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Energy Storage Systems Program Report for FY98

Paul C. Butler

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Energy Storage Systems Program Report for FY98

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Abstract

Sandia National Laboratories, New Mexico, conducts the Energy Storage Systems Program, which is sponsored by the U.S. Department of Energy's Office of Power Technologies. The goal of this program is to collaborate with industry in developing cost-effective electric energy storage systems for many high-value stationary applications. Sandia National Laboratories is responsible for the engineering analyses, contracted development, and testing of energy storage components and systems. This report details the technical achievements realized during fiscal year 1998.

Acknowledgment

Sandia National Laboratories would like to acknowledge and thank the U.S. Department of Energy's Office of Power Technologies for the support and funding of this work. Our appreciation is also extended to all of the contributing organizations that have been instrumental in the success of many ESS Program activities in FY98.

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Acronyms and Abbreviations

ABESS	Advanced Battery Energy Storage System
AC	alternating current
ACE	area-control error
AGM	adsorbed glass mat
AOA	as-ordered agreement
AOP	Annual Operating Plan
APS	Arizona Public Service
ASU	Arizona State University
AZ	Arizona
BCI	Battery Council International
BESS	battery energy storage system
CAES	compressed air energy storage
CRADA	cooperative research and development agreement
CRI	color rendering index
DAS	data acquisition system
DC	direct current
DoD	Department of Defense
DOE	Department of Energy
EC	electrochemical capacitor
ECES	Energy Conservation through Energy Storage
EECI	Electrochemical Engineering Consultants, Inc.
EESAT	Electrical Energy Storage Systems Applications and Technologies
EFOR	equivalent-forced-outage rate
EMC	Electric Membership Cooperative
EOD	end of discharge
EPRI	Electric Power Research Institute
ESA	Energy Storage Association
ESS	Energy Storage Systems
ETO	emitter turn-off thyristor
EU	Energy United
FACTS	Flexible AC Transmission Systems
FES	Flywheel Energy Storage
FETC	Federal Energy Technology Center
FY	fiscal year
GE	General Electric
GEF	Global Environment Facility
GNB	GNB Technologies, Inc.
GTO	gate turn-off thyristor-oriented
HTS	high-temperature superconductivity

Acronyms and Abbreviations (Continued)

IA	Implementing Agreement
IEA	International Energy Agency
IFC	International Finance Corporation
IGBT	insulated gate bipolar transistor
IGCT	integrated gate commutated thyristor
ILZRO	International Lead Zinc Research Organization
I/O	input/output
IRR	internal rate of return
ISOC	intermediate state of charge
IUG	Industry Users Group
IVO	Imatra (a river and a town) Voima (power) Oy (company)
KCPL	Kansas City Power and Light Co.
kW	kilowatt
LANL	Los Alamos National Laboratory
LL	load leveling
LL+SR	load leveling and spinning reserve
LTS	low-temperature superconductivity
LVD	low-voltage disconnect
L/W	lumens per watt
MGTF	Modular Generation Test Facility
MIT	Massachusetts Institute of Technology
MOSFET	metal-oxide-semiconductor field effect transistor
MP&L	Metlakatla Power and Light
MW	megawatt
NERC	National Energy Reliability Council
NRECA	National Rural Electric Cooperative Association
NIST	National Institute of Standards and Technology
NPR	National Public Radio
O&M	operating and maintenance
OPC	OLE for Process Control
OPT	Office of Power Technologies
ORNL	Oak Ridge National Laboratory
PC	personal computer
PCP	power control pair
PCS	power conversion system
PCU	power conversion unit
PEM	Proton Exchange Membrane
PEPCO	Potomac Electric Power Company
PG&E	Pacific Gas & Electric

Acronyms and Abbreviations (Continued)

PNM	Public Service Company of New Mexico
PPM	parts per million
PPU	Power Processing Unit
PS	peak shaving
PSEL	PV System Evaluation Laboratory
PV	photovoltaic
PV4U	Photovoltaics for Utilities
PVSAC	Photovoltaic Systems Assistance Center
R&D	research and development
RAPS	remote area power supplies
RCD	resistive-capacitive-diode
RFP	request for proposal
RFQ	request for quotation
RGS	Renewable Generation and Storage
RMS	root mean square
SCADA	Supervisory Control and Data Acquisition
SCE	Southern California Edison
SHS	solar home systems
SLI	starting-lighting-ignition
SMES	superconducting magnetic energy storage
SNL	Sandia National Laboratories
SOC	state of charge
SOW	statement of work
SPQS	Substation Power Quality System
SR	spinning reserve
SRP	Salt River Project
STAR	Solar Test and Research
STATCOM	Static Synchronous Compensator
SWTDI	Southwest Technology Development Institute
T&D	transmission and distribution
TBESS	Transportable Battery Energy Storage System
TCSC	Thyristor-Controlled Series Compensator
TEAM-UP	Technology Experience to Accelerate Markets in Utility Photovoltaics
UK	United Kingdom
UMR	University of Missouri–Rolla
UN	United Nations
UNDP	UN Development Program
UPS	uninterruptible power supply
USFS	U.S. Flywheel Systems

Acronyms and Abbreviations (Continued)

VIT	Valtion teknillinen tut kimuskeskus (Governmental Engineering Research Center)
VPEC	Virginia Power Electronics Center
VRLA	valve-regulated lead-acid
ZBB	ZBB Technologies, Inc.

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ESS Program
Annual Progress Report for
October 1997 through September 1998

1. Executive Summary

Introduction

The U.S. electric utility industry is undergoing revolutionary change as a result of deregulation and competition, limitations on installing new conventional generation and transmission and distribution (T&D) equipment, and greatly reduced resources for research and development (R&D). The United States Department of Energy (DOE), through the Energy Storage Systems (ESS) R&D Program at Sandia National Laboratories (SNL), continues to work cooperatively with the electricity supply industry and the manufacturing sector to develop energy storage systems that will play a vital role during and after this transition period. In doing so, the ESS Program is furthering the goals of the DOE by developing technology that can be used by industry to (1) strengthen the nation's energy security in terms of electricity supply, (2) reduce the environmental impact of electricity generation and T&D through the increased use of renewables, and (3) increase the global economic competitiveness of U.S. industry with more reliable, higher quality, and cheaper electricity.

The ESS Program is conducting focused R&D, in collaboration with U.S. industry, to make possible the wide-spread use of energy storage systems for renewable generation and other electric system applications. Its goal is the development of new energy storage systems with superior performance and higher energy densities at competitive prices. The program includes research on a portfolio of storage technologies such as advanced batteries, flywheels, and superconducting magnetic energy storage (SMES).

The ESS Program balances the R&D of promising new systems and technologies with focused analytical and educational tasks. The primary emphasis of ESS hardware development projects in fiscal year (FY) 1998 was on the field evaluation of the Mobile PQ2000T and on the continuation of utility field experiments such as the storage project at the GNB Technologies, Inc. (GNB) Lead Recycling Center in Vernon, California, and that for the Metlakatla Indian Community. Program initiatives in FY98 included the Advanced Battery Energy Storage System (ABESS) development and testing project and the Substation Power Quality project. Scoping studies continued on the Renewable Generation and Storage (RGS) Project, which is envisioned as possibly including the design, fabrication, or operation at a host utility site of a modular, integrated RGS system capable of control by a utility. The program plan also includes a broad spectrum of analytical activities such as determining the value of storage to renewables and characterizing advanced storage technologies. Finally, an ESS Industry Users Group will continue to provide program guidance and peer review in order to achieve tighter integration of the program with utility and industry stakeholder needs.

The ESS Program is organized into three interrelated elements:

- Integration
  - System Development
  - System Field Evaluation
- Components
  - Component Development
  - Component Evaluation
- Analysis
  - System Studies
  - Opportunities Analysis
  - Technology Assessments

In keeping with ESS Program goals of maintaining an information base on energy-related technologies and initiatives, the ESS staff often attend meetings and pursue collaborations that may not be associated with a specific project, but could potentially yield valuable information and relationships. These peripheral activities are detailed at the end of each section within this document.

Highlights

The FY98 Annual Operating Plan (AOP) for the ESS Program was implemented. The major hardware project for FY98, the field evaluation of the TBESS, completed initial testing at a utility site. Significant new projects such as the Substation Power Quality System (SPQS) and the ABESS continued to make progress; however, the SPQS suffered a setback late in the year. Data acquisition and analysis was completed on a study aimed at quantifying the state of the art of flywheel and SMES technologies. ESS Program representatives attended several national and international meetings that encompassed a range of energy storage technology issues including energy storage for Remote Area Power Supplies (RAPS) and telecommunications applications. Initiatives related to storage with renewable generation were in progress, including the completion of the market assessment of batteries for photovoltaic (PV) systems. The program continued to build its global relationships through Annex IX work on electric energy storage with the International Energy Agency (IEA), RAPS initiatives with the International Lead Zinc Research Organization (ILZRO), and contact with other international organizations that are pursuing similar goals. Finally, continued active involvement in the ESS Program by industry groups such as the Energy Storage Association (ESA) helped focus the ESS Program on relevant, critically important R&D projects that will benefit the nation.

Integration

System Development

Renewable Generation and Storage and Related Projects: The ESS Program at SNL placed three contracts to investigate new technologies and design concepts for next-generation RGS systems. These contracts represented the first step of a possible multiphase research project to develop and/or test integrated systems. The overall plan of the RGS project was documented in a recent report jointly authored by ESS and PV program personnel (SAND98-0591). The work required in these contracts had two goals: (1) to define the present and future needs of users of RGS systems, and (2) to determine application requirements of RGS systems that would meet these needs. The contracts were a result of a Sandia request for proposal (RFP) for focused, three-month studies to be concluded in FY98, which was accomplished. The ESS received and is reviewing the reports documenting the results from these activities. A summary of the work is provided in Chapter 2 of this report.

Advanced Battery Energy Storage Systems: Under a second contract placed with ZBB Technologies, Inc. (ZBB), work continued on the development and demonstration of a 400-kWh zinc/bromine battery system. The design was completed, and testing of the control systems is continuing. Detroit Edison has agreed to be the host utility for the field test phase of the project, as indicated by a letter of commitment received in the fourth quarter of FY98.

Substation Power Quality: On September 15, 1998, Sandia received a formal letter from PNM stating that they were unable to execute CRADA No. SC97/1509, Electric Utility System Power Quality Demonstration. This ended the effort to construct a substation-level power quality system at SNL's Substation No. 41.

The ESS program still sees value in this application and is interested in constructing a system to address power quality issues at a substation level. It will pursue industry input on this matter.

System Evaluation

Mobile PQ2000T: The Mobile PQ2000T can provide 2 MW for 15 seconds and is used for power quality applications. It was developed collaboratively by ESS with Omnion and Virginia Power. Because of the confusion generated by referring to the Sandia TBESS with the same acronym that is used for the Electric Power Research Institute (EPRI)/Salt River Project (SRP) TBESS, a discussion led to the resolution that the Sandia/Evantage TBESS be renamed to allow for highlighting the true mobility of the unit. Pending general acceptance, it was proposed that the Sandia TBESS be renamed the Mobile PQ2000T, which will highlight the fact that the system is truly mobile and not just portable, as is the EPRI/SRP TBESS.

In late July, a new industrial test site, a printing plant, was identified in the Richmond area. Modifications to the service entry were performed by Virginia Power engineers, and plans were finalized to install the Mobile PQ2000T at the plant during the Labor Day weekend, which would minimize impact to production output during the final installation. The unit was successfully installed, activated, and tested over the three-day holiday weekend. On Monday evening, only hours after activation, the Mobile PQ2000T serviced the first power quality event that would have caused production problems in the plant. During the following week, several events were serviced with no interruption in plant production.

During the second week of operation, a catastrophic fault downstream of the Mobile PQ2000T resulted in a fire in a Virginia Power conduit that ultimately shut down the part of the plant serviced by the Mobile PQ2000T. A detailed investigation revealed that the Mobile PQ2000T was in no way responsible for the fire. It appeared that the cable was seriously damaged by flaws in the conduit during installation. Although the Mobile PQ2000T did not contribute to the outage, the printing plant requested that it be removed to allow access for repairs and that it not be reinstalled, as they felt that they could no longer tolerate the exposure of trying a new technology. The unit was removed from the site and temporarily stored at the Iron Bridge Facility for the remainder of the fiscal year. Evantage immediately began the search for a new customer site.

AC Battery PM250 Field Evaluation: Following the purchase of AC Battery Corporation by Omnion Power Engineering, Inc., in the second quarter of FY98, the PM250 was removed from temporary storage at the AC Battery Facility and transferred to the Omnion facility in East Troy, Wisconsin. In late May, SNL placed a contract with Omnion to perform final field testing of the PM250 prototype at the Omnion facilities in order to complete characterization testing and to retire the unit.

Early in the fourth quarter, it was determined that the system retirement criteria had been met and further testing was cancelled. The PM250 was decommissioned and scrapped, and the battery complement was recycled.

This ends a long and productive testing program for a first-of-its-kind utility-scale battery system. Testing at the PG&E Modular Generation Test Facility (MGTF) yielded a considerable amount of practical information on the use of off-the-shelf batteries in utility applications. Information was gathered on the behavior of long battery strings in cycling applications.

Field Test of Final GNB VRLA Battery Deliverable: SNL has cost-shared with GNB, a major manufacturer of valve-regulated, lead-acid (VRLA) battery products, the development of improved lead-acid batteries for energy storage systems. A field test at Vernon, California, using its ABSOLYTE IIP cell completed a third year of operation. The field test results have been positive. The 3.5-MWh battery, into which the ESS Program development deliverable was incorporated and which makes up about 10% of the battery cells, has proven capable of taking over the entire battery recycling center plant load. This system is helping the Vernon battery recycling center avoid air emission violations in the event of a power interruption from the local electric utility.

Testing in the secondary use of load peak shaving has also continued during FY98. Long-term continuous operation of the system is required to determine the economic benefit provided by the secondary peak shaving mode, but intermittent failures of the data acquisition system and ground faults in the battery energy storage system (BESS) prevented continuous operation and data recording during much of the second quarter. In April, the incidence of ground faults decreased enough that continuous operation was again possible. The peak shaving trigger level was reset to 3100 kW beginning in May, and the BESS was successfully operated with that setting for the remainder of the FY.

Overall in FY98, BESS operation showed successful progress toward achieving optimal battery utilization during summer peak shaving periods. The fourth quarter data suggest that the optimum peak shaving trigger level will likely be between 3000 and 3050 kW. Further tests will be required to conform this estimate and to determine how much seasonal variation occurs.

PV/Hybrid Evaluation Project: In the third quarter, a cooperative project between SNL's ESS and PV Programs reached a milestone by completing testing of a 30-kW Trace Technologies Power Processing Unit (PPU) and Hybrid Controller at SNL. This controller is a state-of-the-art hybrid control system that is expected to improve system performance by better managing the way batteries and other power sources are used in stand-alone hybrid power systems. Since the delivery of the PPU/controller, it has been undergoing testing and modification in preparation for testing at the Arizona Public Service (APS) Solar Test and Research (STAR) Center. The objective of the STAR testing is to determine the effectiveness of the PPU/controller and to investigate the performance of a Yuasa Dynacel DGX battery in the hybrid operating environment. It is anticipated that the state-of-the-art, tubular gel VRLA battery may prove to be effective for this application. The system will operate as the primary power controller and source for the STAR Center using a 30-kW genset, a 17-W PV array and a 210-kWh battery.

Following final shakedown testing of the Trace inverter at STAR early in the fourth quarter, the system was tested initially by using it to provide all the power required by the test facility for instrumentation, lighting, and air conditioning loads as well as to characterize system performance. Following the initial testing period in late September, the system was then connected to the STAR Center grid, thus powering the entire facility.

Metlakatla Monitoring Project: The ESS Program has been monitoring the fuel consumption of the BESS in Metlakatla, Alaska, for three full years. The diesel fuel consumption at Metlakatla has significantly declined since 1996 when there was no BESS to 1997 and 1998 when there was a BESS.

Components

Component Development

VRLA Reliability Improvement Project: VRLA battery reliability has been questioned recently, particularly by users of standby power systems. Because SNL believes that this battery technology offers significant advantages for utility and renewable energy applications, a VRLA reliability improvement project was formulated. Phase 1 of the project, a survey of the industry to objectively assess the status of the VRLA technology, was initiated during FY98. Survey questionnaires for both VRLA battery manufacturers and users were developed and distributed. The questions request information on cell physical characteristics and electrical ratings, cell performance and life characteristics, known instances and modes of failure in the field, R&D database availability, and market and sales data. Copies of both questionnaires are provided in Chapter 3 of this report.

Power Quality and Peak-Shaving Simulators Project: The ESS Program has initiated a collaborative project with the National Rural Electric Cooperative Association (NRECA) to develop, validate, and demonstrate simulators of power quality and peak-shaving systems. The simulators will provide technical and economic data about peak shaving and power quality improvement at electric power suppliers. ESS Program partners Energetics, Inc., and Orion Energy Corporation began building the simulators in the first quarter of FY98. In the second quarter, system engineers were faced with delays while they determined which voltage sensor was best suited for the simulators. By the third quarter, construction of a device that simulates a battery-based integrated storage system for power quality improvement was completed. Laboratory testing of this device and another simulator device that mimics the operation of a storage system to reduce customer demand peaks began. The simulator for power quality will be fielded in FY99 at a site in Slash Pine Electric Membership Cooperative (EMC) (formerly part of Oglethorpe) that has a power-quality device in service. The peak-shaving simulator was fielded in August at a site in Crescent EMC that has a peak-shaving energy-storage system in service.

Component Evaluation

VRLA Battery Characterization

GNB and Yuasa-Exide Testing: Testing of deliverables from the GNB VRLA battery development contract continued at SNL in FY98. Two 18-V batteries, an ABSOLYTE II and an ABSOLYTE IIP, have undergone long-term cycle life tests, and these batteries have accumulated more than 340 and 600 cycles, respectively. Testing was temporarily suspended on these two units because of tester malfunctions but resumed in the second quarter and continued for the remainder of FY98. Testing on the Yuasa-Exide VRLA battery ended in the first quarter of the fiscal year.

SLI and Trojan Battery Testing: SNL completed an in-house battery evaluation on both lead-acid starting, lighting, and ignition (SLI) batteries for Community Power Corporation and VRLA GEL for Trojan Battery Corporation. The SLI batteries are destined for use in offshore domestic PV applications. In the beginning of the second quarter of FY98, the battery was subjected to a final capacity test, which yielded information that the battery was at 58% of original measured capacity. At the time the battery was taken off test, five to six daily deficit cycles (10% of measured capacity removed, 9% returned using the Ah counting technique) were typical as the battery ratcheted down in state of charge to the LVD point. Following the final capacity test, the battery was fully charged and placed in temporary storage.

Testing on four 12-V VRLA Trojan batteries, which are designed for deep-cycling applications primarily in the renewable energy arena, ended in the first quarter of FY98. The last of the four Trojan batteries on test, reached its defined end of life on November 30, 1997.

Intermediate State of Charge Testing: Two modules of Yuasa Exide, Dynacel DGX Tubular GEL VRLA cells were received at SNL. A test plan was developed under the intermediate state of charge (ISOC) test program. These modules will provide data to compare to the Dynacel DGX battery at the APS STAR Center, which will be tested in a hybrid operating environment. The test plan for the Yuasa Dynacell DGX 85-11 ISOC test program was completed in late March 1998.

To expand the ISOC test program to other battery models, during April and May initial contact was made with six battery manufacturers to inquire if they were interested in participating in the ISOC test program. Letters with information on how the manufacturers could participate and details of the test program were distributed to each of the manufacturers in the third quarter. Every manufacturer initially contacted expressed high interest in participating and promised to ship eight modules each, 100-Ah (75- to 125-Ah), 12-V VRLA modules to SNL. By early September, three manufacturers had sent modules, two flat plate gels and one AGM, and preparations got underway to begin testing early the first quarter FY99. Based on the cycling rate for the test, preliminary findings should be available in the second quarter of FY99. Information on the results will be presented at various battery conferences and in the ESS Program quarterly and annual reports.

Zinc-Flow™ Battery Testing

In FY97, the ESS Program initiated a contract with Powercell Corporation to conduct testing on Powercell's Zinc-Flow™ battery. The objective of this project is to characterize the performance of a 9-kWh Zinc-Flow battery. In the second quarter of FY98, the project scope was expanded to include the characterization and demonstration of a 100-kWh PowerBlock product in the field. ESS Program staff met with Powercell and Trace Technologies personnel in the third quarter. The purpose of the meeting was to investigate the new advanced energy storage system technology being developed by Trace and Powercell. The meeting included a demonstration of a 50-kW, 100-kWh storage system, which includes a zinc/bromine battery.

Analysis

The analytical tasks in the FY98 AOP expanded on the scope of previous studies by including analyses of SMES and flywheels as well as analyses of the value of storage when used to support renewable generation sources such as wind and PV.

System Studies

Quantification of Utility Cost Savings from Using Batteries—University of Missouri–Rolla: The University of Missouri–Rolla (UMR) is continuing to use the DYNASTORE computer program to calculate utility-generation, operating-cost savings that can be realized with battery energy storage. A reanalysis of calculations carried out in FY97 for a grid-connected utility system at Kansas City Power and Light Co. (KCPL) has provided data for a combined report comparing results for island and grid-connected utility systems. Work has concentrated on determining the changes in KCPL operating costs/savings caused by inadvertent outages in generation. Study and comparison of these results have been completed, and a report comparing the island and grid-connected systems was delivered in FY98. A new contract to focus on developing an approach for including a renewable generator in DYNASTORE has been placed with UMR. Preliminary findings from this task were received in the fourth quarter of FY98.

Opportunities Analysis

ESA Activities: In November of FY98, staff from the DOE/ESS Program and several contractors played key roles in the fall meeting of the ESA in Rancho Cordova, California. An ESS Program staff member, as an elected member of the board, attended and had a leadership role in the ESA Board of Directors meeting. Attending were 52 participants representing industries and organizations including battery manufacturers, government and nonprofit organizations (e.g., Electric Power Research Institute, Solar Energy Industry Association), and electric utilities. ESS staff and contractors made seven presentations. At a special dinner session, the DOE representative presented an overview of the ESS Program. An open feedback session followed with discussions on the storage community's need for technology development, as proposed in an ESS project on renewable generation and storage. A panel discussion, which included an SNL staff member, considered another new initiative, the Storage 2000 project. A wide range of opinions were expressed on what Storage 2000 should be, but everyone agreed on the need for education of the industry on the benefits and characteristics of storage.

The ESA sponsored a PV Battery Storage Workshop at the SOLTECH 98 conference on April 27, 1998. The workshop included seven panel members from the battery industry, PV system integrators, inverter manufacturers, and SNL, all of whom responded to questions from the audience. The issues that were identified at this meeting strongly reinforce the conclusions and action plan identified in the SNL report titled *Renewable Generation and Storage Project Industry and Laboratory Recommendations* (SAND98-0591).

The DOE/ESS Program Manager and the ESA Executive Director were guests of the National Public Radio (NPR) talk show *Energy Matters*. The show is broadcast on NPR outlets as a weekly forum on energy issues. Technology review and policy issues were discussed for a lay audience. This is part of ESA's continuing promotion of energy storage.

In the third quarter, the ESA's spring meeting, April 7 through 8, 1998, was held in Phoenix, Arizona.

The meeting focused on customer service in competitive markets. More than 50 delegates from the energy technology, research, and end-use sectors attended.

In 1997, the ESS contracted with the ESA to assist in developing communications products that included energy storage brochures with various themes. In FY98, the ESA published four brochures (Appendix B) with the support of the ESS Program.

ILZRO and RAPS Testing Activities: On April 29, 1998, ESS Program staff visited ILZRO to review several collaborative projects. The projects reviewed included the IEA Annex on Electrical Energy Storage, the VRLA battery reliability project, the RAPS initiative, and the RAPS system test definition activity. All projects are making good progress, and ILZRO and ESS are continuing to build a strong working relationship. A highlight of the meeting included a review of the first draft of the RAPS test regimes document, and a plan was developed for its review by a working group and by standards panels.

By the fourth quarter, work by the RAPS Test Subcommittee had encountered several obstacles, which led them to consider previously recommended design practices as a first step for developing test practices and certification testing standards. This process would help to resolve the many peripheral issues that would, if not resolved, mar any certification standard that was developed without the intervening steps. Based on this understanding, members of the committee used a recommended design practice published by Thermie (European Union Energy Program) for solar home systems (SHS) as a template to develop a document for RAPS. Industry review of the SHS standard identified areas where improvement is needed. Therefore, the authors of the draft RAPS report recommended that the design practice team make every effort to address the indicated changes in their new document as they develop it. The draft report is near completion.

Industry Users Group: The second meeting of the DOE/ESS Industry Users Group (IUG) was held in Phoenix, Arizona, on April 9, 1998. The purpose of the meeting was to update IUG members on the 1998 ESS Program and to obtain feedback on how DOE can more effectively respond to the needs of the energy storage industry.

The ESS Program is evaluating T&D reliability, which includes grid stability, asset utilization, and increasing capacity factor, as opportunities resulting from restructuring. Improved reliability is a priority at DOE, and storage, as a contributor to reliability, could give the ESS a more defined role at DOE. Such a focus, though, should not divert attention from what the program already has under way.

One of the suggestions made by the IUG was that in order to have nationwide impact, the program needed to look at end-users rather than individual technologies.

Technology Assessments

International Energy Agency (IEA) Annex IX Project Activities: Work on Annex IX, Phase 2 has begun. Initial Phase 2 activities focused on conducting the essential groundwork associated with the retrospective applications' case studies, the forward-looking project definitions, the collation/dissemination of information, and the identification and initiation of complementary R&D identified in Subtasks 1, 2, and 5 of the Phase 2 proposal. Chapter 4 provides details of the progress that was made in these subtasks in FY98. A summary is provided below.

A full digest of systems that were candidates for detailed case-study analysis (Subtask 1) was prepared and circulated to individual national participants. Such candidate case studies include a full range of applications and also span the majority of the technologies that are of interest.

The case studies will focus on applications, the primary applications being:

- power quality/quality of supply/voltage regulation
- peak shaving/Demand Side Management (DSM)/distribution capacity deferrals
- integration with renewables
- load leveling/frequency regulation/stability

Project Definitions (Subtask 2) specifically aims to place the program in a position that will allow it to initiate two applications demonstration schemes for realization for the year 2000 and beyond. For initial planning purposes it may be assumed that such schemes will be located within Europe and North America.

A letter, structured as a pre-qualification document, was circulated to alert potential suppliers of electrical energy storage systems to the requirements for such systems and to provide them with a formal mechanism, for the registration of their interest in the project. The assessment, identification and definition of such demonstration schemes will take place in a number of stages, outlined in Table 4-5 in Chapter 4 of this document.

Identification and Initiation of Complementary R&D Program Activities (Subtask 5) is the preparatory groundwork that was put in place to launch this initiative, in Session 14 (The Way Forward and Implementation) presented at the EESAT '98 Storage Conference held in Chester, UK. See Appendix C for a copy of the proforma.

PCS Assessment Project: In FY97, the ESS Program began evaluating state-of-the-art power conversion system (PCS) technologies. FY98 plans include assessing the design architecture of and providing cost structures for the various types of PCSs and the associated devices required for storage utility applications. Based on discussions with representatives from industry, academia, and the national laboratories, several recommendations for an R&D plan on the PCS component and subsystem development have been established. On the basis of this R&D plan, two contracts were placed in the third quarter: one with Virginia Polytechnic Institute (Virginia Tech) on April 1, 1998, to begin development on a high-power semiconductor switch; another contract was placed with Electrochemical Engineering Consultants, Inc. (EECI) on May 1, 1998, for the purpose of devising alternative configurations for solar-hybrid systems that will allow more optimal charging of the lead-acid batteries contained in these systems. By the end of the fiscal year, SNL had received several draft reports on this work. SNL is reviewing these reports. The report findings are outlined in Chapter 4 of this report.

ETO Switch Development for PCS: The PCS Assessment Project resulted in the Virginia Tech initiative (contract placed April 1, 1998), which the ESS now characterizes as the ETO Switch Development for PCS Project. The Virginia Tech team delivered three major reports (listed below) along with an ETO piece of hardware in the fourth quarter of FY98. Summaries of the reports are discussed in Chapter 4 of this document.

1. Preliminary Design Report
2. Final Design and Test Report
3. ETO Analysis Report

The above three reports highlight the results of the ETO tests performed under pulse (turn-on or turn-off) conditions; hence, continuous power cycling has not been demonstrated, and questions related to long- and short-term reliability have not been answered. The objective of the next phase of the ETO development project is answer some of these reliability questions and to build and demonstrate the ETO in a high-power converter, with thermal and electric control and reliability all being demonstrated and tested in one unit.

Alternative System Configuration of Batteries for RGS: Another initiative resulting from the PCS project is the Alternative System Configuration of Batteries for RGS Project. As a result of the PCS work, a contract with Electrochemical Engineering Consultants, Inc. (EECI) was placed on May 1, 1998. The purpose of this contract was to devise alternative configurations for solar-hybrid systems that would allow more optimal charging of the lead-acid batteries contained in them.

EECI conceived several practical alternative configurations based on discussions held with a selected group of system integrators, users, component developers, and SNL personnel. They then modeled some of the alternative configurations and made economic estimates that indicated some of the configurations could be beneficial. Because of the patentable nature of the alternative configurations, detailed results will not be presented at this time. Chapter 4 provides background information on solar hybrids and the "smart" battery concept.

Performance and Economic Analysis of SMES, Flywheel, and Compressed Air Energy Storage Systems Project: During the third quarter, the flywheel model advanced rapidly, paving ground for the subsequent development of the SMES model. The improvements to the flywheel energy storage (FES) model included the ability to model multiple-ring rotors of various materials or monolithic rotors. The model capabilities also include various hub designs, types of bearings, and rotor speeds. All of the parameters are cross-checked to ensure practicality. For example, one check ensures that the rotor material can withstand the selected speed of operation, and notifies the user if the rotor is at or beyond its design limit. In addition to improvements in the technical parts of the model, analysts developed the cost and revenue sections of the model to reflect the applications under consideration for the near, mid, and long term.

In the fourth quarter, a draft report from this project was delivered to and is being reviewed by SNL/ESS Program staff. A summary of the report is outlined in Chapter 4 of this report.

EESAT '98 Conference: ESS Program staff attended the Electrical Energy Storage Systems Applications and Technologies (EESAT) '98 Conference and several meetings concerning the International Energy Agency (IEA) activities on energy storage in Chester, UK, from June 15 through 25, 1998. More than 140 scientists and engineers from 15 countries attended the EESAT conference, which consisted of 45 presentations, 9 poster presentations, and an exhibition. The ESS representative presented a paper and chaired a session on behalf of the DOE/ESS Program Manager during the conference. EESAT was the culmination of the first phase of an IEA annex focused on electrical energy storage. Annex IX, Electrical Energy Storage Technologies for Utility Network Optimization, also held a Participating Agents meeting, which the Sandia staff attended, and the Operating Agent, EA Technology Ltd., conducted a tour of its facilities. In addition, tours and technical interactions took place with Urenco, a developer of FES technology, Ionotec Ltd., a supplier of advanced ceramics for electrochemical and other engineering applications, and Ultralife Batteries Ltd., a supplier of advanced primary and secondary lithium batteries. Finally, the IEA Implementing Agreement (IA) for Energy Conservation Through Energy Storage (ECES) held an executive committee meeting that was attended by the Sandia staff for the DOE ESS Program Manager, who is the U.S. delegate. This IA includes Annex IX as well as several annexes working on thermal energy storage. Sandia was selected as the site for the fall meeting of this executive committee, to be held the week of December 7, 1998.

BATTCON '98 Conference: ESS Program staff participated in the Second National Battery Conference, called BATTCON '98, in late April. Battery manufacturers, system integrators, and users gathered from throughout the country to discuss battery problems and solutions. More than 300 persons attended, including representatives from most major battery manufacturers. More than 18 formal papers were presented, including one from ESS staff entitled *Battery Charging in Photovoltaic Applications.*

Many open-forum discussions and substantial networking resulted in a better understanding of the problems and solutions for improved battery use in stationary applications. Of primary interest to conference attendees was the progress being made on improving the reliability and longevity of VRLA batteries. During the question and answer forums, many questions were brought up that indicated a widespread lack of knowledge among users of the need to maintain and monitor VRLA battery strings. It was also pointed out that the battery manufacturers were less than forthright in providing specific information for unusual battery installations. Most manufacturers were reluctant to provide information beyond the scope of a standard operation and maintenance (O&M) manual. In addition, the battery manufacturers contended that integrators and users could not be relied upon to properly interpret and use the information provided in the O&M manuals. Consequently, improper battery system management ultimately leads to premature failures in many systems.

Office of Basic Energy Sciences. On April 13, 1998, the ESS Program staff met with Dr. Paul Maupin during his visit to SNL. Dr. Maupin manages energy storage and chemical sciences programs for the Office of Basic Energy Sciences in the DOE. He was touring Sandia to learn about programs and capabilities. His fundamental work in electrochemical storage and conversion contains several areas of long-term interest to the ESS Program, including research on room-temperature molten salts. An overview of the ESS Program was presented and discussed. Dr. Maupin is also working on fuel cells, photovoltaics, and photochemistry. He also reviewed other battery work at Sandia while visiting SNL. He will monitor the ESS Program and continue to collaborate with Headquarters staff on areas of common inter-est.

Industry, Academia, and Laboratory Interface—Lucent Technologies: ESS Program staff participated in the Lucent Technologies' Premium Power Forum at Bell Labs in Murray Hill, New Jersey, on January 13, 1998. Lucent has been organizing these meetings for more than a year to bring together developers and manufacturers of advanced generation and storage technologies with their telecommunications users of these technologies. The ESS Program staff has participated and has made numerous presentations at these meetings, which are held about every two months. Lucent's objectives regarding premium power have many things in common with the objectives of the ESS Program, namely, to develop advanced energy systems for renewables, power quality, and productivity applications.

On April 30, 1998, ESS Program staff presented a paper on testing results for improved energy storage technologies at Lucent Technologies' Premium Power Forum. The forum, held at Bell Labs, focused on distributed generation and storage technologies for telecommunication applications. This forum was highlighted by talks on fuel cells, photovoltaics, and microturbines, in addition to the ESS presentation.

On August 27, 1998, ESS Program staff presented the results of research on power quality to the Lucent Premium Power Forum at Bell Labs. The ESS Program has been an active participant for several years, along with photovoltaic, wind, flywheel, and many other advanced technology companies. This forum focused on power quality with the ESS presentation on its just-completed study which estimated the impact of poor power quality on the United States economy at $150 billion annually. In a surprise announcement, the Director of Enron's new Power Quality Solutions group presented a summary of its new business venture to market advanced technologies for power quality applications.

MIT Energy Lab: The ESS Program staff met with several staff from the MIT energy laboratory on February 20, 1998, to familiarize representatives of both organizations with their respective activities related to energy storage and the deregulation of the electric utility industry. The energy laboratory is conducting numerous analytical and policy studies on the different scenarios for the future with a deregulated electric utility industry. It has developed sophisticated codes and models with which to carry out these assessments. Many of these models relate to distributed resources such as renewable generation, and could be used to evaluate storage as a technology to address utility grid reliability and stability. Other work is under way, including modeling advanced integrated energy research, researching storage technologies such as flywheels and lithium/ion batteries, developing fuel cells, and continuing work on geothermal energy.

PEPCO: ESS staff met with personnel from Potomac Electric Power Company (PEPCO) on March 2, 1998, to discuss technologies and applications for utility energy storage. PEPCO has developed exciting, proprietary concepts for state-of-the-art energy systems that include storage. There is the potential for PEPCO and the ESS Program to work as a team to fully develop, evaluate, and monitor these concepts during the next year. Successful implementation of these concepts could result in novel new products in the electricity supply and storage technology area.

ORNL: ESS Program staff visited Oak Ridge National Laboratory (ORNL) to review the preliminary analysis that has begun on utility T&D in a deregulated market. ORNL has extensive experience in analyses of deregulated utilities, having published a series of reports on ancillary services and other emerging issues. One member of the ORNL team has been involved with wind analysis and is working with the DOE/HQ Wind Program Manager at the National Renewable Energy Laboratory. In addition, ORNL participated with the Sharp task force on electric system reliability. The task force is focusing on federal legislation and regulatory issues and will address R&D issues at the some time in the future. There is interest in studying spot market electricity prices and in reviewing how renewables and storage could interact.

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2. Integration

Introduction

Under the Integration element, a strategy is being pursued to reduce the inefficient, one-of-a-kind system engineering historically required when an energy storage system is designed and built. A modular approach has been adopted as the preferred method of achieving system flexibility and the lowest possible cost. The major subsystem components (storage, PCS, and controls) are designed as separate modules. This allows integration to take place either at the factory or at the site. From a cost perspective, this modular approach permits more efficient engineering, design, and manufacturing processes to be used. Finally, the large quantity of on-site labor required to assemble and start up the system at the user site is minimized.

System Development

Renewable Generation and Storage and Related Projects

RGS Project

The RGS Project is a new initiative that began in FY97. This project investigates modular, integrated RGS systems capable of control by utilities and other electricity suppliers. The RGS project includes wind and PV generation options.

An integrated RGS system could provide a new option for the utilization of renewable generation. At present, renewable systems typically have been site-integrated; that is, components have been specified and purchased by a designer or an architect and engineering firm and then assembled at the final site. System integration using this approach may not always result in the lowest cost or most reliable system. In several recent utility battery demonstrations, site integration caused significant start-up problems because of control interface mismatches, low-battery state of charge (SOC) resulting from prolonged storage without a charge, and power electronics failures. There are several examples of renewable systems that have been site-integrated that have had similar experiences.

In addition, utilities traditionally have not given a high-capacity credit to renewable systems. This is because of the intermittent nature of most renewable generation and the inherent inability to dispatch such energy by the utility. An integrated, modular renewable system with storage can address many of these issues and thereby greatly increase the environmental and economic benefits of renewable technologies. An RGS system may be a cost-effective way to increase the stability of power from intermittent and fluctuating renewable resources and provide energy upon demand when the utility needs it the most, regardless of the availability of the renewable resource at that time.

Projects related to the RGS initiative include furthering cooperative relationships with renewable (PV and wind) programs at SNL and the National Renewable Energy Laboratory. These programs use batteries in many of their laboratory and field experiments and have expressed interest in having technical contact with the ESS Program. One ESS staff member is partially supported by the SNL PV Program and contributes to several PV projects involving batteries. All of these interactions are leading to increased collaboration on renewable technologies and storage among the national laboratories and will reduce duplication of effort and result in improved RGS systems.

Status

The direction for the RGS initiative came primarily from input made during meetings held with industry. One, in conjunction with the IEEE PV Specialist Conference, was described in the *Energy Storage Systems Program Report for FY97* (SAND98–1733). The feedback from this meeting and from a meeting with the energy storage industry held in early FY98 was reviewed by SNL's ESS and PV Program staff who made three recommendations concerning activities for the RGS project that will be implemented in the near term. These three efforts are as follows (in priority order):

- Prepare an energy storage technology handbook,

- Provide an analysis of existing field test data, and
- Issue a request for proposal (RFP) for work to define the present and future needs of existing users and application requirements.

The PV and ESS Programs documented the conclusions and recommendations from these meetings in SAND98-0591, *Renewable Generation and Storage Project Industry and Laboratory Recommendations*, March 1998. Progress during FY98 for each of the three recommended activities is discussed below.

Energy Storage Technology Handbook

The purpose of the handbook is to:

- Define renewable applications and the issues involved with integrating storage technologies with renewables,
- Provide a detailed characterization of a variety of available batteries and other storage devices in an unambiguous manner, and
- Function as a guide that can be used by system integrators to assist in system design.

From the beginning of the information-gathering process, there was general agreement that information on all storage technologies should eventually be included in the handbook but, because batteries are the most common near-term solution for integrating storage with renewables, the handbook will initially focus on providing information about batteries.

For the purposes of moving forward on this task in a timely manner, it has been recommended that the emphasis be on collecting and publishing battery data that are currently available. Some of this information exists in manufacturers' marketing material and must be restructured in a way that is useful for comparison. The available data, once collected, will be supplemented with test data specific to renewable applications.

In the fourth quarter of FY98, SNL/ESS received and is reviewing a copy of the battery safety chapter from the handbook.

Existing Field Test Data Analysis

The ESS Program tasked Sentech, Inc., to select a renewable generation and storage site equipped with a data acquisition system (DAS) and to analyze the data recorded to determine battery performance. This is expected to be the first task of a multiyear effort to develop a state-of-the-art database capable of analyzing battery system history and performance in RGS systems. SNL has received and is reviewing a preliminary draft of the Analysis of Renewable Generation and Storage Field Data–Rogers Peak, Death Valley National Park report.

Initially, this task was to evaluate one RGS site and then replicate the study in the next fiscal year. The site-selection process was conducted at a meeting at SNL/NM, which was attended by representatives from SNL, Southwest Technology Institute, and Sentech. Several sites were discussed and Rogers Peak was chosen because of its operational record as well as having a good data set available for this study.

The Rogers Peak system provides energy to the telecommunications equipment that serves Southern California Edison (SCE), California Department of Transportation, the National Park Service, California State Police and emergency services, and cellular telephone providers. The system was designed by Applied Power and is owned by SCE.* The system is a hybrid with propane generators, PV panels, and battery storage. There are two systems, each with a PV array, battery bank, rectifiers, DC-power center, and charge controllers. The RGS system provides direct current (DC) power to 12- and 24-V communication loads that were upgraded to two 24-V systems in October 1996. The systems will be referred to a 24-V and 12-V/24-V.

The original RGS system was installed in July of 1995, and data have been collected from the beginning. There was a forming charge when the battery was installed, but the SOC of the batteries was not recorded. In October 1996, the system was reconfigured to two 24-V systems (24-V and the 12-V/24-V). The system on average uses 30.2 kWh of energy per day, which is equivalent to a continuous load of 1.26 kWDC.* The system was upgraded to a 24-VDC system with installation of a cell-phone transceiver. This increased the load four times.

The principal components of the Rogers Peak system are the PV panels, the battery system, the backup propane generator, the charge controller, an inverter, and a DAS. However, because this study focuses primarily on battery performance, only summary information on the other system components will be provided here.

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* Andrew Rosenthal, Steve Durand, Michael Thomas, and Harold Post, Economics and Performance of PV Hybrid Power Systems: Three Case Studies. Proceedings of the 1998 Annual Conference of the American Solar Energy Society, Albuquerque, NM, June 14–17, 1998.

Photovoltaics

Two separate systems exist: one serves the 12-V/24-V battery, and one serves the 24-V battery. The 24-V system consists of 62 Solarex MSX-120 modules and has a nominal rating of 7.44 kWDC at standard test conditions of 1000 W/m^2 irradiance and 25°C module temperature. The 12-V/24-V system has 45 Solarex MSX-120 modules with a nominal rating of 5.4 kWDC at standard test conditions.

These are large-area PV modules that produce more than twice as much power as the typical solar module. Large-area modules reduce the total number of installed pieces; this results in lower installation costs and improves overall system reliability.

Batteries

The Rogers Peak hybrid system includes a total of 36 GNB batteries. The 12-V/24-V system consists of a 130-kWh GNB ABSOLYTE IIP VRLA battery that consists of 100-Ah cells (1-110A-87). There are 12 cells with 5,400 Ah (100-hour rate). The 24-V portion maintains a second 259-kWh battery bank. There are 24 GNB ABSOLYTE IIP batteries in two parallel strings that are rated at 10,800 Ah (100-hour rate).

Propane Generator

The hybrid includes a 35-kW propane engine generator that provides 120/240 VAC for occasional AC loads. The generator is an Onan model 35EK-L unit generating 120/240 single-phase 35 kWAC. The system is used mainly by maintenance personnel to provide light and AC power, but it also provides battery charging backup.

Charge Controller

The battery charge controller was designed by Applied Power Corporation. The system uses a conventional battery charger rather than a custom-designed charger. There are two battery charge controllers, one for each battery bank. These systems are identified as PPS-C400-24-G for the 24-VDC system and the PPS-C400-12-AG for the 12/24-VDC, respectively.

Rectifiers and Converters

The system has four Model No. A36F75-24V LaMarche rectifiers and four DC/DC converters, Wilmore Model No. 1501-24-13-30-24V-12V.

Data Acquisition System

The data acquisition system (DAS) was designed and installed by Southwest Technology Development Institute (SWDTI). The DAS monitors the 12-V/24-V and the 24-V systems separately. It monitors the following operational parameters on both systems:

- PV current for each array
- Generator/battery charger current
- Load current
- Battery voltage
- Battery temperature

The DAS collects data at 10-second intervals and then creates and records an average hourly value. The average hourly battery current represents the Ah either going into or out of the batteries for that hour. The hourly Ah values were algebraically summed to provide a daily charge/discharge summary of the battery's operation. The daily results are then plotted to develop a month-to-month picture of battery performance.

Data Analysis

Detailed data have been collected from the Rogers Peak site for three years and are being compiled and analyzed. Specific calculations and tabular and data plot summaries will be in the final report presented to SNL.

Request for Proposal (RFP)

As recommended, the ESS Program issued an RFP in FY98 for the first step in a possible multiphase research project to identify user needs and application requirements for improved integration of renewables with storage systems. While not directly funding this contract, the SNL PV Program agreed to provide technical support for the RGS project and may help to fund future contracts.

The work identified in the RFP had two goals: (1) to define the present and future needs of users of RGS systems, and (2) to determine application requirements of RGS systems that would meet these needs. At some time in the future, SNL may issue an RFP for additional contracts to develop and test integrated RGS systems, if a need and application are identified. The follow-on RFP process should encourage teaming between component and subsystem manufacturers and system integrators.

The contracts to be awarded included funding for a "needs analysis." It was thought that by including and funding this needs analysis as part of the RGS Project, rather than requiring that bidders for future parts of the project supply (and fund) the needs analysis themselves, a larger number of bidders would be encouraged to compete for the RFP. Additionally, the needs analysis helped those who reviewed the proposals to determine if a particular bid or system posed direct competition to established products; this was a major concern of industry at the project's inception. Finally, it helped to determine the potential number of users for the new products identified. The ability to estimate the number of potential users for the proposed products is essential to ensuring that any system developed under a future contract be "market driven," which was also an industry concern.

The RFP specifically requested proposals for focused, three-month studies to be concluded in FY98. Proposals were due in the third quarter of FY98. Nine proposals were received from eight bidders. ESS and PV Program staff evaluated the proposals and awarded the companies listed below the following three contracts:

- Ascension Technology, Inc.—System and Battery Charge Control for PV-powered, AC Lighting Systems,
- Solarex—Investigation of Synergy between Electrochemical Capacitors, Flywheels, and Batteries as Possible Hybrid Energy Storage in PV Systems, and
- Aerovironment—Solar-powered Bioventing and Vapor Extraction for Environmental Remediation.

Each of these contracts was completed by the end of FY98. Reports documenting the results are being reviewed by SNL and will be published in FY99. A brief summary of the work on each contract is provided below.

Ascension Technology, Inc.

The Ascension Technology team explored the options currently available for stand-alone AC lighting systems. They determined that technology was widely available for small lighting needs (less than 35-W loads), such as PV-powered patio and path lighting and that large lighting needs (greater than 100-W loads), such as area or street lights, were generally beyond the scope of what could economically be powered by PV. They determined that "reliable, rugged equipment is not readily available" for intermediate-sized lighting systems (35 to 100 W).

To meet this need for intermediate-sized systems, the team reviewed currently available AC lamp technology, developed battery and load-charging specifications for an intermediate sized system, and then developed a prototype design for a complete, stand-alone AC lighting system, including the power electronics.

Summary of Lamp Technology

The Ascension Technology team investigated lamp technologies in the 35- to 100-W power range, as well as some lamps above and below that range. The technologies were evaluated for color-rendering index, efficiency, lifetime, and power rating. The color-rendering index scale (0 to 100) measures the ability of a light source to represent colors in objects. The higher the number, the greater the color-rendering ability. The light output of a lamp is measured in lumens. Lamp efficiency is measured in lumens per watt (L/W). Table 2-1 summarizes the specifications of some common types of lamps. Table 2-1 references the Philips Lighting Company, *Lamp Specification and Application Guide*, printed in June 1997. Table 2-2 shows a life-cycle cost analysis of various lamp technologies for an area lighting system. The analysis used 38 lamp characteristics, including lumens, power rating, approximate retail price, and average lifetime in hours to calculate the initial capital costs and average maintenance costs for the system.

In Table 2-2, Case A is where the labor costs for site visits are relatively low, for example, when the system is close to service personnel or when labor rates in the region are low. Case B is where labor and expenses to visit the site are higher, for example, when utility workers visit a remote location. This labor rate is the only parameter varied between cases A and B. Case B reflects the higher cost to service the site periodically, and is especially expensive for lighting technologies that have a short lamp lifetime.

Battery-Charging and Load-Control Requirements

Charging batteries from PV for stand-alone applications occurs in three stages:

- Bulk charging,
- Constant voltage charging, and
- Float voltage charging.

Bulk charging is the first phase. Battery voltage is lower than the voltage regulation set point. During constant voltage charging, as long as power is available, the battery voltage is held at a fixed regulation voltage set point. The float charging operation is the same as charging at constant voltage, except that the set point is lowered to prevent fully charged batteries from being excessively overcharged. The constant-voltage and float-voltage set points must also include temperature compensation, which depends on battery chemistry.

Table 2-1. Summary of Lamp Technologies

Technology	Color rendering index (CRI)	Efficiency (Lumens/Watt)	Lifetime (hours)	Power Rating (Watts)
Incandescent	100	4 to 25	75 to 8,760	3 to 1,500
Halogen	100	10 to 25	1,000 to 4,000	15 to 750
Compact Fluorescent	75 to 82	48 to 86	7,000 to 20,000	5 to 50
Fluorescent	51 to 95	34 to 104	6,000 to 24,000	4 to 215
Mercury Vapor	20 to 50	18 to 63	12,000 to 24,000	50 to 1,000
Metal Halide	65 to 85	59 to 125	3,000 to 20,000	39 to 1,800
Low-Pressure Sodium	0	100 to 183	14,000 to 18,000	18 to 180
High-Pressure Sodium	20 to 85	35 to 150	10,000 to 24,000	35 to 1,000

Table 2-2. Life-cycle Cost Analysis for Lamps Used in PV-powered Lighting Systems

Cost of PV	$4/W
Cost of Batteries (12V)	$1/Ahr
Hours of operation per night	8
Light Requirement	5000 Lumens
Battery Storage Efficiency	80%
System Controller Efficiency	95%
Ballast Efficiency (when used)	90%
Days of Storage Autonomy	4 days 100% DOD
Battery Replacement cycle	5 years
Lamp Replacement at end of life	varies
Labor cost and expense per site visit, Case A Case B	 $50/visit $500/visit
PV Resource, sunhours per day	5
System operates the same in winter and summer.	

Load-control requirements are incorporated into AC lighting systems to ensure that the batteries are not excessively discharged and to extend component life. Specifically, a low-voltage disconnect and reconnect are often used to shut down the system once the battery voltage falls below a set point. Excessive discharging greatly shortens battery life. Additionally, some systems may include an "open lamp detection" circuit that opens whenever a lamp fails in an open position or when a fixture on the system does not have a lamp installed, and the "soft start" feature is designed to extend the lamp's lifetime.

Table 2-3 shows battery charging and load-control set points for flooded and gel lead-acid batteries. These battery types are the two most commonly used in stand-alone PV systems.

Proposed System Design

The batteries and AC lamps investigated during this contract are both mature technologies that are widely manufactured. Consequently, the availability of appropriate batteries and lamps did not have any significant impact on the development and implementation of an intermediate-sized, stand-alone AC lighting system. The main component that prevents large-scale development and implementation of such systems is the power electronics used for controlling the system and the system controller, charger, and inverter. Toward this end, Ascension Technologies developed a prototype controller that would provide the appropriate battery-charging control and would properly regulate the power to the load. This controller has two advantages over off-the-shelf components. First, it has a higher level of integration with the battery charger and inverter components for the given load size (35 to 100 W). Second, it includes a high-quality inverter designed to accommodate the demands of the application (stand-alone AC lighting).

Solarex

The Solarex team investigated the synergy between flywheels and electrochemical capacitors (ECs) in PV systems. Although three quarters of currently-fielded PV systems use batteries as storage, Solarex determined that a gap existed between the needs of the PV application and the battery energy storage system. Further, while ECs cannot fill this need by themselves, they can be combined with flywheels and/or batteries to fill the gaps in the existing technology. Solarex found a Russian EC manufacturer who could provide ECs at one-fifth the cost of most U.S. manufacturers, although this price could reflect to some degree the current instability in the Russian economy.

State-of-the-art flywheel technology includes flywheels that are stronger and weigh less than previous designs and containment systems that are extremely unlikely to be breached. Solarex believes that flywheels have the following characteristics in PV systems:

- Compatibility with remote sites
- Longevity
- Lack of maintenance
- Insensitivity to deep cycling
- Surge capability
- Tolerance of ambient temperature extremes
- Lack of environmental impact

The main disadvantages of flywheels are their cost and the unproven reliability of their control electronics under field conditions. Additionally, flywheels, with relatively slow response times, may not be able to respond

Table 2-3. Standard Battery Charging and Load Control Set Points for 12-V Batteries at 25°C

	Equalization Voltage (V)	Regulation Voltage (V)	Float Voltage (V)	Low Voltage Disconnect (V)	Low Voltage Reconnect (V)	Temperature Compensation (mV / °C)
Flooded Lead-Acid	15.3	14.4 to 14.7	13.65 or Man. Spec	11.5 to 11.88	>13.0	-30
Gel Type	14.1 or 14.4	14.1 or 14.4	Man. Spec	11.46 to 11.88	>13.0	-30 or Man. Spec.

to short-term demand peaks if the peaks require good power regulation. However, Solarex has considered adding an EC to such systems to resolve surge requirement issues.

ECs are essentially maintenance free and environmentally benign. Like flywheels, their longevity is similar to that of the PV components. In other words, the EC could last approximately 20 years when made with the appropriate materials and controlled with appropriate operating parameters. Additionally, they can be discharged at very high rates without damage, although there may be some reduction in the unit's capacitance.

The relatively high self-discharge rate of ECs is a disadvantage. This high self-discharge rate limits their use in stand-alone systems to those where they are used with other storage media. In grid-connected applications, self-discharge is not a major consideration. Other disadvantages include cost and the fact that the output voltage is not constant.

Solarex determined that the most viable hybrid storage options were flywheel-EC and battery-EC combinations. In the flywheel-EC combination, the EC would compensate for the flywheel's slow response time. Additionally, many flywheel systems use electrolytic capacitors for starting motor generators and to smooth transients. Replacing the electrolytic capacitor with an EC would extend the unit's life, improve the system's ability to respond to demand surges, and relax the design requirements for the mechanical components of the system.

The ideal use for a battery-EC combination would be in applications where the batteries are used for large surges (such as telephone substations) or severe cycling (certain UPSs). When combined for these applications, a battery-EC combination could provide fast "bridge" power (the power needed during the short time from the onset of an outage until backup power is on line), cope with transients generated during power source changeover, and absorb demand surges that can stress the batteries.

Aerovironment, Inc.

The objective of the Aerovironment study was to "assess the market and specific applications for solar-powered remediation and to develop design specifications to address the market." Solar-powered remediation involves using solar power to operate conventional environmental remediation equipment. Aerovironment identified several types of remediation and evaluated the corresponding remediation technologies to determine which were most adaptable for use with solar power. Additionally, they performed characterization testing on two different sizes of blower technology, which they then used to develop a spreadsheet model for a solar-powered remediation system.

Aerovironment considered the following nine remediation technologies for possible solar-powered operation:

- Soil Vapor Extraction—vapor
- Bioventing—vapor
- Air Sparging—liquid
- Biosparging—liquid
- Ex-situ soil vapor extraction (biopiles)—vapor
- Groundwater pumping—liquid
- Bioreactors—liquid, vapor
- Air stripping—liquid
- Ion Exchange—liquid

The first four technologies are in-situ remediation methods; the contaminated material can be remediated without extracting it. The last five are ex-situ methods; the contaminated material must be removed to be remediated. As indicated in the list, certain technologies are liquid-based, while others are vapor-based. Liquid-based technologies use pumps as the primary remediation tool, while vapor-based technologies use blowers.

Additionally, remediation technologies may be capable of operating in one or more of three modes: diurnal, variable, and continuous. Diurnal systems operate only when power is available from the sun. They are the most inexpensive and efficient type of system and are suitable for remediation technologies that can be cycled without degradation in process effectiveness. Variable-cycle systems use batteries to store energy during daylight hours for use at night and under low-light conditions. Maximum blower performance is achieved only during a few hours each day. Half-flow rates are available the rest of the day. Variable-cycle systems are most suitable for sites or processes that require a continuous minimum performance with occasional high-performance requirements. Finally, continuous-duty systems operate continuously, as if operating from utility power. These systems are most suitable for processes that require controlled operating conditions.

Solar-powered Remediation System Modeling

Because of the brief nature of this initial study, only those remediation technologies that used blowers were considered for modeling. Aerovironment purchased and characterized two regenerative blowers, a 1.1 hp model and a 2.5 hp model, similar to those currently used for remediation. The variable speed data (flow rate as a function of power) obtained during characterization was then used as the basis for a spreadsheet model.

In the spreadsheet model, the blower data was used to determine the total volume of air pumped in a given day for each of the modeled system's three operating modes (diurnal, variable, continuous). Aerovironment also incorporated into the model mathematical representations of the solar insolation and array, the power electronics, and the batteries used (if any). A numerical simulation was used to determine the appropriate solar array rating and battery size necessary to achieve the desired performance. These specifications were then used to determine the life-cycle cost of the system. Total system costs represent wholesale costs plus a typical commercial mark up. For each of the two blowers, a diurnal, variable, and continuous system were modeled (a total of six systems, see Table 2-4). A cost and performance summary for each of the six systems is provided in Table 2-5.

Economic Analysis of Solar-powered Remediation Systems

Aerovironment compared the costs of solar-powered systems to the costs of grid-supplied systems. The figures below show the results for the monthly cost of power to the end user. The costs represent the price paid by the system's user for access to and supply of electrical power amortized over the period of operation. Figure 2-1 (Subfigures 1a and 1b) represents customer-owned systems. Figure 2-2 (Subfigures 1c and 1d) represents customer-leased systems. The results were calculated for typical durations of remediation site cleanup (12, 24, and 36 months on average). The sample site data, including the calculated cost of electricity at $0.10/kWh, is also shown. A cost of $2.50/ft was assumed (values between $1.50 and $5.00 are common in the U.S.).

Table 2-4. System Numbers for the Modeled Systems

Cycle	1.1 hp	2.5 hp
Diurnal	1	4
Variables	2	5
Continuous	3	6

Table 2-5. Cost and Performance Summary for the Six Systems

	System					
	1	2	3	4	5	6
Equipment Cost[1]	$14,625	$25,638	$59,075	$28,625	$49,200	$124,850
10-yr Life-Cycle Cost[2]	$14,625	$32,475	$64,325	$28,625	$54,575	$146, 225
Cubic Feet/Day (CFD)[3]	29,558	52,800	82,500	63,414	113,280	177,000
CFD/$ (equipment cost)	2.0	2.1	1.4	2.2	2.3	1.4
CFD/$ (life-cycle cost)	2.0	1.6	1.3	2.2	2.1	1.2

1. Equivalent to manufacturer's price.
2. The total cost for the end user over a ten-year span, (2 battery packs total).
3. The total volume of product pumped in a day.

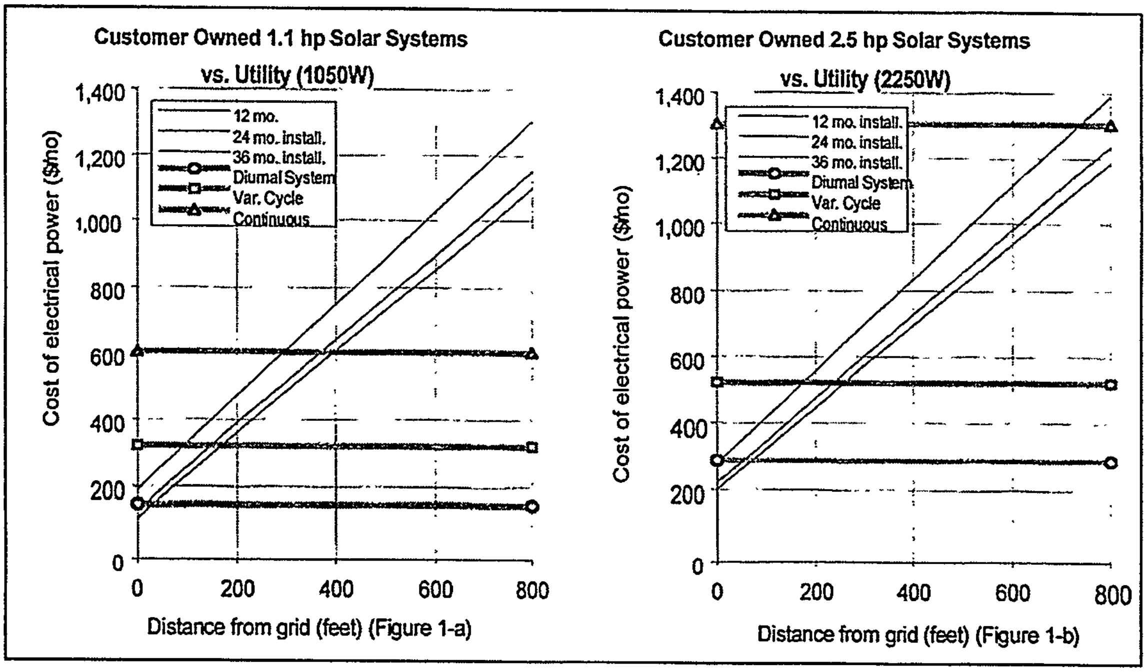


Figure 2-1. **Comparative Monthly Cost of Power-Solar-Powered System Versus Grid-Supplied Power for Customer-Owned Systems.**

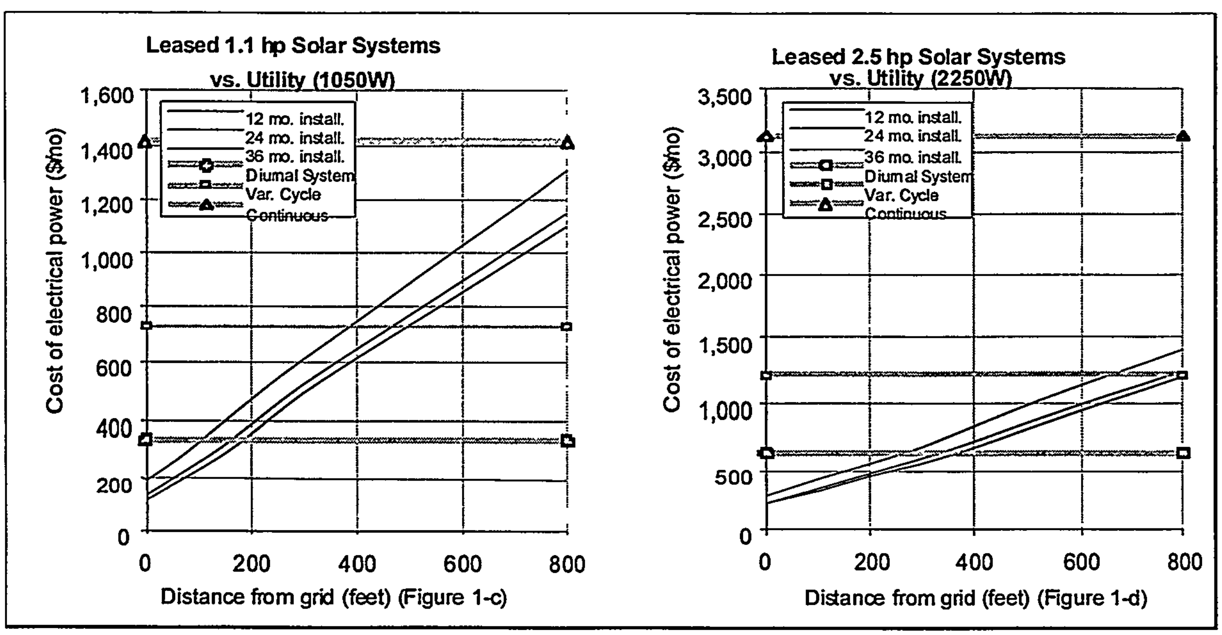


Figure 2-2. **Comparative Monthly Cost of Power-Solar-Powered System Versus Grid-Supplied Power for Customer-Leased Systems.**

As expected, solar-powered systems are most competitive for lower power and more remote systems. However, these results indicate that even solar-powered systems can be cost-effective compared to grid-supplied power for short grid extensions.

Aerovironment feels that the most promising application for solar-powered technologies are diurnal systems used with remediation methods such as bioventing, which are amenable to intermittent operation. The next step toward commercializing solar-powered remediation would be to demonstrate the concept. Demonstration of the technology would have the following objectives:

- Achieve credibility in target markets
- Establish final system technical and performance guidelines
- Validate economic and technical viability
- Create market awareness of the product.

Renewables and Energy Storage: Characterization of Existing Hybrid Power Systems

The ESS Program contracted Sentech, Inc., to characterize renewables and energy storage in existing hybrid power systems. The following information is a summary of the White Paper from this task, submitted to SNL in the fourth quarter of FY98.

Any characterization of RGS systems must start with a definition. In general, these are hybrid power systems that contain some combination of a renewable generator (photovoltaics, wind), fossil fuel generator, (diesel, natural gas), energy storage (usually lead-acid batteries), and control interface electronics that can deliver electricity for a defined application. These systems can range in size from 500 W (a simple residential system consisting of a PV panel, battery, and two to three compact florescent lights) to 1,000 kW (including a large PV array, lead-acid battery array, diesel or other fossil fuel generator, and a power conversion system). One confusing aspect is that these power systems are known by several names, including renewable hybrid-power systems, remote-area power supplies (RAPS), village-power systems, sustainable village-power systems, mini-grids, and green-grids. With minor differences, all of them represent the same thing—a hybrid power source that takes maximum advantage of a renewable resource when it is available.

Larger RGS hybrid-power systems differ markedly from the more simply designed, smaller, single-purpose renewable energy systems. The distributed PV or wind-energy systems designed for residential lighting, water pumping, or battery charging are less complex because they are not required to perform with load variability and have enough flexibility to provide reliable power. The markets for these simple systems are being served well by a variety of specialty suppliers. The bulk of the report focused on the emerging, larger, and more complex hybrid systems that require more sophisticated engineering, control systems, and system integration.

An RGS system has both advantages and disadvantages over fossil-fuel power systems. The disadvantages include greater engineering complexity, higher capital cost (than diesel power), and greater maintenance costs (than PV). The advantages include lower capital costs (than PV), greater load flexibility (than PV), greater load availability (from dual-generator sources), and higher component utilization that could result in lower life-cycle costs. Thus, RGS systems can offer competitive advantages if there are emissions or environmental concerns, high fossil-fuel costs, or customer utilization factors.

The key to a successful RGS system is to get optimum component utilization to meet customer loads. There are four primary considerations to achieve success:

- Characterizing the application loads that must be met along with those that could be met,
- Maximizing the utilization of the available renewable resource,
- Minimizing the life-cycle costs of the fossil-fuel generator and the battery-storage components, and
- Designing the system topology and control system accordingly.

Three types of RGS systems are emerging, based on market demand, to satisfy specific applications. Each of these systems has different design characteristics based on their applications and the appropriate design trade-offs. The systems have been characterized as follows:

- Small (DC-Bus)
- Village Power (AC-Bus)
- Large (PV & Grid)

Small RGS systems (Figure 2-3) typically are designed to meet loads such as residential lighting, water pumping, or other non-grid connected applications. The low power and load requirements favor using the battery storage system (and DC-bus). The load characteristics allow the battery to meet this requirement without deleterious cycling effects that can reduce battery life and require frequent battery change out. The renewable resource is used to charge the battery whenever available. When the RGS is not available, the

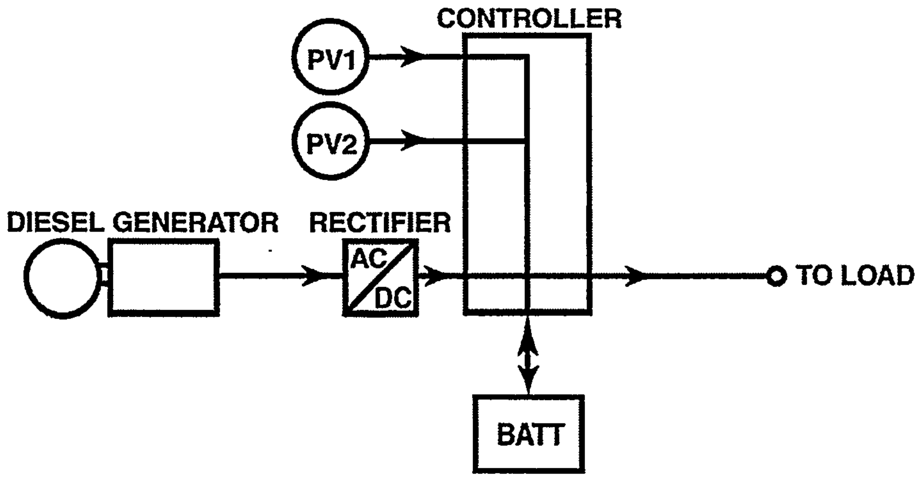


Figure 2-3. Small (DC-Bus) RGS System.

fossil-fuel generator (typically a diesel generator) rapidly charges the battery, resulting in minimal fuel use, battery life extension, and reduced emissions. Although all systems are different in their design, several RGS projects that characterize this topology include: Apex Power Systems (Orion Energy) and the larger DoD grid-independent systems, such as Superior Valley and Dangling Rope.

Medium-sized village-power systems (Figure 2-4) represent a different strategy for RGS design because they typically respond to more fluctuating loads. The basic design is intended to include a "base-load" and a "peak load" that are carefully selected to match operating characteristics. The goal is to run the base-load diesel constantly while using the renewable and storage components for peak-power needs. The peaking diesel is only used when peak-load requirements extend beyond those of the renewable storage system. The efficiency of this system is derived from the high base-load diesel engine loading while minimizing or eliminating the need for a peak diesel. This topology is typical of designs used for remote telecommunications power stations or for larger, more sophisticated village power stations. Examples of projects that incorporate these design features are AES (Australia) products and the newly designed APEX Power Systems from Orion Energy.

Larger grid-connected PV storage systems (Figure 2-5) typically are designed to meet peak loads and provide backup power. In general, the energy storage system (battery) is recharged first from any available renewable resource followed by available power from the grid. The fossil-fuel generators (diesel or natural gas) can be used to charge the battery when the renewable resource is not available and also provides power during an extended outage. The benefits of this topology are reduced emissions, productivity gains (from reduced fuel usage), and lower fuel costs. The larger DoD grid-connected PV projects have employed this strategy, which are best represented by the Yuma project in Arizona.

