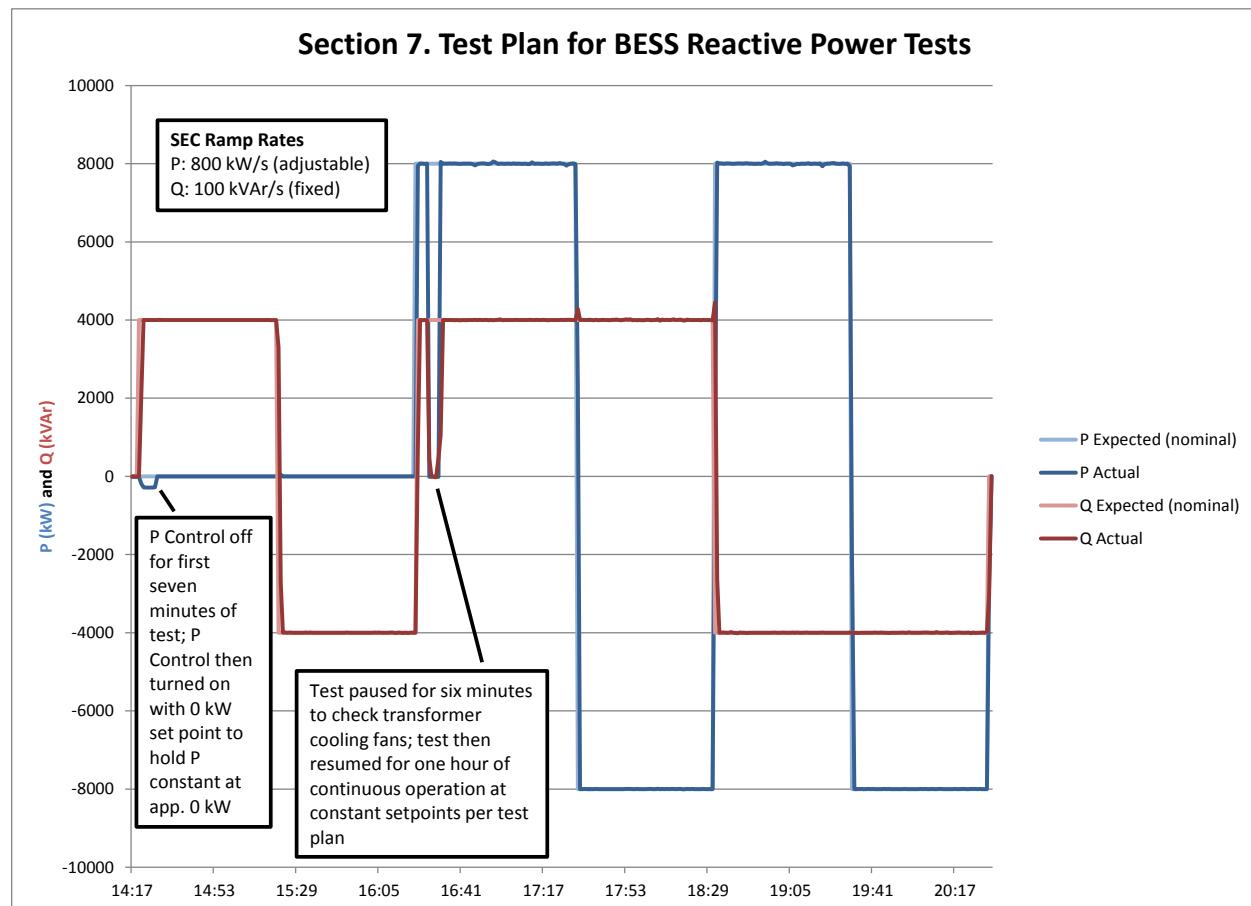
Figure 9-25. CDRL 19 Section 7, Test Plan for BESS Reactive Power Tests

In Figure 9-25 above, the light blue line is the expected real power (nominal, without considering ramp rates or interruptions), while the dark blue line is the measured real power. Similarly, the light red line is the expected reactive power (nominal, without considering ramp rates or interruptions), while the dark red line is the measured reactive power. The BESS delivered each combination of full real and/or reactive power capacity as expected for each block of time. The only differences between the expected real/reactive power and the measured real/reactive power were due to the reasons described below.

At the beginning of the test, real power control (P Control) was not turned on in conjunction with reactive power control (Q Control), which resulted in the BESS not holding the real power output to the set point (0 kW). The concurrent 4 MVAr dispatch caused a relatively small real power dispatch in the opposite direction, as noted in the extreme left of the plot area. As soon as real power control was turned on, the BESS held real power output to the set point (0 kW), and continued the 4MVAr dispatch.

- Near the middle of the test, the PCSs were shut down to manually measure the surface temperature of the 480/12.47 kV transformer cooling fans[21]. This resulted in the real and reactive power dropping to zero for approximately six minutes before resuming the test. After the test was resumed, the BESS provided the remaining real/reactive power combinations as expected for at least one uninterrupted hour each.

The BESS passed this test.

CDRL 19 Section 8, Test Plan for BESS Capacity

The purpose of this test was to verify the BESS could deliver 32 MWh of energy over approximately four hours of continuous discharge at 8 MW.

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[21] This topic is discussed in the conclusion.

Test Plan for BESS Capacity								
		Cycle 1	Cycle 2	Cycle 3	Minimum	Average	Maximum	Max. % diff
Energy (MWh)	Nominal		32.00					
	Actual	31.95	32.04	32.08	31.95	32.03	32.08	0.41
	% error	0.14	0.12	0.27	0.12	0.18	0.27	
Power (MW)	Nominal		8.00					
	Actual	7.99	8.00	7.97	7.97	7.99	8.00	0.32
	% error	0.15	0.04	0.35	0.04	0.18	0.35	
Power Factor	Nominal		1.00					
	Actual	1.00	1.00	1.00	1.00	1.00	1.00	0.15
	% error	0.15	0.00	0.07	0.00	0.07	0.15	
Duration (h:mm)	Nominal		4:00					
	Actual	3:59	4:00	4:01	3:59	4:00	4:01	0:61
	% error	0.17	0.03	0.44	0.03	0.21	0.44	
SOC (%)	Nominal Start		98.00					
	Actual Start	98.70	96.78	96.85	96.70	96.78	96.85	0.15
	Nominal Range		95.50					
	Actual Range	93.40	93.38	93.35	93.38	93.44	93.55	0.19
	Nominal Stop		2.50					
	Actual Stop	3.30	3.40	3.30	3.30	3.33	3.40	2.99

Table 9-20 CDRL 19 Section 8, Test Plan for BESS Capacity

In Table 9-20 the average energy delivered over three discharge cycles was 32.03 MWh, the average power was 7.99 MW, the average power factor was 1.00, the average duration was 4 hours, zero minutes, and the average state of charge (SOC) range was 93.44 percent. These results, along with the corresponding percent error from nominal values, and underlying measurement errors, represent the expected performance of the BESS.

Energy values were calculated by manually integrating 30-second power data recorded during each discharge cycle. The results are in agreement with energy recorded directly from the power measurement instrumentation (energy calculated internally by the instrument), which are shown in Table 9-21.

Cycle	Manually Integrated Energy (MWh)	Instrument Calculated Energy (MWh)	% Difference
1	31.95	31.97	0.06
2	32.04	32.03	0.03
3	32.08	32.10	0.06

Table 9-21 Comparison of Manually Integrated and Instrument Calculated Energy

The BESS passed this test.

CDRL 19 Section 9, Test Plan for BESS Ramp Rate Test

The purpose of this test was to verify the BESS could provide approximately 10-minute real power charge and discharge ramps between 0 and +/- 8 MW (these longer duration ramps are in addition to the shorter duration ramps recorded in other tests; see CDRL 19 Section 6).
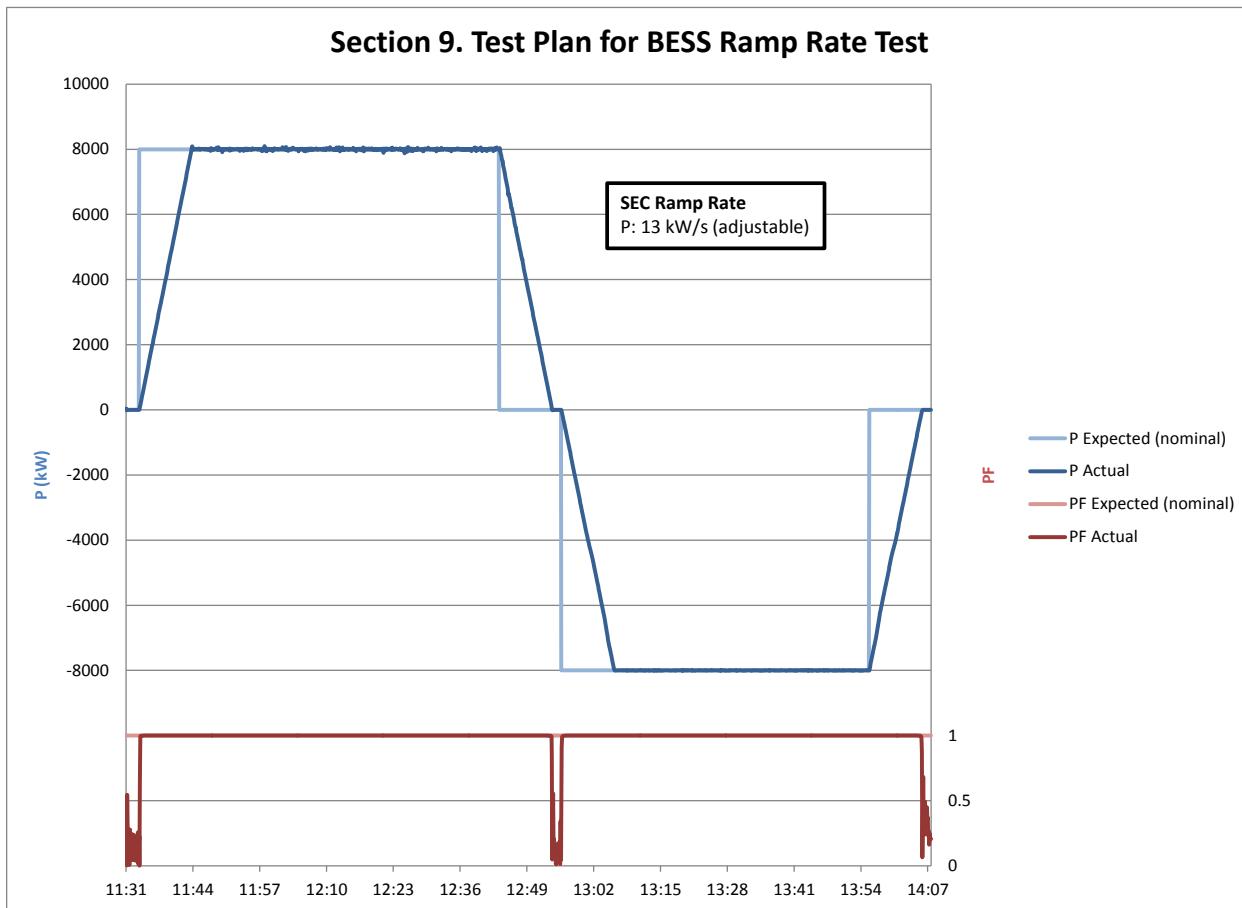
Figure 9-26 CDRL 19 Section 9, Test Plan for BESS Ramp Rate Test

In Figure 9-26 above, the light blue line is the real power set point (expected, nominal real power without considering the ramp rate), while the dark blue line is the measured real power. Similarly, the light red line is the expected power factor, while the dark red line is the measured power factor. The BESS provided the approximately 10-minute real power charge and discharge ramps between 0 and +/- 8 MW as expected, and maintained a near unity power factor throughout each ramp and steady-state output period. The power factor was always unity, except when the BESS was regulating real power output near 0.

The BESS passed this test.

CDRL 19 Section 10, Test Plan for Balancing Function Test

The purpose of this test was to verify the BESS could balance the four battery sections to within 1 percent state of charge (SOC) of each other while the system was discharged from a slightly unbalanced condition.
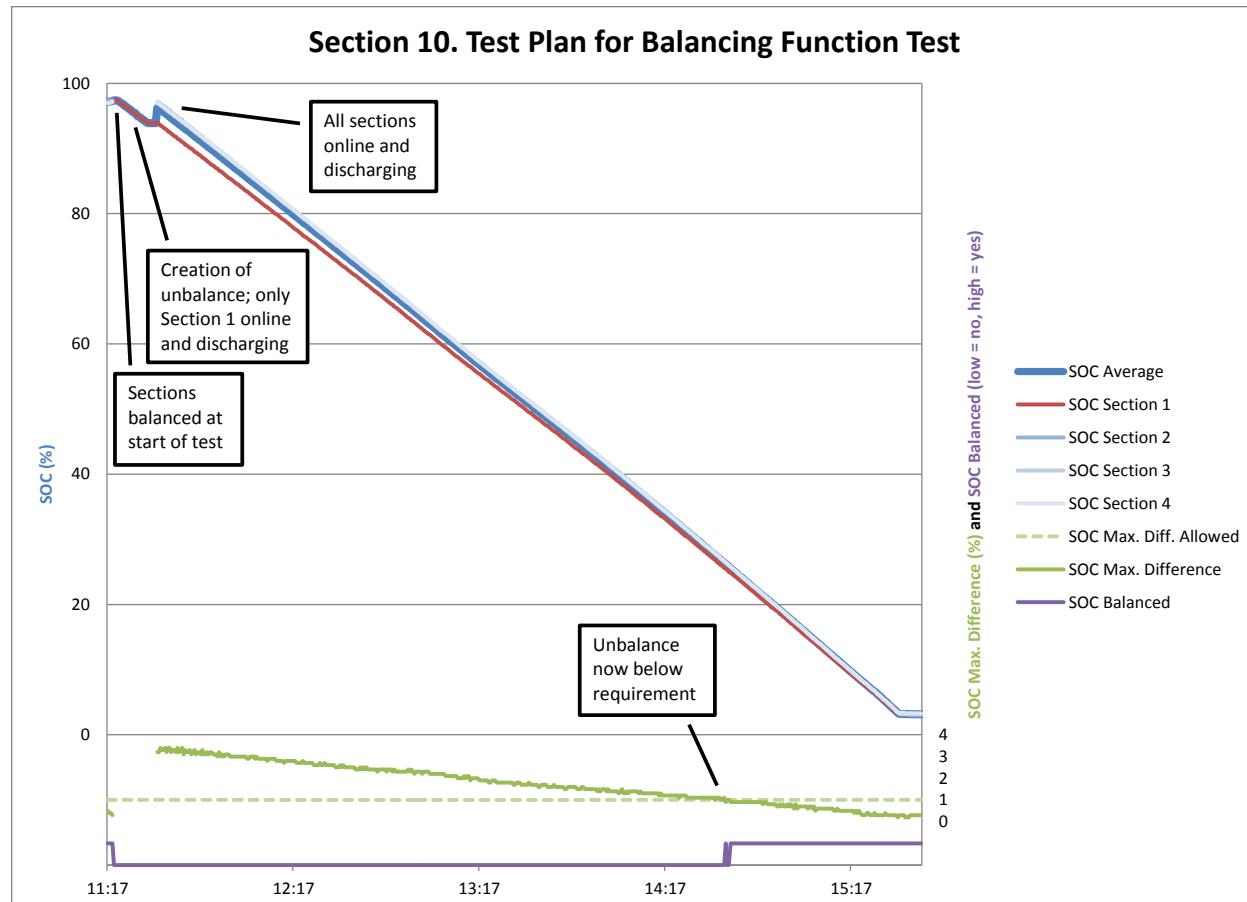
Figure 9-27 CDRL 19 Section 10, Test Plan for Balancing Function Test

