Tehachapi Wind Energy Storage Project

Technology Performance Report #2

Award Number: DE-OE0000201

Sponsoring Office:
U.S. Department of Energy – National Energy Technology Laboratory
Morgantown Campus
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880

Participant:
Southern California Edison Company – Advanced Technology
2131 Walnut Grove Avenue
Rosemead, CA 91770

Doug Campbell – Manager
Tel: 714-895-0258
e-mail: Doug.Campell@sce.com

Naum Pinsky – Principal Investigator
Tel.: 714-895-0645
e-mail: Naum.Pinsky@sce.com

Revision History

ID	Date	Summary of Changes	Revised By
v1	12/31/15	Changes and additions to TPR#1	SCE Team
v2	2/12/2016	Incorporate DOE comments	SCE Team

Acknowledgement

This material is based upon work supported by the Department of Energy (DOE) under Award Number DE-OE0000201.

Disclaimers

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report was prepared by Southern California Edison Company (SCE) as an account of work sponsored by the Department of Energy, an agency of the United States Government, under Award Number DE-OE0000201. SCE, including any of their employees, affiliates and contractors, does not make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by SCE. The views and opinions of authors expressed herein do not necessarily state or reflect those of SCE.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 Executive Summary

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

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

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

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

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

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

The DOE awarded ARRA funding in early 2010 and project work began in October of that year. Installation and commissioning of the BESS was completed in July 2014. Initial design, specification and procurement of the BESS were disrupted by financial issues of the original BESS provider. Subsequently, a revised project plan was developed to select a new BESS provider and continue with the project. Other than the discussion of Project History in section 3.1, this TPR addresses the project after transition to the second BESS provider under the revised project plan including the activities leading to the implementation of initial system testing according to the project test plan.

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

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

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

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

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

Table 1-1 Operational Use & Tests

It should be noted that since the initiation of this project, SCE has completed a large transmission investment in this area. These system upgrades may reduce the impact of the battery system with respect to the 13 operational uses. However, SCE will still conduct experimentation to demonstrate the capabilities of the BESS to affect the identified operational uses. Demonstration of the desired response of the device to grid conditions allows us to extrapolate data, and apply lessons learned to other scenarios where a storage device may have a more significant impact.

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

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

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

Preliminary Characterization Testing began at the end of 2014, further project testing continued in January 2015. Hence, this TPR #2 reports on activities from inception of the project through project plan testing continuing through the end of 2015. Testing of the 13 operational use cases will be reported in this and the subsequent Final Technical Report (TPR#3).

The following table identifies five of the top lessons learned to date. Additional lessons learned are found in Section 6.

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

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

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

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

Table 1-2 Key Lessons Learned To Date

2 Scope

2.1 Abstract

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

2.2 Introduction to SCE

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

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

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

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

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

2.3 Project Overview

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

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

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

1. **Contingency support** in terms of MW and MVAr; applying the BESS/STATCOM system to mitigate power system contingencies.

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

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

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

Transmission Uses

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

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

3. Diminished congestion: Storage could be used to avoid congestion-related costs and charges, especially if the charges become onerous due to significant transmission system congestion. Storage systems traditionally have been installed at locations that are electrically downstream from the congested portion of the transmission system. Energy would be stored when there is no transmission congestion, and it would be discharged (during peak demand periods) to reduce transmission capacity requirements. In the TSP, storage is installed on the transmission system, at a location electrically upstream from the congestion. It will be charged when wind generation output is high to reduce congestion, and it will be discharged when wind generation output is lower to utilize available transmission capacity.

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

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

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

System Uses

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

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

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

CAISO Market Uses

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

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

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

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

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

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

Table 2-2 Relationship of 13 Uses to DOE Applications

2.4 Project Objectives

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

The evaluation of the BESS is based on the premise that there are benefits which should accrue to SCE and to the overall electricity delivery system based on three categories of operational uses: transmission, system and CAISO market. These operational uses are further delineated into a total of 13 areas for the three categories mentioned above. The operational uses are summarized in the following table.

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

Table 2-3 SCE Operational Uses for the BESS

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

2.5 Project Benefits

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

Wind generation output shifting, (operational use 9), is aimed at meeting the electricity system needs with stored energy. The first three CAISO market uses (operational uses 10, 11 and 12) will help evaluate the ability of the BESS to provide benefits to the grid in ways that meet specific needs of the system operator. Some of these uses will address particular problems that exist on the Antelope-Bailey system, and all will be broadly applicable to wind integration problems in general. In addition, several of the operational uses SCE have identified (5-8, and 13) may be used to explore the practical business implications associated with evaluating grid-connected lithium ion BESS.

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

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

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

2.6 Build & Impact Metrics

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

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

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

In addition to Build and Impact Metrics, key BESS performance parameters are addressed as part of the TSP system evaluation. These include system availability, maintenance procedures and costs; energy charged and discharged, capacity degradation over time, and ramp rate capabilities. During the period of this TPR #2, metrics assessment was continued although compromised by typical non-recurring issues relating to design and operations of a new system.

2.7 Project Plan

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

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

	Tasks	Milestone	Completion Date
Phase I- Definition and NEPA Compliance	Task 1.1 – Update Project Management Plan	Submission of PMP to DOE	8/8/2013
	Task 1.2 – National Environmental Policy Act Compliance	Completion of NEPA Compliance (categorical exclusion)	11/4/2010
	Task 1.3 – Develop Interoperability and Cyber Security Plan	Completion of I&CS Plan for every phase of engineering life cycle of the project	11/4/2010
	Task 1.4 – Develop Metrics and Benefits Reporting Plan	Completion of Metrics and Benefits Reporting Plan	1/6/2011
	Task 1.5 – Finalize Energy Storage System Manufacturing Plan	Completion of BESS Manufacturing Plan	11/4/2011
	Task 1.6 – Finalize Plan for Baseline Measurements	Finalization of Baseline Data Measurement Plan	4/4/2011
Phase II – Final Design, Construction, and Baselining	Task 2.1 – Battery and Inverter Systems Development, Manufacture, Assembly, and Installation	Completion of Acceptance Testing for Battery System	5/15/2014
	Task 2.2 – Siting, Construction and Substation and Grid Preparation	Construction and Installation of Equipment	5/15/2014
	Task 2.3 – Baselining	Installation and connection of baselining equipment, beginning to accumulate and prep data	6/29/2011
Phase III – Operations, Measurement and Testing	Task 3.1 – System Operations and Testing	Operation of energy storage system over 24 months to test operations use applications and effects (includes system characterization tests)	6/30/2016
	Task 3.2 – Communications, Interoperability and Cybersecurity	No associated milestone	N/A
	Task 3.3 – Study, Measurement, Validation and Valuation	Complete analysis of data and submission of final report	9/30/2016

Table 2-5 SCE TSP Milestone Log

2.8 Report Organization

This report presents the results of project work performed by the TSP project team from inception of the project through continuation of project plan testing in December, 2015. This report is the second of three TPRs. In the aggregate, the TPRs will report test results and operational experience with the TSP over the entire project period expected to continue through June 2016.

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

3 Technical Approach - Battery Energy Storage System

3.1 Project History

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

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

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

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

3.2 Basic Facility Description

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

Figure 3-1 Monolith Substation and BESS Facility

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

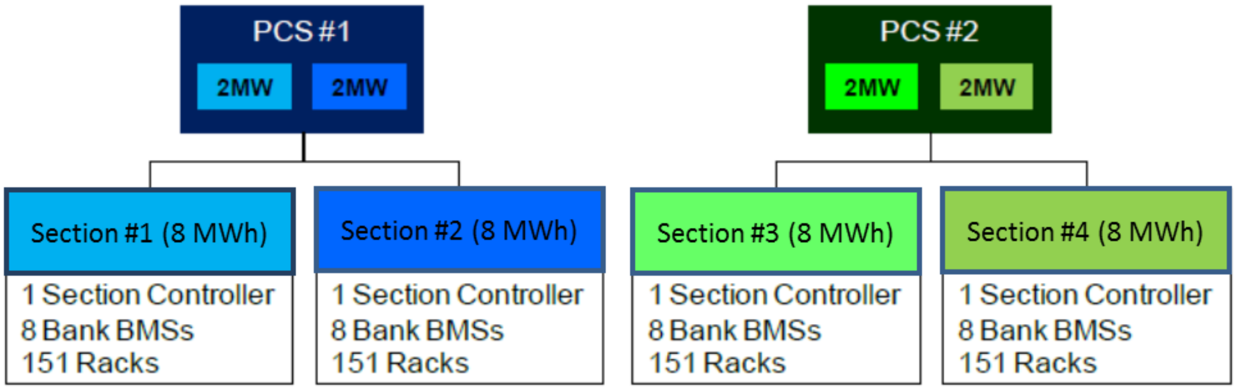


Figure 3-2 System Overview

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

Table 3-1 BESS System Configuration & Specification

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

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

Table 3-2 Operating Conditions

3.3 Battery Design and Layout

The BESS voltage output is 12 kV, and a 12 kV to 66 kV transformer steps voltage to the final 66 kV bus interconnection. Between 17 and 20 Racks make up one Battery Bank and 8 Banks comprise one Battery Section. Each Battery Section is composed of 151 Battery Racks and the

Sections are connecting to 2 MW PCS lineup respectively. The BESS is composed of four Battery Sections (2 M X 4 = 8 MW).

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

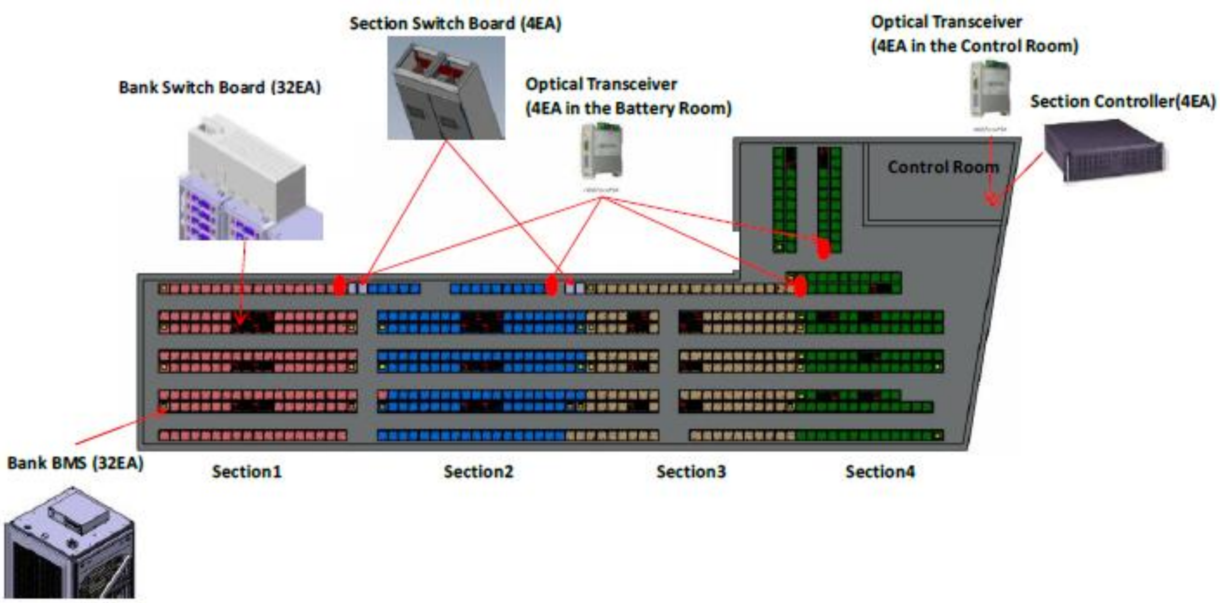


Figure 3-3 Battery Rack Layout

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

Table 3-3 Battery Specification

3.4 Power Conversion System Design

The PCS for the project is composed of two (2) outdoor PCS enclosures made from 40 foot CAISO containers. Each unit is rated for 4 MW/4.5 MVA capacity designed for connection to a

12.47 kV grid network. Each PCS unit is configured to connect to two 2 MW LG Chem battery strings based on a charge-discharge DC voltage range of 750 to 1050 Vdc.