The prior discussion attempts to characterize and categorize these systems based on those developed to serve specific applications or markets. In fact, new products and design strategies are emerging continuously as electronics, renewable components, and energy storage systems continue to improve. There are continuing challenges that are undertaken by product designers and system integrators each time they are asked to provide a renewable storage system to meet specific applications.

The most difficult of these RGS system challenges are discussed below:

Battery Energy Storage System

The selection of the battery type remains the most difficult of the challenges. The reality is that at least part of the market is not satisfied with lead-acid batteries. However, the more exotic solutions (advanced batteries, flywheels, hydrogen storage, etc.) are neither available nor cost-effective alternatives. Selection of a lead-acid battery is not as trivial as flooded versus valve-regulated (either gel or absorbed glass mat). Choosing batteries remains a difficult trade-off for system integrators seeking low initial cost. Finally, the perceived environmental acceptability of lead-acid batteries remains a market barrier for these systems that are being marketed

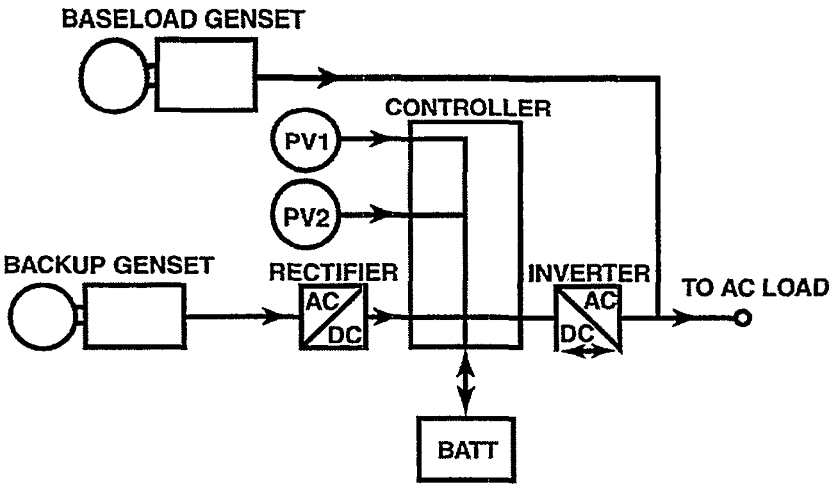


Figure 2-4. Village Power (AC-Bus) RGS System.

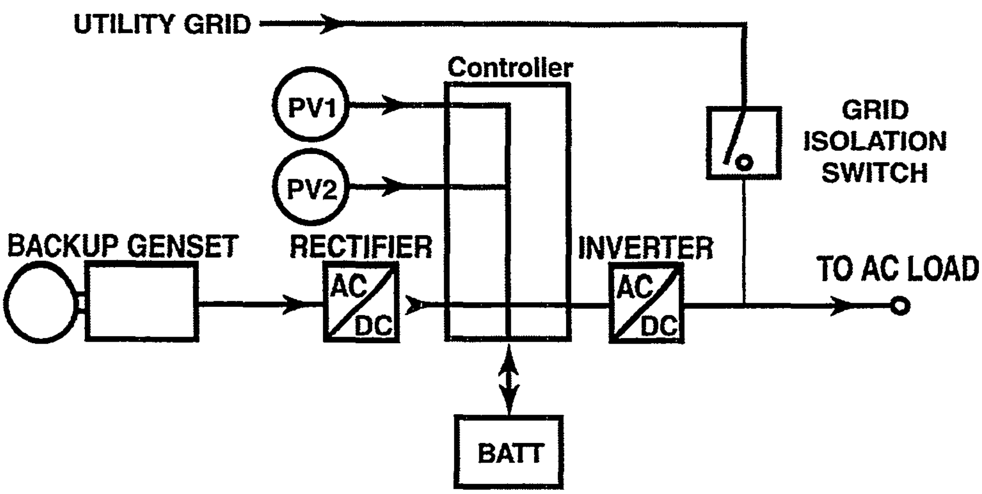


Figure 2-5. Large (PV-Grid) RGS System.

for their environmental benefits. However, lead-acid battery companies are committed to transporting spent battery systems and recycling those batteries, even in developing countries.

Fossil Fuel Generation Options

The selection of the fossil-fuel generator is fraught with uncertainty because system integrators face three challenges: (1) the reliability of the diesel within the duty cycle of the application; (2) various fuel options such as natural gas or propane; (3) the option of alternative fuels (biomass). A further complication is that many systems are designed as a retrofit to existing generators that are not optimally designed for a hybrid-power system.

Power Electronics

The power electronics are the "heart" of the hybrid system and must be integrated with each component to optimize performance. The power electronics need to convert AC to DC for storage in the batteries and reverse the process for providing electricity to serve customer AC needs. The most complex power electronics issue is often battery charging: the charge and discharge protocol must be accurate to meet the manufacturer's battery specifications to ensure warranty compliance and expected battery life.

Control System

The control system is the "brain" of the hybrid system and must provide intelligence to the total system to ensure proper performance, especially if remote applications in extreme environments are anticipated. The controls must also handle remote monitoring and data management, correctly deal with system interactions and detect problems, and be flexible and rugged enough to handle a variety of operating environments.

Packaging Containers

The packaging of these systems is nontrivial because customers demand flexibility, ease of operation, and low cost. The containers must be easy to install, flexible, retrofit to other components ("plug and play" installation), easy to maintain (remote data collection and call-up), and able to handle a variety of climatic conditions (cold, heat, seismic activity, etc.).

In an attempt to create an accurate profile of existing RGS hybrid systems, Sentech has had discussions with organizations ranging from the U.S. government to private industry that have experience with a variety of hybrid RGS projects. The following is a summary of findings from those discussions as well as conclusions and recommendations for areas on which ESS Program should focus.

Project Descriptions

The larger RGS projects are limited in number and primarily are those that have been sponsored by the DoD over the past several years. Additionally, several international projects in Mexico and the Far East were procured by the telecommunications industry and installed to offer power for receiving stations. Other RGS projects have been financed and/or conducted by the World Bank, the United Nations (UN), and the DOE. In general, the market is just emerging and the state-of-the art is best represented by the recently procured DoD projects. Table 2-6 summarizes these projects including the sizes of the major components.

The UN, through the Global Environment Facility (GEF), sponsors several projects dealing with RGS. The Photovoltaic Market Transformation Initiative, co-sponsored by the World Bank and the International Finance Corporation (IFC), uses private sector PV companies with local financial intermediaries to provide grants on a competitive basis to developing countries to promote the expansion of PV technology for rural electrification. The UN, World Bank, and IFC, through the Renewable Energy and Energy Efficiency Fund, invest in grid-connected and off-grid renewable energy projects. The World Bank is catalyzing least-cost rural electrification in Indonesia by supporting a project entitled Solar Home Systems. There is a project in Uganda, Photovoltaics for Rural Electrification, that is sponsored by the UN Development Programme (UNDP) to promote electrification of remote areas that cannot receive access to the national electric grid. Another off-grid photovoltaic initiative (Photovoltaics for Household and

Table 2-6. Summary of Large DoD RGS Projects

			Size		
Project	Application	Company	PV (kW)	Diesel (kW)	Storage (kWh)
Superior Valley	Facility Power	Photocomm/IPC	350	300	3500
YUMA	Grid-tied Facility Power	Utility Power Group	450	250	4500
Grasmere Point	Facility Power	Idaho Power/APC	80	160	750
San Clemente	Facility Power	Photocomm/PC	90	N/A	N/A
Santa Cruz	Facility Power	Idaho Power/APC	120	200	2000
China Lake	Facility Power	Plateau Electric	440	N/A	4500
Twenty-nine Palms	Facility Power	Utility Power Group	70	N/A	2000
Dangling Rope	Facility Power	Idaho Power/APC	115	N/A	2400
Pohakuloa Training Area	Facility Power	TBD	200	TBD	TBD

Community Use) is being undertaken in Zimbabwe by the UNDP. In general, the international development efforts have focussed on bringing electricity to people who do not currently have access to electricity. These efforts focus on simple technology solutions that include small (500 watts - 2 kW) systems.

The DOE has had several initiatives focusing on larger RGS systems to stimulate the market acceptance of photovoltaics in emerging U.S. markets. Two initiatives, Renew the Forests and Renew the Parks, are sponsored by DOE/SNL's Photovoltaic Systems Assistance Center (PVSAC) with the U.S. Forest Service and the National Park Service, respectively. These partnerships were initiated to expand the use of renewable energy technology. A survey of the current uses of PV and an assessment of future applications were performed. The majority of these remote projects are for communications, remote monitoring, restroom power, water pumping, and lighting. The Forest Service identified more than 500 systems currently in place and expressed a great deal of interest in installing new systems. The national parks had several hundred systems operating. See Appendix A for a list of the federal agency projects supported by Sandia's PVSAC. This initiative has cosponsored projects with the Bureau of Land Management, the DoD, the Department of Agriculture Forest Service, and the National Park Service.

The DOE, the Electric Power Research Institute (EPRI), and utilities have formed collaborative partnerships to promote PV technologies. The Technology Experience to Accelerate Markets in Utility Photovoltaics (TEAM-UP) Program is co-sponsored by the DOE and the Utility PhotoVoltaic Group. This partnership was initiated to promote PV purchase commitments to utilities and to accelerate the utilization of cost-effective, small-scale, and new large-scale applications of PV technologies. Under the Photovoltaics for Utility-Scale Applications initiative, utilities research and demonstrate full-scale PV systems, they evaluate the cost and performance of PV technologies, and they demonstrate the technologies to gain hands-on experience. Photovoltaics for Utilities (PV4U) coordinates state use of PV through the Interstate Renewable Energy Council. PV4U consists of working groups of manufacturers, universities, utilities, and state energy offices. The goal of the above organizations is to promote the use of PV technology for domestic electric utility markets. See Appendix A for a list of projects.

Project Costs

The costs of larger RGS projects are variable and depend on complexities such as terrain, grid connected or independent, individual component size (especially the PV array), and the control system requirements. Table 2-7 summarizes several of the major DoD projects including their size (rating), total project costs, and cost per kilowatt. The costs per kilowatt for recent projects range from $10/W to as high as $22/W. The trend for larger (>100-kW) systems incorporating existing diesel equipment has been approaching the lower end of this range.

Discussions with several suppliers allowed the postulation of a "rule of thumb" for estimating the costs of these projects. In general, the costs of the photovoltaic array ($7500/kW), wind turbine ($800/kW), and battery storage ($100/kWh) components could be estimated by

Table 2-7. Overall Costs of Selected Large RGS Projects

Project	Company	PV size	Cost ($M)	Approximate Cost
Superior Valley	Photocomm/IPC	350 kW	3.5	$10
YUMA	Utility Power Group	450 kW	4.3	$10
China Lake	Plateau Electric	440 kW	6.3	$14
San Clemente	Photocomm/IPC	80 kW	1.0	$12.5
Santa Cruz	Idaho Power/APC	120 kW	2.65	$22
Twenty-nine Palms	Utility Power Group	80 kW	1.0	$12.5

the product of these costs by their rated size. For systems less than 500 kW, the costs for the diesel, one-time engineering and balance-of-system approximated $100/kW. For systems greater than 500 kW, these costs approximated $50/kW. Table 2-8 summarizes a cost-estimating algorithm for these larger RGS systems.

Conclusions

Much like the energy storage markets, the emerging markets for RGS systems are defined by market niches at differing stages of evolution. For smaller nongrid connected systems, these markets are emerging rapidly, driven by the World Bank and other multilateral funding agencies that seek to improve quality of life for developing nations without exacerbating the world's environmental problems. Several companies are marketing simple renewable/storage electric products for lighting and other applications including Golden Genesis, Power Pod, SunLight, and many others. Medium sized systems such as those for village power are being introduced by a few companies. The integration of these systems are more complex but innovation is occurring as products are delivered. Companies such as Orion Energy, Applied Power Corporation, and others are examples of companies that have integrated products.

The larger RGS systems, whether grid or non-grid connected, have been slower to emerge and have less integration and packaging. In general, these systems tend to be custom designed, accommodate existing assets or resources (wind turbines, diesel, etc.) and require more flexibility in design or controls than the smaller "packaged" systems. The larger systems have been developed for DoD, telecommunications, or island power systems, and only one or two dozen projects are available for analysis. The slow emergence of this market has yet to result in a great deal of innovation or standardization as these systems typically have individually designed controllers and electronics that were uniquely adapted for these projects.

Advanced Battery Energy Storage System

The zinc/bromine battery is an emerging technology that has many attributes that make it attractive for energy-storage applications. The main advantage of the zinc/bromine battery system is good gravimetric energy density, which results in a modular transportable battery system with a sufficient capacity to be placed anywhere on the utility grid. The battery is made almost entirely from plastic (high-density polyethylene), which makes it cost-competitive with lead-acid batteries without the hazardous manufacturing and recycling concerns. Also, the battery operates efficiently over a wide temperature range and functions under intermittent charge/discharge conditions. It can experience complete discharge hundreds of times without damage.

ZBB Technologies, Inc., one of the ESS Program's industry partners on this project, participated in one of the largest turnkey advanced battery demonstrations in the United States. This major demonstration, a 100-kWh zinc/bromine battery system, was partially funded by the DOE/ESS Program and was completed at the ZBB test facility.

Following the completion of the 100-kWh battery tests, in FY97, a new project was competitively placed with ZBB for the development and testing of a 400-kWh

Table 2-8. Large RGS System Initial Cost Estimating Algorithm

Size	PV Cost		Wind		Battery Storage		Diesel/BOS		Total
< 500 kW	$7500/kW(a)	+	$800/kW(b)	+	$100/kWh(c)	+	$100/W(d)	=	Total Cost $
> 500 kW	$7500/kW(A)	+	$800/kW(B)	+	$100/kWh(C)	+	$50/W(D)	=	Total Cost $

For systems < 500 kW
- a size of PV array (kW)
- b size of wind turbine (kW)
- c size of battery storage (kWh)
- d size of diesel engineer (kW)

For systems >500 kW
- A size of PV array (kW)
- B size of wind turbine (kW)
- C size of battery storage (kWh)
- D size of diesel engine (kW)

ABESS. Field testing a prototype integrated energy storage system should enable ZBB to validate the technology and refine the quality and reliability to the satisfaction of the electric utilities.

The statement of work (SOW) for the new project involves the following activities:

- ABESS specifications and field-test plan preparation
- Engineering design definition
- ABESS fabrication
- Acceptance testing
- Documentation and training for field testing
- Preparation for testing
- Field test
- Decommissioning

The objectives of the ABESS project are to design, fabricate, evaluate, and optimize a zinc/bromine battery system suitable for electric utilities. The soundness of the battery technology was demonstrated and new larger cell stacks, designed for an electric utility battery, were developed during previous contracts between ZBB and SNL. The end product of the present contract is to demonstrate a 400-kWh system at a utility installation. Based on the results of this testing and utility interest, larger systems may be tested in the future.

In the initial phase of the development of the 400-kWh system, ZBB identified the following task list:

1. Applications Analysis/Preliminary Field Test
2. Complete Preliminary System Specifications
3. PCS Specifications Development
4. Design/Assemble/Test Improved Modules

Because proving the feasibility of this technology is critical to the final production-engineering phase of development, the focus and end product of this task will be a field demonstration at a utility or customer site. This prototype integrated system (battery, PCS, controls) will perform one of several energy storage applications. Therefore, active participation of an advanced battery developer, a utility customer, and a PCS manufacturer is required. In addition, targeted applications must be consistent with the needs identified in the Opportunities Analysis that cannot be optimally satisfied with lead-acid technology.

The initial phase of the contract involved the development and testing of a 50-kWh battery module. A 50-kWh battery module was assembled in the latter part of FY97 and is presently being tested.

Status

In the fourth quarter of FY98, progress was made in finding a host utility for the field test phase of this project. The contract calls for a field test at a host utility of a transportable 400-kWh zinc/bromine ABESS. Detroit Edison has agreed to be the host utility for this test, as indicated in a letter of commitment received in early August. On August 13, 1998, ESS Program staff, ZBB staff, and Detroit Edison personnel met to determine which application best suited the zinc/bromine battery and visited the site that was the first choice of Detroit Edison for the field test. It was agreed that within one month a final site selection will be made and the application and test specification will be completed. Within two months a detailed system design that includes the utility interface will be generated.

In the third quarter, SNL received a ZBB report documenting testing of the improved 50-kWh module design and specifications for the PCS for the 400-kWh zinc/bromine battery.

Although a report was completed, more work is required to build a satisfactory module. It is this continuing work, which focused primarily on Tasks 3 and 4 from the above list, that is reported here.

A proprietary PCS specification was completed in the third quarter and has been submitted to a select group of inverter manufacturers for review. These specifications provide suppliers with information on the following topics:

- Battery system specifications
- Test cycle specifications
- PCS specifications and ratings
- PCS enclosure specifications
- Isolation transformer ratings
- Wiring specifications
- Control strategy/system integration
- System protection
- Factory testing results on the PCS
- Warranty and cost

Separator Development

A number of significant improvements have been achieved in the development of a zinc/bromine battery separator. Silica and oil types as well as separator compositions, which give good performance characteristics, have been identified. Separator material will be provided from a vendor process line in the fourth quarter. The zinc/bromine battery separator is a silica-filled polyethylene sheet, which is needed to separate the reactive components of the battery (electroplated zinc and complexed bromine). A low rate of diffusion of bromine across the separator is essential to minimize the self-discharge of the battery. It is also important for the separator to have low electrical resistance for high-power characteristics of the battery. The separator is manufactured by extruding polyethylene, silica, and a processing oil. The processing oil is later extracted from the separator.

Diffusion and resistivity results for samples manufactured by a vendor are presented in Table 2-9. The B samples were post-treated to alter the ability of the material to absorb electrolyte. The results show that the post-treatment for sample No. 2-B significantly reduced both the bromine diffusion and resistivity of the material. It also improved the diffusion for sample No. 1-B, but did not appear to improve the resistivity of this sample. Even with the treatment, sample No. 1-B did not absorb electrolyte. Although the post-treatment improves the properties of the separator, previous experience has demonstrated a rapid decrease in battery performance associated with separator material degradation post-treatment. After realizing that the post-treatment was not permanent, it was decided that it would be necessary to manufacture a separator material that possesses good properties without using this type of post-treatment.

Table 2-10 shows results for separator samples that were compounded with different silica types, and pressed at ZBB's facility. Even though the manufacturing method is crude, reasonably good results were obtained. The samples were made by mixing the oil, silica, and polyethylene until a paste-like consistency was obtained. The samples were then heat-pressed until the material had reasonable strength. The variable in this series was the type of silica used.

Table 2-10 demonstrates that the type of silica used can have a dramatic effect on separator properties. From this set of tests, four silica types that can be used to manufacture separator materials with good properties were identified.

After reviewing the results of the previous tests, a number of separator samples were manufactured by a vendor. The four promising silicas, as well as two additional silica types, were tested in this series of samples. Other factors examined during this trial were the type of processing oil and composition of the separator material. Results of the separator trials are provided in Table 2-11. These results indicated that the type of silica and the composition of the material had the most significant effects on separator performance.

A total of 25 samples were manufactured. Sample numbers not included in Table 2-11 had insufficient strength to form a sheet. It was determined that composition No. 2 gave better results than composition No. 1. Also, oil type No. 1 generally did not give sheets with adequate strength. Following this set of tests, two additional compositions were manufactured with oils Nos. 2 and 3. Both of these additional compositions were slight variations from compositions Nos. 1 and 2. The effect of separator composition can be seen in Table 2-12. All samples were made with the same type of silica (No. 1).

The results indicate that composition affects separator performance, with composition No. 4 giving the best results, followed by composition No. 2.

Table 2-9. Effect of Post Treatment on Separator Properties

Sample	Normalized Diffusion (to Asahi)[1]	Normalized Resistivity (to Asahi)[1]
1 A	1.03	4.95
2 A	High[2]	2.04
1 B	0.08	5.05
2 B	0.78	0.74

1. Bromine Diffusion and resistivity results are normalized to a baseline material = 1.00.
2. High diffusion indicates complexed phase bromine transferred to the anolyte side.

Table 2-10. Bromine Diffusion and Resistivity Results for Various Silica Types

	A	B	C	D	E	F
Silica Type	Silica No.1	Silica No. 2	Silica No. 3	Silica No. 4	Silica No. 5	Silica No. 6
Sheet Thickness (mils)	27.5	30	22	28	24	22.5
Bromine Diffusion[1]	1.22	1.20	1.20	1.23	2.46	High[2]
Resistivity[1]	1.07	1.18	0.58	0.91	3.06	High[3]

1. Bromine Diffusion and resistivity results are normalized to a baseline = 1.00.
2. High diffusion indicates complexed phase bromine transferred to the anolyte side.
3. High value indicates that the resistivity is too high to be measured on the meter.

Table 2-11. Separator Results of Vendor Trial

Sample No.	Silica Type	Oil Type	Composition	Diffusion[1]	Resistivity[1]
1	1	1	1	2.71	0.81
2	1	2	1	High[2]	5.26
4	1	2	2	1.62	0.67
6	2	2	1	High[2]	5.59
8	2	2	2	1.68	0.75
10	3	2	1	High[2]	6.50
14	4	2	1	High[2]	High[3]
17	5	2	1	High[2]	High[3]
18	5	2	2	High[2]	High[3]
20	1	3	2	1.64	0.55
21	1	3	1	High[2]	6.21
23	2	3	1	High[2]	6.32
24	Experimental	3	1	High[2]	High[3]
25	5	3	2	High[2]	8.66

1. Bromine Diffusion and resistivity results are normalized to a baseline = 1.00.
2. High diffusion indicates complexed-phase bromine transferred to the anolyte side.
3. High value indicates that the resistivity is too high to be measured on the meter.

Table 2-12. Effect of Separator Composition on Properties

Sample	Composition	Oil Type	Diffusion[1]	Resistivity[1]
2	1	2	High[2]	5.26
21	1	3	High[2]	6.21
4	2	2	1.62	0.67
20	2	3	1.64	0.55
27	3	2	High[2]	1.39
29	3	3	2.39	0.81
26	4	2	1.32	0.51
28	4	3	1.39	0.51

1. Bromine diffusion and resistivity results are normalized to a baseline = 1.00.
2. High diffusion indicates complexed-phase bromine transferred to the anolyte side.

Bromine Complexing Agent Development

A task to develop better performing and lower-cost bromine complexing agents has been initiated. The zinc/bromine battery uses a complexing agent in the electrolyte to bond with the bromine. This is necessary to reduce the self-discharge of the battery and improve the safety of the system. Investigations are in progress to develop lower-cost complexing agents that can be used to improve the performance of the battery system.

Work on this program will include the following:

- Synthesize complexing agents;
- Investigate the stability of the complex formed using nuclear magnetic resonance;
- Investigate the bromine complexing and its releasing properties by determining bromine concentrations in the aqueous-phase electrolyte;
- Determine the physical properties of relevant bromine complexes, including their physical states at various levels of bromination, and conductivity as a function of temperature; and
- Evaluate the most promising complexing agents in small zinc/bromine cells.

This work is an extension of previous work detailed in a report titled *Complexing Agents for Zinc/Bromine Battery Electrolyte*† and is based on recommendations from that report.

50-kWh Battery Module Testing

Several minor problems were encountered while testing the 50-kWh module during the quarter. An attempt was made to perform a 300-A discharge, but a minor "overcurrent" fault was encountered. At this point, the system was discharged at 280 A. Measured currents were compared to the current sensor values monitored by the system and are shown in Table 2-13. From this information, it can be seen that the current sensors were not as accurate as anticipated. This caused an overcurrent fault when the attempt was made to discharge at 300 A. The overcurrent limit in the software was changed from 330 to 360 A in order to allow for this high-rate discharge.

Other minor problems included chattering of the strip signal and momentary closing, then opening of the DC contactor when the breaker switch in the control panel was turned on. When the breaker switch in the control panel was turned on, the DC contactor closed for a moment, and then opened. Both of these situations have since been resolved. After these problems were addressed, constant-current discharge tests (75 A, 150 A

† S. E. Klassen, C. H. Hayes, L. Deck, B. Chamblee, *Complexing Agents for Zinc/Bromine Battery Electrolyte, Proprietary Report*, SAND94-0440.

Table 2-13. Discharge Currents for Individual Battery Stacks

	Current Measured With Meter	Current From Monitoring PC
Stack No. 1	95.4 A	109 A
Stack No. 2	93.7 A	105 A
Stack No. 3	90.0 A	101 A
Module	279.1 A	315 A

and 300 A) were performed on the system. For each test, the module was charged at 150 A for 4.5 hours. The module was completely stripped before and after each cycle. Module performance for the constant-current discharge cycles is presented in Table 2-14. Voltage and current profiles are shown in Figures 2-6 through 2-8.

Amp-hours and kWhs for each of these tests were measured using separate meters. The individual stack currents were measured using hole current sensors. Cooling water was used to control the temperature of the module. Water is not circulated until the temperature in the reservoirs rises to above 30°C, and it is turned off if the temperature goes below 28°C. The maximum temperature reached was 38°C during the 300-A discharge.

The performance of this system is slightly lower than expected, which is attributed to the fact that the batteries used in this module are several years old, and performance has declined from the original values. The installation of new battery stacks in the module should enable energy efficiencies of better than 75% to be achieved. The performance for the 75-A and 300-A discharges could also be improved by changing the rate at which complexed-phase bromine is added during discharge. The rate at which complexed-phase is added was optimized for the 150-A discharge, but should be varied depending on the discharge current. Future battery systems will be designed to automatically adjust the rate that complexed-phase bromine is added based on the discharge rate.

The power supplied to the pumps was measured during the 150-A discharge cycle. The pumping losses are shown in Figure 2-9.

Table 2-14. Module Performance for 50-kWh Module at Various Discharge Rates

	75-A Discharge	150-A Discharge	300-A Discharge
Coulombic Efficiency			
(Until 60 Volts)	77.5%	80.0%	75.5%
(Until 30 Volts)	79.4%	81.1%	81.4%
(Until 0 Volts)	82.9%	87.4%	87.5%
Voltaic Efficiency			
(Until 60 Volts)	84.8%	2.8%	76.8%
(Until 30 Volts)	83.6%	82.6%	75.9%
(Until 0 Volts)	80.9%	79.2%	72.6%
Energy Efficiency			
(Until 60 Volts)	65.7%	66.2%	58.0%
(Until 30 Volts)	66.4%	67.0%	61.8%
(Until 0 Volts)	67.1%	69.2%	63.5%

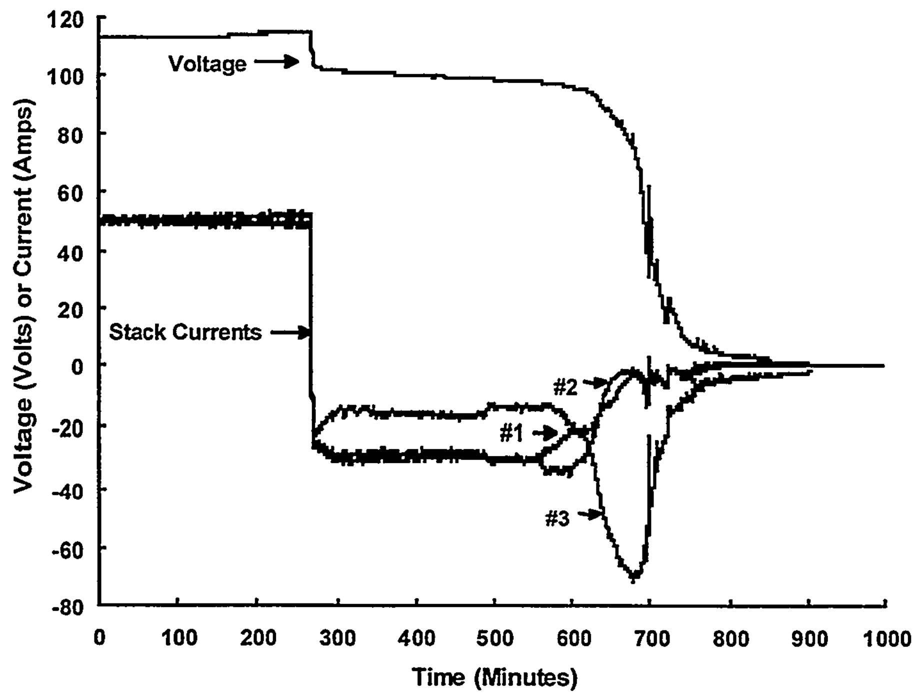


Figure 2-6. Voltage and Current Profiles for 50-kWh Module During a 75-A Discharge.

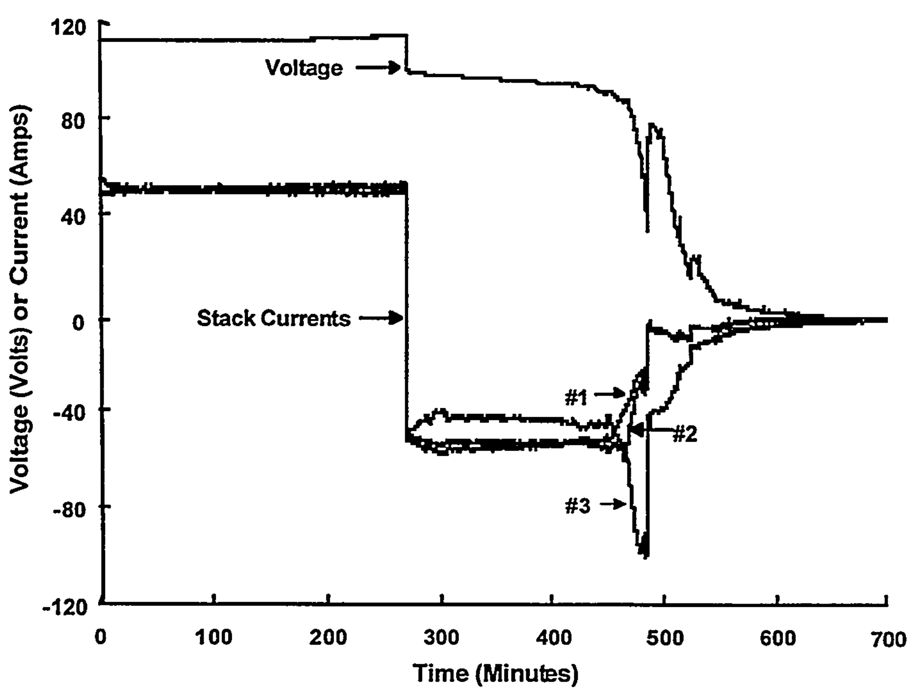


Figure 2-7. Voltage and Current Profiles for 50-kWh Module During a 150-A Discharge.

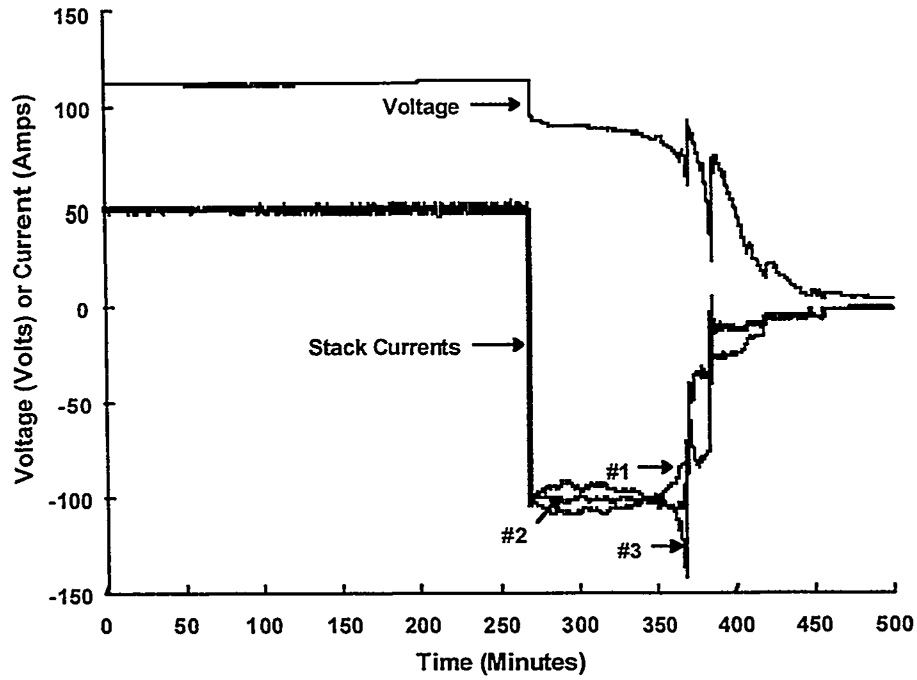


Figure 2-8. Voltage and Current Profiles for 50-kWh Module During a 300-A Discharge.

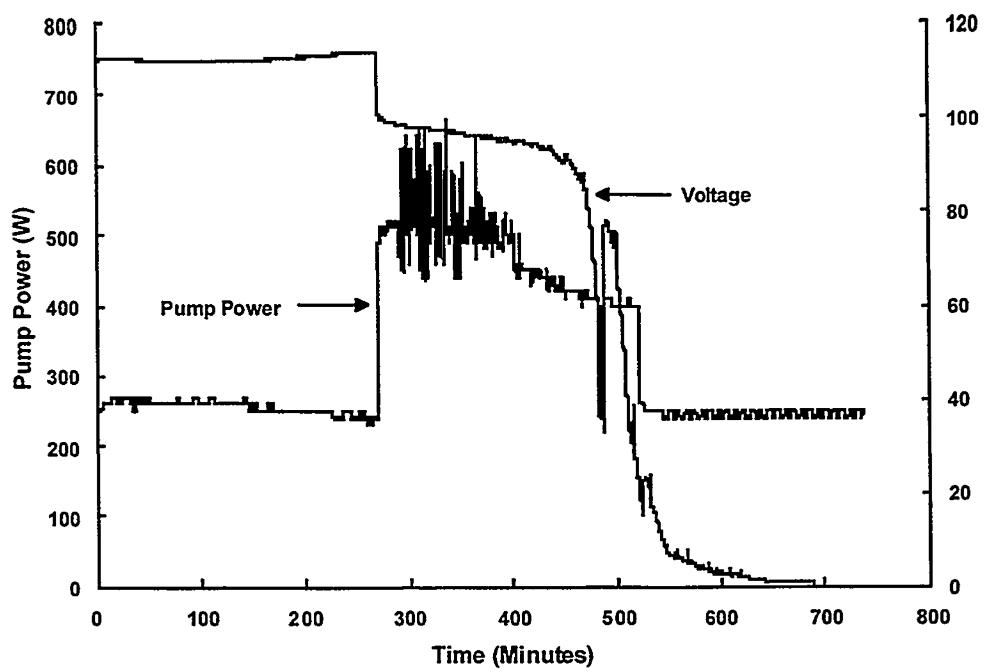


Figure 2-9. Pumping Losses and Battery Voltage for 50-kWh Module During a 75-A Discharge.

The power increases when discharge begins because the complexed-phase bromine pump is started. The maximum power consumption is observed during the first half of the discharge because the complexed-phase is highly viscous, and the pump speeds change regularly to compensate for the addition of complexed-phase. The pump speeds change so that the levels in the reservoirs are maintained at a constant level. The pumping losses again decrease when the module voltage reaches 30 V because this is considered the strip phase, and the complexed-phase pump no longer runs during strip. The total power consumed by the pumps during various portions of the cycle are provided in Table 2-15. From this information, it was determined that the pumps for the system will use approximately 2.5% of the energy supplied to the system during a normal charge/discharge cycle.

Substation Power Quality Project

On September 15, 1998, Sandia received a letter from PNM stating that they were unable to execute CRADA no. SC97/1509, Electric Utility System Power Quality Demonstration. This ended the effort to construct a substation level power quality system at SNL's Substation No. 41 with PNM.

The ESS program still sees value in this application and is interested in developing and/or evaluating a system to address power quality issues at a substation level. The question that remains is to what extent is industry interested in this concept. In order to assess this interest, ESS program staff planned a series of presentations to be given at industry technical meetings in an attempt to gain industry input. The first of these presentations will be given at the Energy Storage Association meeting on October 7, 1998. A second presentation will be given at the Power Systems World '98 meeting on November 11, 1998.

System Evaluation

Mobile PQ2000T System

The goal of the Mobile PQ2000T (formerly TBESS) project is to further the development of prototype battery systems built with commercially available and advanced components and to evaluate these systems in typical utility operating environments. The project covers the design, fabrication, siting, installation, testing, and reporting on the first prototype system. The system is designed to be moved to a new location (on the same or on a different utility grid), installed, and tested. The prototype is being developed for use by one or more utilities over a multiyear period to obtain field data at more than one site to prove reliability, functionality, and cost-effectiveness.

Status

The Sandia TBESS prototype system name was changed to the Mobile PQ2000T. This was done to reduce confusion caused by referring to the unit as TBESS, which is used for the Electric Power Research Institute/Salt River Project (EPRI/SRP) TBESS, and to highlight the fact that the system is truly mobile and not just portable as is the EPRI/SRP TBESS.

On October 1, 1997, the prototype Mobile PQ2000T rolled out of the AC Battery facilities en route to Richmond, Virginia. It was installed at the Virginia Power Iron Bridge Maintenance Facility where it underwent characterization testing by Virginia Power in preparation for possible use at a Virginia Power customer site.

Figure 2-10 shows the Mobile PQ2000T in place at Iron Bridge with AC Battery field engineers preparing the system to be connected to the 480-VAC service at the facility. Figure 2-11 shows the single point of entry for the service and load connections. Virginia Power installed a network of cable trays as shown in Figure 2-12 to manage the interconnection cables from

Table 2-15. Pumping Losses for 50-kWh Module During 150-A Discharge Cycle

	Charge	Discharge	Strip	Total
Pumping Losses	1.17 kWh	1.75 kWh	1.17 kWh	4.09 kWh

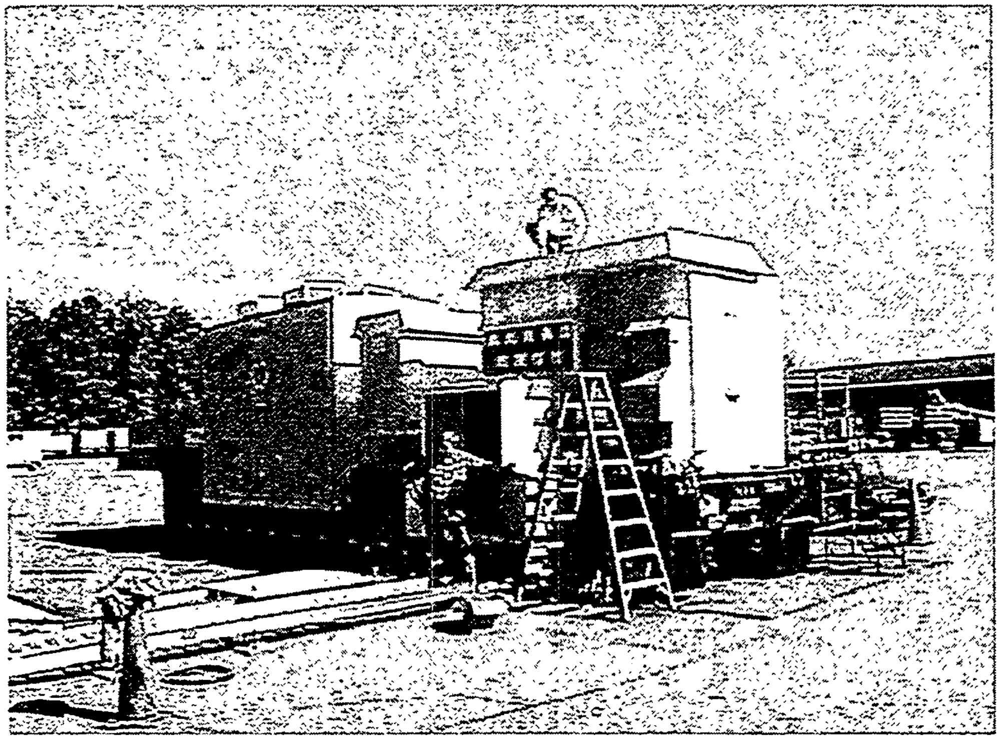


Figure 2-10. Engineers Prepare the Mobile PQ2000T for Connection to 480-VAC Service at the Virginia Power Iron Bridge Maintenance Facility.

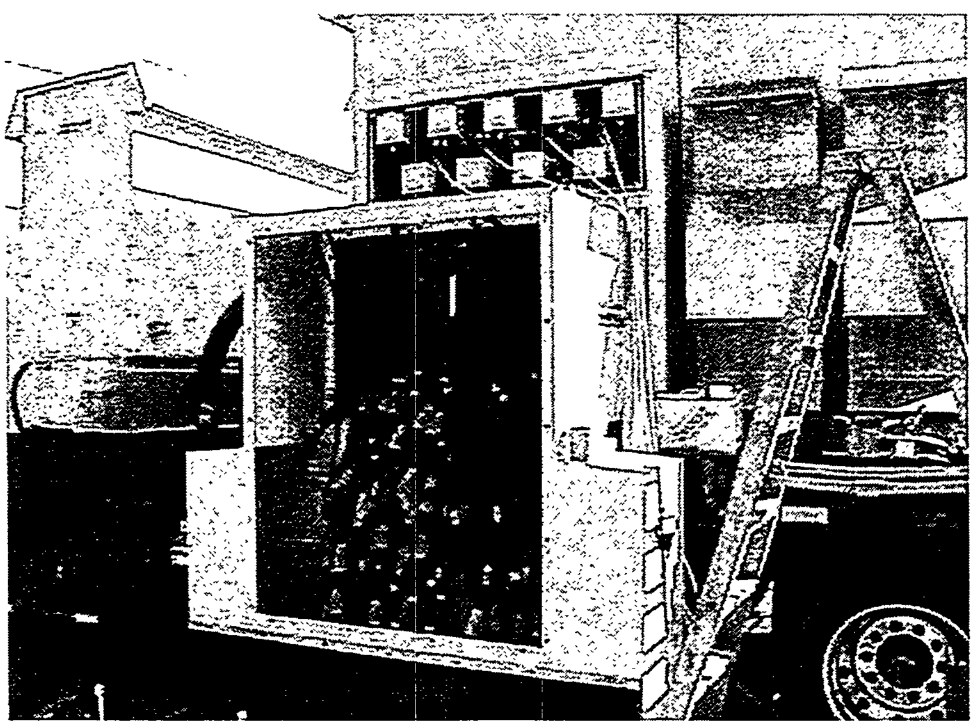


Figure 2-11. Single Point of Entry for the Mobile PQ2000T Service and Load Connections.

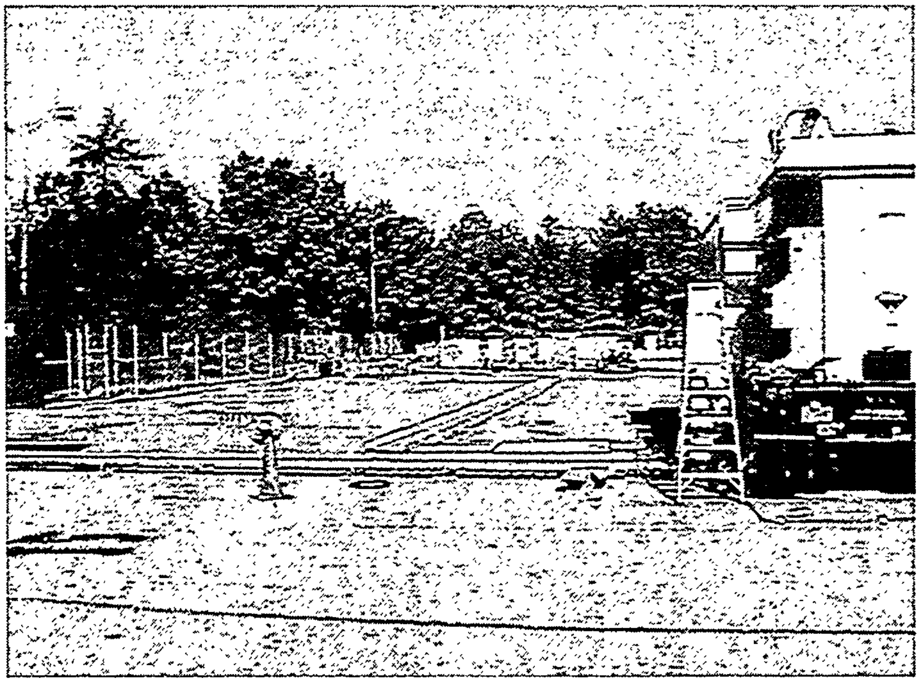


Figure 2-12. A Network of Cable Trays Manages the Interconnection Cables from the Source to the Load Interfaces.

the source to the load interfaces. Installation work continued through mid-November when the Mobile PQ2000T was successfully powered up for the first time at a remote site. From mid-November through mid-December, trials were conducted to replicate the acceptance tests. Several small problems were identified and corrected by AC Battery field engineers. Virginia Power accepted the Mobile PQ2000T on December 18, 1997. Plans were to continue characterization testing through March 1998, when the Mobile PQ2000T was to be installed at the first customer site.

In early January 1998, AC Battery Corporation announced that it had been sold to Omnion Power Engineering Corporation of East Troy, Wisconsin. With the approval of SNL, all contractual requirements for Mobile PQ2000T were transferred to Omnion effective the second quarter of FY98. Because of the turmoil created by the transition of the Mobile PQ2000T contract from AC Battery to Omnion, negotiations with Virginia Power to name its first customer site were delayed.

The prototype Mobile PQ2000T continued characterization testing throughout the second quarter at the Virginia Power Iron Bridge Facility. Figure 2-13 is an artist's rendering of the layout of the test setup at the Virginia Power test site.

To facilitate the test program through the control of each of the three electrical phases, Virginia Power installed a remote-controlled, oil bath switch to allow the loss of any single-phase, loss of two phases, or total power loss to be sensed and supported by the Mobile PQ2000T. The use of this switch contributed significantly to the characterization test program.

During the characterization testing phase, several problems were noted and corrected based on test results. One significant finding was the ability to operate the Mobile PQ2000T at zero power by moving a sensor to a different location. Originally, the Mobile PQ2000T could not support a load of less than 100 kW because sensed signals were too noisy below that power level. Relocating the power sensor eliminated the noise problem.

The Mobile PQ2000T characterization testing at the Iron Bridge Facility was completed in early April 1998, and the system was placed off line. Early in the third quarter of FY98, a visual inspection of several module trays revealed that a number of batteries exhibited significant corrosion at one of the terminal posts. Delphi immediately corrected the problem in all subsequent builds of the Delphi 1150 battery. Replacement batteries were supplied by Delphi under the battery warranty. Inspection and replacement of corroded batteries was completed in mid-June.

By early June, the selection for the first commercial site for the Mobile PQ2000T was in its final stages.

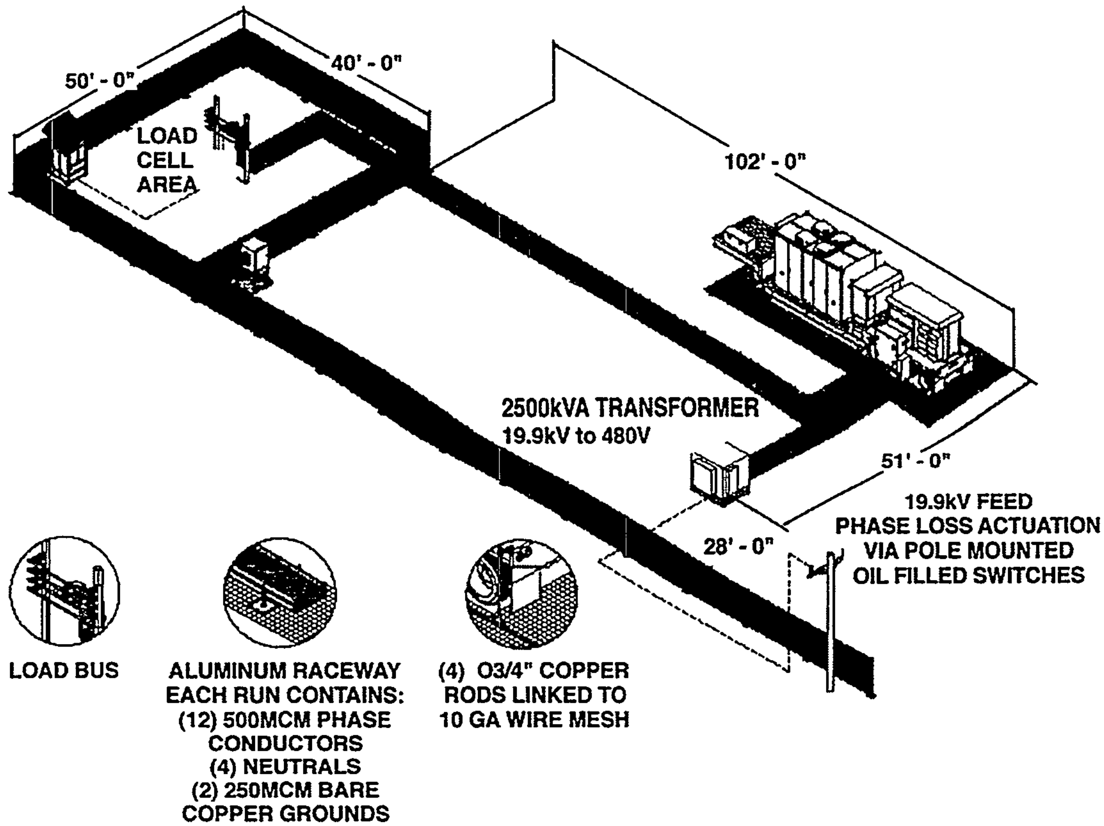


Figure 2-13. Artist Rendering of Mobile PQ2000T Test Setup at the Virginia Power Iron Bridge Maintenance Facility.

Because of the sensitivity of the site, Evantage requested that confidentiality be maintained until the final agreement was completed with the customer. In mid-June, the potential customer unexpectedly withdrew from the program, citing apprehension that the system might cause problems, not solve them. Evantage immediately began negotiations with several other potential customers that had been contacted early in the program.

In late July, a new customer, a printing plant, had been identified in the Richmond area. Modifications to the service entry were performed by Virginia Power engineers and plans were finalized to install the Mobile PQ2000T at the plant during the Labor Day weekend, which would minimize impact to production output during the final installation. The unit was successfully installed, activated, and tested over the three-day holiday weekend. On Monday evening (September 7, 1998), only hours after activation, the Mobile PQ2000T serviced the first power-quality event that would have caused production problems in the plant. During the following week, several events were serviced with no interruption in plant production.

During the second week of operation, a catastrophic fault downstream of the Mobile PQ2000T resulted in a fire in a Virginia Power conduit that ultimately shut down the part of the plant serviced by the Mobile PQ2000T. A detailed investigation revealed that the Mobile PQ2000T was in no way responsible for the fire. It appeared that the cable was seriously damaged by flaws in the conduit during installation. Although the Mobile PQ2000T did not contribute to the outage, the customer requested that it be removed during the repair period and not be reinstalled. The customer no longer cared to risk trying a new technology. The unit was removed from the site and temporarily stored at the Iron Bridge Facility for the remainder of the fiscal year. Evantage immediately began the search for a new customer site.

AC Battery PM250 Field Evaluation

The AC Battery PM250 was assembled and factory-tested in 1993 under a contract with Omnion Power Engineering Corporation of East Troy, Wisconsin. In October 1993, the PM250 began field testing at the

Pacific Gas & Electric (PG&E) modular generation test facility in San Ramon, California. After approximately 100 deep-cycle discharges, field testing ended. The unit remained idle at the test facility until late 1995, when it was returned to AC Battery Corporation for retrofit of the battery complement and correction of problems identified in field testing. Following completion of the retrofit and factory checkout in FY97, additional testing of the PM250 may be performed if a host site is found.

Status

Following the purchase of AC Battery Corporation by Omnion Power Engineering Corporation in the second quarter of FY98, the PM250 was removed from temporary storage at the AC Battery Facility and transferred to the Omnion facility in East Troy, Wisconsin. In late May, a contract was issued to Omnion to perform final field testing of the prototype PM250 at the Omnion facilities in order to complete testing of the PM250 and to retire the unit. This contract encompassed three tasks: (1) remove the Prototype PM250 from storage and prepare for testing, (2) cycle the PM250 to 100% depth of discharge until the battery reaches end-of-life according to specified end-of-life criteria, and (3) decommission the PM250 and dispose of the batteries and hardware.

During June, the PM250 was removed from storage and was visually inspected to determine its physical readiness for test resumption. Everything was found to be ready for reconnection to the utility source. By the end of June, Task 1 was complete and the system was ready to enter the end-of-life testing activity.

In early July, following an initial charge and discharge operation, it was discovered that system capacity had fallen to well below end-of-life criteria. After careful evaluation of each of the eight modules in the system, it was determined that only two modules had acceptable capacities while all the others exhibited end-of-life voltages and capacities. Consequently, the criteria for completing Task 2 were met before any meaningful testing could be completed. Task 3 was initiated and the PM250 was decommissioned and scrapped, and the battery complement was committed to battery recycling.

This ended a long and productive testing program for a first-of-its-kind utility-scale battery system. Testing at the PG&E Modular Generation Test Facility (MGTF) yielded a considerable amount of practical information on the use of off-the-shelf batteries in utility applications. Information was gathered on the behavior of long battery strings in the cycling environment. Documentation was thorough during the development activity and test program. Sandia Report SAND97-1276, printed August 1998, is a comprehensive view of all phases of the development activity. A final report on the results of the test program is in progress as well as a lessons-learned report that highlights conclusions and recommendations on how to manage long battery strings. Both documents should be published in FY99.

Field Test of Final GNB VRLA Battery Deliverable

As the final deliverable from its VRLA battery development contract, GNB furnished a battery that is capable of providing approximately 250 kW/500 kWh for a field test. The site selected through a competitive process for this test was the GNB lead recycling center in Vernon, California, and a new contract was placed with GNB at the beginning of FY96 to carry out the field testing. GNB installed a battery system at the recycling center to support critical plant loads during utility power outages to prevent violations of air emission standards. The total system is capable of providing 3.5 MW of power to the plant for one hour and a peak power of 5 MW for 10 sec. The battery consists of two parallel strings of GNB ABSOLYTE IIP type 100A99 VRLA cells. Each string contains 378 modules (three cells per module) and operates at a nominal 756 VDC. Battery energy is converted to the plant AC voltage by means of three General Electric power conversion units, each rated at 1.25 MW. The battery is also available for periodic block loading to reduce plant peak demand and the associated utility demand charges. Operation of this system is providing an opportunity to evaluate the performance of a large VRLA battery while it is being used in an actual field application. Approximately 10% of the battery cells at Vernon were supplied by the ESS Program.

A communications link was established between the Vernon site and GNB's engineering laboratories in Lombard, Illinois. This communications link makes it possible to monitor from a remote terminal all status screens of the control system, including battery status and SOC, plant power requirements, status of the power conversion equipment, whether peak shaving is active or inactive, and alarm conditions. The data presented by the battery monitor screens include battery voltage, battery current, battery temperature, and ambient temperature. It is possible to manipulate BESS parameters to activate peak shaving, initiate an equalization charge, or perform a discharge test; this can be done remotely or locally.

A daily analysis of the Vernon BESS operation began on July 1, 1997. In July and August, a relatively high 3,400-kW trigger level was set to permit GNB engineers to observe peak-shaving events, yet barely exercise the battery. This resulted in relatively few battery discharges, as expected, since average plant demand was less than 3,100 kW on weekdays. In September, the number of peak-shaving events increased because of a slight increase in plant demand and a reduction in trigger level to 3,300 kW. Based on these activities, it was surmised that a trigger level between 3,000 and 3,100 kW may yield optimum overall efficiency and maximum cost savings during specified summer peak-shaving periods. GNB therefore decided to continue decreasing the trigger level until the BESS SOC fell to 60 to 70% by the end of the peak-shaving period. The lowest observed SOC during the first three months of daily analysis was 88%.

Status

Figure 2-14 shows the average and daily peak-plant demand compared to the trigger level (3,250 kW) for the month of October 1997. From July through October, the system was trouble-free, and performance data were obtained for each day. If alarm conditions occurred at any time, GNB engineering staff corrected the problem so that peak shaving was possible during the specified times. For each month following August 1997, the trigger level was lowered slightly so that the BESS could be exercised more frequently. Tables 2-16 and 2-17 show the first quarter FY98 data.

In mid-November 1997, the BESS began experiencing a series of ground-fault alarms that interrupted its ability to peak shave continuously during the specified times of 12:00 p.m. to 8:00 p.m. Because of this, the months of November and December were categorized as "lost" because it takes only one demand spike to exceed the peak-shaving trigger level and thus forfeit any cost savings.

In late December, methods were found to deal with the ground fault alarms so that peak shaving activities could continue without obstruction. Peak-shaving operations resumed in January 1998, but data acquisition was problematic throughout the month, as shown in Table 2-18. For reasons not known at the time, the interface computer began experiencing difficulties when storing data to its hard drive. This caused computer "lock-ups" and consequent loss of daily data files. The BESS was still able to perform its normal functions because this computer simply acts as a "window," enabling GNB operators to monitor the state of the

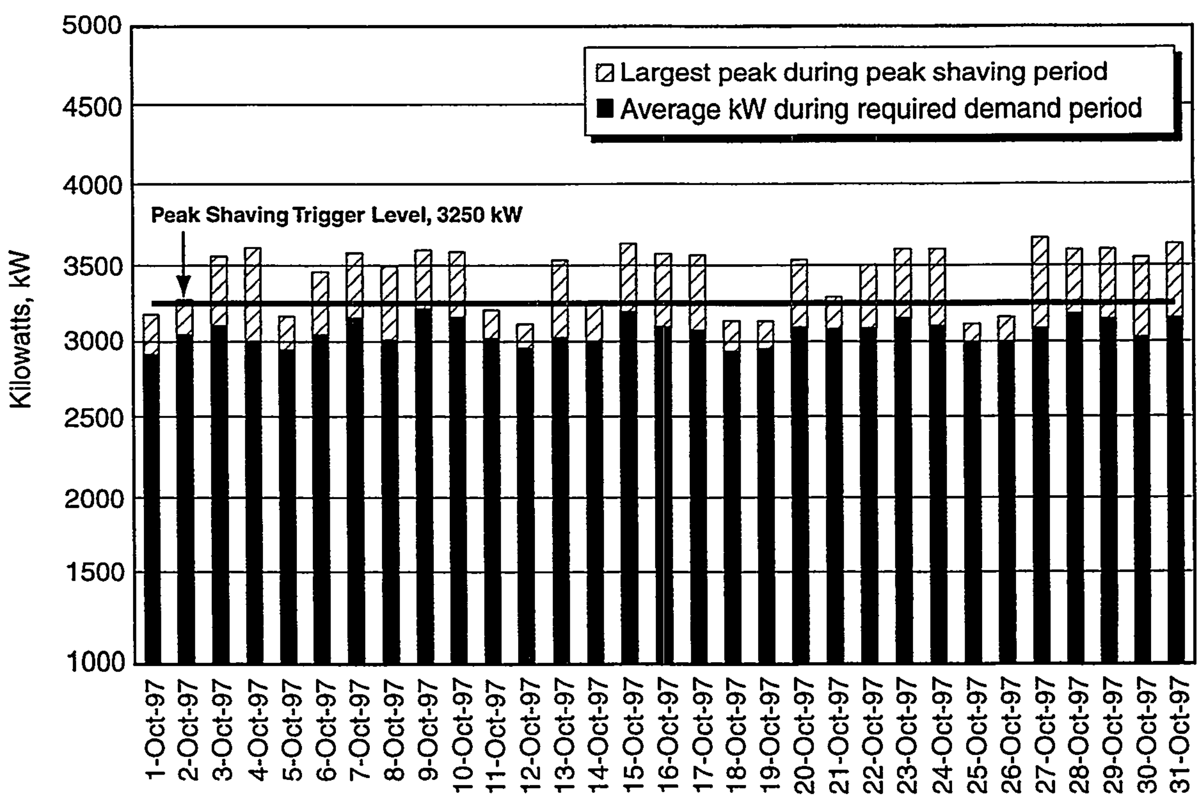


Figure 2-14. Daily Average and Peak Plant Demand for the Month of October 1997.

Table 2-16. October 1997 Discharge Data on Vernon BESS Operations

October 1997: 3,250-kW Trigger Level

Date	Day of the Week	No. of Discharge Operations During Required Demand Period	Average kW During Required Demand Period	Largest Peak During Peak-Shaving Period	Lowest SOC During Peak-Shaving Period
10/1/97	W	0	2026	3182	93%
10/2/97	Th	12	3054	3277	92%
10/3/97	F	45	3108	3557	92%
10/4/97	Sa	14	3005	3597	92%
10/5/97	Su	0	2946	3164	92%
10/6/97	M	83	3051	3451	92%
10/7/97	Tu	286	3147	3568	92%
10/8/97	W	52	2999	3478	92%
10/9/97	Th	436	3205	3588	88%
10/10/97	F	274	3163	3569	91%
10/11/97	Sa	0	3017	3200	92%
10/12/97	Su	0	2961	3109	92%
10/13/97	M	41	3020	3518	92%
10/14/97	Tu	0	2998	3230	92%
10/15/97	W	427	3192	3623	91%
10/16/97	Th	109	3088	3555	92%
10/17/97	F	101	3073	3547	92%
10/18/97	Sa	0	2926	3136	92%
10/19/97	Su	0	2938	3130	92%
10/20/97	M	129	3081	3519	92%
10/21/97	Tu	67	3069	3279	92%
10/22/97	W	178	3079	3482	91%
10/23/97	Th	323	3155	3584	90%
10/24/97	F	158	3105	3586	92%
10/25/97	Sa	0	2983	3104	92%
10/26/97	Su	0	2985	3150	92%
10/27/97	M	172	3076	3657	90%
10/28/97	Tu	367	3178	3579	91%
10/29/97	W	253	3141	3578	92%
10/30/97	Th	50	3023	3529	92%
10/31/97	F	290	3147	3625	90%

(Note: Data acquired from BESS have 10-sec sample rates on discharge and 3-min on recharge.)

Largest of the month:			3657	
Average for entire month:	125	3059	3424	91.6%
Average for weekdays only:	168	3090	3503	91.4%

Table 2-17. November 1997 Discharge Data on Vernon BESS Operations

November 1997: >3,200-kW Trigger Level

Date	Day of the Week		No. of Discharge Operations During Required Demand	Average kW During Required Demand Period	Largest Peak During Peak-Shaving Period	Lowest SOC During Peak-Shaving Period
11/1/97-11/9/97		3200 kW	*Data not able to be retrieved from computer*			92%
11/10/97	M		641	3165	3565	91
11/11/97	Tu	3200 kW	647	3183	3601	89
11/12/97	W	Note A	0	2980	3491	95
11/13/97	Th	Note B	0	3050	3480	--
11/14/97	F	Note B	0	3114	3296	--
11/15/97	Sa	Note B	0	3016	3195	--
11/16/97	Su	Note B	0	3083	3246	--
11/17/97	M	Note B	12	3284	3705	--
11/18/97-11/30/97		Note B	*Data not able to be retrieved from computer*			--
(Note: Data acquired from BESS have 10-sec sample rates on discharge and 3-min on recharge.)						
Largest of the month:					3705	
Average for entire month:			--	--	--	--
Average for weekdays only:			--	--	--	--

Note A: Power Conversion Pair No. 3 went off line for unknown reasons; computer also tried loading data onto bad sectors, so data acquisition wasn't possible.

Note B: No peak shaving–String No. 2 was off line and being inspected for acid and ground paths.

entire system. Loss of this computer renders BESS operators blind to instantaneous data acquisition and analysis, but the BESS still operates.

From February through March 1998, the BESS resumed proper data acquisition as shown in Tables 2-19 and 2-20. However, there was an exception of five days in late February when data retrieval was again obstructed for the same reason explained above. Ground-fault trip occurrences were now a minimal concern. However, the peak-shaving trigger was set artificially high for February and March (3600 and 3900 kW respectively), as shown in Figures 2-15 and 2-16. The intent of this approach was to use peak shaving for cost mitigation while barely exercising the battery. Once the operational difficulties were completely resolved, the search for an optimum trigger level could be resumed.

Peak shaving continued without significant interruption through the months of April, May and June 1998. Tables 2-21 through 2-23 and Figures 2-17 through 2-19 show the third quarter FY98 data. For April 1998, the peak-shaving trigger level was left at 3900 kW as shown in Figure 2-17. GNB engineers wanted to observe for an entire month whether ground-fault alarms would occur even when the battery was barely exercised during daily peak shaving operations, hence the arbitrarily high trigger level. No abnormal events were encountered, so it was decided to return to aggressive peak shaving in the following months.

During May and June of 1998 (Figures 2-18 and 2-19), the BESS resumed peak shaving with a trigger level of 3100 kW. Peak shaving operation continued with only one interruption that occurred when all three

Table 2-18. January 1998 Discharge Data for Vernon BESS Operations

January 1998: 3600-kW Peak-Shaving Trigger Level

Date	Day of the Week		No. of Discharge Operations During Required Demand Period	Average kW During Required Demand Period	Largest Peak During Peak-Shaving Period	Difference Between Largest & Average kW Values (at left)	Lowest SOC During Peak-Shaving Period
1/1/98	Th	Note A	0	3084	3289	205	93%
1/2/98	F	No PS	0	3084	3306	222	--
1/3/98	Sa	No PS	0	3039	3249	210	--
1/4/98	Su	No PS	4	3125	3832	707	--
1/5/98	M		1	3188	3609	421	86%
1/6/98	Tu	*Data could not be retrieved from computer*				0	86%
1/7/98 - 1/31/98		Peak shaving, but not data acquisition (computer unable to log data)				0	86%
(Note: Data acquired from BESS have 10-sec sample rates on discharge and 3-min on recharge.)							
Largest of the month:					3832		
Average for entire month:			1	3104	3457		87.8%
Average for weekdays only:			0	3119	3401		87.8%

Note A: No peak shaving; system went off line about 12:30 p.m. "Phantom ground fault alarm" caused the trip, which was possibly due to high humidity levels in California.

power conversion units went off line briefly on June 23. There was one weekday (June 19, 1998) when data acquisition stopped, as shown in Figure 2-19. Peak shaving continued, although data for that day was not available. Ground-fault alarms tended to occur frequently because of the high sensitivity alarm threshold. This tended to generate more ground-fault alarms because of the battery overcharging that is automatically started as part of each ground-fault alarm "reset" operation. Cell venting is caused by the varying internal cell pressures experienced during these frequent overcharge periods. This ground fault alarm and recharge cycle was compounded by the high humidity and high ground moisture that was present as well as a few instances of cell leakage. All of these things contributed to the higher incidence of ground faults. Overall in the third quarter, BESS operation indicated that progress was being made toward realizing optimal levels for battery utilization during peak-shaving periods.

Peak-shaving operations continued smoothly through July, August, and September 1998. In early July 1998 the Vernon smelter facility intended to replace some on-site power equipment, so BESS peak shaving was disabled as preparations were made for these activities (Figure 2-20). When peak shaving was enabled once again, the trigger level remained set at 3100 kW, and peak shaving resumed without incident as shown in Table 2-24.

For the months of August and September 1998, the BESS continued daily peak-shaving operation with a trigger level of 3100 kW. Peak shaving was disabled on the weekends, as demand charges are not recorded during those times; this allowed the BESS to regain maximum capacity and avoid adding unnecessary cycles on the battery. Ground-fault alarms still tended to occur, but they were less frequent than in previous quarters. The data for the months of August and September are presented in Figures 2-21 and 2-22, and Tables 2-25 and 2-26.

Overall, this FY of BESS operation showed successful progress toward achieving optimal battery utilization during summer peak-shaving periods. The lowest battery SOC recorded during a peak-shaving period in September was 64% and the average low SOC for September was 77.6%. These values are approaching the target range of 60-70%. Although the exact optimum peak trigger level has not yet been demonstrated, the data indicate that it will likely be near 3000 kW with some seasonal variation.

Table 2-19. February 1998 Discharge Data from Vernon BESS Operations

February 1998: >3600-kW Peak-Shaving Trigger Level

Date	Day of the Week	No. of Discharge Operations During Required Demand Period	Average kW During Required Demand Period	Largest Peak During Peak-Shaving Period	Difference Between Largest and Average kW Values (at left)
2/1/98	Su	0	3043	3213	170
2/2/98	M	0	3101	3492	391
2/3/98	Tu	0	3093	3537	444
2/4/98	W	0	3081	3494	413
2/5/98	Th	0	3090	3432	342
2/6/98	F	7	3210	3668	458
2/7/98	Sa	1	3033	3766	733
2/8/98	Su	0	3048	3281	233
2/9/98	M	0	3090	3565	475
2/10/98	Tu	0	2726	3146	420
2/11/98	W	0	2966	3441	475
2/12/98	Th	1	2983	3693	710
2/13/98	F	0	3102	3487	385
2/14/98	Sa	0	3027	3346	319
2/15/98	Su	0	3062	3199	137
2/16/98	M	0	3102	3503	401
2/17/98	Tu	0	3100	3517	417
2/18/98	W	0	3094	3489	395
2/19/98	Th	0	3097	3489	392
2/20/98	F	*Data could not be retrieved from computer*			0
2/21/98	Sa	↓			0
2/22/98	Su	↓			0
2/23/98	M	↓			0
2/24/98	Tu	↓			0
2/25/98	W	↓			0
2/26/98	Th	↓			0
2/27/98	F	0	3032	3254	222
2/28/98	Sa	0	2925	3160	235

(Note: Data acquired from BESS have 10-sec sample rates on discharge and 3-min on recharge.)