In Figure 9-27 above, the thick dark blue line is the average SOC of the four battery sections, while the three lighter blue lines are the individual SOCs of battery sections 2, 3, and 4. The red line is the SOC of battery section 1. The dashed green line is the targeted maximum allowed percent SOC difference between each of the battery sections (1 percent), while the solid green line is the actual maximum percent SOC difference between each of the battery sections throughout the test. Lastly, the purple high/low line at the bottom of the plot area indicates if the battery sections are all within the targeted maximum allowed percent SOC difference (i.e., balancing during the discharge was successful).

The test started with all battery sections balanced (at approximately the same SOC), and near a complete charge. Then, the corresponding PCS lineups for battery sections 2, 3, and 4 were shut

down, and only section 1 was discharged to approximately 94 percent SOC. The PCS lineups for the other three sections were then restarted, creating an unbalance of approximately three percent SOC. The BESS was then discharged at maximum power. The BESS slowly balanced the four battery sections over the discharge, as shown by the convergence of the red and blue lines. By approximately 20 percent SOC, all four battery sections were within 1 percent SOC of each other.

The BESS passed this test.

CDRL 19 Section 11.1, Test 1, Steady State Voltage Regulation

The purpose of this test was to verify the BESS could provide up to +/- 4 MVAr of reactive power to maintain the substation's 66 kV bus voltage within +/- 5 percent, while also maintaining the state of charge (SOC) of the batteries.
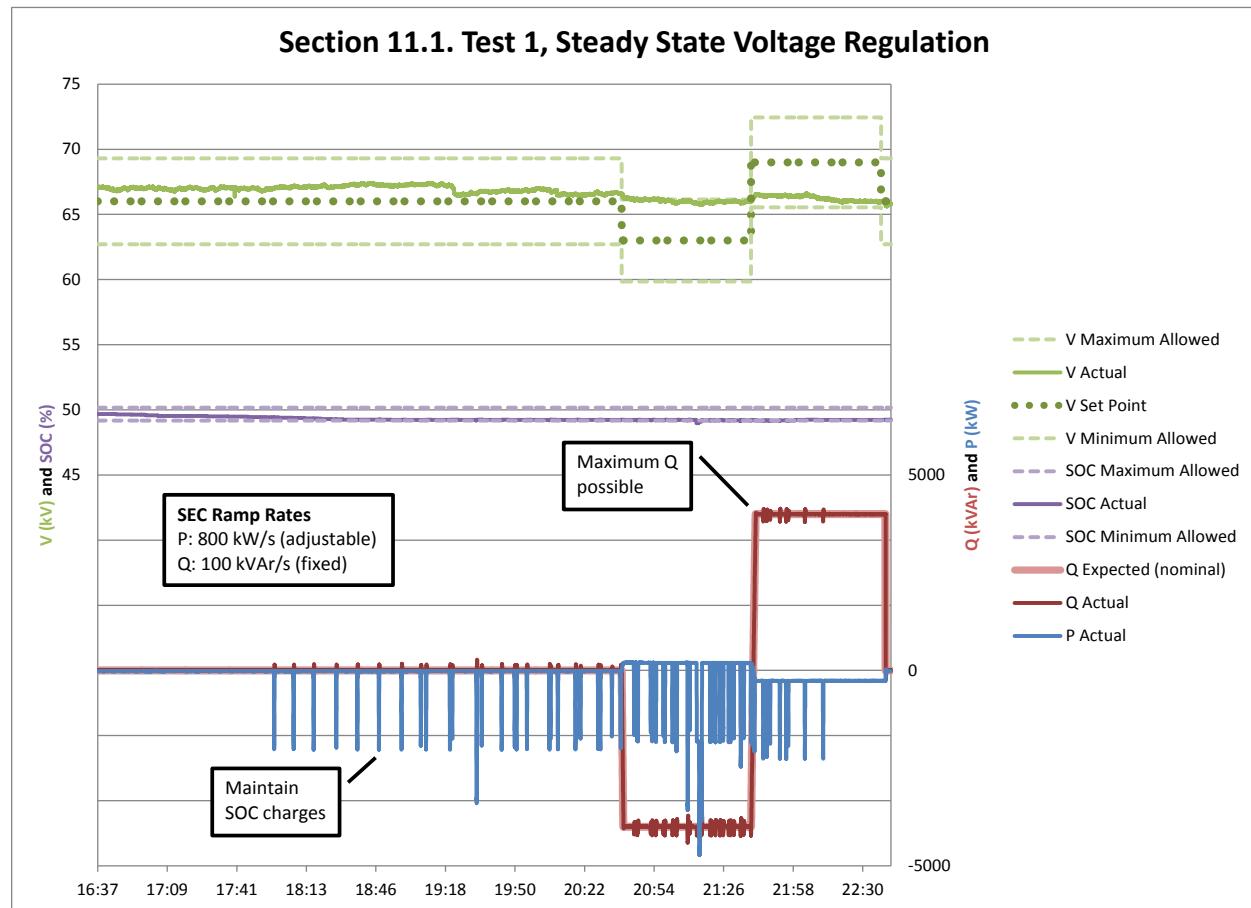
Figure 9-28 CDRL 19 Section 11.1, Test 1, Steady State Voltage Regulation

In Figure 9-28 above, the green lines are the set point, maximum allowed, minimum allowed, and measured 66 kV bus voltages, as shown in the chart legend. Similarly, the purple lines are

the maximum allowed, minimum allowed, and measured SOCs, the red lines are the expected (nominal) and measured reactive powers, and the blue line is the measured real power.

For the first four hours of the test, the voltage set point was set at 66 kV, and the measured voltage remained well within the maximum/minimum allowed voltages. As a result, the system remained idle, except for an occasional real power charge to maintain the battery SOC (as seen in the measured SOC dropping to the minimum allowed SOC, and the subsequent pulses of real power). For the fifth hour of the test, the voltage set point was intentionally lowered to 63 kV, which placed the measured voltage above the maximum allowed voltage. This triggered a full -4 MVAr dispatch in an attempt to lower the bus voltage. As shown in the measured voltage, this action may have very slightly lowered the 66 kV bus voltage from where it otherwise would have trended. Similarly, for the sixth and final hour of the test, the voltage set point was intentionally raised to 69 kV, which placed the measured voltage below the minimum allowed voltage. This triggered a full +4 MVAr dispatch in an attempt to raise the bus voltage. As shown in the measured voltage, this action may have very slightly raised the 66 kV bus voltage from where it otherwise would have trended.

Due to existing conditions and characteristics of the substation's 66 kV bus, the first four hours of the test didn't demonstrate the BESS' voltage regulation function. Similarly, the behavior for the last two hours of the test was intentionally induced, and the BESS still had negligible impact on the bus voltage. Regardless, the BESS exhibited the expected behavior for the existing conditions and characteristics of the bus.

The BESS passed this test.

CDRL 19 Section 11.2, Test 3, Charge during High Line Load/Discharge during Low Line Load

The purpose of this test was to verify the BESS could charge during periods of high line loading and discharge during periods of low line loading[22] per the algorithm defined in system documentation and implemented in the control software.

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[22] The BESS is upstream of bottlenecks in transmission system capacity.
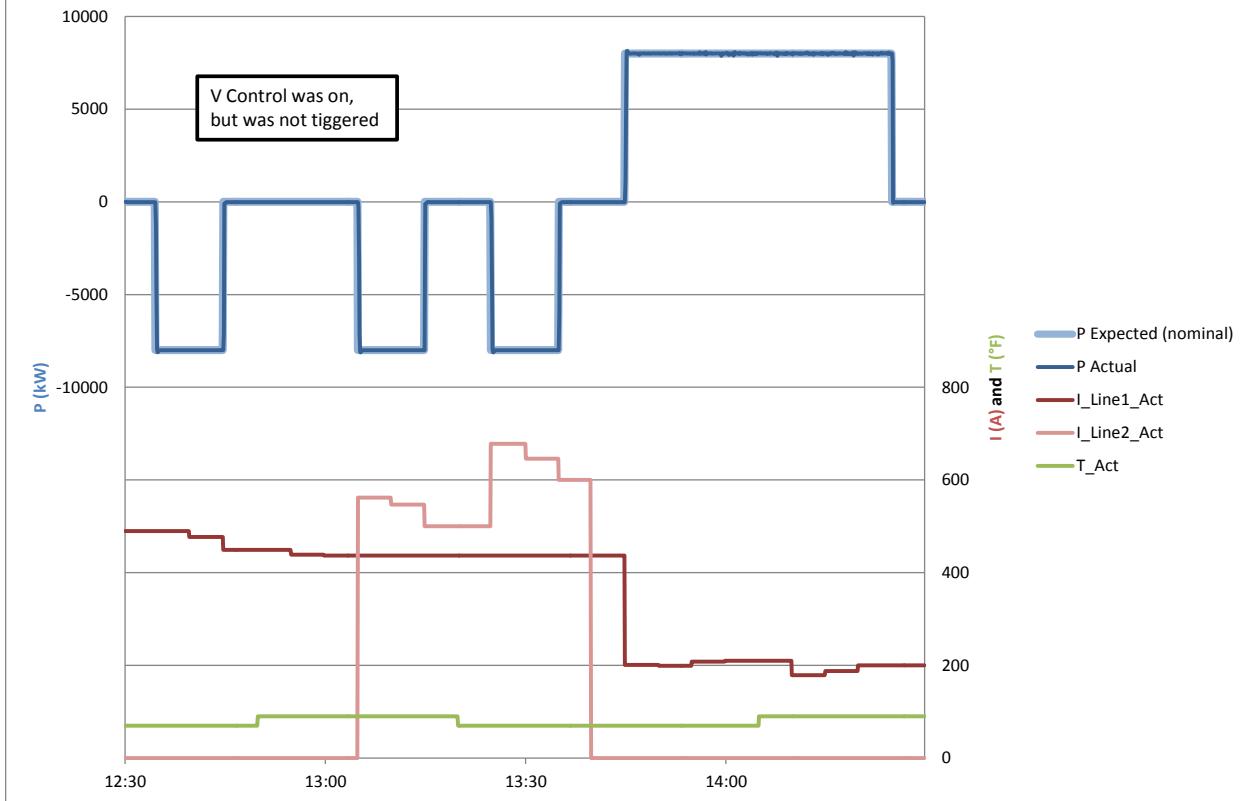
Figure 9-29 CDRL 19 Section 11.2, Test 3, Charge during High Line Load/Discharge during Low Line Load

In Figure 9-29 above, the blue lines are the expected (nominal) and measured real powers, the red lines are I_Line1_Act and I_Line2_Act (line currents, representing line loading) entered for the test, and the green line is T_Act (ambient temperature) entered for the test, as shown in the chart legend. As shown by the blue lines, the BESS charged and discharged as expected throughout the test. Even though Test 2, Steady State Voltage Regulation under Any Mode was also enabled, it was not triggered due to the existing conditions and characteristics of the substation's 66 kV bus (see CDRL 19 Section 11.1).

The BESS passed this test.