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

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

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

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

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

Table 3-4 PCS Specification

3.5 BESS Auxiliary Systems

3.5.1 Auxiliary Power System

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

3.5.2 HVAC System

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

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

3.5.3 Fire Suppression System

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

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

3.6 TSP Data Acquisition System

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

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

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

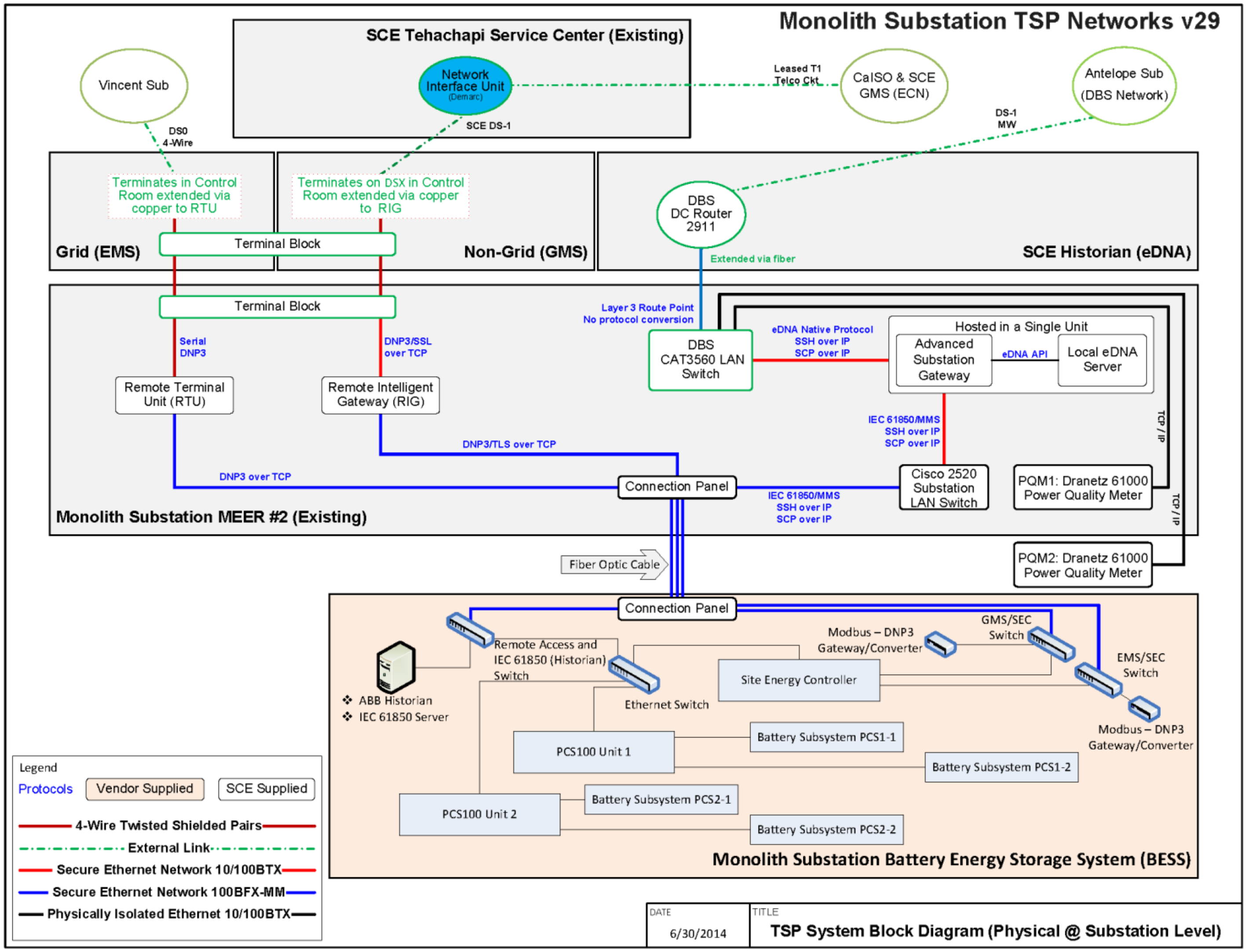


Figure 3-4 Data Acquisition System

4 Measurement and Validation Strategy

4.1 Methodology and Approach

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

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

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

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

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

All of the above sources provide physical data inputs to the engineering analysis which becomes the basis for the impact metrics. The project team will have at its disposal a RTDS (a parallel processor computer used to simulate the power system in real time) to simulate system performance in cases where it is physically impractical to conduct field tests in an operational substation. Additionally, when an expected event doesn't occur under normal operating conditions (such as a fault, line trip, or contingency) this "test condition" can be simulated and analyzed on the RTDS. More information on the use of RTDS is found in the appendices.

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

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

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

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

The ability of the BESS to respond to CAISO market signals or its ability to follow a prescribed schedule as a result of being awarded for an acceptable bid into the market will be examined. The intent of the first year of operation is to let the SCE Energy Operations Group simulate market awards and dispatches to the BESS control system. The Energy Operations Group will observe the operation of the BESS to respond to CAISO signals via the RIG and make an assessment whether the BESS would pass CAISO requirements as a market resource. The plan is to set up prescribed charge/discharge schedules in year 1 that would test the capability of the BESS to follow regimented patterns. Concurrently, the project team will collect data and note system conditions and opportunities via data mining to further support one or more of the 13 operational uses.

During year 2 of the BESS field test, the SCE Energy Procurement & Management Group are taking the lessons learned from initial operations and actually bid the BESS into the CAISO market with real financial implications and exposure. This activity will be conducted under the close scrutiny of the project team while monitoring the BESS performance and benefits under real market conditions. Since issue of TPR #1, the project team has split the market testing into two parts. Part 1 is a simulation of market dispatch signals and AGC signals that represent flat schedules and varied AGC signals. Part 2 is an actual market based demonstration that will have Bids, Awards, and Dispatches from the ISO systems as if it was a wholesale market resource. This includes all the groups in SCE's Energy Procurement Management (EPM) from market planning to settlements.

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

4.2 Operational Uses

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

4.2.1 Transmission Uses

4.2.1.1 Voltage Support/Grid Stabilization

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

4.2.1.2 Decreased Transmission Losses

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

4.2.1.3 Diminished Congestion

Effectiveness of the BESS to diminish congestion will be measured by the reduction of transmission line loading wind generation curtailment and/or the frequency of wind curtailment events. This will be provided through system operator control of on-peak charging and off-peak discharging of the BESS. Existing EMS SCADA data collection systems along with PMU/DFR/PQM devices will be used to collect and archive data. The RTDS will be used for simulation and validation.

4.2.1.4 *Increased System Reliability by Load Shed Deferral*

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

4.2.1.5 *Deferred Transmission Investment*

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

4.2.1.6 *Optimized Size and Cost of Renewable Energy-Related Transmission*

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

4.2.2 System Uses

4.2.2.1 *Provide System Capacity/Resource Adequacy*

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

4.2.2.2 *Renewable Energy Integration (Smoothing)*

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

4.2.2.3 *Wind Generation Output Shifting*

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

4.2.3 CAISO Market Uses

4.2.3.1 Frequency Regulation

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

4.2.3.2 Spin/non-Spin Replacement Reserves

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

4.2.3.3 Deliver Ramp Rate

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

4.2.3.4 Energy Price Arbitrage

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

4.3 Baseline Development

4.3.1 Overview

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

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

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

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

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

4.3.3 Requirements for a Valid Baseline

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

4.3.4 Alternatives to Use of Historical Data as a Baseline

Not all of the tests to be performed would depend on a baseline even if one were available. Several tests to demonstrate the response of the system to a signal from the CAISO to the TSP cannot be compared to a baseline, as if there were no TSP there would be nothing to send the signal to.

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

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

4.4 Data Collection and Analysis

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

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

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

SCE expects that each of the above tests will be conducted independently. In addition, some of the tests will also be conducted concurrently in various combinations (stacking) to develop an understanding of an operator's ability to deploy the BESS for multiple operational uses simultaneously. The ability to respond to multiple uses will be an important factor in determining the cost effecetivness of the battery system. The table below shows which tests are expected to provide data for each of the operational uses.

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

Table 4-1 System Test and Operational Use Matrix

4.4.1 Steady State Data Collection

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

Transmission data to be captured during these tests includes:

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

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

- Frequency response requirements and the response provided by the BESS over time
- Spin/non-spin reserve requirements and the response provided by the BESS over time
- Generation reserve requirements and the response provided by the BESS over time

- Energy price signals and the charge and discharge patterns of the BESS

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

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

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

Table 4-2 BESS Data Collection

4.4.2 Transient Event Data Collection

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

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

5 Measurement and Validation Test Plan Summary

5.1 Baseline Data Analysis

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

EMS Data:

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

Non EMS Data:

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

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

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

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

5.2 M&V Analysis Assumptions

The Test Plan assumes the BESS will always be operated within the specifications given by the manufacturer, and with safety constraints determined by SCE. The BESS will be taken off-line in any circumstance that places additional stress on the system, or when it may interfere with system operations or grid reliability. When bidding into the CAISO market, the BESS will be operated and scheduled in accordance with established procedures like any other CAISO resource. It is expected that lessons learned in early testing will inform future tests, particularly as they relate to market participation. As such, financial constraints and expectations during year 1 of operation will be appropriately measured.

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

5.3 Mini-System

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

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

Mini-System characteristics include the following:

Original Build (October 2013)	Expansion (December 2015)
• 77 sq. ft. footprint • 30 kW • 116 kWh • 1 mini Power Conversion System cabinet • 1 Section • 1 Bank	• 154 sq. ft. footprint • 60 kW • 232 kWh • 2 mini Power Conversion System cabinets • 2 Sections • 2 Banks

• 2 Racks • 36 Modules • 2,016 Cells	• 4 racks • 72 modules • 4,032 Cells

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

5.4 System Acceptance Test Plan

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

- Performance and Capabilities
    1. Real/reactive power dispatch accuracy
    2. Sustained full real/reactive power dispatch capability
    3. Real power discharge capacity and duration
    4. Real/reactive power ramp rate
    5. Automatic battery section balancing
- SEC Control Algorithms
    1. Test 1: Steady State Voltage Regulation
    2. Test 3: Charge During High Line Load/Discharge During Low Line Load
    3. Test 4: Charge Off-peak/Discharge On-peak
    4. Test 5: Charge and Discharge as Needed for Grid Purposes
    5. EMS–GMS Transition
    6. EMS and GMS Communication Fault Handling
    7. Manual and CAISO Power Dispatch

5.5 Characterization Test Plan

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

5.5.1 Charge/Discharge Duration Test

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

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

5.5.2 8 MW Cycle Test

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

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

---

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

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

Table 5-1 SEC Test 4 on Peak Schedule

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

Table 5-2 SEC Test 4 off Peak Schedule

5.5.3 4 MW Cycle Test

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

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

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

Table 5-3 SEC Test 4 on Peak Schedule

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

Table 5-4 SEC Test 4 off Peak Schedule

5.5.4 8 MW Cycle Test without Approximately 30 % SOC Rest

The purpose of the 8 MW Cycle Test without Approximately 30 % SOC Rest is to characterize the behavior and performance of the system during continuous full charge/discharge cycles at 8 MW, without a daily rest at approximately 30 % SOC. Prior to starting the test, the SEC On/Off Peak schedules should be optimized using the results of the Charge/Discharge Duration Test.

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

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

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

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

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

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

Duration of test	At a minimum, until bus voltage has stabilized at the command value. A minimum of one hour is suggested to demonstrate the ability to sustain the scheduled MVAr flow
Data to be collected	▪ 66 kV Monolith bus voltage profile ▪ Storage dispatch (BESS reactive power output)
Relevant DOE Metrics	▪ Reactive power at BESS 66 kV connection

	▪ Storage Dispatch
Operational Uses	Voltage support/grid stabilization
Expected Results and Benefits	Monolith bus voltage expected to respond with up to 5% change in value in response to BESS discharging. The percentage change will depend on the system topology and wind generation level.
Test Results	Tests began in 2015 and results to be reported in the final Technology Performance Report.

Table 5-5 Test 1 Plan Procedure

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

Table 5-6 Test 1 Source of Test Data

5.7 Test 2 Steady State Voltage Regulation under Any Mode

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

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

Preconditions for this test not required for all tests	Coordinate schedule with operational sequence for capacitor banks
Simulation	Real Time Digital Simulation with Hardware in the Loop (RTDS) 1. Representing voltage, generation and load values before test. 2. With BESS at changed voltage setpoint. 3. With capacitor switched off, BESS off 4. With capacitor off, BESS at maximum MVAr injection.
Timing of test	▪ High and low expected wind generation o High wind months are May and June. o Low wind months are from September through February o March, April, September and October vary from year to year. ▪ High and low expected local load ▪ Real power BESS modes: charging, discharging, and inactive
Duration of test	At a minimum, until bus voltage has stabilized at the command value. A minimum of **one hour** is suggested to demonstrate the ability to sustain the scheduled MVAr flow
Data to be collected	▪ 66 kV Monolith bus voltage profile ▪ Storage dispatch (BESS real and reactive power output)
Relevant DOE Metrics	▪ Real and reactive power at BESS 66 kV connection ▪ Storage Dispatch
Operational Uses	Voltage support/grid stabilization
Expected Results and Benefits	Monolith bus voltage fluctuation will be reduced greatly in response to BESS voltage support and the number of switching operations for the substation shunt capacitors will be greatly reduced (reduce the maintenance requirements).
Test Results	Tests began in 2015 and results to be reported in the final Technology Performance Report.