Largest of the month:			3766	
Average for entire month:	0	3048	3437	
Average for weekdays only:	1	3058	3480	

Table 2-20. March 1998 Discharge Data from Vernon BESS Operations

March 1998: 3900-kW Peak-Shaving Trigger Level

Date	Day of the Week	No. of Discharge Operations During Required Demand Period	Average kW During Required Demand Period	Largest Peak During Peak-Shaving Period	Difference Between Largest & Average kW values (at left)	Lowest SOC During Peak-Shaving Period
3/1/98	Su	0	2954	3215	261	--
3/2/98	M	0	3384	4107	723	--
3/3/98	Tu	0	3169	3672	503	--
3/4/98	W	0	3291	3746	455	--
3/5/98	Th	0	3258	3885	627	--
3/6/98	F	0	3127	3669	542	--
3/7/98	Sa	0	2890	3241	351	--
3/8/98	Su	0	2991	3274	283	--
3/9/98	M	0	3197	3626	429	--
3/10/98	Tu	0	3252	3747	495	--
3/11/98	W	0	3165	3667	502	--
3/12/98	Th	0	3154	3714	560	--
3/13/98	F	0	3223	4049	826	--
3/14/98	Sa	0	3110	3401	291	--
3/15/98	Su	0	3117	3391	274	--
3/16/98	M	0	3229	3824	595	--
3/17/98	Tu	0	3226	3850	624	92%
3/18/98	W	0	3275	3830	555	91%
3/19/98	Th	0	3146	3769	523	91%
3/20/98	F	0	2744	3195	451	91%
3/21/98	Sa	1	2949	3473	524	92%
3/22/98	Su	0	3073	3321	248	99%
3/23/98	M	0	3146	3315	169	99%
3/24/98	Tu	0	3136	3424	288	92%
3/25/98	W	0	3228	3762	534	92%
3/26/98	Th	0	3328	3908	580	92%
3/27/98	F	1	3374	4000	626	93%
3/28/98	Sa	0	3162	3370	208	99%
3/29/98	Su	0	3133	3383	250	99%
3/30/98	M	0	3333	3842	509	92%
3/31/98	Tu	0	3377	3903	526	92%
(Note: Data acquired from BESS have 10-sec sample rates on discharge and 3-min on recharge.)						
Largest of the month:				4107		
Average for entire month:		0	3166	3631		93.7%
Average for weekdays only:		0	3216	3750		92.5%

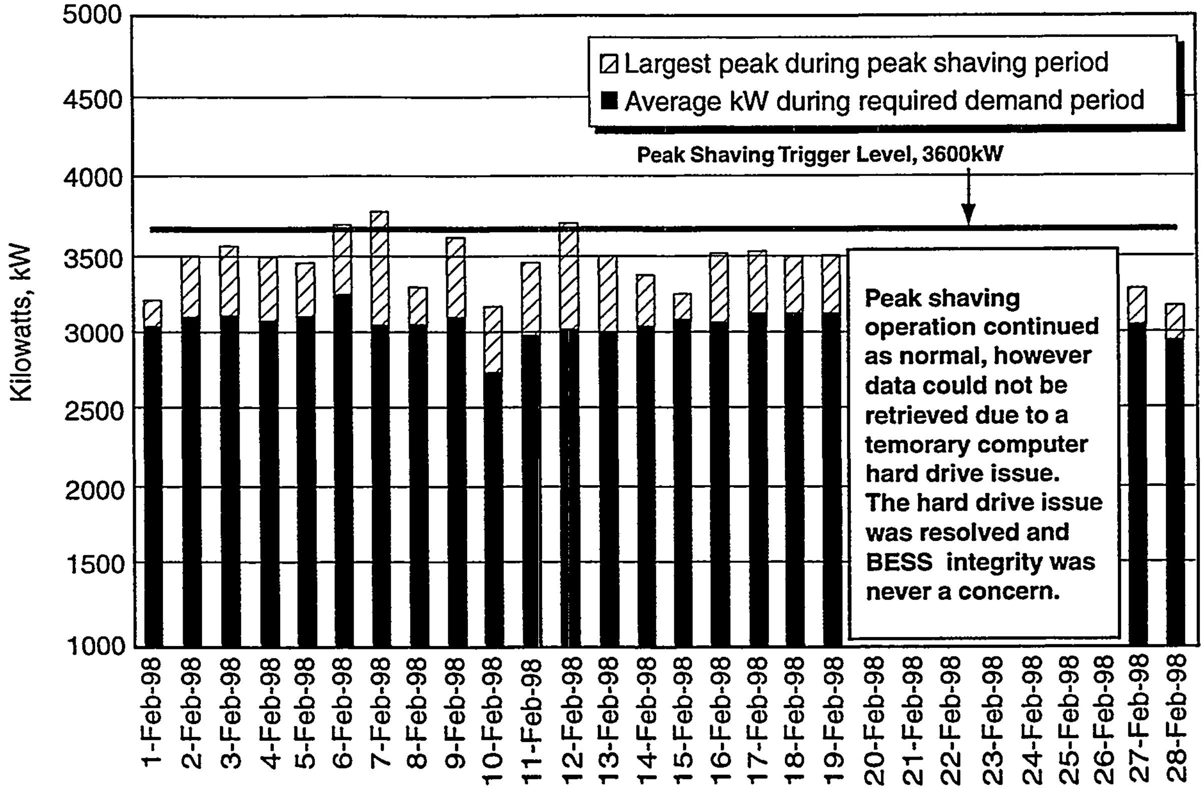


Figure 2-15. Daily Average and Peak Plant Demand for the Month of February 1998.

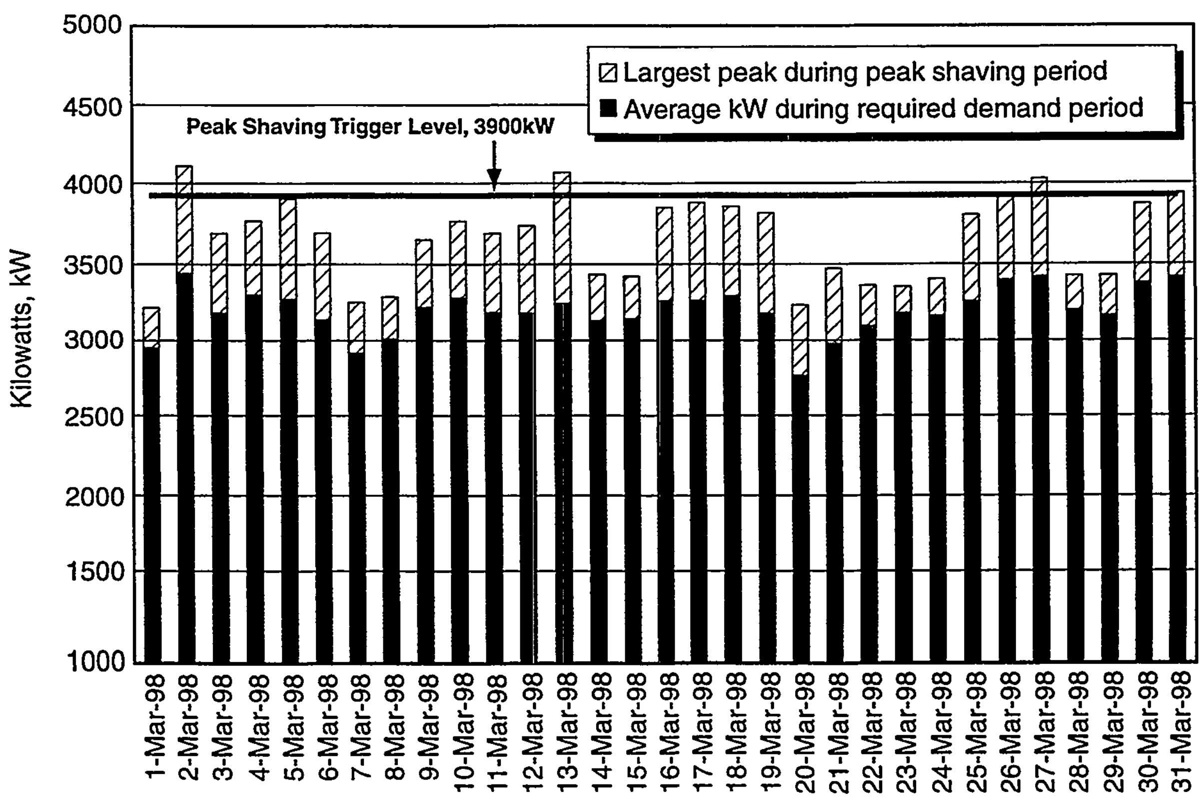


Figure 2-16. Daily Average and Peak Plant Demand for the Month of March 1998.

Table 2-21. April 1998 Discharge Data from Vernon BESS Operations

April 1998: 3900-kW Peak-Shaving Trigger Level

Date	Day of the Week	No. of Discharge Operations During Required Demand Period	Average kW During Required Demand Period	Largest Peak During Peak-Shaving Period	Difference Between Largest & Average kW values (at left)	Lowest SOC During Peak-Shaving Period
4/1/98	W	0	3335	3763	428	92%
4/2/98	Th	0	3154	3733	579	92%
4/3/98	F	0	3163	3669	506	92%
4/4/98	Sa	0	3027	3310	283	92%
4/5/98	Su	0	3104	3338	234	92%
4/6/98	M	0	3145	3785	640	92%
4/7/98	Tu	2	3349	3945	596	92%
4/8/98	W	0	3178	3548	370	92%
4/9/98	Th	0	3138	3351	213	92%
4/10/98	F	0	3022	3219	197	91%
4/11/98	Sa	0	2996	3193	197	92%
4/12/98	Su	0	3065	3235	170	93%
4/13/98	M	0	3165	3670	505	92%
4/14/98	Tu	1	3368	3915	547	92%
4/15/98	W	0	3399	3872	473	92%
4/16/98	Th	1	3392	3910	518	92%
4/17/98	F	0	3329	3743	414	92%
4/18/98	Sa	0	3061	3242	181	92%
4/19/98	Su	0	2980	3210	230	93%
4/20/98	M	0	3120	3781	661	92%
4/21/98	Tu	1	3361	3932	571	92%
4/22/98	W	0	3291	3768	477	92%
4/23/98	Th	0	3302	3861	559	92%
4/24/98	F	0	3298	3819	521	92%
4/25/98	Sa	0	3394	3893	499	92%
4/26/98	Su	0	3168	3382	214	92%
4/27/98	M	0	3290	3839	549	92%
4/28/98	Tu	0	3288	3738	450	92%
4/29/98	W	0	3231	3698	467	92%
4/30/98	Th	0	3235	3702	467	92%

(Note: Data acquired from BESS have 10-sec sample rates on discharge and 3-min on recharge.)

Largest of the month:			3945		
Average for entire month:	0	3212	3635		92.0%
Average for weekdays only:	0	3253	3739		92.0%

Table 2-22. May 1998 Discharge Data from Vernon BESS Operations

May 1998: 3100-kW Peak-Shaving Trigger Level

Date	Day of the Week		No. of Discharge Operations During Required Demand Period	Average kW During Required Demand Period	Largest Peak During Peak-Shaving Period	Difference Between Largest & Average kW Values (at left)	Lowest SOC During Peak-Shaving Period
5/1/98	F		1183	3105	3467	362	78%
5/2/98	Sa		840	3076	3324	248	91%
5/3/98	Su		762	3084	3190	106	91%
5/4/98	M		752	3102	3555	453	65%
5/5/98	Tu		721	3099	3504	405	73%
5/6/98	W		671	3074	3510	436	90%
5/7/98	Th		705	3086	3561	475	90%
5/8/98	F		738	3098	3611	513	78%
5/9/98	Sa	No PS	-	3125	3756	631	-
5/10/98	Su	No PS	-	3071	3226	155	-
5/11/98	M		792	3098	3490	392	67%
5/12/98	Tu		849	3099	3710	611	64%
5/13/98	W		815	3098	3321	223	85%
5/14/98	Th		921	3184	3463	279	84%
5/15/98	F		672	3084	3501	417	89%
5/16/98	Sa		720	3048	3105	57	92%
5/17/98	Su	No PS	-	3116	3316	200	93%
5/18/98	M		-	3069	3551	482	91%
5/19/98	Tu		841	3104	3511	407	90%
5/20/98	W		812	3101	3547	446	89%
5/21/98	Th		990	3106	3609	503	65%
5/22/98	F		889	3104	3509	405	68%
5/23/98	Sa	No PS	-	3052	3312	260	93%
5/24/98	Su	No PS	-	3049	3211	162	93%
5/25/98	M	Holiday	1183	3101	3334	233	90%
5/26/98	Tu		994	3102	3411	309	79%
5/27/98	W		804	3103	3487	384	85%
5/28/98	Th		898	3107	3540	433	77%
5/29/98	F		858	3103	3512	409	68%
5/30/98	Sa		812	3106	3729	623	88%
5/31/98	Su		758	3068	3226	158	86%
(Note: Data acquired from BESS have 10-sec sample rates on discharge and 3-min on recharge.)							
Largest of the month:					3756		
Average for entire month:			839	3094	3455		82.5%
Average for weekdays only:			854	3103	3508		78.7%

PS = peak shaving

Table 2-23. June 1998 Discharge Data from Vernon BESS Operations

June 1998: 3100-kW Peak-Shaving Trigger Level

Date	Day of the Week		No. of Discharge Operations During Required Demand Period	Average kW During Required Demand Period	Largest Peak During Peak-Shaving Period	Difference Between Largest & Average kW Values (at left)	Lowest SOC During Peak-Shaving Period
6/1/98	M		812	3102	3522	420	86%
6/2/98	Tu		756	3099	3531	432	79%
6/3/98	W		611	3096	3498	402	89%
6/4/98	Th		665	3092	3725	633	86%
6/5/98	F		697	3102	3446	344	79%
6/6/98	Sa	No PS	--	2993	3543	550	91%
6/7/98	Su	No PS	--	3091	3273	182	--
6/8/98	M		817	3098	3478	380	84%
6/9/98	Tu		751	3100	3530	430	69%
6/10/98	W		665	3080	3468	388	81%
6/11/98	Th		806	3105	3509	404	59%
6/12/98	F		1018	3103	3486	383	58%
6/13/98	Sa	No PS	--	3207	3452	245	95%
6/14/98	Su	No PS	--	3162	3295	133	91%
6/15/98	M		1074	3101	3534	433	77%
6/16/98	Tu		951	3104	3504	400	57%
6/17/98	W		807	3103	3492	389	60%
6/18/98	Th		708	3098	3651	553	62%
6/19/98	F		Logging stopped, reason unknown – restarted 6/22			0	--
6/20/98	Sa	No PS				0	--
6/21/98	Su	No PS				0	--
6/22/98	M		794	3102	3478	376	68%
6/23/98	Tu	PS Halt	-	3561	4622	1061	--
6/24/65	W		832	3103	3469	366	76%
6/25/98	Th		947	3102	3797	695	61%
6/26/98	F		1219	3108	3542	434	76%
6/27/98	Sa	No PS	--	3290	3457	167	--
6/28/98	Su	No PS	--	3208	3385	177	--
6/29/98	M		1070	3106	3675	569	69%
6/30/98	Tu		704	3098	3716	618	64%
(Note: Data acquired from BESS have 10-sec sample rates on discharge and 3-min on recharge.)							
Largest of the month:					4622		
Average for entire month:			835	3130	3558		74.7%
Average for weekdays only:			835	3100	3553		72.0%

PS = peak shaving

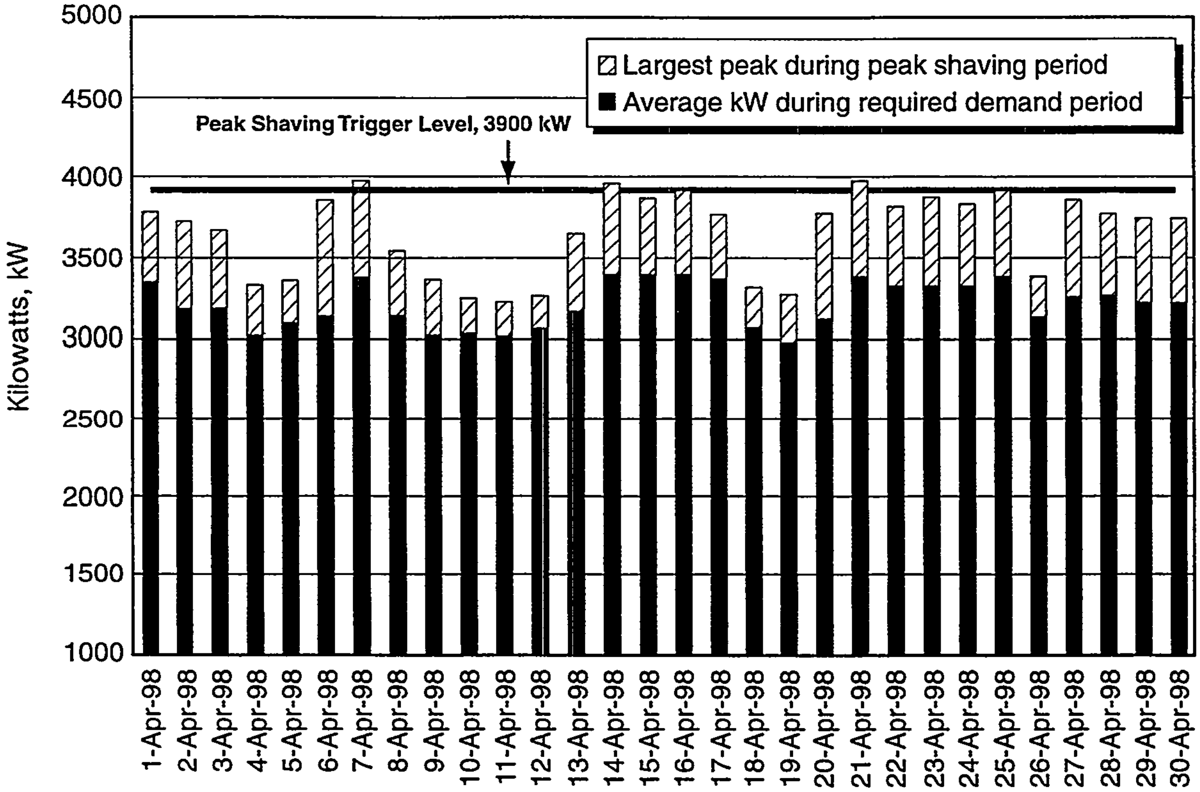


Figure 2-17. Daily Average and Peak Plant Demand for the Month of April 1998.

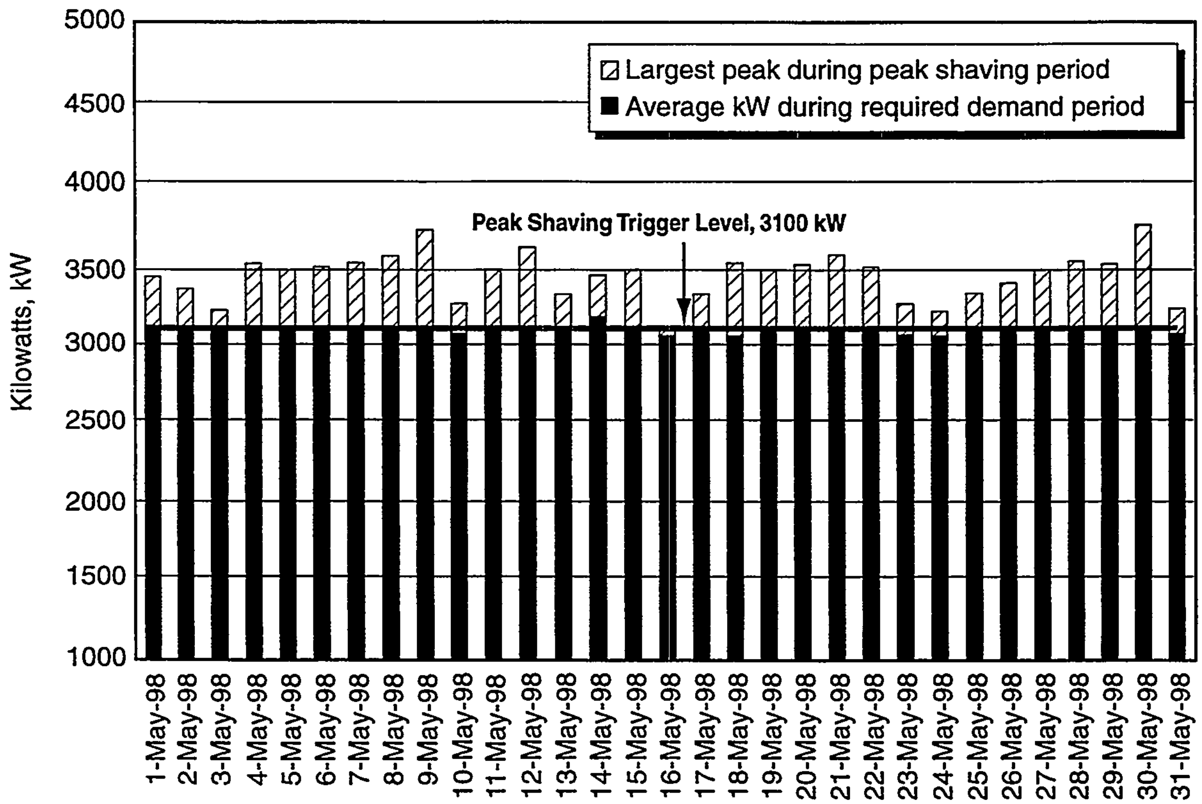


Figure 2-18. Daily Average and Peak Plant Demand for the Month of May 1998.

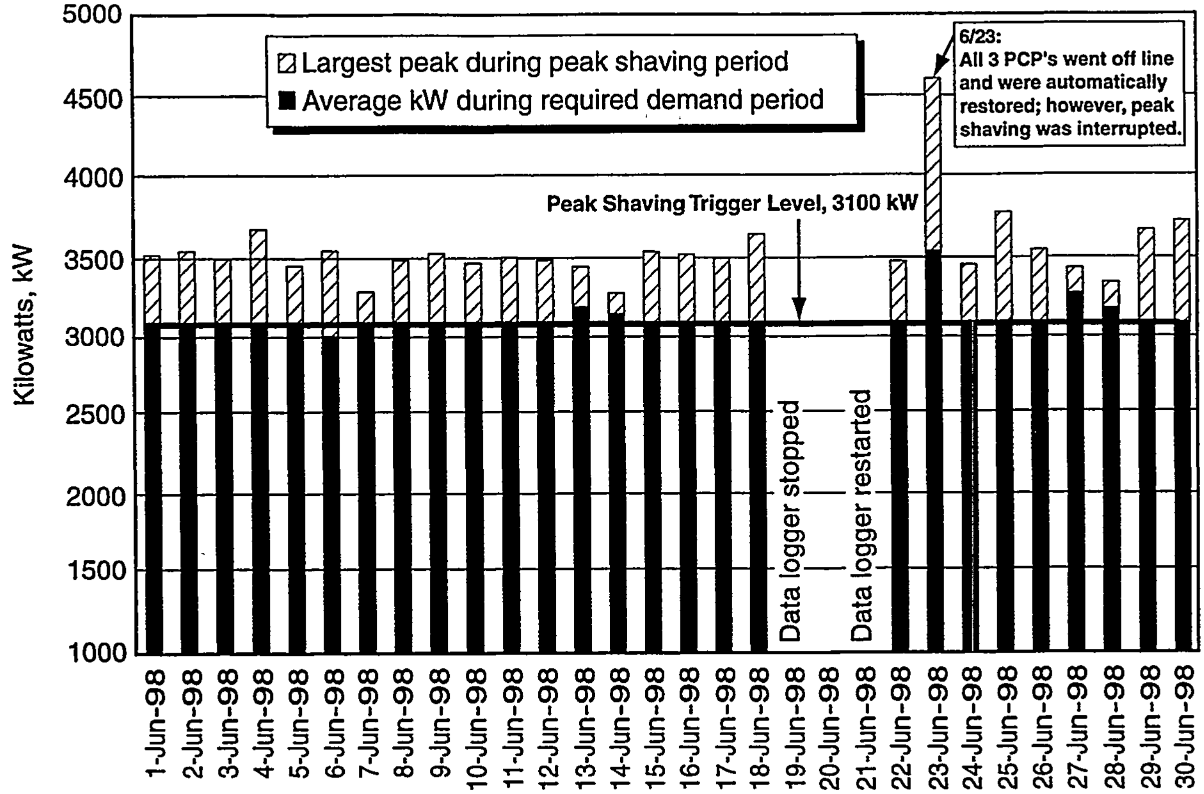


Figure 2-19. Daily Average and Peak Plant Demand for the Month of June 1998.

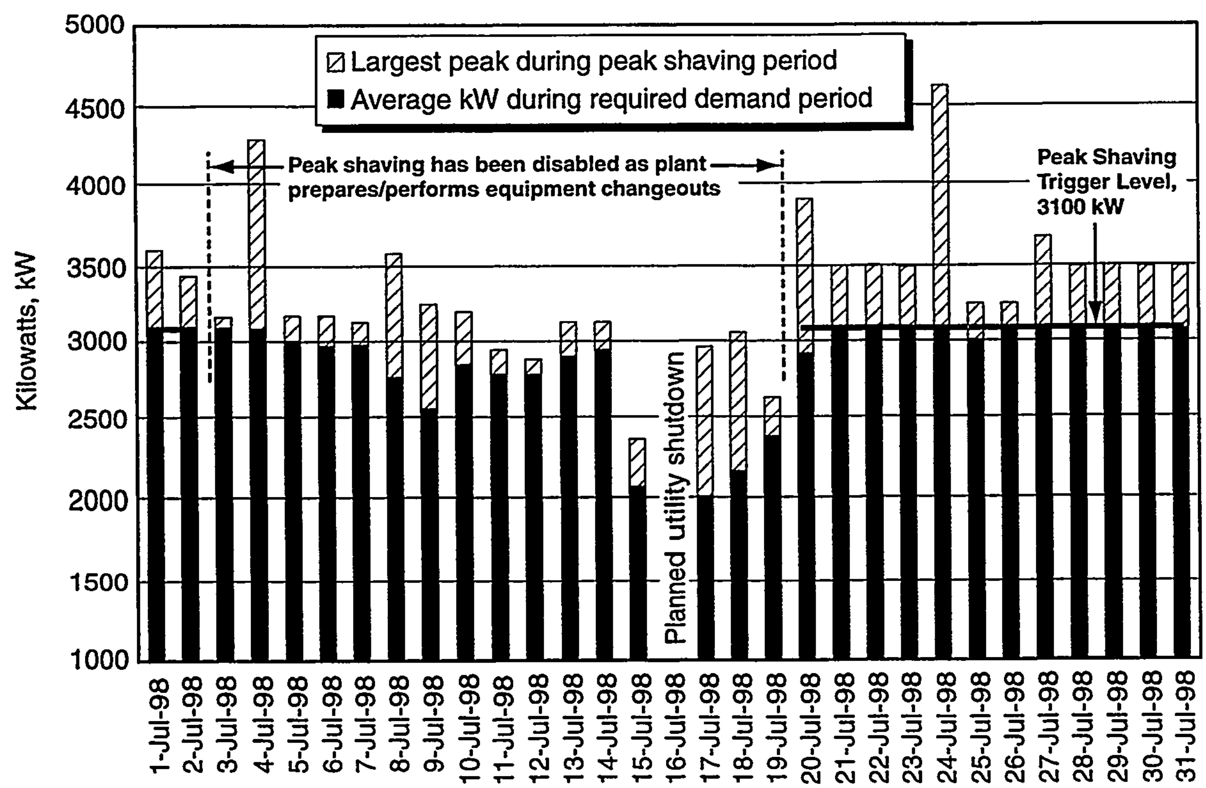


Figure 2-20. Daily Average and Peak Plant Demand for the Month of July 1998.

Table 2-24. July 1998 Discharge Data from Vernon BESS Operations

July 1998: 3100-kW Trigger Level

Date	Day of the Week		No. of Discharge Operations During Required Demand Period	Average kW During Required Demand Period	Largest Peak During Peak-Shaving Period	Difference Between Largest & Average kW values (at left)	Lowest SOC During Peak-Shaving Period
7/1/98	W		804	3101	3631	530	65%
7/2/98	Th		665	3095	3446	351	89%
7/3/98	F	*Note A*	–	3118	3209	91	93%
7/4/98	Sa	*No PS*	–	3062	4276	1214	93%
7/5/98	Su	*No PS*	–	2997	3201	204	95%
7/6/98	M	*No PS*	–	2946	3210	264	94%
7/7/98	Tu	*No PS*	–	2920	3144	224	94%
7/8/98	W	*No PS*	–	2763	3593	830	94%
7/9/98	Th	*No PS*	–	2576	3254	678	93%
7/10/98	F	*No PS*	–	2813	3229	416	93%
7/11/98	Sa	*No PS*	–	2716	2888	172	98%
7/12/98	Su	*No PS*	–	2667	2765	98	94%
7/13/98	M	*No PS*	–	2757	3151	394	92%
7/14/98	Tu	*No PS*	–	2844	3121	277	92%
7/15/98	W	*No PS*	–	2062	2326	264	93%
7/16/98	Th	*Note B*	*Planned utility shutdown*		–	–	–
7/17/98	F	*No PS*	–	1993	2939	946	92%
7/18/98	Sa	*No PS*	–	2168	3084	916	92%
7/19/98	Su	*No PS*	–	2361	2654	293	94%
7/20/98	M		140	2887	3871	984	92%
7/21/98	Tu		883	3093	3489	396	85%
7/22/98	W		888	3097	3503	406	83%
7/23/98	Th		922	3099	3473	374	85%
7/24/98	F		766	3100	4666	1566	66%
7/25/98	Sa	*No PS*	–	3000	3289	289	93%
7/26/98	Su	*No PS*	–	3060	3294	234	94%
7/27/98	M		999	3105	3656	551	70%
7/28/98	Tu		952	3101	3476	375	91%
7/29/98	W		933	3103	3479	376	90%
7/30/98	Th		755	3094	3486	392	89%
7/31/98	F		519	3056	3503	447	92%
(Note: Data acquired from BESS has 10-sec sample rates on discharge and 3-min on recharge.)							
Largest of the month:					4666		
Average for entire month:			769	2858	3344	–	89.3%
Average for weekdays only:			769	2886	3412	–	87.6%

Note A: Peak shaving has been disabled as plant prepares to perform equipment changeouts.
Note B: Planned utility shutdown; plant intended to be supported by BESS.
PS = peak shaving

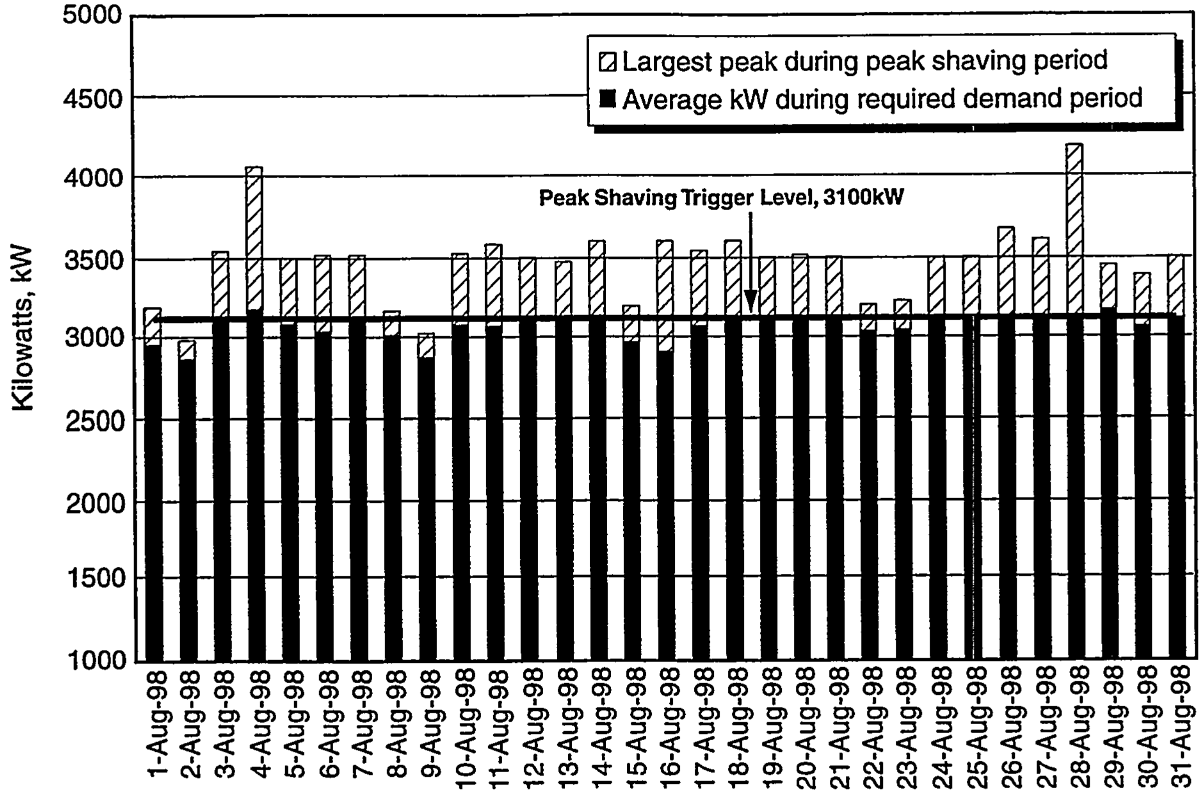


Figure 2-21. Daily Average and Peak Plant Demand for the Month of August 1998.

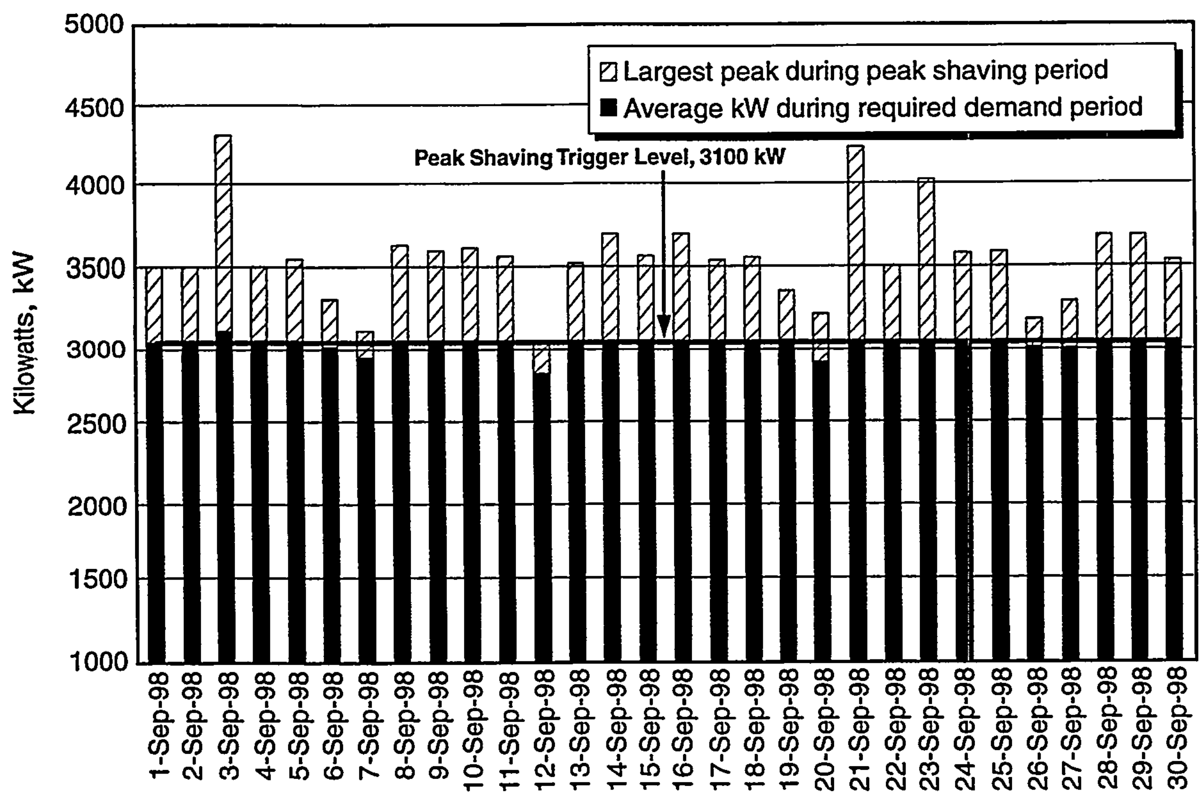


Figure 2-22. Daily Average and Peak Plant Demand for the Month of September 1998.

Table 2-25. August 1998 Discharge Data from Vernon BESS Operations

August 1998: 3100-kW Trigger Level

Date	Day of the Week		No. of Discharge Operations During Required Demand Period	Average kW During Required Demand Period	Largest Peak During Peak-Shaving Period	Difference Between Largest & Average kW values (at left)	Lowest SOC During Peak-Shaving Period
8/1/98	Sa		57	2915	3170	255	98%
8/2/98	Su		0	2779	2921	142	94%
8/3/98	M		726	3093	3550	457	88%
8/4/98	Tu		1312	3173	4134	961	91%
8/5/98	W		544	3070	3492	422	90%
8/6/98	Th		526	3013	3502	489	89%
8/7/98	F		709	3091	3520	429	88%
8/8/98	Sa	*No PS*	–	2977	3174	197	98%
8/9/98	Su	*No PS*	–	2821	2994	173	94%
8/10/98	M		535	3062	3500	438	91%
8/11/98	Tu		462	3040	3641	601	90%
8/12/98	W		857	3103	3535	432	74%
8/13/98	Th		944	3101	3453	352	81%
8/14/98	F		722	3096	3676	580	89%
8/15/98	Sa	*No PS*	–	2940	3271	331	93%
8/16/98	Su	*No PS*	–	2766	3650	884	93%
8/17/98	M		606	3075	3563	488	87%
8/18/98	Tu		941	3098	3687	589	78%
8/19/98	W		792	3098	3469	371	76%
8/20/98	Th		724	3092	3529	437	78%
8/21/98	F		761	3102	3486	384	85%
8/22/98	Sa	*No PS*	–	2996	3182	186	98%
8/23/98	Su	*No PS*	–	3026	3243	217	98%
8/24/98	M		617	3096	3496	400	87%
8/25/98	Tu		775	3092	3490	398	82%
8/26/98	W		920	3097	3728	631	79%
8/27/98	Th		580	3095	3601	506	86%
8/28/98	F		857	3098	4264	1166	79%
8/29/98	Sa	*No PS*	–	3153	3449	296	98%
8/30/98	Su	*No PS*	–	3022	3377	355	98%
8/31/98	M		896	3099	3490	391	82%

(Note: Data acquired from BESS has 10-sec sample rates on discharge and 3-min on recharge.)
PS = peak shaving

Largest of the month:			4264		
Average for entire month:	690	3041	3492	–	88.1%
Average for weekdays only:	753	3090	3610	–	84.3%

Table 2-26. September 1998 Discharge Data from Vernon BESS Operations

September 1998: 3100-kW Trigger Level

Date	Day of the Week		No. of Discharge Operations During Required Demand Period	Average kW During Required Demand Period	Largest Peak During Peak-Shaving Period	Difference Between Largest & Average kW values (at left)	Lowest SOC During Peak-Shaving Period
9/1/98	Tu		1031	3105	3477	372	72%
9/2/98	W		746	3096	3478	382	91%
9/3/98	Th		199	3168	4314	1146	80%
9/4/98	F		565	3091	3489	398	84%
9/5/98	Sa	*No PS*	–	3112	3527	415	97%
9/6/98	Su	*No PS*	–	3031	3315	284	98%
9/7/98	M	*No PS – Holiday*		2953	3174	221	98%
9/8/98	Tu		597	3091	3599	508	81%
9/9/98	W		532	3070	3568	498	92%
9/10/98	Th		843	3097	3592	495	71%
9/11/98	F		869	3099	3551	452	72%
9/12/98	Sa	*No PS*	–	2832	3104	272	97%
9/13/98	Su	*No PS*	–	3051	3511	460	98%
9/14/98	M		878	3116	3688	572	71%
9/15/98	Tu		1507	3099	3546	447	89%
9/16/98	W		994	3099	3652	553	64%
9/17/98	Th		792	3101	3510	409	76%
9/18/98	F		756	3102	3549	447	70%
9/19/98	Sa	*No PS*	–	3064	3351	287	98%
9/20/98	Su	*No PS*	–	2902	3216	314	98%
9/21/98	M		537	3064	4284	1220	88%
9/22/98	Tu		831	3101	3483	382	68%
9/23/98	W		725	3099	4007	908	86%
9/24/98	Th		997	3105	3633	528	78%
9/25/98	F		734	3101	3631	530	67%
9/26/98	Sa	*No PS*	–	3025	3233	208	98%
9/27/98	Su	*No PS*	–	2999	3305	306	98%
9/28/98	M		937	3105	3743	638	75%
9/29/98	Tu		860	3101	3723	622	67%
9/30/98	W		805	3090	3510	420	87%
(Note: Data acquired from BESS has 10-sec sample rates on discharge and 3-min on recharge.)							
Largest of the month:					4314		
Average for entire month:			797	3069	3559	–	83.6%
Average for weekdays only:			797	3100	3668	–	77.6%

PV/Hybrid Evaluation Project

The initial evaluation of the Omnion PV/battery hybrid controller at the SNL PV System Evaluation Laboratory (PSEL) was completed in FY95. The project plan called for the installation of the prototype control unit in an industry facility in combination with a PV array and a diesel generator. A multiyear operational test plan was successfully negotiated with APS to perform a complete system field test of the controller at APS's STAR Center in Tempe, Arizona. A memorandum of understanding and a loan agreement were finalized in FY97, and a second controller will be tested at APS for a period of two to three years.

Status

The Trace Technologies Model HY-30-2 hybrid-power conversion unit was delivered to SNL in late FY97 for initial testing at the PSEL. Initial test results indicated that significant modifications needed to be made in order for the unit to operate autonomously in the hybrid operating environment. The implementation of the modifications and subsequent testing delayed delivery of the unit to the APS STAR Center until early in the third quarter of FY98. Figure 2-23 is a photo of the unit installed in the APS STAR Center Hybrid Test Facility.

To formulate a plan for maintaining the Yuasa Dynacell Tubular Gel 210-Ah battery while waiting for delivery of the HY-30-2 inverter to start the test program, a team meeting was held at the APS STAR Center in mid-November 1997 to plan for the delay. At this time, it was decided that the Yuasa battery should be fully characterized before exposing it to testing on the high-power AES inverter. The consensus of the team was that the Omnion 4200 Hybrid Controller, stored at SNL, was the best controller available to perform the characterization tests. Arrangements were made to ship the controller to the STAR Center in early December 1997, and the battery characterization tests were conducted for early January 1998. Contractual arrangements were made with Electrochemical Engineering Consultants, Inc. (EECI) of Morgan Hill, California, to conduct the characterization tests.

Characterization testing was initiated in early January, following the receipt and installation of the Omnion controller at the STAR Center in mid-December. Early testing indicated that one cell exhibited early failure. Further testing in late March confirmed that the cell was indeed in failure. The cell was replaced with one of several spare cells provided by Yuasa, Inc., and the failed cell was returned to Yuasa for evaluation.

Characterization testing consisted of discharge/charge cycling in a fully-automated mode, one cycle following another at various rates of discharge. An assumption was made that the recharge following a discharge brought the battery back to a full SOC before the next cycle was initiated. If the battery was allowed to stand for several days between cycle tests, the battery was precharged before initiating a cycle-test sequence. The conditions for the pre-charges were varied during the characterization testing, as described below, in order to try to establish a mechanism to always return the battery to the same SOC and to learn how to maximize the available capacity from the battery.

Characterization of the Yuasa battery was completed in late May 1998. Following the removal of the Omnion unit in late June, the Trace Technologies Model No. HY-30-2 inverter was installed in its place at the APS STAR Center Hybrid Test Facility.

Because of the high data rates required to properly evaluate battery performance to the detail desired for the Dynacell battery, a Campbell Scientific CA9000, was used for the DAS system. Much of the delay in getting the system on-line before the end of the third quarter was caused by several minor problems associated with this new DAS. In addition, an unfortunate incident occurred during voltage and resistance measurement activities that resulted in the shorting of the battery to ground, which blew several fuses and caused a major failure within the DAS unit. After the restoration of the damaged fuses and components, Campbell Scientific worked closely with Arizona State University (ASU) in bringing the system back to full operation.

One major discovery during early testing activities that affected the capability of the DAS to correctly measure ampere-hours was the use of Hall-effect transducers in the DC lines to measure battery current. At low currents, especially near the end-of-charge, noise levels caused by the lack of sensitivity of the transducers at very low currents caused serious errors in ampere-hour measurements. The dynamic range of the current measurement spanned currents of less than half an ampere to 80 amperes. Standard DC shunts were installed and calibrated, and the problem was eliminated.

In mid-June, Yuasa battery engineers inspected the battery installation and reviewed performance data provided by ASU under their data management task for Sandia. It was noted that one cell of the 240 cells installed was in premature failure. The cell was replaced under warranty, and the battery was returned to operation.

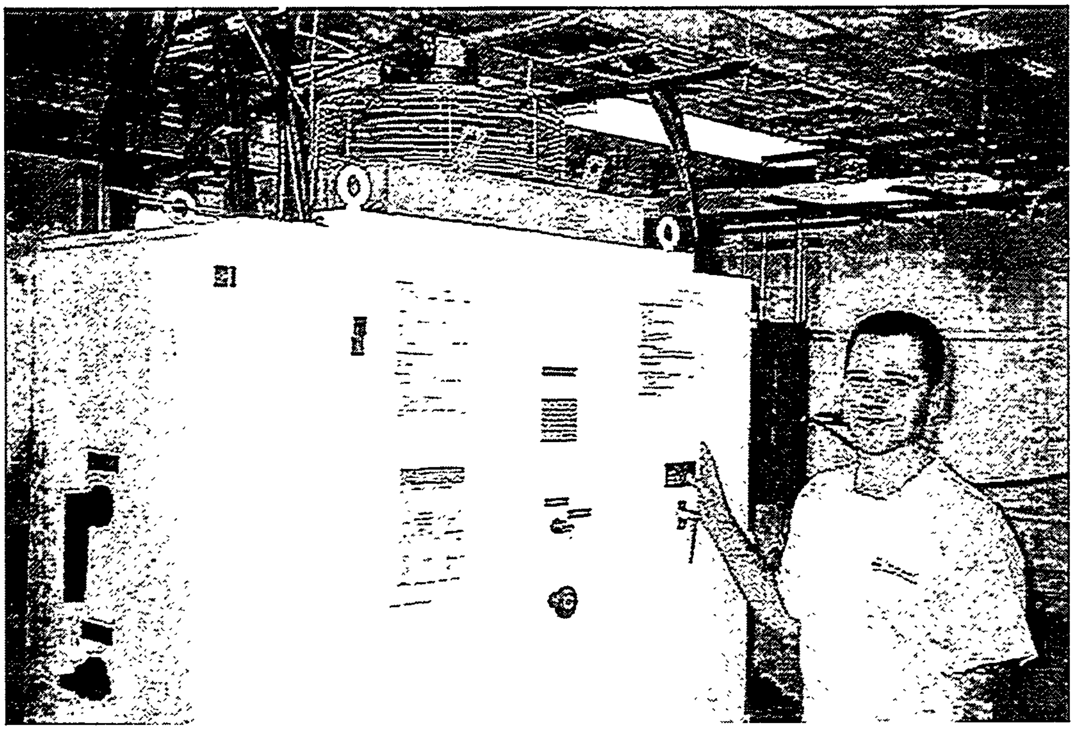


Figure 2-23. Trace Technologies Inverter at APS STAR Center Hybrid Test Center.

Following final checkout of the Trace inverter early in the fourth quarter, the system was tested initially by using it to provide all the power required by the test facility for instrumentation, lighting, and air conditioning loads as well as to characterize system performance. Following the initial testing period in late September, the system was then connected to the STAR Center grid thus powering the entire facility. The system operated successfully for the last several weeks of FY98. Then it was temporarily placed in storage and replaced with a new inverter slated for installation in a new APS project. Testing of the new inverter should be finished early in FY99 when the original inverter will be returned to service. Following installation, operational testing of the 30-kW inverter will continue throughout FY99.

Metlakatla Monitoring Project

A 1-MW/1.4-MWh battery system, designed and built under a partnership of GNB and GE with support from the ESS Program, was installed in Metlakatla, Alaska, in February 1997. The BESS is designed to compensate for severe voltage and frequency excursions caused by the operation of large motors at the local lumber mill in the remote island Indian village. Several years ago, Metlakatla Power and Light (MP&L) installed a fast-response diesel genset to stabilize the system. The diesel operated continuously and augmented existing hydrogeneration units that were too slow to respond to the rapid fluctuations caused by the lumber mill machinery. However, operation of the diesel in this mode incurred fuel and maintenance expenditures of more than $400K/year. With input from the ESS Program, MP&L recognized battery energy storage as a potential alternative to the diesel and contracted with the GNB/GE team to supply a turnkey battery system.

The storage system consists of a string of 378 GNB ABSOLYTE IIP series-connected 2-V VRLA cells. The battery has a nominal rating of 756 VDC and is operated at around 80% SOC to enable it to accept energy during voltage spikes. It consists of a PCS, an automatic generation control system, and the batteries, which are housed in a 40-by-70-foot steel battery building on a concrete pad at the 12.47-kV substation for MP&L's diesel generator. The ESS Program funded the installation of a first-of-a-kind remote monitoring capability that displays the battery system status on personal computers equipped with a modem that connects through commercial phone lines.

Status

The ESS Program continues to monitor fuel consumption at the Metlakatla system and has collected data from the system for three full years. The diesel fuel consumption at Metlakatla has significantly declined since 1996 when there was no BESS. As shown in Table 2-27, by 1998, when there was a BESS for almost two years, fuel consumption is less than 25 percent of what it was in 1996.

Table 2-27. Total Fuel Consumed for the Years 1996, 1997, and 1998*

Year	Fuel (Gal)
1998	75,118 (Jan. - Sept.)
1997	143,957
1996	331,534

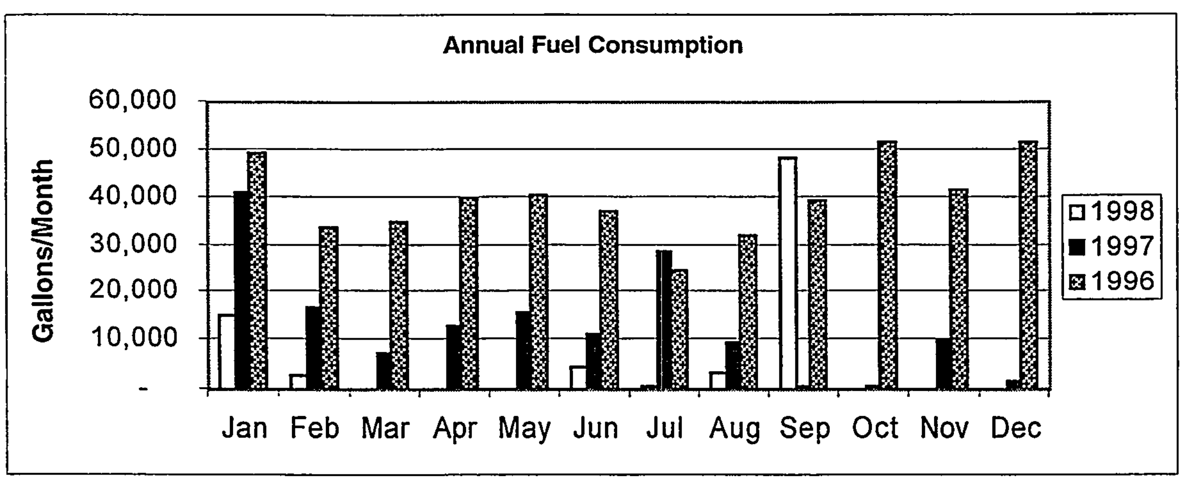
* No data for October, November, or December 1998.

As Figure 2-24 illustrates, there were several months in 1998, March (209 gals), April (125 gals), May (70 gals), and July (712 gals), when the fuel usage was substantially reduced compared to the same periods in 1996 and 1997. The fuel-usage numbers are so insignificant in fact that Excel plots these numbers on the X-axis baseline. The spike in September of 1998 is caused by hydro maintenance and the diesel generator getting more use.

The second seminar on Battery Energy Storage for rural Alaska was held in Anchorage, Alaska, November 4 through 5, 1997. The seminar was hosted by the Alaska Division of Energy and the invited presenters included SNL, GMB, MP&L, and GE. The seminar was attended by 18 managers and operators representing 71 communities out of the 173 villages that receive the Power Cost Equalization subsidy through the Division of Energy. The purpose of the seminar was to highlight the success of the Metlakatla battery system, discuss the key features that contribute to its economic benefits and create an awareness of similar battery storage benefits that might be available to other Alaskan communities.

In his remarks, Percy Frisby, Director, Division of Energy, emphasized that these Alaskan villages consumed 55 million gallons of diesel during 1996 to generate electricity in these villages, and battery energy storage could help reduce this consumption. Following this seminar, the Division of Energy representative indicated that he had hopes of funding site-specific feasibility studies that could lead to installation of more battery-storage systems in rural Alaska.

Representatives of MP&L gave unqualified endorsements of their battery system performance and shared information on the fuel savings to date and other operating benefits of the battery system.



* No data for October, November, or December 1998.

Figure 2-24. Comparison of Diesel Fuel Consumption at Metlakatla, Alaska, for 1996, 1997, and the First Nine Months of 1998.*

3. Components

Introduction

Work in the Components element focuses on improving the subsystems that make up energy storage systems: improved devices are developed and evaluated in the storage device (e.g., battery), the electrical equipment (power conversion), and the controls. The ESS Program is developing storage components that cost less, have higher performance, and are better integrated with other parts of the system than those currently available.

SNL continues to pursue the VRLA battery reliability initiative, which is attempting to address reliability issues in cooperation with industry. SNL believes a critical component of this activity is continued laboratory testing. Controlled laboratory tests are the best method of determining capacity degradation rates and of providing mechanisms to understand the relevant cause-and-effect relationships.

As part of its technical mission in support of the ESS Program, SNL performs in-house battery evaluation tasks. These tasks utilize specialized and unique facilities and capabilities established during many years of program activities in battery and other storage technologies. Current tasks include the evaluation of VRLA (AGM and gel), starting, lighting, and ignition (SLI); and advanced batteries. These independent, objective tests use computer-controlled testers capable of simulating application-specific test regimes, and they provide critical data for the assessment of the status and probable success of these technologies.

Component Development

VRLA Reliability Improvement Project

VRLA batteries have been commercially available for more than 10 years and have been enthusiastically embraced by users of uninterruptible power supplies because of anticipated reduction in maintenance costs and the smaller footprint that is available with this technology. As field experience has accumulated, it has become more widely appreciated that VRLA batteries are more sensitive to their operating conditions than flooded lead-acid batteries. This is particularly true under conditions such as elevated temperature or overcharging, which can result in battery dry-out in starved-electrolyte designs, thereby shortening battery life compared with that to which users are accustomed. Although some VRLA failures may be attributed to abusive environments or improper float-charging conditions, there is a lack of confidence among some users that all of the possible life-limiting conditions for VRLA batteries have been identified. The information on recent failures has made potential utility battery customers, including users of standby power systems, more reluctant to adopt battery energy storage technology, particularly if VRLA designs are being proposed.

Because SNL believes that VRLA battery technology offers real advantages in utility and renewable energy applications, a VRLA reliability improvement project was formulated. The primary objective of the project is to determine VRLA cycle and calendar life under typical utility battery operating conditions and use modes. The ESS Program and ILZRO established a collaboration to address VRLA reliability issues. There is general agreement among the two organizations that to address VRLA battery performance issues, the following areas would have to be advanced: optimizing VRLA batteries for stationary applications, establishing the best charge control system, and performing a VRLA reliability assessment. Another important issue is that no current method exists to rapidly characterize VRLA battery life.

A three-phase project was defined to identify and resolve these life issues. Phase 1 involves a survey of the industry, in cooperation with VRLA manufacturers and users, to determine objectively and accurately the status of the technology. Phase 2 investigates the critical issues identified in Phase 1 and suggests improvements to the charging methods or other aspects of the technology. Because it is expected that charging protocols will be one of the most critical areas identified for optimum operation, Phase 2 includes a charging study that focuses on those issues. Phase 3 then attempts to correlate and match the various types of VRLA technologies to the numerous applications now using lead-acid batteries. This will assist users and battery suppliers in selecting a design for an intended application, so that the battery will be appropriately specified.

The Phase 1 study comprises three tasks:

- *Task 1:* Identify all VRLA manufacturers and characterize their share of the market by design type and application. Invite each to participate in the study and to involve representative users of the products.
- *Task 2:* Develop a detailed list of data needed to characterize the VRLA technology and problems identified by the users. Recover field monitoring data on the systems wherever possible. Organize a database to receive the information.
- *Task 3:* Collect the data, analyze for trend information, and summarize the results in a final report.

Status

During the first quarter of FY98, ILZRO and SNL evaluated the two responses to the request that ILZRO had issued for quotes on a subcontracted study to perform Phase 1. In the second quarter of FY98, ILZRO placed two contracts to initiate the three tasks in the Phase 1 Study. Also, work began on writing the VRLA manufacturers survey. One contract to analyze survey results and then to develop mechanisms and solutions for problems identified in the survey was awarded to Rutgers University. Rutgers will collaborate with Energetics, Inc., the company that was awarded the contract to develop the database to be used to compile the information and to collect the survey data.

During the third quarter of FY98, a survey questionnaire designed to obtain information from VRLA battery manufacturers was completed (Figure 3-1). The survey requests information on cell physical characteristics and electrical ratings, cell performance and life characteristics, known instances and modes of failure in the field, R&D database availability, and market and sales. The final version of this survey is presented below. A list of suggested sources from which to obtain the data was collected, and the questionnaires were distributed to these sources.

In the fourth quarter, a survey questionnaire designed to obtain information from users of VRLA batteries was completed. This survey requests information about the manufacturer, battery application and operational requirements, manufacturer/vendor specifications, battery monitoring specifications, cell performance and life characteristics, known instances and modes of failure. The system's data acquisition capability was also a point of inquiry in the survey. The final version of this survey is presented below in Figure 3-2.

Power Quality and Peak-Shaving Simulators Project

The ESS Program initiated a collaborative project with the National Rural Electric Cooperative Association (NRECA) to develop, validate, and demonstrate simulators of power quality and peak shaving systems. The project provides technical and economic data about peak shaving and power quality improvement at electric membership cooperatives. More importantly, the project introduces a technology assessment tool that is more exact and no more expensive than a traditional feasibility study.

The ESS portion of the project supports the development and validation of energy storage simulators that will mimic the operation of two BESSs: one that Brockway Standard operates for power quality improvement and one that Crescent Electric Membership Cooperative (now Energy United) operates for peak shaving. Work began on the ESS portion of the project in June 1997.

The NRECA portion of the project supports field demonstrations of the energy storage simulators and the development, validation, and field demonstration of a diesel generator simulator. NRECA validation and demonstration activities will be hosted at sites within Energy United (EU) and other utilities' service territories. Work on the NRECA portion of the project began in late August 1997.

Status

Early in FY98, the project team of Energetics, Inc., and Orion Energy Corporation began building the simulators, conducting the simulations, and analyzing the output of the simulators. For the validations, analysis will consist of comparing the simulator behavior with the real energy storage systems. For the demonstrations, analysis will determine the financial feasibility of the utility hardware being simulated.

By the third quarter, construction of a device that simulates a battery-based integrated storage system for power quality improvement was completed. The power quality applications will include a battery simulation. Laboratory testing of this device and another simulator that mimics the operation of a storage system to reduce customer demand peaks began. The peak shaving applications will include battery and diesel simulations. The two simulators have identical hardware, and differ only in the software that controls the simulation (Figure 3-3).

PRODUCTS AND MANUFACTURING SITES

How many VRLA cell types do you manufacture? ____

Which cell do you address in this survey (name or #)? ________________

Where do you manufacture this product?

❑ North America ❑ South America ❑ Asia
❑ West Europe ❑ East Europe ❑ Africa

PHYSICAL CHARACTERISTICS OF CELLS

What are the cell's exterior dimensions (cm)?

Length Width Height

In what medium is the electrolyte suspended?

❑ Absorbed glass mat ❑ Thixotropic gel ❑ Other

Are there any characteristics unique to this electrolyte?

____

What is the separator material and thickness (mm)?

❑ Polyvinylchloride ❑ Polyetheleyne ❑ Other
❑ Porous rubber ❑ Glass cloth

What is the separator saturation (%)? ____________

How much electrolyte is in each cell (ml)? __________

What is the specific gravity of the electrolyte in a fully charged new cell? ________________

What is the cell case material and thickness (mm)?

❑ Polyvinylchloride ❑ Polypropylene ❑ ABS
❑ Polycarbonate ❑ Polystyrene ❑ Other

What process is used to seal the cover to the case?

❑ Ultrasonic weld ❑ Asphalt ❑ Hot plate
❑ Bead mash heat ❑ Epoxy ❑ Other

What are the vent-valve opening/reseal points (psi)?

Open: ________________

Seal: ________________

What is the allowable valve opening/reseal variation (%)?

Open: __________ Seal: __________

What is the Ah of the plates? Positive ____ Negative ____

PHYSICAL CHARACTERISTICS (Cont.)

What is the plate geometry?

Geometry	*Positive plate*	*Negative plate*
Flat	❑	❑
Tubular	❑	❑
Other	❑	❑

What is the nominal stack compression (psi)? ________

What is the allowable variation in compression (%)?

____

What elements do the past alloys contain (wt%)?

Element	*Positive paste*	*Negative paste*
Antimony	❑	❑
Tin	❑	❑
Calcium	❑	❑
Other	❑	❑

What elements do the grids contain (wt%)?

Element	*Positive grids*	*Negative grids*
Antimony	❑	❑
Tin	❑	❑
Calcium	❑	❑
Other	❑	❑

What elements do the post/busbars alloys contain (wt%)?

Element	*Positive*	*Negative*
Lead	❑	❑
Copper	❑	❑
Cadmium	❑	❑
Antimony	❑	❑
Silver	❑	❑
Other	❑	❑

How is the post/cover seal made?

❑ Welded ❑ Expoxied ❑ Other

In what orientation are the cells designed to operate?

❑ Plates horizontal ❑ Plates Vertical ❑ Either/both

Please circle the maximum and minimum recommended operating temperatures for this cell (°C).

-80 -70 -60 -50 -40 -30 -20 -10 0 10 20 40 50 60 70 80

Figure 3-1. ILZRO Valve-Regulated Lead Acid Battery Manufacturer's Survey (continued on next page).

PHYSICAL CHARACTERISTICS (Cont.)

Does this cell use/require thermal management?

☐ No ☐ Yes, method

How much space is between cells in a module (cm)?

Vertical space Horizontal space

How much space is between modules in a string (cm)?

Vertical space Horizontal space

What is the separator material and thickness (mm)?

Vertical space Horizontal space

ELECTRICAL CHARACTERISTICS

What is the cell capacity at 77°F (Ah)?

What is the cell's internal resistance (mΩ)?

What is the cell's monthly self-discharge rate (%)?

What is the cell's specific energy at the given rates (Wh/kg)?

C/20: C/8: C/2:

If you sell this cell in modules, please indicate module ID, the number of cells per module, voltage of the module, and the nominal capacity for each product.

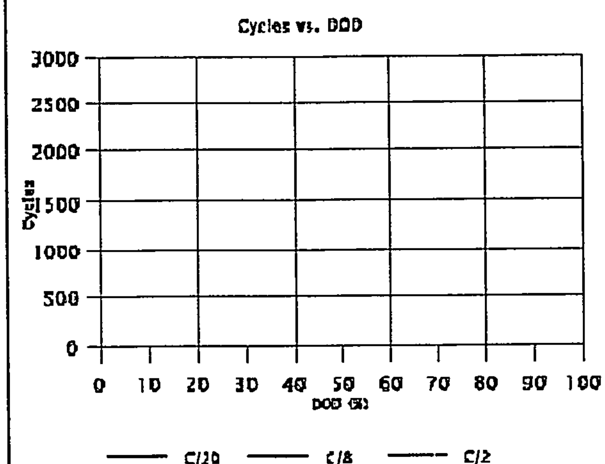
ID	# cells/volts/Ah	ID	# cells/volts/Ah
	____/____/____		____/____/____
	____/____/____		____/____/____
	____/____/____		____/____/____
	____/____/____		____/____/____
	____/____/____		____/____/____
	____/____/____		____/____/____

PERFORMANCE & LIFE CHARACTERISTICS

For what application(s) is this cell designed?

☐ Float ☐ Deep Cycle ☐ Shallow Cycle

Sketch the cell's cycle life vs. depth-of-discharge is ideal temperature, discharge and charge conditions.



3 curves: C/20, C/8 and C/2 discharge rates

Please sketch the cell's ideal charge characteristics.

4 curves: charge voltage and current and cell voltage vs. time

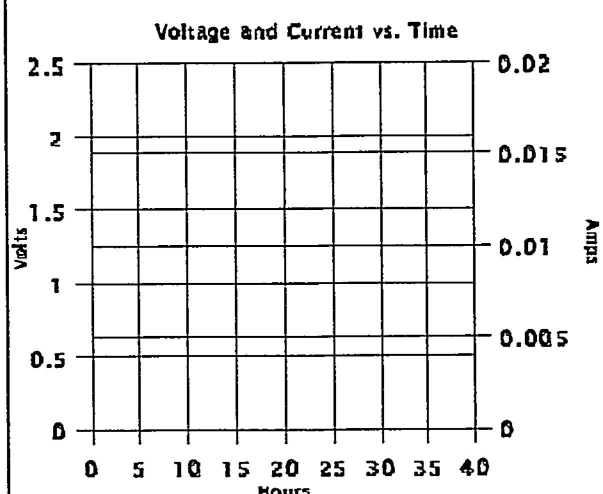


Figure 3-1. **ILZRO Valve-Regulated Lead Acid Battery Manufacturer's Survey** (continued on next page).

PERFORMANCE AND LIFE CHARACTERISTICS (Cont.)

What is the cell's recommended float voltage and current:

Voltage: ________ Current: ________

Please circle the float service warrantee (years).

1 2 3 4 5 6 7 8 9 10 15 20

What maintenance procedures do you recommend?

How often should cells receive equalization recharge?

☐ Specified interval ______ ☐ Other indicator

Have customers reported premature cell failures?

☐ No ☐ Yes

☐ Float ☐ Deep Cycle ☐ Shallow Cycle

Does your company conduct in-house root-cause analysis of cells that fail in service?

☐ No ☐ Yes

Does your company out-source root-cause analysis of cells that fail in service?

☐ No ☐ Yes

Analyst

What is the most prevalent cause of in-service cell failures:

☐ Float ☐ Deep Cycle ☐ Shallow Cycle

R&D TESTING

How many single cells have been tested in your laboratory to determine and verify cell performance?

Shallow Cycle Deep Cycle Float

How many single cells have been tested in your laboratory to determine and verify cell service life?

Shallow Cycle Deep Cycle Float

How many units of each type of module product have been tested in your laboratory to determine and verify performance?

Shallow Cycle Deep Cycle Float

How many units of each type of module product with this cell have been tested in your laboratory to determine and verify service life?

Shallow Cycle Deep Cycle Float

CONTACT AT YOUR COMPANY

Name Address

MARKET AND SALES

How many of these cells are sold each year?

As individual cells In modules

How many individual cells are sold each year?

Float Deep Cycle Shallow Cycle

How many cells are sold in modules each year?

Float Deep Cycle Shallow Cycle

How many of these cells are sold each year for the following applications?

Telecom Industrial UPS

Utility substation Motive power

CUSTOMER CONTACTS

Please supply contact information for customers and distributors whom we may contact to gather data on the actual service conditions that this cell experiences?

Name Company/Address Telephone

COMMENTS

Please write any comments you consider important regarding VRLA reliability and performance in stationary applications, especially with respect to charging and charge controls.

Figure 3-1. **ILZRO Valve-Regulated Lead Acid Battery Manufacturer's Survey** (concluded).

BATTERY IDENTIFICATION

Please provide the manufacturer's name and model number for the valve-regulated lead acid (VRLA) product that you will describe below.

Manufacturer: ________________ Model: ________

What application does the battery serve?

How many volts/amps does the application require?

From who did you purchase the batteries?

- ❑ Battery manufacturer
- ❑ Original equipment manufacturer
- ❑ Battery vendor/distributor
- ❑ Other

How many have you purchased?

BATTERY OPERATIONS

Did the manufacturer/vendor provide operating specifications?

❑ Yes ❑ No

FLOAT

What float voltage do you maintain (volts/cell)?

CYCLE

How many cycles/year does the battery experience?

Do cycles occur at regular intervals?
If yes, what is the interval length?
If no, is cycling ❑ Random ❑ Clustered

What are the maximum, average, and minimum depth of discharge that cycles demand (%)?
Max. DOD ____ Avg. DOD ____ Min. DOD ____

What percentage of the cycles are at a maximum, average and minimum depth of discharge?
Max. ______ Avg. ______ Min. ______

At what rate does the battery discharge (A)?

BATTERY MONITORING

Which parameters do you monitor, how often?

Cell	Module String
°C/°F	❑ ________ ❑ ________ ❑ ________
Volts	❑ ________ ❑ ________ ❑ ________
Amps	❑ ________ ❑ ________ ❑ ________
Other	❑ ________ ❑ ________ ❑ ________

If you log readings, what format is used?

❑ Print ❑ Electronic

What are the maximum, average, and minimum ambient temperatures in the battery room (°C)?

Max. Temp ____ Avg. Temp ____ Min. Temp____

What percentage of a year is the temperature at or near the maximum?

Do you use thermal management for this battery?
If yes, please specify method.

On attached page, please sketch the recharge regime (for charge voltage and current and expected cell voltage).

Were there any issues of concern related to the operation or performance of this battery?

What is the warranted service life (years)?

Have you ever had a failure analysis performed and, if so, by whom?

❑ Yes ❑ No

❑ Vendor ❑ Manufacturer ❑ In-house ❑ Consultant

What percentage of the batteries at your facility achieved the following service lives?

1/4 warranteed life ______ 3/4 warranteed life ______
1/2 warranteed life ______ Warranteed life ________

What were the root caused (in order of frequency)?

Figure 3-2. ILZRO Valve-Regulated Lead Acid Battery User's Survey (continued on next page).

Please provide the following information for the battery in service for the longest amount of time.	
Vendor	**Date of purchase**
Date of installation	**Date of removal from service**
Reason for removal from service. ______	
Please attach copies of operating and monitoring logs.	

Please provide the following information for the battery that failed previous to its warranteed service life (if applicable).	
Vendor	**Date of purchase**
Date of installation	**Date of removal from service**
Reason for removal from service. ______	
Please attach copies of operating and monitoring logs.	

ADDITIONAL COMMENTS
Please feel free to add any additional data or comments?

Figure 3-2. ILZRO Valve-Regulated Lead Acid Battery User's Survey (concluded).

Energetics will operate the simulators for three to six months to validate them against the peak-shaving and power-quality systems that they mimic. Validation is different than demonstration. In validation, the issue is only that the simulator mimics the hardware accurately. In demonstration, the main consideration is system life and economics, which will include cost and savings (cost includes life-cycle O&M, savings are avoided costs). After validation of the devices is complete, NRECA will be sponsoring demonstrations of the simulators at various sites in member co-ops' service territories.