CDRL 19 Section 11.3, Test 4, Charge Off-peak/Discharge On-peak

The purpose of this test was to verify the BESS could discharge during on-peak periods and charge during off-peak periods.
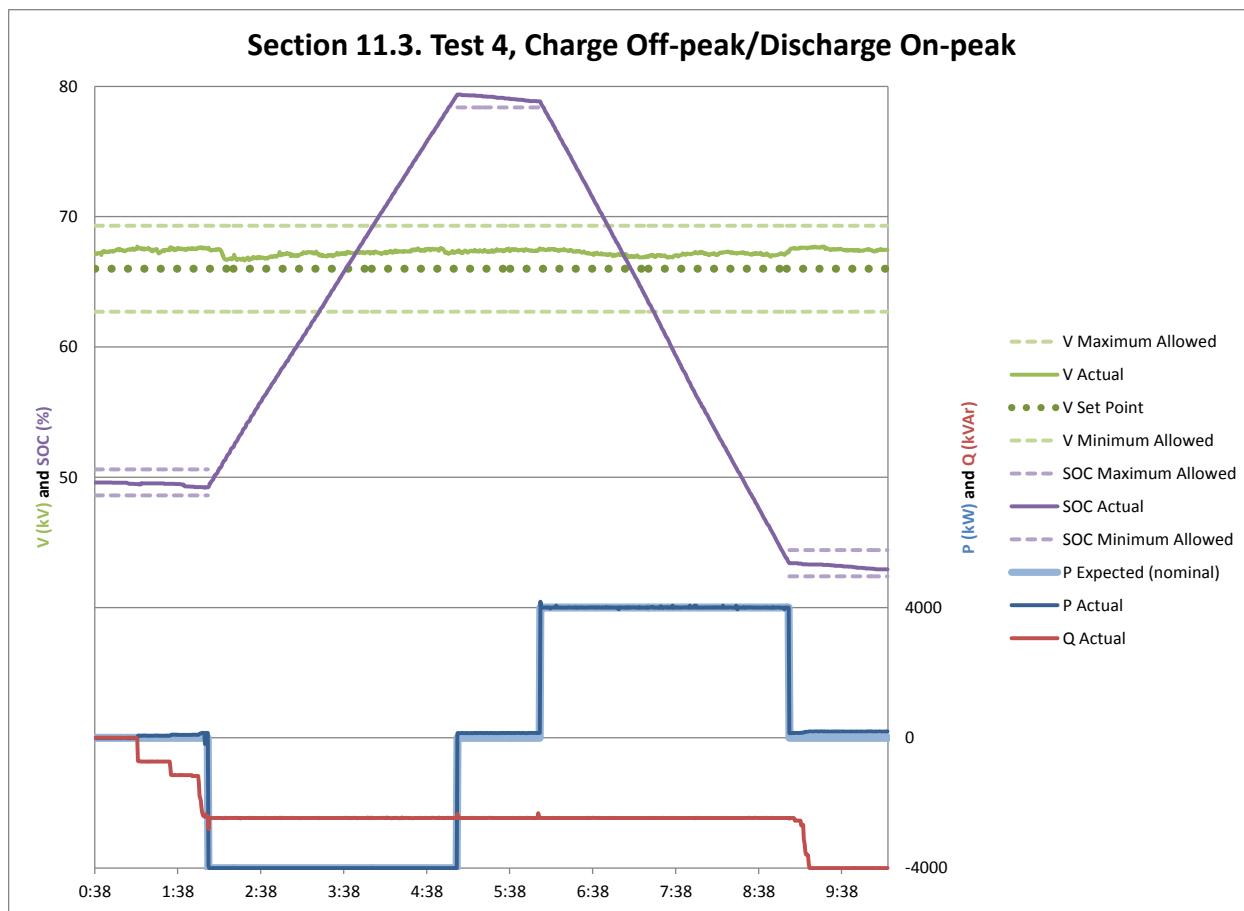
Figure 9-30 CDRL 19 Section 11.3, Test 4, Charge Off-peak/Discharge On-peak

In Figure 9-30 above, the green lines are the set point, maximum allowed, minimum allowed, and measured 66 kV bus voltages, as shown in the chart legend. Similarly, the purple lines are the maximum allowed, minimum allowed, and measured state of charges (SOCs), the blue lines are the expected (nominal) and measured real powers, and the red line is the measured reactive power.

As shown by the blue and purple lines, the BESS charged and discharged as expected over approximately three hour periods, with a one hour rest between the two periods, per the on/off peak schedule set in the control software.

Test 2, Steady State Voltage Regulation under Any Mode was also enabled, and was triggered in stages as shown by the red line near the beginning of the charge ramp, and again near the end of the discharge ramp. Voltage regulation was triggered even though the measured voltage did not appear to exceed the maximum or minimum allowed voltage limits shown by the green lines. This behavior was not expected, and should be further investigated by LG Chem and ABB23.

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[23] This topic is discussed in the conclusion.

With the exception of the unexplained voltage regulation behavior, the BESS passed the core component of this test.

CDRL 19 Section 11.4, Test 5, Charge and Discharge as Needed for Grid Purposes

The purpose of this test was to verify the BESS could charge and discharge as needed for grid purposes by accurately following wind turbine generation data, and dispatching proportionate real power ramps in the opposite direction to smooth the wind generators' output.
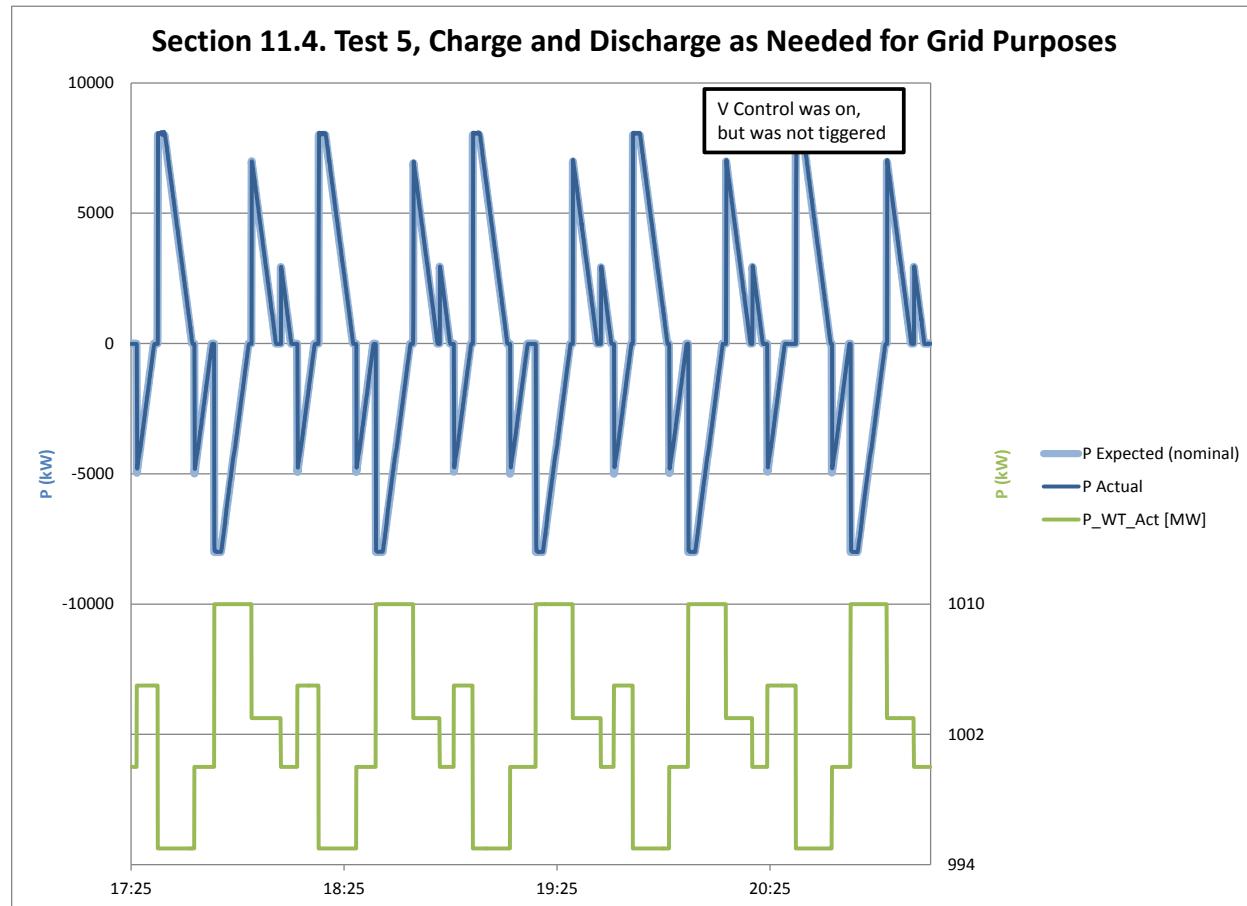
Figure 9-31 CDRL 19 Section 11.4, Test 5, Charge and Discharge as Needed for Grid Purposes

In Figure 9-31 above, the blue lines are the expected (nominal) and measured real powers, and the green line is P_WT_Act [MW] (wind turbine generation) entered for the test. As shown by the blue lines, the BESS dispatched proportionate real power ramps as expected throughout the test. Even though Test 2, Steady State Voltage Regulation under Any Mode was also enabled, it was not triggered due to the existing conditions and characteristics of the substation's 66 kV bus (see CDRL 19 Section 11.1).

The BESS passed this test.

CDRL 19 Section 11.5, EMS–GMS Transition

The purpose of this test was to verify the BESS exhibited the expected behavior when transitioning between EMS and GMS operation under different scenarios, per the interlocks and behaviors defined in system documentation and implemented in the control software.
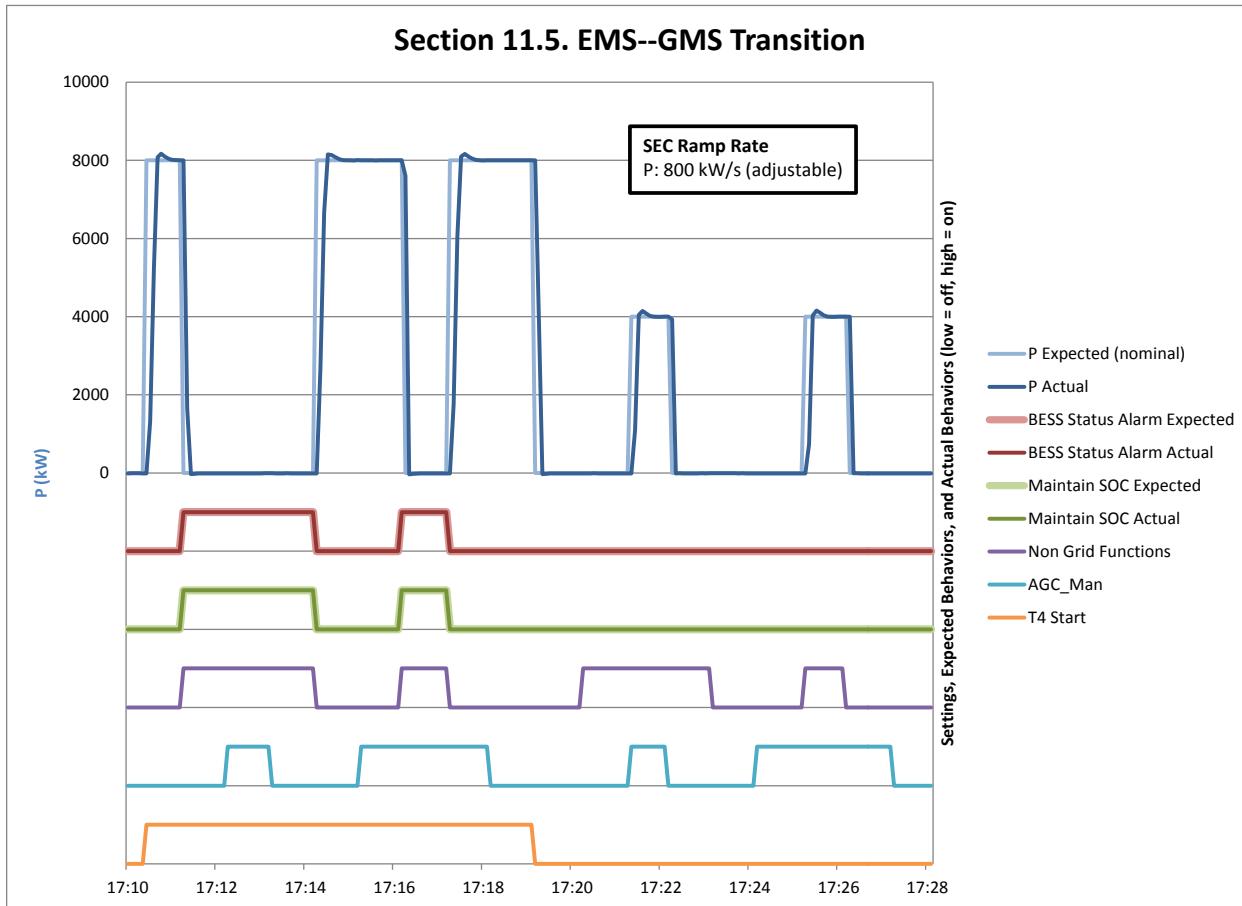
Figure 9-32 CDRL 19 Section 11.5, EMS–GMS Transition

In Figure 9-32 above, the blue lines are the expected (nominal) and measured real powers, the red high/low lines are the expected and observed BESS Status Alarm statuses (on/off), and the green lines are the expected and observed Maintain SOC statuses (on/off), as shown in the chart legend. Also, the purple, teal, and orange high/low lines are the Non Grid Functions, AGC_Man, and T4 Start control points entered for the test (on/off), respectively.

As shown by the blue, red, and green lines, the BESS charged, generated BESS Status Alarms, and maintained SOC as expected throughout the test.

The BESS passed this test.