Table 5-7 Test 2 Plan Procedure

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

Table 5-8 Test 2 Source of Test Data

5.8 Test 3 Charge during Periods of high loading for the export lines And Discharge during low Loading periods Under SCE System Operator Control

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

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

	▪ Low expected wind generation for discharging o Low wind months are from September through February ▪ The test should be repeated under high and low expected load conditions.
Duration of test	For steady state tests, a four hour period is required to fully charge or discharge at maximum rate. Consideration should be given to charging/discharging at a lower rate for a longer time to demonstrate this capability
Data to be collected	▪ Transmission loads on the following 66 kV lines. o Monolith – Breeze line 1 & 2 o Monolith – Cummings line o Monolith – Loraine line o Monolith – Cal Cement line o Monolith – MidWind line o Monolith – ArbWind line ▪ Wind generation profile ▪ Wind generation curtailment requiring compensation ▪ CAISO price data ▪ Storage dispatch
Relevant DOE Metrics	▪ Transmission line load ▪ Transmission losses ▪ Congestion and congestion cost ▪ Storage dispatch
Operational Uses	▪ Decreased transmission losses ▪ Diminished congestion ▪ Increased system reliability by load shed deferral ▪ Deferred transmission investment ▪ Optimized size and cost of renewable energy-related transmission
Expected Results and Benefits	Lines flow expected to respond with 5-25% change in line flow values in response to BESS (dis)charging. The percentage depends

	on the system topology wind generation and load level during the discharge period.
Test Results	Tests began in 2015 and results to be reported in the final Technology Performance Report.

Table 5-9 Test 3 Plan Procedure

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

Table 5-10 Test 3 Source of Test Data

5.9 Test 4 Charge during Off-Peak Periods & Discharge during On-Peak Periods under SCE System Operator Control

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

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

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

Table 5-11 Test 4 Plan Procedure and Results

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

Table 5-12 Test 4 Source of Test Data

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

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

Primary Method for test	Operational control center dispatches operates the BESS at an appropriate configured mode for a specified level and duration

Expectations for this test not expected for all tests	▪ Intermittent generation output is firmed and shaped, both in ramp up and ramp down conditions
Preconditions for this test not required for all tests	▪ Approximately 50% SOC at start of test ▪ Set BESS in AGC/Dispatch mode ▪ Validate market awards and schedules
Simulation	N/A
Timing of test	N/A
Data to be collected	▪ Transmission loads on the following lines o Monolith – Breeze lines 1 & 2 o Monolith – Cummings line o Monolith – Loraine line o Monolith – Cal Cement line o Monolith – MidWind line o Monolith – ArbWind line ▪ Wind generation ▪ Storage dispatch
Relevant DOE Metrics	▪ Transmission line load ▪ Transmission losses ▪ Congestion and congestion cost ▪ Storage dispatch
Operational Uses	▪ Deferred transmission investment ▪ Optimized size and cost of renewable energy-related transmission ▪ Renewable energy integration (Firming and Shaping)
Expected Results and Benefits	BESS charge and discharge according to wind farm generation mitigating intermittency
Test Results	Tests began in 2015 and results to be reported in the final Technology Performance Report.

Table 5-13 Test 5 Plan Procedure and Results

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

Table 5-14 Test 5 Source of Test Data

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

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

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

Table 5-15 Test 6 Plan Procedure and Results

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

Table 5-16 Test 6 Source of Test Data

5.12 Test 7 Respond To CAISO Market Awards to Provide Energy And Spin/ Non-Spin Reserves

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

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

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

Table 5-17 Test 7 Plan Procedure and Results

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

Table 5-18 Test 7 Source of Test Data

5.13 Test 8 Follow A CAISO Market Signal for Energy Price

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

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

	▪ SCE GMS MW signals
	▪ Storage dispatch events with timing
	▪ BESS parameters
	  ○ Status
	  ○ State of Charge (%)
	  ○ Energy Available
	  ○ Charge/discharge rate (MW/MVAr

Relevant DOE Metrics	▪ Congestion and congestion cost ▪ Storage dispatch
Operational Uses	▪ Provide system capacity/resource adequacy ▪ Wind generation output shifting
Expected Results and Benefits	BESS charge and discharge according to market signals within acceptable CAISO performance guidelines
Test Results	Tests began in 2015 and results to be reported in the final Technology Performance Report.

Table 5-19 Test 8 Plan Procedure and Results

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

Table 5-20 Test 8 Source of Test Data

5.14 Detailed Test Plans

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

6 Measurement and Validation Test Results and Conclusions

6.1 Status & Timing of Tests

Prior to onsite project commissioning activities, Mini-System testing was performed at SCE lab facilities. In parallel, Hardware-In-The-Loop RTDS Testing using an actual PCS controller was conducted. SCE engineers reached a level of confidence in the system through RTDS and Mini-System Testing and onsite commissioning activities were initiated to verify function and integration of system components. Subsequent to project commissioning and trial demonstration use of the BESS, System Acceptance Testing was performed in July 2014 to demonstrate that the system met all design specification and criteria. Finally, a Characterization Test Period was initiated in December 2014 to determine key characteristics of the total system. Characterization testing concluded in early 2015. Preliminary results of this characterization testing were reported in the initial TPR #1. The TSP project began initial operations and resolved various startup issues. Although, multiple operating issues took some time to resolve, the project subsequently began operations of tests 1 through 8 and was able to obtain limited test results as in this TPR #2.

6.2 Mini-System Test Results

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

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

Issues identified included:

- Potential overcharging and over-discharging the battery due to incorrect BMS safety limits

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

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

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

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

6.3 System Acceptance Test Results

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

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

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

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

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

6.4 Characterization Test Results

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

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

6.4.1 First Period Test Results – December 2014

The Characterization Test was started in December 2014, and is scheduled to continue into January 2015. This TPR contains preliminary results from the data that has been collected as of December 22. The next TPR will contain full results from characterization testing.

The two 8 MW cycles from the Charge/Discharge Duration Test were completed on December 12 and December 14, respectively. As described in Section 5, the purpose of these cycles was to determine the amount of time it takes the system to fully charge and discharge, in order optimize the charge/discharge schedules for the later cycle tests. Results from the two 8 MW cycles are shown in Table 6-2.

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

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

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

	Day of week		Time	
Sequence/Description	Start	Stop	Start	Stop
1. Full discharge from ~30 % SOC	Su	Su	0000	0115
3. Full discharge	Su	Su	0553	1000
5. Full discharge	Su	Su	1438	1845