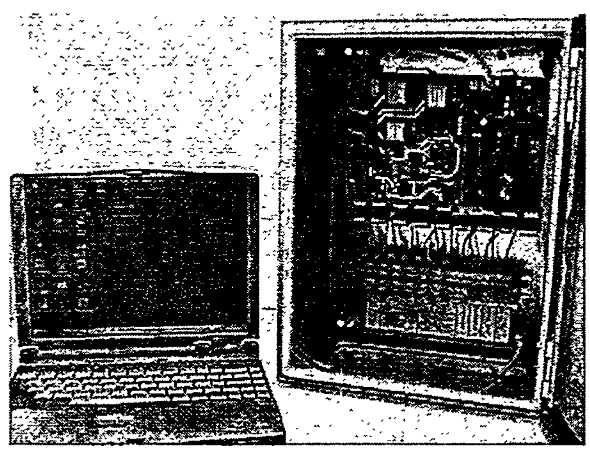


Figure 3-3. Simulator Hardware and Control System.

The original schedule was delayed slightly because of computer interface and data sensing issues, which were resolved. Three simulators have been installed and are being validated against operating hardware. Demonstrations are planned at up to five sites, at EU located in Statesville, NC, and other utilities. Demonstrations will also include economic assessments. The EU peak shaving simulator was installed in August of FY98. A schematic of a simulator is shown in Figure 3-4. The system began reading data continuously and transmitting data successfully, indicating that validation analysis was underway. Figure 3-5 shows peak shaving data from the EU simulator for the first five days in September 1998. The data demonstrate that the simulator is sensing and recording information about the battery operation.

The technical attributes of the simulator are that it:

- Mimics operation of electric power hardware in real time
- Consists of three components
  - Power monitoring equipment
  - Simulation controller
  - Remote host computer
- Predicts technical performance and cost/benefit of hardware
- Is housed in one or two steel enclosure(s)
  - Single-enclosure system: 600 mm × 600 mm × 200mm
  - Two-enclosure system: two boxes that are somewhat smaller
- Operates unattended and communicates with remote host computer

The correlation between actual and simulated peak-shaving events at EU is shown in Table 3-1. Three types of events have occurred during validation (1) coincident BES/simulator operation, (2) simulation/no actual event, and (3) actual event/no simulation. On August 18, the BES dispatched for 2 hours and 54 minutes, and the simulator 'dispatched' for 3 hours. On September 1, the BES dispatched for 2 hours and 56 minutes, and the simulator 'dispatched' for 5 hours. It is necessary to determine why the simulator indicated a prolonged dispatch, which is an unacceptable discrepancy. On September 16, the BES dispatched, but the end time was not recorded, and the simulator 'dispatched' for 2 hours and 15 minutes. The manual record-keeping of actual BES operation dispatch complicated validation.

Simulated peak shaving with no actual event is shown in Table 3-2. In some instances, the simulator 'dispatched' when no actual dispatch was recorded. Several reasons can account for this such as: BES testing and maintenance (that is not recorded) can imply a need for dispatch by the simulator; manual record-keeping is not perfect; and sometimes events are not recorded.

On August 18, 1998, an actual peak-shave event occurred from 3:00 to 5:45 p.m. while the simulated event occurred from 3:15 to 6:00 p.m. The times are not exactly in correlation because the simulator receives information at 15-minute intervals. At EU, someone must be physically present to see the signal light go on

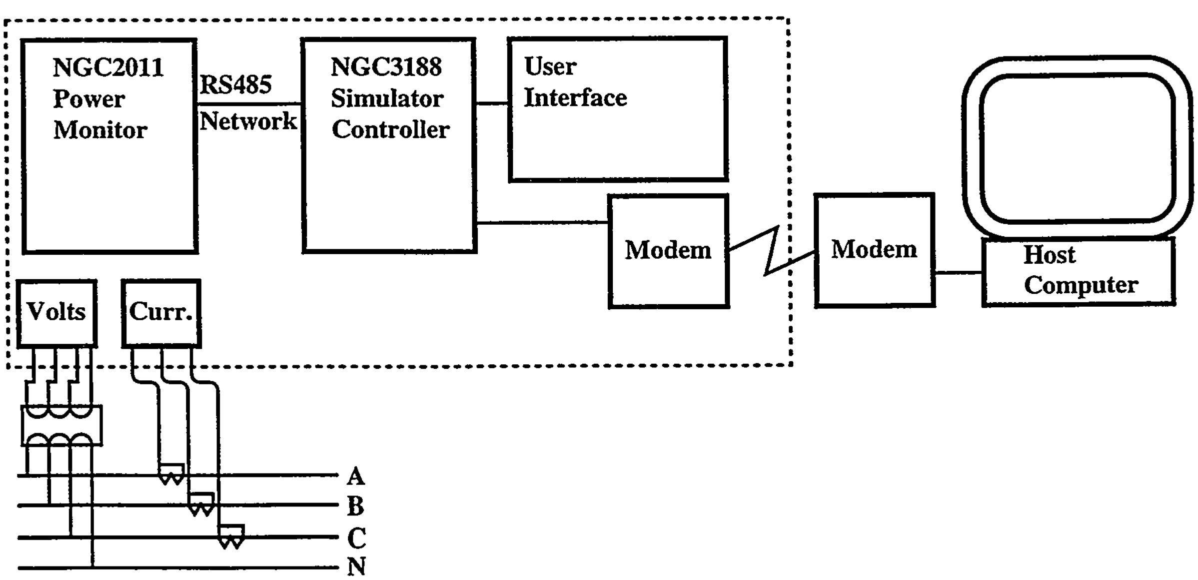


Figure 3-4. Schematic of a Simulator.

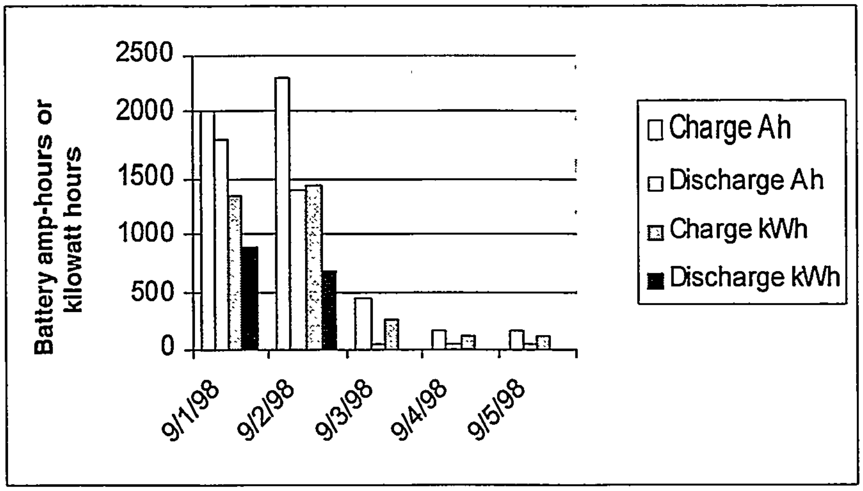


Figure 3-5. Peak Shaving Battery Simulator Data for the First Five Days in September 1998 for the Energy United System.

Table 3-1. Correlation of Actual and Simulated Peak-Shaving Events at Energy United

Date	Actual Dispatch	Simulated Dispatch
August 18, 1998	3:00 - 5:54 p.m.	3:15 - 6:00 p.m.
September 1, 1998	3:00 - 5:56 p.m.	3:00 - 8:00 p.m.
September 16, 1998	3:30 p.m. - (unrecorded)	3:45 - 6:00 p.m.

Table 3-2. Simulated Peak Shaving–No Actual Event

Date	Simulated Dispatch	Suspected Cause
August 31, 1998	4:30 - 6:00 p.m.	Testing of maintenance system
September 1, 1998	7:00 - 8:00 p.m.	Testing of maintenance system
September 2, 1998	3:00 - 6:00 p.m.	Failure to record actual peak-shaving event

to record the battery discharging. As a result, the time written as an actual peak-shave event could be imprecise. However, on this day, it appears that the simulator is nearly perfect. Included with the data (Table 3-3) is a graph of power versus time (Figure 3-6). Graphs of the meter load, power control unit (PCU) output, and AC output are presented in Figures 3-6 and 3-7.

- PCU power–power delivered to and from the battery–simulated.
- AC output–power delivered to the EU customer–actual.
- Meter load–during normal operation, the power transmitted into the building where the batteries are located is derived from Duke–simulated.

During a peak-shaving operation, the battery delivers power to the customer and to the EU complex. At this time, the meter load takes into account only power delivered within the complex, and that is a negative value.

On September 2, 1998, the simulated peak-shave event occurred between 3:00 and 6:00 p.m. On that day, the simulator was peak shaving while there was no record of an actual peak-shave event. Comparing the data (Table 3-4) and graph of September 2 (Figure 3-7) with August 18, the data illustrate that on September 2, an actual peak-shave event most likely occurred. Because there is no system set up to record how the actual battery is operating, the Energetics team must rely on EU's handwritten records of when a peak-shave event occurs. Unfortunately, this leads to human error. There are times when events are recorded improperly or not recorded at all. It is believed that the event that occurred on September 2 is an example of this.

The simulator was off line for 6 of the 12 total actual peak-shaving events because of computer problems, remote-access complications, and human error. The system failed to simulate one actual event because in a unique instance, two peak-shaving events occurred in one day, and the simulated battery was being recharged during the second event. The EU peak shaving simulator is shown in Figure 3-8.

Resolutions to problems that arose during these exercises are as follows:

- Establish more reliable record keeping of actual events
  - Carefully define manual record keeping
  - Automate monitoring of actual batteries
  - Compare impact with overall system economics
  - Eliminate sources of "unacceptable" levels of false events
- Improve remote access methods and technologies
- Develop daily system-check methodology
  - Automate remote testing
  - Implement manual testing

The record keeping at validation sites must be more carefully defined in advance of validations, which can be done manually if there is no automated system, but the process must be tightly controlled. Anomalies like two-dispatch events may be so statistically unusual that they could be disregarded in the data. To determine the appropriate treatment of this issue, it must be determined whether the frequency of these types of events is significant and evaluate them relative to the economic significance of the events to the overall system economics.

If the anomalies are significant statistically or economically, then system software should be modified. Remote access processes and technologies should also be improved. If superior technologies are available (and not cost-prohibitive) then the current remote-access software should be replaced. There is also a need to investigate functions, cost, and compatibility of options. If it is determined that alternative technologies are not available, then improved processes are necessary. A formal list of "do's" and "don'ts" for using PCAnywhere in simulator documentation would be required. Ensure that all users are aware of the software limitations so that simulator crashes might be avoided. There is also a need to develop system status checks to ensure that unavoidable system crashes do not last long when they do occur. At a minimum, there is a need to call the site daily and verify system operation. Automated system status monitors that trigger an alarm at the remote site if the system crashes are also an option depending on cost and difficulty.

A proposed expansion of Phase I work to include the demonstration and simulation of additional technologies is currently being discussed by the DOE/ESS, NRECA, and DOE/Office of Industrial Technologies (OIT) and DOE/Federal Energy Technology Center (FETC). The goal is to enhance existing simulators to model all technologies, add three demonstrations of multipurpose simulators, and develop, validate, and demonstrate new simulators–one fuel cell and one microturbine simulator. The goal in these instances would be to demonstrate the fuel cell simulator at two sites, and the microturbine simulator at another two sites, and provide comprehensive reporting on the findings for both technologies.

Table 3-3. August 18, 1998, Successful Simulated Peak-Shave Event

Time	V(A) Volts)	I(A) (amps)	AC Power (kW)	Temp (°C)	Vbatt (volts)	Ibatt (amps)	BSOC (%)	PCU PWR (kW)	Meter (kW)	Peak Signal
14:30	491.24	15.42	7.60	20.63	582.16	-1.91	97.89	-0.10	7.70	0
14:45	491.32	15.41	7.59	20.66	582.15	-1.91	97.87	-0.10	7.69	0
15:00	491.35	25.15	13.22	20.69	588.70	-1.91	97.86	-0.10	-236.78	0
15:15	488.13	320.73	180.43	20.72	586.71	-472.82	94.91	250.00	-69.57	0
15:30	488.30	321.68	180.98	20.75	584.64	-474.12	91.94	250.00	-69.02	0
15:45	488.20	323.11	181.91	20.82	582.57	-475.80	88.97	250.00	-68.09	0
16:00	487.82	325.65	183.07	20.85	580.49	-477.50	85.99	250.00	-66.93	0
16:15	487.68	327.77	184.08	20.90	578.40	-479.22	82.99	250.00	-65.92	0
16:30	488.65	330.68	186.18	20.93	576.30	-480.95	79.98	250.00	-63.82	0
16:45	487.96	334.56	187.95	20.96	574.19	-482.71	76.97	250.00	-62.05	0
17:00	487.36	339.15	190.27	20.95	572.08	-484.49	73.94	250.00	-59.73	0
17:15	488.04	344.77	193.66	20.94	569.96	-486.28	70.90	250.00	-56.34	0
17:30	487.86	352.31	197.64	20.96	567.83	-488.10	67.85	250.00	-52.36	0
17:45	487.75	362.35	202.90	20.95	565.69	-489.93	64.79	250.00	-47.10	0
18:00	488.97	214.09	119.43	20.97	677.77	-459.08	61.92	233.33	321.93	0
18:15	491.39	15.55	7.66	20.95	673.61	339.04	64.04	-202.50	210.16	0
18:30	491.70	15.67	7.73	20.89	675.79	333.59	66.12	-202.50	210.23	0

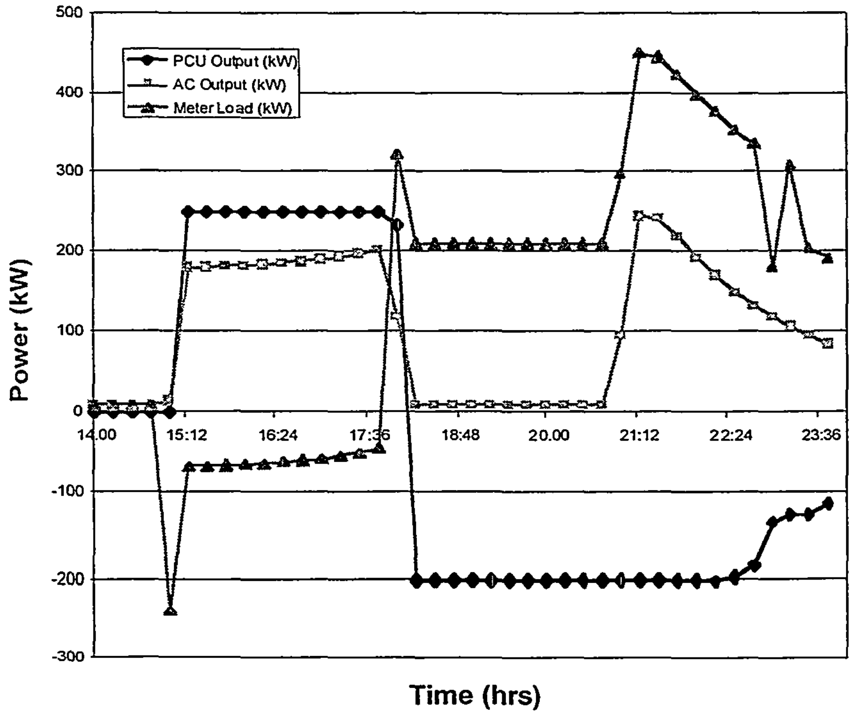


Figure 3-6. Simulated Peak Shave with Actual Event for August 18, 1998.

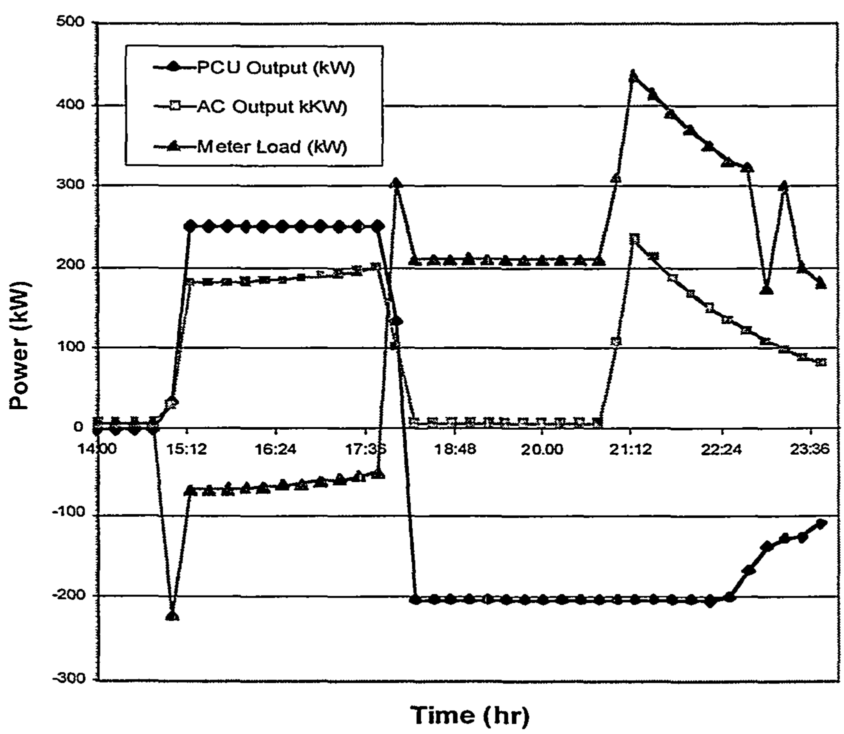


Figure 3-7. Simulated Peak Shave with No Recorded Event for September 2, 1998.

Table 3-4. September 2, 1998, Simulated Peak Shave with No Recorded Actual Event

Time	V(A) (volts)	I(A) (amps)	AC Power (kW)	Temp (°C)	Vbatt (volts)	Ibatt (amps)	BSOC (%)	PCU PWR (kW)	Meter (kW)	Peak Signal
14:15	491.53	15.58	7.69	21.10	582.01	-1.91	97.68	-0.10	7.79	0
14:30	491.59	15.53	7.65	21.15	582.00	-1.91	97.67	-0.10	7.75	0
14:45	491.40	15.53	7.65	21.17	582.00	-1.91	97.65	-0.10	7.75	0
15:00	490.62	50.56	27.69	21.12	588.35	-64.94	97.25	33.25	-222.31	0
15:15	488.24	318.37	179.25	21.14	586.28	-472.80	94.29	250.00	-70.75	0
15:30	488.41	319.32	179.73	21.20	584.21	-474.46	91.33	250.00	-70.27	0
15:45	488.12	321.36	180.65	21.24	582.14	-476.15	88.35	250.00	-69.35	0
16:00	488.28	323.97	182.03	21.28	580.05	-477.85	85.37	250.00	-67.97	0
16:15	488.18	326.64	183.52	21.30	577.96	-479.58	82.37	250.00	-66.48	0
16:30	488.30	328.80	184.80	21.26	575.86	-481.32	79.36	250.00	-65.20	0
16:45	488.27	331.90	186.64	21.28	573.75	-483.08	76.34	250.00	-63.36	0
17:00	488.49	336.31	189.09	21.26	571.64	-484.86	73.31	250.00	-60.91	0
17:15	488.13	341.57	191.78	21.25	569.51	-486.66	70.27	250.00	-58.22	0
17:30	487.72	348.01	195.32	21.26	567.38	-488.48	67.22	250.00	-54.68	0
17:45	487.97	355.68	199.55	21.25	565.24	-490.32	64.15	250.00	-50.45	0
18:00	489.55	181.38	101.40	21.25	678.44	-263.19	62.51	133.29	303.90	0
18:15	490.82	15.48	7.61	21.22	674.22	338.74	64.62	-202.50	210.11	0
18:30	490.56	15.38	7.57	21.17	676.40	333.29	66.71	-202.50	210.07	0
18:45	490.85	15.46	7.63	21.11	678.57	332.22	68.78	-202.50	210.13	0

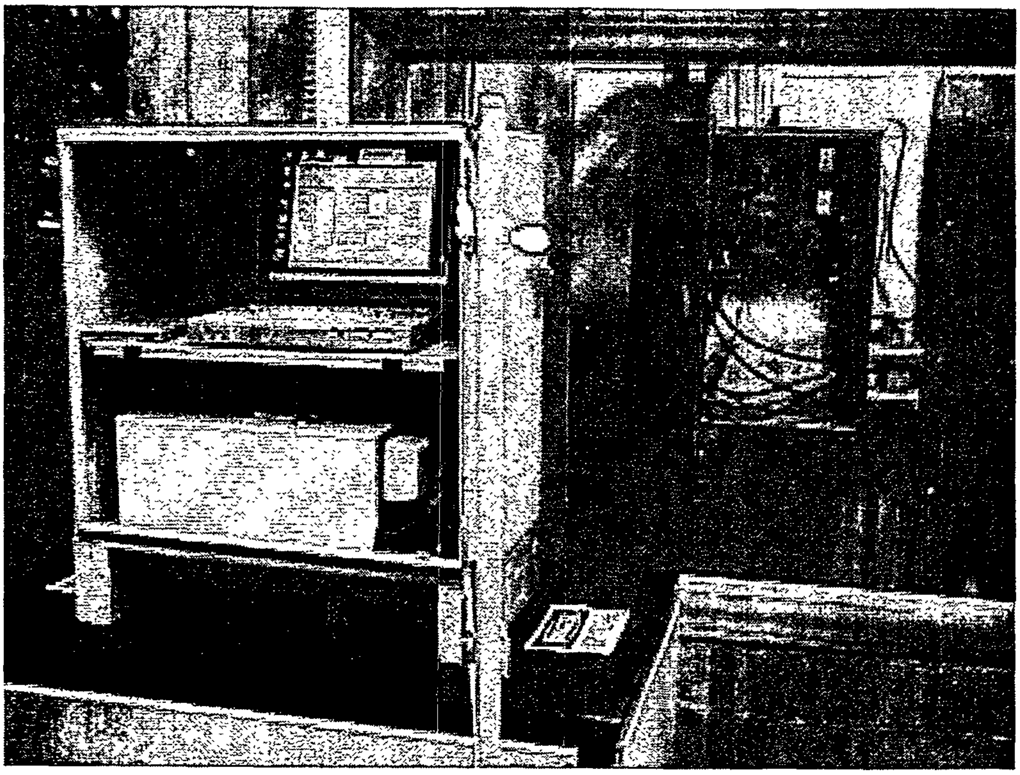


Figure 3-8. Peak Shaving Simulator at Energy United Site in Statesville, NC. Front left: host computer and UPS in enclosure in control room at BES facility. Rear right, slave and supervisory boards in enclosure.

Component Evaluation

VRLA Battery Characterization

SNL has been testing the performance of VRLA AGM batteries both to evaluate the performance of deliverables from the GNB battery development program and to determine the suitability of various technologies for energy storage applications. Utility and telecommunications users of VRLA-based systems have experienced unexpected field failures and reliability problems. Controlled laboratory tests are the best method of evaluating battery performance and determining capacity degradation rates and mechanisms. While field tests and controlled laboratory tests both reveal similar information, with field tests there are almost always too many uncontrolled variables to allow a complete understanding of the relevant cause-and-effect relationships.

Testing of deliverables from the GNB VRLA development contract continued at SNL in FY98. Two 18-V batteries, an ABSOLYTE II and an ABSOLYTE IIP, have undergone extensive testing. In addition, a VRLA battery from Yuasa-Exide was tested extensively at SNL; this battery reached its end of life in the first quarter. The two ABSOLYTE units will remain on test until they have lost 20% of their rated capacity. The data generated in these tests will also be used in the VRLA Reliability Improvement task.

SNL also performed an in-house battery evaluation on VRLA gel batteries for Trojan Battery Corporation and on lead-acid, starting, lighting, and ignition (SLI) batteries for Community Power Corporation. The SLI batteries are destined for offshore domestic PV applications. In general, SLI batteries have not performed well in a cycling environment. Consequently, there is high interest in demonstrating whether, with proper care and management, they could support a cycling application.

ABSOLYTE IIP Testing

Status

The ABSOLYTE IIP battery was placed on open circuit on September 19, 1997, when a tester malfunction halted testing. Testing resumed February 23, 1998. At the time of the malfunction, battery capacity measured approximately 1100 AH, about 100 Ah less than the rated capacity of 1200 Ah at a C/8 discharge rate. Cell 3 was bypassed in FY97, with eight cells remaining in the string. Testing continued through the second, third, and fourth quarters of FY98 using the ABSOLYTE IIP H-Test regime shown in Table 3-5. The ABSOLYTE IIP H-Test Regime is the same as the ABSOLYTE II H-Test regime except for the adjustment of the charge and discharge voltages to allow for the absence of Cell 3.

Measured capacity of the ABSOLYTE IIP battery (150-A discharge rate) is shown in Figure 3-9. The capacity declined steadily through most of the third and fourth quarters. The capacity at the end of FY98 was approximately 970 Ah, very near 80% of the rated capacity, 1200 Ah.

The capacity did not show the fluctuations evident in the testing of the ABSOLYTE II battery, apparently because of the much more stable room temperature. Figure 3-10 shows battery capacity versus end of discharge battery temperature. The room ambient temperature monitor was not coupled to the ABSOLYTE IIP database, and was not available for inclusion in this plot. End of discharge battery temperature fluctuated less than two degrees through most of the testing. Some correlation of the capacity with the EOD battery temperature can be seen, but overall fluctuations are minor.

Cell voltages at end of discharge for the ABSOLYTE IIP are shown in Figure 3-11. Cell 5 has been weak throughout testing, and declined sharply in the fourth quarter.

ABSOLYTE II Testing

Status

Except for a maintenance discharge/recharge on October 13, 1997, the ABSOLYTE II battery was placed on open circuit on March 11, 1997, when a tester malfunction halted testing. Testing resumed March 5, 1998, using the ABSOLYTE II H-test regime shown in Table 3-5. At the time of the tester malfunction, the measured battery capacity was approximately 1160 Ah, with a manufacturer-specified capacity of 1040 Ah at a C/8 discharge rate (130 A) to a cutoff voltage of 15.75 V, equivalent to 1.75 V per cell. At the beginning of testing in 1995, the measured capacity was 1300 Ah at a 150-A discharge rate.

To allow direct comparison to be made with the ABSOLYTE IIP battery also on test, which has a 1200-Ah rating at a C/8 discharge (150 A), it was decided to use a 150-A discharge rate for life-cycle testing of the ABSOLYTE II battery in FY97 and FY98. The ABSOLYTE II battery capacity from resumption of testing through the end of FY98 using the 150-A dis-

Table 3-5. ABSOLYTE IIP and ABSOLYTE II Test Regime

H-Test Regime	
ABSOLYTE IIP	**ABSOLYTE II**
Discharge at 150 A to 14.0 V	Discharge at 150 A to 15.75 V
5-min rest	5-min rest
Charge at 300 A to 19.2 V	Charge at 300 A to 21.6 V
1-min rest	1-min rest
Charge at constant 19.2 V, with a maximum 300 A, tapering to 24 A or to 7% overcharge	Charge at constant 21.6 V, with a maximum 300 A, tapering to 24 A or to 7% overcharge
1-min rest	1-min rest
Charge at 24 A to 7% overcharge	Charge at 24 A to 7% overcharge
Wait 8 hrs	Wait 8 hrs

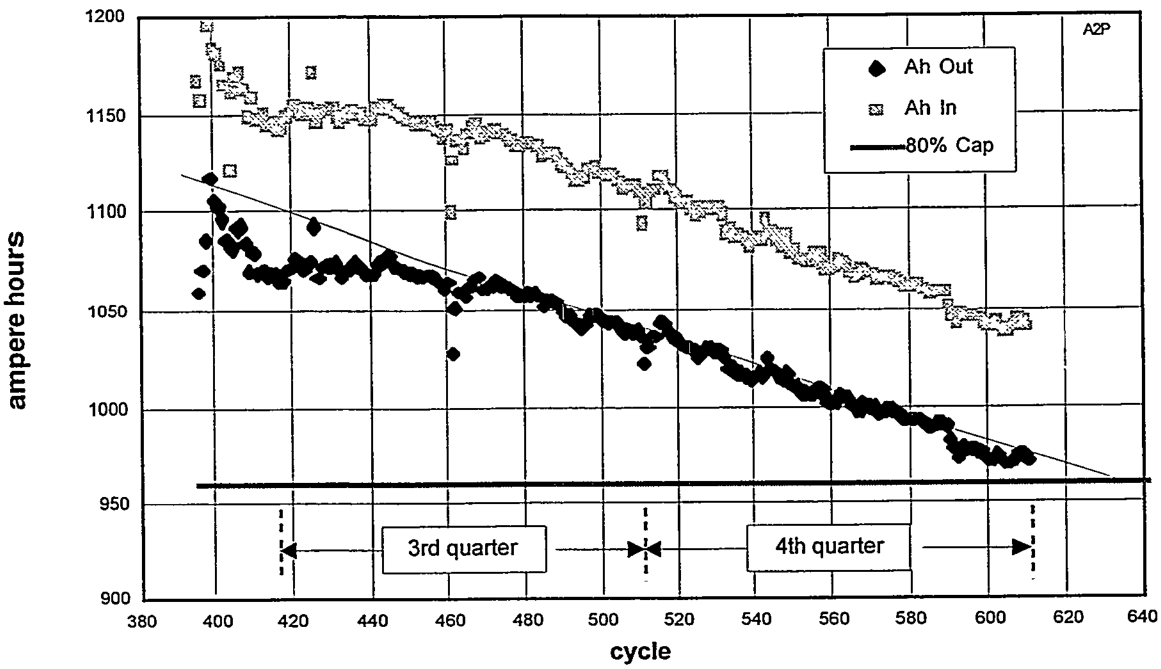


Figure 3-9. **Amp-Hours Removed (Capacity) and Returned for the ABSOLYTE IIP Battery for the Third and Fourth Quarters of FY98.**

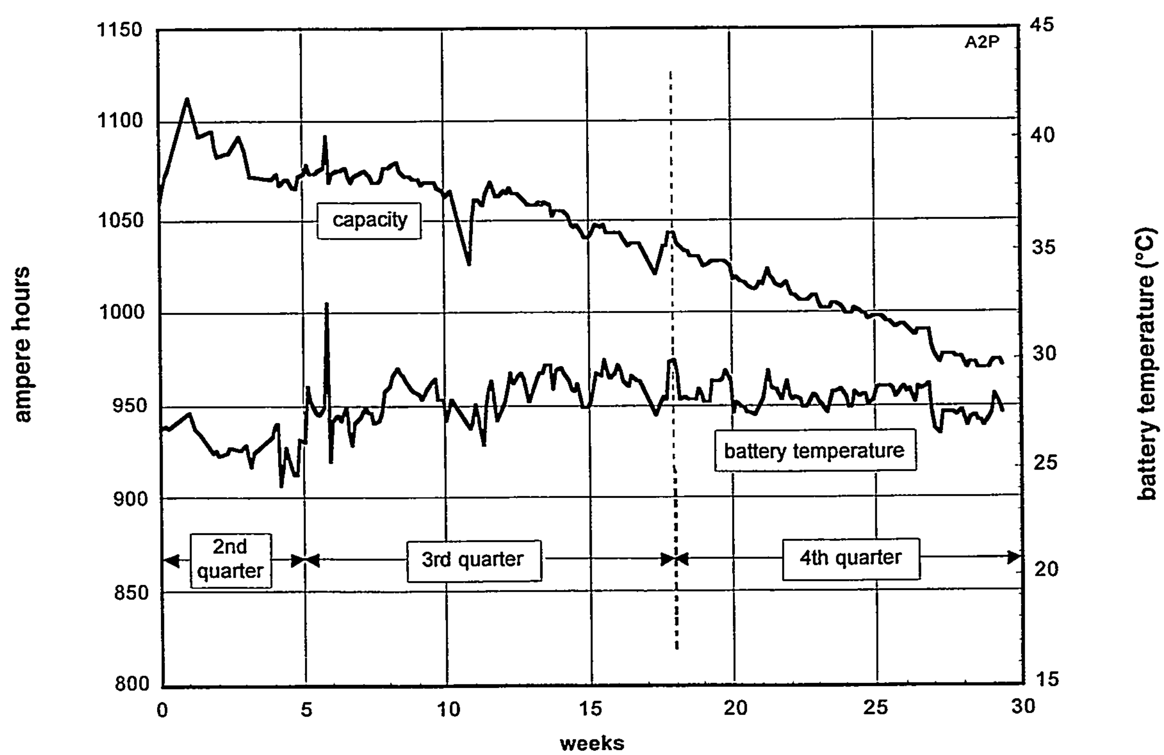


Figure 3-10. **Amp-Hours Removed (Capacity) and End of Discharge Battery Temperature for the ABSOLYTE IIP Battery for the Second, Third, and Fourth Quarters of FY98.**

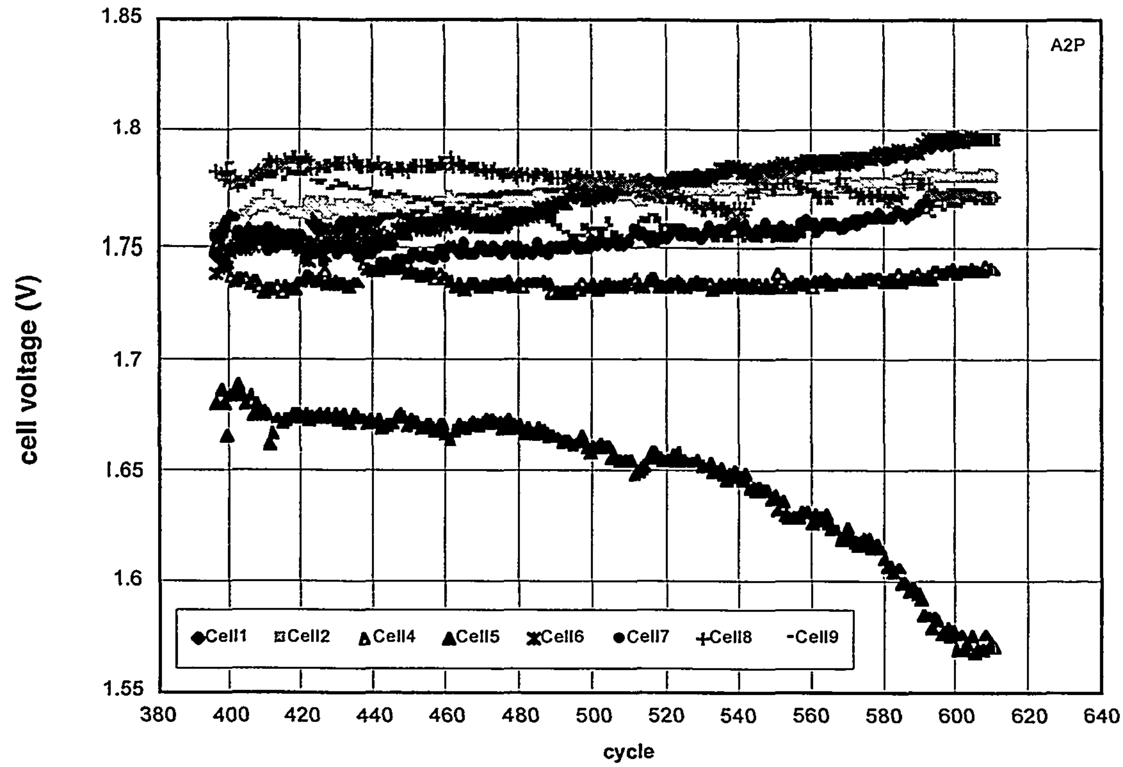


Figure 3-11. Cell Voltages at EOD for the ABSOLYTE IIP Battery for the Second, Third, and Fourth Quarters of FY98.

charge rate is shown in Figure 3-12. Capacity rose slightly at first and was then reasonably steady at about 1100 Ah through most of the third quarter although a slight decline (to approximately 1075 Ah) toward the end of the quarter was observed. The capacity continued to decline steadily through the fourth quarter, to approximately 965 Ah at the end of FY98. A linear projection of the capacity trend shown indicates 80% of the rated capacity (832 Ah) may be reached at approximately 430 cycles.

The capacity of the ABSOLYTE II battery showed considerable fluctuation during testing. An examination of the data showed that the capacity fluctuation was closely correlated to variations in the ambient temperature of the test facility. The ABSOLYTE II is being tested in a temporary building because of space constraints in the principal test laboratory. Figure 3-13 shows the battery capacity plotted vs. time (time set to zero at the beginning of this test series) with the battery and room ambient temperatures measured at the same time as the battery capacity measurement, that is, at end of discharge. There are also daily cyclic variations in room temperature of 3°C to 5°C that are not shown in this plot. The room ambient temperature and the battery temperature track very closely, and the minimum and maximum capacity correspond closely in time to the temperature minimum and maximum at end of discharge. The capacity appears to vary about 0.6% to 0.8% per degree Celsius, but this does not take into account any variation of temperature during the approximate 8-hour discharge.

Cell voltages for the ABSOLYTE II battery at end of discharge are shown in Figure 3-14. Cell 4 began to decline in EOD voltage in the fourth quarter. Several of the cells show a cyclic variation in EOD voltage that corresponds to the temperature-related variation of capacity.

Yuasa-Exide Testing

Status

The battery contains 11 Dynacell DD gel cells. At the end of the fourth quarter of FY97, the voltage of Cell 6 was erratic and declining, but during the first quarter of FY98, the Yuasa-Exide battery was still being tested. The battery had reached 90 Ah, with capacity very close to 88 Ah, or 80% of rated capacity end-of-life limit.

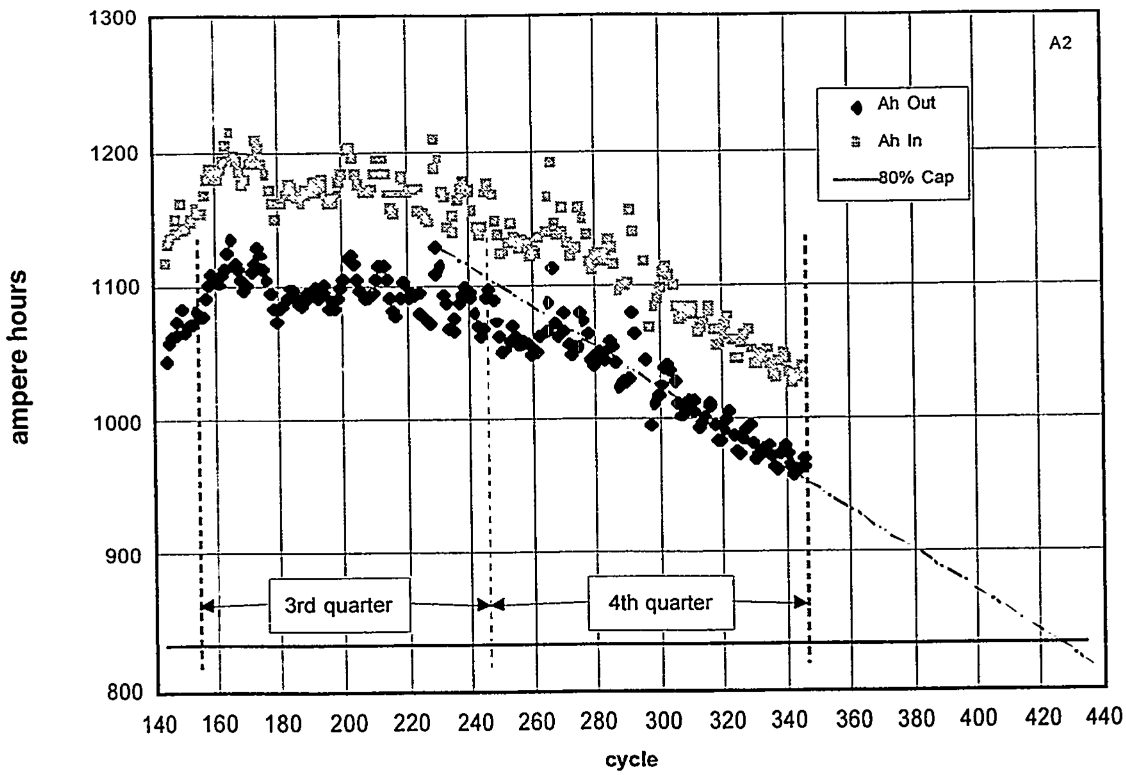


Figure 3-12. Amp-Hours Removed (Capacity) and Returned for the ABSOLYTE II Battery for the Third and Fourth Quarters of FY98.

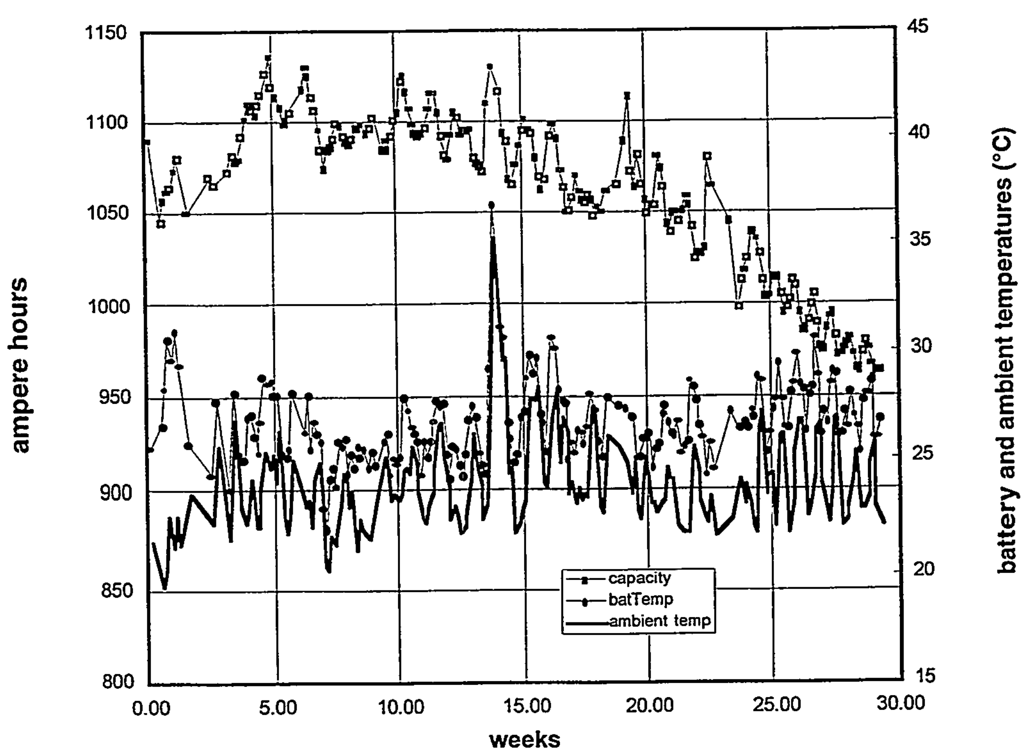


Figure 3-13. Battery Capacity, Battery Temperature, and Room Ambient Temperature at EOD vs. Time for the ABSOLYTE II Battery.

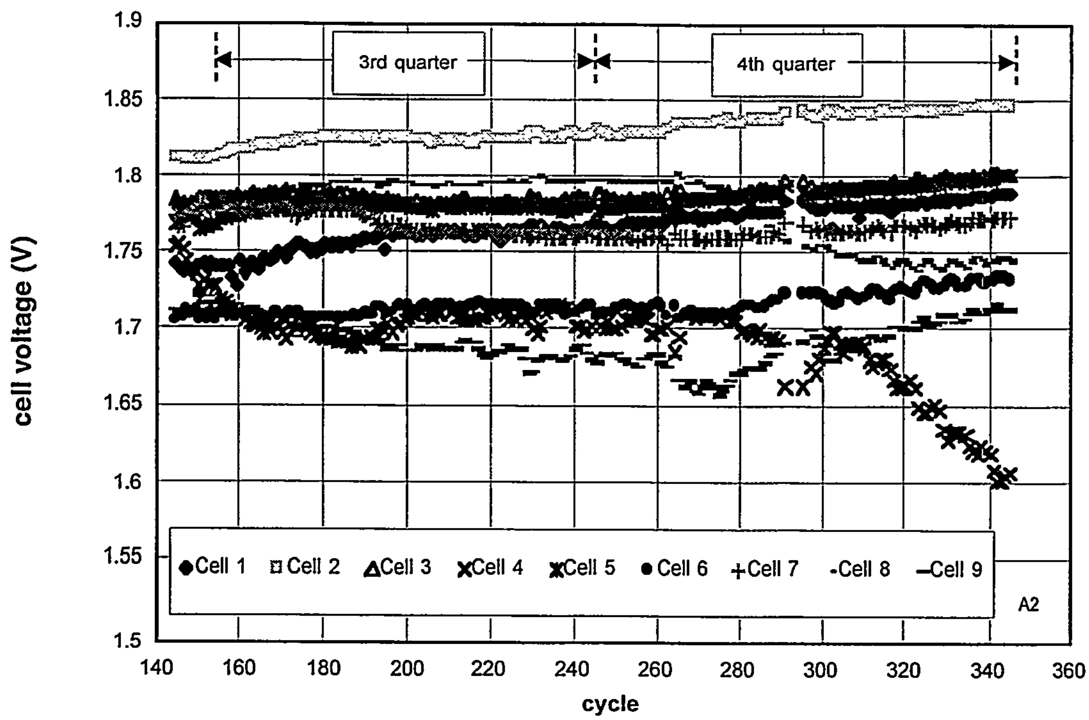


Figure 3-14. Cell Voltages at EOD for the ABSOLYTE II Battery for the Third and Fourth Quarters of FY98.

Testing continued for approximately one month in FY98 using the type H test regime shown in Table 3-6. Figure 3-15 shows the Ah removed and returned and Figure 3-16 shows the cell voltages for the 22 cycles run. Capacity fell steadily to less than 88 Ah after 5 cycles. Testing continued, but cycling was interrupted for 16 days for a tester power supply change at Cycle No. 321. After the interruption, battery capacity was low, but returned slowly to the previous trend, below the end-of-life capacity. The battery was removed from test on November 4, 1997. Yuasa-Exide will perform diagnostic disassembly of the battery in the future.

Trojan Battery Prototype—VRLA Gel

Battery Testing

Status

SNL completed its life-cycle testing on four Trojan Battery Corporation gelled VRLA batteries. These batteries are low maintenance, deep-cycle, and designed for a 3- to 8-hour duty cycle, with recharging to be performed on any charger with a gel or VRLA setting. The batteries were evaluated in Trojan's laboratories under a number of test conditions and were then distributed to the field for further evaluation, including the testing that was performed at SNL. The tests were designed to verify performance, determine cycle life, and identify failure modes.

The objectives of the testing at SNL were to (1) confirm the electrical performance ratings, (2) evaluate the batteries' ability to meet Trojan customer requirements, and (3) determine the service life of the batteries. SNL received these batteries on September 17, 1996.

The batteries that underwent life-cycle testing are described in Table 3-7. The preconditioning procedure consisted of charging at a constant voltage of 15.0 V for 24 hours. The Battery Council International (BCI) life-cycle procedure that was used is shown in Table 3-8. The battery tests started on October 10, 1996.

During the fourth quarter of FY97, SNL ID No. 722 and No. 723 reached their defined end of life of 50% of initial capacity. SNL ID No. 726 was previously removed from test in April 1997 because of a cell failure after it was moved to a different test facility for temperature stabilization. Testing of SNL ID No. 727 continued into the first quarter of FY98 until it reached its defined

Table 3-6. Yuasa-Exide Test Regime

H-Charge
Discharge at 13.5 A to 19.25 V
Charge at 44 A to 23.5 V, or cutoff at 5% overcharge or current drop to 0.1 A
5-min rest
Charge at 3 A for 8 hours, or to a cutoff at 24.5 V
5-min rest
Wait until battery cools below 29°C

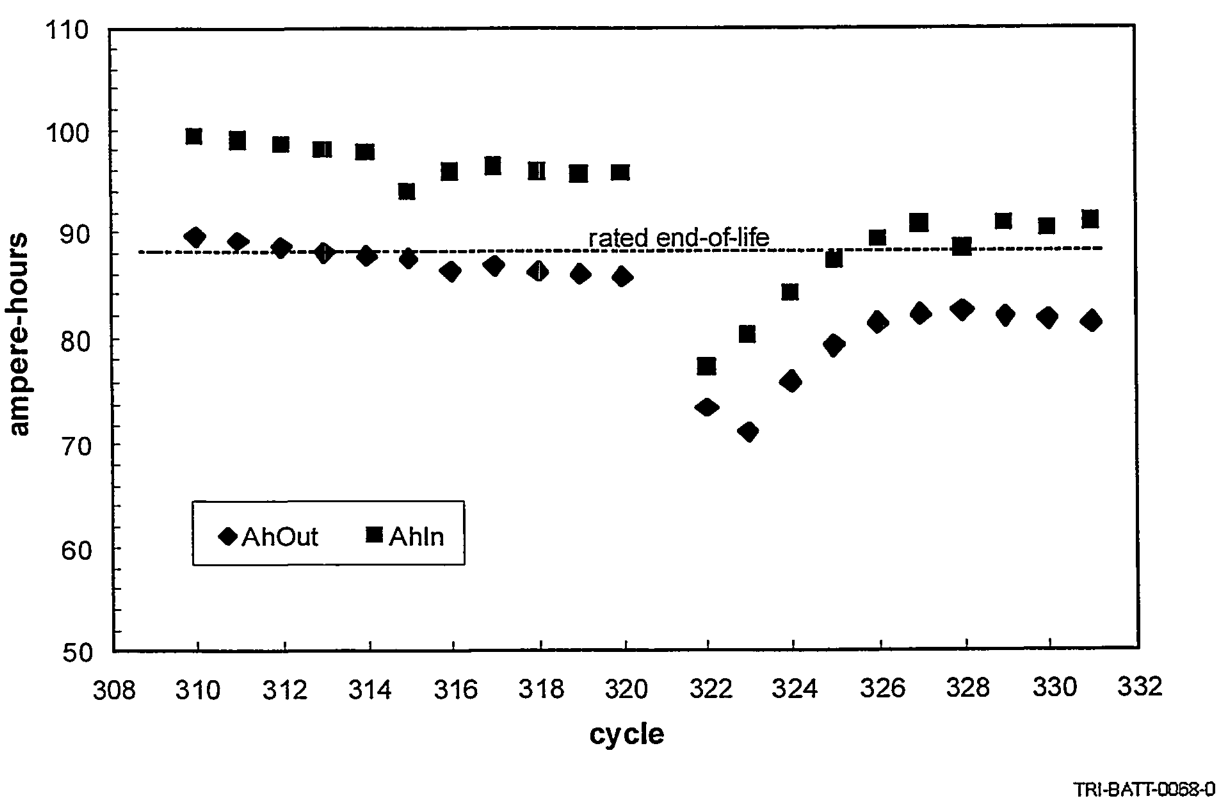


Figure 3-15. Amp-Hours Removed (Capacity) and Returned for the Yuasa-Exide Battery for the First Quarter of FY98.

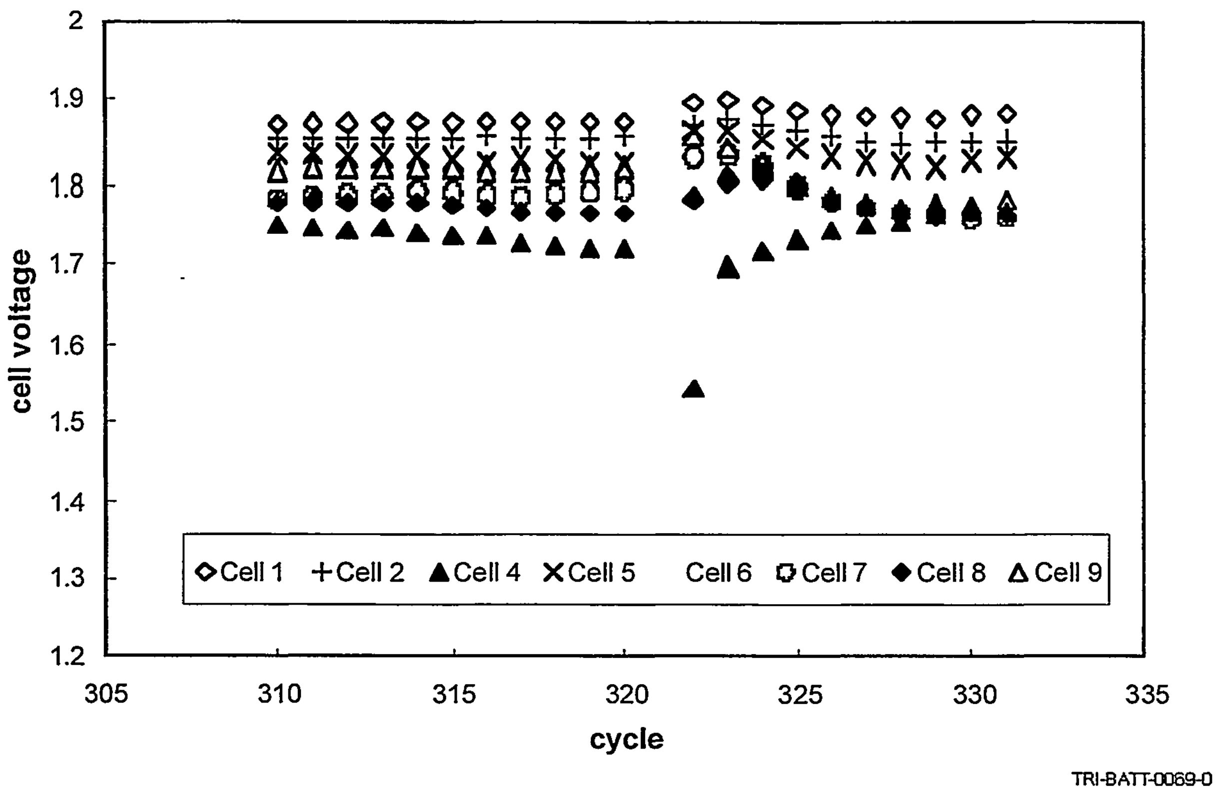


Figure 3-16. Cell Voltages at End of Discharge for the Yuasa-Exide Battery for the First Quarter of FY98.

Table 3-7. Trojan Gel VRLA Batteries at SNL

SNL Battery ID	722	723	726	727
Battery Type	2410GEL	2410GEL	30H14GEL	30H14GEL
Serial No.	1364	1365	1383	1384
Weight (kg)	21.37	21.27	28.75	28.86
Voltage	12	12	12	12
Initial Capacity (Ah)	34	35	58	60

end of life on November 30, 1997. Figure 3-17 shows the capacity of SNL ID No. 727 after each cycle as well as the external battery case temperature. Table 3-9 shows the status of the four Trojan batteries at the end of the first quarter of FY98.

Flooded Lead-Acid Battery Characterization

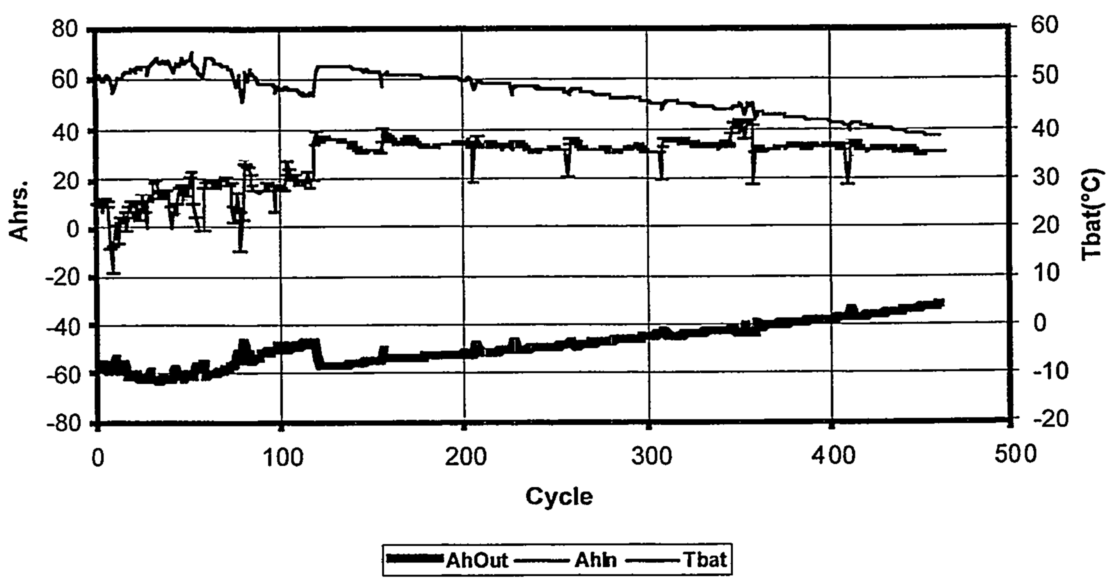
SLI Battery Cycle Testing

Status

Late in FY96, Community Power Corporation approached ESS Program staff with a proposal to test an SLI battery destined for use in offshore domestic PV applications. Community Power Corporation's system

Table 3-8. BCI Test Regime for Trojan VRLA Batteries

Discharge at 25 A constant-current discharge to 10.5 V, record Ah removed
30-min rest
Charge at constant current of 20 A until the voltage rises to 14.40 V, then hold the voltage constant and allow the current to taper. Terminate recharge at 15% overcharge or after a total recharge time of 12 hours, whichever comes first
2-hr rest
Repeat above for 50 cycles, then perform one boost cycle of constant-current charge for 20 hours at 1.0 A and 1.4 A for battery types 24 and 30H, respectively
Repeat above until battery reaches failure, which is defined as < 50% of rated (initial) capacity for two successive cycles



TRI-BATT-0072-0

Figure 3-17. Trojan Battery Capacity and EOD Temperature Plot, SNL ID No. 727.

is to be used in Indonesia for a government-sponsored electrification project. A locally manufactured SLI battery, a Yuasa Pafecta type, must be used because there are restrictions on importing batteries to Indonesia and no deep-cycling batteries are manufactured there. Prior experience has shown that SLI batteries do not perform well in a cycling environment. Consequently, high interest was generated at the prospect of seeing if an SLI battery, with proper care and management, could support a cycling application.

The batteries were tested at a C/20 discharge rate, and the regime consisted of life-cycling the batteries under a PV test plan that uses electronic power supplies and loads that simulate PV stand-alone components. The duty cycle was determined by the customer

Table 3-9. Status of the Four Trojan Batteries at the End of First Quarter of FY98

SNL ID No.	722	723	726	727
Battery Type	2410GEL	2410GEL	30H14GEL	30H14GEL
Initial Capacity (Ah, C/3)	34.0	35.0	58.0	60.0
Final Capacity (Ah)	16.9	17.2	cell failure	31.0
No. of Battery Council International Life Cycles	318	399	155	460
Date of Defined End of Life	9/8/97	9/13/97	cell failure	11/30/97
Months Under Test	11.0	11.2	6.0	13.5

Table 3-10. Customer-Determined Duty Cycle for SLI PV Batteries

SNL ID No.	Battery Rated Capacity (Ah)	No. of Battery Cells	Array Charge (A)	Nominal Array Output (W)	Daily Array Recharge (Ah)	Load Discharge (A)	Daily Load Discharge (Ah)	Nominal Load (W)
730	100	6	4.73	80	17.6	5.54	19.6	67

(Table 3-10) and is based on array output, battery sizing, and load demand. The battery is slated for use as a residential stand-alone PV/battery system for home lighting, radio, and television. Each system works the same way but differs in array and battery size and will be tailored to meet different system load demands. Strong constraints were placed on rates, PV panel sizing, battery depth of discharge, and low-voltage disconnect (LVD) levels. Several batteries were placed on test in ESS Program laboratories. The test target for the batteries was to complete 1,000 daily cycles of 10% depth of discharge with periodic excursions to the LVD. Energy available for charging the batteries was limited to what could be provided by a 250-W panel on a typical solar day. Partial funding for the project was provided by a small business grant.

During the first quarter of FY98, after more than 15 months, the only battery that was still on test, SNL Battery ID No. 730, began to show signs of aging. As shown in Figure 3-18, the initial PV cycle count between a full charge and reaching the LVD was 13 cycles during the early months of testing. Figure 3-19 indicates that the number of PV cycles fell to 6, indicating a significant reduction in capacity for the battery.

By the middle of December 1997, the battery was still able to operate for up to 6 cycles before LVD was reached. At the end of December, the battery had completed 1,077 PV cycles, exceeding the key test objective of 1,000 PV cycles. Because we had reached the goal of greater than 1,000 PV cycles and funds were no longer available to continue testing, a decision was reached to terminate cycle testing and perform a final capacity test.

In addition to continuous cycling, the battery was jarred and rocked periodically to allow gas bubbles to escape. Also, the 100-Ah model was vigorously bubbled from time to time to alleviate acid stratification. Specific gravity checks before and immediately after the bubbling confirmed the successful, albeit temporary, elimination of stratification. Water levels were checked, and water was added when necessary (344 ml added in the first quarter of FY98), usually at the end of full recharge.

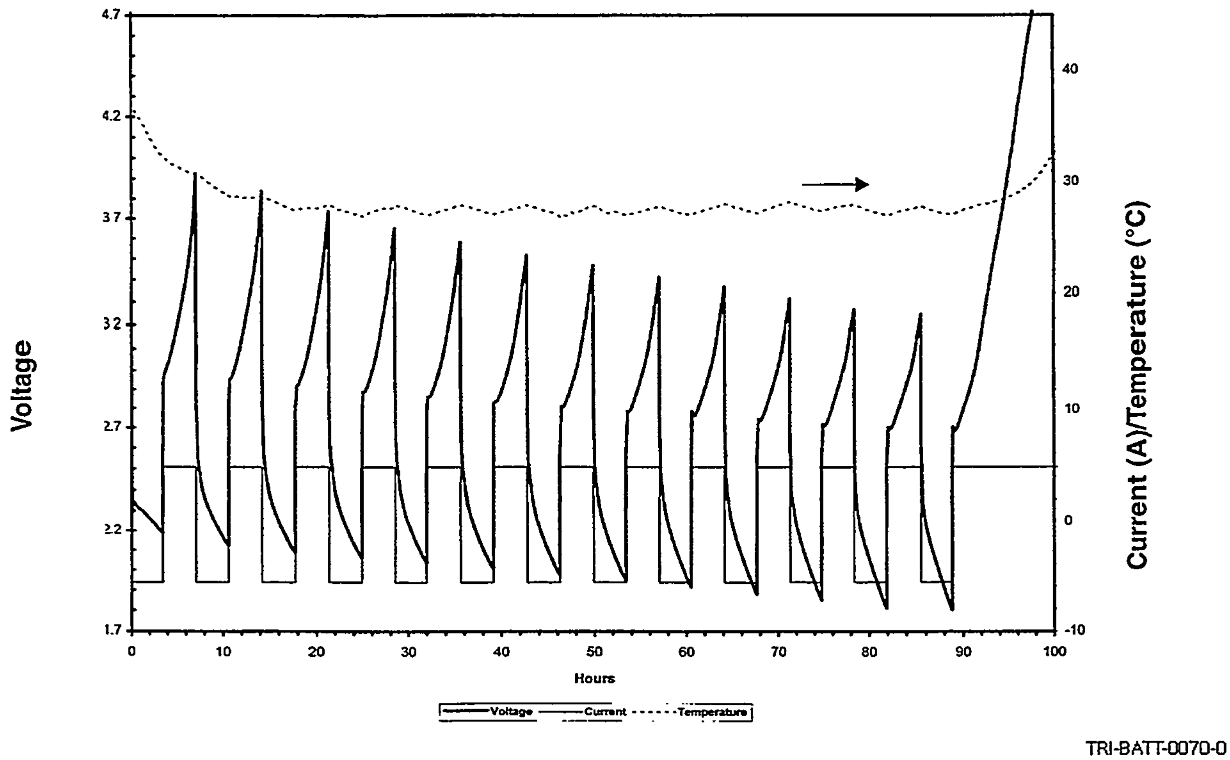


Figure 3-18. **PV Cycle Performance of SLI Battery (SNL ID No. 730) during Early Part of Testing Showing Thirteen Cycles Between a Full Charge and Reaching LVD.**

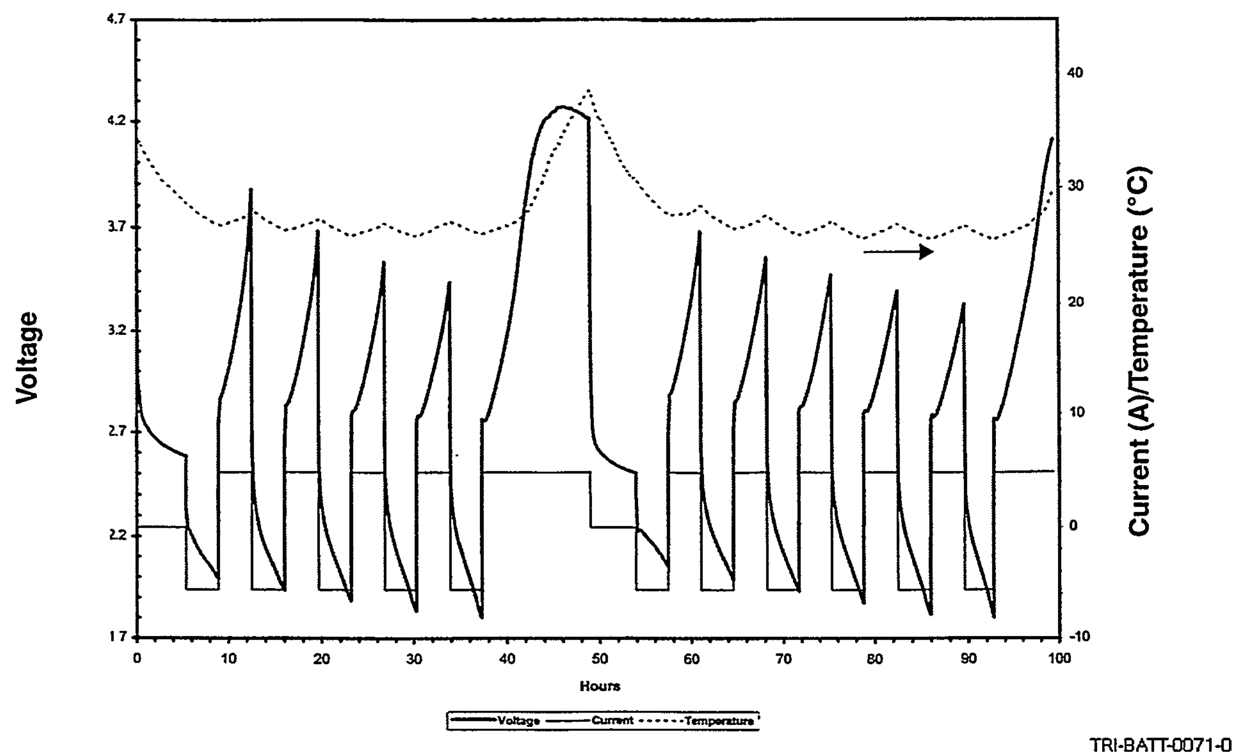


Figure 3-19. **PV Cycle Performance of SLI Battery (SNL ID No. 730) during the First Quarter of FY98 Showing Six Cycles Between a Full Charge and LVD, Indicating a Significant Reduction in Capacity.**

In mid-January 1998, battery ID No. 730 was subjected to a final capacity test, which yielded information that the battery was at 58% of original measured capacity. At the time the battery was taken off test, five to six daily deficit cycles (10% of measured capacity removed, 9% returned using the Ah counting technique) were typically obtained as the battery ratcheted down in state of charge to the point of LVD. Following the final capacity test, the battery was fully charged and placed in temporary storage. The Yuasa Pafecta battery testing at SNL was successful in demonstrating that an SLI battery can be used in a PV cycling environment if it is properly managed.

Intermediate State of Charge Testing

Status

During the second quarter (early January 1998), SNL received two modules of Yuasa, Dynacel DGX Tubular GEL VRLA cells. A test plan was developed under the intermediate state of charge (ISOC) test project. These modules will provide data for comparison to the Dynacel DGX battery at the APS STAR Center, which will be tested in a hybrid operating environment. The modules were exposed to the cycling regime shown in Figure 3-20. Table 3-11 details the various phases of the ISOC full-capacity test cycle. Each sequence number correlates to the sequence plot in Figure 3-20.

The test plan for the Yuasa Dynacell DGX 85-11 ISOC test was completed in late March 1998, and preparations for ISOC testing began shortly thereafter. Figure 3-21 shows Module 1 uncovered and waiting for wiring and Module 2 below it with its cover in place.

After completing an extended shakedown test of the test equipment and tune-up of the tester software, testing began during the third quarter (mid-April) with the discovery that several cells were in premature failure, perhaps because of improper handling during shipping. Spares were available from the STAR test project, and arrangements were made to ship the cells to SNL. A request was also made to Yuasa to replace the cells at SNL and the spares at STAR. Yuasa responded that the cells would be shipped as soon as possible after the next DGX 85-11 production run. ISOC testing for the Yuasa DGX was resumed immediately after the failed cells were replaced.

To expand the ISOC test program to other battery models, initial contact was made during April and May with six battery manufacturers to inquire whether they

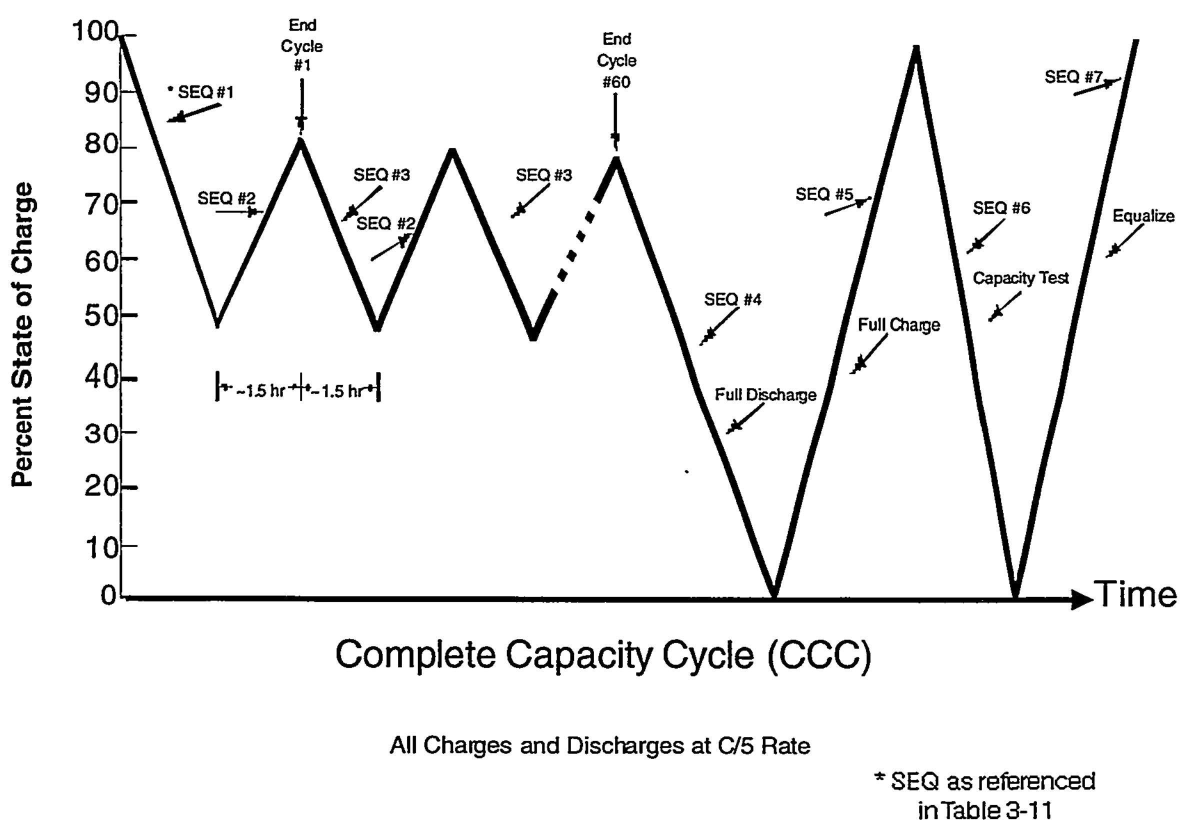


Figure 3-20. Intermediate State of Charge Cycle.