CDRL 19 Section 11.6, EMS and GMS Communication Fault Handling

The purpose of this test was to verify the BESS exhibited the expected behavior when encountering EMS and GMS communication faults under different scenarios, per the interlocks and behaviors defined in system documentation and implemented in the control software.
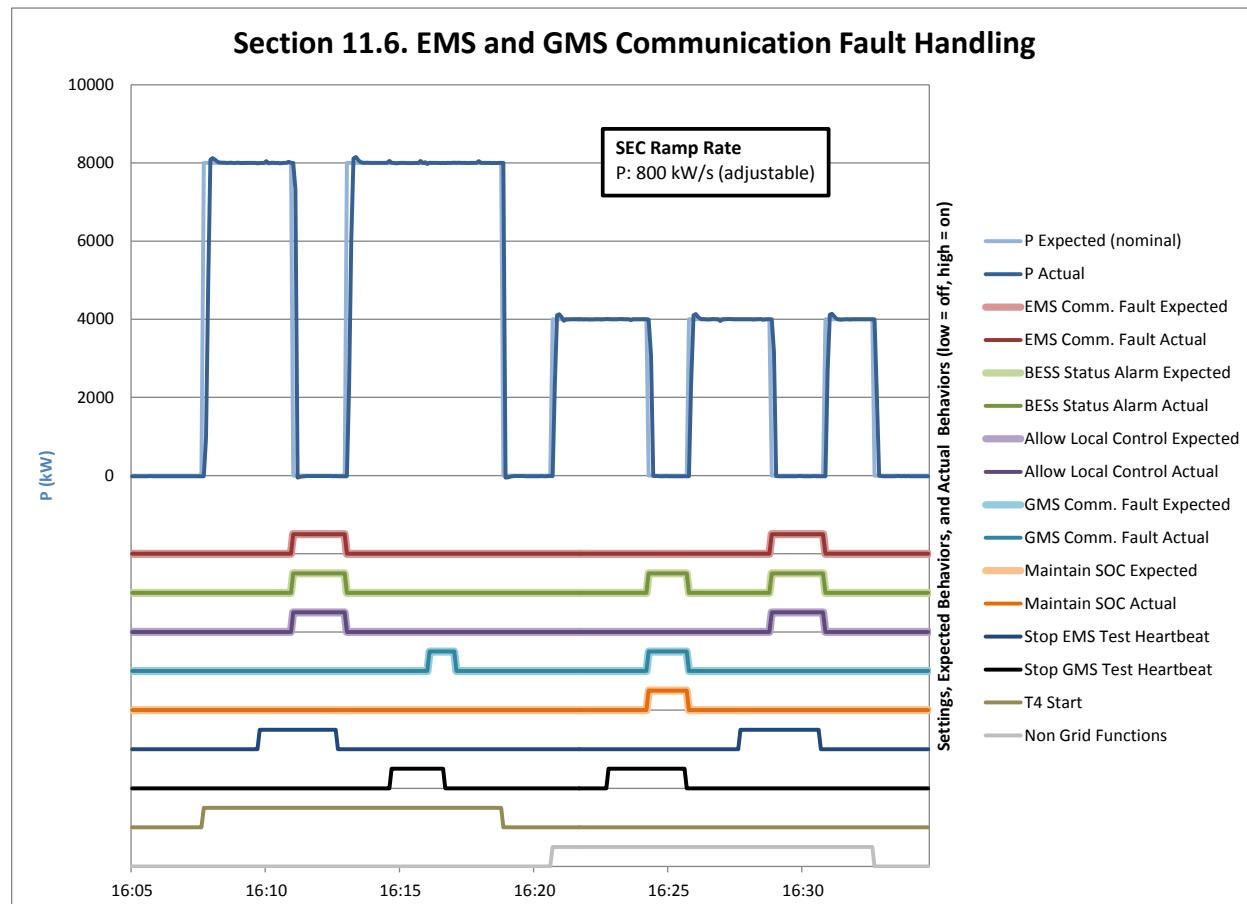
Figure 9-33 CDRL 19 Section 11.6, EMS and GMS Communication Fault Handling

In Figure 9-33 above, the blue lines are the expected (nominal) and measured real powers, the red high/low lines are the expected and observed EMS Communication Fault statuses (on/off), the green high/low lines are the expected and observed BESS Status Alarm statuses (on/off), the purple high/low lines are the expected and observed Allow Local Control statuses (on/off), the teal high/low lines are the expected and observed GMS Communication Fault statuses (on/off), and the orange high/low lines are the expected and observed Maintain SOC statuses (on/off), as

shown in the chart legend. Also, the navy blue, black, tan, and gray high/low lines are the Stop EMS Test Heartbeat, Stop GMS Test Heartbeat, T4 Start, and Non Grid Functions control points entered for the test (on/off), respectively.

As shown by the blue, red, green, purple, and teal lines, the BESS charged, generated EMS and GMS Communication Faults and BESS Status Alarms, allowed local control, and turned on Maintain SOC as expected throughout the test.

The BESS passed this test.

CDRL 19 Section 12.1, Manual and CAISO Power Dispatch

The purpose of this test was to verify the BESS could dispatch real power using GMS commands.
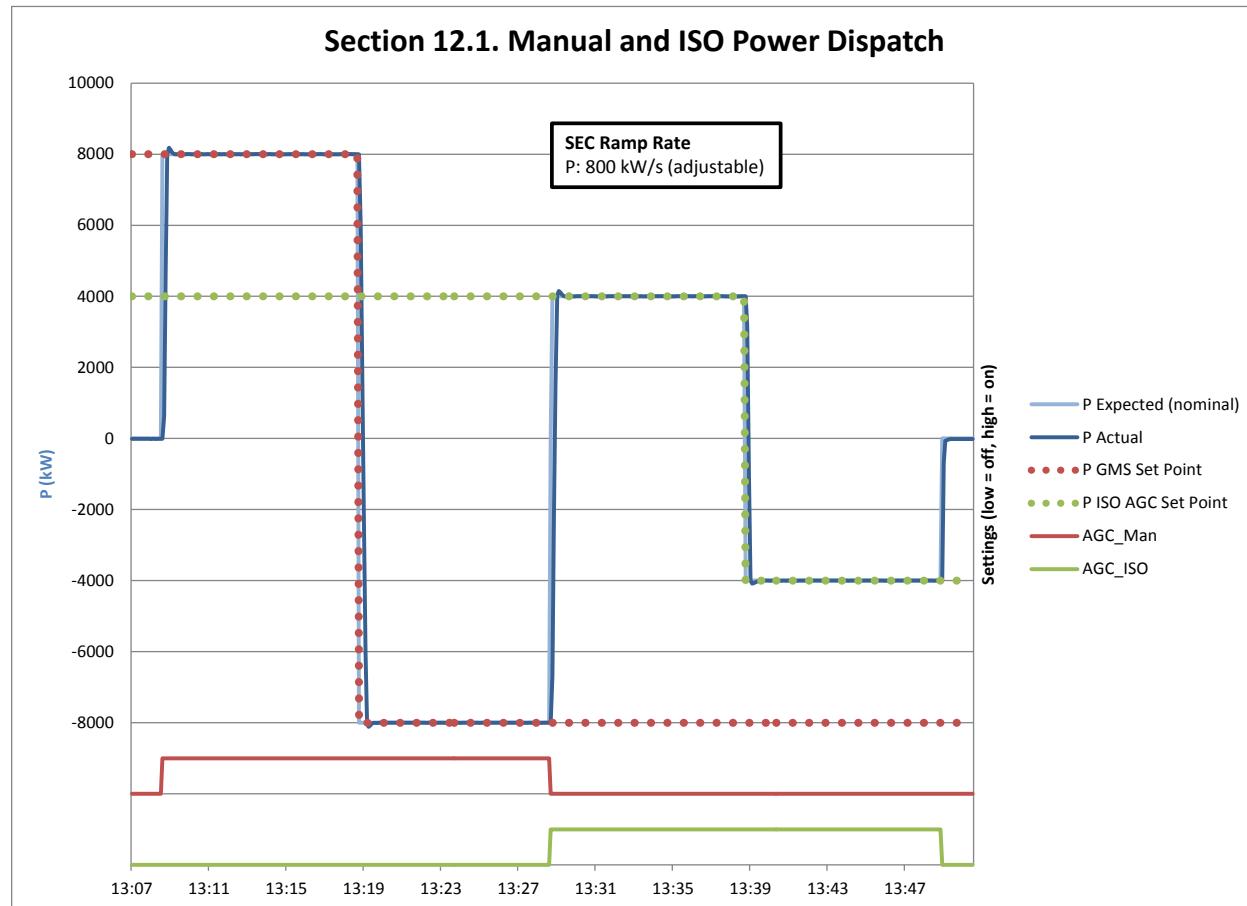
Figure 9-34 CDRL 19 Section 12.1, Manual and CAISO Power Dispatch

In Figure 9-34 above, the blue lines are the expected (nominal, without considering the real power ramp rate) and measured real powers, the red and green dotted lines are the P GMS Set

Point and P CAISO AGC Set Point entered for the test, respectively, and the red and green solid high/low lines are the AGC_Man and AGC_CAISO control points entered for the test (on/off), respectively.

As shown by the blue lines, the BESS charged and discharged as expected throughout the test.

The BESS passed this test.

Conclusion

Throughout SAT, the BESS largely exhibited the expected behavior and passed each test. With the successful completion of SAT, SCE hereby confirms that the Performance Tests have been satisfactorily completed and the Performance Guarantees have been achieved, as set forth in Exhibit O of the project contract and further established in "CDRL 19, System Acceptance Test Plan", and required by section (iv) of the definition of "Substantial Completion".

However, there are a number of open items, both related to behaviors and issues observed during SAT, as well as other items, all of which must be addressed by LG Chem and ABB prior to final acceptance. Notable items related to behaviors and issues observed during SAT are described below, and all items (SAT-related and otherwise) will be provided to LG Chem in separate documentation.

Notable Items Related to Behaviors and Issues Observed During SAT

As mentioned in CDRL 19 Section 7, one of the PCS containers had a 480/12.47 kV transformer cooling fan motor failure near the beginning of SAT, in addition to an identical failure shortly before the start of SAT. During SAT, all 12 of these fans were replaced in both PCS containers as a precautionary measure, and the tests were completed without any further failures. ABB reported they are investigating the cause of the failures, and SCE is waiting on their findings.

During CDRL 19 Section 11.3, Test 4, Charge Off-peak/Discharge On-peak (see CDRL 19 Section 11.3), the voltage regulation function was triggered, even when the measured voltage didn't appear to exceed the maximum or minimum allowed voltage limits. This behavior was unexpected and should be investigated by ABB. SCE would like a detailed description of the voltage regulation algorithm, including an explanation of its operation, and its sensitivity to voltage transients and other potential causes for it to trigger.

Per CDRL 19, SCE is waiting for an updated system communication diagram from ABB (ABB document number 3AUP000A110-R3) showing the current equipment IP addresses provided to ABB and verified by SCE during SAT.

The ABB local data historian was unable to recall logged data (or wasn't logging data at all) during SAT. ABB should fix the local data historian and confirm it automatically records all data as long as the OPC server is running and the data historian is powered on.

The OPC server configuration applet currently resides on the ABB local computer, requiring both the local computer and ABB local data historian be powered on in order for the ABB and

SCE data historians to receive and log data. The OPC server configuration applet should be moved and configured to run on the ABB local data historian, so daily operation of the system is no longer dependent on the ABB local computer.

Appendix A

Report Approvals and Revisions: SAT Report approved and signed July 2014

Report Distribution:

SCE, LG Chem

9.9 Appendix I: CDRL 19, System Acceptance Test Plan

CDRL 19, System Acceptance Test Plan

Customer	Southern California Edison
Project	8MW/32MWh Tehachapi Wind Energy Storage Project
Customer Contact	Mr. Blake Chalson (Contracts Manager / +1 626 940 9861)
Date of Submission	January 29, 2014
LG Chem Ltd. Contact	Kevin Fok (Sales Manager) +1 248 825 1043 / kfok@lgchem.com LG Chem Power, Inc. 1857 Technology Dr., Troy, MI 48083, USA
	Jaehong Park (Project Manager) +82 10 9955 7749 / jaehongpark@lgchem.com LG Chem Ltd. 20, Yeouidodong Yeoungdeunpogu, Seoul, 150-721, Korea

Revision History

Date	Revision	Writer	Contents
Oct 08, 2013	AA	ABB : DMPC /LGC : Gyongjin Oh	Preliminary Release
Dec 12, 2013	AB	ABB : Igor Hot /LGC : Gyongjin Oh	Revised per SCE provided comments
Dec 13, 2013	AC	LGC : Gyongjin Oh	Revised Battery Fully charge and discharge
Dec 13, 2013	AD	LGC : Kevin Fok	Edits
Jan 29, 2014	AF	SCE : Grant Davis, Daryl Coleman, Loic Gaillac, Andy Paylan	Additions, corrections, and clarifications throughout
Feb 10, 2014	AG	ABB : Igor Hot	General Revision
Feb 13, 2014	AH	SCE : Grant Davis	Review
Feb 24, 2014	AI	ABB : Igor Hot	Minor Updates
Feb 27, 2014	AJ	SCE : Grant Davis	Review, minor updates to address SEC functionality, added power accuracy test
March 14, 2014	AK	ABB : Igor Hot	Minor Updates
April 07, 2014	AL	SCE : Grant Davis	Review
June 17, 2014	AM	SCE : Grant Davis	Review, formatting, minor updates suggested by ABB

Table of Contents

SAFETY

This document contains important information regarding the configuration and operation of the PCS equipment for ESS applications. All operations on the PCS should be carried out by a trained technician familiar with the contents of this document.

DANGER!
This symbol indicates an imminent danger resulting from mechanical forces or high voltage. A non-observance leads to life-threatening physical injury or death.

WARNING!
This symbol indicates a dangerous situation. A non-observance may lead to serious or life-threatening physical injury or death.

CAUTION!
This symbol indicates a dangerous situation. A non-observance may lead to physical injury or cause damage to the equipment.

NOTICE!
This symbol emphasizes important information. A non-observance may cause damage to the equipment or other adverse effects.

IMPORTANT!
This symbol indicates useful information. Not to be used to indicate dangerous situations.

⚠ Work performed on any part of the equipment must be by a trained technician familiar with servicing this product.

⚠ Ensure power is isolated and locked off before attempting any work on this equipment.

⚠ Ensure the Equipment Under Test (EUT) and electrical equipment is properly grounded before attempting any work on this equipment.

⚠ Follow all applicable safety procedures enforced by the company / facility where the testing is to be performed.

⚠ Many parts in this equipment, including printed circuit boards operate at lethal voltages. DO NOT TOUCH components or connections that have voltage present.

⚠ This equipment is a high energy device and requires strict precautions to be taken. Stored charge is present after the device is switched off.

⚠ Normal operation of this equipment requires all protective covers to be in place and doors secured closed.

⚠ Ensure proper PPE, including safety glasses, outerwear and Electrical Hazard safety footwear, are worn at all times while working on the equipment.

⚠ When the PCS100 ESS is powered down, lethal voltages (up to 1050Vdc) will remain in the energy storage element and the complete PCS100 ESS should be considered alive.

INTRODUCTION

This document provides the System Acceptance Test Plan for Southern California Edison's (SCE's) Tehachapi Storage Project (TSP) 32MWh battery energy storage system (BESS) installed at Monolith Substation near Tehachapi, California. The BESS consists of 32MWh of Li-ion batteries and an 8MW/4MVAr/9MVA bidirectional power conversion system (PCS). The PCS is designed to connect to a 12.47kV, 3-Phase, 60 Hz bus, and is divided into two 4.5 MVA units. Each PCS unit is controlled by a PCS controller, and is connected to two battery sections.