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

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

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

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

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

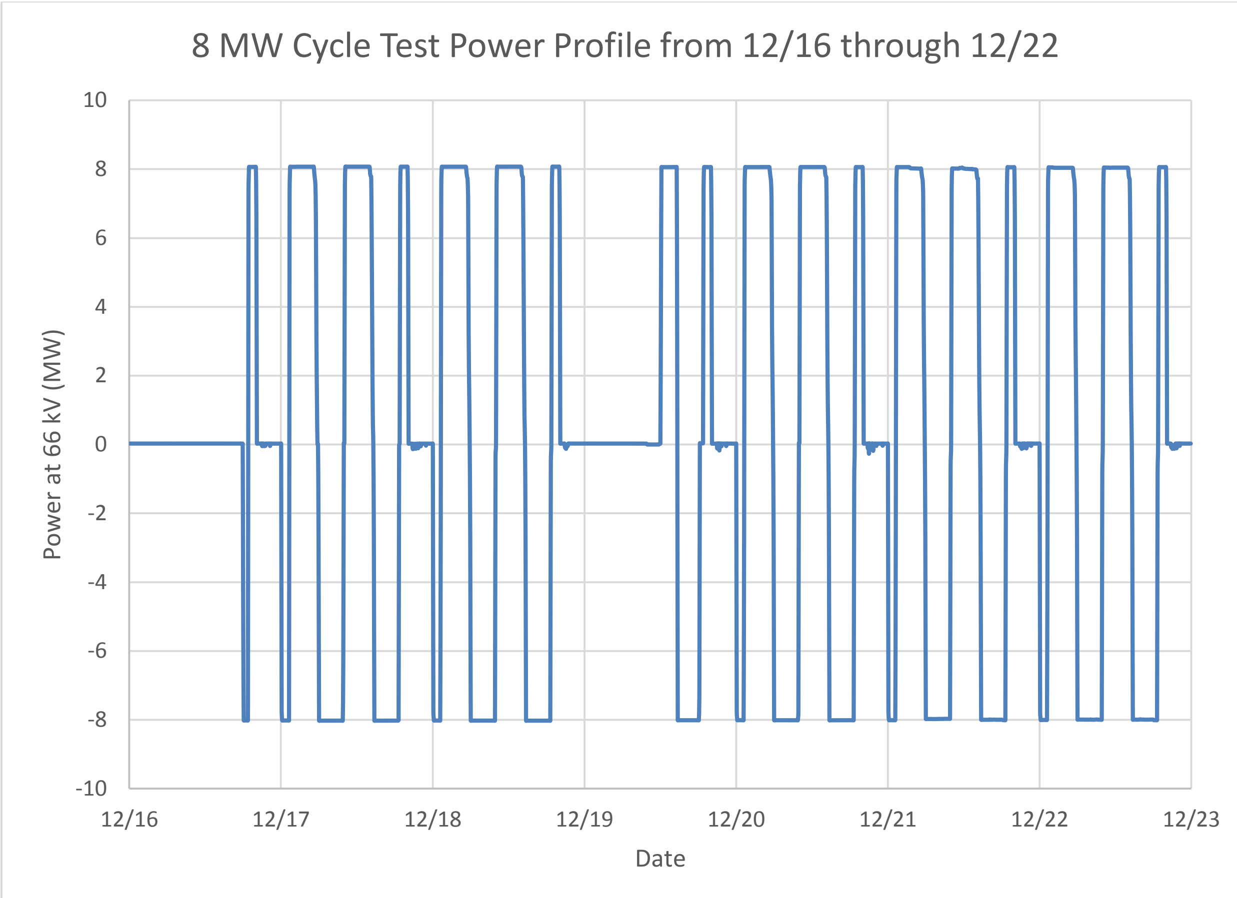


Figure 6-1 8 MW Cycle Test Power Profile from 12/16 through 12/22

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

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

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

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

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

6.4.2 Second Period Test Results – April to June 2015

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

6.4.2.1 State of Charge (SOC) profile for the BESS

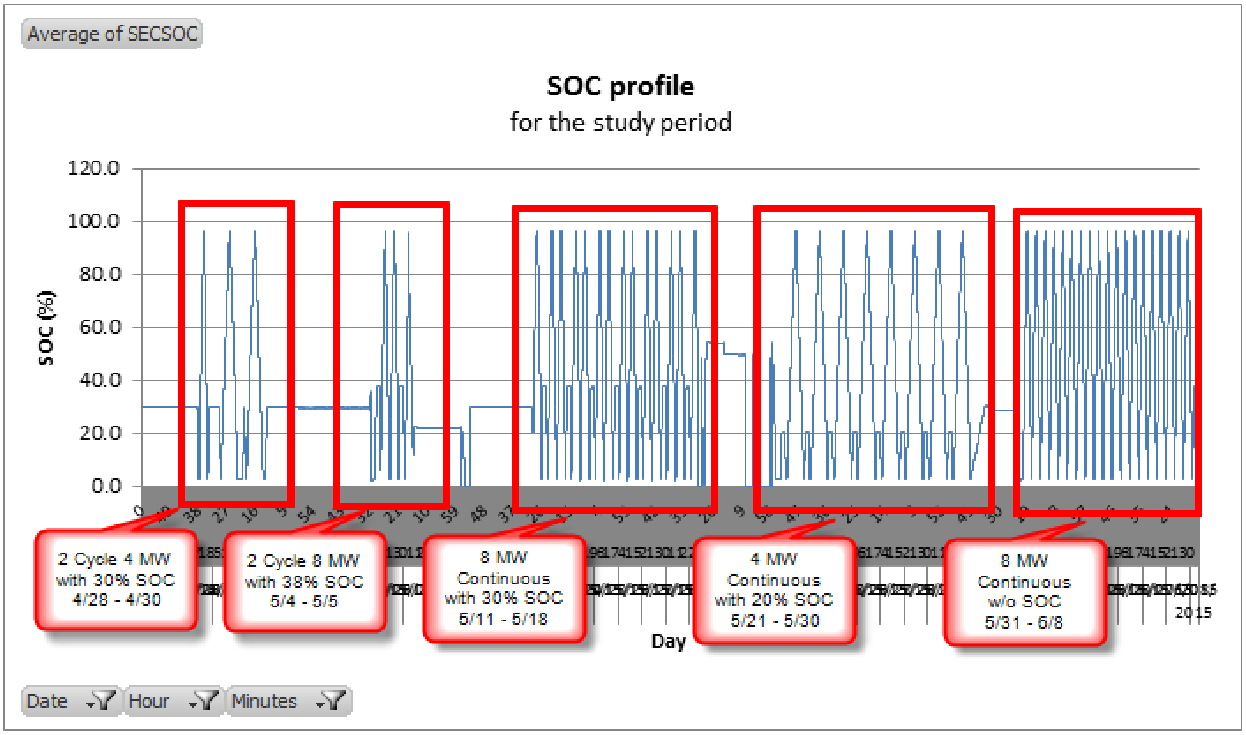


Figure 6-2 - SOC profile for the reporting period

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

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

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

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

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

The results are tabulated in the sections that follow at several different measuring points (MPs) as identified below. Each MP is recorded in the system data historian, but is measured by a different, un-calibrated instrument. For example, PCC_CC1 and PCC_CC2 are measured by two separate, un-calibrated power meters installed in the two PCS containers. These meters are primarily intended to provide control system feedback for the PCS, rather than measurement data. Similarly, the inverter lineup and battery section MPs are provided by the respective components' internal feedback circuitry. Furthermore, the overall PCC efficiency at 12 kV is a calculated average of PCC_CC1 and PCC_CC2, so either CC1 or CC2 may have an efficiency greater than the overall PCC at 12 kV. This data is provided for reference only, and in some cases, the efficiencies at each MP may not correlate well with upstream/downstream efficiencies.

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

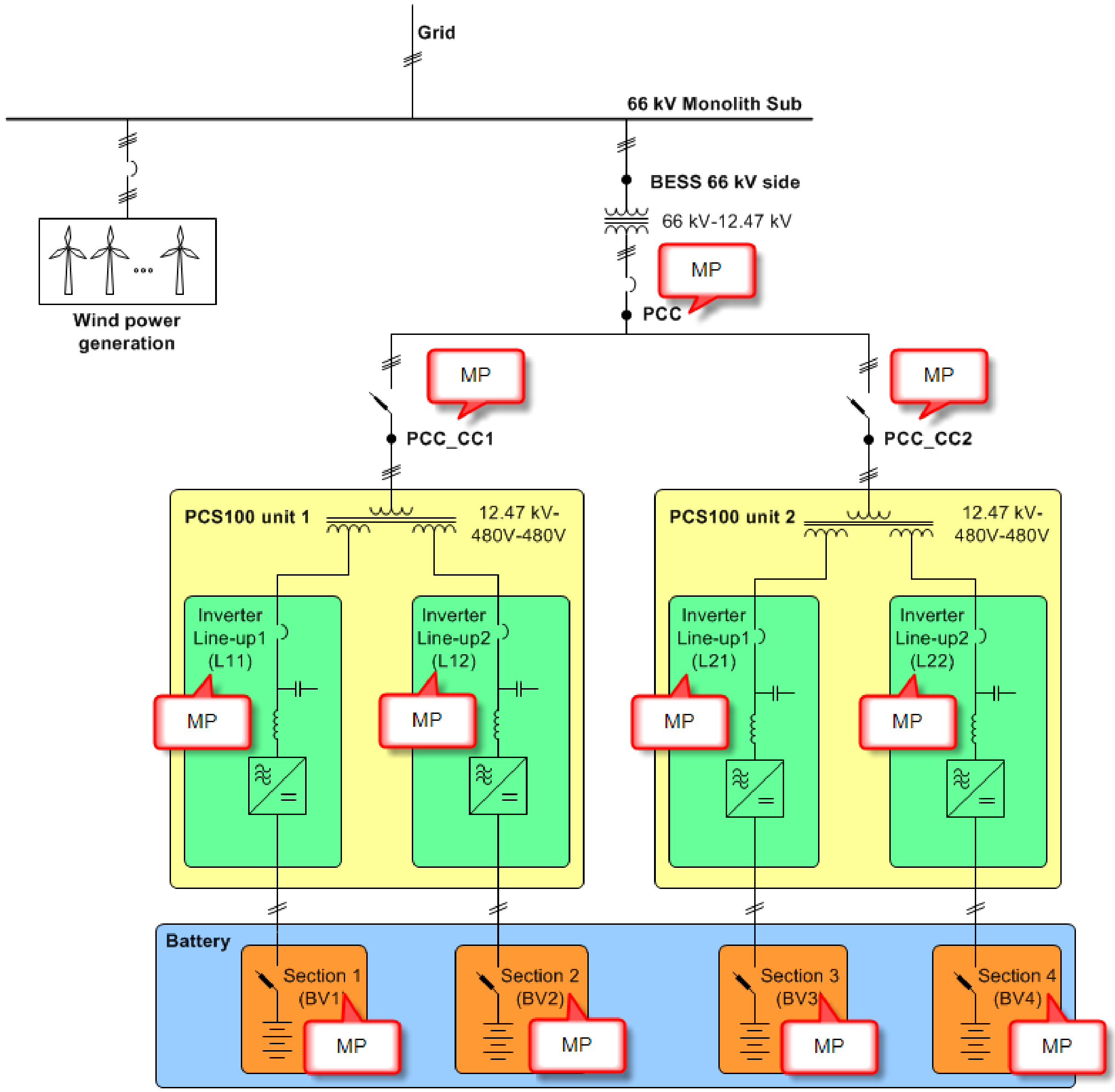


Figure 6-3- The BESS system, major components and measuring points (MP)

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

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

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

Table 6-7 - BESS efficiency at 66 kV based on PQM data for 2-cycle 4-MW test with ~30% SOC rest

Bldg. and PCS auxiliary energy included	Round trip efficiency		
	Cycle 1	Cycle 2	Average
NO	0.907	0.909	0.908
YES	0.893	0.894	0.893

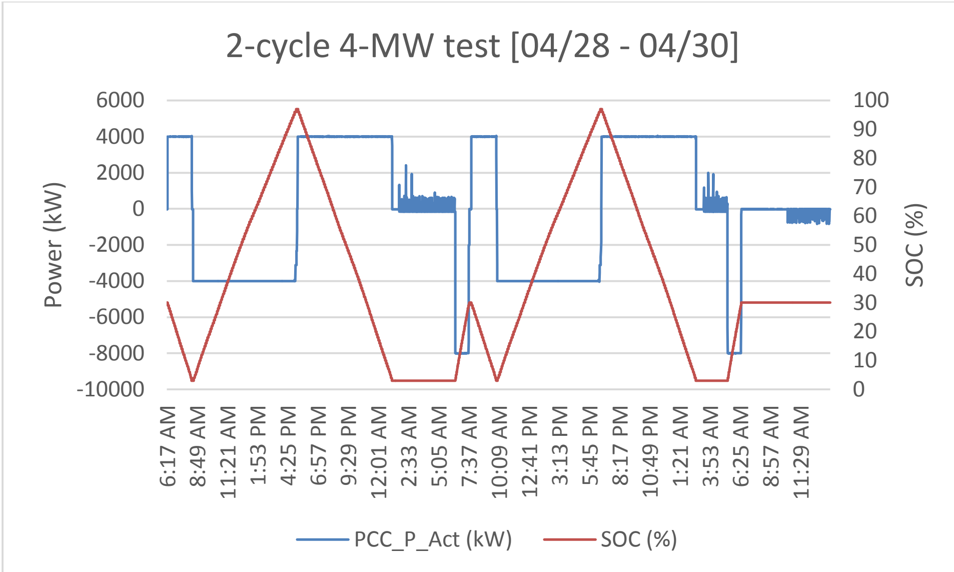


Figure 6-4- Actual power at PCC (kW) and BESS SOC (%) for 2-cycle 4-MW test with ~30% SOC rest