Table 3-11. Definition of ISOC Cycle Sequence

Sequence No.	Activity	Test Specifies (Applies to both modules and strings)
1	C/5 Constant Current Discharge to 50% Rated Capacity	Beginning at a point where the battery is fully charged, discharge battery at C/5 rate to 50% of the C/5 rated capacity.
2	C/5 Constant Current Charge to 80% Rated Capacity	Charge battery at the C/5 rate to 80% of the C/5 rated capacity.
3	C/5 Constant Current Discharge to 50% Rated Capacity	Discharge battery at the C/5 rate to 50% of the C/5 rated capacity. Note: Ah returned in Sequence No. 2 should be removed in Sequence No. 3, then restored by repeating Sequence No. 2 and Sequence No. 3 59 more times. At the end of the 60th charge cycle, move to Sequence No. 4.
4	Discharge at the C/5 Rate to 1.75 vpc	After completing Sequence No. 3, discharge battery at the C/5 rate until nominal cell voltage reaches 1.75 vpc (10.5 V for 12-volt modules, 52.5 V for 60-volt strings).
5	C/5 Constant Current Charge to 100% SOC	Charge battery at the C/5 rate to the manufacturer's recommended overcharge point to restore the battery to full SOC.
6	C/5 Constant Current Discharge to 1.75 vpc	After a minimum of a 4-hr rest period following the completion of Sequence No. 5, discharge the battery at the C/5 rate to 1.75 vpc (10.5 V for 12-volt modules, 52.5 V for 60-volt strings) to determine battery capacity. If capacity falls below 75% manufacturer's rated C/5 capacity, complete Sequence No. 7, then terminate test.
7	C/5 Constant Current Boost Charge	Immediately after completion of Sequence No. 6, perform a manufacturer's recommended equalize charge. After completion of the equalize charge, and after a 4-hr open circuit rest period, return to Sequence No. 1 and resume test.

were interested in participating in the ISOC test program. Letters with information on how the manufacturers could participate and details of the test program were distributed to each of the manufacturers in the third quarter. Every manufacturer initially contacted expressed high interest in participating and promised to ship eight modules each, 100-Ah (75- to 125-Ah), 12-V VRLA modules to SNL. By early September, three manufacturers had sent modules, two flat-plate gels and one AGM, and preparations were made to begin testing early in the first quarter FY99. Based on the cycling rate for the test, preliminary findings should be available in the second quarter of FY99. Information on the results will be presented at various battery conferences and in the ESS Program quarterly and annual reports.

Zinc-Flow™ Battery Testing

In the third quarter of FY97, the ESS Program initiated a contract after a competitive procurement with Powercell Corporation to conduct testing on Powercell's Zinc-Flow™ battery. The objective of this project is to characterize the performance of a 9-kWh Zinc-Flow battery. The operation of the battery is expected to establish the dynamic and long-term performance capabilities of the technology and its suitability as a robust and reliable electrical storage device for applications within the electric supply industry.

The project task list has been updated and expanded primarily to include the field characterization of a 100-kWh unit that Powercell calls the PowerBlock®:

Task 1: Deliver the Zinc-Flow battery. A 64-cell battery will be assembled, integrated with a controller, and delivered to SNL.

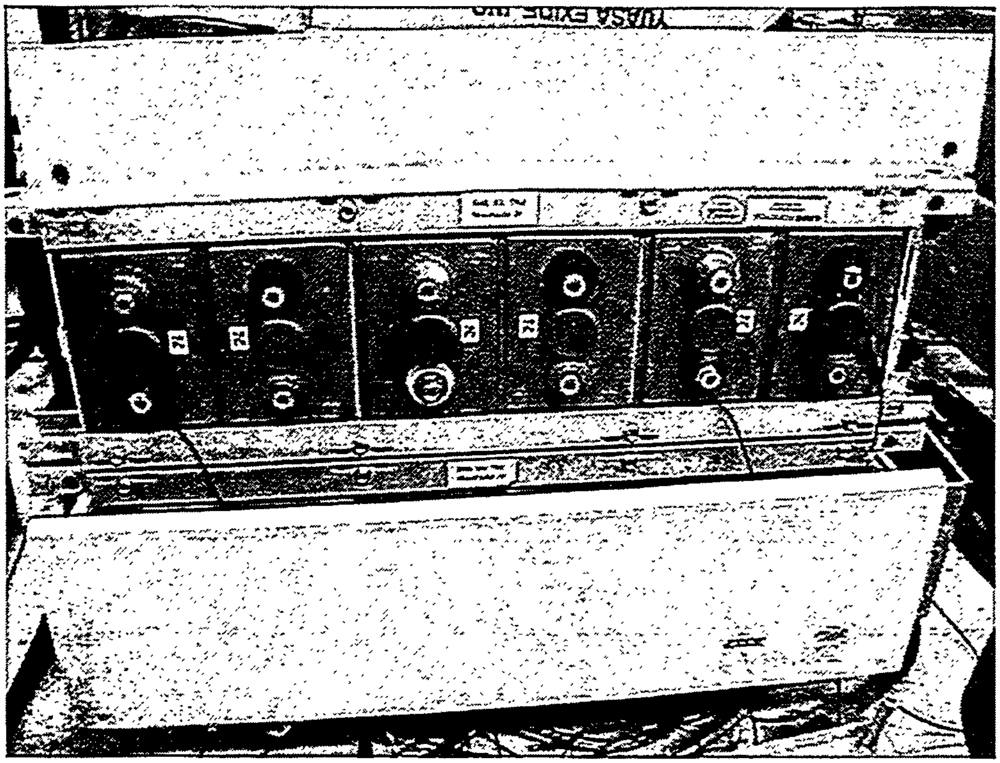


Figure 3-21. Yuasa Dynacel DGX 85-11 Being Assembled for Testing Sequence.

Task 2: Create a draft test plan. A suitable plan for testing at SNL will be compiled for the Zinc-Flow battery. While it is intended to focus on life-cycle testing, additional input will be sought to round out the test plan to encompass the widest possible array of applications.

Expanded: Write the test plan for the PowerBlock® to perform a detailed analysis of its operating characteristics. This test protocol will emulate the previous system tests performed with SNL involvement on other battery systems.

Task 3: Dispose of Zinc-Flow test battery once tests are complete.

Task 4: Powercell will provide SNL with quarterly progress reports.

Task 5: Provide informal reporting on the 9-kWh Zinc-Flow battery testing at SNL.

Expanded: Report on factory acceptance testing and field testing of the PowerBlock unit as well as the Zinc-Flow battery at PVUSA and SNL.

Task 6: Develop a monitoring system for the demonstration of a PowerBlock® unit to be fielded in Livermore, California. The monitoring system will collect data directly via the serial communications port on the unit controller. In addition, input and output power quality perturbations will be quantified using a sensing device such as a basic measuring instrument (to aid in the development of the monitoring system, the design will leverage off the Powercell monitoring and analysis capacity developed for the test facility at PVUSA in Davis, California). Quantify the basic performance parameters of the PowerBlock® unit.

Task 7: Develop remote monitoring capabilities for the PowerBlock® to enable centralized performance monitoring and analysis, which will include modem control capabilities to enable remote dispatch of installed systems. This is primarily targeted at centralized control for peak shaving requirements, but also enables remote diagnostic testing without the need for site access.

Status

The 9-kWh Zinc-Flow battery has been designed and fabricated and has been equipped with a controller that monitors temperature, integrity, and electrolyte flow within and disengages the battery under unsafe conditions. The unit was delivered to SNL in the fourth quarter of FY98. The test plan for the 9-kWh battery, which is in process calls for it to be cycled 20 times per week with one strip cycle per week. This test regime should yield cycle-life capacity results within approximately one year.

The project scope has been expanded to include the characterization and demonstration of a 100-kWh PowerBlock product in the field, shown in Figure 3-22. The development and factory testing of the PowerBlock remote monitoring system (Tasks 6 and 7), the communications server, and the preliminary design of the remote users interface was completed in the fourth quarter. A remote monitoring system operational screen is shown in Figure 3-23.

Powercell engineers have verified that information on the OLE for Process Control (OPC) programming interface was current. A skeleton C++ code, which will receive appropriate functionalities, is being used and code capabilities are being added to keep incoming serial communications and ongoing data supply from interfering with each other. This will take some time because of the large volume of parameters. The layout of the preliminary user interface may require variations.

Planned activities include completing the foundations code, incorporating dummy data and testing it by setting up a user interface code to display the dummy data. Also, the coding of a Trace Technologies communications protocol is in process.

The Histograph screen from the remote monitoring system, which provides operational history, is shown in Figure 3-24.

ESS Program staff visited Trace Technologies, and met with Powercell Corporation and Trace personnel in the third quarter. The purpose of the meeting was to discuss the ESS contract with Powercell and to investigate the new advanced energy storage system technology being developed by Trace and Powercell. The meeting included a demonstration of a 50-kW, 100-kWh storage system that includes a zinc/bromine battery. Technology design is shown in Figure 3-25. The demonstration showed that the system is capable of taking over a 33-kW load when the grid is turned off with no noticeable change in the utility power as shown on a scope. The footprint of this system, once fully developed, is estimated at about 20% of an equivalent system based on lead-acid batteries.

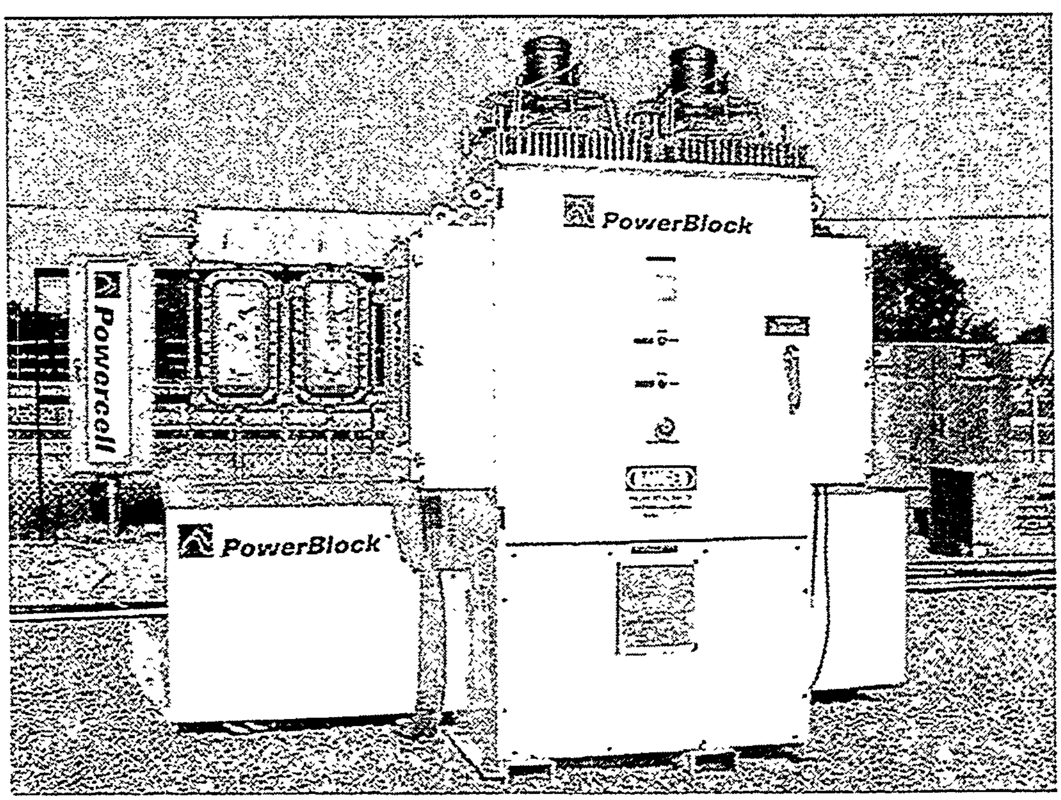


Figure 3-22. 50-kW, 100-kWh PowerBlock (Zinc-Flow™ Technology).

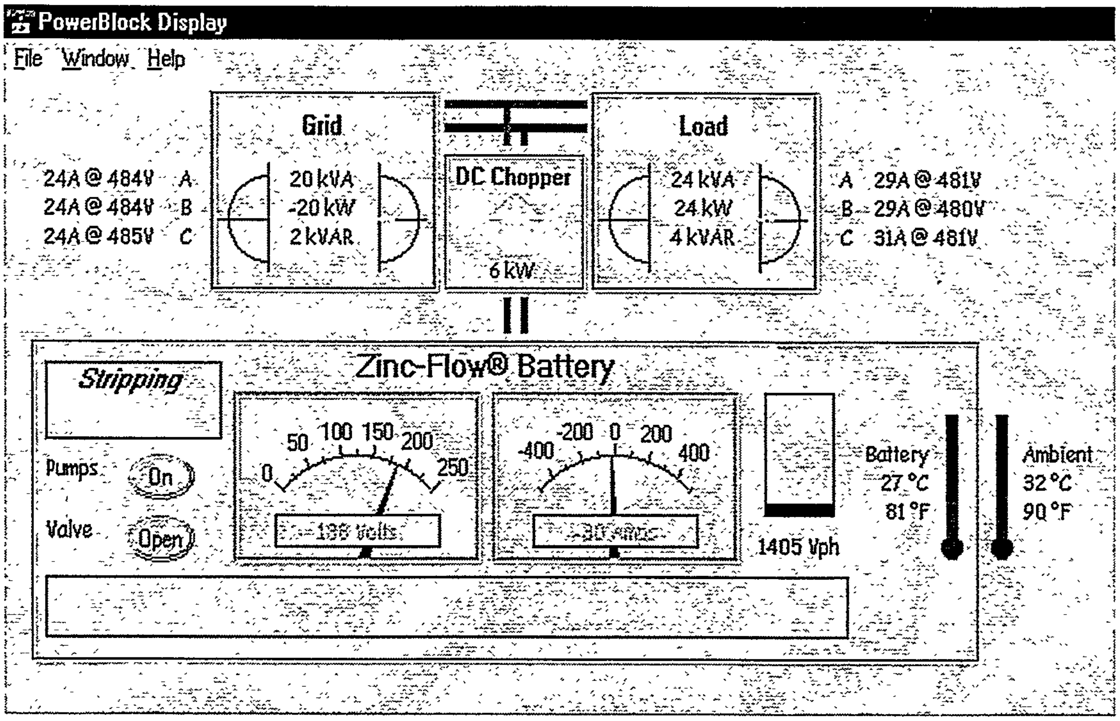


Figure 3-23. System Operating Screen from Remote Monitoring Unit.

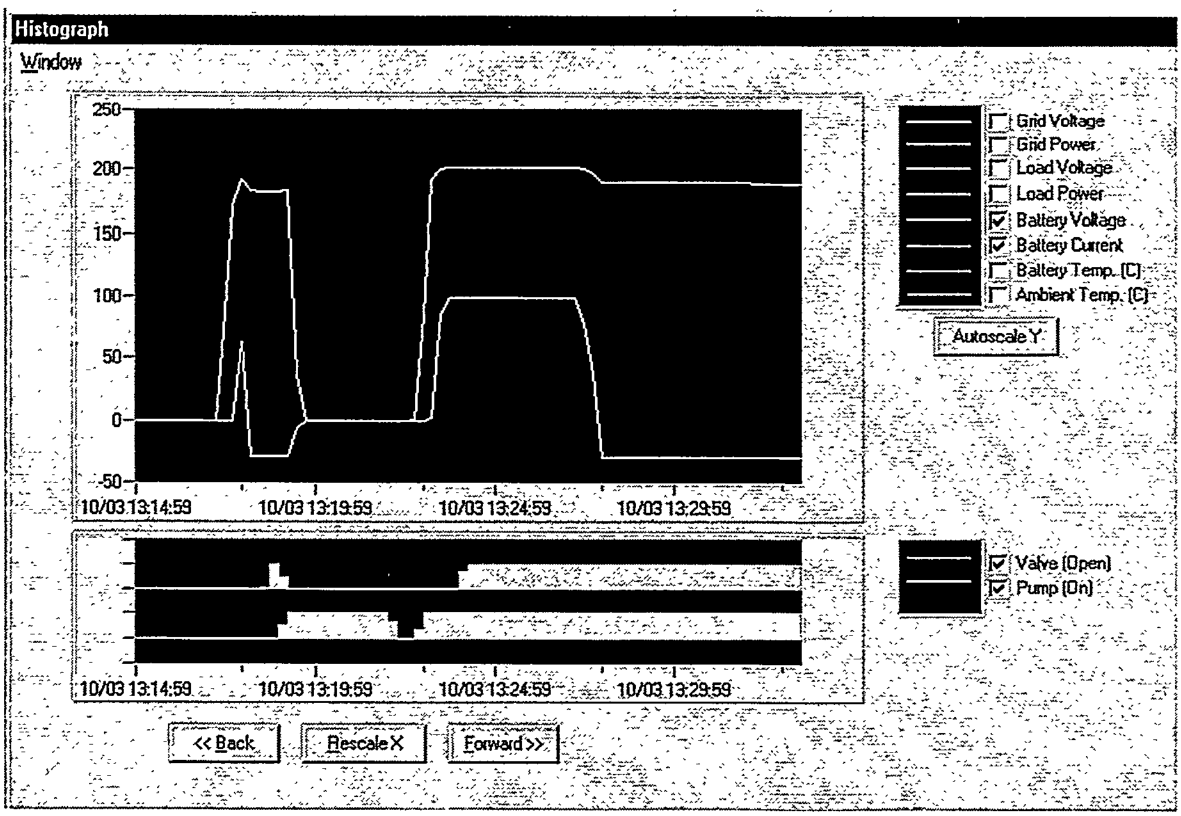


Figure 3-24. Histograph Screen from Remote Monitoring System Provides Operational History.

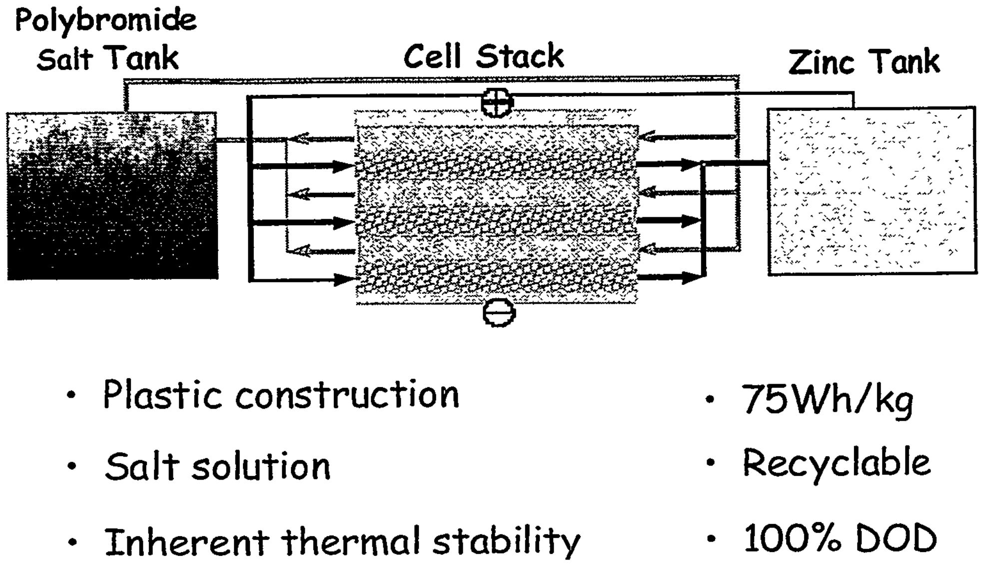


Figure 3-25. Zinc-Flow™ Technology Design.

4. Analysis

Introduction

The analytical tasks being performed in FY98 derive from studies conducted in past years. The set of studies for FY98 was designed to establish a tighter link between storage and renewables through analysis that would determine the value of storage when it is used to support renewable generation sources such as wind and PV. There are three subelements in the Analysis Program element: (1) system studies, (2) feasibility studies, and (3) opportunities analysis.

A "system study" is an initial screening study performed in collaboration with a host to identify and evaluate the potential benefits of energy storage to that organization. This screening study establishes a rough estimate of the benefit-to-cost ratio of storage using a limited examination of specific operating and financial data as a basis.

A follow-on "feasibility study" firmly establishes the quantitative value of energy storage by examining detailed forecasts of operating costs and other operational parameters for the entire operational life of the storage system. A site-specific conceptual design is included in the feasibility study to determine the cost of the storage system needed to generate these benefits.

Using the findings of the system and feasibility studies, the "opportunities analysis" (1) estimates the benefits of storage on a national level by identifying the market size, specific applications, and timing of the market, and (2) defines the application requirements at the system level and matches each battery technology with application requirements that fit the battery's characteristics.

Other studies are focusing on the value of storage as a distributed resource on the electricity grid.

System Studies

Quantification of Utility Operating Cost Savings from Using Batteries—UMR

This task was initiated during FY94 through the placement of a contract with UMR to use the Electric Power Research Institute's DYNASTORE computer program to perform calculations of utility generation operating costs with and without battery energy storage. Operating cost savings are one important component of the battery system cost/benefit picture, along with the system capital cost and other projected utility benefits. In this initial study, UMR calculated generating costs for a medium-sized utility system (Utility B) that was not interconnected with other utilities. The results of this work showed that significant production cost savings could be obtained by using a battery system for spinning reserve.

In FY95, a new contract was placed with UMR for a follow-on study to perform a similar operating cost analysis for a grid-connected utility system. Kansas City Power and Light Co. (KCPL), which was selected as the subject for this new study, is a typical Midwestern electric utility with many interconnections and a mix of generating plants. As with the previous study, the approach was to run a unit commitment program on energy storage units along with generating units and calculate operating costs with and without energy storage, so that savings could be quantified. This study was completed at the end of the third quarter of FY96, and the greatest production cost savings were projected for frequency regulation applications.

A reanalysis of data from the grid-connected utility system study was begun in FY97 in order to take into account factors not addressed in the first case, such as battery operating and maintenance costs, and to clarify the reasons for certain trends observed in the previous results. The impact of fixed and variable BESS O&M costs were studied, and forced outages were investigated by means of a Monte Carlo analysis. While the Monte Carlo results are viewed as being the most realistic, the differences compared to a deterministic method that does not simulate forced outages were small in most cases.

Status

Work in the beginning of FY98 concentrated on completing calculations of KCPL operating costs/savings for various battery energy storage applications while including inadvertent outages in generation.

Many of the cases studied for KCPL in the prior contract were rerun using the Monte Carlo mode (12 iterations). This mode takes into account the forced outages that occur randomly at the effective forced outage rate. Comparisons were then made to calculations for the same application but without inadvertent outages.

Study cases for BESSs of one-, four-, and eight-hour duration and capacities of 40, 100, 200, and 300 MW were rerun using the Monte Carlo mode (12 iterations) to properly model the forced outages. To recognize the impact of plants having maintenance/refueling intervals longer than one year, the number of years for the study scenario was also increased. This provides an additional check for data errors.

Recalculation of the operating-cost benefits from the use of battery energy storage for the grid-connected utility case (KCPL) was completed by the second quarter of FY98. A draft report of these results was prepared and presented at Sandia by UMR at the beginning of the quarter. The major results included in the report were those describing the significance of fixed and variable operating and maintenance costs for the BESS and the effect of scheduled as opposed to unscheduled generation-equipment outages on the operating cost estimates. Ways to include renewable energy generators in DYNASTORE were considered, but a preferred approach was not identified. A summary of that report is presented here.

Operating and Maintenance Costs

Operating and maintenance (O&M) costs are of two types: fixed and variable. Fixed costs for low maintenance (sealed or VRLA) cells have been quoted at $2.2 to $2.4/kW per year for new battery technologies and $1.15/kW per year for mature battery technologies.[1] These numbers translate to $230K per year for a 100-MW developmental BESS and $115K per year for a mature technology BESS. Another reference gives fixed costs of $1.55/kW per year, which would scale to ~$150K for a 100-MW BESS. These numbers were calculated for smaller BESS sizes of 0.5 to 5 MW and therefore are likely to be overestimates for a 100-MW BESS (economy of scale is not considered).

Variable costs have been given as zero in one reference[1] because there are no consumables, and the same value was also assumed by KCPL. A second reference gives variable costs of $0.005/kWh, and utility B suggested a similar value of $0.003/kWh.[2]

It was suggested that the O&M costs for the Chino BESS be used as another point of comparison. Data gathered from the Chino facility were extracted from EPRI reports, and costs for battery watering and handling of battery chemicals were subtracted out (these costs will not occur in a VRLA BESS). The remaining O&M costs were much less than the cost estimates quoted above.

When variable O&M costs were included in the calculations, a conservative value of $3/MWh was assumed in all cases. Even at this high level, the effect of BESS O&M costs on operating cost savings was small. An upper limit is probably represented by the cost of one technician servicing one facility ($100K per year estimated). The impact of both fixed and variable BESS O&M on operating cost savings is, in general, minimal with only small curve shifts seen for applications with larger savings values. In cases with smaller savings, the analysis is complicated by the fact that two large cost values must be subtracted to arrive at the savings. The variability in these two large values caused by truncation and round-off errors is comparable to their difference, and this causes the savings curves for the small savings applications to show nonuniform trends in some cases. This also obscures effects from O&M costs.

KCPL Study Results–Savings in Operating Costs due to BESS

The first study of the KCPL system showed that the impact of forced outages on cost savings was relatively small.[3] This results from two primary factors. First, the forced-outage rate is low compared to island utilities similar to Utility B. Second, KCPL has a quality, detailed maintenance program for generating units, such that scheduled outage time was greater than the resulting forced outage time.

DYNASTORE has the following simulation methods of interest: deterministic and standard Monte Carlo. The deterministic method does not simulate forced outages; it does include scheduled outages, for maintenance. The Monte Carlo method creates probability distributions for failure and repair according to the equivalent-forced-outage rate (EFOR). Fortunately, the savings calculated by each method were fairly close together. We initially opted to use the deterministic method because it was much faster (it took less time to run the program), and the estimate of savings seemed sufficiently accurate. The Monte Carlo method does calculate a more accurate cost savings, but it takes about

[1] *EPRI Technical Assessment Guide*, Volume 5, TR-105124, May 1995, pp. 2-67 to 2-70.

[2] Schoenung, Susan M., Burns, Clayton, "Utility Energy Storage Applications Studies," *IEEE Transactions on Energy Conversion*, Vol. 11, No. 3, p. 658, September 1996.

[3] Final Report, Contract AO-4841, June 28, 1996.

20 minutes to calculate operating cost savings for one year, using a Pentium 90. For this study, the standard Monte Carlo simulation method was used to model the randomness of the forced outages and more accurately determine the impact of these inadvertent outages on savings and operating costs.

To date, UMR's approach has been to assume that BESSs would be used to cover both scheduled and forced outages. This may not be realistic in that replacement equipment could and would be placed on line during a scheduled outage. For example, if a generator were scheduled to be down for maintenance, then replacement power would also be scheduled from another generating unit or purchased externally. Spinning reserve would not be depended on to cover the outage in this case. For this reason, UMR is proceeding with its reanalysis of battery energy storage, taking into account mainly forced outages and, to a lesser extent, scheduled outages if spinning reserve is available.

Input data supplied by KCPL have been used again to calculate savings afforded by BESS. Detailed maintenance schedules were provided by KCPL for each generating unit out past the year 2015. These data were entered into a DYNASTORE data file. Alternatively, scheduled maintenance outages can be set up as annual (or multiyear) cycles. For this study inadvertent (forced/unscheduled) outage statistics, including the EFOR were entered into a file, along with maintenance cycles for each unit. This is contrasted with the first study, reported June 28, 1996, which used only the maintenance schedules and ignored the inadvertent outages. (Reminder: outage time because of scheduled maintenance was much greater than outage time because of inadvertent outages for KCPL.)

Operating cost estimates for the year 1997 were added to the calculations to help resolve differences between results for 1995 and 1996. Reruns for 1995 and 1996 plus additional runs for 1997 suggest that the differences were because of variations in annual load profiles and the 18-month refueling schedule of a nuclear power plant (Wolf Creek).

Spinning Reserve Only Application: Savings increase rapidly with BESS MW capacity up to the spinning reserve requirement of 6% (approximately 180 MW). Increase in MW capacity above 200 MW produces no increase in savings because of additional costs for BESS capacity that is never allocated to spinning reserve. Also note that the one-hour battery has sufficient time duration (energy) to satisfy the spinning-reserve requirement. Extending the BESS energy capacity to four- and eight-hour durations does not increase BESS usage for spinning reserve. Hence, Figures 4-1 through 4-3 show that the curves calculated using the Monte Carlo method for one-, four-, and eight-hour BESS lie on top of each other (coincident).

Savings in operating costs are slightly greater using the Monte Carlo method than they are using the deterministic method. For each year simulated, the range of savings for various BESS MW sizes is given below.

Year	Savings Range ($K) Monte Carlo Method
1995	1800–3700
1996	900–4800
1997	1600–4500

Load-Leveling Only Application: Savings increase monotonically with BESS MW capacity and MWh energy (duration in hours). The savings are much greater for an eight-hour battery than for a one-hour battery because the eight-hour BESS can serve much more of the peak load. A BESS with longer energy duration affords greater savings for peak shaving than a BESS with short energy duration (less than two hours). This is particularly important to KCPL, because its typical summer peak is more than seven hours long. The savings reach nearly $4000K for all years of the study (1995-1997), indicating that all of the BESS capacity is being assigned even though the annual load profiles are different. This suggests that more capacity (MW and MWh) could produce even greater savings. If the duration of the peak load in MWh is greater than the BESS capacity, the utility must have the MW generation capacity to carry the load after the BESS has run its duration, and consequently there are no savings.

In this application, savings in operating costs using the deterministic simulation method are generally slightly less than savings obtained using the Monte Carlo method. Figures 4-4 through 4-7 show the Monte Carlo results. For each year simulated, the range of savings for different BESS sizes (MW) is given below:

Year	Savings Range ($K) Monte Carlo Method
1995	600–4000
1996	300–4000
1997	200–4000

Load Leveling with Spinning Reserve Application: Load leveling with spinning reserve is implemented to allocate BESS resources to load leveling first, then to spinning reserve for any remaining BESS capacity that cannot be allocated to load leveling. The operat-

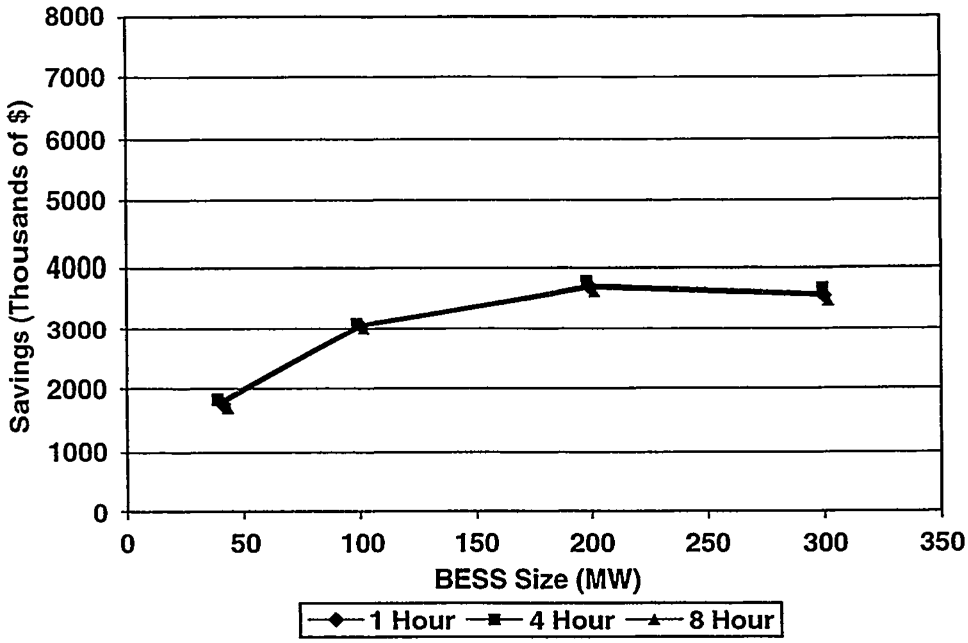


Figure 4-1. **Operating Cost Savings with a BESS Used for Spinning Reserve Only by KCPL (1995) (Simulation Method: Monte Carlo, 12 Iterations).**

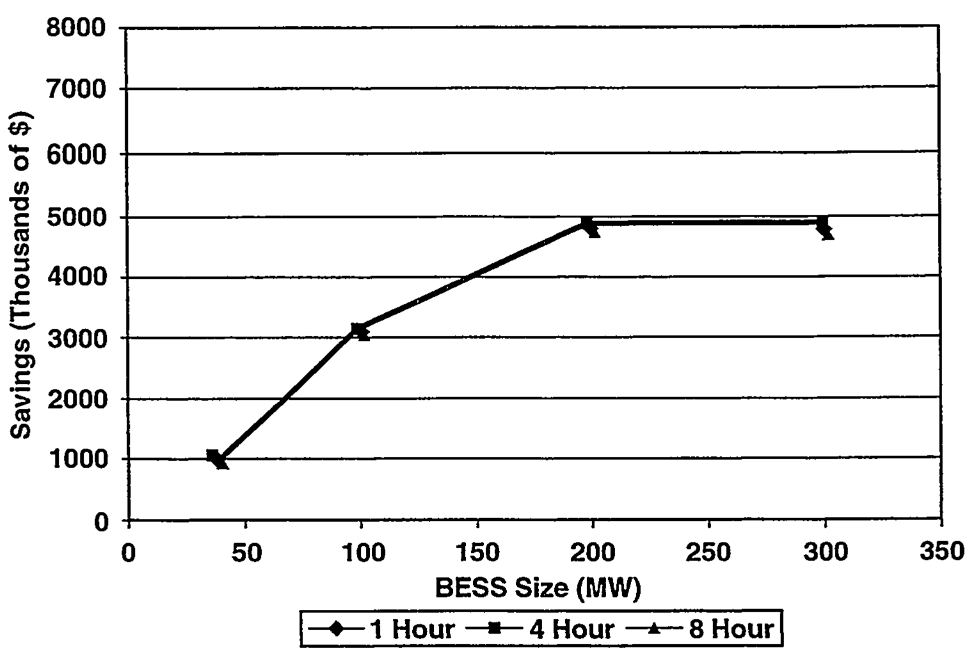


Figure 4-2. **Operating Cost Savings with a BESS Used for Spinning Reserve Only by KCPL (1996) (Simulation Method: Monte Carlo, 12 Iterations).**

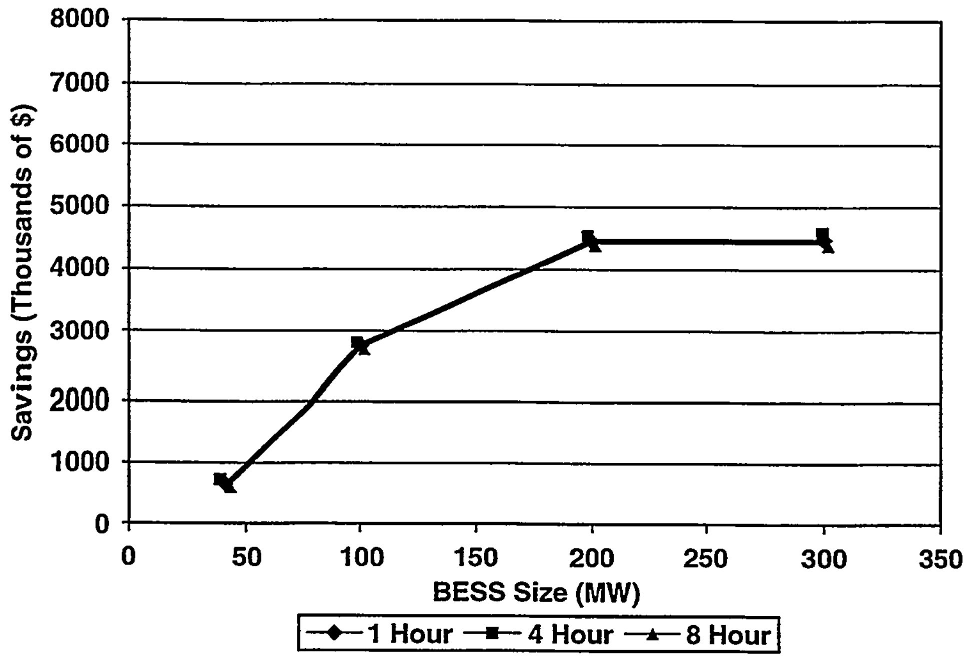


Figure 4-3. **Operating Cost Savings with a BESS Used for Spinning Reserve Only by KCPL (1997) (Simulation Method: Monte Carlo, 12 Iterations).**

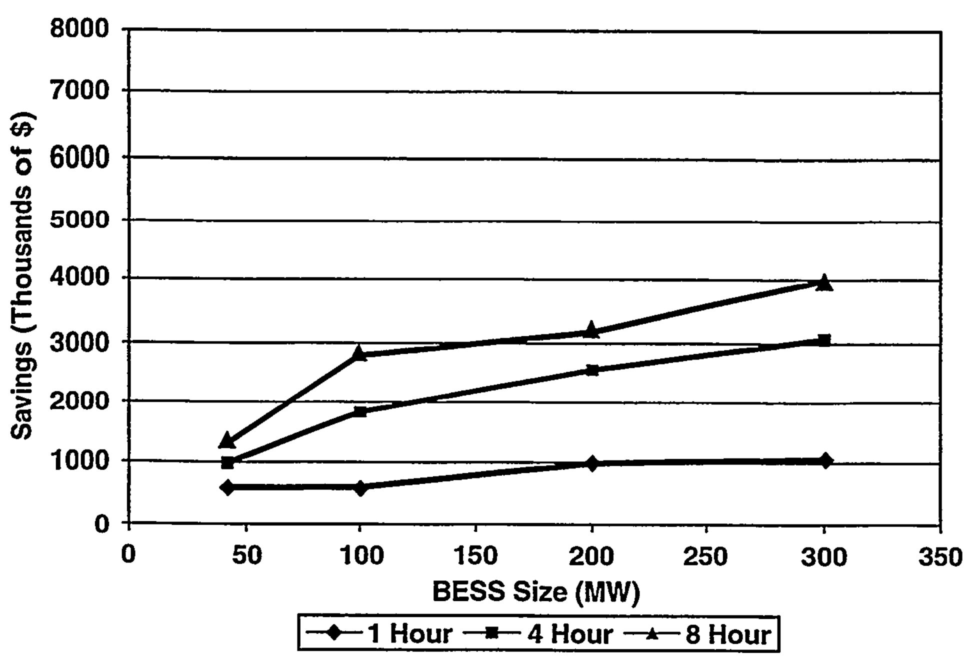


Figure 4-4. **Operating Cost Savings with a BESS Used for Load Leveling Only by KCPL (1995) (Simulation Method: Monte Carlo, 12 Iterations).**

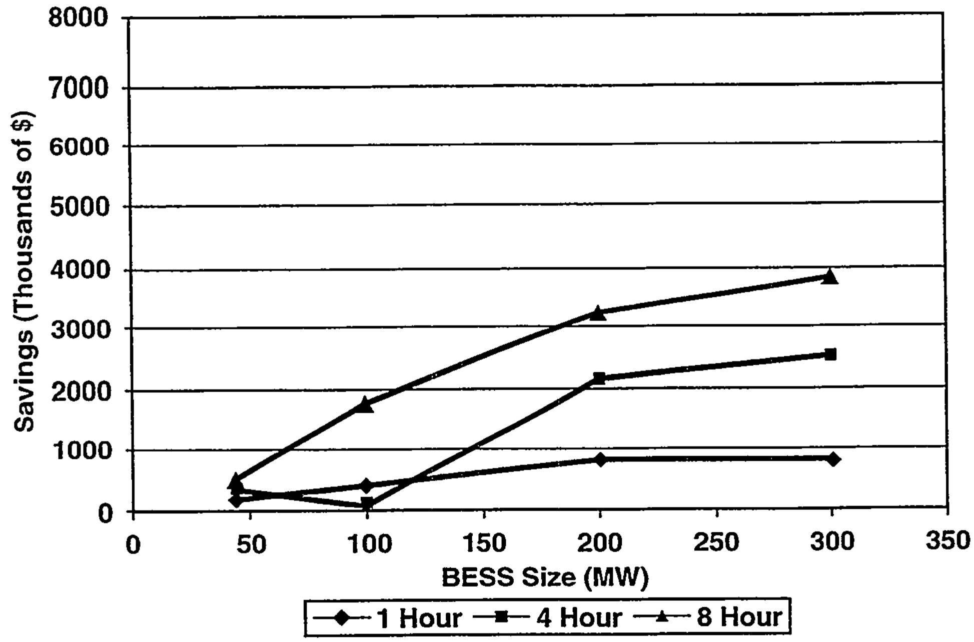


Figure 4-5. **Operating Cost Savings with a BESS Used for Load Leveling Only by KCPL (1996) (Simulation Method: Monte Carlo, 12 Iterations).**

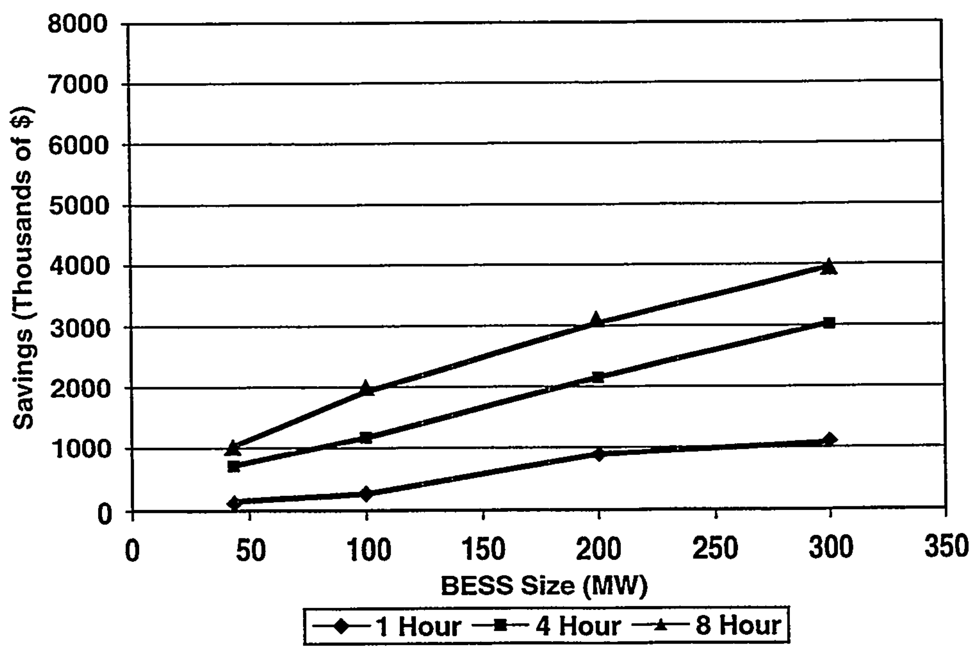


Figure 4-6. **Operating Cost Savings with a BESS Used for Load Leveling Only by KCPL (1997) (Simulation Method: Monte Carlo: 12 Iterations).**

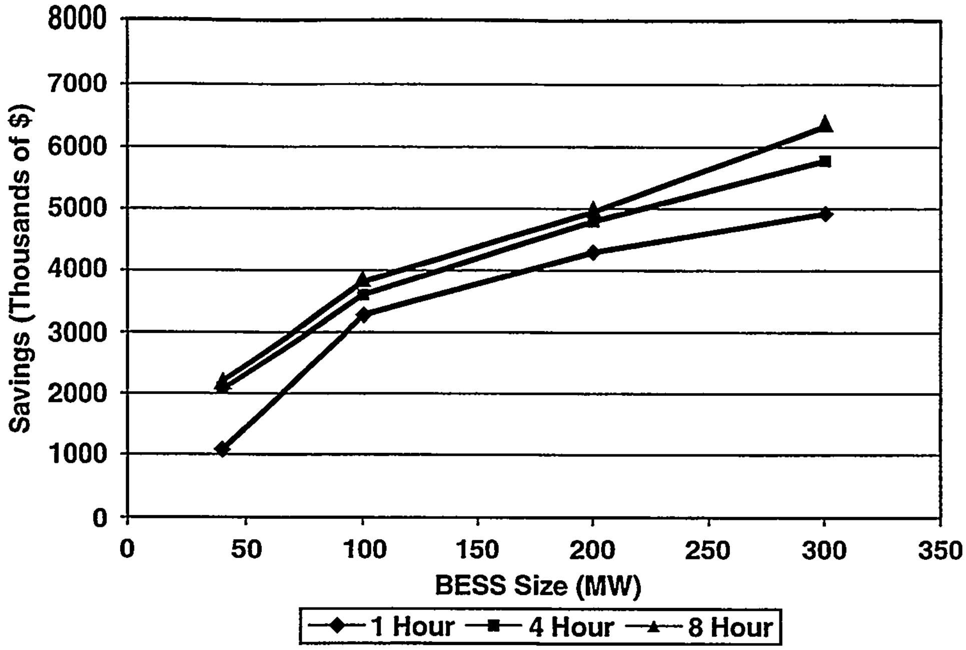


Figure 4-7. Operating Cost Savings with a BESS Used for Load Leveling Including Spinning Reserve by KCPL (1995) (Simulation Method: Monte Carlo, 12 Iterations).

ing-cost-savings curves calculated using the Monte Carlo method, shown in Figures 4-7 through 4-9, are monotonically increasing for all years and BESS capacities in MW and MWh. For capacities that are less than 200 MW, the curves are fairly close together, indicating a small increase in savings as the BESS energy duration increases from one to four to eight hours. This would suggest that most of the BESS capacity is being allocated to spinning reserve. For MW capacities that are greater than 200 MW, the curves increase more divergently, indicating that more of the capacity is allocated to load leveling.

Savings in operating costs using the deterministic simulation method are less than the savings obtained from the Monte Carlo simulation method in this case. For each year simulated, the range of savings for different BESS sizes (MW) is given below:

Year	Savings Range ($K) Deterministic	Monte Carlo Method
1995	700–5800	1100–6400
1996	1000–6500	1500–6800*
1997	1000–6200	1800–7600

* Ignores outlying value at 700.

Note: Savings for load leveling only plus savings for spinning reserve only do not necessarily equal savings for load leveling with spinning reserve, because of calculations for unit commitment and economic dispatch. However, the load leveling with spinning reserve application does produce smoother curves than calculating these quantities independently, most likely because of the higher level of savings. The smoother curves and generally larger savings values may also be responsible for small differences between the deterministic and the Monte Carlo results becoming visible. In general, the Monte Carlo results are viewed as being most realistic.

Frequency Regulation Application: Investigation of the frequency regulation application did not reveal significant differences between Monte Carlo and deterministic results. The frequency-regulation application yields savings similar to the load leveling with spinning reserve application over the range of sizes examined. The savings, ranging from $1500K to $7600K, increase with increases in BESS capacity. For frequency regulation, a one-hour BESS seems to be adequate because of the National Energy Reliability Council (NERC) requirement that the area-control error (ACE) must be controlled to zero every ten minutes.

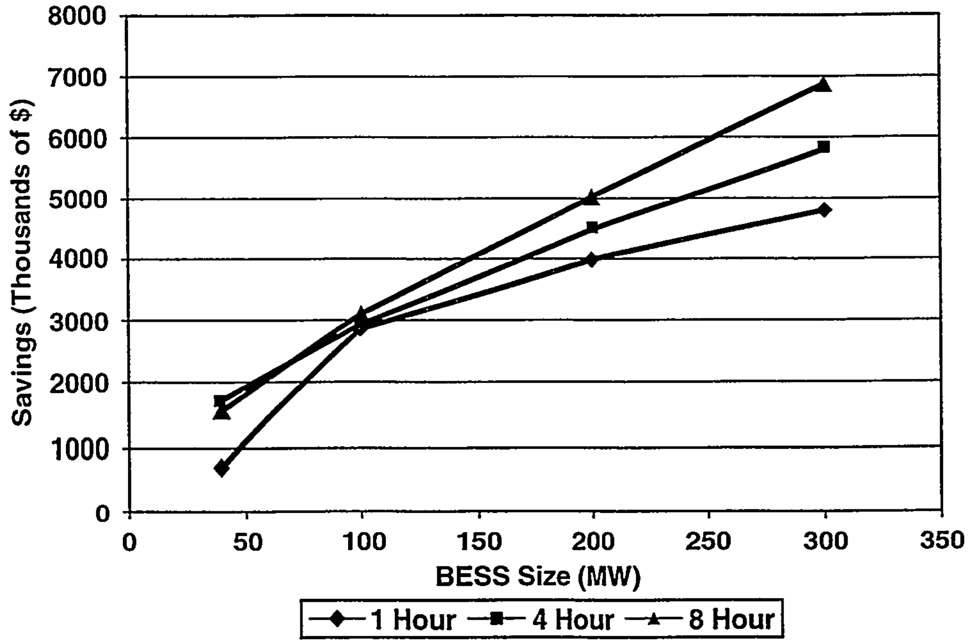


Figure 4-8. Operating Cost Savings with a BESS Used for Load Leveling Including Spinning Reserve by KCPL (1996) (Simulation Method: Monte Carlo, 12 Iterations).

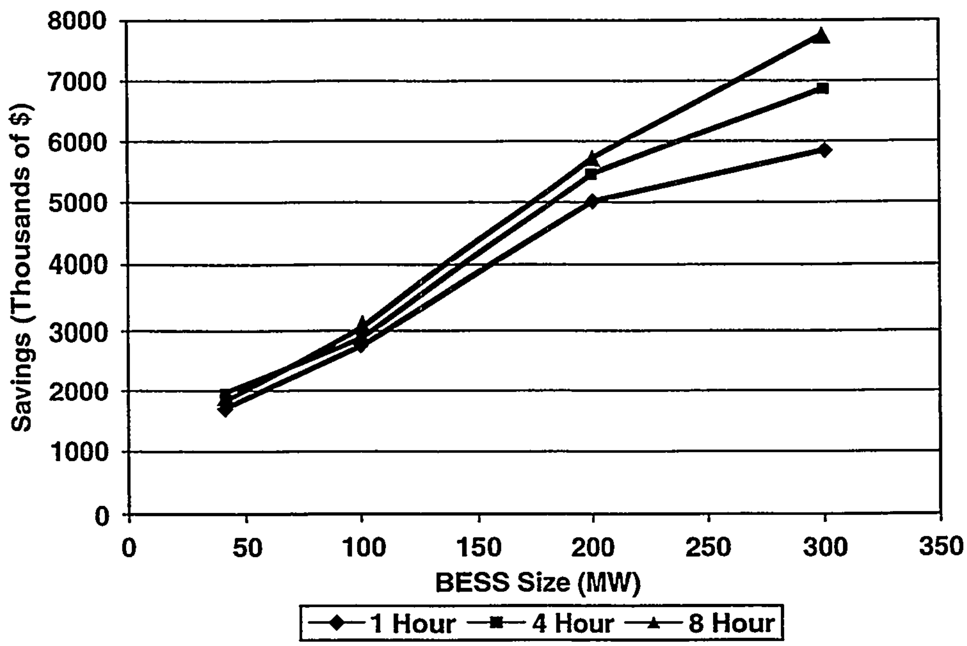


Figure 4-9. Operating Cost Savings with a BESS Used for Load Leveling Including Spinning Reserve by KCPL (1997) (Simulation Method: Monte Carlo, 12 Iterations).

Comparison to Utility B Study Results: Savings in Operating Costs Resulting From BESS Use

Some of these cases were rerun for Utility B so that they were calculated in the same way as the KCPL cost estimates, but the results did not change very much. BESS still returned the most savings in operating costs for spinning reserve only. For BESS up to 100-MW capacity, savings reached almost $4M per year, comparable to the situation at KCPL.

For load leveling only, BESS returned the least savings in operating costs. Savings remained less than $1M even for a BESS discharge duration as long as eight hours and capacity up to 100 MW. This application is much less favorable for Utility B than for KCPL.

For load leveling including spinning reserve, the curves for savings closely follow the curves for spinning reserve only because savings for load leveling are so small by comparison. This application is valuable because it gives the user a good check on the other applications, and provides smoother curves of savings when savings for load leveling only are small. For BESS up to 100-MW capacity, savings are nearly $4M for durations as long as eight hours. These savings are slightly less than for KCPL, where the contribution from load leveling is much higher.

Frequency control is calculated to be a less valuable application for Utility B (operating cost savings < 20% of the spinning reserve value). The estimate for KCPL is comparable to the load leveling with spinning reserve operating cost savings value.

Incorporation of Renewable Energy Generators into DYNASTORE

It was believed that there was a way to model the operation of a renewable energy generator, even though this type of generation is not explicitly included in DYNASTORE. If it could be done, then the operating cost benefits of energy storage could be estimated for a utility with that type of generation mix. Two possible ways to include renewables are to:

1. Add generation with zero fuel cost and other renewable characteristics.

2. Add renewable generation as an hourly transaction.

A new contract to develop and validate an approach for including a renewable generator in DYNASTORE was placed with UMR at the end of the second quarter of FY98. Preliminary findings from this task were received in the fourth quarter of FY98 and are presented below. A more comprehensive report that will include all the associated data from this work will be available in the first quarter of FY99.

The major goal of this task during FY98 was to continue to develop the capability to model the integration of a renewable energy source with conventional utility generation sources using DYNASTORE. Then the operating costs of such a system would be calculated with and without BESS to investigate the benefits of storage in this type of configuration. First, it was necessary to determine whether or not this could be accomplished using DYNASTORE. After trials of various generator inputs, it was determined that a renewable energy source could best be simulated as an hourly transaction input. It was also possible to give such a source an hourly generation profile based on a probability distribution.

Two renewable sources were considered: solar/PV and wind. PV was chosen for this initial study because it was more familiar to the researchers, and the emphasis was on finding ways to use DYNASTORE to model renewable energy sources rather than evaluating different renewable energy sources. The following assumptions were made for the generation profile for a 200-MW PV array (Table 4-1), during the three months of winter.

A generation curve shape was approximated based on the times for sunrise and sunset during each of the four seasons. To cover the full year, it was divided into four periods: January through March, April through June, July through September, and October through December. Table 4-1 was used for the January through March period. Similar tables were constructed for each of the other three periods, but with appropriate modifications to cover the longer daylight periods of the seasons.

The maximum PV generation capacity was assumed to be 200 MW, even though this may be unreasonably large for a PV plant. This was done so that the effects of the PV source would be significant compared to the total operating costs (as small numbers have been subject to round-off and truncation errors in past DYNASTORE results.) Peak load for the utility is approximately 2800 MW.

It was assumed that there were no costs associated with PV. Capital costs are not considered as part of the operating costs. O&M costs can be included as part of the transaction (to be entered later), and a probability of having full sunlight can also be entered.

Table 4-1. Assumptions for the Generation Profile for a 200-MW PV Array

Time	Power Output (MW)
0800	0
0900	40
1000	90
1100	150
1200 noon	200
1300	200
1400	150
1500	90
1600	40
1700	0

DYNASTORE simulations included both a BESS and PV plant. A simulation was run without BESS, but with a PV plant, which gave values for savings afforded by PV alone. Because PV generation is used in the same manner in all cases, PV generation savings should be constant; thus they can be subtracted from the total savings. This was done in order to find the savings in operating costs afforded by BESS with and without PV generation.

The Monte Carlo (12 iteration) method was used for all of the DYNASTORE calculations and included the unscheduled failure of generating units.

Savings in Operating Costs Because of BESS Plus Renewable Sources

Savings in operating costs are shown in Table 4-2. These include savings due to BESS plus the renewable energy sources for the BESS applications of Spinning Reserve (SR) only, Load Leveling (LL) only, and Load Leveling with Spinning Reserve (LL+SR). Calculations for each of these applications were done for the years of 1995, 1996, and 1997 inclusive. BESS powers were 40, 100, 200, and 300 MW (columns), and BESS energy (duration) ranged from one, to four, and to eight hours (rows). The format is the same one used in the work documented in *Electric Utility Savings from BESS Applications, Final Report.*[4] To summarize, savings in operating costs for the years 1995 through 1997 range over the numbers shown below:

Application	Savings Range ($K/yr)
Spinning Reserve only	7900–11900
Load Leveling with Spinning Reserve	7500–13000
Load Leveling Only	6400–9000

For comparison, savings in operating costs due to BESS only are shown in Table 4-3. These data are from *Electric Utility Savings from BESS Applications, Final Report.*[4] Similarly, savings for years 1995 through 1997 range over the numbers shown below.

Application	Savings Range ($K/yr)
Spinning Reserve only	900–4800
Load Leveling with Spinning Reserve	700–7600
Load Leveling Only	200–4000

The difference between the two sets of numbers shown above is a result of the presence of a renewable generator, which is PV in this case. Note that the savings afforded by renewables appear to be, in most cases, greater than the savings afforded by BESS.

The above comparison of savings is somewhat misleading because savings afforded by renewables are compared with savings resulting from BESS. This does not provide a complete picture of savings afforded by BESS with and without the renewable sources, which is the question that UMR will attempt to answer through a more comprehensive analysis of the various DYNASTORE simulations performed.

PQ2000T/PM250 System Analysis

An initiative began in third quarter of FY98 to investigate specific issues related to testing conducted on the AC Battery/Omnion PQ2000T and PM250 utility-scale battery systems at the PG&E Modular Generation Test Facility (MGTF). The scope of the project includes the acquisition of existing data and analysis of that data to yield battery performance parameters. Anticipated results will be pertinent to determining the

4 M.D. Anderson, J.D. Stickley, Electric Utility Savings from BESS Applications, Final Report, Document No. Au-7834, August 31, 1998.

Table 4-2. Savings in Operating Costs Afforded by BESS and Renewable Generation Sources at KCPL (Simulation Method: Monte Carlo, 12 Iterations)

	Spinning Reserve Only 1995				Spinning Reserve Only 1996				Spinning Reserve Only 1997			
MW	40	100	200	300	40	100	200	300	40	100	200	300
1 hr	7900	9400	10400	10800	9800	11000	11500	11400	8000	9800	11800	11900
4 hr	7900	9400	10400	10800	9800	11000	11500	11400	8000	9800	11800	11900
8 hr	7900	9400	10400	10800	9800	11000	11500	11400	8000	9800	11800	11900
	Load Leveling w/Spinning Reserve 1995				Load Leveling w/Spinning Reserve 1996				Load Leveling w/Spinning Reserve 1997			
1 hr	7700	9400	10600	11100	8500	10900	11400	12200	7700	9500	11100	12100
4 hr	7700	9300	10500	11700	8400	10900	11300	12600	7600	8800	11000	12400
8 hr	7700	9400	10800	12100	8400	10900	11600	13000	7500	9000	11200	12700
	Load Leveling Only 1995				Load Leveling Only 1996				Load Leveling Only 1997			
1 hr	6400	6300	6600	6800	7200	7600	7600	7900	6400	6800	6800	7000
4 hr	6600	6800	7100	7300	7500	8200	8200	8500	6800	7800	8000	8300
8 hr	6700	7000	7700	7900	7600	8200	9000	9000	7000	7800	8400	8800

Table 4-3. Savings in Operating Costs Afforded by BESS Without Renewable Generation Sources at KCPL (Simulation Method: Monte Carlo, 12 Iterations)

	Spinning Reserve Only 1995				Spinning Reserve Only 1996				Spinning Reserve Only 1997			
MW	40	100	200	300	40	100	200	300	40	100	200	300
1 hr	1800	3000	3800	3600	900	3100	4800	4700	1600	2800	4400	4500
4 hr	1800	3000	3800	3600	900	3100	4800	4700	1600	2800	4400	4500
8 hr	1800	3000	3800	3600	900	3100	4800	4700	1600	2800	4400	4500
	Load Leveling w/Spinning Reserve 1995				Load Leveling w/Spinning Reserve 1996				Load Leveling w/Spinning Reserve 1997			
1 hr	1100	3300	4400	4900	700	3100	4000	4700	1700	2800	5000	5800
4 hr	2100	3600	4800	5700	1500	3100	4400	5800	1800	2800	5300	6800
8 hr	2100	3800	4900	6400	1600	3300	5000	6800	1800	3000	5600	7600
	Load Leveling Only 1995				Load Leveling Only 1996				Load Leveling Only 1997			
1 hr	600	600	900	1000	300	460	800	850	200	500	900	1200
4 hr	1000	1700	2400	3000	500	130	2100	2600	600	1200	2200	3000
8 hr	1500	2800	3200	4000	700	1700	3200	3900	1000	2000	3100	4000

adequacy of the battery management systems for the respective applications. Specific issues related to the PM250 testing program will result in the investigation of (1) the effect of temperature and temperature differentials on the performance of battery strings and the role of air flow design in mitigating string imbalance, (2) the effect of string imbalance in long-term degradation of the string. The study is expected to result in an attempt to determine a cost-effective means to characterize strings and predict and monitor failure modes for long battery strings.

The purpose of the PQ2000T study will be to document known issues based upon experience both in the field and during field testing at the PG&E MGTF. Specific issues to be investigated are (1) operational issues, such as dropout of sensitive loads during activation of off-line systems, (2) control issues, such as the method of reconnection of off-line systems after battery energy is spent, and behavior with motor loads, (3) economic assessment issues, such as how to treat energy loss in series-connected designs, (4) design issues, such as cable sizing for low voltage, temperature control, and noise, (5) outage mitigation alternatives, such as traditional and rotating UPSs and static switches with dual feed, (6) electrochemical battery performance and alternative storage technologies, (7) PM/PQ multi-mode compatibility, and (8) siting issues, such as utility interconnection, safety, and permitting.

Status

An RFQ was issued late in the second quarter of FY98 that resulted in the placement of a contract with Gridwise Engineering of Danville, California, to conduct the study. A review meeting was held at SNL in mid-May to determine the status of the project. Some difficulty was experienced in gaining access to the test data because of the deactivation of the PG&E Research and Development Department. However, arrangements were made to have the data released to SNL for the study. Two draft-reports, one from the PM250 study, and the other from the PQ2000T study, were received in the fourth quarter and are summarized below.

PM250 Data Analysis Report

This report documents the assessment of performance and design issues related to a 250-kW prototype battery energy storage system developed by Omnion Power Engineering Corporation and tested by Pacific Gas and Electric Company (PG&E). Performance and design issues include system performance, operator interface, and reliability. The report also discusses how to detect failed strings with strategically placed voltage measurements.

A prototype 250-kW BESS, developed by Omnion from 1991 through 1993 and tested in 1993 and 1994 by PG&E, provided the foundation for assessing system-level design issues related to grid-connected energy storage technologies.

A number of design issues are being explored based upon the experience of the prototype unit as related to system performance, operator interface, and reliability. In addition, a methodology was developed for detecting failed strings by using strategically located voltage measurements.

Some of the more significant system design issues are listed below:

Battery Technology. The test experience suggests that the lead-acid battery technology selected for demonstration in the prototype PM250, while produced in high volumes to ensure quality control and low initial cost, may not meet the cycling requirements of utility peak-shaving applications. Other battery designs and technologies promise enhanced life and higher energy density.

Advanced charging methodologies, made possible through enhanced voltage and current control of integrated-gate-bipolar transistor-power conditioning equipment, promise to extend battery service life and provide greater reliability.

Utility Interconnection. BESS designers must meet various protection requirements before connecting to the grid. Independent power producers and cogenerators generally meet these requirements through standard mechanical relays. Battery energy storage systems, however, may eliminate the cost of such relays by using the inherent detection and disconnect capabilities of modern solid-state power conditioning equipment. This approach is gradually gaining acceptance by utilities.

Dispatch Strategies. Load-following dispatch provides for meeting peak-load reduction with minimal battery hardware investment. However, the communications schemes required to implement load following in a utility environment are complex as illustrated in Figure 4-10, and implementation requires some customization for compatibility with existing supervisory control and data-acquisition infrastructure. The control interface is designed to simplify information presented to dispatch operators, and most of the control intelligence resides at the remote BESS.

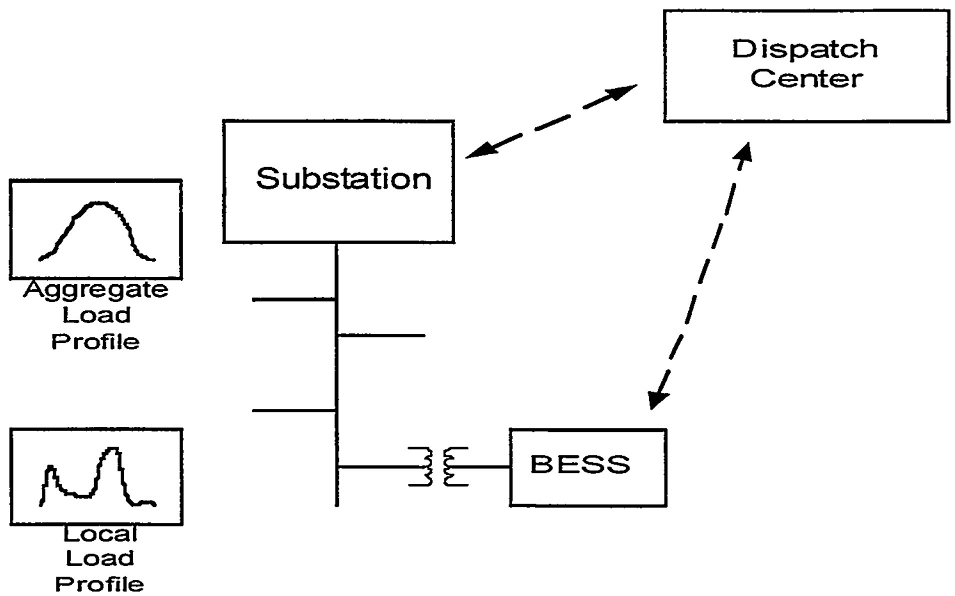


Figure 4-10. BESS Communications Scheme over Utility SCADA Network.

Thermal Regulation. During the course of testing, thermal gradients within the strings were identified as a potential cause of premature string failure. In response, the manufacturer modified the airflow design in order to reduce the variability among batteries. A high-capacity blower was added to the thermal regulation system, and baffling was introduced to direct air currents across batteries for enhanced, uniform cooling. As a result, thermal gradients within and between modules were significantly reduced.

Variations among battery temperatures are shown to correlate strongly with variability in end-of-discharge voltages. Strings with poor thermal regulation show a wide range of variability in voltage distributions in comparison with strings under more controlled thermal conditions.

In addition to voltage distributions, end-of-discharge voltage levels are shown to be strongly correlated with temperature. String segments that were isolated at higher temperatures displayed higher EOD voltages, and this contributed to overall string imbalance. Cell capacities were calculated by integrating the energy discharged over a high-rate test, and these were correlated with average battery discharge temperatures as shown in Figure 4-11.

Additional insights gained from these exercises came from the understanding that there are benefits in the ability to predict end of life, which is discussed below.

End-of-Life Prediction. Voltage measurements taken across a mid-string grounded resistor (a measure of voltage imbalance) were shown during testing to be a low-cost and simple means to characterize the health of the string. If such a methodology could be validated, it would eliminate the need to monitor individual battery voltages in the string.

This investigation shows that, while string imbalance is an indicator of cell failure, it is inadequate to detect failure when the effects of two shorted cells counterbalance each other on opposite sides of the string.

The analysis therefore develops an improved technique that uses quarter-string measurements in which battery voltages in four separate string segments are compared to the string average. This technique is shown to overcome the counterbalance problem and provide greater accuracy with the addition of only two voltage tap points. Figure 4-12 illustrates how the quarter-string technique detected a failure in string segment Q2.

The method can be used to schedule battery replacements and eliminate unnecessary downtime. It lowers the life-cycle cost of the BESS by maximizing battery string life and providing for coordinated replacements.

PQ2000 Data Analysis Report

This report documents the 1996 evaluation by PG&E of an advanced reserve power system capable of

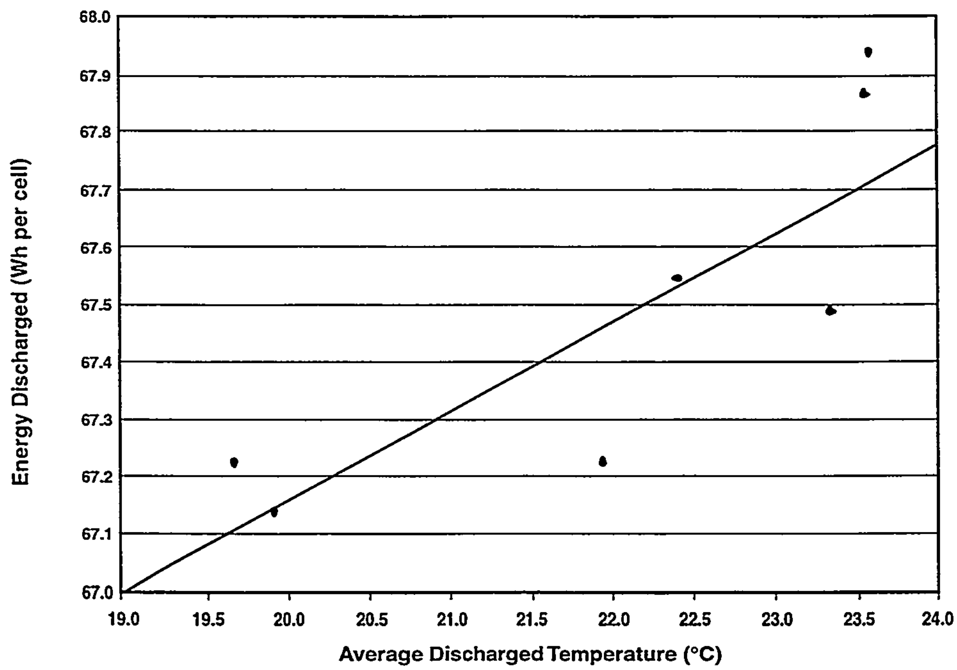


Figure 4-11. Correlation Between Discharge Temperatures and Cell Capacity.