To allow for a central interface between the BESS and Southern California Edison, ABB implemented a site energy controller (SEC). The basic function of the SEC is to interpret the remote command functions (end user commands) and relay this information to the individual PCS units. In addition to accepting remote commands and providing status information, the SEC employs built-in logic to successfully run the system acceptance tests. The SEC aggregates the electrical parameters measured by each of the PCS power meters to act as a central interface for status reporting. The measured SEC values and/or separate data logger(s) will be used to serve as the validation mechanism for the system acceptance tests defined in this document. The accuracy of the power meters, inclusive of the current transformers (CTs), potential transformers (PTs), burden due to conductor runs from PTs and CTs to the power meters, and power meters themselves, will be provided, along with current calibration certificates. In addition, accuracy will be provided when aggregated electrical parameters are used to determine the performance of the system.

REFERENCES

TECHNICAL & CONTRACTUAL DOCUMENT REFERENCES

The tests described in this document shall demonstrate that the BESS conforms, at a minimum, to the technical requirements set forth in the following documents.

Item	Doc. Owner	Description	Document No.	Revision / Date
1	SCE	Technical Specification	TSP BESS SOW	v2-2 - FINAL
2	LG Chem	Technical Plan and Approach	CDRL 5.0	v1.0
3	ABB DMPC	Technical Proposal	PE-2161	c1-Conformed
4	SCE & LG Chem	Contract, Performance Tests & Performance Guarantees	Exhibit O	Executed

Table 9-22, Technical & Contractual Document References

DESIGN DOCUMENT REFERENCES

The containerized PCS has been designed, fabricated, and assembled based on a Master List of Documents (3AUP000A110-G). The current revisions in the document list will be available for Buyer review prior to the commencement of the scheduled test. The table below only includes the documents which will be referenced during the procedures detailed within this document.

Item	Doc. Number	Description	Revision / Date
1	3AUP000A110-R3	Communication Diagram – System Overall	TBD
2	3AUP080A108-V1	Control and Interface Concept	TBD
3	3AUP000A108-V2	DNP3/Modbus TCP/IP interface	TBD
4	3AUP080A108-V3	IEC61850 & Local Historian Data	TBD

Table 9-23, Design Document References

REQUIRED DATA ACQUISITION, RECORDING EQUIPMENT, AND INVERTER SYSTEM PERFORMANCE POWER ACCURACY

The following data acquisition and recording equipment is required for the test. Ensure all equipment is calibrated. During the test, fill in the serial number and calibration due dates. Do not use equipment without current calibration certificates.

To allow for a comprehensive and accurate analysis of the test results for each test outlined in this document, test data will be recorded with data logger(s), in addition to the local Data Historian.

The BESS inverter system power accuracy per PCS100 ESS technical specifications shall be +/-3% of the power set point.

Item	Description	Man. / Model	Quantity	Serial Number (Cal. Date / Due Date)
1	Local Historian	ABB / COM600	1	n/a
2	PQM	Janitza / UMG604	2 @ 12.47kV	PCS100 - Unit 1, SN:7001/9226 Calibration Date: Nov 3, 2013

PCS100 - Unit 2, SN:7001/9224 Calibration Date: Nov 3, 2013 |
| 3 | PQM | Janitza / UMG604 | 1 @ 66kV | SEC, SN: 7001/9227 Calibration Date: Nov 3, 2013 |
| 4 | CT | GE-ITI / Model 120, Catalog Number 120-401, Current Ratio 400:5 | 6 | PCS100 - Unit 1, SN: 003525712, 003525711, 003525710

PCS100 - Unit 2, SN: 003552258, 003552254, 003552253 |
| 5 | PT | ABB / Model VIZ-11, Primary Voltage 13800/13800Y, Secondary Voltage 120, Ratio 115:1, Highest Accuracy 0.3 % Z | 4 | PCS100 - Unit 1, SN: 41301546, 41301547

PCS100 - Unit 2, SN: 41301548, 41301549 |
| 6 | Data Logger Software Installed on Commissioning PC | L.H. Controls /OPC Data Logger, Ver 1.72f | 1 | N/A |

Table 9-24, Required Data Acquisition & Test Equipment

REQUIRED PROGRAMMING AND CONFIGURATION SOFTWARE

The following programming and configuration software (including specific versions) is required for the test. Ensure all software is up-to-date. During the test, fill in the actual version of the software.

Item	Description	Man.	Required Version	Actual Version
1	Compact Control Builder AC 800M	ABB	5.1.0/1 (Build 5.1.100.13)	
2	Panel Builder 800	ABB	5.1/0 (Build 353)	
3	GridVis software used for configuration and monitoring of PQMs	Janitza	3.1.1	
4	ProSoft Configuration Builder	ProSoft	4.1.0 (Build 4)	

Table 9-25, Required Programming and Configuration Software

REQUIRED COMPONENT SOFTWARE AND FIRMWARE

The following component software and firmware (including specific versions) is required for the test. Ensure all software and firmware is up-to-date. During the test, fill in the actual version of the software and firmware.

Item	Component Description	Man. / Model	Required Version	Actual Version
1	PLC - Processor Module - SEC	ABB / PM860	Firmware: FW866 5.1.100.13 2011-04-17 (BasicHwLib 5.1-0) Application: Rev TBD	
2	PLC - Processor Module - PCS100	ABB / PM856	Firmware: FW866 5.1.100.13 2011-04-17 (BasicHwLib 5.1-0) Application: Rev TBD	
3	CEX - Modbus TCP Module	ABB / CI867	Firmware: FWCI867 5.1.0111.0 (CI867ModbusTcpHwLib 2.0-30)	
4	HMI - Operator Interface - SEC	ABB / PP840	Application: Rev TBD	
5	HMI - Operator Interface - PCS100	ABB / PP835	Application: Rev TBD	
6	PCS100 - Lineup #1 Controller	ABB / PCS100 Master Controller	Firmware: R2I3	
7	PCS100 - Lineup #2 Controller	ABB / PCS100 Master Controller	Firmware: R2I3	
8	COM600	ABB / COM600HRH22TPNNNND	SW Ver: 4.0	
9	Section Controller	LGC / Battery System Controller	Section Controller SW Ver: TBD	
10	Battery Management System	LGC / Battery System Controller	BMS Firmware Ver: TBD BMS Hardware Ver: 1.0	

Table 9-26, Required Component Software and Firmware

TEST PREREQUISITES

The prerequisites for acceptance testing are:
- All commissioning tasks are completed.
- The BESS is ready for coordinated control, and all SEC local control functions have been tested (Q Control, V Control, P control, Standby Mode, SOC Control, and Maintain SOC Control).
- The SEC/SCE communication interfaces (EMS DNP3/Modbus TCP/IP and GMS DNP3/Modbus TCP/IP) are tested and fully functional.[24]

Set the following on the SEC Reference screen for all tests, unless specified otherwise by a specific test:
- SOC Max [%] = 100
- SOC Min [%] = 1.5
- SOC DB [%] = 0.5
- V [kV] = 66
- P Charge [kW] = -8000
- P Discharge [kW] = 8000
- P Ramp + [kW/sec] = 800
- P Ramp - [kW/sec] = 800
- Fully Charge BESS = Off
- Fully Discharge BESS = Off
- Maintain SOC Allowed for T1&T4 = On
- V Ctrl Selected for T3, T4 or T5 = On
- Critical Testing = On

IEC61850 INTERFACE AND LOCAL HISTORIAN

All logged signals should be recorded throughout the acceptance testing by the IEC61850 and Local Data Historian. Signals should be properly logged in the local historian and transferred to the SCE IEC61850 historian. Signals should be verified for accuracy and scaling per the IEC61850 & Local Historian Data document (3AUP080A108-V3).

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[24] If any of these interfaces are not functional at the time of testing, the corresponding SEC EMS and/or GMS Test mode will be used for system acceptance testing.

TEST PLAN FOR BESS POWER ACCURACY (DAY 1)

The purpose of this test is to verify the output accuracy of the BESS at several real and reactive power set points. Active and reactive power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s).

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC, in order to have adequate charge and discharge capacity throughout the test.
- Using P Control and/or Q Control (Local Control), set the following in succession on the Reference screen. Wait at least one minute after each setting and then verify the actual output.

Step	Real	Reactive	Description
1	-8 MW	0 MVAr	Maximum active charge
2	-4 MW	0 MVAr	Mid-range active charge
3	-1 MW	0 MVAr	Small active charge
4	1 MW	0 MVAr	Small active discharge
5	4 MW	0 MVAr	Mid-range active discharge
6	8 MW	0 MVAr	Maximum active discharge
7	0 MW	-4 MVAr	Maximum reactive consume
8	0 MW	-2 MVAr	Mid-range reactive consume
9	0 MW	-0.5 MVAr	Small reactive consume
10	0 MW	0.5 MVAr	Small reactive supply
11	0 MW	2 MVAr	Mid-range reactive supply
12	0 MW	4 MVAr	Maximum reactive supply
13	-4 MW	-2 MVAr	Mid-range active charge, reactive consume
14	-4 MW	2 MVAr	Mid-range active charge, reactive supply
15	4 MW	-2 MVAr	Mid-range active discharge, reactive consume
16	4 MW	2 MVAr	Mid-range active discharge, reactive supply
17	-8 MW	-0.5 MVAr	Maximum active charge, small reactive consume
18	-8 MW	0.5 MVAr	Maximum active charge, small reactive supply
19	8 MW	-0.5 MVAr	Maximum active discharge, small reactive consume
20	8 MW	0.5 MVAr	Maximum active discharge, small reactive supply
21	-1 MW	-4 MVAr	Small active charge, maximum reactive consume
22	-1 MW	4 MVAr	Small active charge, maximum reactive supply
23	1 MW	-4 MVAr	Small active discharge, maximum reactive consume
24	1 MW	4 MVAr	Small active discharge, maximum reactive supply

The BESS shall exchange real and reactive power at the set points above, with an error no greater than +/- 3 percent of rated output (+/- 240 kW and +/- 120 kVAr).

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST PLAN FOR BESS REACTIVE POWER TESTS (DAY 2)

The purpose of this test is to verify that the BESS can deliver 4MVAr of reactive power and 8MW of real power as measured at the 12.47kV monitoring point. Active and reactive power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s).

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC, in order to have adequate charge and discharge capacity throughout the test.
- Using Q Control (Local Control) with a 4MVAr Q set point, the BESS shall supply 4MVAr for one hour (no active power will be exchanged).
- Using Q Control (Local Control) with a -4MVAr Q set point, the BESS shall consume 4MVAr for one hour (no active power will be exchanged).
- Using P Control (Local Control) with an 8MW P set point and Q Control (Local Control) with a 4MVAr Q set point, the BESS shall discharge at 8MW and supply 4MVAr for one hour.
- Using P Control (Local Control) with a -8MW P set point and Q Control (Local Control) with a 4MVAr Q set point, the BESS shall charge at 8MW and supply 4MVAr for one hour.
- Using P Control (Local Control) with an 8MW P set point and Q Control (Local Control) with a -4MVAr Q set point, the BESS shall discharge at 8MW and consume 4MVAr for one hour.
- Using P Control (Local Control) with a -8MW P set point and Q Control (Local Control) with a -4MVAr Q set point, the BESS shall charge at 8MW and consume 4MVAr for one hour.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST PLAN FOR BESS CAPACITY (DAYS 3, 4, AND 5)

The purpose of this test is to verify that the BESS can deliver 8MW of active power and 32MWh of energy over a 4 hour period as measured at the 12.47kV monitoring point.[25] Active power and energy measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s).

The test shall be performed in the following manner:

- The BESS shall begin each cycle at 30% +/- 0.5% SOC.
- Using P Control (Local Control) with Fully Charge BESS On, the BESS shall charge at 8MW and unity PF, automatically scaling back as it nears full charge, until the SOC reaches 100% (or a level considered to be equivalent to a complete charge as defined by LG).
- After an optional rest (P Control off and Maintain SOC on) of up to 1 hour, using P Control (Local Control) and Fully Discharge BESS On, the BESS shall discharge at 8MW and unity PF, until the SOC reaches 1.5% (or a level considered to be equivalent to a complete discharge as defined by LG).
- After an optional rest (P Control off and Maintain SOC on) of up to 1 hour, using SOC Control (Local Control) with a 30% SOC set point and a 0.5% dead band, the BESS shall charge at maximum available charge power and unity PF, until the SOC reaches 30% +/- 0.5%.
- After an optional rest (P Control off and Maintain SOC on), the cycle shall be repeated two additional times within 72 hours.
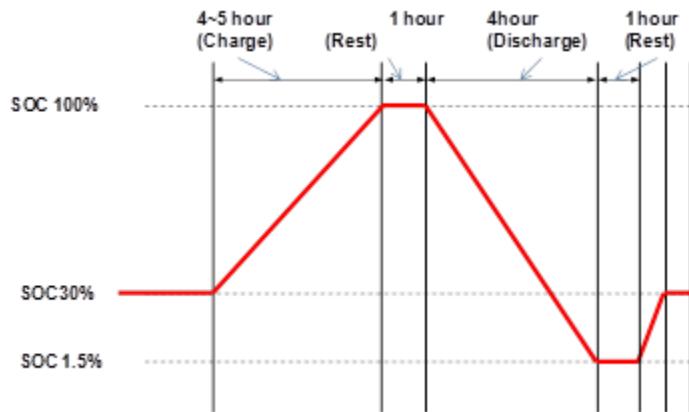
Figure 9-35, BESS Capacity Charge and Discharge Profile

The BESS shall provide a minimum of 8MW of AC active power and 32MWh of AC energy during each cycle.[25]

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

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[25] Energy capacity is subject to revision per mutual agreement between SCE and LG Chem.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST PLAN FOR BESS RAMP RATE TEST (DAY 6)

The purpose of this test is to verify that the BESS can provide approximately 10-minute active power charge and discharge ramps from 0MW to 8MW. Active power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s).