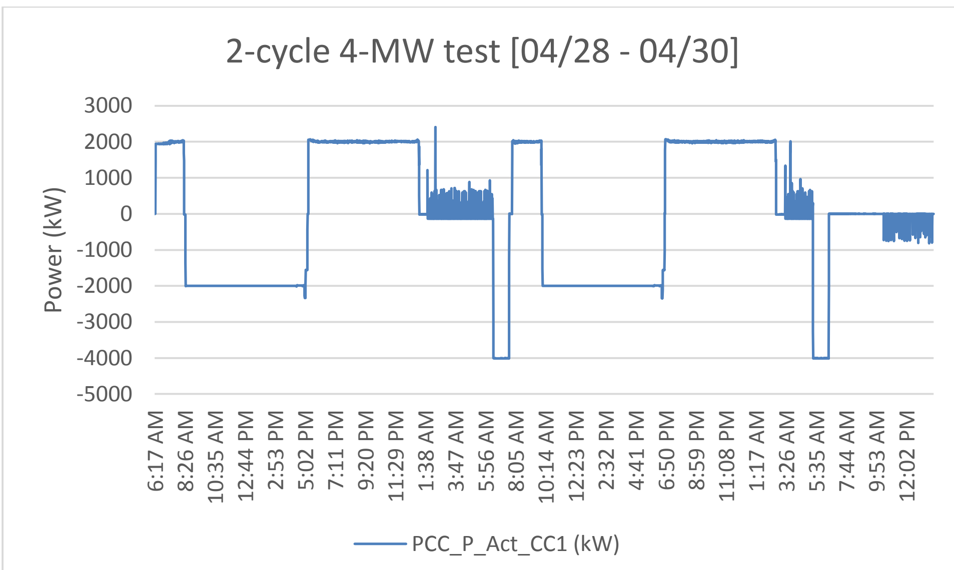


Figure 6-5- Actual power at PCC_CC1 for 2-cycle 4-MW test with ~30% SOC rest

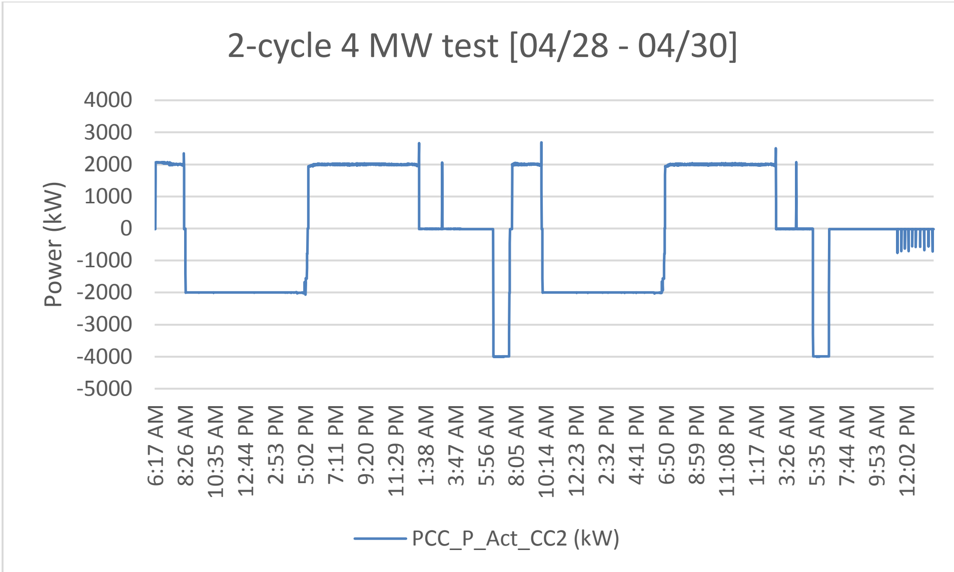


Figure 6-6- Actual power at PCC_CC2 for 2-cycle 4-MW test with ~30% SOC rest

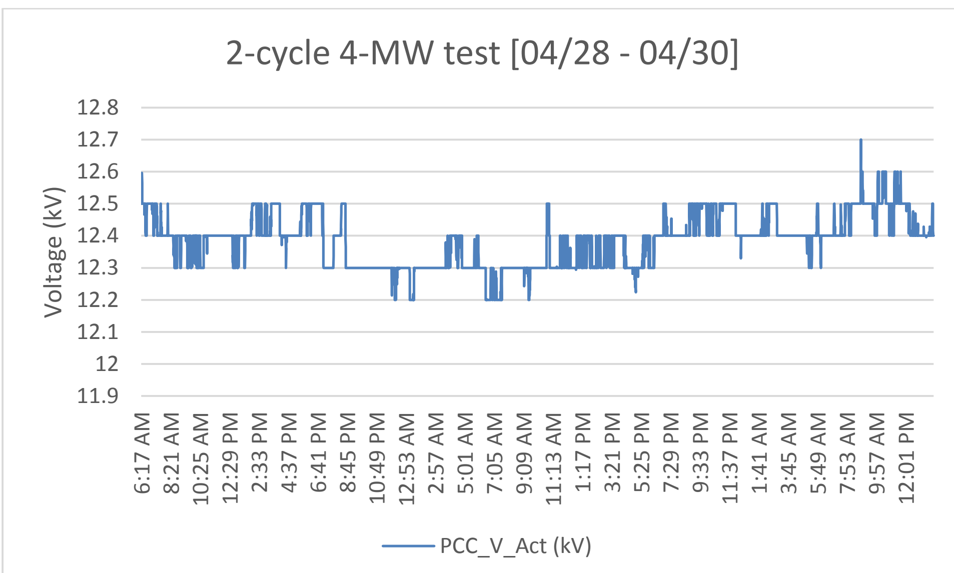


Figure 6-7- Voltage at PCC for 2-cycle 4-MW test with ~30% SOC rest

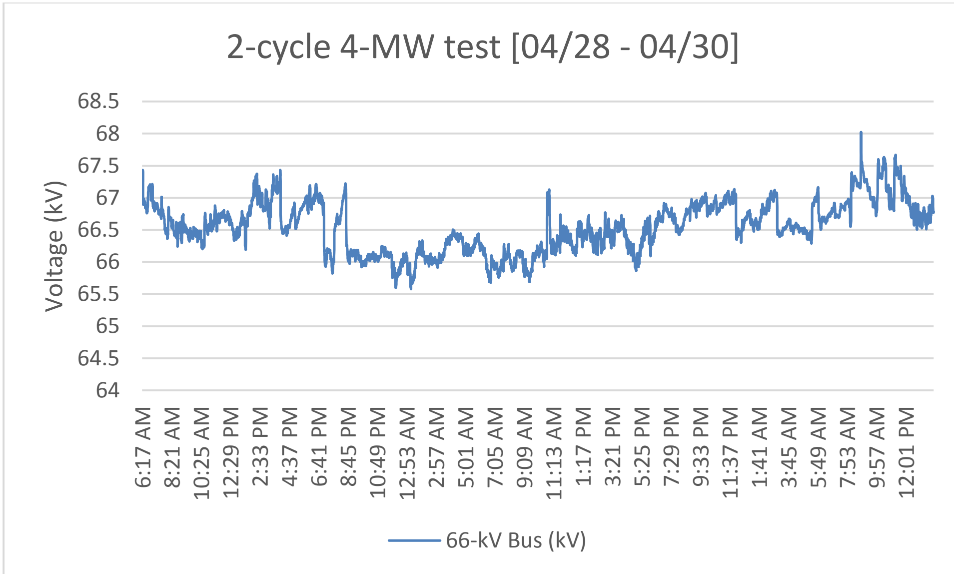


Figure 6-8- Voltage at 66 kV for 2-cycle 4-MW test with ~30% SOC rest

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

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

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

Table 6-9 - BESS efficiency at 66 kV based on PQM data for 2-cycle 8-MW test with ~30% SOC rest

Bldg. and PCS auxiliary energy included	Round trip efficiency		
	Cycle 1	Cycle 2	Average
NO	0.911	0.903	0.907
YES	0.900	0.891	0.896

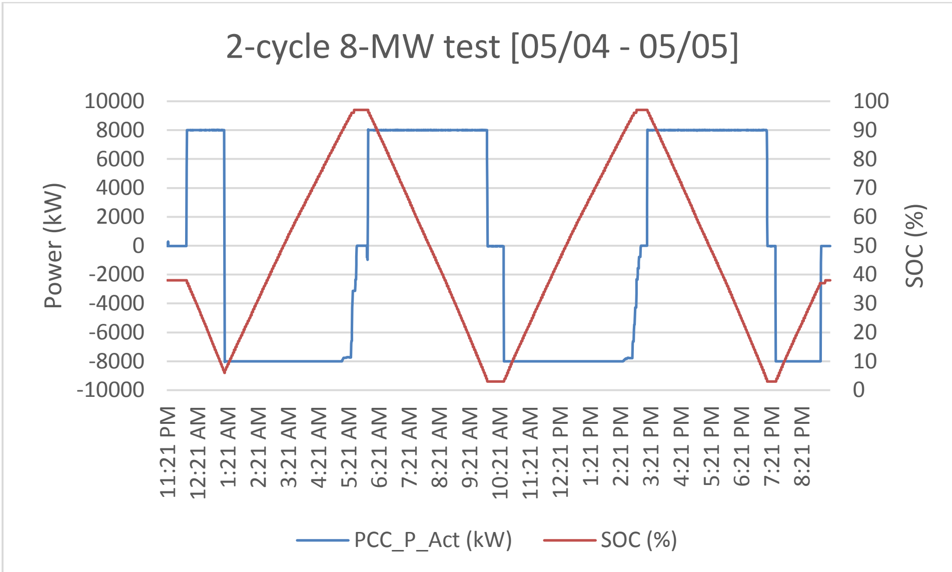


Figure 6-9- Actual power at PCC (kW) and BESS SOC (%) for 2-cycle 8-MW test with ~30% SOC rest

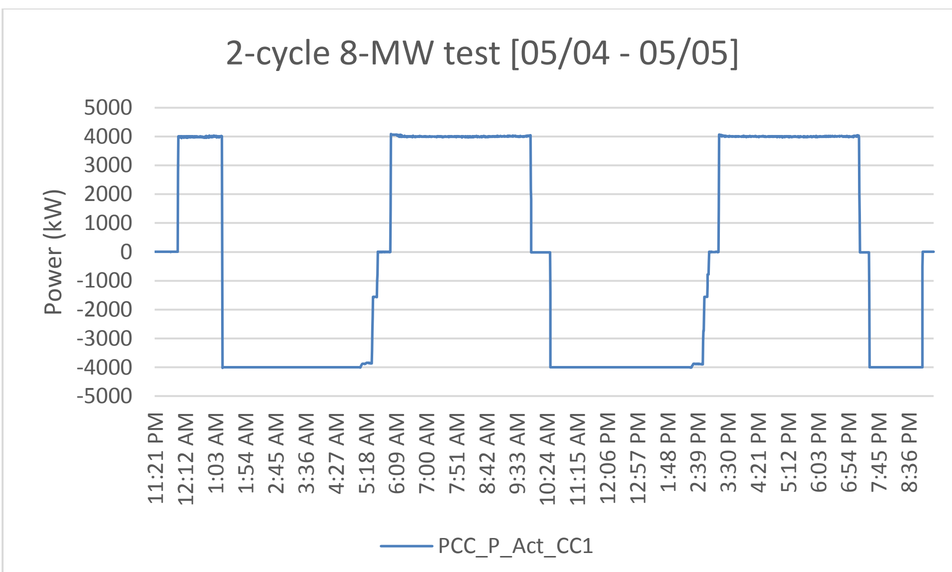


Figure 6-10- Actual power at PCC_CC1 for 2-cycle 8-MW test with ~30% SOC rest

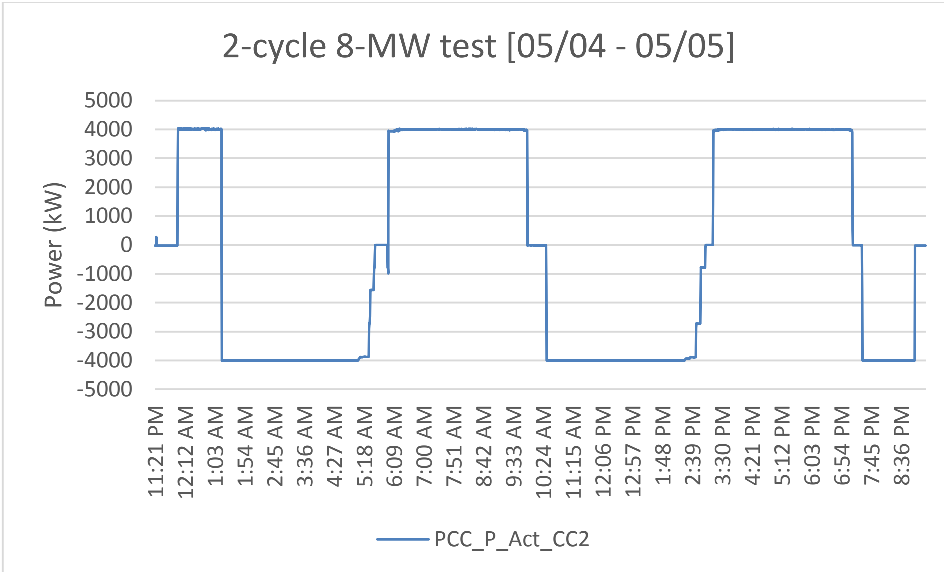


Figure 6-11- Actual power at PCC_CC2 for 2-cycle 8-MW test with ~30% SOC rest

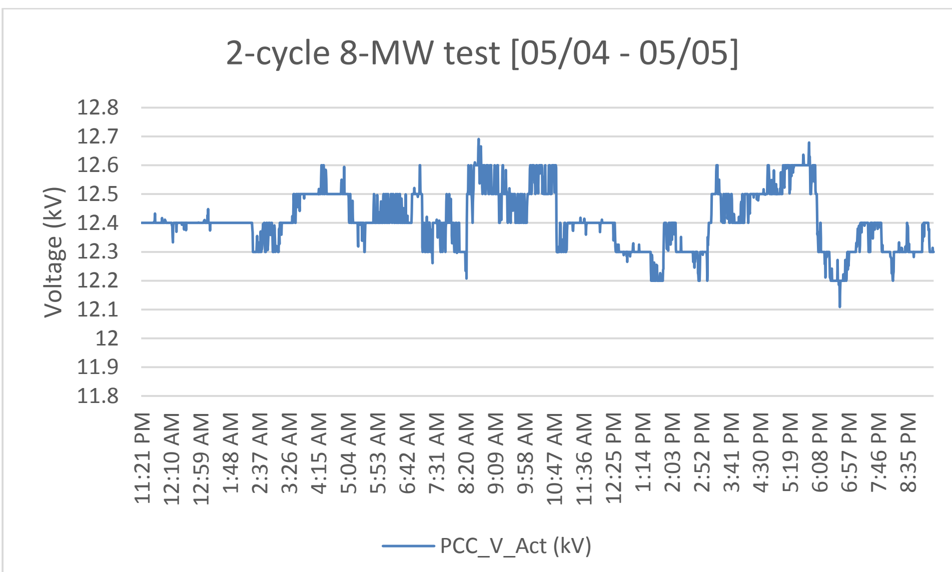


Figure 6-12- Voltage at PCC for 2-cycle 8-MW test with ~30% SOC rest

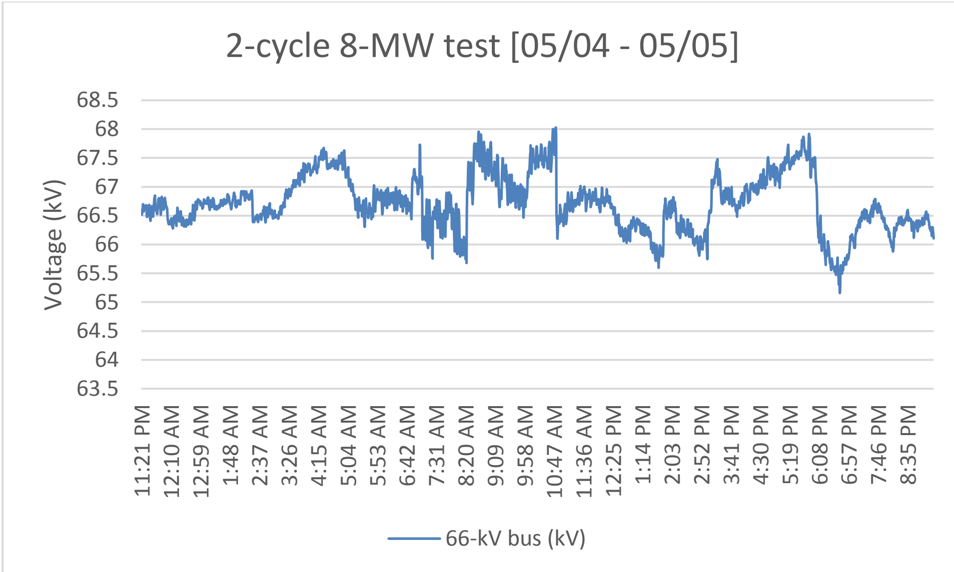


Figure 6-13- Voltage at 66-kV for 2-cycle 8-MW test with ~30% SOC rest

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

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

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

Table 6-11 - BESS efficiency at 66 kV based on PQM data for 8-MW continuous cycle test with 30% SOC rest