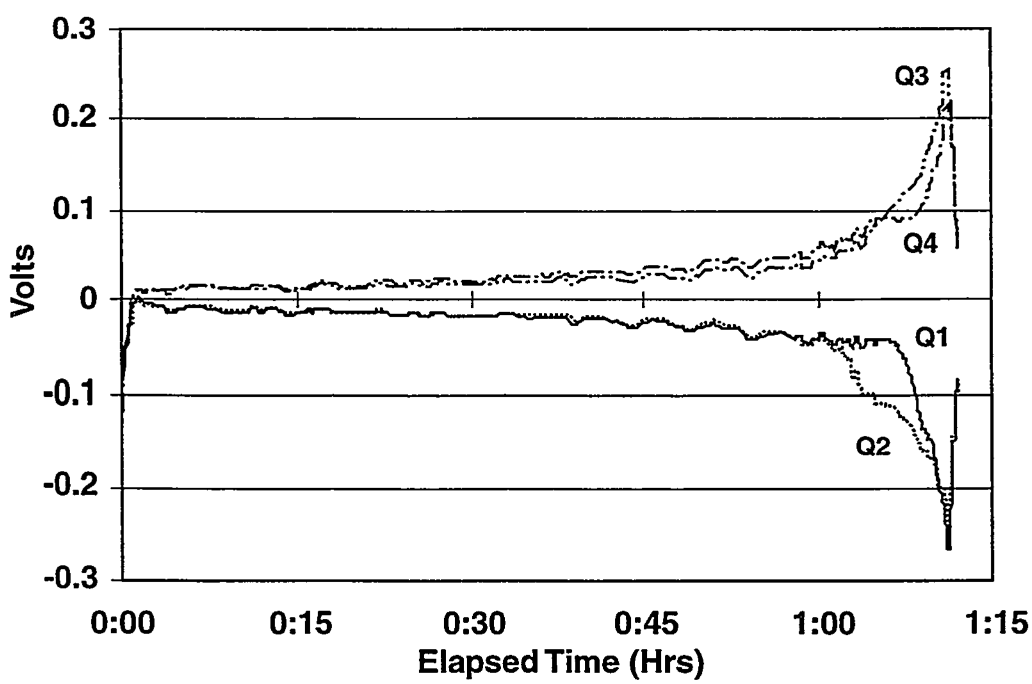


Figure 4-12. Sample Quarter-String Voltages Showing Failure in Segment Q2.

supporting 2 MW of load for 10 seconds. The system, developed under contract by AC Battery Corporation of East Troy, Wisconsin, contains features that enable industrial facilities to "ride through" momentary outages. The system can provide support until backup generation can be brought on line. The evaluation consisted of system performance tests that used a variety of load types and operating conditions. The tests, which included simulated utility outages and voltage sags, demonstrated that the system could provide continued power during utility outages and other disturbances and that it was compatible with a variety of load types found at industrial-class customer sites.

An advanced "off-line" reserve power system, capable of supporting 2 MW of load for 10 seconds, was evaluated in 1996 by PG&E at its test facility in San Ramon, California. The system was developed under contract to SNL by AC Battery Corporation.

The system featured a container housing 384 low maintenance lead-acid batteries, a high-speed static transfer switch, and control circuitry that enabled it to detect utility source disturbances and isolate and support critical customer electric loads. It enabled mission-critical loads at industrial customer facilities to "ride through" momentary outages, and it provided support until backup generation could be brought on line.

Testing was designed to demonstrate system performance using a variety of load types and operating conditions that would be found at actual customer sites in the field. These tests, summarized in Table 4-4, included operation at partial load and full load, and included simulated utility outages and voltage sags.

As shown in Figure 4-13, the facility provided for testing with resistive, reactive, rotating, capacitive, and electronic loads. Traces 1, 2, and 4 were taken at PQ Node No. 1, as shown in Figure 4-13. Traces 3 and 5 were taken at PQ Node No. 2, as shown in Figure 4-13.

The typical load transfer (Figure 4-14) shows the second trace of the utility voltage dropping to zero–a simulation of a utility outage caused by opening a line-side breaker (identified as Breaker 52-20) shown in Figure 4-13. The third trace shows that voltage at the load is supplied by the system after the utility is lost, and that only a minor change in the waveform at the moment of transfer is observed. The third and fourth traces represent utility- and load-side current waveforms, respectively. Figure 4-15 shows the corresponding waveforms as the utility is restored (by closing Breaker 52-20, thus simulating the return of utility power). The testing demonstrated that the system could be used to provide continuity of power during momentary utility outages and other disturbances, and that it was compatible with a variety of load types found at industrial-class customer sites.

A number of lessons were learned with respect to the design and application of off-line reserve power systems that used energy storage. Some of the issues that were identified led to on-site design modifications of the prototype itself, some led to improved designs for subsequent generations of the PQ2000, and some remain

Table 4-4. List of PQ2000 System Tests

Test	Dates 1996	Tests
1	April 15-24	Installation, interconnection, and protection
2	April 24-25	Grid synchronization/standby and no-load tests
3	June 6-July 29	Partial-load tests (500 kVA)
3.1		Passive resistive and reactive loads
3.2		Resistive and capacitive loads
3.3		Resistive and rotating machine loads
3.4		ASD, resistive, and various-single phase and electronic loads
4	August 6-21	Full-load tests (2 MVA)
4.1		Ten-second tests
4.2		Short-duration tests

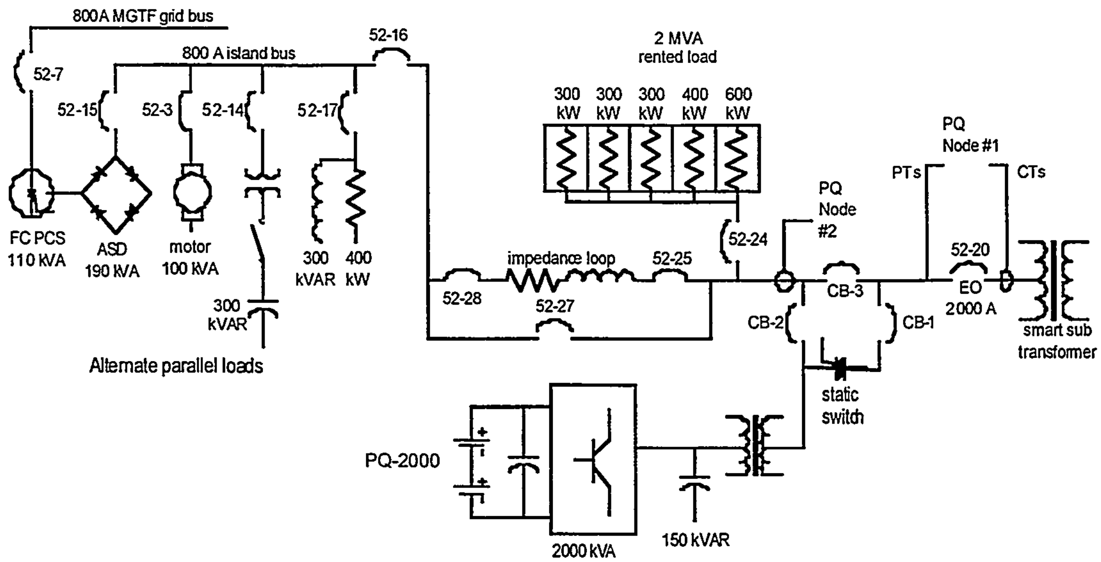


Figure 4-13. Test Facility Layout.

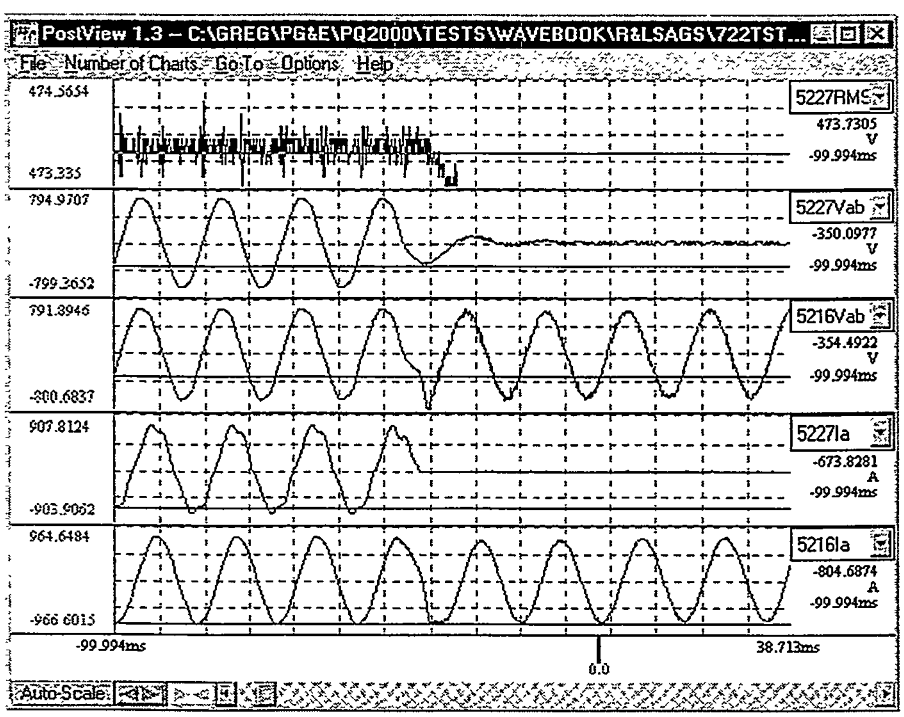


Figure 4-14. Load Transfer Upon Loss of Utility Source.

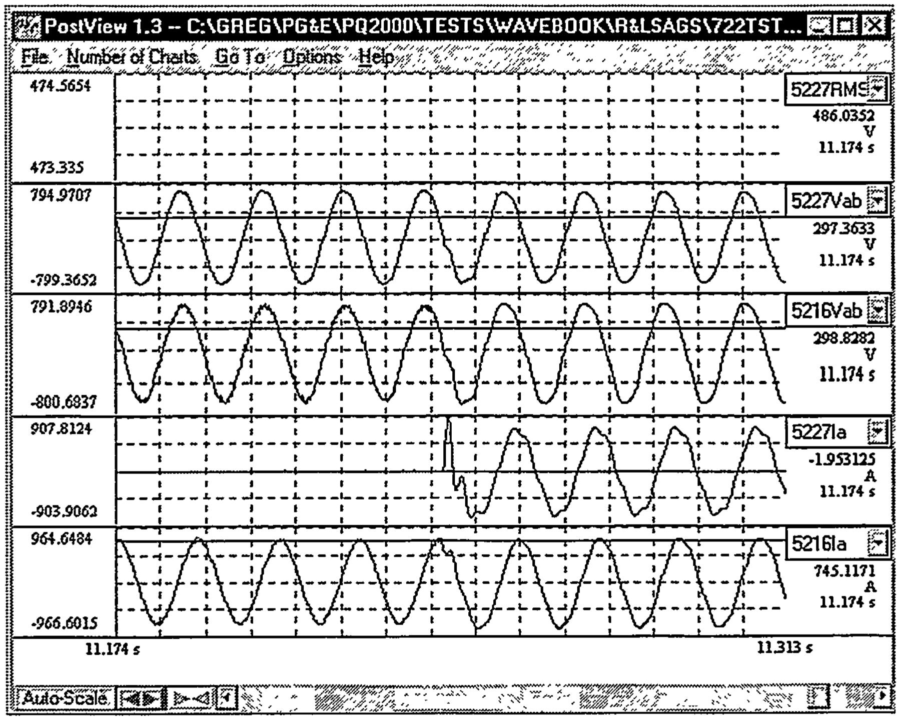


Figure 4-15. Restoration of Utility after Outage.

for the marketplace to resolve. The issues are outlined below:

- *System Design Ratings.* The optimal unit size ratings (in both power and time) remain elusive. Performance ratings are somewhat conservative because the field experience is still limited. True ratings would couple power and time (MW-seconds) because the design constraints are largely driven by component heating.
- *Reconnection Logic.* While the testing demonstrated that off-line designs can support momentary outages within the design performance envelope, it is not clear how the system should respond when the outage is approximately equal to the system's temporal rating. For example, if the utility is restored while discharging but it does not have adequate time to resynchronize, should the system transfer the load back to the utility out-of-phase in order to provide continuity of power?
- *Switch-Commutation Impacts.* Certain sensitive loads tripped off-line during the transition from the utility source because the transfer scheme requires a momentary overvoltage condition. While the magnitude of the overshoot has been reduced for subsequent designs, the manufacturer and customer should coordinate protection settings as a normal activity during installation to prevent unnecessary loss of load.
- *Synchronizing with Utility/Oscillations.* Some oscillations were observed during the resynchronization periods before the utility was restored. Such oscillations can generally be expected with loads that react dynamically to supply frequency variations.
- *Frequency Detection.* Under certain conditions, rotating loads were observed to generate back-emf on the load circuit during a utility outage. The presence of voltage initially confounded the utility-monitoring circuitry. To accommodate this situation, frequency detection was added to determine whether protective action is necessary.
- *Energy Loss Savings.* The off-line design approach results in a significant cost savings to the customer by eliminating demand and energy charges associated with rectification and inversion losses. These benefits are estimated to be

nearly \$300/kW, as much as one-third of the total capital cost.

- *Energy Management/Power Quality Multimode Operation.* While combining multiple economic benefits is attractive, various technical and cost hurdles will have to be overcome in a multimode design, particularly in the case of off-line systems that incorporate short-term component ratings.
- *Energy Storage Technology.* While the system revealed no shortcomings in the battery component, the utility power source industry in general faces enormous challenges with respect to systems requiring long-term storage. Advanced battery technologies promise greater reliability and consistency for these applications.

A number of follow-on research activities are suggested, given the current stage of power quality technology and the market requirements. These include integration of an off-line system with diesel generation, interconnection at medium voltage (e.g., 12 kV), assessment of alternative storage technologies, and operation of multiple off-line systems in parallel.

Flexible AC Transmission Systems with Storage

ESS staff presented a seminar and toured the laboratories at UMR's Electrical Engineering Department on March 26, 1998. The seminar, which reviewed the ESS Program and work at SNL, was attended by more than 30 faculty and students and generated many positive comments. UMR is Missouri's primary science and engineering university. It has more than 25 faculty members in the EE department alone with a specialty in power electronics for utility and energy applications. It has a newly enlarged and renovated facility devoted entirely to electrical engineering. The seminar was prompted by the analytical project that was being conducted at UMR for the ESS Program, which is using an EPRI model to calculate the generation cost benefits of energy storage for specific utilities. A potential follow-on activity was identified as a result of the seminar. One of the professors expressed interest in exploring the operational benefits of adding energy storage to Flexible AC Transmission Systems (FACTS). Laboratory-scale FACTS equipment, which can be used to determine the impact of energy storage, such as batteries, on the performance and benefits of systems, is available. This potential project will be pursued because of the opportunity for quantifying storage benefits with new FACTS technology now entering into utility service.

FACTS devices offer increased flexibility in decentralized control of transmission systems. As the vertically integrated utility structure is phased out, centralized control of bulk power systems will no longer be possible. Transmission providers will be forced to seek a means to gain local control to address a number of potential problems such as (1) uneven power flow through the system (loop flows), (2) transient and dynamic stability, (3) subsynchronous oscillations, and (4) dynamic overvoltages and under voltages. Several FACTS topologies have been proposed to mitigate these potential problems, but transmission service providers have been reluctant to install them, usually because of cost. The integration of an energy storage system into FACTS devices, however, may lead to a more economically feasible and flexible transmission controller that has greater appeal to transmission service providers.

Of the four types of potential problems affecting the transmission system listed above, only the voltage-related problems can be significantly mitigated by reactive power injection. The problems of uneven power flow, transient and dynamic stability, and sub-synchronous oscillations can be addressed only by active power control. Integrating an energy storage system into a FACTS device would provide active power capabilities and can give transmission service providers much needed flexibility for mitigating transmission-level power-flow problems.

Status

On June 30, 1998, an ESS staff member met with faculty and students at UMR's Electrical Engineering Department. The meeting focused on the benefits of adding energy storage to the FACTS. One laboratory houses two experimental FACTS devices that could be used to determine the impact of energy storage on the feasibility and performance of the system—a 1200-V, 50-A Static Synchronous Compensator (STATCOM) and a 1200-V, 110-A Thyristor Controlled Series Compensator (TCSC). The STATCOM could be used to determine the impact on energy storage on the feasibility and performance of the system. The STATCOM is a solid-state synchronous voltage source that can rapidly exchange real and reactive power with the distribution system without the use of bulk switched capacitors or reactors. By varying the amplitude and the phase angle of the output of the power converter, the STATCOM can control the terminal voltage and improve the system power factor by variable shunt reactive compensation. The STATCOM can provide automatic regulation of the distribution line voltage, correction of the distribution line power factor, and reduction in harmonics produced by nonlinear loads.

The STATCOM implemented in the laboratory at UMR consists of two six-step IGBT-based inverters coupled by means of a three-winding (Y-Δ to Δ) transformer. The device is housed in a cabinet that contains three racks. The top rack consists of voltage and current sensors that measure the output quantities of the transformer. The second and third racks consist of the two inverters. The transformer is in the base of the cabinet. A brief description of the racks follows. The electrical diagram of the laboratory setup is shown below in Figure 4-16.

The top rack consists of three voltage sensors and three current sensors. These sensors measure the output voltages and currents of the primary windings of the transformer. The top rack also has a DC power supply that generates +/- voltages.

Each inverter rack consists of a 1200-V, 50-Ah IGBT module. This module consists of six-diode-IGBT pairs. The module is mounted on a heat sink that has an exhaust fan. The IGBTs are switched by means of a specially designed gate-drive circuit board. This board, in addition to switching the IGBTs, includes logic circuitry for device protection as well as control of each IGBT in the module. The gate-drive board also requires six isolated 20 Vdc supplies to power the special gate drive chips required to switch the IGBTs. There is capacitor bank that is connected to the IGBT module. Each rack also has three current sensors (two of them used for IGBT output current measurement and one for capacitor current measurement) and one voltage sensor used to measure the capacitor voltage. Each rack has a front panel that provides inputs to charge the capacitor, outputs for IGBT module, inputs for the control switching signals for the transistors, and outputs for the sensors.

The STATCOM is controlled by a 120 MHz Pentium-based PC with a National Instruments Lab PC+ data acquisition board. This board has three eight-pin digital I/O ports, eight analog input channels and two analog output channels. The output of the sensors on the board is fed into the computer. A program then carries out the computation required to implement the control algorithm and generates the switching signals for the inverters. The STATCOM device will be investigated further.

The basic theory of TCSC operation, which is typically installed in series with a transmission line, is to control the impedance of the transmission line to either reduce or increase the power flow through that line. This is accomplished by switching the inductors at appropriate times to increase or decrease the impedance of the line. This can be accomplished without energy storage. Since the TCSC concept requires no energy

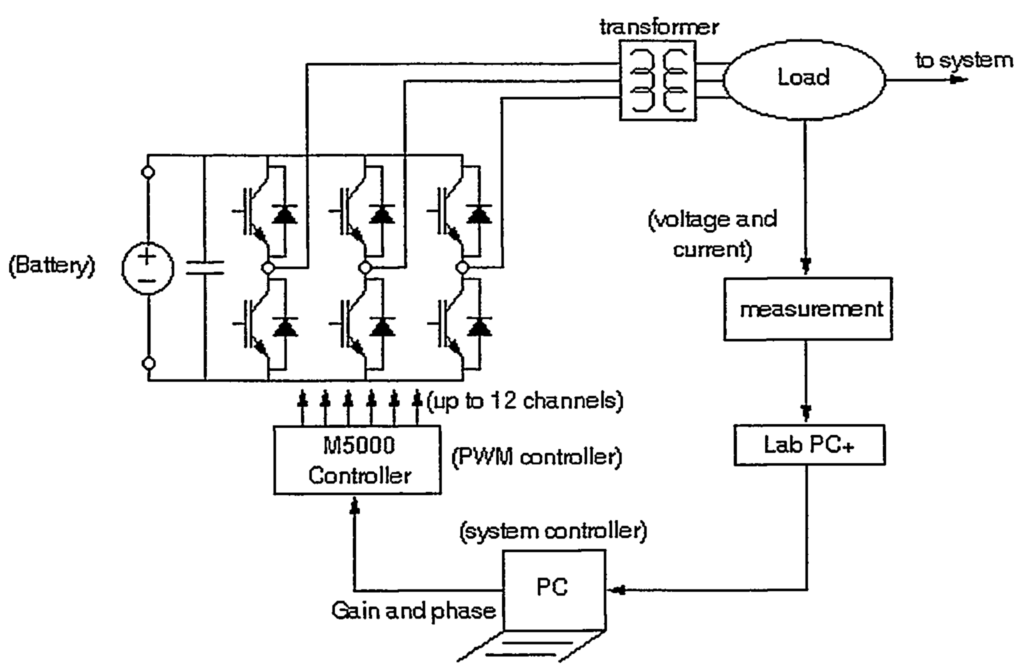


Figure 4-16. Electrical Diagram of the STATCOM Laboratory Setup at UMR.

storage to implement, no further pursuit of this technology will be preformed by SNL.

Opportunities Analysis

ESA Activities

In the first quarter of FY98, staff from the DOE/ESS Program and several contractors played key roles in the fall meeting of the ESA. An ESS Program staff member, as an elected member of the board, attended and had a leadership role in the ESA Board of Directors meeting. Attending were 52 participants representing industries and organizations including battery manufacturers, government and nonprofit organizations (e.g., Electric Power Research Institute, ILZRO), and electric utilities. ESS staff or contractors made seven presentations. A special dinner session was held at which the DOE representative presented an overview of the ESS Program. An open feedback session followed in which attendees discussed the needs of the storage community for technology development in a proposed ESS project on renewable generation and storage. A panel discussion, which included an SNL staff member, considered another new initiative, called the Storage 2000 project. A wide range of opinions were expressed on what Storage 2000 should be, but the one approach with which everyone agreed was the need for education of the industry on the benefits and characteristics of storage.

The theme of the meeting, "The Value of Energy Storage in a Restructured Utility Market," piqued the interest of energy providers and users, technology developers, and regulators. Meeting attendees gained insights from representatives from the UK, whose market is already restructured, and California, the state anticipated to be the first to commence full retail competition. Attendees also got answers to the question of how storage will fit into the restructured utility market.

In an effort to better identify PV battery testing and use issues, the ESA sponsored a PV Battery Storage Workshop at SOLTECH on April 27, 1998. The workshop format included seven panel members from the battery industry, PV system integrators, inverter manufacturers, and staff from SNL responding to questions from the audience. The meeting was informative and facilitated better communication between the battery manufacturers and the battery users in the field.

A staff member of SNL's PV Program, who was one of seven panel members at the workshop, expressed the view that batteries in PV systems need to be considered as part of the entire power system. PV system design and control needs should be sensitive to the specific requirements of the particular battery used. The SNL PV Program staff member was also of the opinion that many battery failures result from continued undercharging and incompatible system design and controller function. The solutions to the battery problems are better communication with battery manufacturers, better and more reliable system design and controllers, and better battery performance information for the PV application.

Panel members from the battery industry and ILZRO, indicated that they thought that the battery was not the source of the problems in PV systems. They suggested that the PV industry look toward better system design and control for the solution of battery problems. Two inverter manufacturers who served on the panel suggested better system integration. One also identified what he considered to be a more significant problem—the over-selling of PV technology. Examples of over-selling were that (1) a good warranty implies high reliability, (2) PV systems require little or no maintenance, (3) PV will extend the life of your generator, and (4) PV will work the first time the way you want it to without optimization.

In the second quarter, as ESA's continuing promotion of energy storage, the DOE/ESS Program Manager and the ESA Executive Director were guests of the National Public Radio (NPR) talk show Energy Matters, which is broadcast on NPR outlets as a weekly forum on energy issues. Technology review and policy issues were discussed for a lay audience.

In the third quarter, the ESA's spring meeting, April 7 through 8, 1998, was held in Phoenix, AZ. The focus was on customer service in competitive markets. More than 50 delegates from the energy technology, research, and end-use sectors attended. Because international speakers and members attended, meeting participants learned of effective and modernized customer service practices in the U.S. and abroad. The meeting was enhanced by the divergence of perspectives and interests represented. There were tours of the Salt River Project's transportable battery and the Arizona Public Service Company's STAR Project, which provided a first hand view of Arizona's cutting edge energy storage facilities.

In 1997, the ESS contracted the ESA to assist in developing communications products that included energy storage brochures with various themes. In the fourth quarter, the ESA published one brochure with a focus on power quality. In FY98, the ESA published three brochures for the ESS Program (see Appendix B).

Copies of these brochures can be obtained upon request from the ESS.

ILZRO RAPS Testing Activities

The ESS Program continues to coordinate with staff from ILZRO on several ongoing collaborative projects. Each project is being co-funded by DOE/ESS and by ILZRO, at varying levels of cost sharing ranging from 50-50 to 80-20, with ILZRO taking the lead in some projects and DOE/ESS in others. A continuing project with the objective of defining the international standard test cycle regimes for RAPS systems has now begun setting specific schedule goals for drafting test procedures and reviewing the procedures.

A new project involves a system feasibility study supported by ILZRO, the Solar Energy Industries Association, the government of Peru, the Energy Storage Association, and now the DOE/ESS Program. The study, in progress since September 1997, is determining the best sites and designs for RAPS systems in remote areas of Peru for village power. Preliminary design work has been completed and will be finalized with DOE/ESS participation.

Asia-Pacific Initiative

On October 17, 1997, ILZRO and SNL sponsored a seminar titled "An Improved Energy Storage for RAPS," in Jakarta, Indonesia. This seminar was held in conjunction with the Asia-Pacific Initiative meeting. The agenda encouraged participation by the renewables experts at the meeting who were interested in storage. Presentations were made on reliability of RAPS in field sites and on the components critical to RAPS, including batteries, wind turbines, PV, and power electronics.

Power electronics for RAPS were described as modifications of motor controllers and automotive power supplies, which already have huge commercial markets. Many apparently inexplicable power conversion system (PCS) failures in RAPS have occurred, some caused by a limited overload margin in the power electronics. A failure rate of 10 PPM, typical in automotive power supplies, is achievable for RAPS but will require a significant investment in development. Current costs are in the range of $4/VA, and an attainable cost goal is $1/VA.

ILZRO staff presented a proposal for a RAPS battery test laboratory. Test protocols representative of RAPS applications would be used with commercially available computer control, data acquisition, and charge/discharge equipment. Sample sizes would be selected to provide representative data. While testing could last a few years for any one design, the results could be used to validate battery types for RAPS duty.

During the conclusion of the seminar, several overall points were made. In order to fully develop test procedures for use by any laboratory, better definition of system sizes, storage duration, and application requirements are needed. An overriding concern was expressed that more battery data, specifications, and parameters are needed by the RAPS industry. Without this information, perhaps in an industry-standard format, RAPS system designers will continue having difficulty designing high-reliability, lower-cost products.

Intelec '97

From October 19 through 23, 1997, ESS Program staff attended Intelec '97, presented a technical paper, and staffed an exposition booth. Approximately 500 people from the telecommunication, vendor, and research industries attended this meeting, which was held in Melbourne, Australia.

The technical paper related to ESS activities that was presented was titled "Battery Evaluation Methods and Results for Stationary Applications." It emphasized VRLA battery evaluation for utility and renewable applications and SLI.

Because of conclusions in the ESS paper and the other papers presented, the battery industry is now recognizing the need for additional research on VRLA technology. The key areas identified for further development are charging characteristics, operating environment specifications, and manufacturing improvements for increased product uniformity and cost reduction. Lifetime and reliability under both float and cycling duty cycles are a concern to the user community at this time.

ILZRO/SNL RAPS Meeting

On October 24 through 25, 1997, ESS Program staff attended a workshop titled "Battery Test Cycles for RAPS Applications" in Brisbane, Australia. The Queensland State Department of Mines & Energy hosted the meeting, which was sponsored by ILZRO and SNL. About 45 people from industry, academia, and R&D laboratories attended.

The purpose of the meeting was to review the existing test methodology and results for batteries in RAPS systems. Based on that review, a key objective was to identify RAPS test regimes that could be standardized and applied at test labs worldwide. A secondary purpose was to consider the value of a specialized test facility for RAPS batteries.

During the discussion sessions, it was concluded that four RAPS applications suitable for standard test regimes were as follows:

1. Small, single home (100 Wh)
2. Small community (25 kWh)
3. Village with commercial load-hybrid with diesel (75 kWh)
4. Telecommunications (5 kWh)

It was also concluded that to accurately evaluate candidate RAPS products, complete systems would be tested. Battery tests could be derived from the system tests but would not be the focal point of a new test laboratory. The ultimate objective of the facility would be certification of complete systems.

In order to follow up on the definition of full descriptions of the test regimes and on the concept of establishing a RAPS system test facility, several committees were established, including a steering committee, with an ESS representative to oversee the feasibility of a test facility. A system test committee to fully define the four test regimes was established with a U.S. representative associated with the ESS Program serving as the chairperson.

In the third quarter, ESS Program staff visited ILZRO to review several of these collaborative projects. The projects reviewed included the International Energy Agency (IEA) Annex on Electrical Energy Storage, the VRLA battery reliability project, the RAPS initiative in Peru, and the RAPS system test definition activity. A highlight of the meeting included a review of the first draft of the RAPS test regimes document, and a plan was developed for its review by a working group and by standards panels.

By the fourth quarter, work by the RAPS Test Subcommittee was well underway. Members of the committee had encountered several obstacles, which led them to consider previously recommended design practices as a first step for developing test practices and certification testing standards. This process would help to resolve the many peripheral issues that would, if not resolved, mar any certification standard that was developed without the intervening steps. Based on this understanding, members of the committee used a recommended design practice published by Thermie (European Union Energy Program) for solar home systems (SHS) as a template to develop a document for RAPS. Industry review of the SHS standard identified areas where improvement is needed. Therefore, the authors of the draft RAPS report recommended that the design practice team make every effort to address the indicated changes in their new document as they develop it. The draft report is near completion. However, some issues delayed further work.

The first delay resulted from changes in the federal contracting process, which temporarily interrupted ESS Program funding to the project. ILZRO provided interim support to allow for the continuation of the work on the draft report and continuation of meetings with the test subcommittee members. Other events that occurred caused the test subcommittee chairperson to question whether the continued work on the draft report was the best possible approach to the goal of developing certification standards.

At least two draft design standards that could address the single-family home and village (without diesel) systems are at various stages of development (from IEC and IEEE). Another design standard for RAPS was developed by the South African Department of Energy and Mines and is being reviewed. While none of these documents exactly meet the needs of the RAPS certification standard, they may eliminate the need to draft a design practice report for multiple RAPS system types.

In addition to the discovery of the possible need for design practice documents, the subcommittee learned that the IEEE now has a new industry-sponsored, fast-track method to advance standards. Under this mechanism, industry consortia can sponsor standards development under the IEEE (using staff that industry elects to do the work). The process can go from concept to balloting in less than a year. Attempts to contact the coordinators of this industry program at IEEE are underway.

Industry Users Group

Status

The DOE/ESS Industry Users Group (IUG) met in Phoenix, Arizona, on April 9, 1998. The purpose of the meeting was to update IUG members on the 1998 ESS Program and to obtain feedback on how DOE can more effectively respond to the needs of the energy storage industry.

The ESS Program is evaluating T&D reliability, which includes grid stability, asset utilization, and increasing capacity factor, as opportunities resulting from restructuring. Improved reliability is a priority at

DOE, and storage, as a contributor to reliability, could give the ESS a more defined role at DOE. Such a focus, though, should not divert attention from what the program already has under way.

One of the suggestions made by the IUG was that in order to have nationwide impact, the program needed to look at end-users rather than individual technologies.

The ESS Program has continued to develop relationships with utilities but is also forging relationships with the telecommunications market, particularly Lucent Technologies, for power quality telecommunications applications. Through closer coordination with the DOE and SNL PV programs, the ESS Program has improved relations with the PV industry and will move to work more closely with the DOE Wind Program. The ESS's recent involvement in a remote power project in Peru will impact international markets.

Another suggestion that the IUG made was for the ESS Program to look at storage technologies that are on the horizon. This has been behind the ESS motivation to look not only at advanced batteries but also at SMES and flywheels. Although high-power inverter and power electronics are not fully developed technologies, they are strategic to all energy storage systems that are being investigated for integration and system-level issues by the ESS.

The DOE/ESS Program manager gave an ESS Program overview presentation and solicited input on a number of subjects from IUG members who provided their impressions of the program's plans, their perceptions of industry's needs for storage technology development, and an assessment of program performance. Comments from the participants follow.

Utility Restructuring

- Restructuring will result in more reliance on the market to stabilize and optimize the whole energy delivery system. Dispatch will depend on who buys what from whom. The market will create an operating efficiency that is relatively independent of the dispatch system. The areas of inefficiency and weakness should be identified and studied.
- The pressures of a competitive market offer opportunities for improving the operation and extending the life of the existing T&D infrastructure. The customer for such an application could be an independent system operator. The DOE should become familiar with EPRI on their technology roadmap project for the storage technologies that will have a role in the future utility market.

Power Quality

- There is a market for high quality power, but the size of that market is unclear. The market may be limited to the construction of new industrial facilities or major plant expansions. In an existing manufacturing plant, one or more UPS systems are likely to exist, and the plant manager may not want to make another purchase beyond existing capital costs. The benefits of installing a power quality system can only be proven if more attention is given to qualifying the costs of power quality events.
- The market may be driven by the demand for productivity and the desire to avoid power quality disturbances at all costs. If power quality events represent a large component of product costs for a particular customer, then solving those disturbances has a high benefit-to-cost ratio. Articulating how the solution reduces total production costs will be useful in selling the technology.

Technology Introduction

- Industry wants to know how reliable systems are before buying them. A utility may reduce some of the risk by offering guarantees to the customer, but until there is more market experience, industry will not buy a new technology. Energy service companies may use "premium pricing" as a method to market power quality (and alter their rates to properly reflect quality power). However, this would involve filing a tariff (a lengthy process) and fixing a price, thereby reducing the company's flexibility and competitive advantage.
- For a new technology to be successfully introduced to the market, it must be cost-effective and introduced through an efficient channel. At one time, utilities were the distribution channel for a technology like energy storage, but that is not likely after restructuring. The ESS Program should examine probable market penetration paths, including coordination with the distribution channels for renewable energy technologies.
- The ESS should support projects that focus on the integration of storage technologies into workable systems. Grid-connected applications

for storage will be more demanding in terms of life-cycle costs and performance.

- On the energy supply side, the more motors that are running (rotating mass), the more stable the system is when faced with short-term dips in voltage. Some of the new supply-side solutions, in particular renewables, do not have these characteristics and therefore may increase system instability. Storage can help stabilize the supply-side. As these other supply-side technologies gain in importance, there may be a role for storage to stabilize the system.

- Consistent with its customer focus, the ESS should concentrate on the technology that is closest to market readiness, demonstrate success to customers, and get additional funding to develop other technologies. At some point, it may be necessary to go forward and create market pull rather than perfecting the technology.

Emerging Technologies

- There is a tremendous need for someone to track emerging technologies. One meeting participant, San Diego Gas & Electric is looking at storage to stabilize the grid for the scenario of daytime electric car recharging. Which storage technologies would be appropriate in such applications?

- The ESS needs to look at the competing technologies. By preparing cost comparisons, it might be possible to make a case for storage based on long-term cost advantages.

- The telecommunications industry has expressed some concern about the lead-acid batteries and will support flywheels as that technology emerges. Nickel-metal hydride batteries are an alternative to lead-acid and have a higher energy density, but at a much greater cost. At issue is whether the benefits of nickel-metal hydride batteries outweigh its higher costs.

Program Focus

- The ESS Program's R&D emphasis on a three-to-five-year payback window is fair but it represents a longer time frame than most private industry will consider. The five-year payback needs to be shortened. The value of storage in an application will be customer-specific.

- The ESS should aim for projects that provide more complete solutions for niche problems (problems that are unique to particular customers) rather than funding projects that simply fill in the gaps in other programs' efforts to solve a problem. The ESS should look to leverage other programs by providing direction and complementary projects; be aggressive in pointing out which gaps storage is filling; and work to further expand its constituency.

- Case studies to demonstrate that a product performs its intended function will help to reduce perceived risk. The program should give more attention to those applications for which technologies delivered more benefits than expected.

- PV manufacturers, integrators, and customers should share their most recent experience with integrated systems to assess issues such as cost and reliability. This information can be used to educate people on the performance of integrated systems. There should be a forum created for exchanging experience and ideas.

Program Budget

- The ESS Program structure with three major projects, one in each market area, is a good middle ground. The markets for reliability and productivity are huge, but they cannot be the only drivers for the program. The renewable market is still emerging and still does not have a lot of expertise.

- For projects with smaller funding levels, select those with the highest risks and longest terms that are not funded by other sources. The funding decisions should be based on what that program's customers say.

- The ESS should have one high-profile project for visibility. A winner should be picked and funded rather than spreading funds among several projects. If the objective is to defend the budget, then it is safer to stay with the low-profile, low-risk project. But the interest of the constituency should be maintained by continuing those activities in which the program is doing well.

- Power quality and productivity are not mutually exclusive. Productivity includes power quality. Nonetheless, productivity should be distinguished from power quality.

- The productivity focus should be on energy services, energy delivery, and energy management.

Program Performance

- The ESS is to be complemented for getting industry input through the IUG. All DOE programs should be using this format.
- The ESS appears to be in a good position based on the presentation and views expressed.

Technology Assessments

One of the goals of the ESS Program is to characterize and identify the challenges for advanced energy storage components (flywheels, SMES, etc.) to set the stage for component development projects in coming years. The DOE made a commitment to participate in the IEA Energy Conservation through Energy Storage Implementing Agreement through the Electrical Energy Storage Annex IX project, which includes performing a comprehensive state-of-the-art review of electrical energy storage technologies worldwide. Other projects are assessing the state of the art of PCS, SMES, and flywheel technologies.

International Energy Agency Annex IX Project Activities

The DOE Office of Power Technologies (OPT) is a signatory to the Implementing Agreement for the IEA program called Research and Development on Energy Conservation through Energy Storage. In June 1996, the DOE OUT made a commitment to participate in the recently created Electrical Energy Storage Annex IX by pledging funding in support of its activities. The primary benefits of U.S. participation are increased awareness of analytical and technical developments in storage in the international arena, identification of projects of mutual interest, and the ability to assess the competitive position and market opportunities for energy storage systems in overseas markets. ILZRO is also interested in these objectives and has contributed funding for U.S. participation in Annex IX.

DOE/OPT and ILZRO have designated the SNL ESS Program as their representative for Annex IX activities. This responsibility requires attending participating agent and experts meetings in the U.S. and abroad, coordinating U.S. representation by experts for the various storage technologies, identifying projects of common interest to the participants, and supporting the implementation of these projects.

Throughout FY97 and FY98, both participating agent and experts meetings were held in various locations in the U.S. and abroad. This series of meetings has succeeded in establishing broad dialogue and promoting the formal exchange of ideas among the U.S. storage community and its counterparts in Europe and Canada. In addition to these meetings, Phase 1 included the development of two computer models intended as first-level screening tools for BESS applications. The development of the two models, a techno-economic, cost/benefit model and an energy/emissions model, was completed in FY97. These screening models will help identify rigorous BESS applications as part of Phase 2 objectives.

Status

Phase 2 has been initiated and will follow the successful work program that was undertaken in Phase 1. Phase 2 aims to move storage systems toward their true commercial market implementation. Such a move will represent a significant advance in the application of storage systems, permitting their benefits in terms of enhanced integration of renewables, energy/emissions savings, power quality, quality of supply, and others to be realized.

Specific objectives of the Phase 2 work program may be summarized as follows:

- To be strongly driven by applications and end-user needs.
- To build on the foundation of the Phase 1 work program.
- To move storage systems/applications closer to market realization.
- To provide selected opportunities to explore new themes and concepts, as appropriate.
- To develop the Annex membership base, both in terms of the range of participating countries and also in terms of the individual national participants.
- To build upon the success of the 1998 EESAT conference as the major dissemination vehicle for storage applications and technologies and to establish a framework for holding such conferences on a bi-annual basis.

The Annex IX Phase 2 work program comprises the following six subtasks:

Subtask 1: The execution and delivery of a series of authoritative application case studies, suitable for widespread dissemination.

Subtask 2: The delivery of two fully costed project definitions, to be used as the basis for any follow-on applications demonstration schemes.

Subtask 3: The development and delivery of a storage system network applications model.

Subtask 4: The ongoing collation and dissemination of applications and systems information and data.

Subtask 5: The development of a series of complementary R&D program activities, to feed into the parent Annex IX Phase 2 work program.

Subtask 6: Project management and reporting.

Work in the third and fourth quarters focussed primarily on the initial Phase 2 activities, associated with the retrospective applications case studies, the forward-looking project definitions, the collation/dissemination of information, and the identification and initiation of complementary R&D outlined in Subtasks 1, 2, 4, and 5 of the Annex IX Phase 2 proposal.

The progress made in Subtasks 1, 2, and 5 is summarized below.

Subtask 1: Applications Case Studies—A full digest of candidate systems, for detailed case study analysis, was prepared and circulated to individual national participants. Such candidate case studies include a full range of applications and also span the majority of the technologies themselves, of current interest.

The case studies will be structured with an applications focus, the primary applications being:

- power quality/quality of supply/voltage regulation
- peak shaving/Demand Side Management/distribution capacity deferrals
- integration with renewables
- load leveling/frequency regulation/stability

Two primary mechanisms will be employed for accumulating the data on existing storage schemes. First, information will be gathered from sources in the public domain, such as conference papers, manufacturer's publicity material, magazine articles, etc. It was felt, however, that the information available in the public domain would not be sufficiently balanced to use as the sole basis for defining a future storage system proposal. It was therefore decided that the second mechanism to be employed would be a questionnaire, which would be sent to the operators of existing storage systems to probe deeper into the practical issues related to putting together a demonstration program. A copy of the questionnaire is contained in Appendix C. The first draft of the questionnaire was reviewed at the Participating Agents meeting in Atlanta, and a revised version was sent out to the participating agents shortly thereafter. The plan now is for the participating agents to circulate the revised questionnaire to known operators of energy storage systems within their own countries.

The introduction of the questionnaire has caused some delay in the progress for Subtask 1, partly because of the difficulties experienced in communicating with the participating agents (i.e., not receiving e-mail messages or not responding to e-mail). The delay can also be attributed to some of the Participating Agents, who do not realize that although EA Technology as the Operating Agent has responsibility for the work program, Participating Agents also have responsibility for coordinating the activities within their own country.

Subtask 2: Project Definitions—A specific aim of the present Phase 2 work program is to position the program so as to enable the initiation of two applications demonstration schemes for realization for the year 2000 and beyond. For initial planning purposes it may be assumed that such schemes will be located in Europe and North America.

A letter, structured as a prequalification document, was circulated to alert potential suppliers of electrical energy storage systems to the requirements for such systems and to provide them with a formal mechanism for the registration of their interest in the project. The assessment, identification, and definition of such demonstration schemes will take place in a number of stages, outlined in Table 4-5.

Having received the prequalification material from interested parties, EA Technology will then begin the various submissions in relation to the applications of interest. It is anticipated that those systems on the short list for more detailed appraisals will be identified and the various parties notified accordingly. Following this, and in conjunction with the Annex participants, the two lead applications demonstration schemes will be selected by the end of January 1999 and the various interested parties advised. Appropriate funding partnerships will then be developed with a view to realizing the chosen schemes for the year 2000 and beyond.

Subtask 5: Identification and Initiation of Complementary R&D Program Activities—The groundwork to launch this initiative began in Session 14 (The Way Forward and Implementation) of the EESAT '98 Conference. See Appendix D for a copy of the proforma.

Table 4-5. Scheduled Stages for the Applications Demonstration Schemes

Date	Activity
September 1998	Alert suppliers to requirements
By October 23, 1998	Receive prequalification material
By November 13, 1998	Make initial assessment of supply options/ranking of potential host sites
By December 18, 1998	Complete first pass project definitions; promulgate Annex participants
By January 29, 1999	Select two lead application demonstration scheme candidates
By December 31, 1999	Format funding consortia, for enactment of schemes
From January 2000 on	Initiate applications demonstration schemes

The strategic objectives of Annex IX Phase 2 work were presented at the EESAT '98 Storage Conference held in Chester, UK, in June 1998. One of the stated objectives was to expand the participant base from the sound foundation of the six-member countries that participated in Phase 1. Encouraging moves in this direction have taken place, with two additional countries joining Phase 2 of Annex IX, making a total of eight countries demonstrating committed support. Most of the Phase 1 participants returned their signed agreements promptly. However, two agreements were not received until the beginning of June, just before EESAT '98. This caused the Operating Agent to have to hold back slightly on Subtasks 1 and 2 activities. The participation of these individual countries is described below.

- Canada
- Finland
- Germany
- Netherlands
- Spain
- Sweden
- United Kingdom
- United States

Canada. The Canadian utility Hydro Quebec has formally committed to the Phase 2 work program and therefore discharges the role of the designated Canadian participating agent. Ontario Hydro, who had previously participated in Phase 1, is at present still unable to recommit because of internal financial constraints. The Canadian Executive Committee delegate is continuing to investigate where to find matching funds to satisfy the full Canadian participation to the Annex.

Finland. Finland is the first of the new countries to join the Annex. Formal participation is through the Helsinki University of Technology, with a national team comprised of representatives from the power utility IVO, the technical university and the governmental laboratory, VTT Energy.

Germany. The German technology services company EUS has formally committed to the Phase 2 work program with the support of their national team.

Netherlands. The Netherlands Agency for Energy and the Environment provides the Dutch contribution toward the operating agent budget, with KEMA T&D continuing to discharge the role of the Netherlands participating agent.

Spain. The Spanish utility Iberdrola is the second of the new countries to join the Annex. Formal contractual agreements have now been completed.

Sweden. Swedish participation continues to be through the offices of Elforsk, the R&D company of the Swedish power utilities.

United Kingdom. EA Technology continues in its role as the UK participating agent and has pulled together a reconstituted national team of 12 organizations, with further companies currently considering joining.

United States. The DOE and ILZRO provide the U.S. contribution toward the operating agent budget, while SNL/ESS continues to perform the role of the designated U.S. participating agent. In addition, the ESA forms a very effective interface with the predominant utility and industry groups and has developed a good working relationship with EA Technology, as Annex IX Operating Agent.

PCS Assessment Project

In FY97, the ESS Program began evaluating state-of-the-art PCS technologies. FY98 included assessing the design architecture of and providing cost structures for the various types of PCSs required for storage utility applications. Also, the report generated from these evaluations outlined the state-of-the-art PCS when integrated with various storage technologies, e.g., batteries, flywheels, SMES, and supercapacitors. The resulting report also identified standards relevant to PCS use within the utility industry. Ultimately, the study includes recommendations for an R&D plan on PCS component and subsystem development.

The likely objective of possible future PCS development will be to advance a multitechnology, low-cost, and low-footprint PCS. At present, PCS cost is approximately \$200 to \$300/kW for utility-grid-connected systems and constitutes about 30% of the overall system costs. GNB and GE have made remarkable progress in improving the PCS design and functionality, as demonstrated by the Vernon facility PCS, but cost and footprint are still not optimized. As new storage technologies are integrated into energy storage systems, it will be desirable to have a single PCS that can serve the needs of batteries, flywheels, and SMES, as well as renewable generation sources. The ultimate goal of this activity will be to develop a PCS that can serve all of these technologies, that has an installed cost of approximately \$80/kW for utility-grid-connected systems, and that has a footprint one-third the size of existing PCS designs.

Status

Based on discussions with representatives from industry, academia, and the national laboratories, and extensive analysis, a strategy for an R&D plan on PCS component and subsystem development has been established. This strategy and the findings from this analysis were documented in the SNL Report *Summary of State-of-the-art Power Conversion systems for Energy Storage Applications*, SAND98-2019, published in September 1998. The report provides a general overview of PCS technology, a description of several state-of-the-art PCSs and how they are used in specific applications, and a summary of four basic configurations of PCSs used in energy storage applications. The report also provides a discussion of PCS costs and potential cost reductions, and a summary of the standards and codes relevant to the technology, as well as recommendations for future research and development, which are summarized below.

- Explore near-term development of higher-rated power semiconductor switches.
- Explore the availability of cheaper, lighter, and smaller magnetics and explore the possibility of reducing the cost of filter inductors and line-frequency transformers.
- Research advances in PCS controllers for hybrid energy storage systems, including reducing software development time and cost.
- Encourage industry R&D in advanced converter concepts specifically for energy storage applications.
- Support the development of standards and codes specifically related to the PCS used with energy storage systems and renewables.

Publishing the PCS report represents the end of the PCS Assessment Project and the beginning of several initiatives that are the direct result of these activities.

In pursuit of the outlined recommendations, two contracts were placed in the third quarter of FY98. One contract was placed with Virginia Polytechnic Institute (Virginia Tech) and the other with EECI.

ETO Switch Development for PCS

The contract with Virginia Tech was placed on April 1, 1998, and development of a high-power semiconductor switch began. The PCS, a vital part of the energy storage system, is used to interface between the storage component (battery, SMES, FES, etc.) and the generation and T&D equipment. At the heart of the PCS are the topological connections of high-power semiconductor devices. To meet the demand of these devices, efforts were made in the past few years to improve the gate turn-off thyristor (GTO) device. The emitter turn-off thyristor (ETO) is a type of GTO device that could substantially benefit high-power applications. Based on the mature technology of the GTO and the power capability of the metal-oxide-semiconductor field effect transistor (MOSFET), the ETO could provide a low cost, superior solution to MW applications. The contract called for the design, fabrication, and prototype testing of the high-power semiconductor switch (ETO) for use in a high-power PCS. Generating a quarterly and final report was also included in the contract.

After the ETO development contract was placed, SNL staff participated on April 15, 1998, in a project kickoff meeting at the Virginia Tech in Blacksburg, Virginia. Virginia Tech faculty provided an overview of their power electronics program, also known as the Virginia Power Electronics Center (VPEC). The center gives students the opportunity to gain hands-on experience through sponsored research. VPEC's research covers the areas of power semiconductor devices, power integrated circuits, magnetics, inverters, converters, power-processing systems, power quality, modeling, control, and distributed power. The VPEC team consists of five core and nine affiliate faculty members, two research associates, six support staff members, 60 graduates students, and 10 visiting scholars and professors from industry and academia. The center is involved in all aspects of power electronics research and development, from power supplies and motor drives, to space and industrial power systems. Faculty expertise includes high-frequency power conversion, modeling, analysis, motor drives, electronic devices, MOS-gated power switching devices, and high-power applications. An overview of the energy storage program at SNL was also presented at this meeting.

Status

The Virginia Tech work is one of the resulting initiatives and is categorized by the ESS as the ETO Switch Development for PCS Project. The VPEC Team delivered three major reports (listed below) along with an ETO prototype in the fourth quarter of FY98. Summaries of the reports are discussed below.

1. Preliminary Design Report
2. Final design and Test Report
3. ETO Analysis Report

Report No. 1—Preliminary Design Report

The preliminary design report reviews some previous ETO research and basic design considerations, and the new design including material selection and layout. In the third quarter, VPEC ordered GTOs and MOSFETS for this project. VPEC's ETO tester was also upgraded from a 2-kA to 6-kA capability in the fourth quarter. For the purpose of clarity, it is important to provide background information on the ETO as well as the preliminary results of the report.

The ETO is a hybrid semiconductor device that combines the advantages of the GTO device and the MOSFET device, having the GTO's high current/voltage ratings and the MOSFET's easy control features. In the past year, several kinds of ETO samples have been developed and tested at VPEC. Those samples included 2-kA/4.5-kV-, 1.2-kA/1.3-kV-, and 1-kA/4-kV-rated devices. These samples demonstrated the basic features expected in an ETO, hence the promising overall performance that is strongly competitive in very high-power applications.

The objective of the ETO development project is to fabricate and demonstrate the most powerful MOS semiconductor switch in the world, rated at 4-6 kA/4-6 kV. To successfully fabricate these devices, layout, design, and packaging technique are critical. The design of the ETO4045 was based on the previous design of ETO1040S. A photo of 1-kA/4-kV ETO1040S is shown in Figure 4-17. The disc layout of the ETO4045 (4.0-kA/4.5-kV) device is similar to that of the ETO1040S. The final result of the disc layout is shown in Figure 4-18 and the cross-section layout is shown in Figure 4-19.

Report No. 2—Final Design and Testing Report

During the fourth quarter, the proposed 4-kA/6-kV ETO device was designed, fabricated and tested. The device demonstrated all the basic features that the ETO theory predicted. These include voltage-control turn-off, faster switching speed, and smaller switching loss. With the development of the device, the ETO tester has also been upgraded to a higher pulse-power level and is now capable of testing at 6 kA and 6 kV. Report No. 2 presents the final design of the ETO and the preliminary testing results.

Two types of GTOs were used to make the 4-kA ETO. One is a GTO made by Mitel Semiconductor, a 4.5- kV device with maximum turn-off current of 4 kA. Another one is a GTO made by Toshiba, a 6-kV device with a maximum turn-off current of 4 kA. Both of these GTOs have the same diameter, package dimension and current rating. Because the voltage does not affect the design of the emitter and the gate MOSFET switches, a single ETO MOSFET disc design was made that was used for the ETO4045 (4.0-kA and 4.5-kV device) and ETO4060 (4.0-kA and 6.0-kV device) design. One of the key design features of this ETO is in the reduction of stray inductance in the circuit. To minimize stray inductance and maximize performance, a circular design was established as shown in Figure 4-20. The final design required 63 MOSFETS to optimize the ETO performance. Figures 4-20 and 4-21 show the ETO4060 final layout design and a photograph of the ETO4060 and its gate driver.

A comparison was made between the Toshiba GTO and ETO4060 devices. Table 4-6 lists four basic switching times for both the GTO and ETO.

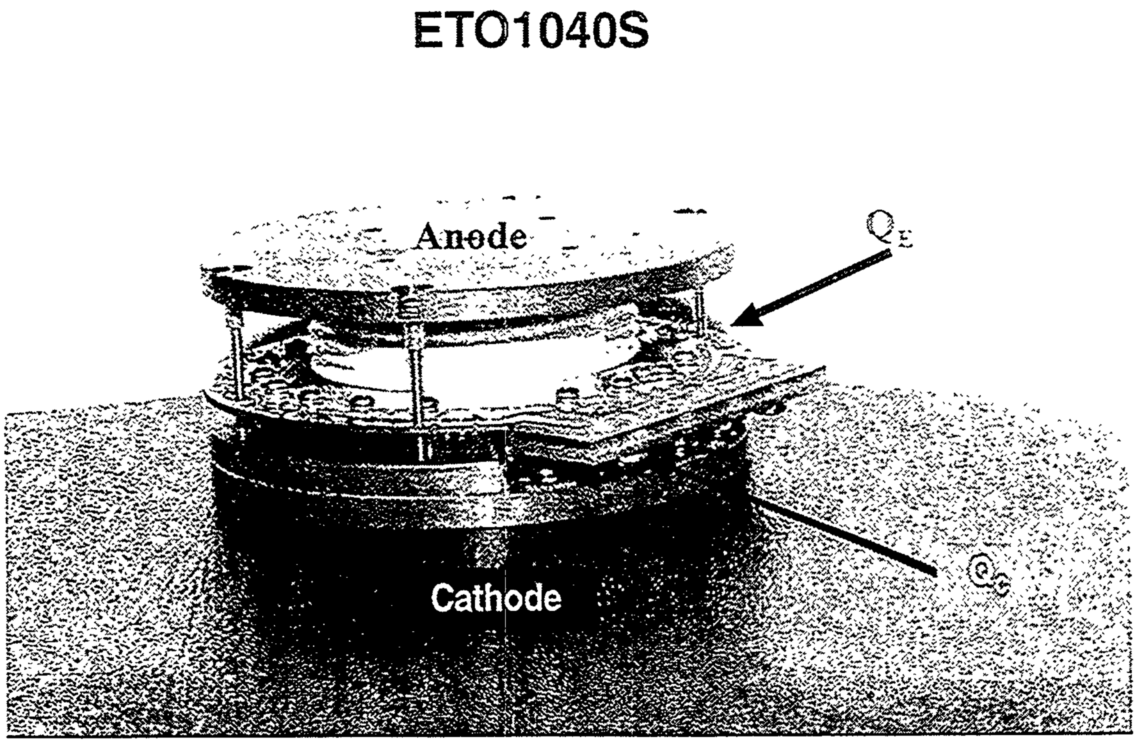


Figure 4-17. Photograph of 1-kA/4-kV ETO1040S.

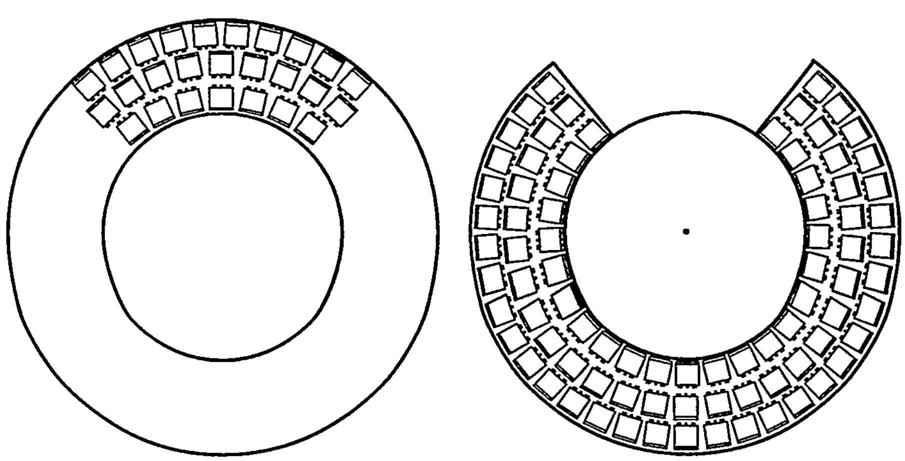


Figure 4-18. Upper and Lower Disc Layout of ETO4045 (GTO located in center).

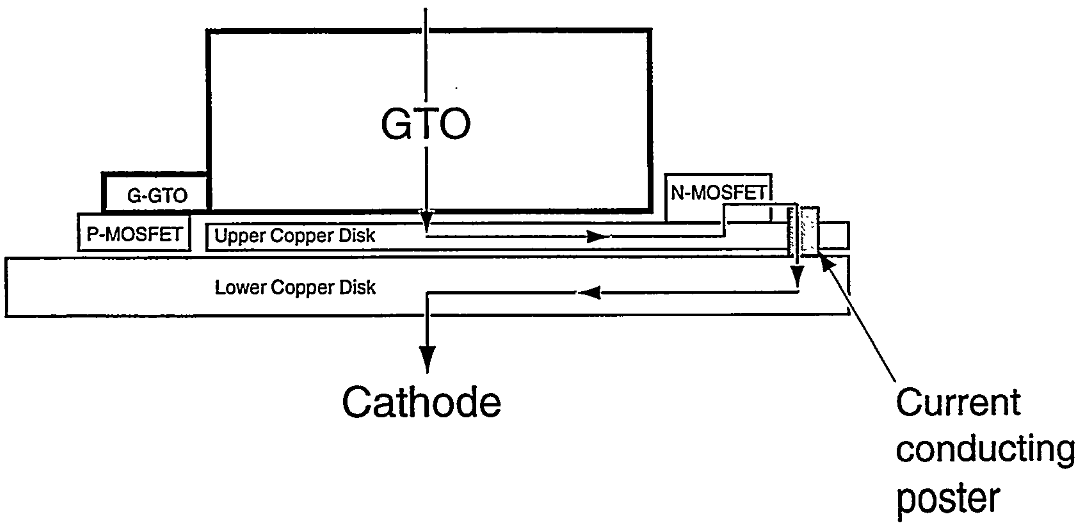


Figure 4-19. The Cross-Sectional Layout of ETO4045.

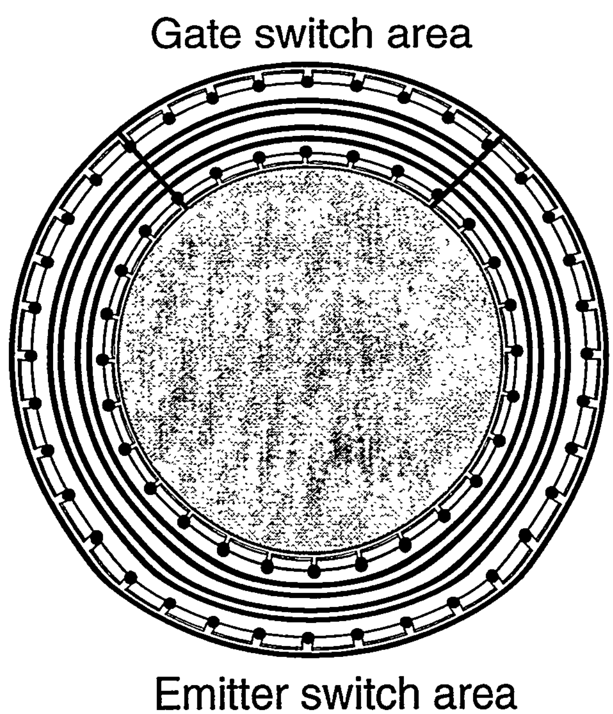


Figure 4-20. ETO4060 Layout Design.

The conclusions on the GTO and ETO comparison follow:

- ETO greatly reduces the turn-off storage time from 25 to 1.5 msec.
- ETO has better current-fall time from 2 to 0.7 msec.
- ETO has better turn-on voltage fall time from 4.3 to 1 msec.
- ETO has better (both turn-on/off) switching loss.

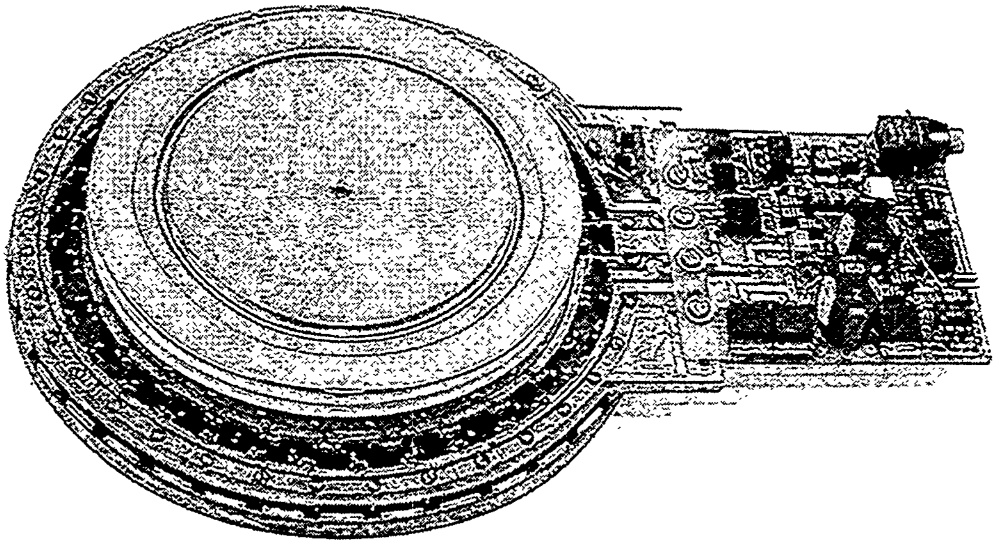


Figure 4-21. 4-kA/6-kV ETO4060 and its Gate Driver (GTO by Toshiba).

Table 4-6. Switching Parameters Comparison for Both GTO and ETO

Device Type	Turn-off storage time t_s (μsec)[1]	Turn-off fall time t_f (μsec)[2]	Turn-on delay time t_d (μsec)[3]	Turn-on voltage fall time t_{fv} (μsec)[4]
GTO SG4000JX26	25	2	0.7	4.3
ETO ETO4060	1.5	0.7	0.7	1

1 t_s : time interval between a specified point at the beginning of the gate pulse and the instant when the current has dropped to 0.9 of its initial value.
2 t_f : time interval between the instant when the current has dropped from 0.9 of the initial current, and the instant when it drops to 0.1 of its initial current.
3 t_d : time interval between a specified point at the beginning of the gate pulse and the instant when the voltage has dropped to 0.9 of its initial value.
4 t_{fv} : time interval between the instant when the voltage has dropped from a 0.9 of the initial voltage, and the instant when it drops to 0.1 of its initial voltage.

Based on the test results, and comparison with the GTO, the following was concluded for the ETO4060 device:

- ETO4060 has voltage-controlled turn-off capability.
- Unity turn-off gain exists up to 6 kA.
- Turn-off storage time is significantly less than that of GTOs.
- Turn-off current fall time is also less.
- Turn-on voltage fall time is less.
- Overall switching loss is lower.

Report No. 3—ETO Analysis Report

In the third report, additional parameters of the ETO and GTO were gathered, ETO power conversion in terms of cost and size was analyzed, and a list of industry partners interested in the ETO device was generated. For the purpose of clarity, background information is provided along with key highlights and a summary of results.

The semiconductor switch is the core of the power-conversion system. The system's architecture is generally based on the performance of the main switch. The operating frequency, the system protection strategy, and the system-control strategy are determined over a wide range by the switch instead of the requirement of the system. The preliminary findings of the analysis of the ETO device indicate that the ETO can benefit the power conversion system in several ways: higher operating frequency, better protection, smaller gate driver, and smaller snubber circuits. Snubber circuits are electronics circuits that protect the semiconductor switch from rapid rise in voltage and current that could destroy them.

The ETO can operate at higher frequency. This conclusion comes from the higher switching speed and lower switching loss. The turn-off storage time of the ETO is 2 μsec, which constitutes significant savings to the transient time. And because of the lower turn-on and lower turn-off loss, the ETO's operating frequency can be much higher keeping the same switching loss as that of the GTO. The targeted operation frequency for the ETO4060 can be as high as 1 kHz.

Device protection is a serious problem for the GTO because of a low maximum turn-off current. If the device tried to turn off over its current rating, the device would be destroyed. The protection circuitry for the GTO is very complex; the ETO protection strategy, on the other hand, is much less complex. Once over-current or some other phenomenon is detected, the ETO can simply be turned off. Two parameters are crucial here. The 2 μsec turn-off storage time guarantees almost instant reaction to the control command; and the much higher maximum turn-off current makes it safe to shut down the device even in a short-circuit situation. The ETO has a MOSFET in series with the GTO, thus allowing a faster turn-off of the ETO device. The ETO gate driver board can trigger turn-off of the device automatically.

The gate driver size is a burden for the GTO but is quite manageable for the ETO. The experimental ETO gate driver for the ETO4060 has a size of 3.6×3.4 in^2. This gate driver has on-board isolated power supply, fiber-optical control input. The power required for the gate driver is mainly for turn-on and maintaining the on-state of the device.

The dv/dt (change in voltage of the device during turn-off) is crucial for the GTO. Because of the non-uniform turn-off process of the GTO chip, the dv/dt snubber is used to decrease the change in voltage on the device during the transient. Theoretically, a dv/dt snubber is not necessary for the ETO because of the uniform turn-off process. A smaller snubber circuit can be used for the ETO. Since the last report submitted to Sandia, further refinement of the ETO design has shown that the ETO can operate without any dv/dt snubber. Table 4-7 highlights additional parameters of the GTO and ETO.

Along with testing the ETO, a typical PCS was studied to demonstrate the expected reduction in size and cost of the PCS as a result of the ETO development. In particular, a comparison was made between the insulated gate bipolar transistor (IGBT), GTO, integrated gate commutated thyristor (IGCT), and ETO for the same power conversion system. A typical PCS consists of a turn-on snubber, six main switches and their gate drivers, six anti-parallel diodes, six turn-off snubbers, and three output inductors. For the purpose of comparison, a 5-MW system was considered using the devices outlined in Table 4-8.

The system, for comparison, is assumed to be a two-level, three-phase inverter. The assumed DC input voltage is 3000 V so that the IGCT can be used. The system assumes the IGBTs to be connected in series and parallel so each switch is implemented by four devices as shown in Figure 4-22. The output voltage of this system will be 2000 V (RMS) and the output current is 1500 A. This gives a three-phase output power of 5.2 MW. Higher power systems would use a different topology such as full bridges for each phase or a three-level inverter structure. Table 4-9 summarizes the key findings. The GTO is used as a baseline. Figure 4-23 shows the resistive-capacitive-diode (RCD) voltage clamp employed by high-power systems with no dv/dt snubber.

Potential industry partners for the future ETO development were identified. Currently, five industry partners expressed interest in the ETO technology. Westcode has initiated a 6-month review program to evaluate the feasibility of the ETO device as a potential commercial product. On the basis of the plan, the commercial product could be introduced in one and half years. The General Electric (GE) in Salem, Massachusetts, which works on the very high-power motor drive systems up to 15 MW, is turning their efforts to the IGCT-based PCS. The IGCT offers almost the same performance as that of the ETO. By using the IGCT,

Table 4-7. Comparison of Key Characteristics of a 4-kA/6-kV GTO and ETO

Parameters	TOSHIBA GTO	ETO4060
Device diameter (inch)	4.8	6.4
Blocking voltage (V)	6000	6000
Maximum turn-off current @ 3µF snubber (A)	3000	3700 (tested) may be up to 6000
Forward voltage drop @ 3000 A (V)	4.0	4.5
Turn-on delay time (µsec)	0.7	0.7
Turn-on voltage fall time (µsec)	4.3	2
Turn-off current delay time 4000 A (µsec)	25	1.5
Turn-off current fall time 4000 A (µsec)	2	1
Gate driver turn-off output power @ 200Hz 4000 A (W)	~60	~0
Total gate driver output power @ 200Hz 1600 A (RMS) (W)	100	20
di/dt snubber	500 A/µsec	500 A/µsec
dv/dt snubber below 3000 A	3µF	Can be less
dv/dt snubber @ 4000 A	6µF	<=3µF
Possible operation frequency (Hz)	<500Hz	Up to 1kHz
Protection	No over-current shut-down	On-board over-current turn-off

they gain a lot on their system performance. Currently they are investigating the possibility of using the ETO for their drive systems. PEMCO, a Virginia company located in Bluefield, Virginia, is investigating the possibility of the ETO as their power circuit breaker. Their applications are at a 2.5-kA DC level, and they need over-current protection. Not only will the ETO handle high DC current, it also has high over current turn-off capability. Combined with the current detection feature, the ETO can construct a very compact circuit breaker at lower cost and size. York International, one of the largest makers of air conditioning equipment, is very interested in the ETO for their very high power systems. Another company that has expressed interest in using the ETO is Power Paragon, located in Anaheim, California. Power Paragon's application is also in high-current DC breaker. SNL will continue to seek collaborative opportunities with these interested parties.