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC, in order to have adequate charge and discharge capacity throughout the test.
- In addition to Section 4, Test Prerequisites, set the following on the Reference screen:
  - P Ramp + [kW/sec] = 13
  - P Ramp – [kW/sec] = 13
- Using P Control (Local Control) with an 8MW P set point, the BESS shall ramp linearly from 0MW to an 8MW discharge at unity power factor over approximately 10 minutes, and then sustain an 8MW discharge for one hour.
- After the one hour discharge, using P Control (Local Control) with a 0MW P set point, the BESS shall ramp linearly from an 8MW discharge to 0MW over approximately 10 minutes.
- After an optional rest (P Control off and Maintain SOC on) of up to 1 hour, using P Control (Local Control) with a -8MW P set point, the BESS shall ramp linearly from 0MW to an 8MW charge at unity power factor over approximately 10 minutes, and then sustain an 8MW charge for one hour.
- After the one hour charge, using P Control (Local Control) with a 0MW P set point, the BESS shall ramp linearly from an 8MW charge to 0MW over approximately 10 minutes.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST PLAN FOR BALANCING FUNCTION TEST (DAY 7)

The purpose of this test is to verify that the BESS can balance the four battery sections to within 1% SOC of each other while the system is discharged from a slightly unbalanced condition.

NOTE: The purpose of the SOC balancing function is to keep the SOC of all four battery sections within 1% SOC of each other during a discharge. The SOC balancing function is not intended to correct SOC imbalances if the four battery sections are at significantly different SOCs prior to the start of a discharge.

The test shall be performed in the following manner:

- Using P Control (Local Control) with a -8MW P set point, the BESS shall charge at 8MW and unity PF, automatically scaling back as it nears full charge, until the SOC reaches 100% (or a level considered to be equivalent to a complete charge as defined by LG).
- After an optional rest (P Control off and Maintain SOC on) of up to 1 hour, shut down the PCSs for battery sections 2, 3, and 4. Only the PCS for battery section 1 shall be online.
- Using P Control (Local Control) with an 8MW P discharge set point, the BESS shall discharge at maximum power possible with battery section 1.
- Stop the discharge once battery section 1 reaches 97% SOC. Start the PCSs for battery sections 2, 3, and 4. All PCSs shall be online.
- After an optional rest of up to 30 minutes, using P Control (Local Control) with a 4MW P discharge set point, the BESS shall discharge at maximum power possible until the four battery sections are within 1% SOC of each other, and then discharge at 4MW until the SOC reaches 1.5% (or a level considered to be equivalent to a complete discharge as defined by LG).

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST PLANS FOR EMS TESTS

TEST 1, STEADY STATE VOLTAGE REGULATION (DAY 8)

The purpose of this test is to verify that the BESS can provide up to 4MVAr of reactive power injection/absorption to maintain the Monolith 66kV bus voltage within +/- 5%, while also exchanging real power as needed to maintain the battery SOC throughout the test. Active and reactive power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s), and voltage measurements will be obtained by the 66kV Janitza PQM.

The test shall be performed in the following manner:

-   The BESS shall begin the test at approximately 50% SOC.
-   Using Test 1 (EMS Test) with a 66kV V set point, the BESS shall provide up to 4MVAr of reactive power injection/absorption, and shall maintain the Monolith 66kV bus voltage within +/- 5% for at least 6 hours.

The 66kV bus voltage tolerance may be exceeded only if the BESS is operating at its maximum reactive power capacity of 4MVAr, and 4MVAr is still not sufficient to maintain the voltage within the tolerance. The BESS shall also exchange real power as needed to maintain the battery SOC within +/- 1% of the SOC at the start of the test.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST 2, STEADY STATE VOLTAGE REGULATION UNDER ANY MODE, AND TEST 3, CHARGE DURING HIGH LINE LOAD/DISCHARGE DURING LOW LINE LOAD (DAY 9)

The purpose of this test is to verify that the BESS can charge during periods of high line loading and discharge during periods of low line loading, while concurrently providing up to 4MVAr of reactive power injection/absorption to maintain the Monolith 66kV bus voltage within +/- 5%. The BESS should also exchange real power as needed to maintain battery SOC during periods of inactivity. Active and reactive power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s), and voltage measurements will be obtained by the 66kV Janitza PQM.

NOTE: Test 2 is not explicitly selected on the SEC EMS Test screen like Test 1, Test 3, Test 4, or Test 5. Instead, Test 2 (which provides voltage regulation and may be operated in conjunction with one of the other tests) is enabled by turning on the V Control selection on the Reference screen.

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC.
- In addition to Section 4, Test Prerequisites, set the following on the Reference screen:
    o I_Calc_Lim1 = 646
    o I_Calc_Lim2 = 610
    o I_Calc_Lim1_Lower = 320
    o I_Calc_Lim2_Lower = 300
    o I_Limit_Lower_Deadband = 10
    o I_Limits_Deadband = 10
    o T_Lim = 80
    o I_Line1_Lim1 = 486
    o I_Line1_Lim2 = 450
    o I_Line1_Lim1_Lower = 200
    o I_Line1_Lim2_Lower = 180
- Set the following on the EMS Test screen:
    o I_Line1_Act [A] = 490
    o I_Line2_Act [A] = 0
    o T_Act [F] = 70
    o I_Line1_Act_Coef = 1
    o I_Line2_Act_Coef = .31
- Using Test 3 (EMS Test), the BESS shall provide up to 4MVAr of reactive power injection/absorption, and shall maintain the Monolith 66kV bus voltage within +/- 5%.
- Set the following in succession on the EMS Test screen. Wait at least five minutes after each setting, and then record the actual behavior.

Step	Setting	Expected Behavior
1	I_Line1_Act = 477	System charges
2	I_Line1_Act = 449	System maintains SOC
3	T_Act = 90	System maintains SOC
4	I_Line1_Act = 439	System maintains SOC
5	I_Line1_Act = 437	System maintains SOC
6	I_Line2_Act = 562	System charges
7	I_Line2_Act = 547	System charges
8	I_Line2_Act = 500	System maintains SOC
9	T_Act = 70	System maintains SOC

10	I_Line2_Act = 678	System charges
11	I_Line2_Act = 646	System charges
12	I_Line2_Act = 600	System maintains SOC
13	I_Line2_Act = 0	System maintains SOC
14	I_Line1_Act = 201	System discharges
15	I_Line1_Act = 199	System discharges
16	I_Line1_Act = 208	System discharges
17	I_Line1_Act = 210	System discharges
18	T_Act = 90	System discharges
19	I_Line1_Act = 179	System discharges
20	I_Line1_Act = 188	System discharges
21	I_Line1_Act = 200	System discharges

The BESS shall charge, discharge, and maintain SOC per the expected behavior above, and the Test 3 algorithm in Section 6.7 of the Tehachapi Wind Energy Storage Project Control and Interface Concept document (3AUP080A108-V1, revision TBD). The 66kV bus voltage tolerance may be exceeded only if the BESS is operating at its maximum reactive power capacity of 4MVAr, and 4MVAr is still not sufficient to maintain the voltage within the tolerance. The BESS shall also exchange real power as needed to maintain battery SOC within +/- 1% of the SOC at the start of a maintain SOC period.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST 2, STEADY STATE VOLTAGE REGULATION UNDER ANY MODE, AND TEST 4, CHARGE OFF-PEAK/DISCHARGE ON-PEAK (DAY 10)

The purpose of this test is to verify that the BESS can discharge during on-peak periods and charge during off-peak periods, while concurrently providing up to 4MVAr of reactive power injection/absorption to maintain the Monolith 66kV bus voltage within +/- 5%. The BESS shall also exchange real power between on/off-peak periods as needed to maintain battery SOC. Active and reactive power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s), and voltage measurements will be obtained by the 66kV Janitza PQM.

NOTE: Test 2 is not explicitly selected on the SEC EMS Test screen like Test 1, Test 3, Test 4, or Test 5. Instead, Test 2 (which provides voltage regulation and may be operated in conjunction with one of the other tests) is enabled by turning on the V Control selection on the Reference screen.

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC.
- In addition to Section 4, Test Prerequisites, set the following on the Reference screen:
  o P Charge [kW] = -4000
  o P Discharge [kW] = 4000
  o Off Peak Period = Mo-Fr 0900-1200
  o On Peak Period = Mo-Fr 1300-1600

NOTE: The Off Peak and On Peak periods may be adjusted to accommodate actual test times, as long as the two periods are at least three continuous hours each, with a continuous one hour break between.

- Using Test 4 (EMS Test), the BESS shall provide up to 4MVAr of reactive power injection/absorption, and shall maintain the Monolith 66kV bus voltage within +/-5%.

The BESS shall charge at 4MW from 9:00 to 12:00, maintain SOC from 12:00 to 13:00, and discharge at 4MW from 13:00 to 16:00. The 66kV bus voltage tolerance may be exceeded only if the BESS is operating at its maximum reactive power capacity of 4MVAr, and 4MVAr is still not sufficient to maintain the voltage within the tolerance. The BESS shall also exchange real power between on/off-peak periods (inter-on/off-peak period) as needed to maintain battery SOC within +/- 1% of the SOC at the start of the inter-on/off-peak period.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST 2, STEADY STATE VOLTAGE REGULATION UNDER ANY MODE, AND TEST 5, CHARGE AND DISCHARGE AS NEEDED FOR GRID PURPOSES (DAY 11)

The purpose of this test is to verify that the BESS can charge and discharge as needed for grid purposes by accurately following wind turbine generation data. Whenever wind power quickly increases or decreases, the BESS will charge or discharge in the opposite direction to cancel out the non-compliant power ramp. This test will also verify that the BESS can concurrently provide up to 4MVAr of reactive power injection/absorption to maintain the Monolith 66kV bus voltage within +/- 5%. Active and reactive power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s), and voltage measurements will be obtained by the 66kV Janitza PQM.

NOTE: Test 2 is not explicitly selected on the SEC EMS Test screen like Test 1, Test 3, Test 4, or Test 5. Instead, Test 2 (which provides voltage regulation and may be performed in conjunction with one of the other tests) is enabled by turning on the V Control selection on the Reference screen.

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC.
- In addition to Section 4, Test Prerequisites, set the following on the Reference screen:
    o P_WT_Act Allowed Ramp + [kW/sec] = 17
    o P_WT_Act Allowed Ramp - [kW/sec] = 17
- Set the following on the EMS Test screen:
    o P_WT_Act [MW] = 1000
    o P_WT_Act_Coef = 1
- Using Test 5 (EMS Test), the BESS shall provide up to 4MVAr of reactive power injection/absorption, and shall maintain the Monolith 66kV bus voltage within +/- 5%.
- Set the following in succession on the EMS Test screen and then record the actual behavior.

Step	Setting	Expected Behavior
1	P_WT_Act [MW] = 1005	System follows P ramp and charges at approximately 5MW, and then ramps to 0MW over approximately five minutes
2	P_WT_Act [MW] = 995	System follows P ramp and discharges at 8MW for two minutes, and then ramps to 0MW over approximately eight minutes
3	P_WT_Act [MW] = 1000	System follows P ramp and charges at approximately 5MW, and then ramps to 0MW over approximately five minutes
4	P_WT_Act [MW] = 1010	System follows P ramp and charges at 8MW for two minutes, and then ramps to 0MW over approximately eight minutes
5	P_WT_Act [MW] = 1003	System follows P ramp and discharges at approximately 7MW, and then ramps to 0MW over approximately seven minutes
6	P_WT_Act [MW] = 1000	System follows P ramp and discharges at approximately 3MW, and then ramps to 0MW over approximately three minutes

- Repeat the sequence at least five additional times.

The BESS shall charge and discharge per the expected behavior above. The 66kV bus voltage tolerance may be exceeded only if the BESS is operating at its maximum reactive power capacity of 4MVAr, and 4MVAr is still not sufficient to maintain the voltage within the tolerance.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

EMS–GMS TRANSITION (DAY 12)

The purpose of this test is to verify that the BESS exhibits the expected behavior when transitioning between EMS and GMS operation under different scenarios. Active power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s).

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC.
- In addition to Section 4, Test Prerequisites, set the following on the Reference screen:
  - Maintain SOC Allowed for T4 = Off
  - V Ctrl Selected for T3, T4, or T5 = Off
  - Off Peak Period = Mo-Fr 2359-0001
  - On Peak Period = Mo-Fr 0001-2359
- Set the following on the GMS Test screen:
  - P_GMS_SetPoint [kW*10] = 400
- Using Test 4 (EMS Test), the BESS shall discharge at 8MW.
- Set the following in succession on the indicated screens and then record the actual behavior.

Scenario	Step	Screen	Setting	Expected Behavior
EMS running test and GMS idle	1	EMS Test	Non Grid Functions = On	BESS Status Alarm, Maintain SOC on
	2	GMS Test	AGC_Man = On	Same
	3	GMS Test	AGC_Man = Off	Same
	4	EMS Test	Non Grid Functions = Off	BESS Status OK, system discharges at 8MW
EMS and GMS running tests	5	GMS Test	AGC_Man = On	Same
	6	EMS Test	Non Grid Functions = On	BESS Status Alarm, Maintain SOC on
	7	EMS Test	Non Grid Functions = Off	BESS Status OK, system discharges at 8MW
	8	GMS Test	AGC_Man = Off	System continues discharging at 8MW
EMS and GMS idle	9	EMS Test	T4 Start = Off	System idles
	10	EMS Test	Non Grid Functions = On	Same
	11	GMS Test	AGC_Man = On	System discharges at 4MW
	12	GMS Test	AGC_Man = Off	System idles
	13	EMS Test	Non Grid Functions = Off	Same
EMS idle and GMS running test	14	GMS Test	AGC_Man = On	Same
	15	EMS Test	Non Grid Functions = On	System discharges at 4MW
	16	EMS Test	Non Grid Functions = Off	System Idles
	17	GMS Test	AGC_Man = Off	Same

The BESS shall discharge or idle per the expected behavior above.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

EMS AND GMS COMMUNICATION FAULT HANDLING (DAY 12)

The purpose of this test is to verify that the BESS exhibits the expected behavior when encountering EMS and GMS communication faults under different scenarios. Active power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s).