Round-trip efficiency							
Bldg. and PCS aux. energy included	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Ave.
NO	0.886	0.894	0.909	0.918	0.920	0.919	0.908
YES	0.875	0.884	0.898	0.907	0.909	0.908	0.897

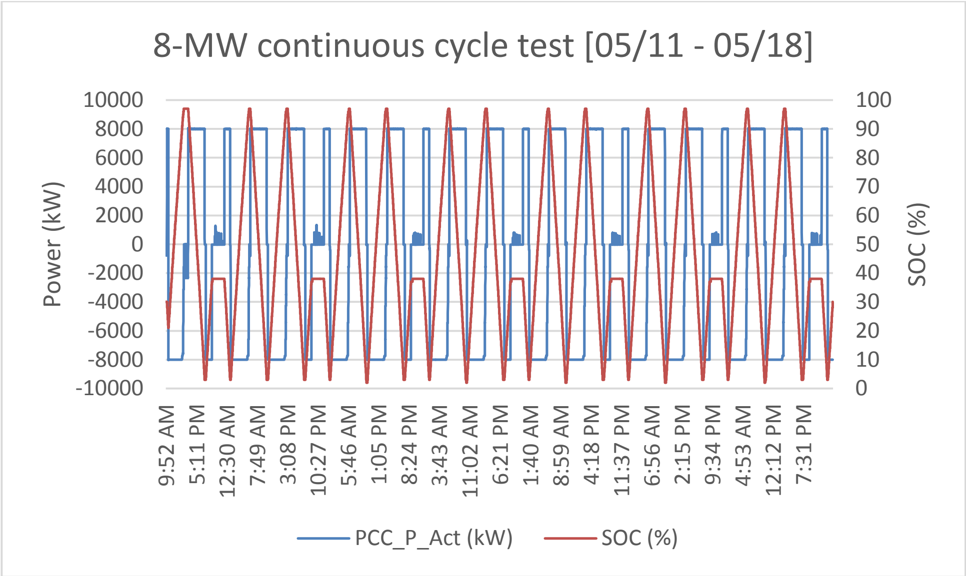


Figure 6-14- Actual power at PCC (kW) and BESS SOC (%) for 8-MW continuous cycle test with 30% SOC rest

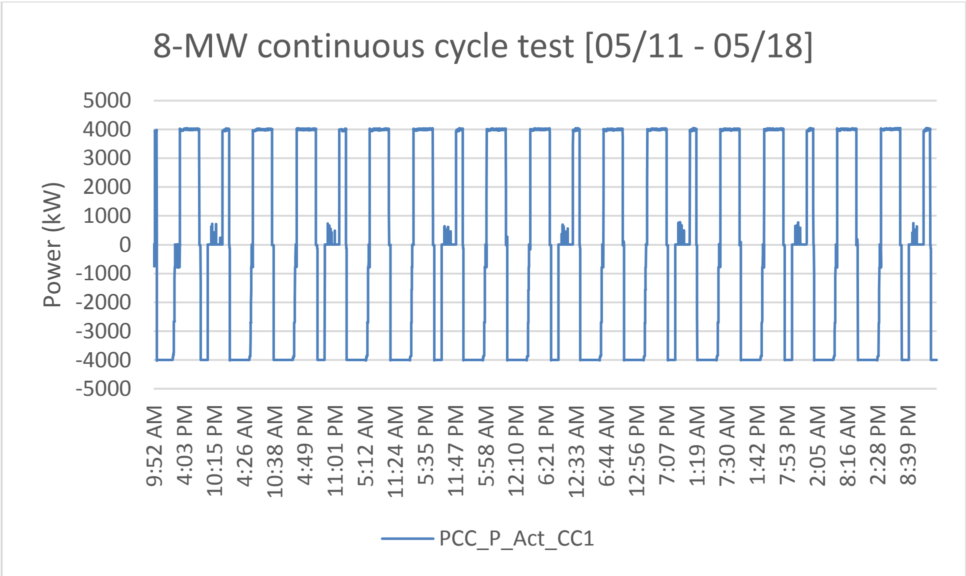


Figure 6-15- Actual power at PCC_CC1 for 8-MW continuous cycle test with 30% SOC rest

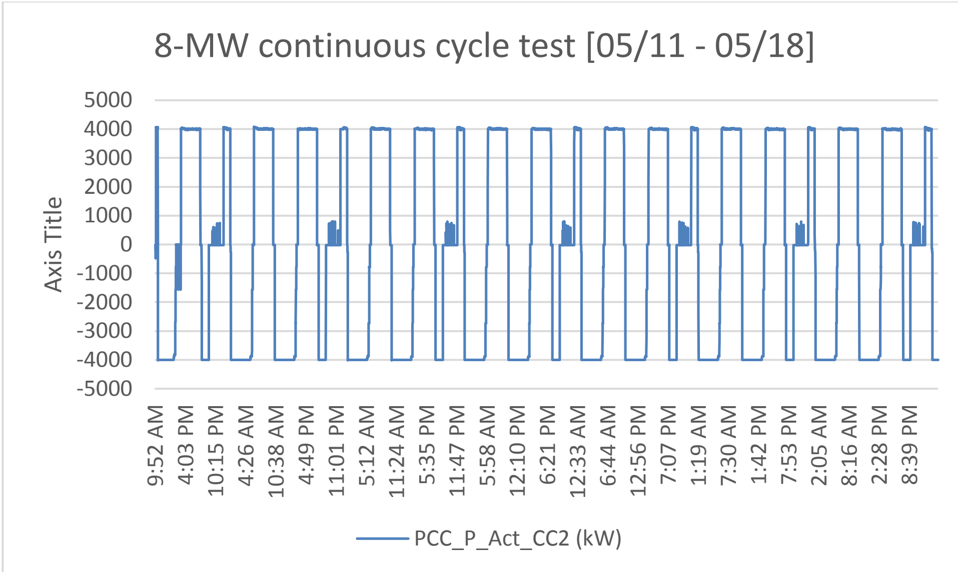


Figure 6-16- Actual power at PCC_CC2 for 8-MW continuous cycle test with 30% SOC rest

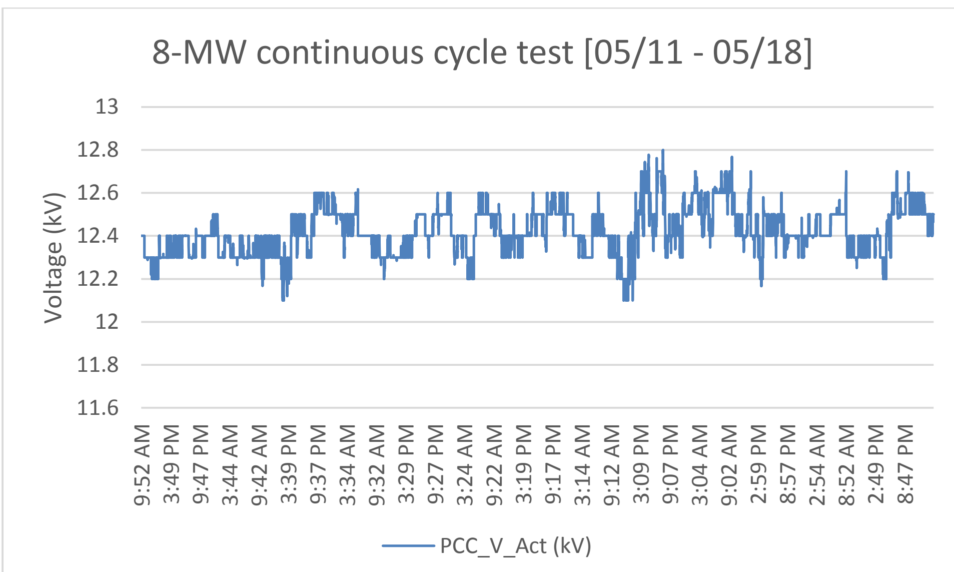


Figure 6-17- Voltage at PCC for 8-MW continuous cycle test with 30% SOC rest

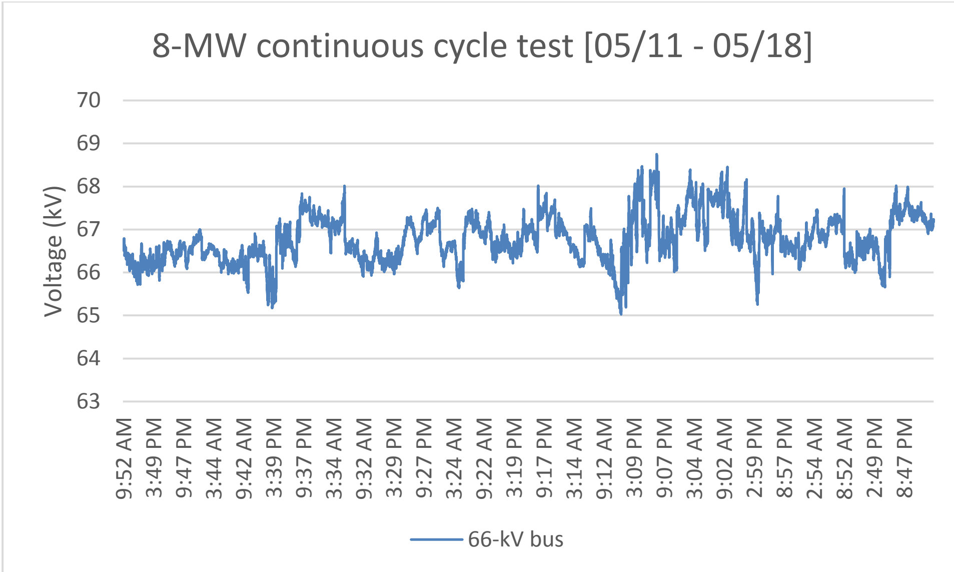


Figure 6-18- Voltage at 66-kV for 8-MW continuous cycle test with 30% SOC rest

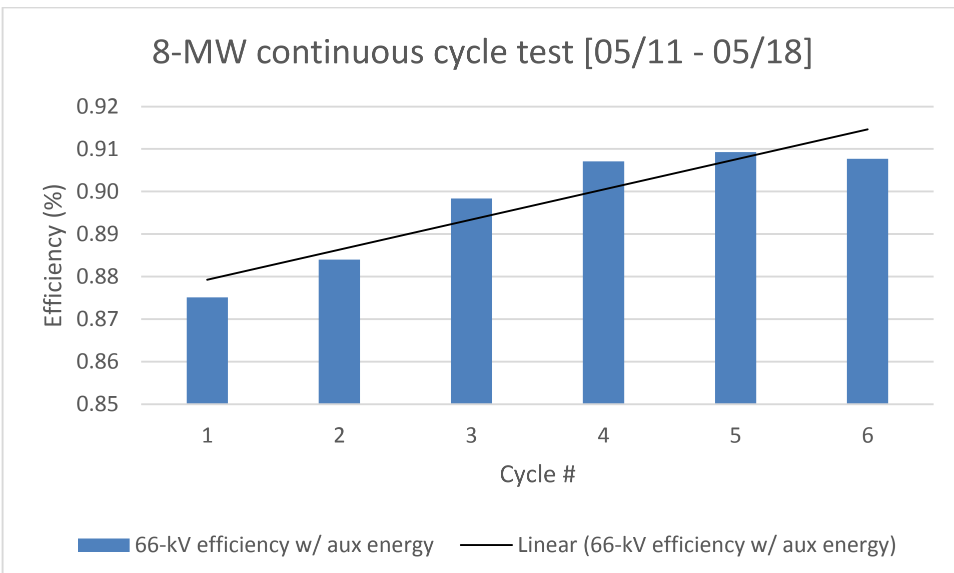


Figure 6-19- Calculated efficiency for the six test cycles during the 8-MW continuous cycle test with 30% SOC rest

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

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

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

Table 6-13 - BESS efficiency at 66 kV side based on PQM data for 4-MW continuous cycle test with ~30% SOC rest

Bldg. and PCS aux. energy included	Round-trip efficiency								
	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	avg
NO	0.895	0.905	0.894	0.895	0.904	0.896	0.895	0.904	0.899
YES	0.884	0.892	0.881	0.882	0.891	0.882	0.881	0.887	0.885