The above three reports highlight results of the ETO tests performed under pulse (turn-on or turn-off) conditions, hence continuous power cycling has not been demonstrated in order to answer questions related to long- and short-term reliability. The objective of the next phase of development is to build and demonstrate the ETO in a high power converter, with thermal and electric control and reliability all being demonstrated and tested in one unit.

Alternative System Configuration of Batteries for RGS

Another one of the initiatives resulting from the PCS project is the Alternative System Configuration of Batteries for RGS Project. As a result of the PCS work, a contract with EECI was placed on May 1, 1998. The purpose of this contract was to devise alternative configurations for solar hybrid systems that would allow more optimal charging of the lead-acid batteries contained in them. The term "configuration" refers to the electrical arrangement of the major components of hybrid systems

Table 4-8. Semiconductor Devices Used for 5-MW Comparison

Manufacturer	GTO Toshiba	ETO VPEC[1]	IGBT Mitsubishi	IGCT Mitsubishi
Part Number	SG4000JX26	ETO4060	CM1200HB-66H	FGC4000BX-90DS
Peak Voltage (V)	6000	6000	3300	4500
DC Working Voltage	3600	3600	1650	3000
Peak Controllable Current (A)	4000	4000	2400	4000
RMS On-State Current (A)	1600	TBD	800	1880
Allowed Power Dissipation (W)	4000	TBD	15630	4500
Mounting Size[2]	Dia.=125 mm	Dia.=152 mm	140 mm x 190 mm	Dia.=160 mm

1 The ETO 4060 uses Toshiba GTO and Harris MOSFET HRF3205L.

2 This is a measurement of the size of the device that must be mounted on a heatsink. This measurement does not include the gate drivers. It does include the clearance required within the mounting clamp for the IGCT gate driver board but not the gate driver itself.

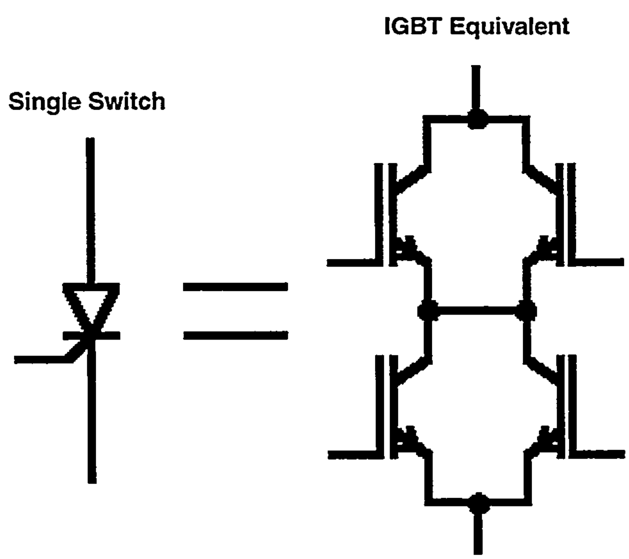


Figure 4-22. IGBTs Connected to Match Thyristor Ratings.

(i.e., PV and/or wind generator, diesel generator, storage device, and PCS). "Optimal charging" refers to charging that (1) maximizes the performance as well as the life of the lead-acid battery and (2) minimizes the system life-cycle cost that relates to the batteries.

Status

The contractor conceived several practical alternative configurations based on discussions held with a selected group of system integrators, users, component developers, and SNL personnel. The contractor modeled some of the alternative configurations and made

Table 4-9. Summary of Semiconductor Switch Comparison

	GTO	ETO4060	IGBT [?]	IGCT [?]
Typical Operation Frequency	1	2	3	2
Turn-Off Snubber Capacitor Size	1	1/3 → 0[1]	0	0
Turn-Off Snubber Power Dissipation[2]	1	1/100	1/100	1/100
Turn-Off Snubber Cost[2]	1	1/5	1/5	1/5
Gate Drive Size	1	1/4	1/10	1/2
Gate Drive Cost	1	1/2	1/10	1.5
Output Inductor Size[3]	1	1/2	1/3	1/2
Output Inductor Cost	1	1/2	1/3	1/2
Number of devices	6	6	24	6
Turn-On Snubber Size[4]	1	1	0	1
Turn-On Snubber Cost	1	1	0[5]	1
Turn-On Power Loss	1	0.5	3[5]	0.5
Overall Size	1	3/4	2	3/4
Overall Cost	1	3/4	2	3/4

1 Small ETOs (1000 A) have demonstrated snubberless capability. Work is ongoing to determine the snubber requirement of the 4000A ETO.
2 High-power systems with no dv/dt snubber employ an RCD voltage clamp as shown in Figure 4-24. This clamp's power dissipation and cost are included in the snubber section for snubberless devices.
3 For motor drive applications, there is no discrete output inductor; the motor inductance is used.
4 With faster devices such as the ETO and IGCT, the slow diodes designed to match GTOs are a limiting factor at turn-on. These slow diodes must be protected by the turn-on snubber so no improvement is seen here despite the fact that the ETO and IGCT have high di/dt ratings at turn-on.
5 IGBTs can limit the turn-on di/dt by slowing down the rate that they transition through the linear active region. This eliminates the di/dt snubber but greatly increases the power dissipation in the IGBT.

economic estimates that indicated some of the configurations could be beneficial. Because of the patentable nature of the alternative configurations, detailed results from this work will not be presented at this time. The following provides background information on solar hybrids and the "smart" battery concept.

Solar-hybrid systems are being increasingly used to provide power to electricity end-users that are remote from the transmission and distribution systems of utilities. In order for solar hybrid systems to be cost-competitive with a utility distribution line, it is necessary to minimize the size of each of the components and to make sure the system operates so as to maximize component life and to minimize operating costs. Solar hybrid systems generally consist of a PV array, a propane- or diesel-fueled engine-generator, an energy storage element, and a combination power conversion unit (PCU) and system controller. The conceptual design of solar-hybrid systems is shown in Figure 4-24. Lead-acid batteries are currently the most commonly used energy storage element of solar-hybrid systems. For a solar-hybrid system on a sunny day, DC electricity from the solar PV array(s) is used to supply AC power to the load with a DC-to-AC converter (the PCU), and to charge the batteries with any power not needed for the

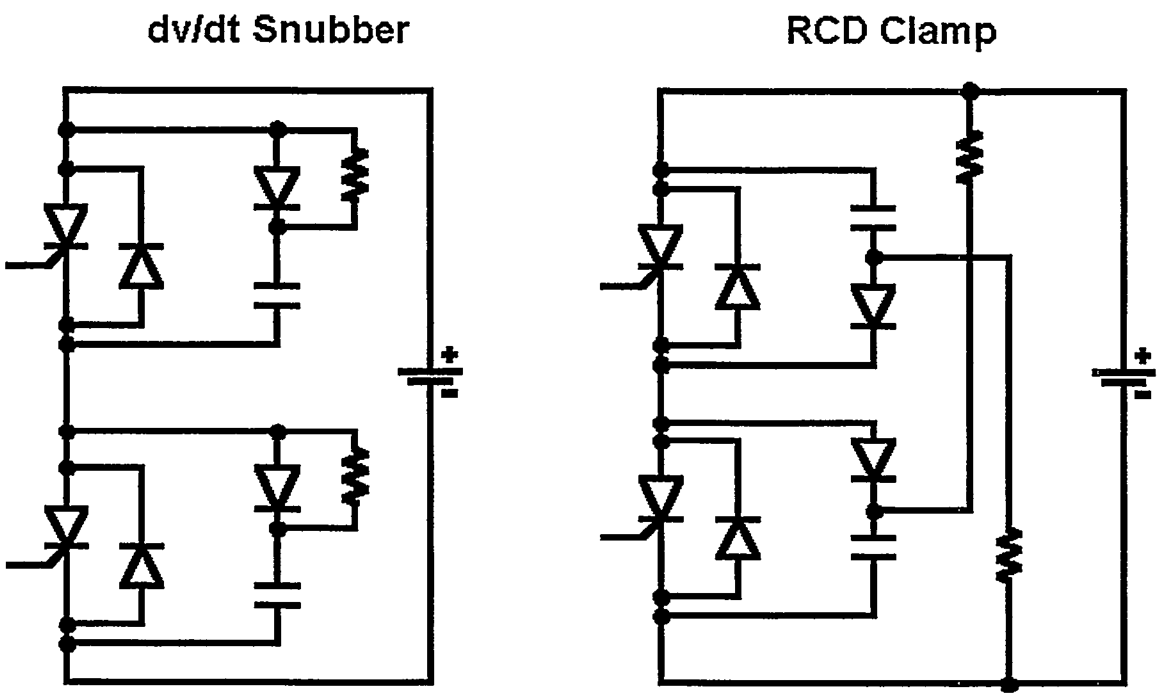


Figure 4-23. dv/dt Snubber and RCD Voltage Clamp.

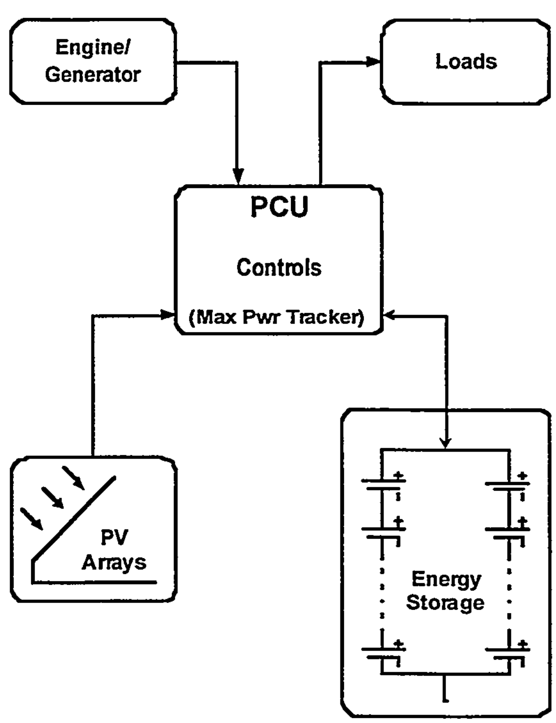


Figure 4-24. Conceptual Design of Solar Hybrid System.

loads. Sometimes the DC from the PV arrays is passed into the system by way of a maximum power tracker (a DC-to-DC converter), in which case the inverter and the maximum power tracker are collectively called the PCU. At night or during periods of cloudiness, the electricity for the loads is supplied by the batteries, again by way of the PCU, until it is determined that the batteries need recharging, when the generator is turned on. The generator then supplies the loads, while the power-flow through the PCU is reversed, so that any electricity from the generator that is not consumed by the load is used to charge the batteries. The generator stays on until the battery is charged. The controls within the PCU govern all the actions by the PCU and the generator to ensure that the loads are supplied according to the customer's requirements and that the batteries are charged at appropriate times. In the past, the PCU controls have also been programmed to handle any conditioning cycles, such as equalization, that the battery manufacturer may have indicated are necessary to ensure good battery performance and life.

Historically, a lack of collaboration between the different parties involved in making solar-hybrid systems has existed. System integrators, renewable resource suppliers, energy storage suppliers, PCU manufacturers, and end users must work together to make these systems reliable and economically competitive. Specifically, PCU/controller developers and battery suppliers have in the past communicated poorly. As a result, many solar-hybrid systems are not at this time configured for optimal utilization of lead-acid batteries. Current configurations force the components to operate in ways that do not properly charge the battery. Equalization of batteries is often accomplished by running the engine-generator for the period of equalization. This results in high operating and maintenance (O&M) costs and tempts the system designer to program inadequate equalization cycles. In many operating solar-hybrid systems, improper charging has resulted in reductions in the performance and life of the lead-acid battery within the ESS. Consequently, the life-cycle-cost (or total cost of ownership) for the hybrid systems has been higher than expected.

The design of an alternative configuration developed under study is shown in Figure 4-25. The figure shows that the addition of an "alternative configuration unit" could in essence make the battery "smart," so that the solar hybrid system PCU might be able to operate without regard to any special charging requirements of the lead-acid batteries used for energy storage. The costs for the additional hardware and/or software using the alternative configuration unit must of course be balanced against the economic benefits that might result from longer battery life or lower O&M costs. It is total

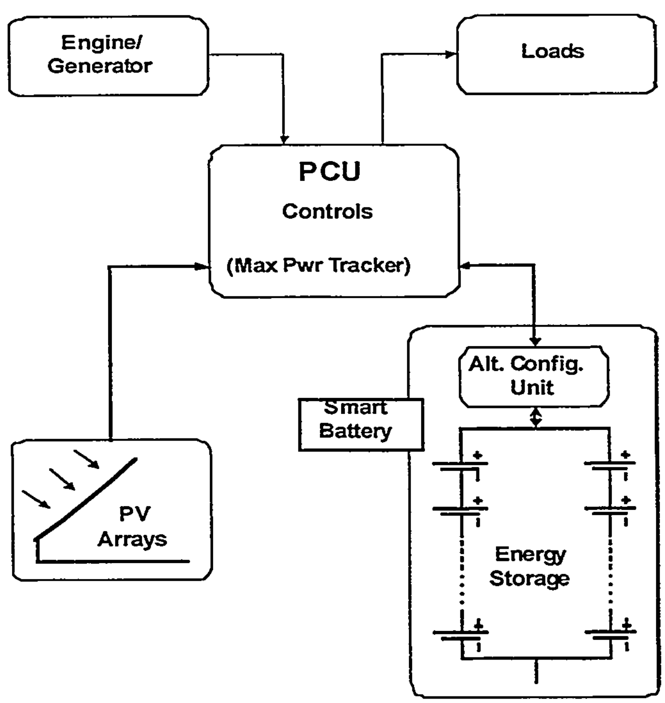


Figure 4-25. Conceptual Design of Solar Hybrid System with "Smart" Battery.

life-cycle cost that includes battery life and O&M costs, and other items, as inputs that will be the primary measure against which the various alternative configurations will ultimately be evaluated.

Full evaluations and validation of the alternative configurations would require hardware implementation. Prototype development of the alternative configuration and testing will be considered as a future project.

Performance and Economic Analysis of SMES, Flywheels, and Compressed Air Energy Storage Systems Project

The scope of the ESS Program includes a portfolio of energy storage technologies for electric utility applications. The program approach has been to apply expertise gained from work with battery energy storage to the development of storage media, PCSs, peripheral devices, and advanced storage systems that depend on similar components. The ESS Program initiated this analysis project with Energetics, Inc., in FY97 to identify the areas in which program expertise directly applies to this expanded range of technologies and where such program expertise must be developed.

Over the past several years, many organizations have conducted research and development on energy storage systems and components, and they have gathered a vast amount of information. However, much of the information is proprietary and not available to the public. Information in the public domain is often scattered in discrete reports. Therefore, literature searches that precede new research projects easily miss information, and new projects can duplicate work that other researchers have done. In addition, research projects that do not have the benefit of reports from previous work are likely to pursue avenues that have already been shown less fruitful than others. Energetics has compiled a comprehensive library of information on the state of storage system technologies and developed an analytic tool to assess their economic and technical viability for electric power applications.

Status

In the fourth quarter, a draft report from this project was delivered to and is being reviewed by SNL/ESS Program staff. A summary of the report is outlined below.

The scope of the study was limited to three technologies: superconducting magnetic energy storage (SMES), flywheel energy storage (FES), and compressed air energy storage (CAES) systems.[5] The project compiled a comprehensive data source on cost, performance, potential markets, and availability of information for all three technologies. The data include a bibliography of relevant literature, a contact database of manufacturers and researchers, and a primer on the three storage system technologies.

For SMES and FES systems, the project also included development and use of a spreadsheet analytic model that details cost and performance of system components, and calculates a measure of performance for SMES and FES systems. The project included sensitivity analysis of the measure-of-performance to identify R&D that has potentially high value to the development of technically and economically viable SMES and FES systems.

Approach and Methodology

The project consisted of four thrusts: identify and survey manufacturers and researchers; characterize subsystems and components; develop spreadsheet analytic models; and conduct technical and economic analyses. Literature and Internet searches identified manufacturers and researchers with whom the ESS Program was not already affiliated. It also identified literature concerning SMES, FES, and CAES technologies. Interviews with selected manufacturers and researchers provided information about the current state of the technologies and a basis for projections of cost and performance for the next decade. From this information, the project team characterized subsystems and components in terms of key performance parameters and correlated technology characteristics with applications requirements.

Analysts developed spreadsheet models that used system and application characteristics to calculate a measure-of-performance for SMES and FES systems. Sensitivity analyses of the calculated parameter indicated whether specific characteristics strongly affected system cost and performance. The models included component technology characteristics and the value of electric power applications for storage systems.[6] The project team selected the internal rate of return (IRR) that would result from the purchase and operation of a SMES or FES system in a specific electric power application as the calculated measure-of-performance for the technologies. Sensitivity analysis of the IRR to specific

5 Existing programmatic expertise in battery energy storage systems precluded the need for detailed investigation. Budget and time constraints precluded the inclusion of other storage technologies in this phase of the project.

6 Another ESS Program activity, the Phase II Opportunities Analysis, will refine the 'value' of specific applications. These new values, inserted into the SMES and FES models, will focus the results of the models output even more tightly.

inputs identified areas in which targeted R&D could accelerate development of technically and economically viable SMES and FES systems. From the identified areas, this report suggests priorities and recommends potentially high-impact R&D for the ESS Program.

Results – Summary

A comprehensive data source on cost, performance, markets, and availability for SMES, FES, and CAES systems was compiled. Spreadsheet analytic models for SMES and FES systems were developed as a tool for the ESS Program to identify high-impact R&D. The models are structured so that analysts can enter new economic and technical information as it becomes available and continuously update the results. The models use cost and technical attributes of system components to calculate IRR as a measure of performance for the systems. Sensitivity analysis of the IRR to specific model inputs identifies areas in which R&D has significant potential to accelerate development of technically and economically viable SMES and FES systems. Results of the sensitivity studies support recommendations for R&D.

Results – Comprehensive Data Source for SMES, FES, & CAES

Literature searches in the library and on the internet and interviews with representatives of industry/academia produced a bibliography of technical papers, textbooks, and product-literature pieces on SMES, FES, and CAES components and systems. A library at the headquarters of Energetics in Columbia, Maryland, houses documents to which analysts could gain access.

The literature searches and interviews also contributed to a set of primers that are appendices to the final project report. The primers address the physics of storage media; components of the system; and cost, performance, and availability of specific components of SMES, FES, and CAES systems. The primers also present summary overviews on supporting technologies and engineering concepts including cryogenics (for the superconductors in SMES coils and FES bearings and motor/generators), power conditioning systems, high-temperature and low-temperature superconductivity (HTS and LTS), and strength of materials/engineering mechanics.

Summaries of interviews with industry and academia are in the appendices of the final project report. The summaries reflect researchers' and manufacturers' perspectives on SMES, FES, and CAES systems, and on their research needs. The organizations listed in Table 4-10 have had the opportunity to review the summaries.

The project team constructed and maintained an electronic database of contacts made during the project and of other energy-storage stakeholders. The database can be searched for information about corporate interest areas, company names and addresses, names of individ-

Table 4-10. Organizations Visited During the SMES/FES Study

Company/Institution	Location	Date Visited	Technology
University of Texas, Center for Electromechanics	Austin, Texas	1/6/98	FES
Active Power	Austin, Texas	1/7/98	FES
American Superconductor	Middleton, Wisconson	1/8/98	SMES
Penn State University, Applied Research Laboratory	University Park, Pennsylvania	2/18/98	FES
Beacon Power	Woburn, Massachusetts	2/19/98	FES
US Flywheel Systems	Los Angeles, California	4/1/98	FES
Boeing Corporation	Seattle, Washington	9/2/98	FES
Lawrence Livermore National Laboratory	Livermore, California	9/3/98	FES, SMES
Trinity Flywheel Corporation	Livermore, California	9/3/98	FES

uals, telephone/FAX numbers, e-mail addresses, and notes of interest. A hard copy of the database is an appendix in the final project report. Electronic copies of the database are maintained at headquarters of Energetics in Columbia, Maryland, and at Sandia National Laboratories in Albuquerque, New Mexico.

Results – Spreadsheet Models of SMES and FES Systems

The project team produced spreadsheet analytic models of specific SMES and FES systems. The SMES-model allows the user to define the power and energy of the device, the type of superconducting material in the SMES coil, and a number of other inputs defined in more detail in the full project report. From these inputs, the model selects the appropriate cryogen and calculates the size of the cryostat, as well as the size of the area around the coil from which personnel must be excluded. Users can also select the type of current leads to the coil, and the cryogenic and electrical losses associated with the system operation. They can also define characteristics of equipment for connection to the electric utility grid. With a complete set of user inputs, the model calculates an IRR for a specific SMES system that is suited to and used in a specific electric power application. To enable the sensitivity studies of the IRR, the model accepts user-selected modifications to the unit-cost of materials and components, terms and interest rates for financing options, and the dollar value of several applications. Table 4-11 shows the application that the analysis determined to be most appropriate for the SMES in the near- and long-term.

The FES model allows the user to define the power and energy of the device by way of the speed, size, configuration and material (steel or fiber-reinforced epoxy options) and manufacturing process for the rotor. From these inputs, the model determines the most appropriate containment system, vacuum system, and need for cryogenics. Users can also select the type of bearing and motor/generator. As in the SMES model, user selections define the parameters by which the model calculates an IRR for a specific FES system. To enable sensitivity studies, the model permits user modifications of the unit cost of materials and components, terms and interest rates for financing options, and the dollar value for the system selected. Table 4-12 shows the applications that this analysis determined to be the most appropriate for the FES systems in the near- and long-term.

Figure 4-26 shows the flowchart that illustrates the input functions and output of both models. Use of a model identifies areas in which technical and economic information is sparse and areas in which the state of the technology must advance before systems for electric power applications will gain widespread acceptance and adoption. Therefore, the models identify R&D that could help advance the technologies in electric power applications.

Table 4-11. SMES Applications

Current Use	Future Use
Power Quality	Power Quality

Table 4-12. FES Applications

Current Use	Future Use
Power Quality	Power Quality Telecommunications Renewable Hybrids

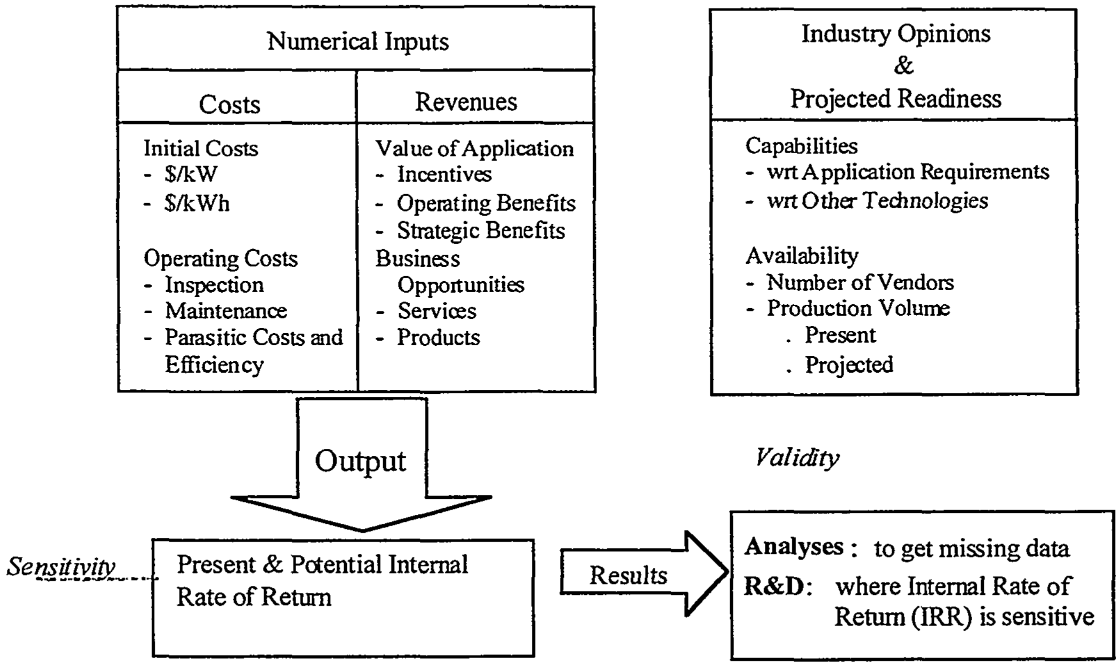


Figure 4-26. Flowchart of SMES and FES Models.

With the models, project analysts identified cost goals that SMES and FES technologies must achieve in order to gain widespread acceptance. Figure 4-27 shows total system cost thresholds that will permit acceptance and adoption of SMES and FES in specific electric power applications. The solid portion of each of the bars spans the range from the lowest to the highest threshold costs. The low end of the bars represents commercial applications that are not critical or for which alternative technologies already compete. The high end of the bars represents critical applications in which service problems involve either tremendous cost or physical risk (for example, defense applications, semiconductor manufacturer).

Further exercise of the models determined the present cost of SMES and FES systems and the cost break-down of the systems at present, in the near- and in the long-term. Given the cost thresholds and technical capabilities of SMES and FES systems, both are applicable to short-duration peak shaving, power quality, and serve as a means to extend the life of batteries in UPS. Long-duration peak shaving and remote power-supply applications will be feasible only when SMES and FES systems can supply several hours of energy in a cost-competitive manner. Active Power Inc., of Houston, Texas, is currently marketing its flywheel product to extend the life of batteries in UPS, and is considering its product as a future battery replacement system.

For both SMES and FES, system cost reductions will be necessary to promote widespread acceptance and adoption. From the first generation of SMES to the current generation, one can see that the greatest cost improvements are most likely in the area of cryostats. Improvements for the next generation include further technical advances in cryogenics and reduced cryogenic demands from the use of more high-temperature superconducting materials as well as magnet improvements. Figure 4-28 shows the relative cost distributions of components for SMES.

Figure 4-29 illustrates percentages of cost contributions of components for FES systems. Researchers emphasized the need for R&D on advanced bearings which account for only about 9% of the total system cost. The emphasis is based, instead, on the reduced operating and maintenance costs for advanced bearings (less friction, greater efficiency, long bearing life, fewer replacements).

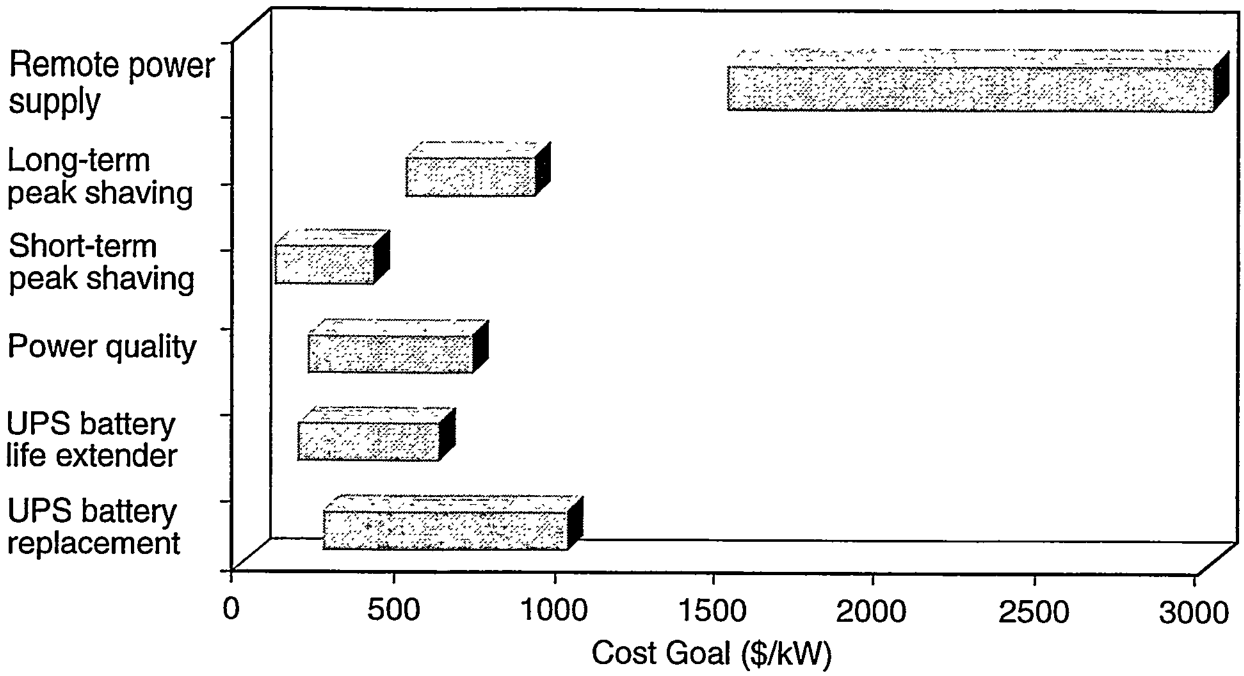


Figure 4-27. Cost Threshold for Adoption of SMES and FES in Electric Power Application.

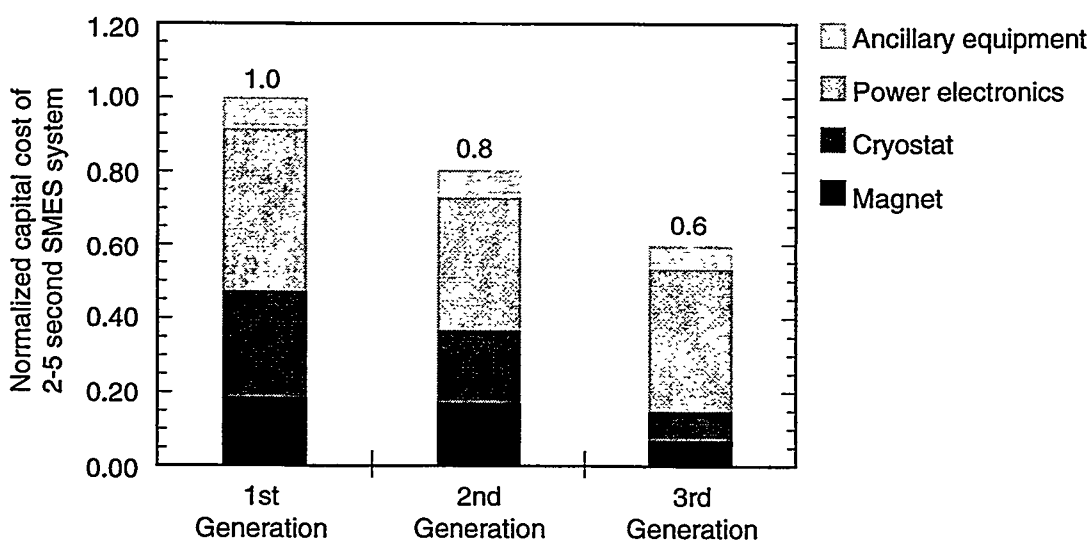


Figure 4-28. Costs of Components as a Percentage of Total Cost of Several Generations of SMES.

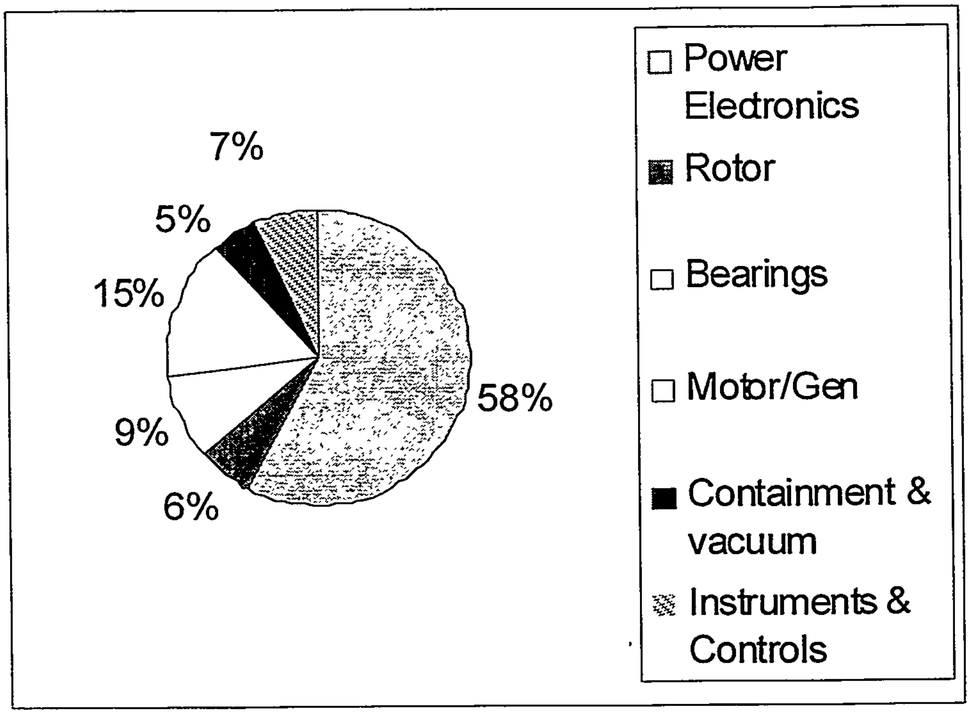


Figure 4-29. Percentage of Total Cost of FES Components in Present Systems.

Conclusions

This analysis has confirmed that increased discharge time does not affect the cost of the power electronics for the FES system. Therefore, a unit that can discharge power for an hour as opposed to several seconds has a lower relative cost of power electronics. However, as shown in Figure 4-30, increased discharge duration does substantially increase the cost of the rotor relative to the system cost. This increase is the result of the large amount of expensive carbon fiber that is necessary in long-discharge, composite rotor FES systems. As a result, most developers are focusing on rotor R&D and not on power electronics.

With the information from industry and academia interviews and exercise of the models, analysts determined the number of R&D areas that have the potential to advance SMES and FES systems in electric power applications. Figure 4-31 identifies areas for SMES R&D that were identified in the study. The R&D goals plotted at the left side of the graph are expected to be easy to achieve relative to those on the right. The objectives plotted at the top of the graph have potentially high impact on SMES cost and performance relative to those at the bottom. Therefore, SMES would benefit most from activities such as improving coil materials and winding processes in which the difficulty is moderate and the potential impact is high.

At present, flywheel developers are conducting R&D on fiber-winding processes, the use of low-cost and high-strength fibers in composite rotors, and advanced bearings to reduce operating and maintenance costs of the systems. FES developers identified R&D needs in the areas of continued study into rotor failure, codification of the rotor manufacturing process, further advancement of the fiber-winding process, and continued research into advanced motor. Figure 4-32 presents a graph of potential R&D in terms of likely FES advancement, and it shows the difficulty of achieving the goal. The goals in the upper left quadrant of the graph have the highest likelihood of improving cost and performance of FES and are relatively easy to achieve.

Recommendations

Given the cost thresholds identified for various applications of SMES and FES that are shown in Figure 4-27, and the impact versus the difficulty of specific R&D activities shown in Figures 4-31 and 4-32, several areas of R&D have more promise to advance SMES and FES in electric power applications than others. For SMES, the most significant advances would result from

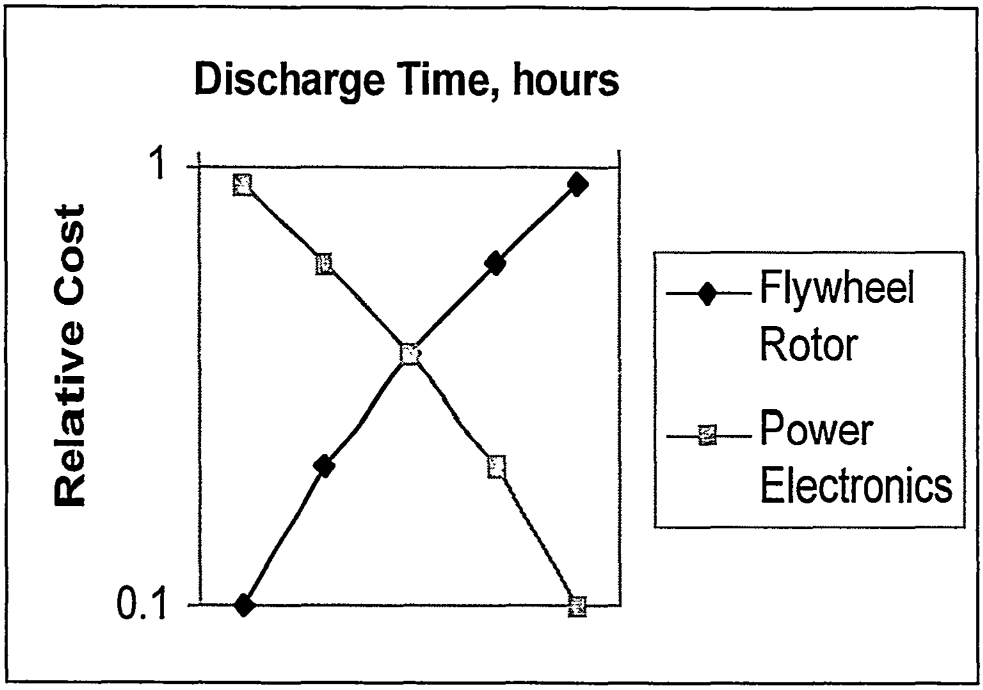


Figure 4-30. Relative Costs of FES Systems Components as a Function of Discharge Time.

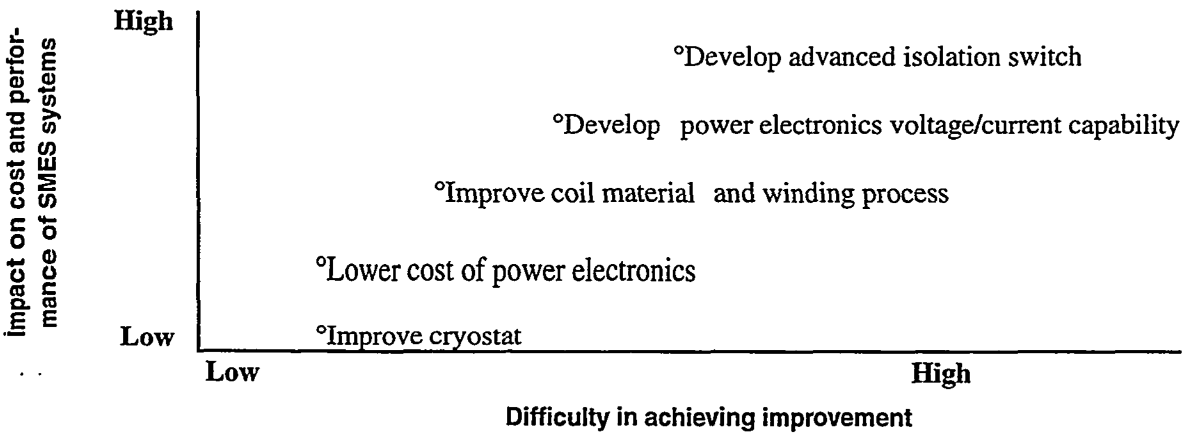


Figure 4-31. Potential Areas of R&D for SMES Based on Impact vs. Difficulty.

improvements in the coil material and winding to reduce the demands on the cryogenics and power electronics, development of power electronics that are specifically suited to SMES devices, and development of an advanced-isolation switch or "cold switch" that operates inside of the cryogenic area and improves system efficiency and performance in the power quality applications that it is likely to address the near- and mid-term. The risks associated with pursuing these relatively difficult R&D tasks are high. Therefore, the R&D is unlikely to be performed in the private sector without federal involvement.

For FES, the high-risk high-impact R&D areas include development of advanced bearings and HTS motor/generators. However, the pressing need for rotor failure data and codes and standards for manufacturing

Potential impact on FES systems	Low difficulty	High difficulty
High	Rotor failure data Codes and standards Fiber winding process Advanced motors	HTS bearings Active magnetic bearings HTS motor Multi-incident touchdown bearings
Low	Advanced sensors Power electronics Thermal management	Containment systems High-strength fibers Press fit rotor
		Light-weight hub

Low / High — Difficulty in achieving improvement

Figure 4-32. Flowchart of SMES and FES Models.

and operating composite-rotor FES also make those R&D activities appropriate federal activities. Unlike development of advance sensors, improvements of power electronics specific to FES and development of thermal management, R&D of bearings, HTS motors, and a uniform set of codes and standards are outside of the near-term reach of the private sector, and are necessary for FES to perform cost-effectively in any application that requires more than a few minutes of discharge duration.

Therefore, the results of industry interviews, literature searches, and iterative techno-economic modeling suggests that the ESS Program place priority on the R&D activities for SMES and FES as shown in Table 4-13.

Industry, Academic, and Laboratory Interfaces

Status

Lucent Technologies. ESS staff participated in the Lucent Technologies Premium Power Forum at Bell Labs in Murray Hill, New Jersey, on January 13, 1998. Lucent has been organizing these meetings for more than a year to bring together developers and manufacturers of advanced generation and storage technologies with their telecommunications users of these technologies. The ESS Program staff has participated and has made numerous presentations at these meetings, which are held about every two months. Lucent's objectives in premium power have many things in common with those of the ESS Program to develop advanced energy

Table 4-13. High-Priority R&D for SMES and FES Systems

- Improve coil material and winding process
  - to increase power and energy
  - to reduce demands of power electronics
  - to increase efficiency
- Improve power electronics
- Develop advanced isolation switch
  - to reduce system thermal losses
  - to eliminate transients caused by ambient cryogenic interface
- Develop advanced bearings to improve system efficiency and reduce O&M costs
  - HTS materials
  - active and passive magnetic types
  - multi-incident touch down types
- Assist in development of codes and standards (and failure data) for composite rotors
  - manufacture
  - operation

systems for renewables, power quality, and productivity applications.

At this premium power forum, presentations were made by:

- Bell Labs on global warming,
- MIT Energy Laboratory of global warming and deregulation on the utility industry,
- NIST on its premium power advanced technology request for proposal,
- GPU International on photovoltaics in Europe,
- SNL on its lithium battery activities, and
- Maxwell on ultracapacitors.

On April 30, 1998, ESS Program staff presented a paper on testing results for improved energy storage technologies at Lucent Technologies' Premium Power Forum. The forum, held at Bell Labs, is a continuing series of meetings for discussion of distributed generation and storage technologies for telecommunication applications. This forum was highlighted by talks on fuel cells, photovoltaics, and microturbines, in addition to the ESS presentation. Of interest was the discussion of a 10-kW (peak), Proton Exchange Membrane fuel cell that included a 3-kW (continuous) fuel cell and a 6-kW/1-hour battery for peaking output. This 10-kW fuel cell system was projected to cost $6,000 in production quantities of 1000 units per year. Of this cost, 47% was attributed to the fuel processor, 21% to the PEM fuel cell stack, 18% to the PCS (including battery), and 13% to the controller. Also, as a result of the ESS presentation, several contacts were made for additional interactions with ESS projects to better include telecom needs in the program.

On August 27, 1998, the ESS Program presented the results of research on power quality to the Lucent Premium Power Forum at Bell Labs. The forum provides an exchange of information on evolving and environmentally conscious energy technologies for what Lucent calls premium power: power at the point of use. The ESS Program has been an active participant for several years, along with photovoltaic, wind, flywheel, and many other advanced technology companies. This forum focused on power quality with the ESS presentation on its just-completed study, which estimated the impact of poor power quality on the US economy at $150B annually. In a surprise announcement, the Director of Enron's new Power Quality Solutions group presented a summary of its new business venture to market advanced technologies for power quality applications. This initiative was approved by Enron upper management two weeks ago and could lead to strong validation of the ESS Program's work on PQ technologies. Later during the forum, Lucent presented its plans to reduce energy use and associated greenhouse gas emissions by about 5% from 1990 levels by 2005. The ESS Program will continue collaborating with Lucent through these forums and other venues.

MIT Energy Lab. The ESS Program staff met with several persons from the MIT energy laboratory on February 20, 1998, to familiarize representatives of both organizations with their respective activities related to energy storage and the deregulation of the electric utility industry. The energy laboratory is conducting numerous analytical and policy studies on the different scenarios for the future with a deregulated electric utility industry. It has developed sophisticated codes and models with which to carry out these assessments. Many of these models relate to distributed resources such as renewable generation, and could be used to evaluate storage as a technology to address utility grid reliability and stability. Other work is underway, including modeling of advanced integrated energy research, researching storage technologies such as flywheels and lithium/ion batteries, developing fuel cells, and continuing work on geothermal energy. A presentation of an overview of the ESS Program was attended by the laboratory director, Professor Jeff Tester. The presentation generated many questions on storage technologies, on the role of storage in future electricity supply, and on the economics of storage. CAES was a topic of discussion for long-term storage applications. Opportunities for future collaboration of the energy laboratory and the ESS Program were considered and could be very productive.

PEPCO. ESS staff met with personnel from Potomac Electric Power Company (PEPCO) on March 2, 1998, to discuss technologies and applications for utility energy storage. PEPCO has developed exciting, proprietary concepts for state-of-the-art energy systems that include storage. There is the potential for PEPCO and the ESS Program to work as a team to fully develop, evaluate, and monitor these concepts during the next year. Successful implementation of these concepts could result in novel new products in the electricity supply and storage technology area. Teaming mechanisms and task definitions will be considered in the next few months.

ORNL. ESS Program staff visited Oak Ridge National Laboratory (ORNL) to review the preliminary analysis that has begun on utility T&D in a deregulated market. ORNL has extensive experience in analyses of deregulated utilities, having published a series of reports on ancillary services and other emerging issues. One member of the ORNL team has been involved with wind analysis and is working with the DOE/HQ Wind Program Manager the National Renewable Energy Laboratory. In addition, ORNL is participating with the Sharp Task Force on electric system reliability. The Task Force is currently focusing on federal legislation and regulatory issues and will address R&D issues at the some time in the future. There is interest in studying spot-market electricity prices and in reviewing how renewables and storage could interact.

Coordination issues were reviewed; it was agreed that exchanging technical reports and maintaining open communication are essential.

Appendix A:

Renewable and Energy Storage Project Lists

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Appendix A:
Renewable and Energy Storage Project Lists

Table A-1. Existing Photovoltaic Systems in the Bureau of Land Management

Application	Number of Existing PV Systems	Number of Potential PV Systems
Remote Auto Weather Stations	337	--
Communications	88	10
Monitoring	56	--
Power	34	18, 24*
Water Pumping	26	92
Electric Fences	8	--
Other	3	46
Lighting	--	20

* 18 systems for facility power and 24 systems for portable power.

Table A-2. Existing Photovoltaic Applications in the USDA Forest Service*

Application	Percent of Existing PV Systems (%)	Percent of Potential PV Systems (%)
Communications	62	21
Other	10	1
Remote Monitoring	9	1
Restroom Power	9	--
Water Pumping	6	29
Lighting	3	7
Remote Facilities Power	1	33
Recreation	--	8

* This breakdown represents the applications for over 500 systems currently installed. Existing power needs have identified at least 200 potential PV systems.

Table A-3. Existing Photovoltaic Applications in the National Park Service

Application	Number of Existing PV Systems
Facilities Power	20
Other	5
Water Pumping	3
Restroom Power	2
Communications	2

Table A-4. World Bank Projects: Photovoltaic Home Systems in Selected Countries

Country	Year	Size (Wp)
Kenya	1993	53
China	1994	10
		20
		20
Indonesia	1994	06
		12
		40
		53
		53
		100
Philippines	1993	48
		53
Sri Lanka	1995	20
		30
		40
		50
Brazil	1994	50
		100
Dominican Republic	1993	25
		35
		48
Mexico	1994	50
USA - Navajo Housing Services Dept.	1994	1,000

Table A-5. PVUSA Utility Demonstration Systems at Davis and Kerman, California

System Technology	Supplier	Completion Date	AC Power Rating (kW)
Davis Systems			
Amorphous silicon, fixed tilt, APS PCU	Advanced PV Systems	9/92	479
Ribbon silicon (MSEC EFG), one-axis active-tracking, KWI PCU	Integrated Power Corp.	6/93	196
Single-crystal silicon, one-axis passive-tracking, Bluepoint PCU	Siemens Solar	5/94	67
Kerman System			
Single-crystal silicon, one-axis passive-tracking, Omnion PCU	Siemens Solar	6/93	498

Table A-6. PVUSA Emerging Technologies Tested

Supplier	Technology	DC Power Rating (kW)	Completion Date
Siemens Solar (ARCO)	Micro-gridded single-crystal silicon	18.7	1/89
Ovonics	Tandem-junction amorphous silicon	17.3	6/89
Utility Power Group	Tandem-junction amorphous silicon	15.7	12/89
Solarex	Bifacial polycrystalline silicon	15.7	10/90
ENTECH	22x linear concentrator, crystalline silicon	16.5	3/91
AstroPower	Thin-film polycrystalline silicon on ceramic	17.1	3/91
Solar Cells	Cadmium telluride	12.0	12/95
Amonix	260x point-focus concentrator, crystalline silicon	19.0	12/95

Table A-7. PVUSA Host Utility Demonstration Systems

System Technology	Host Utility Sponsor	Supplier	Completion Date	Power Rating (kW)
Tandem-junction amorphous silicon, fixed tilt, DECC PCU	Maui Electric (HI)	Ovonics	10/89	18.5 DC
Ribbon silicon (MSEC EFG), one-axis active tracking, Omnion PCU	City of Austin (TX)	IPC	7/92	17.9 AC
Tandem-junction amorphous silicon (USSC) fixed tilt, Omnion PCU	NREL, New York Power Authority (NY)	IPC	7/93	12.9 AC
Ribbon silicon (MSEC EFG), one-axis active tracking, Omnion PCU	New York State Energy Research & Development Administration (NY)	IPC	8/93	17.9 AC
Single-crystal silicon (SSI), one-axis active tracking, Omnion PCU	Sacramento Municipal Utility District (CA)	UPG	4/94	207 AC
Single-crystal silicon (SSI), one-axis active tracking, Omnion PCU	Central & Southwest (TX)	UPG	11/94	98 AC
21 x linear concentrator, crystalline silicon, Omnion PCU	Central & Southwest (TX)	ENTECH	9/95	83 AC
Single-crystal silicon (SSI), fixed-tilt, Kenetech PCU	Dept. of Defense (AZ)	UPG	12/96	375 AC
Single-crystal silicon (AstroPower), one-axis active-tracking, Omnion PCU	Public Service of Colorado (CO)	New World Power	6/96	22 AC

Table A-8. UPVG Team-Up Ventures, 1995

Lead Utility	AC Power Rating (kW)	Key Objectives
Niagara Mohawk	100	Power quality correction
Hawaii Electric	15	Evaluate attachment of modules to roofing insulation
Sacramento Utility District and eight other utilities	1,400	Rooftop, building-integrated, and transmission and distribution support
Arizona Public Service	50	Standardize rooftop systems for covered parking garages
Arizona Public Service	125	Tracking systems for transmission and distribution support
Arizona Public Service, Nevada Power, Central & Southwest	72	High concentration (230x) systems
Eight utilities	350	Validate green pricing programs
Public Service of Colorado	22	Transmission and distribution support
Northern States Power	2	Dual-axis tracker, 22x concentration in a cold climate
UtiliCorp United, Nevada Power	40	Power quality
Gainesville Regional Utility	10	Uninterruptible power supply, green pricing

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Appendix B:

Brochures

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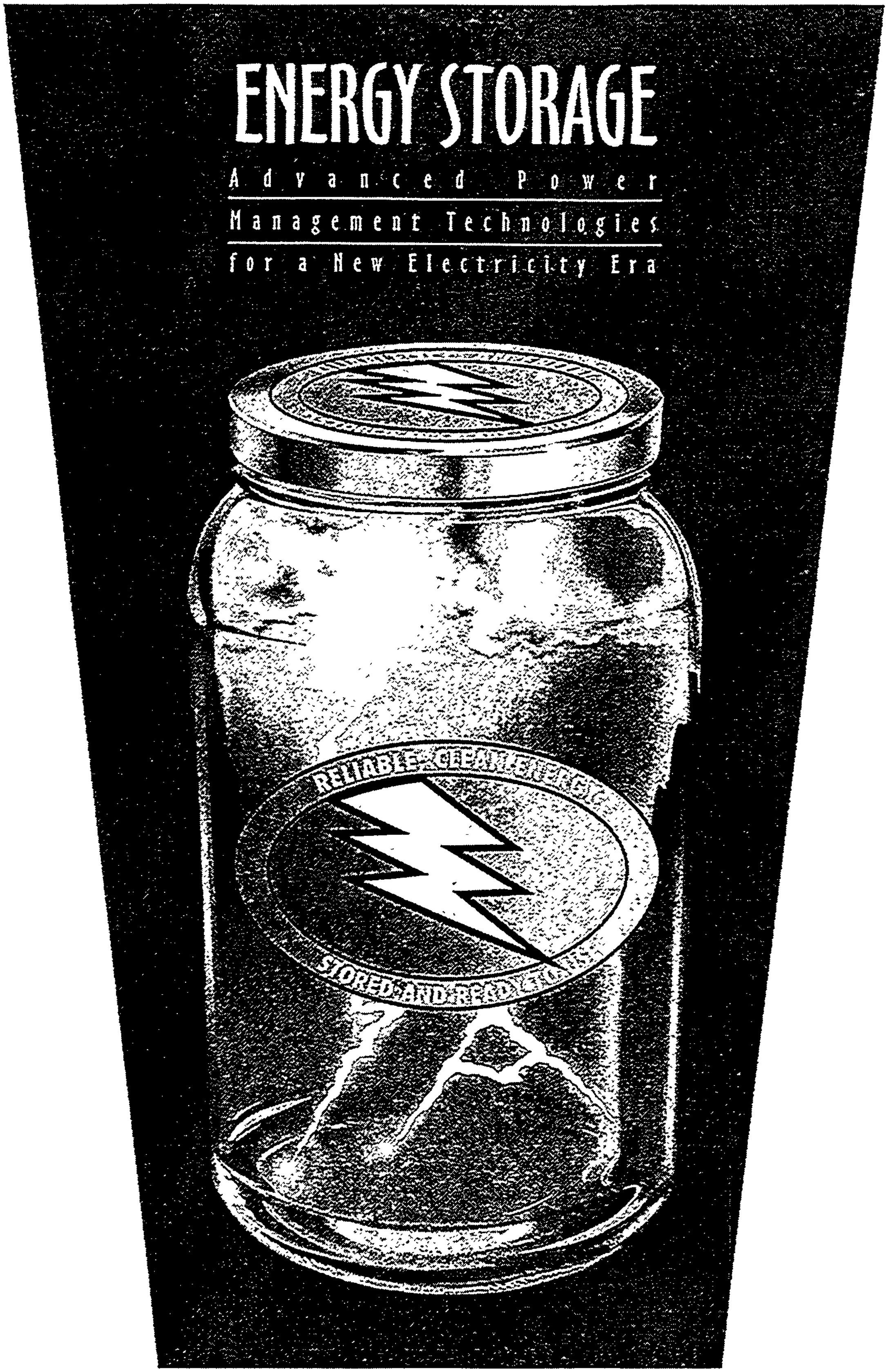

ENERGY STORAGE
Advanced Power
Management Technologies
for a New Electricity Era

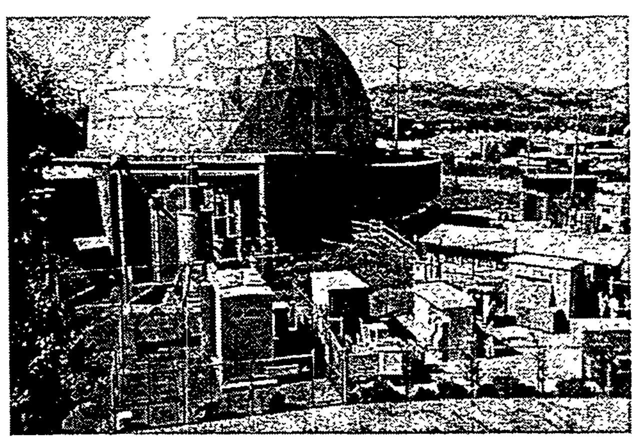
Using Energy Storage

We are all familiar with storage devices such as batteries which have been used for decades to provide portable electricity supply in millions of automobiles, appliances, and electronic devices. And, since the 1930s, electric utilities around the world have employed pumped hydroelectric storage to meet fluctuating demand. Despite these experiences, there is still the common perception that bulk electricity storage for utilities is not practical. But now a new generation of smaller, modular energy storage technologies are emerging. These new systems offer tremendous value and opportunities for both electricity providers and users.

Electrical energy can be either stored directly or converted and stored in different forms such as chemical, mechanical, or potential energy. The stored energy can be quickly converted on demand and used in a wide variety of electric applications and load sizes. Advancements in battery technology, superconducting materials and flywheels have resulted in systems that can now provide reliable power on demand and with reduced capital investment. Because of the modularity of distributed energy storage, additional benefits are gained from their strategic placement within the electric network.

Types of Energy Storage

- Batteries
- Compressed air
- Flywheels
- Pumped hydroelectric
- Supercapacitors
- Superconducting magnets

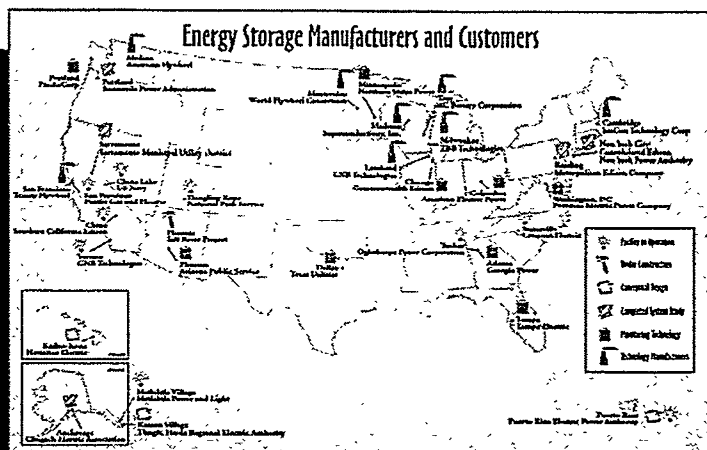


The first modular battery storage system was developed in a partnership with the U.S. Department of Energy/Sandia National Laboratories and the AC Battery Corporation and tested at Pacific Gas & Electric's San Ramon test facility.

Competition to Provide Electricity

The U.S. electric utility industry, a regulated monopoly since its inception at the turn of the century, is undergoing a massive restructuring that will result in significant changes as well as opportunities for emerging technologies. The creation of competition in wholesale and retail electricity markets will result in new products and services such as premium power, energy supply contracts, electricity commodity futures, and green power.

Distributed energy storage technologies have matured to the point of gaining industry and investor confidence. More than 70 megawatts (MW) of battery storage (enough power to start half all of the cars in the US each day) have been installed by utilities and their customers to provide ancillary transmission services, premium power quality, and to firm intermittent renewable resources. Superconducting magnetic energy storage (SMES) devices are being leased or sold around the world to provide instantaneous premium power quality for electricity both domestically and internationally. As developing countries continue to upgrade and expand electric supply, energy storage systems are being used to facilitate economic development. At least four U.S. firms are developing flywheel (electro-mechanical) storage products which initially will be marketed for power quality and uninterruptible power supply applications.



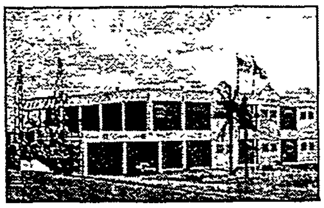
Energy Storage Provides Many Benefits for US Economy

Electricity competition will open up many new opportunities for services, products and new technologies. Energy storage is one of those critical technologies and will create new businesses for both manufacturing the technologies and for providing the services such as premium power, green power, or reliability reserves. Market projections for energy storage are likely to result in:

- *Installation of 900 MW annually of energy storage devices by 2010*
- *Productivity improvement for US industrial sector of $150 billion annually*
- *Markets exceeding $1 billion by 2010 resulting in 7,000 new high-technology manufacturing and service jobs*
- *Enhanced renewable energy market penetration by 2010 with concomitant emissions savings of 250,000 metric tons of carbon*
- *Emerging high-technology leadership with export market potential to exceed $500 million annually by 2010*

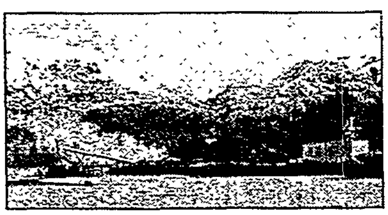
Energy Storage Applications

Managing Power for an Island Economy



The Puerto Rico Electric Power Authority (PREPA), the island's utility, determined that a battery energy storage system would be the most cost-effective option to meet the island's unique circumstances. Four 400-MW oil-fired units were added (nearly doubling PREPA's generation capacity) during the 1960s and 1970s when Puerto Rico experienced rapid demand growth. When growth stagnated after the 1979 oil crisis, PREPA recognized that an unscheduled shutdown of a 400-MW power plant caused electrical overload of generators that remained on line. As a result, standby generation could not reach full speed during the critical first seconds. The only other option, load shedding, caused blackouts and negated the economy of scale that originally justified construction of large generating plans. After a thorough analysis, PREPA installed 20 MW of battery storage at Sabana Llana, a 115-kV substation. PREPA is planning another 20 MW energy storage system which will allow the utility to make the most efficient use of existing generating capacity and provide reliable service to their customers.

Economical Solutions for Village Power

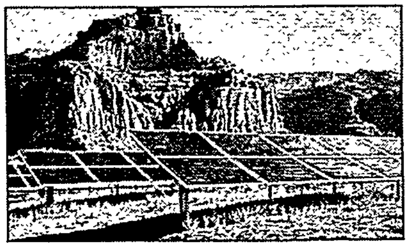


A sawmill constitutes a large portion of the demand for the 8.0 MW combined hydro and diesel generation capacity of Metlakatla (Alaska) Power and Light. Other village customers include residences and commercial loads. The mill's heavy motor loads caused substantial fluctuations in both system voltage and frequency and a 3.3 MW diesel generator was required to satisfy response rate requirements. The recent addition of a 1 MW battery energy storage system allows Metlakatla Power and Light to adjust to fast power swings without using the diesel generator. The battery storage system also means less money spent for diesel fuel and less risks associated with fuel handling and environmental clean up.

Maintaining Critical Safety and Environmental Operations

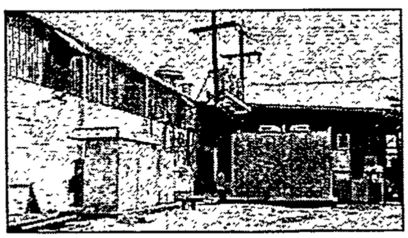
Many industrial and commercial users face substantial losses due to momentary or sustained power interruptions. The GNB Lead Reclamation Facility in Vernon, California, recently installed a battery energy storage system rated at 3.5 MW for one hour to supply uninterruptible power to ensure the plant's critical loads are met. One of the most critical processes is the operation of the plant's emission control systems. The storage system allows GNB to ensure that possible emissions are avoided even if electrical power is interrupted.

Adding Value to Renewable Energy Systems



Distributed energy storage has become an important ally with state-of-the-art renewable energy technology. Dangling Rope Marina on the northern shore of Utah's Lake Powell was powered solely by diesel generators operated by the Glen Canyon National Recreation Area at an average cost of $.38/kWh. In 1996, a solar photovoltaic system, two propane-fueled engine generators, a battery system of 2.4 MWh, and a hybrid power converter were installed to replace the diesel system. The result is a savings of $100,000 per year as well as a significant reduction in noise and air pollution.

Mitigating Losses and Assuring Productivity



Lightning is a frequent visitor to Homerville, Georgia, often causing power disturbances to the local lithograph plant, a major employer in this small rural community. The Slash Pine Electric Membership Cooperative (SPEMC) and Oglethorpe Power Corporation, the local power providers, recognized that the occurrence of frequent short circuit faults on the utility's transmission and distribution systems caused by storms, falling lines and small animals were impacting their customer's operation. The search for solutions to these problems resulted in a collaboration between SPEMC, Oglethorpe, and the Electric Power Research Institute. As a follow-on to a US Department of Energy/Sandia National Laboratories research and development effort, they purchased and installed a battery storage system from AC Battery Corporation in 1996 that has improved power quality resulting in increased productivity and safety for the plant. This productivity enhancement is helping to ensure the plant's continued existence and expansion.

Ways to Use Energy Storage

For the Customer:
*Provide uninterruptible power supply
*Voltage support
*Power quality
*Peak Shaving
*Optimize renewable energy systems

For Transmission Networks/Substations
*Increase Power Flow
*Stabilization
*VAR support
*Load-leveling
*Peak shaving

For Distribution Feed
*Peak shaving
*VAR support
*Voltage support
*Power quality

Generation systems
*Firming intermittent power sources
*Frequency control
*Operating (Spinning) reserve
*Ramping/Peak shaving

Developers and Organizations

Utilities / Electricity Providers

Arizona Public Service (AZ)
Detroit Edison (MI)
National Power (UK)
Crescent Electric EMC (NC)
Northern States Power (MN)
Oglethorpe Power Corporation (GA)
Ontario Hydro Technologies (Canada)
Pacific Gas & Electric (CA)
Pacificorp (OR)
Potomac Electric Power Company (DC)
Salt River Project (AZ)
Southern California Edison (CA)
Southern Company (Georgia Power) (GA)
Tampa Electric Company (FL)

Engineering / Consulting Companies

The Brattle Group (MA)
Decision Focus, Inc. (CA)
ECG Consulting Group, Inc. (NY)
Electrochemical Engineering Consultants, Inc. (CA)
Energetics, Inc. (MD)
SENTECH, Inc. (MD)
SVS, Inc. (NM)

Product Manufacturers

AC Battery Corporation (WI)
C&D Charter Power Systems (PA)
Delphi Energy & Engine Management Systems (General Motors) (IN)
Exide Electronics (NC)
GE Drive Systems (VA)
GNB Technologies (IL)
Intermagnetics General (MA)
Omnion Power Engineering (WI)
Precise Power Corporation (FL)
SAFT America (GA)
Silent Power Systems (PA)
Superconductivity, Inc. (WI)
Trace Technologies (CA)
Yuasa-Exide (PA)
ZBB Technologies (WI)

Institutions

Electric Power Research Institute (CA)
Energy Storage Association (MD)
Energy Storage Technology Institute (TX)
International Lead Zinc Research Organization (NC)
Sandia National Laboratories (NM)
Solar Energy Industries Association (DC)

Using Stored Electricity

The value of energy storage lies in its flexibility, reliability and the strategic benefits it offers to its customers. Both electric utilities and consumers can incorporate energy storage to provide premium services (power quality or uninterruptible power, for example) or to take advantage of flexible rates by discharging the stored energy when rates are the most expensive and charging the system when electricity is inexpensive. Utilities can incorporate large-scale energy storage as load leveling facilities to maximize their return on investment by improving plant capacity factors.

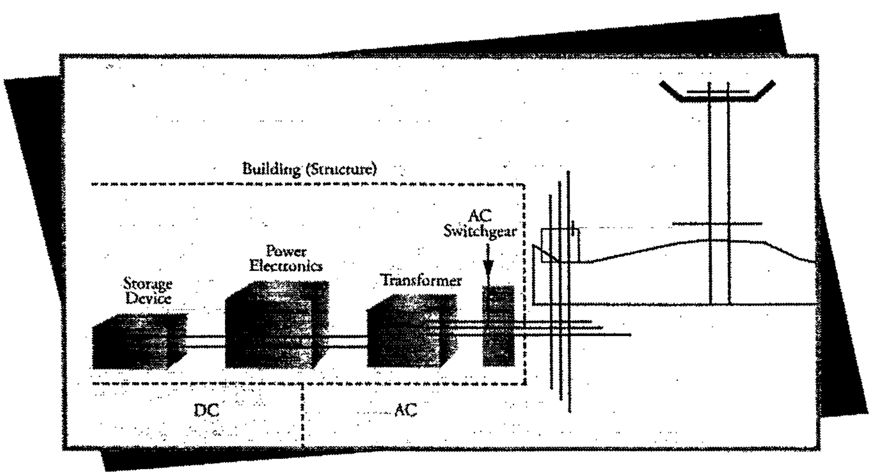
Special applications for energy storage are either grid-tied or grid-independent renewable energy systems. The emergence of renewable energy, especially wind and photovoltaics, has created broader market opportunities for energy storage. Whether buffering and firming the resource variation, or by matching the resource availability to the peak load and obtain the highest price for electricity, energy storage can enable greater use of renewable energy.

What Makes an Energy Storage System?

Generally four components are included in a typical energy storage system:

- **Storage device** such as a battery, supercapacitor, superconducting magnet coil, or rotating mass (flywheel)
- **Power electronics** to convert utility electricity (AC) into stored energy and back again
- **Control system** to receive signals from the user and direct the electronics when to turn on and off
- **Building or structure** to house the components and protect them from the weather

These components together are offered as a packaged system and are referred to as an energy storage system. Joint efforts between the U. S. Department of Energy/Sandia National Laboratories and the private sector are primarily focused on optimizing the output and compatibility of individual components into packaged systems. Fully integrated, reliable energy storage systems are critical to meet the needs of energy consumers and providers in a new electricity era.