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC.
- In addition to Section 4, Test Prerequisites, set the following on the Reference screen:
  - Fully Charge BESS = On
  - Maintain SOC Allowed for T4 = Off
  - V Ctrl Selected for T3, T4, or T5 = Off
  - Off Peak Period = Mo-Fr 2359-0001
  - On Peak Period = Mo-Fr 0001-2359
- Set the following on the Control Mode screen:
  - SEC Control Point Selection = Remote
  - P Control = On
- Set the following on the GMS Test screen:
  - AGC_Man = On
  - P_GMS_SetPoint [kW*10] = 400
- Using Test 4 (EMS Test), the BESS shall discharge at 8MW.
- Set the following in succession on the indicated screens. Wait a maximum of five minutes after each setting and then record the actual behavior.

Scenario	Step	Screen	Setting	Expected Behavior
EMS running test with EMS comm. Fault	1	EMS Test	Stop EMS Test Heartbeat = On	EMS Communication Fault, BESS Status Alarm, Allow Local Control Actual Value Yes, system idles
	2	EMS Test	Stop EMS Test Heartbeat = Off	EMS Communication OK, BESS Status OK, Allow Local Control Actual Value No, system discharges at 8MW
EMS running test with GMS comm. fault	3	GMS Test	Stop GMS Test Heartbeat = On	GMS Communication Fault, system continues discharging at 8MW
	4	GMS Test	Stop GMS Test Heartbeat = Off	GMS Communication OK, system continues discharging at 8MW
GMS running test with GMS comm. fault	5	EMS Test	T4 Start = Off	System idles
	6	EMS Test	Non Grid Functions = On	System discharges at 4MW
	7	GMS Test	Stop GMS Test Heartbeat = On	GMS Communication Fault, BESS Status Alarm, Maintain SOC on
	8	GMS Test	Stop GMS Test Heartbeat = Off	GMS Communication OK, BESS Status OK, system discharges at 4MW
GMS running test with EMS comm. fault	9	EMS Test	Stop EMS Test Heartbeat = On	EMS Communication Fault, BESS Status Alarm, Allow Local Control Actual Value Yes, system idles
	10	EMS Test	Stop EMS Test Heartbeat = Off	EMS Communication OK, BESS Status OK, Allow Local Control Actual Value No, system continues discharging at 4MW

The BESS shall discharge and idle per the expected behavior above.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST PLAN FOR GMS TESTS

MANUAL AND ISO POWER DISPATCH (DAY 12)

The purpose of this test is to verify that the BESS can dispatch active power using GMS commands. Active power measurements will be obtained by the 12.47kV Janitza PQMs.

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC.
- Using AGC_Man (GMS Test) with an 8MW P GMS Set Point, the BESS shall discharge at 8MW for ten minutes.
- Using AGC_Man (GMS Test) with a -8MW P GMS Set Point, the BESS shall charge at 8MW for ten minutes.
- Using AGC_ISO (GMS Test) with a 4MW P ISO AGC Set Point, the BESS shall discharge at 4MW for ten minutes.
- Using AGC_ISO (GMS Test) with a -4MW P ISO AGC Set Point, the BESS shall charge at 4MW for ten minutes.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST REVIEW (DAYS 13 AND 14)

Days 13 and 14 are reserved for reviewing and organizing test results, and for completing any necessary retests.

APPENDIX A – TEST NOTES

FILL IN NOTE ID -
NOTE:

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9.10   Appendix J: List of Issues and Events that had an Impact on System Availability

Start Date/Time	End Date/Time	Total Power Available	Total Energy Available	Duration of Event (h:m:s)	Description of Event & Resolution	Parts Replaced
2014-08-19 T 08:35	2014-08-27 T 08:55	0	0	192:20:00	System shut down for grid outage.	N/A
2014-09-11 T 09:38	2014-09-11 T 22:07	0	0	12:29:00	System shut down due to substation transformer outage.	N/A
2014-09-16 T 08:39	2014-09-17 T 10:26	0	0	25:47:00	Replaced Section 2 bank 4 rack 17 DC protection box & section 1 bank 2 rack 17 module 17	S2B4R17 DC Protection Box S1B2R17 Module 17
2014-09-17 T 10:26	2014-09-23 T 15:00	0	0	148:34:00	System offline due to substation maintenance outage and PCS filter change	PCS Filters
2014-09-24 T 10:00	2014-09-24 T 13:00	0	0	3:00:00	TSP Ribbon Cutting Tours	N/A
2014-09-30 T 08:04	2014-10-04 T 08:00	0	0	95:56:00	Substation Maintenance Outage	N/A
2014-10-06 T 08:00	2014-10-10 T 11:00	0	0	99:00:00	PCS module replacement and transformer thermal barrier installation.	PCS 2 module replaced PCS 2 smoke detector replaced PCS 12 kV transformer heat shields installed
2014-10-14 T 11:00	2014-10-22 T 15:01	0	0	196:01:00	System shutdown for substation maintenance outage, SCE tour, LG tour, and ABB work on PCS. ABB rebooted PCS 2 GDM to resolve error messages observed by LG.	N/A
2014-10-23 T 17:06	2014-10-27 T 12:30	4	16	91:23:25	PCS 2 tripped offline due to ac/dc breakers opened unexpectedly and smoke detector	N/A

					error. Issue still present.	
2014-10-27 T 12:30	2014-10-29 T 15:00	0	0	50:30:00	Entire system tripped offline due to No. 3 bank opened by Vincent to perform switching related to a CB with low gas charge. PCS 2 investigation found and corrected loose wire nut for smoke detector power circuit to correct smoke detector alarms. Replaced master controller and relay to correct startup-related alarms.	PCS 2 Master Controller PCS 2 Relay
2014-10-31 T 16:49	2014-11-04 T 12:00	0	0	91:11:00	System shutdown for precautionary measure in case of rain and roof leaks. Replaced display panel on fire suppression system and updated section controller software and BMS firmware.	Fire suppression system display panel
2014-11-05 T 08:51	2014-11-05 T 12:00	6	24	3:09:00	PCS 1 Section 1 tripped by unknown cause. Reset and restarted PCS 1 Section 1.	N/A
2014-11-05 T 10:20	2014-11-06 T 12:00	8	32	25:40:00	S2B4R3 tripped due to current sensor wire error. Replaced battery protection unit (BPU) to address trip.	S2B4R3 battery protection unit
2014-11-06 T 12:30	2014-11-06 T 12:45	4	16	0:15:00	PCS 2 tripped due to smoke alarm issue. Reset and restarted PCS.	N/A

2014-11-18 T 07:54	2014-11-21 T 07:31	0	0	71:37:00	System offline for LG and ABB to troubleshoot PCS 2 trip on smoke detector alarm issue.	N/A
2014-11-26 T 14:16	2014-12-09 T 15:00	0	0	312:44:00	System offline to close 12kV CB and have open house internally.	N/A
2014-12-15 T 11:55	2014-12-16 T 17:27	0	0	29:32:00	System shutdown for PBS News Hour interview/filming.	N/A
2014-12-18 T 21:18	2014-12-19 T 11:59	0	0	14:41:00	System shutdown for Vincent 66kV relay testing.	N/A
2014-12-24 T 01:08	2015-01-12 T 20:00	6	24	474:51:31	Lineup 1 tripped due to fire system trouble. Tried reconnecting on 2014-12-24 T 12:00 but could not due to DC breaker FC0001 T unexpected status. PCS 1 disconnect opened to further investigate. Issue still present.	N/A
2015-01-12 T 20:00	2015-01-13 T 13:30	4	16	17:30:00	PCS 1 offline to investigate lineup 1 trip. Changed PCS 1 12kV transformer tap and software settings to allow operation at lower voltage. Charged section 1 racks in BMS manual mode. Issue still present.	N/A
2015-01-13 T 13:30	2015-04-21 T 09:34	0	0	2348:04:00	System shutdown due to two blown disconnect fuses on No. 3 bank 12kV rack. Determined PCS 1 & 2 12kV transformers require replacement due to design flaw that	PCS 1 & 2 12kV/480V transformers

					doesn't allow unbalanced/single lineup operation. Replaced both PCS 1 & 2 12kV/480V transformers.	
2015-04-22 T 08:53	2015-04-22 T 17:00	0	0	8:07:00	S2B4R6 & S3B5R11 tripped due to Under Voltage Faults. Replaced two modules.	S2B4R6 module S3B5R11 module
2015-05-06 T 05:50	2015-05-08 T 08:00	6	24	50:09:20	Section 2 PCS tripped due to current sensor wire error. System shutdown to investigate. Issue still present.	N/A
2015-05-08 T 08:00	2015-05-08 T 20:00	0	0	12:00:00	System shutdown to investigate section 2 issue. S2B2R6 battery protection unit replaced. S2B3R1 18 modules replaced.	S2B2R6 Battery Protection Unit S2B3R1 18 modules
2015-05-18 T 08:15	2015-05-18 T 20:00	0	0	11:45:00	Outdoor E-stop cover installation and site visit.	N/A
2015-05-20 T 08:00	2015-05-21 T 10:45	0	0	26:45:00	System shutdown for SEC software updates. Reinstalled backup battery in SEC PLC.	N/A
2015-06-13 T 14:20	2015-06-15 T 10:33	6	24	44:12:36	PCS 2 Lineup 3 tripped due to Battery Communication Loss. Restarted PCS 2 Lineup 3.	N/A
2015-06-16 T 10:48	2015-06-23 T 10:00	4	16	167:12:00	PCS 2 tripped. Found blown fuse for PCS 2 Lineup 3 PCC voltage measurement & replaced.	PCC voltage measurement fuse

2015-06-23 T 10:14	2015-06-23 T 11:40	0	0	1:26:00	System shutdown to check PCC voltage measurement.	N/A
2015-06-29 T 09:52	2015-06-29 T 22:00	0	0	12:08:00	System shutdown for BMS update.	N/A
2015-07-15 T 17:09	2015-07-15 T 18:36	4	16	1:26:49	PCS 1 Section 1 and 2 tripped on transformer temperature high fault. Issues still present.	N/A
2015-07-15 T 18:36	2015-07-22 T 21:30	0	0	170:54:00	Shutdown system for Monolith Substation work. Restarted PCS 2 but kept PCS 1 offline.	N/A
2015-07-22 T 21:30	2015-07-23 T 15:44	4	16	18:14:55	PCS 1 still offline due to transformer temperature high fault. Issue still present.	N/A
2015-07-23 T 15:44	2015-07-24 T 13:20	2	8	21:35:05	PCS 1 offline due to transformer temperature high fault. Lineup 4 Section 4 tripped. Lineup 4 restarted. PCS 1 issue still present.	N/A
2015-07-24 T 13:20	2015-07-24 T 16:15	4	16	2:55:00	PCS 1 offline due to transformer temperature high fault. Issue still present.	N/A
2015-07-24 T 16:15	2015-08-24 T 17:00	0	0	744:45:00	System offline due to unplanned Monolith work; PCS 1 is still offline due to transformer temperature high fault. Installed BSC software version 3.1, removed insulation in PCS 1 transformer, and restored system to operation.	N/A

2015-08-24 T 17:00	2015-08-25 T 12:00	0	0	19:00:00	S3B6R16 Module 13 & 15 bad. Replaced both modules.	S3B6R16 Module 13 & 15
2015-09-02 T 14:21	2015-09-03 T 11:00	6	24	20:39:00	PCS 2 Lineup 3 tripped due to Battery Communication Loss. Restarted PCS 2 Lineup 3.	N/A
2015-09-14 T 08:38	2015-09-15 T 15:00	4	16	30:22:00	While fixing S1B5R11, Section 1 and 2 tripped. Replaced S2B5R11 Module 15. Reset PCS 1.	S2B5R11 Module 15
2015-09-20 T 13:10	2015-09-24 T 20:30	8	32	103:19:41	S2B2R6 offline due to Over Charge Power Limit Warning. S2B5R11 offline due to under SOC warning. Attempted to charge S2B5R11 but rack fuse blew. Replaced fuse.	S2B5R11 fuse
2015-10-15 T 01:00	2015-10-15 T 16:07	0	0	15:07:00	System tripped due to various loss of communication messages. This was due to electrical storms in the area. Restarted system. S2B5R11 offline due to module loss of communication. Lineup 4 unable to start.	N/A
2015-10-15 T 16:07	2015-10-21 T 19:16	6	24	147:09:00	S2B5R11 offline due to module loss of communication. Lineup 4 offline due to BSC 4 computer issues. Power cycled section 4 BMS and restarted system. S2B5R11 still offline.	N/A

2015-10-26 T 07:33	2015-10-30 T 13:05	6	24	101:32:00	S2B5R11 offline due to module loss of communication. Lineup 4 offline without access to Section 4 BSC. Issue still present.	N/A
2015-10-30 T 13:05	2015-11-02 T 23:00	6	24	81:55:00	S2B5R11 offline due to module loss of communication. Lineup 4 offline without access to Section 4 BSC. P1L2M12 offline due to zero sequence absolute current high. Restarted PCS 1 Lineup 2 to restore M12. Section 4 restarted and restored to operation. S2B5R11 fuse replaced and restored to operation.	S2B5R11 Fuse
2015-11-03 T 08:30	2015-11-06 T 09:54	6	24	73:24:18	Section 4 offline. Issue still present.	N/A
2015-11-06 T 09:54	2015-11-06 T 10:50	4	16	0:55:42	Section 4 and section 2 offline due to battery communication loss. Section 2 restarted after battery communication loss cleared. Section 4 still offline.	N/A
2015-11-06 T 10:50	2015-11-16 T 03:00	4	16	232:10:00	Section 4 still offline. Section 1 tripped when resetting section 2. Issues still present.	N/A
2015-11-16 T 03:00	2015-11-16 T 11:15	0	0	8:15:00	Sections 1/4 still offline. Section 2/3 tripped caused by auxiliary power voltage sag. Section 1 restored partially	N/A

					with bank 7 and one other rack offline. Other sections still offline.	
2015-11-16 T 11:15	2015-11-18 T 16:00	2	7	52:45:00	Section 2/3/4 offline. Section 1 partially online with bank 7 and one rack offline. Replaced section 4 BSC and restored section 1, 2, and 3 by power-cycling BMS.	Section 4 BSC
2015-11-19 T 15:25	2015-11-23 T 08:01	6	24	88:36:00	Lineup 3 tripped due to battery communication loss. Issue still present.	N/A
2015-11-23 T 08:01	2015-11-23 T 15:17	4	16	7:16:00	Lineup 3 still tripped. Lineup 4 offline due to clock synchronization. Restarted system and synchronized section 4 BSC clock.	N/A
2015-11-27 T 13:16	2015-12-03 T 14:57	6	24	145:41:00	Lineup 4 tripped due to battery communication loss. Restarted BSC and restored lineup 4.	N/A
2015-12-03 T 12:00	2015-12-11 T 08:15	6	24	188:15:00	Lineup 3 tripped due to communication loss. Lineup 3 controller froze during reboot. Rebooted and restarted lineup.	N/A
2015-12-12 T 14:37	2015-12-13 T 08:12	6	24	17:35:00	Lineup 3 tripped due to loss of communication with inverter controller. Issue still present.	N/A
2015-12-13 T 08:12	2015-12-17 T 09:05	2	8	96:53:00	Lineup 3 still tripped. PCS 1 tripped on smoke detector fault. Issues still present.	N/A