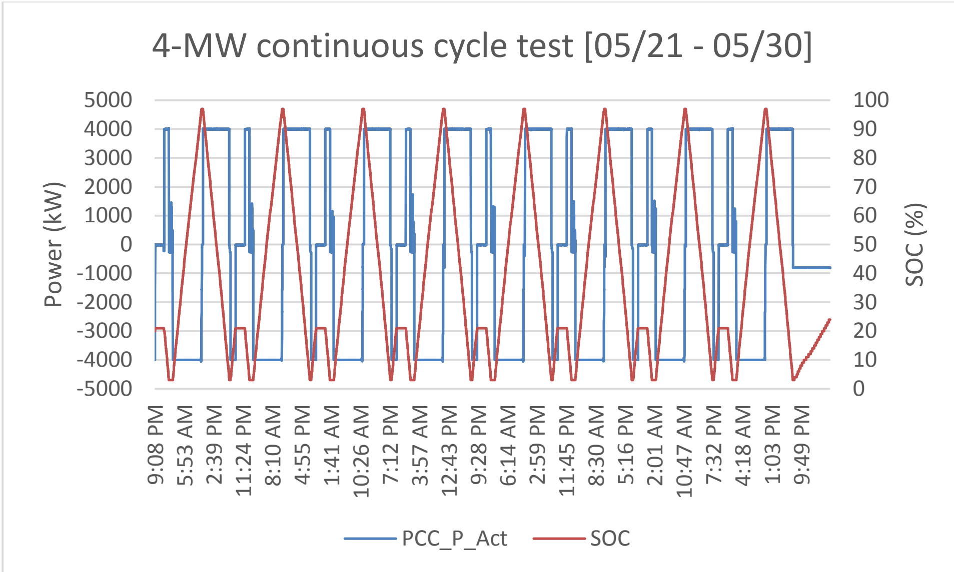


Figure 6-20- Actual power at PCC (kW) and BESS SOC (%) for 4-MW continuous cycle test with ~30% SOC rest

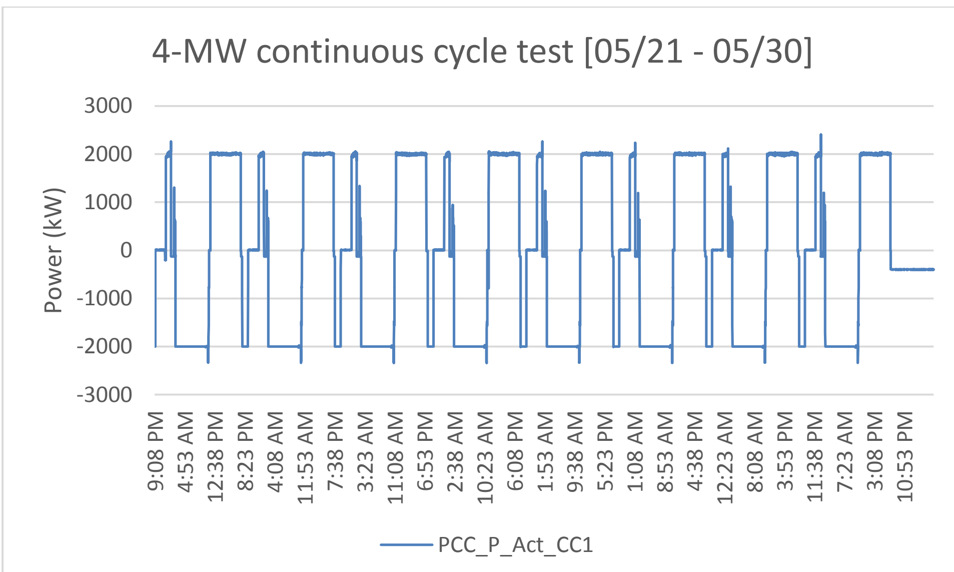


Figure 6-21- Actual power at PCC_CC1 for 4-MW continuous cycle test with ~30% SOC rest

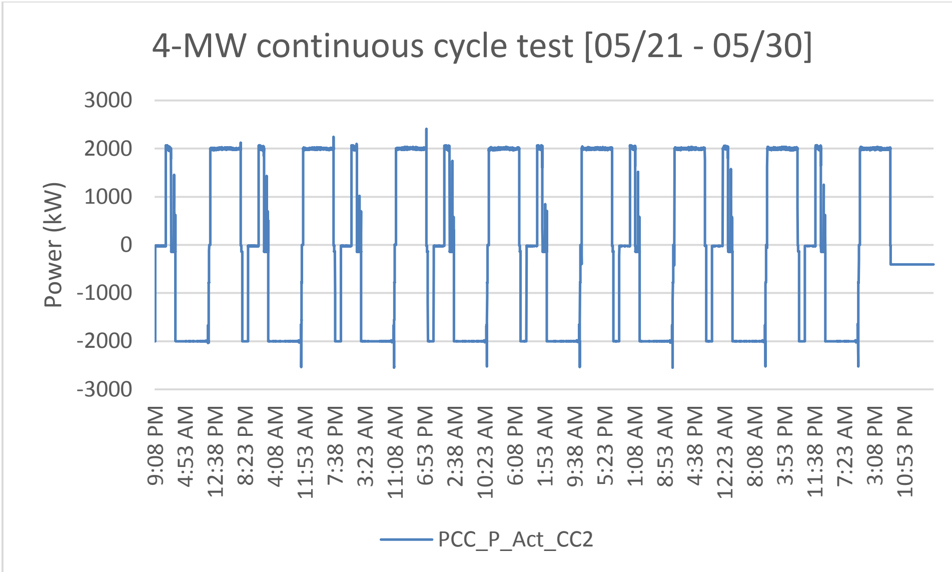


Figure 6-22- Actual power at PCC_CC2 for 4-MW continuous cycle test with ~30% SOC rest

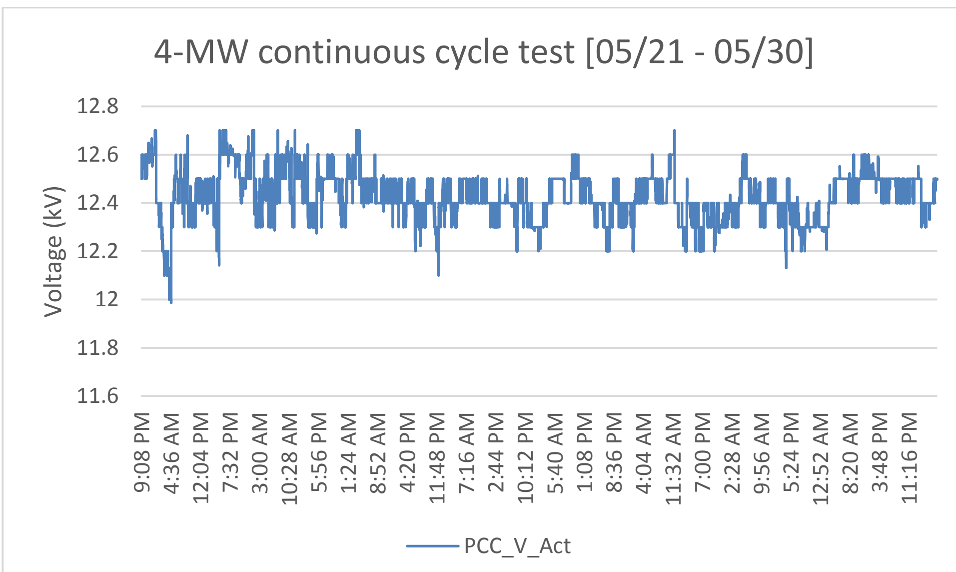


Figure 6-23- Voltage at PCC for 4-MW continuous cycle test with ~30% SOC rest

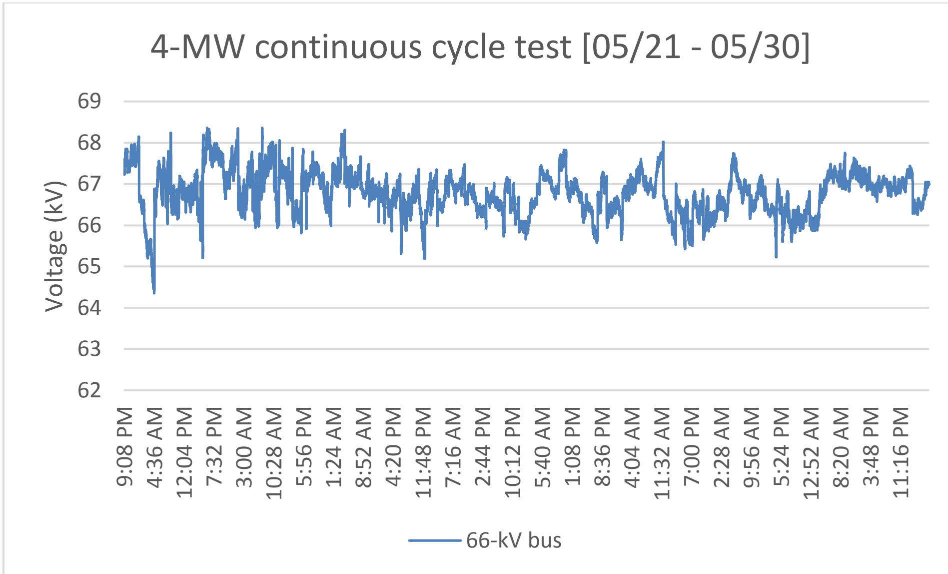


Figure 6-24- Voltage at 66-kV for 4-MW continuous cycle test with ~30% SOC rest

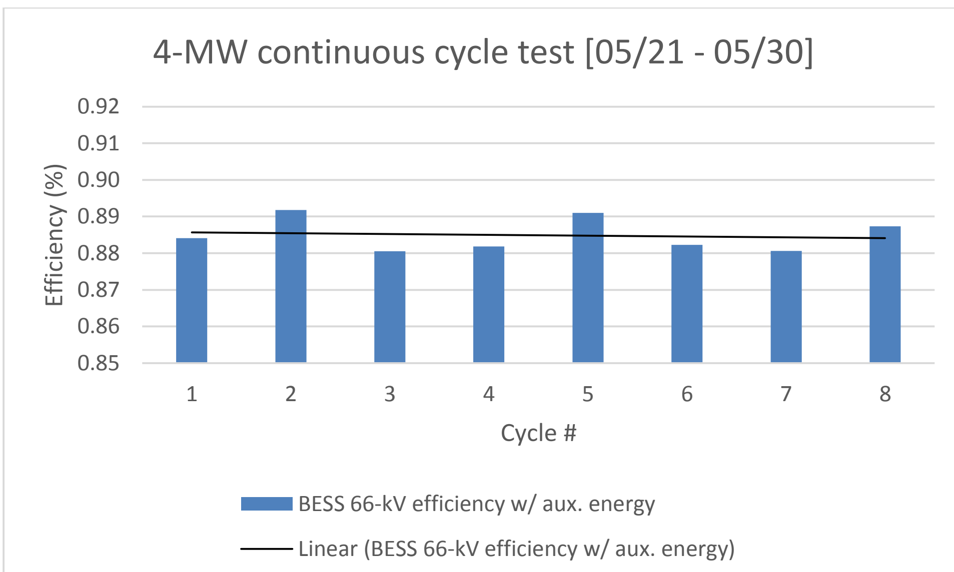


Figure 6-25- Calculated efficiency for the eight test cycles during the 4-MW continuous cycle test with ~30% SOC rest

6.4.2.6 8-MW continuous cycle test w/o rest

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

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

Table 6-15 - BESS efficiency at 66 kV based on PQM data for 8-MW continuous cycle test w/o rest

Bldg. and PCS aux energy included	Round-trip efficiency																			
	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10	Cycle 11	Cycle 12	Cycle 13	Cycle 14	Cycle 15	Cycle 16	Cycle 17	Cycle 18	Cycle 19	Ave.
NO	0.868	0.898	0.898	0.899	0.897	0.879	0.898	0.897	0.885	0.898	0.878	0.878	0.885	0.879	0.878	0.877	0.878	0.898	N/A	0.886
YES	0.857	0.884	0.886	0.888	0.884	0.868	0.885	0.884	0.874	0.884	0.866	0.866	0.872	0.867	0.864	0.863	0.867	0.882	N/A	0.874