Energy Storage offers exciting opportunities for researchers, product manufactures, electricity providers, and electricity customers. To learn more about these opportunities please contact:

ESA

Energy Storage Association
4733 Bethesda Avenue
Suite 608
Bethesda, MD 20814
Phone: 301-951-3223
Fax: 301-951-3235

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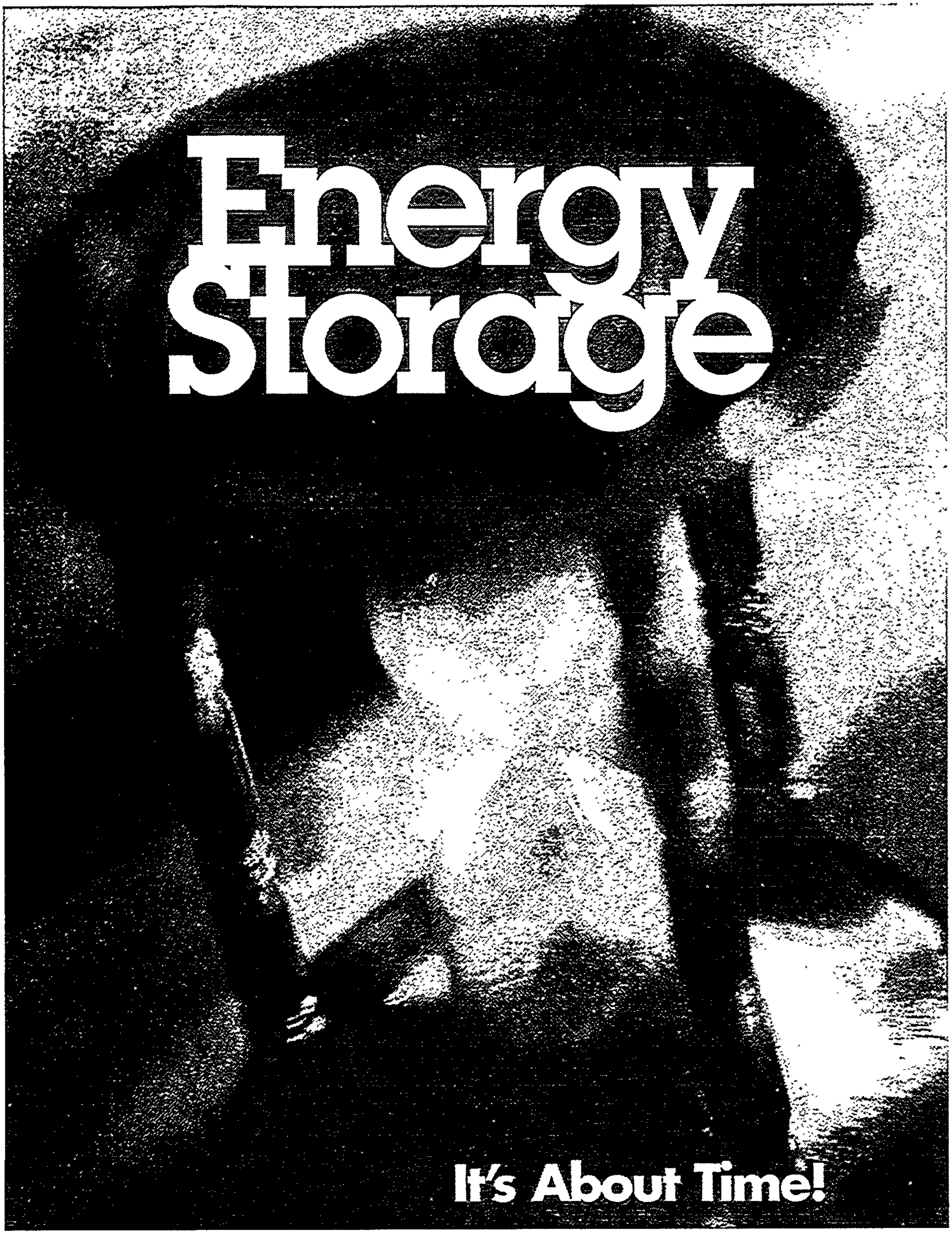
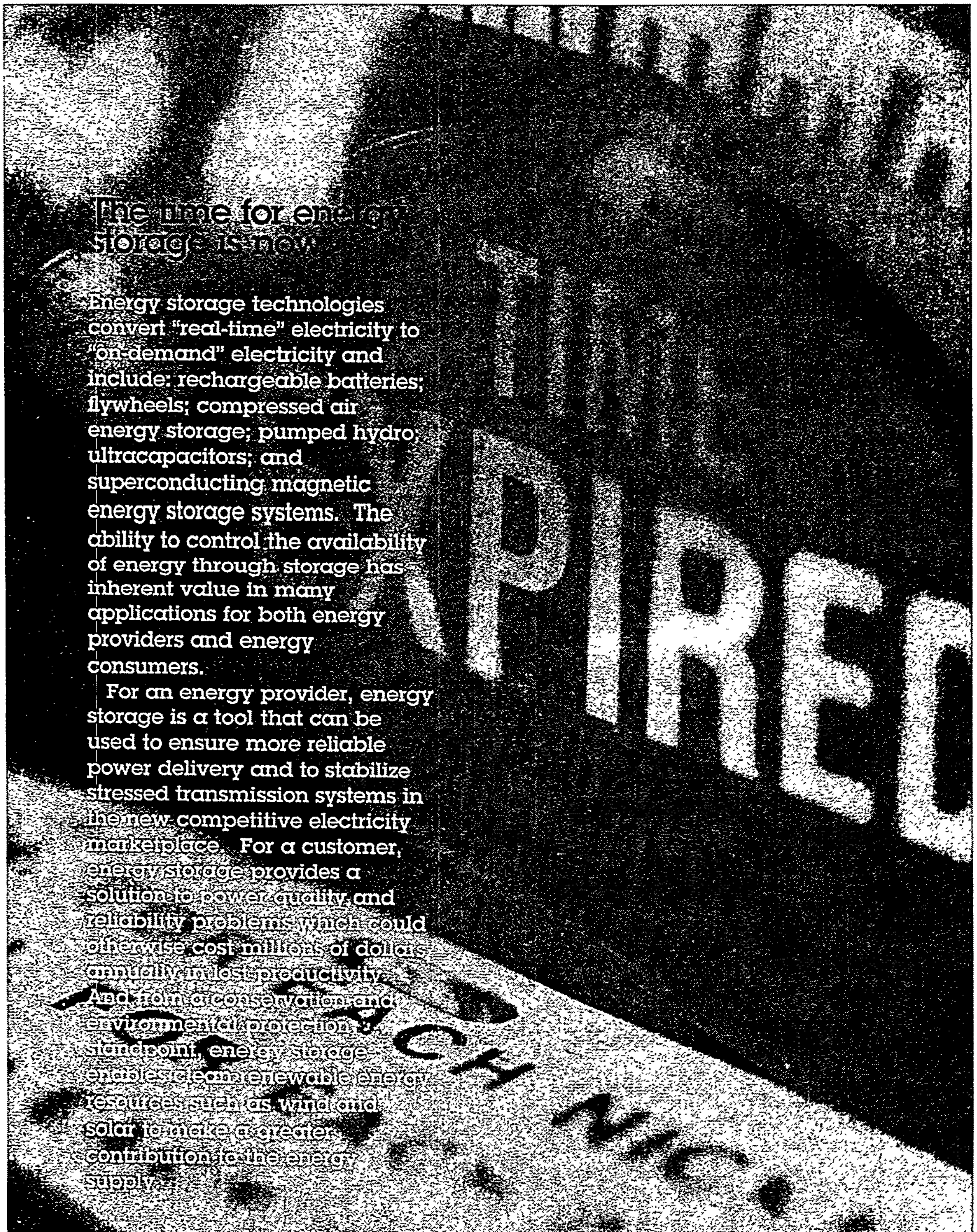

Energy
Storage
It's About Time!



The time for energy storage is now

Energy storage technologies convert "real-time" electricity to "on-demand" electricity and include: rechargeable batteries; flywheels; compressed air energy storage; pumped hydro; ultracapacitors; and superconducting magnetic energy storage systems. The ability to control the availability of energy through storage has inherent value in many applications for both energy providers and energy consumers.

For an energy provider, energy storage is a tool that can be used to ensure more reliable power delivery and to stabilize stressed transmission systems in the new competitive electricity marketplace. For a customer, energy storage provides a solution to power quality and reliability problems which could otherwise cost millions of dollars annually in lost productivity. And from a conservation and environmental protection standpoint, energy storage enables clean renewable energy resources such as wind and solar to make a greater contribution to the energy supply.

Energy storage

includes a broad range of technologies from very large pumped hydroelectric dams to compact ultracapacitors. Their common denominator is that they can take available electricity generated from any source and store it for a period of time. What distinguishes the various technologies is storage capacity and discharge time. Selecting a storage technology for an application requires an understanding of needs, such as: operation and maintenance issues; cost; required lifetime; and size constraints.

Most storage systems can perform multiple duties resulting in multiple benefits. For example, the same storage system installed by a utility for deferring a transmission upgrade may also provide voltage area regulation (VAR) support to stabilize the grid. These multiple benefits add to the strategic value of a storage system for almost any user.

Hybrid systems that integrate energy storage with renewable generation such as photovoltaics and a back-up generator greatly increase the availability and convenience of remote power systems. In some remote applications, hybrid systems have virtually eliminated the use of diesel generators and the associated emissions, fuel use, and noise.

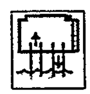
Technology Overview

The most well known and well developed storage technology is the **battery** which

converts electricity into chemical energy for storage and operates in reverse to deliver electricity to a load. Because batteries are modular they can be connected together to provide increasing storage capacity for many different applications.

Pumped hydro, already in use in many

utility systems, and **compressed air energy storage** (CAES), store potential energy either as water



behind a dam or air compressed in a large, underground reservoir. Because of longer response (minutes) times, these methods of energy storage are traditionally used for supplementing power generation.

Newer storage technologies include **superconducting magnetic energy storage**

(SMES), flywheels and ultracapacitors. SMES stores energy in a magnetic field that is produced by the flow of electric current in coils of superconducting wire. SMES wires are superconducting which means a current can circulate through them indefinitely without resistive losses.

Flywheels are dynamic storage systems which store energy in a rotating disk.

Discharge takes place when the rotational energy is translated into electrical energy in a motor generator. The steel rotors common in today's flywheel systems rotate at thousands of revolutions per minute (RPM.) Systems using composite materials will spin much faster, from 10,000 to 100,000 RPM, giving flywheel systems higher energy density.

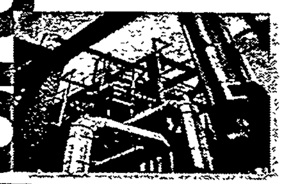
Ultracapacitors work by similar principles as the capacitors found in electronic circuitry.

They store energy at a high power density and can have charge/discharge cycles upward of 500,000. They may be used alone or in combination with batteries and flywheels in energy storage systems.

Power Quality and Reliability

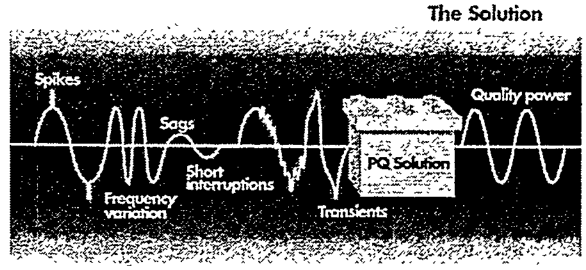
Count on it all the time....

To the average electricity consumer, small fluctuations in power quality are more of an annoyance than a hardship. Sags in the power delivered from the utility can cause lights to flicker or VCR clocks to reset to 12:00. However, to large industrial and commercial electricity consumers, any disruption in electricity supply, even ones that last a fraction of a second, can cost millions of dollars in lost productivity due to machinery malfunction or shutdown. The rapidly expanding telecommunications industry also depends on reliable and high quality power to keep data systems and control centers in operation.



Before restructuring, electric utilities were required to ensure a level of reliable electric service to all customers. In the future, those customers wanting greater reliability might have to pay a premium for such service from the utility. However, industrial and commercial facilities with critical systems requiring high quality, reliable power beyond what is ensured by the utility or to avoid paying the high price for reliable power, have been taking their own precautionary measures. Facilities such as manufacturing plants and hospitals have installed uninterruptible power supply (UPS) systems and back-up generators to keep the electricity flowing during a power disturbance. Energy storage is the key component, not only in the commonly used battery-backed UPS systems, but also in the newer alternatives to the UPS including flywheel-UPS systems and SMES that will be designed to provide ride-through power during a power interruption and to correct voltage sags and other anomalies.

The Solution



Transmission and Distribution

Managing time...

Restructuring of the electric utility industry is forcing energy providers to find ways to minimize costs while improving services. One way to reduce electricity prices and gain a competitive edge is to transfer electricity from regions with cheap generation such as Northwest hydropower, and made available to regions with high electricity rates.

The reserve margins normally maintained by utilities on the transmission and distribution system to absorb load swings will be reduced with the increase in bulk power transfers. Although the results may be less expensive

The Economics of Power Quality

To assess the value of an energy storage system in a power quality application, data from two independent studies has been combined. The National Power Laboratory conducted a survey of the frequency of power quality events at a number of different sites, and Duke Power collected information from its large industrial and commercial customers on the cost of several power disruption conditions.

Extrapolating the data from the two studies, the annual estimated cost of power quality disturbances from voltage sags and momentary outages is $509,000 from facility downtime and lost productivity. The installation of a $1,000,000 energy storage system with a 20-year life span would eliminate the power quality disturbances therefore avoiding the $509,000 in lost productivity. The payback on the energy storage system would be less than two years but the benefits would accrue for many more.

Source: National Power Laboratory, Power Quality Study, Best Power Technology, Inc

Making Electrons from "Green" Resources

Energy production is not always a clean process. Coal, oil and gas-fired power plants emit air pollution as a by-product of the combustion processes used to produce energy. This pollution is sometimes visible as a brown haze hovering over power plants. When renewable energy such as wind, solar or hydro power is used to produce electricity, there is no resulting air pollution. These "green" technologies (named for their negligible impact on the environment) offer a cleaner and more sustainable alternative to traditional energy production methods.

Energy storage will play an important role in the large-scale success of renewable energy. Storage allows energy produced from intermittent renewable resources to be stored and then delivered to meet demand. According to the President's Council of Advisors on Science and Technology "wind [generation] with compressed air energy storage in the plains could one day replace retiring baseload coal-fired plants."

Source: Report of the Energy Research and Development Panel, The President's Council of Advisors on Science and Technology November 1997

power it may come at the cost of potentially less reliable power. Low voltage conditions similar to those that resulted in the West Coast power outages in July of 1996 can be caused by over loading the transmission and distribution system and reducing the system's ability to respond to load swings.

A storage system can help support the transmission system by giving utilities the ability to increase capacity and stabilize voltage levels on the transmission lines as needed.

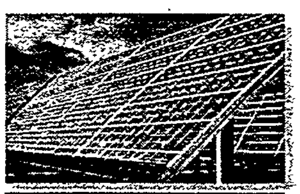
Storage can also extend the life of generation units by responding to load swings that would otherwise require a more rigorous duty-cycle from the unit.

At the distribution level, lightning strikes, nesting animals, and human accidents that interfere with overhead lines can result in voltage drops or other electric perturbations. Storage can help protect and prolong the life of existing equipment or other physical assets by absorbing real power and regulating voltages. Storage has the added benefit of allowing utilities to incrementally add capacity when and where it is needed to solve specific capacity bottlenecks.

Renewables

When the time is right...

Renewable resources such as wind and sunlight are domestic energy resources available in large enough quantities to supply most of the U.S. electricity demand. But a major barrier to utilizing renewable energy on a large scale is intermittence, the availability of the resource relative to demand. The sun is only available during daylight hours and the wind when weather conditions permit, neither of which necessarily fit electricity demand patterns. In combination with renewable resources, energy storage can increase the value of photovoltaic and wind-generated electricity by making supply coincide with demand.



According to the President's Committee of Advisors on Science and Technology, "if intermittent renewable energy technologies are to make very large contributions to electricity supplies in the longer term.... technologies are needed that would make it possible to store energy for many hours at attractive costs."

Hybrid renewable systems integrating photovoltaics (PV) or wind with storage and/or generator sets are gaining popularity for off-grid and remote power applications. It is anticipated that hybrid renewable systems will also become more widely used for grid-tied applications. Larger systems may be used at utility sites to generate excess capacity and smaller systems in residential applications.

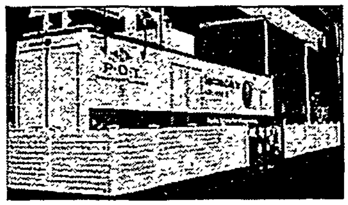
Storage in Action

PROBLEM: POWER FLUCTUATIONS AND LOAD SWINGS
SOLUTION: BATTERIES HANDLING PEAK SHAVING

Metlakatla Power and Light serves 800 customers on a small island 25 miles off-shore from Ketchikan, Alaska. Its largest customer, a sawmill with a heavy motor load, was creating 400-900 kW load swings on the utility's system. To solve problems of voltage and frequency fluctuations on its distribution system, Metlakatla P & L installed a 1.0 MW, 1.4 MWh battery energy storage system with its existing 5.0 MW hydro and 3.3 MW diesel generation. The results were immediate. The battery corrected frequency and voltage fluctuations and accommodated load swings, the root cause of the power fluctuations. The battery storage system also provides the spinning reserve otherwise supplied by the 3.3 MW diesel engine. ▪ With the battery to handle peak-shaving, the hydro plants have been able to supply almost all of the island's baseload power; and use of the diesel generator has been greatly reduced. For the first eight months of operation, diesel fuel utilization has been reduced by 180,000 gallons, translating into a savings of about $20,000 per month in avoided fuel costs. The risk of diesel spills during transport and storage has been greatly reduced. ▪ In addition to providing reliable power to the mill, many of the utility's customers have reported improved power quality and have noted how much quieter it is without the diesel generator. The utility is enjoying additional spinning reserve and frequency control thanks to the battery storage system.

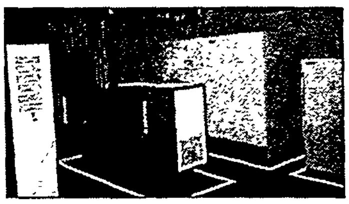
PROBLEM: VOLTAGE SAGS COST CUSTOMER DOWN-TIME
SOLUTION: SMES RIDES THROUGH VOLTAGE DIPS AND CORRECTS VOLTAGE LEVEL

Stanger Mill, located in the Kwa-Zulu Natal region of South Africa, is operated by SAPPI Limited, a manufacturer of high quality wood-free coated paper and tissue paper from locally grown sugar cane. The mill employs a high-speed process which continuously feeds a paper web through several independently driven, speed-synchronized units. The synchronized processes are easily disrupted by voltage sags, even as short as 200 milliseconds, in the power delivered from the utility. The resulting loss of product and production down-time was impacting the mill's economics as well as its ability to compete in the global market. ▪ The power quality problem at the Mill was traced to voltage sags on the distribution line. Attempts by the utility to mitigate the problem failed. So it turned to "best-fit-technology" to solve the problem at the customer site. The technology of choice was a Superconducting Magnetic Energy Storage System (SMES system.) The SMES system provides one Megawatt of electrical energy for more than one second to ride through the dips while the system inverter boosts the voltage to the mill's prescribed level. ▪ The SMES unit was specially designed for the mill with a "dip protector" configuration that allows it to stay connected to the utility line while the voltage is boosted, thereby using energy available from the utility along with the stored energy for the ride-through. This permitted an appropriate sizing of the SMES unit for the particular application. ▪ Mill operators reported that the system has achieved a 100% success rate, protecting against 45 dips of which over half would have shut down the plant.



PROBLEM: POWER DISRUPTIONS IMPERIL SENSITIVE ELECTRONIC EQUIPMENT
SOLUTION: FLYWHEEL-UPS SYSTEM PROVIDES SUFFICIENT RIDE-THROUGH

Greeley, Colorado is home to **Hewlett Packard's** Hard Copy, Home Imaging and Storage Systems Divisions that are responsible for the production of optical storage libraries, image/text scanners and high-end computer subsystems. The facility's sensitive manufacturing and testing systems and processes rely on clean, well regulated AC power. But its location at the end of a long radial distribution line exposes the facility to frequent power disruptions, many of which are caused by the area's frequent lightning storms • Hewlett Packard installed a UPS system with a battery back-up to protect critical loads in the plant. However, this UPS system was not capable of providing the necessary ride-through to transfer to the auxiliary diesel generator during major disruptions. In 1996, the UPS was replaced with an extended ride-through rotary power system that consists of a flywheel and a UPS system. • Energy is stored in the flywheel which spins at about 2250 rpm. The flywheel's DC output is fed directly to the UPS system and can provide 15 seconds of ride-through which is sufficient to either transfer to the back-up generators or, if necessary, to allow for an orderly shut-down of systems. • In the first seven months of operation, the flywheel-UPS system smoothly transferred power to the engine generators more than 30 times, and, in 10,000 hours of operation, has performed reliably and trouble free. The facility is now experiencing a degree of power protection for critical loads never before known. The local utility also benefits from the new system. It no longer needs to notify the facility of planned load-shifts or area maintenance that previously caused problems in the facility.



PROBLEM: UNCERTAIN PEAK CAPACITY FROM THE LOCAL UTILITY
SOLUTION: PHOTOVOLTAIC-STORAGE SYSTEM HYBRID PROVIDES PEAK CAPACITY AND EMERGENCY POWER

In early Spring 1997, the **U.S. Army's Yuma Proving Ground** in southwest Arizona became owner/operator of a 825-kW photovoltaic hybrid power plant. The system was built for two primary functions—to offset peak demand and to provide emergency power for the site's water treatment plant during utility outages. • The Department of Defense, with assistance from the Department of Energy and other agencies, undertook the planning and design of a photovoltaic power system in response to a new policy instituted by the Western Area Power Administration that required large customers to formulate an Integrated Resource Plan which included developing renewable energy resources. The Proving Ground was anticipating a 40% increase in electricity use as a result of the transfer of activities to the facility from other military bases scheduled to be closed. Faced with buying expensive power from the local utility to cover additional load growth, base planners decided that a new, independent power supply was needed • The 441-kW (p) photovoltaic array was designed with a one-axis tracking system to follow the sun and maximize the benefits of photovoltaics. A 5.6 MWh battery load-leveling system was integrated to provide a total of 825-kW capacity with a guaranteed minimum of 450-kW peak-shaving capacity on overcast days. The battery is charged when the output from the photovoltaics exceeds the demand for electricity, otherwise it is charged at night when power is less expensive from the utility grid to ensure a full recharge at the end of each day. • The battery also provides back-up power to the waste-water treatment plant and emergency communications in the event of a utility power outage. The system is able to operate while isolated from the utility grid. So when power from the utility is interrupted, the system automatically switches to stand-alone mode. When utility power is restored, the system automatically resumes its grid-connected mode. • In addition to the direct benefits of the system (namely excess capacity and reliability) the Department of Defense will be gaining valuable experience with renewable power systems.

Energy Storage Association

The Energy Storage Association is a membership trade association established to foster development and commercialization of energy storage technologies. Its mission is "to promote the development and commercialization of competitive and reliable energy storage delivery systems for use by electricity suppliers and their customers."

For information regarding membership or energy storage uses, contact the ESA at

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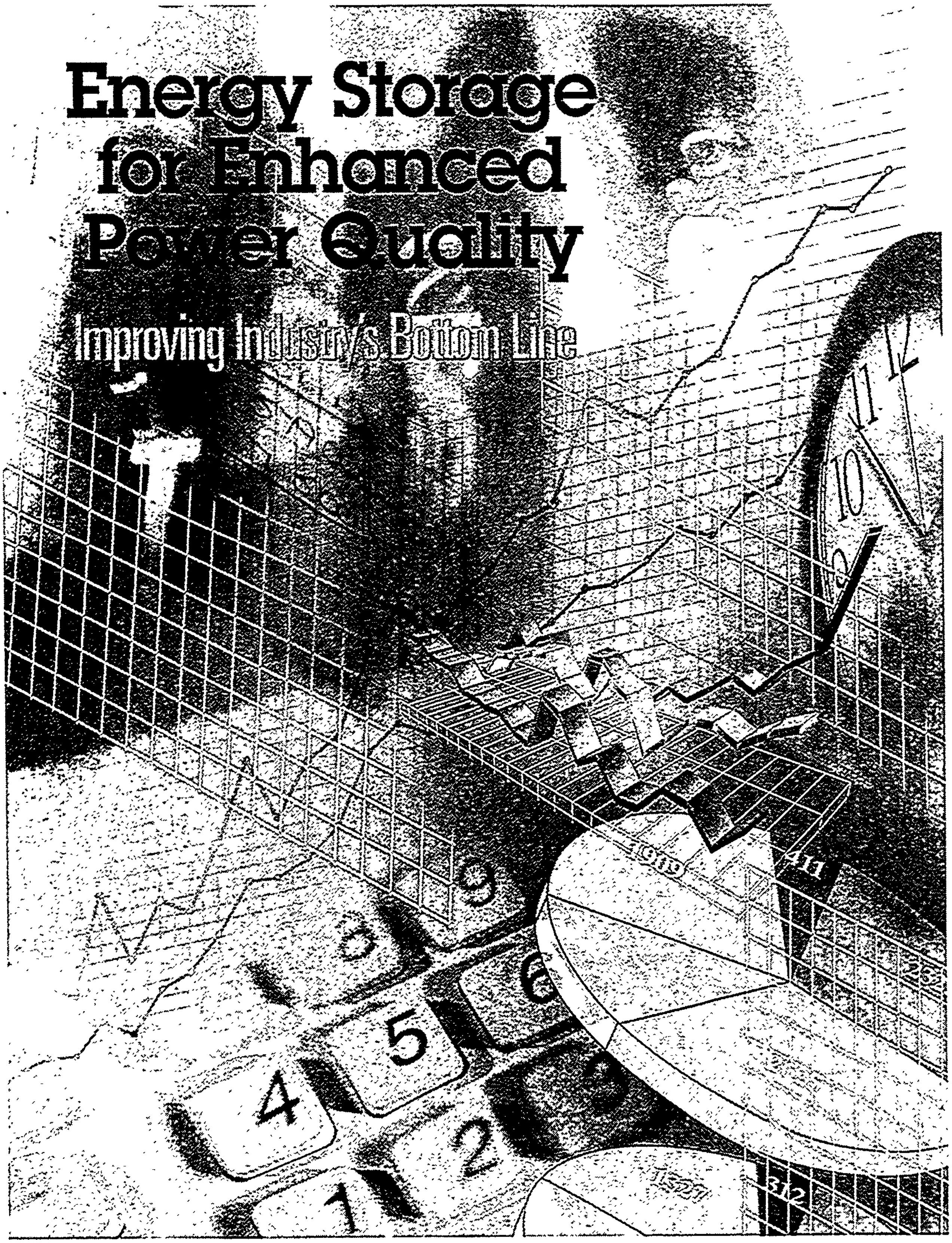
This document was prepared by the Energy Storage Association with assistance from the Solar Energy Research and Education Foundation. Support for this document was provided by the Energy Storage Systems Program of Sandia National Laboratories.


Energy Storage
for Enhanced
Power Quality
Improving Industry's Bottom Line

"Lightning and overvoltage transients cause millions of dollars in damage to cellula
alone is estimated to be $1.2 billion annually, and this doesn't inclu

Principles of Lightning Protection fo

The advanced electronic equipment found in the modern workplace requires an unparalleled level of electricity reliability. While microcomputers, adjustable-speed drives, and robotic devices are setting the standard for manufacturing and communications, they are also necessitating innovative products and services from electricity suppliers to meet the demand for quality power. When power quality is degraded, large industrial and commercial customers can lose valuable product, suffer costly production setbacks, or waste resources due to corrupt data systems.

Energy storage devices that include batteries, flywheels, capacitors, or superconducting magnetic energy storage, can solve power quality problems and save industry millions of dollars each year, adding to their bottom line.

At what cost?

Quantifying the cost of power quality problems is difficult because the value of reliable power varies from one user to another. The cost may be expressed in idled labor costs, cleanup costs, restart costs, and damage to equipment and lost product. Two estimates have been derived for the cost of power quality problems using different methods. The Institute of Electrical and Electronic Engineers' estimated the cost of power quality events to be $25 billion a year based on one and a half to three cents of every sales dollar for the U.S. manufacturing industry going to solve power quality problems. The Electric Power Research Institute, using an estimate of idled employee hours in the commercial sector, suggested $400 billion annually.

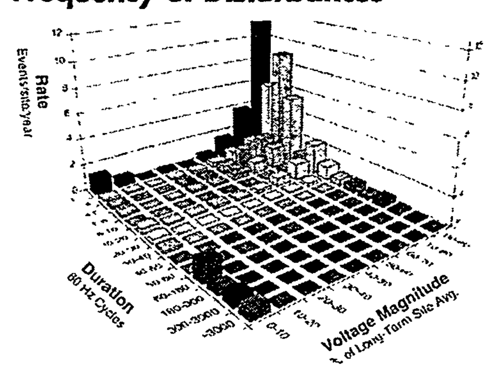
Sources: Carl DeWinkel, Storing Power for Critical Loads, IEEE Spectrum, June 1993; Power Quality in Commercial Buildings, EPRI BR105018.

Nature of the Problem

Transients, frequency disturbances, and variations in steady state of the electric supply are the broad categories of power quality problems. Voltage sags and swells lasting only a fraction of a second are typically the most damaging to sensitive process equipment of large industrial companies.

According to an analysis of U.S. power quality problems conducted by Sentech, Inc. for Sandia National Laboratories, the national loss experienced by large industrial companies due to just voltage sags and undervoltage conditions is an estimated $114 billion annually.

Frequency of Disturbances



The Electric Power Research Institute conducted a two year (1993-1995) study of power quality levels on U.S. distribution systems. Three hundred sites were monitored on 24 utility systems. The findings reveal that a typical distribution system customer experiences about 50 events per year where the voltage drops below 90% of normal, and there are about 20 events per year where the voltage drops below 70% of normal.

adio and telecommunications installations each year. Damage to equipment in the US
the losses associated with lost productivity and business downtime."

elecommunications Facilities, A.J. Surtees, ERICO Inc., (Solon, Ohio), *Power Quality*, May/June 1998.

Energy Storage May Be the Answer

How power quality problems are solved will depend on the source, the duration, the frequency and the impact on end-use equipment. A solution may be as simple as improving the wiring in a facility. A larger problem may require more complex solutions. In the emerging competitive electricity marketplace, electricity suppliers will be working closely with their customers to develop cost-effective solutions to power quality problems.

There are a variety of tools available today for mitigating power quality events and they may be applied at different levels of intervention:

- At the substation level to eliminate or modify the source of the disturbances;
- At the facility level to eliminate or modify the path for the disturbances between the source and the affected equipment; and
- At the device level to protect the affected equipment.

Modifying the source at the substation level may only be cost effective if many downstream customers are affected. At the facility level, an entire plant or process line can be protected which may be required by large manufacturing or commercial facilities. A device level approach can be used to shield a single, highly sensitive piece of equipment.

Energy Storage Products

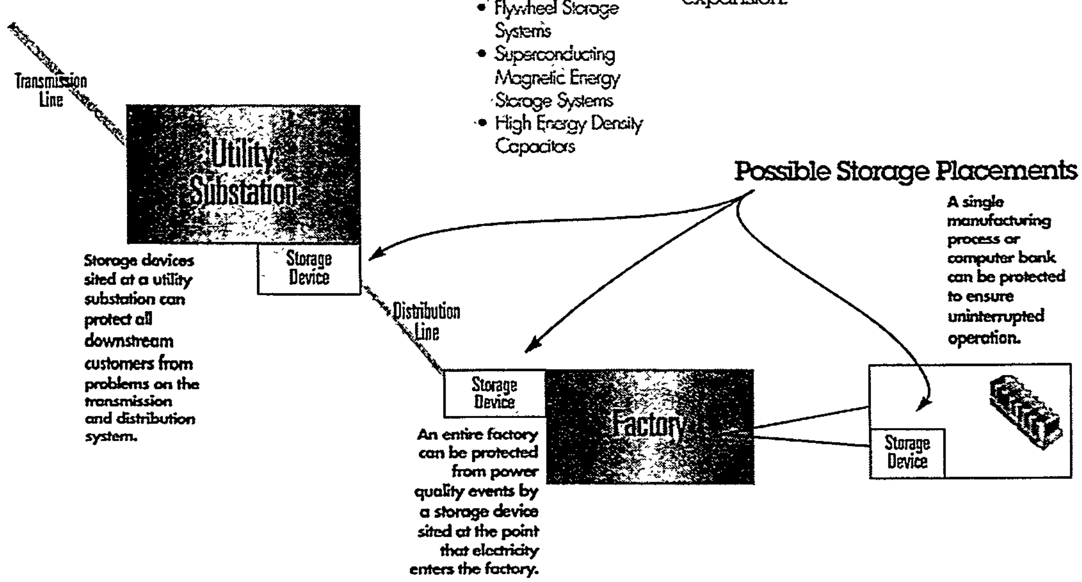
- Power Quality Battery Storage Systems
- Flywheel Storage Systems
- Superconducting Magnetic Energy Storage Systems
- High Energy Density Capacitors

Solutions to Power Quality Problems

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Energy Storage	X	X	X	X	X
Surge arrestor	X				
Filter	X			X	
Isolation transformer	X			X	
Constant voltage transformer		X			
Dynamic voltage restorer		X			
Backup generator			X		

[illegible]

Energy storage systems are a flexible solution to power quality problems. Unlike other power quality solutions, storage devices are able to address more than one problem at a time, such as voltage sag protection and power factor correction (see above). Because they come in a variety of sizes and capabilities, storage systems can be used at any mitigation level, from device to substation. Storage systems are often modular in design and can be sized for a specific application. They can also keep up with facility expansion.



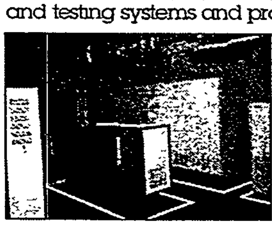
Actual Costs of a Brief Power Outage

Semiconductor Plant: $80,000/hour product loss • Paper Mill: 30 hours of cleanup • Glass Plant: Weeks of cleanup • Mutual Fund Facility: Loss of phone system for several hours • Hospital: Lost critical patient data; blood analysis corrupted • Computer Center: $600,000 data processing loss.

POWER QUALITY $UCCESS STORIES

FLYWHEEL

A computer imaging facility's sensitive manufacturing and testing systems and processes rely on high quality and reliable power. But, its location at the end of a distribution line exposes the facility to power disruptions, many caused by the area's frequent lightning storms. A 100 kVA extended ride-through rotary power system built by International Computer Power (City of Industry, CA) and consisting of a flywheel and an uninterruptible power supply, was installed to provide a minimum of 15 seconds of full-load ride-through. The ride-through protects sensitive equipment from short-term power disruptions and for longer disruptions allows for transfer to back-up generators. Since installation, the facility has experienced an unprecedented degree of power protection for its critical loads.



BATTERY

A 2000 kW power quality battery energy storage system from Omnion Power Engineering Corp. (East Troy, WI), was installed at a lithograph plant to protect against faults on the utility transmission and distribution system that were causing plant shutdown and resulting loss of product. The high capacity, quick discharge system responds within approximately 1/4 cycle to correct voltage sags and swells and momentary interruptions. The improved power quality has increased plant productivity and the safety of its workers. This productivity enhancement is helping to ensure the plant's continued existence and enable its future expansion. The plant manager credits the battery energy storage system with an 18% increase in productivity and a 30% reduction in scrap. During the first two years of service, it has protected the plant from more than 150 voltage sags and brief outages.

SUPERCONDUCTING MAGNETIC ENERGY STORAGE (SMES)

Events on the power grid feeding a vinyl siding production facility were causing voltage drops of twenty-percent or more and lasting for one second or less. With virtually every voltage drop the facility's sensitive synchronized extrusion processes shut down leading to time intensive clean up and recalibration. According to the production manager, each outage was costing on the order of $2,900 in lost product. The facility's local utility contacted American Superconductor Corporation (Middleton, WI), manufacturer of a micro-SMES power quality system, and together they determined that it was the motors that drive the extrusion lines that needed protection. The solution to the facility's power quality problem was the installation of a 1400-kVA superconducting magnetic energy storage system (SMES). The SMES unit detects voltage sags and responds within 2-4 milliseconds to provide the power to avert shutdown. In the first year of operation, the SMES has protected the facility's production lines from more than 139 voltage sags.

ESA

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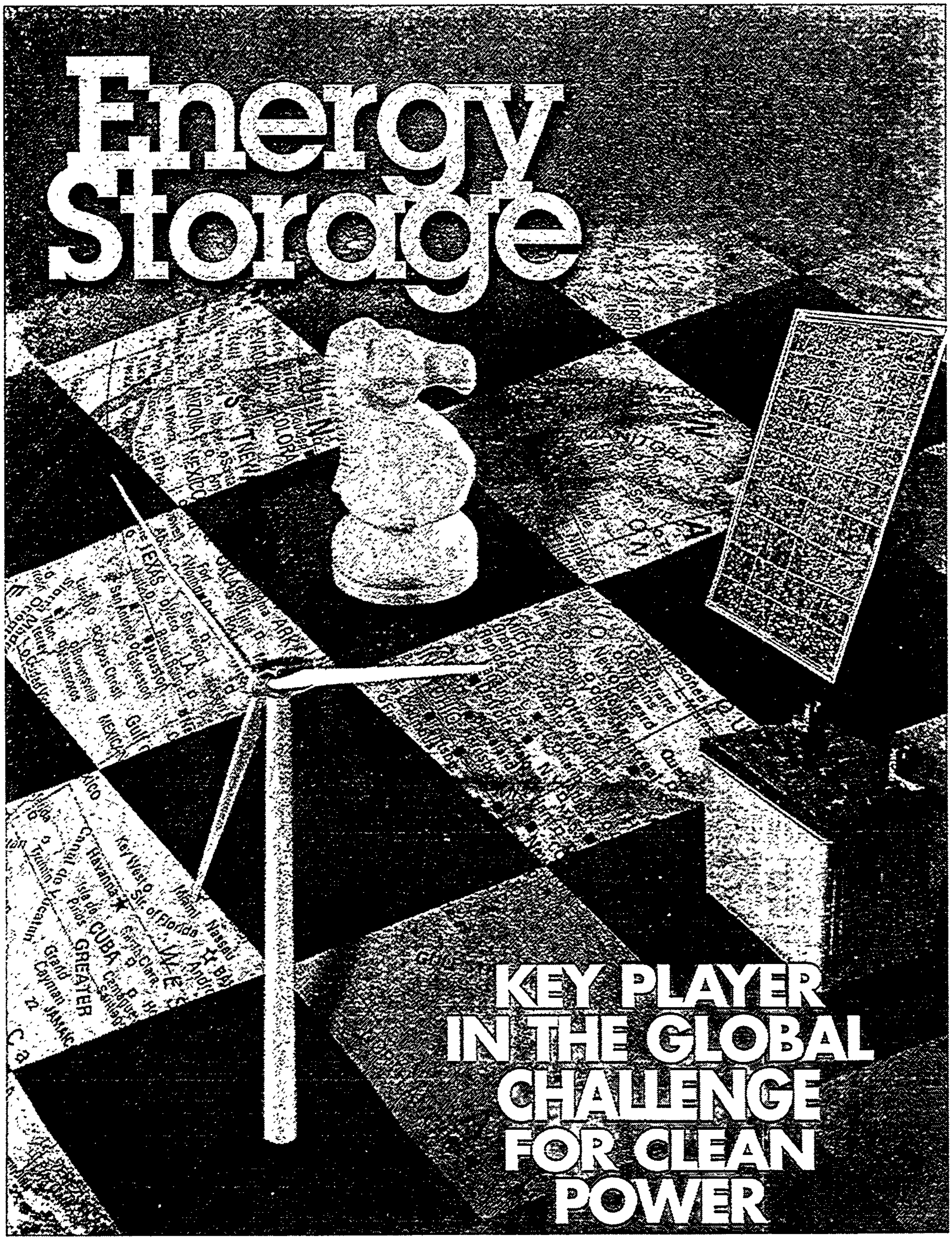

Energy Storage
KEY PLAYER IN THE GLOBAL CHALLENGE FOR CLEAN POWER

Both U.S. and international scientists have declared 1998 to be the hottest year on record. The worldwide average surface temperature, about 58 degrees Fahrenheit, was measured at 0.27 degree above the previous record set only a year ago. ▪ The World Meteorological Organization (WMO), a United Nations-sponsored agency made up of more than 180 meteorological organizations from around the globe, reported that 1998 marks the 20th consecutive year in which global surface temperatures were above normal, and the third record-breaking year since 1995. Seven of the hottest years on record have occurred in this decade. ▪ An official release from the U.S. National Aeronautics and Space Administration issued as the 1998 data was announced stated "El Nino, by itself, cannot account for either the observed long-term global warming trend or the extreme warmth of 1998."

ENERGY AND GLOBAL CLIMATE CHANGE—NEW SOLUTIONS NECESSARY

An ever-growing body of science indicates that the world's climate is [illegible] the most recent decades [illegible] increase in natural disasters and insured losses resulting from these increases. Predictions of potential long-term impacts resulting from changes in the earth's temperature and atmosphere include rising water levels, shifts in agricultural production, and many new health problems that can only add to the potential economic impact of global climate changes.

Harmful gases and particulates are considered to be the primary cause of global climate change, and they come from a variety of activities. However, the production of electricity and transportation are by far the most polluting.

Pollutant Emissions for Electrical Generation (g/kWh)

	CO_2	NO_x	SO_x
Coal	322.8	1.8	3.400
Oil	258.5	0.88	1.700
Natural Gas	178.0	0.9	0.001
Nuclear	7.8	0.03	0.030
Photovoltaics	5.3	0.007	0.020
Biomass	0.0	0.6	0.140
Geothermal	51.5	trace	trace
Wind	6.7	trace	trace
Solar Thermal	3.3	trace	trace
Hydropower	5.9	trace	trace

Fossil fuel emission factors provided by the American Gas Association; nuclear and renewable energy sources from the Council for Renewable Energy Education.

As all nations struggle individually and collectively with the problems of global climate change, the most significant issue seems to be the cost of change. Almost everyone agrees that cleaner air, water, and soil would be beneficial; but debate hinges on whether or not those benefits are affordable. This issue of cost is particularly important to the energy sector, as the cost of energy directly impacts the cost of all other goods and services produced.

Outside of the debate on global climate change, another worldwide trend is underway that will further impact how energy is produced and what it will cost. That trend is green pow

Environm

are also being

around the world,

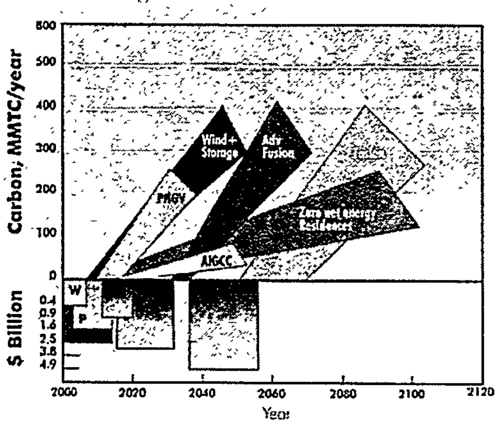
underway in Aust

Netherlands, Norw

Kingdom

ARE NEW TECHNOLOGIES THE ANSWER?

There are strong indications that new, less-polluting technologies can—and will—emerge in the marketplace in the near future. A report issued in 1998 by the President's Committee of Advisors for Science and Technology (PCAST) included an analysis of the carbon-reduction potential of new energy technologies. The graph below summarizes the findings and shows that wind energy combined with energy storage represents the least-cost, quickest-to-market



PNGV=Electric vehicles AIGCC=Advanced Integrated Gasification Combined Cycle

This illustration depicts an approximate range of times when a technology might be available for commercialization as determined by PCAST. Where the wedges (which represent new, cleaner technologies) meet the horizontal time axis is matched with the approximate dollar amounts that are estimated to be required to bring each technology to full commercialization. The graph also indicates the projected reduction in carbon emissions per technology.

- fostering sustainable and stabilizing economic development; and
- strengthening U.S. leadership in science and technology.

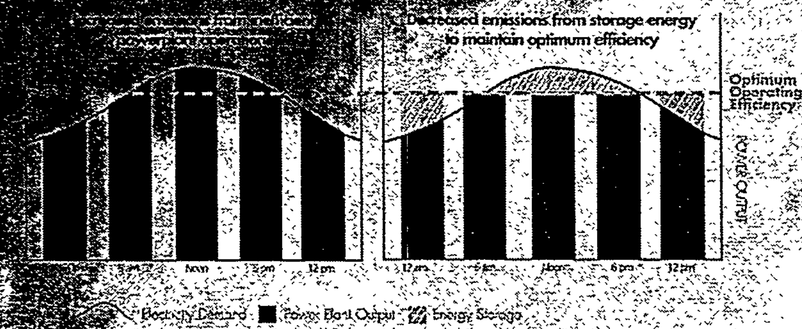
ENERGY STORAGE: A CRITICAL PART OF THE SOLUTION

Energy storage technologies include both some very tried and true products, such as batteries and flywheels, and some newly commercialized products such as superconducting magnets and compressed air. But all have three attributes in common:

- they provide the necessary flexibility to optimize power produced today from conventional fuels;
- they enable the introduction of new, cleaner technologies.
- they improve reliability of electric networks.

ENABLING RENEWABLE ENERGY

Renewable energy technologies, such as solar, wind, geothermal, and bioenergy, are far less-polluting than fossil-based fuels. Nearly every region or nation of the world has indigenous sources of renewable energy that could provide some



IMPROVING OPERATING EFFICIENCY REDUCES POLLUTION

The perfect energy generating system — if one could be operated — would deliver power at maximum efficiency and minimum emissions resulting in greatest profit. That goal is difficult to achieve because it is impossible to consistently match energy supply with demand while maintaining power plant efficiency. The necessity to vary power generation causes the system to function less efficiently, which results in greater emissions. Electric power plants must instantaneously match demand to avoid outages or brownouts. Storing energy that is produced at times when power generators are operating at maximum efficiency, but demand is below production, significantly reduces emissions as well as economic losses. Power generating units that vary output operate inefficiently, increasing pollution emissions. The pollution often coincides with pollution from other sources (cars, factories, etc.), which contributes to dangerous levels of air contamination and is also believed to increase the earth's atmospheric temperature. An electric system using energy storage is optimal since energy can be stored and released as demand increases. The added cost of energy storage is offset by improved asset utilization and a reduction in environmental burden.

or most of their energy needs. Despite these advantages, renewable energy still provides only a fraction of the world's energy needs.

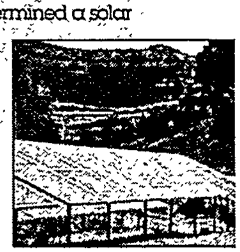
Although sources of renewable energy are abundant, their inherent nature may require other components to create systems capable of matching resource to demand. Energy storage is one of the most critical balance-of-systems components.

It allows for energy to be saved during periods when the sun or wind are capable of producing energy. That stored energy can then be released when demand requires. Storage also allows for energy to be collected during times of low demand and then offered at a time when demand—and the price of energy—is highest.

HOW ENERGY STORAGE WORKS

Three recent projects clearly demonstrate how energy storage is simultaneously helping make renewable projects more cost-effective, helping suppliers meet ever-growing demands for energy, and improving the environment .

Energy engineers at the **U.S. Army's Yuma Proving Ground** recently faced a critical situation. They projected a rapid 40% increase in the base's peak energy demand due to consolidation of military activities from around the country. The increased demand would mean purchasing power at peak rates. It also raised concerns about the reliability of a sufficient supply of clean water, a very limited and valuable commodity in Arizona's desert region. In addition, the base's energy supplier, the Western Area Power Administration, required their larger customers to implement integrated resource plans to meet the country's challenge of reducing emissions. After careful consideration, the Army determined a solar system with energy storage would best address all the concerns of sufficient and reliable power, cost control, clean air, and water.



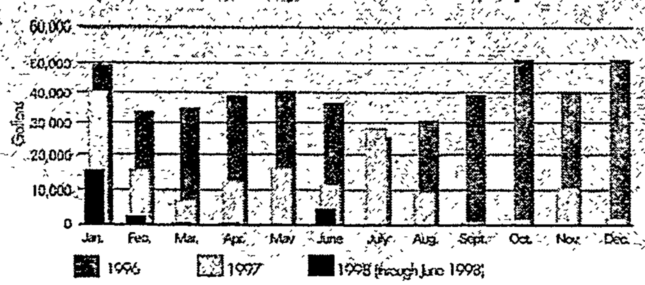
A tracking photovoltaic system with integrated battery storage was designed and installed to maximize the production of emission-free solar energy when the sun was shining and then store the excess energy for delivery during evenings or on overcast days. It also assured sufficient back-up power to operate the site's water treatment facility during utility outages.

Two other installations are significantly reducing fuel emissions. **The Dangling Rope Marina in Utah** is operated by the National

[illegible] country's most pristine areas. In August of 1996, a 9.6 kW photovoltaic system with propane backup and [illegible] was installed, replacing the all-[illegible] system that had been used [illegible]. In the first year of operation, the [illegible] availability was 99.6% and fuel use was reduced by nearly one-half. Not only has Dangling Rope saved considerable money [illegible] it has also substantially reduced the risk of diesel fuel spills, contamination and noise as well.

[illegible] system operated by Metlakatla Power and Light serves 800 customers including a sawmill on a small island in Alaska. In 1997, [illegible] 4 MWh battery storage system was added to the existing [illegible] MW hydro and [illegible] MW diesel generators. The storage system has added much greater stability to the distribution system on the island. It has also allowed the hydro plants to supply almost all of the island's baseload power, and the use of diesel fuel has been greatly reduced—from 476,189 gallons in 1996 to less than 23,000 in 1998.

Metlakatla Monthly Diesel Fuel Consumption



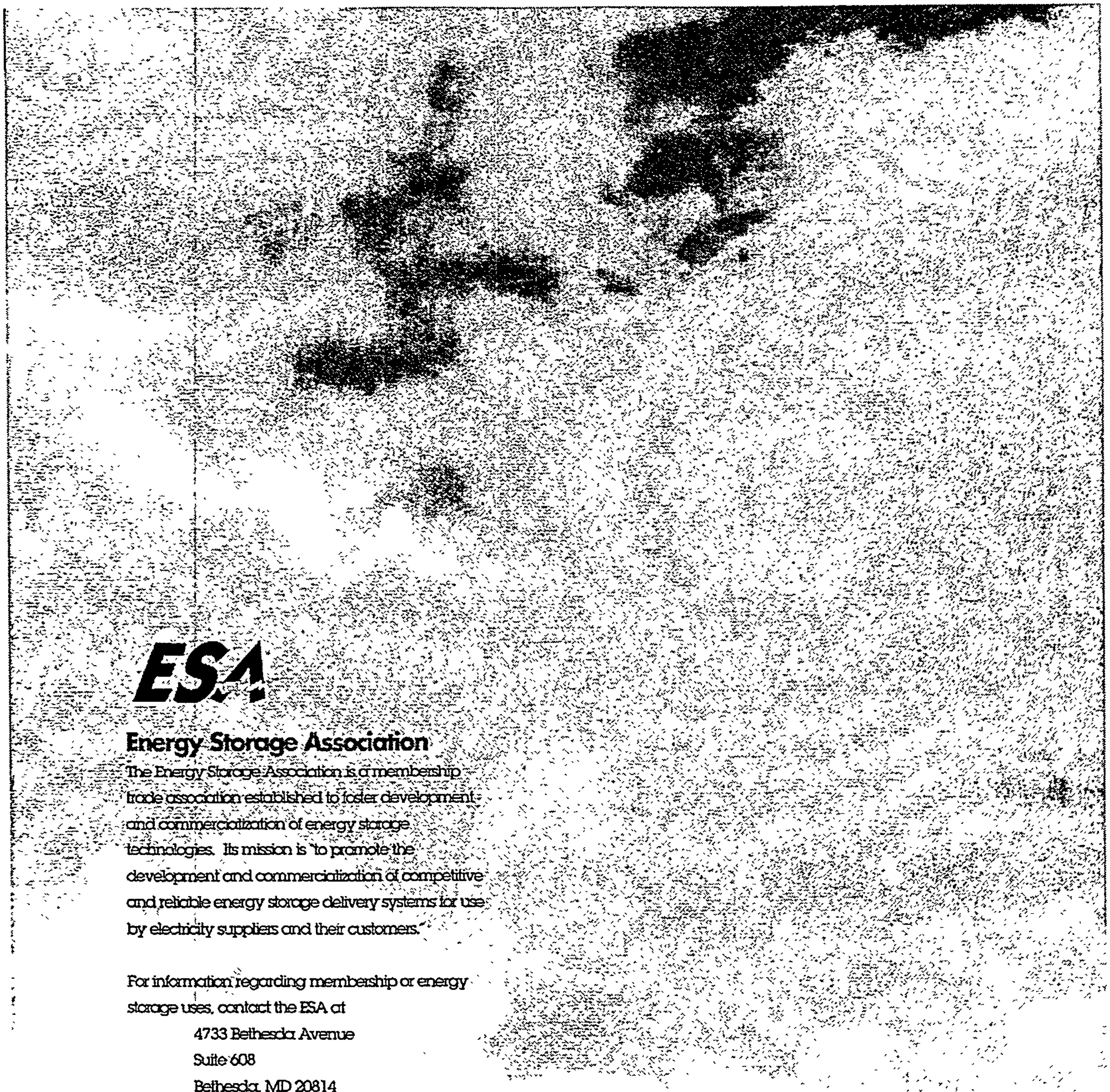
ENABLING SUSTAINABLE ECONOMIC DEVELOPMENT

Currently, almost 75% of the world's population is without electricity. Some rely on diesel generators but have to contend with the problems of erratic fuel supply, maintenance, noise, and pollution. Renewable technologies with energy storage can allow communities without power or conventional fuels to develop indigenous resources in the most cost-effective manner and provide them the flexibility and management tools to deliver [illegible] power. A new project in Peru [illegible] how remote communities can [illegible] renewable energy to provide energy and foster economic development.

Many of the villages in Peru's Amazon River Basin are without power. A joint, public/private partnership between the U.S. and Peruvian governments and the solar and energy storage industries is focused on the social and economic aspects of delivering clean power to 50 villages in the region, one of the most ecologically sensitive areas of the world. The partnership is planning to install Remote Area Power Supply Systems (RAPS) to provide 300 kWh/day of renewable energy to these villages. RAPS systems retrofit existing diesel generators with solar photovoltaic panels and battery storage to supply the necessary electricity for villagers to build and expand local products and services. Two systems are already being designed for the villages of Padre Cocha and Indiana.

CHALLENGES FOR TODAY AND TOMORROW

The U.S. Department of Energy (DOE) and the energy storage industry are focused on integrating storage with electric power systems, both today and in the future. Energy storage products, services and all the components of highly reliable, cost-effective systems already exist, although research continues to improve each of these separate pieces. But most of today's energy storage systems require custom designs and installation and the benefits of each unique design are difficult to quantify. DOE and industry emphasis on integration is vital to understanding and maximizing the capabilities of new, sophisticated and cleaner energy systems. Continued efforts are necessary to provide state-of-art, pre-packaged energy storage systems with predictable performance. Experience has proven the environmental and economic advantages of these systems. Those benefits will accrue as new energy storage systems penetrate the existing power markets.



Energy Storage Association

The Energy Storage Association is a membership trade association established to foster development and commercialization of energy storage technologies. Its mission is "to promote the development and commercialization of competitive and reliable energy storage delivery systems for use by electricity suppliers and their customers."

For information regarding membership or energy storage uses, contact the ESA at

4733 Bethesda Avenue
Suite 608
Bethesda, MD 20814
Phone: 301-951-3223
Fax: 301-951-3235
Web: www.energystorage.org

This document was prepared by the Energy Storage Association with assistance from the Solar Energy Research and Education Foundation. Support for this document was provided by the Energy Storage Systems Program of Sandia National Laboratories.

Appendix C:

Electrical Energy Storage Applications Case History Questionnaire

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Appendix C:

Electrical Energy Storage Applications Case History Questionnaire

for

Annex IX

of the

International Energy Agency

program:

Electrical Energy Storage Technologies

for

Utility Network Optimization

20 October 1998
Rev: D

Office use only	
Date received	
Ref no	
PA	
Company	

International Energy Agency (IEA)

IMPLEMENTING AGREEMENT ON "ENERGY CONSERVATION THROUGH ENERGY STORAGE"

Please could you take the time to complete this questionnaire?

The information obtained will be used to compile a set of comprehensive case studies of existing electrical energy storage systems and their applications. The case studies will be published in a report, which may eventually appear in the public domain.

At this stage, however, the information provided is intended to be confidential to participating agents, and will not be attributable. It will not be placed in the public domain without further discussion and due notice.

The questionnaire has been compiled by

EA Technology (UK), in collaboration with...

Hydro Quebec (Canada),
EUS (Germany),
KEMA (Netherlands),
Elforsk (Sweden),
Sandia National Laboratories (USA),
Helsinki University of Technology (HUT) (Finland), and
Iberdrola (Spain)

The questionnaire is part of a study examining applications of electrical energy storage. The focus of the study is on the application of energy storage rather than particular energy storage technologies, in order better to understand the market drivers for such storage systems.

This is in turn part of a larger study being carried out under the auspices of the International Energy Agency. It is entitled "Electrical Energy Storage Technologies for Utility Network Optimization," (more generally referred to as "Annex IX, Phase 2" within the energy storage community). More information about Annex IX can be found in the two accompanying data sheets.

The company details given on this page will be entered in our existing directory of energy storage users and systems suppliers. If you do not want this information entered into the directory, please indicate this by ticking the appropriate box.

Please do not enter this information into any contact database ☐

1. Organization Details

Name of Organization

Address:

No. of employees:

Contact name:

Job title:

Telephone:

Fax:

e-mail:

NATURE OF ORGANIZATION

Research & development services ☐

Electricity utility ☐

Industry ☐

Other (please specify) ☐

Area of Business:

Generation ☐

Transmission ☐

Distribution ☐

Industry (please specify) ☐

2. General Questions on the Storage Application

Should you have more than one storage installation and application to describe, please copy the relevant pages and fill in one set of questions for each individual case.

2.1. Name of project

2.2. Who was the customer?

2.3. Into which of these broad categories does/did the application fall?

1	power quality/quality of supply/voltage regulation	
2	peak shaving/DSM/distribution capacity deferrals	
3	integration with renewables	
4	Other (please specify)	

2.4. Into which detailed category or categories does/did it fall?

If more than one entry, please rank in order of importance: 1=most important

1	Load leveling	
2	Spinning reserve	
3	Frequency regulation	
4	Voltage regulation	
5	Network stability	
6	Integration with renewables	
7	Deferral of capacity/network reinforcement	
8	Improved asset management	
9	Demand-side management	
10	Energy efficiency benefits	
11	Emissions/environmental benefits	
12	Quality of supply improvements	
13	Power quality improvements	
14	Other (please specify)	

2.5. Additional motives for development of the application

(Please attach any relevant documents if desired.)

2.6. Performance specification

Storage capacity of the installation (MWh)

Power rating (MVA for specified time)

MVA:	Time:

Storage technology/technologies used

1	Batteries (please specify chemical system used)	
2	Flywheels	
3	SMES	
4	Supercapacitors	
5	Other (please specify)	
	Hybrid (i.e., combination of above)	

Converter Unit (Power Electronics)

Power Device Type	
Thyristor	
GTO	
IGBT	
Other (please specify)	

Building

Stationary	
Mobile (moveable occasionally)	
Containerized (moveable easily or frequently)	

Modularity

Number of modules	
Module power rating (kVA)	
Total power rating (kVA)	

Controls

Any controls in hands of the utility?	
Any remote monitoring?	
Any remote control?	
Was the system reconfigurable?	

Grid connection

Was a protection relay required?	
Was protection installed against…	
Loss of mains	
Overvoltage	
Undervoltage	
Overfrequency	
Underfrequency	
Was permission to connect required from the utility (Y/N)?	
What were the switchgear requirements for connection?	

Please add any other important connection information …

Was it an 'experimental' system?

For example, did it have extra monitoring aiming to optimize future systems? Please classify as...

Experimental	
Precommercial	
Commercial	

3. Project Preliminaries and Construction

3.1. Timescales

Please fill in the following chart to indicate both time spent and total elapsed time. If possible, please include information on ...

- Duration of the planning process;
- Time from approval to start of construction work;
- Duration of construction work; and
- Time from commissioning to customer acceptance.

Task Name	Start date (or weeks from start)	Finish date (or weeks from start)	Working time used/ weeks	Elapsed time/ weeks

3.2. Duration

For how long has the system operated or did it operate?

What is the project's current status?

3.3. Partners

Did you have partners collaborating in the project?

If you wish, please name the partners ...

3.4. Project Funding

Where did the financing come from for the project?

(Please tick boxes for all sources.)

	Source	% Contribution	Value	Current Unit
1	Your own company			
2	Government grant			
3	International agency grant			
4	Electricity supply industry			
5	Energy storage industry			
6	Other (please specify)			
	Total			

How were the project costs distributed?

(Headings based on Sandia report SAND98-1905.)

Item	Cost
Capital	
Equipment load interface	
Power conversion system	

Item	Cost
Storage device	
Monitors and controls	
Facilities	
Financing costs	
Transportation	
Taxes	
Project management	
Start-up and initial maintenance	
Other (please specify if possible)	
Total initial cost	

Item	Cost
Operation and maintenance	
Manpower	
Transportation	
Maintenance	
Consumables	
Electricity and water	
Consumables	
Storage device spares and replacements	
Other (please specify if possible)	
Total running cost	

4. During Operation of the Installation

4.1. Monitoring

4.1.1. What was monitored?

Parameter	Measurement Interval
Voltage	
Current	
Power	
Switch/breaker status	
Temperature	
Transients	
kWh in	
kWh out	
Water consumption	
Battery electrolyte level	
Air conditioning status	
Auxiliary power consumption	
Others	

4.1.2. Who did the monitoring?

Supplier	
Customer	
Other	

4.1.3. Was sufficient monitoring done?

4.1.4. What alarm states were monitored?

Parameter	
Fire	
Hydrogen	
Loss of mains	
Others	

4.2. Reliability

4.2.1. Was reliability an important issue?

4.2.2. Which elements were least reliable?

4.2.3. What failures occurred?

Item	Routine?	Repair?	Man-hours	Cost

4.3. Maintenance

4.3.1. Was maintenance an important issue?

4.3.2. Which items required maintenance? - How much?

Item	Routine?	Repair?	Man-hours	Cost

4.4. Operation

4.4.1. What did the system cost to operate?

Task	Man-hours	Cost

4.4.2. What experimentation was performed (if any)?

Type of Experiment	No. of Experiments	Man-hours	Cost

4.4.3. What limitations were encountered?

Limitation	Inherent in Technology	Determined by Experiment

5. Benefits of the system

Please outline the benefits the system provided to the utility and its network ...

6. Conclusions and Reporting

6.1. Reporting of results

6.1.1. How were the results disseminated?

6.1.2. Please provide references to relevant publications

6.2. What were the principal lessons learned?

6.3. What was the biggest problem encountered?

6.4. What was the biggest achievement; greatest success?

6.5. Planned budgets vs. real costs

How did they compare?

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Appendix D:

R&D Partnerships

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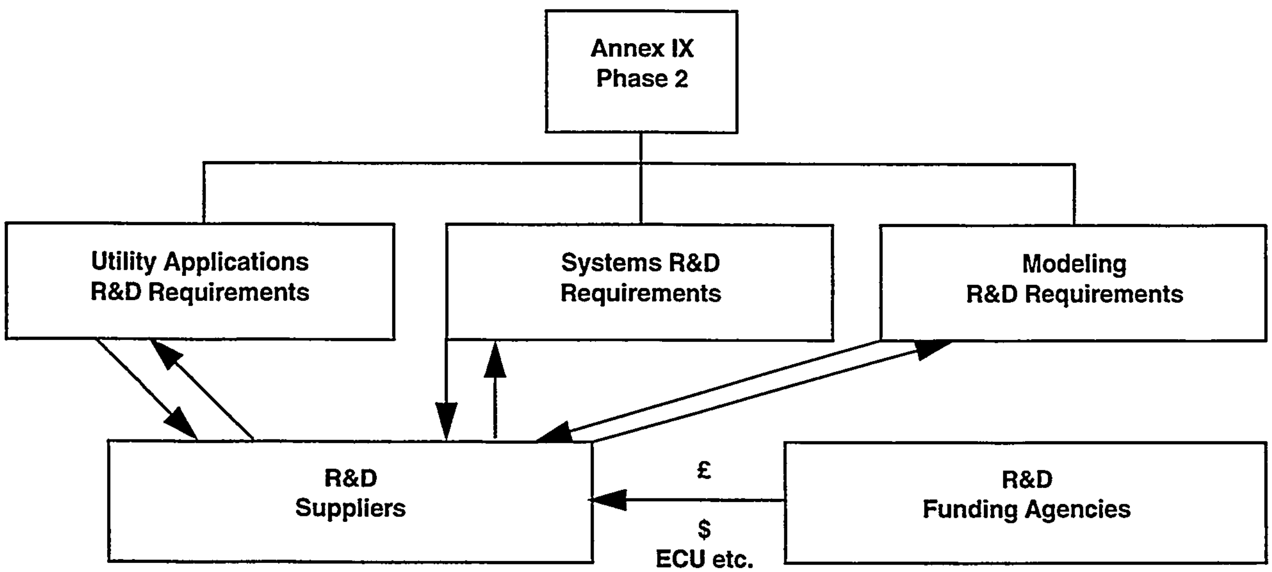
Appendix D:

R&D Partnerships

1. Introduction

The conference has floated the idea of using the IEA Annex IX electrical energy storage work program as a cost-effective and independent 'vehicle' for the stimulation of a series of strategic R&D partnerships, as, for example, shown in the diagrammatic representation below:



Proposed R&D Enabling Mechanism

Interested parties are now invited to register their preliminary interest in this concept, on an entirely non-obligatory basis. EA Technology will then collate such information and revert to respondents, beginning in Fall 1998.

2. Contact Details

Name: ____________________________

Organization: ____________________________

Address: ____________________________

Country: ____________________________

Telephone: ____________________________

Fax: ____________________________

e-mail: ____________________________

3. Organization Details

Do you consider yourself to be primarily a:

Utility/end user of storage systems
a systems developer/supplier
an R&D supplier
an R&D funding agency

4. R&D Requirements

From your individual perspective, where do you see the primary need/application of targeted R&D:

end use applications of storage
systems development
modeling
energy and environmental aspects

Additional comments: ____________________________

5. R&D Partnerships

Would you, in principle, recognize the 'added value' of entering into suitable strategic R&D partnerships?

YES NO

Comments: ______________________________

____

____

____

____

Signed: ______________________ Dated: ____________

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Appendix E:

Presentations and Publications

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Appendix E:

Presentations and Publications

Presentations

P. C. Butler, "An Improved Energy Storage for RAPS," presented at the Asia-Pacific Initiative and ILZRO RAPS Meeting, Jakarta, Indonesia, October 17, 1997.

P. C. Butler and P. A. Taylor, "Battery Test Cycles for RAPS Applications," presented at the Workshop on RAPS Battery Testing, Brisbane, Australia, October 24-25, 1997.

A. A. Akhil, "Energy Storage Systems Program Overview," G. C. Corey, "Design and Performance of Modular Battery Systems," presented at the Electric Utility Battery Energy Storage–Seminar II, Anchorage, AK, November 4-5, 1997.

P. C. Butler, "Renewable Generation and Storage Project," presented at the Energy Storage Association Fall Meeting, Sacramento, CA, November 17, 1997.

P. C. Butler, "Overview of Energy Storage Systems and PV Programs," presented at the Lucent Technologies Premium Power Forum, Mesquite, TX, February 5, 1998.

P. C. Butler, "Overview of Energy Storage Systems Program," presented at the Massachusetts Institute of Technology (MIT), Cambridge, MA, February 20, 1998.

P. C. Butler, "Overview of Energy Storage Systems Program," presented at the University of Missouri, Rolla, MO, March 26, 1998.

C. Platt and P. C. Butler, "Energy Storage Systems Program Overview," presented to the Industry Users Group at the Energy Storage Association Spring Meeting, Phoenix, AZ, April 7-8, 1998.

T. D. Hund and G. C. Corey, "Energy Storage Information Needs for PV–Integrated Systems," presented at the SOLTECH, IREC, and UPVG Annual Meeting, Orlando, FL, April 27, 1998.

P. C. Butler, "Energy Storage Systems Cost Study Overview," presented at the Lucent Technologies Premium Power Forum, Bell Labs, Murray Hill, NJ, April 30, 1998.

P. C. Butler, "Performance and Economic Analysis of Superconducting Magnetic Energy Storage, Flywheel, and Compressed Air Energy Storage Schemes for Electric Power Applications," presented at the Electrical Energy Storage Systems Applications and Technologies (EESAT) 98 Conference–ESS Program Overview, Chester, UK, June 16, 1998.

P. C. Butler, "RAPS Testing Overview," presented to the IEEE Standards Committee, Winter Park, CO, July 20, 1998.

P. C. Butler, "SMES/FES Study Status Report," presented to the Department of Energy, Washington, DC, August 6, 1998.

P. C. Butler, "Result of Research on Power Quality Issues," presented at the Lucent Technologies Premium Power Forum, Bell Labs, Murray Hill, NJ, August 27, 1998.

Publications

S. Atcitty, S. Ranade, and A. Gray-Fenner, September 1998, *Summary of State-of-the-Art Power Conver-*

sion Systems for Energy Storage Applications, SAND98-2019. Sandia National Laboratories, Albuquerque, NM.

P. C. Butler, J. F. Cole, and P. A. Taylor, *Test Profiles for Stationary Energy Storage Applications*, 6th European Lead Battery Conference, Prague, Czech Republic, September 24-25, 1998.

P. A. Taylor, P. T. Moseley, and P. C. Butler, *ILZRO-Sponsored Field Data Collection and Analysis to Determine Relationships Between Service Conditions and Reliability of VRLA Batteries in Stationary Applications*, 6th European Lead Battery Conference, September 24-25, 1998.

P. C. Butler, T. Crow, and P. A. Taylor, *Battery Evaluation Methods And Results For Stationary Applications*, Intelec 97 (19th International Telecommunications and Energy Conference), Melbourne, Australia, October 19-23, 1997.

G. P. Corey, Don't Scapegoat the Battery – Shoot the System Designer, in *Batteries International Editorial Magazine*, October 1997.

G. A. Buckingham and G. P. Corey, *Datalogging and Control Through a Remote Interface for a Power Quality System*, International Telemetering Conference/USA, Las Vegas, NV, October 27-30, 1997.

R. L. Hammond, J. F. Turpin, G. P. Corey, T. D. Hund, and S. R. Harrington, October 1997, *Photovoltaic Battery and Charge Controller Market and Applications Study*, SAND96-2900. Sandia National Laboratories, Albuquerque, NM.

C. Platt, P. A. Taylor, L. Charles, and P. C. Butler, November 1997, *Report on the Energy Storage Systems Program Executive Meetings Project*, SAND97-2700. Sandia National Laboratories, Albuquerque, NM.

S. Swaminathan, W. T. Flynn, and R. K. Sen, December 1997, *Modeling of Battery Energy Storage in the National Energy Modeling System*, SAND97-2926. Sandia National Laboratories, Albuquerque, NM.

N. H. Clark, P. C. Butler, and C. P. Cameron, March 1998, *Renewable Generation and Storage Project Industry and Laboratory Recommendations*, SAND98-0591. Sandia National Laboratories, Albuquerque, NM.

G. P. Corey, W. Nerbun, and D. Porter, August 1998, *Final Report on the Development of a 250-kW Modular, Factory-Assembled Battery Energy Storage System*, SAND97-1276. Sandia National Laboratories, Albuquerque, NM.

P. C. Butler, August 1998, *Energy Storage Systems Program Report 1997*, SAND98-1733. Sandia National Laboratories, Albuquerque, NM.

H. W. Zaininger, August 1998, *Analysis of the Value of Battery Storage with Wind and Photovoltaic Generation to the Sacramento Municipal Utility District*, SAND98-1904. Sandia National Laboratories, Albuquerque, NM.

Distribution

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