2015-12-17 T 09:05	2015-12-18 T 17:00	0	0	31:55:00	System shutdown for investigation for Lineup 3 and PCS 1. Found loose connection on lineup 3 controller and replaced PCS 1 smoke detector.	PCS 1 Smoke Detector
2015-12-19 T 14:42	2016-01-13 T 08:00	6	24	593:18:00	Lineup 3 tripped due to inverter not running expectedly. Issue still present.	N/A
2016-01-13 T 08:00	2016-01-13 T 13:00	0	0	5:00:00	System offline due to Lineup 3 investigation. S1B4R3 & S2B1R2 current sensor wire error. Replaced PCS 2 Lineup 3 master controller module and restarted system. S1B4R3 & S2B1R2 still offline.	PCS 2 Lineup 3 master controller module
2016-01-19 T 10:25	2016-01-19 T 16:14	7.72	32	5:49:00	PCS 1 Lineup 2 Module 12 offline. Stopped and restarted all lineups. PCS 1 Lineup 2 Module 12 online.	N/A
2016-01-22 T 13:48	2016-01-22 T 16:15	6	24	2:27:00	Lineup 1 offline due to battery communication loss. Alarms cleared and restarted lineup 1.	N/A
2016-02-18 T 22:28	2016-02-19 T 08:20	7.72	32	9:52:00	PCS 2 Lineup 4 Module 12 offline. Reset fault. Lineup 4 module 12 online.	N/A
2016-02-29 T 01:30	2016-02-29 T 14:33	6	24	13:03:00	PCS 2 lineup 4 offline due to master controller loss of communication with inverter module. PCS 2 lineup 4 online after restarting lineup.	N/A

2016-03-02 T 08:00	2016-03-02 T 21:00	0	0	13:00:00	System shutdown to replace S1B4R3 BPU and S2B1R2 BPU.	S1B4R3 BPU S2B1R2 BPU
2016-03-06 T 22:41	2016-03-07 T 09:05	7.72	32	10:23:05	PCS 1 Lineup 2 Module 12 offline. Stopped and restarted all lineups. PCS 1 Lineup 2 Module 12 online.	N/A
2016-03-09 T 07:26	2016-03-10 T 08:20	7.72	32	24:54:00	PCS 1 Lineup 2 Module 12 offline. Online after PCS 1 reset	N/A
2016-03-10 T 20:52	2016-03-11 T 11:50	8	26	14:58:00	Section 1 Bank 1/2/3/5/7/8 offline. Issue still present.	N/A
2016-03-11 T 11:50	2016-03-11 T 12:27	0	0	0:37:00	Shut system down to bring section 1 bank 1/2/3/5/7/8 back online. Connected all sections.	N/A
2016-03-12 T 11:18	2016-03-18 T 17:01	6	24	149:43:00	Lineup 3 offline due to battery communication loss. S2B5R18 BPU reliability improvement modification, S3B7R1 module replaced, S2B8R18 module replaced, S3B2R18 module replaced. System online.	S2B5R18 BPU modification S3B7R1 module S2B8R18 module S3B2R18 module
2016-03-20 T 03:24	2016-03-21 T 13:00	7.72	32	33:36:00	PCS 1 Lineup 2 Module 12 offline. Online after investigation	N/A
2016-03-24 T 09:09	2016-03-24 T 09:45	7.72	25	0:36:00	PCS 1 Lineup 2 Module 12 offline. Section 1 Bank 2/3/4/5/6/7/8 offline. Issue still present.	N/A
2016-03-24 T 09:45	2016-03-30 T 11:15	5.72	24	145:30:00	PCS 1 lineup 2 module 12 offline. Lineup 1 shutdown	N/A

					to investigate section 1 bank 2/3/4/5/6/7/8. Issue still present.	
2016-03-30 T 11:15	2016-04-06 T 12:00	0	0	168:45:00	System offline due to Monolith Substation work. PCS 1 lineup 2 module 12 issue and section 1 bank 2/3/4/5/6/7/8 issues still present. Replaced S1B5R10 BPU and PCS 1 lineup 2 module 12. System back online.	S1B5R10 BPU PCS 1 L2 Module 12
2016-06-20 T 09:07	2016-06-20 T 15:30	0	0	6:23:00	System offline due to system taken off transfer bus by Vincent. System back on transfer bus and is back online.	N/A
2016-06-27 T 09:15	2016-06-30 T 15:24	4	16	78:09:00	PCS 1 shutdown due to incorrect PCC voltage measurement. Replaced PCS 1 PCC voltage measurement fuse.	PCS 1 PCC voltage measurement fuse
2016-07-08 T 10:10	2016-07-08 T 13:40	0	0	3:30:00	System shut down for battery 12 kV CB check. CB checked and system returned to service.	N/A
2016-07-11 T 07:54	2016-07-19 T 13:43	0	0	197:49:00	System shut down for Monolith CB maintenance. System back online after Monolith CB maintenance	N/A
2016-07-27 T 09:15	2016-07-27 T 14:30	0	0	5:15:00	System shut down to repair HVAC. Replaced compressor in HVAC unit 1 and condenser/fan unit in HVAC unit 2. System returned to	HVAC unit 1 compressor HVAC unit 2 condenser/fan

					service.	
2016-07-28 T 07:30	2016-07-28 T 08:30	4	16	1:00:00	Section 1 and 2 offline to repair section 2 bank 1 rack 2. Replaced BPU in S2B1R2 and returned system to service.	S2B1R2 BPU
2016-08-01 T 09:53	2016-08-04 T 08:55	4	16	71:02:00	PCS 2 in local mode due to section 4 racks offline because of over voltage warning. Manually discharged and balanced section 4 racks to return to service.	N/A
2016-09-08 T 09:12	2016-09-08 T 09:24	6	24	0:12:00	Lineup 4 offline due to battery communication loss. Reset lineups to restore lineup 4.	N/A
2016-09-09 T 09:50	2016-09-09 T 10:23	6	24	0:33:00	Lineup 4 offline due to battery communication loss. Reset lineups to restore lineup 4.	N/A
2016-09-12 T 09:50	2016-09-12 T 20:00	6	24	10:10:00	Lineup 4 offline due to battery communication loss. Switched to alternate the pair of fiber cables between SEC and PCS 2 container. Also replaced S3B1R8 module 7.	S3B1R8 module 7
2016-09-16 T 15:56	2016-09-16 T 16:05	6	24	0:09:00	Lineup 4 offline due to battery communication loss. Issue still present. Switched PCS 2 to local control.	N/A

2016-09-16 T 16:05	2016-09-23 T 14:04	4	16	165:59:00	PCS 2 in local control due to lineup 4 offline. Replaced BSC 4-to-PCS fiber converters in SEC and PCS container and restarted system.	BSC 4-to-PCS fiber converters in SEC/PCS
2016-10-01 T 07:39	2016-10-14 T 08:05	4	16	312:26:00	Lineup 4 offline due to battery communication loss. PCS 2 switched to local control. BSC 4 needs replacement. Returned PCS 2 to remote control to return lineup 3; lineup 4 still offline.	N/A
2016-10-14 T 08:05	2016-10-16 T 04:17	6	24	44:12:00	Lineup 4 still offline due to battery communication loss. Issue still present.	N/A
2016-10-16 T 04:17	2016-10-16 T 19:56	2	8	15:39:00	Lineup 4 still offline due to battery communication loss. PCS 1 tripped due to L1/2 AC/DC CB open unexpectedly. Issues still present.	N/A
2016-10-16 T 19:56	2016-10-18 T 20:00	0	0	48:04:00	Lineup 4 offline due to battery comm loss. PCS 1 offline due to L1/2 AC/DC CB open. Lineup 3 offline due to battery comm loss. Replaced PCS 1/2 smoke detectors which was the cause of PCS trips and replaced BSC 4.	PCS 1/2 smoke detectors BSC 4
2016-10-28 T 08:21	2016-11-02 T 13:41	0	0	125:20:00	PCS 2 tripped due to smoke detector fault. PCS 1 tripped due to L1/2 AC/DC CB open unexpectedly.	PCS 1/2 smoke detectors

					Replaced smoke detectors in both PCS' and restarted system.	
2016-11-04 T 10:35	2016-11-04 T 13:35	4	16	3:00:00	PCS 2 in local control and sections 3 and 4 offline due to BSC 3 Radmin communication issue. Restarted sections and brought lineups 3 and 4 back online.	N/A
2016-11-07 T 10:24	2016-11-07 T 12:29	6	24	2:05:00	Lineup 3 offline due to battery communication loss. Reset lineup to bring it back online.	N/A
2016-11-07 T 19:27	2016-11-17 T 09:44	6	24	230:17:00	Lineup 3 offline due to battery communication loss. Issue still present.	N/A
2016-11-17 T 09:44	2016-11-21 T 00:01	0	0	86:17:00	Lineup 3 offline due to battery communication loss. System shut down for fire system test. After fire test unable to clear battery and AC CB faults to start system. BSC 2 replaced after blue-screening. Loose connections on e-stop time delay relays in PCS 1/2 fixed. Started system	BSC 2
2016-11-22 T 07:35	2016-11-24 T 20:42	6	24	61:07:00	Lineup 3 offline due to battery communication loss. Issue still present.	N/A
2016-11-24 T 20:42	2016-11-26 T 09:26	4	16	36:44:00	Lineup 3 offline due to battery communication loss. Lineup 2 offline due to PCS trip. Issue still present.	N/A

2016-11-26 T 09:26	2016-11-26 T 14:24	0	0	4:58:00	Lineup 3 offline due to battery communication loss. Lineup 2 offline due to PCS trip. System fully offline due to Vincent switching. System back online, but lineup 2/3 issues still present.	N/A
2016-11-26 T 14:24	2016-12-05 T 09:00	4	16	210:36:00	Lineup 3 offline due to battery communication loss. Lineup 2 offline due to PCS trip. Restarted PCS 1 to restart lineup 2. Lineup 3 issue still present.	N/A
2016-12-05 T 09:00	2016-12-07 T 11:09	6	24	50:09:00	Lineup 3 offline due to battery communication loss. Restarted lineup 3.	N/A
2016-12-09 T 12:52	2016-12-12 T 16:10	6	24	75:18:00	Lineup 3 offline due to battery communication loss. Replaced BSC 3 and restarted lineup 3.	BSC 3
2016-12-13 T 03:29	2016-12-13 T 13:20	6	24	9:50:10	Lineup 2 offline due to PCS trip with AC/DC breaker open unexpected. Restored lineup 2 to operation.	N/A
2016-12-31 T 09:04	1/1/2017 0:00	0	0	14:56:00	System shut down for maintenance contract.	N/A

9.11 Appendix K: Glossary of Abbreviations

AC	Alternating Current
ACE	Area Control Error
ADS	Automatic Dispatch Signal
AGC	Automatic Generation Control
ARRA	American Reinvestment & Recovery Act
BBMS	Bank Battery Management System
BESS	Battery Energy Storage System
BMS	Battery Management System
BPU	Battery Protection Unit
BSC	Battery Section Controller
CAISO	California Independent System Operator
CSWE	Current Sensor Wire Error
DAS	Data Acquisition System
DFR	Digital Fault Recorder
DOE	Department of Energy
eDNA	Corporate Depository of Electrical Measurements
EKWRA	Eastern Kern Wind Resource Area
EMS	Energy Management System
EPM	Energy Procurement Management (SCE)
GWh	Gigawatt-hour
GMS	General Management System
GUI	Graphical User Interface
Hz	Hertz
HVAC	Heating Ventilation Air Conditioning
I&CS	Interoperability and Cyber Security Plan
IR	Interconnection Request
kV	Kilovolt
kVA	Kilovolt Ampere
kVAr	Kilovolt Ampere Reactive
kWh	Kilowatt-hour
M&V	Measurement and Validation
MBMS	Module Battery Management System
MBRP	Metrics and Benefits Reporting Plan
MP	Measuring Point
MVA	Megavolt Ampere
MVAr	Megavolt Ampere Reactive
MW	Megawatt
MWh	Megawatt-hour
PF	Power Factor
PMU	Phasor Monitoring Unit
PPS	Protective Power Sharing
PQM	Power Quality Meter
PSLF	Positive Sequence Load Flow

QC	Queue Cluster or Quality Control
RA	Resource Adequacy
RAS	Remedial Action Scheme
RIG	Remote Intelligent Gateway
RBMS	Rack Battery Management System
RTDS	Real Time Digital Simulator
SAT	System Acceptance Test
SCADA	Supervisory Control and Data Acquisition
SCE	Southern California Edison
SEC	Site Energy Controller
SFM	Schedule Follow Mode
STATCOM	Static Synchronous Compensator
T&D	Transmission and Distribution
TPR	Technology Performance Report
TSP	Tehachapi Wind Energy Storage Project
V	Volt
Vac	Volt Alternating Current
Vdc	Volt Direct Current
WECC	Western Electric Coordinating Council