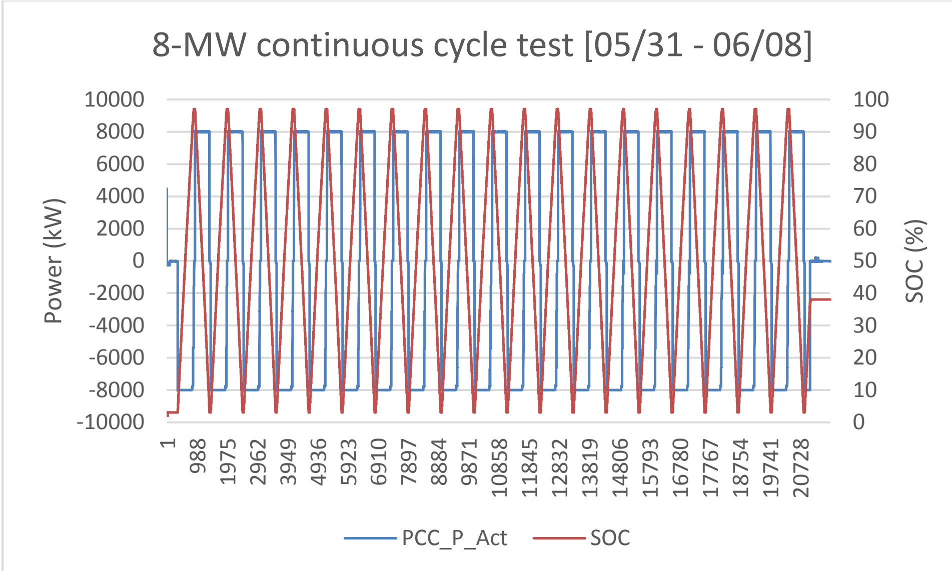


Figure 6-26- Actual power at PCC (kW) and BESS SOC (%) for 8-MW continuous cycle test w/o rest

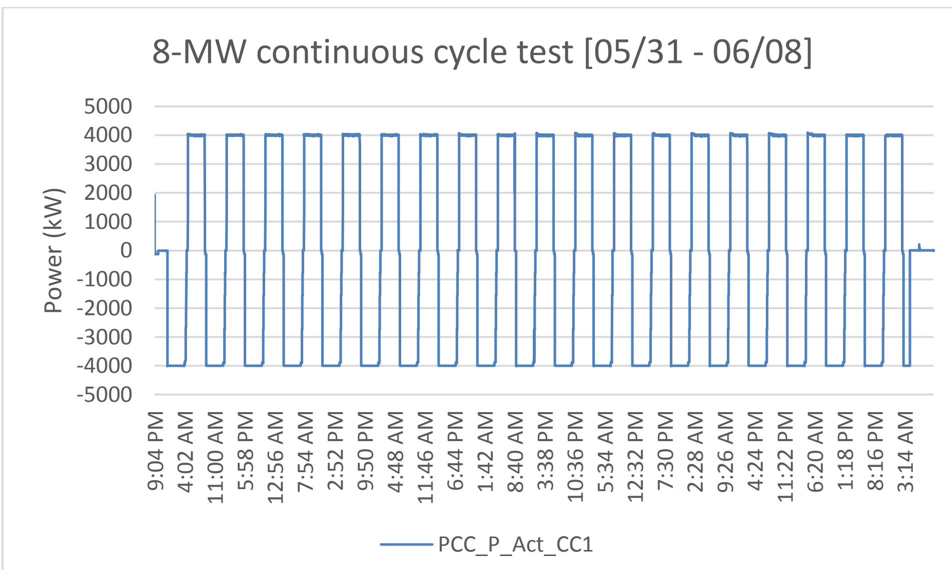


Figure 6-27- Actual power at PCC_CC1 for 8-MW continuous cycle test w/o rest

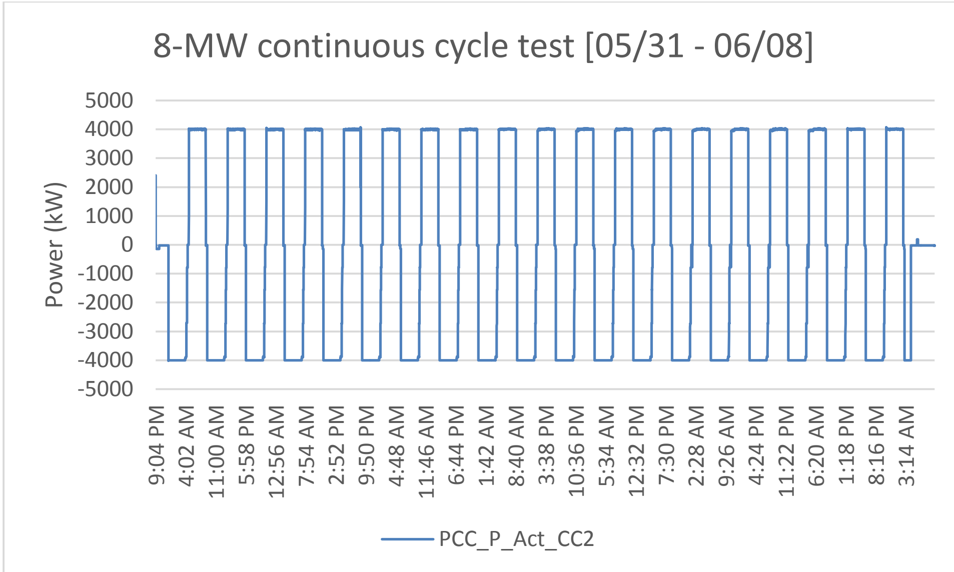


Figure 6-28- Actual power at PCC_CC2 for 8-MW continuous cycle test w/o rest

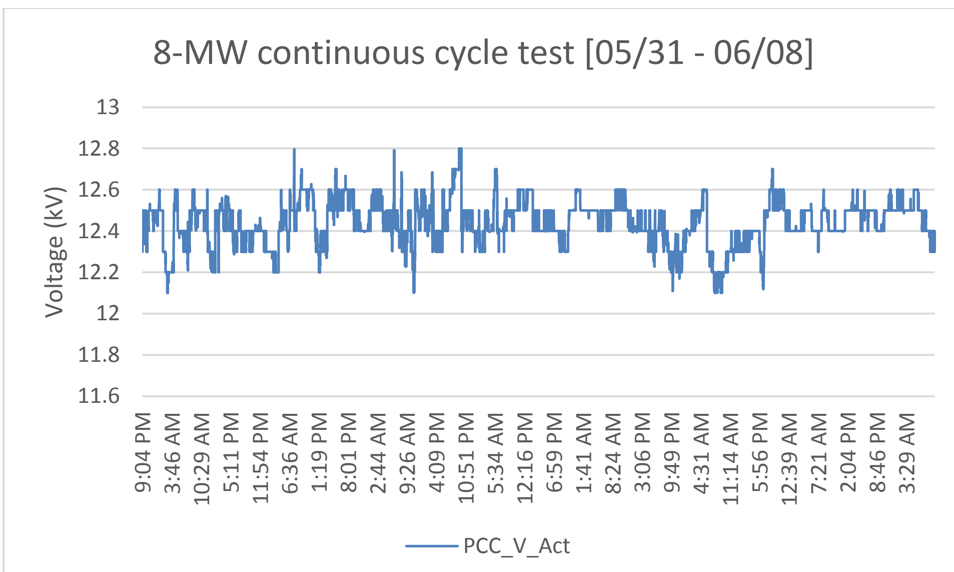


Figure 6-29- Voltage at PCC for 8-MW continuous cycle test w/o rest

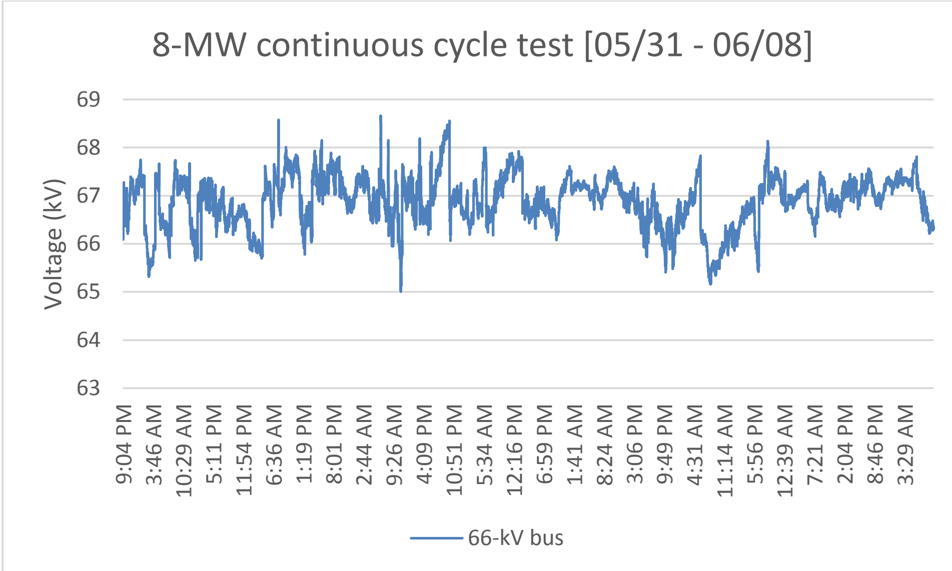


Figure 6-30- Voltage at 66-kV for 8-MW continuous cycle test w/o rest

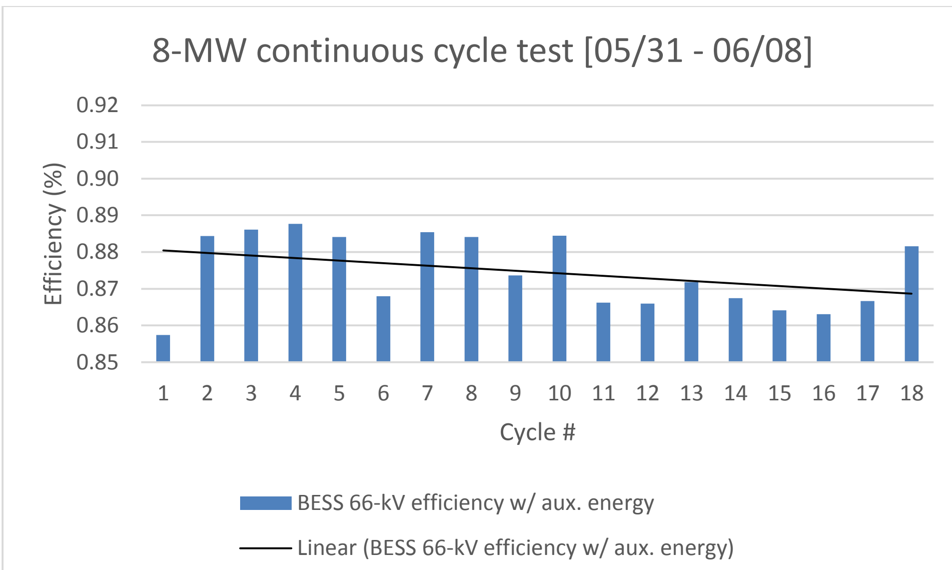


Figure 6-31- Calculated efficiency for the 20 test cycles during the 8-MW continuous cycle test w/o rest

6.5 M&V Results to Date

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

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

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

6.5.1 Market Participation

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

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

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

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

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

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

6.5.2 Operator Log and Incident Reports

An important factor in developing and implementing a BESS strategy is that the system performance is reliable. The system experienced various events such as trips, alarms, and failures throughout the M&V period. Major events and lessons learned are discussed in section 6.7. While typical non-recurring issues relating to design and operations of a new system startup can be expected, the key performance indicator is the speed at which problems and issues can be identified and corrected to cause an insignificant impact on system availability. The following are issues that had a significant impact on system availability that were unexpected operational or maintenance issues that had a significant impact on system availability:

Event Description	**% of system available**	**Dates**	**Event Duration**
PCS module replacement	0%	10/06/14 – 10/10/14	4 days
PCS work	0%	10/17/14 – 10/22/14	5 days
Loose connection in the smoke detector circuit	50%	10/24/14 – 10/29/14	5 days
PCS inverter lineup 1 trip	75%	12/24/14 – 01/08/15	19 days
PCS 1- 12kV/480V transformer failure	50%	01/13/15 – 04/21/15	99 days
Current sensor issue in BPU of Section 2	75%	05/06/15 – 05/08/15	2 days

Blown fuse for PCS 2	50%	06/16/15 – 06/23/15	7 days
PCS 1 transformer high temperature fault	50%	07/20/15 – 07/24/15	4 days
BSC hardware & software issue of PCS 1	75%	10/15/15 – 10/21/15	6 days

Table 6-15. Percentage and time intervals of which the system was not available for maximum operation

Figure 6-32 below provides a representation of the percent availability of the system over a duration of the project from August 01, 2014 through October 31, 2015. Note that for more than a third (35%) of the time over a period of 425 days of operation, the system availability was below 100%. The 425 days of operation excluded time for substation maintenance, site tours, etc.

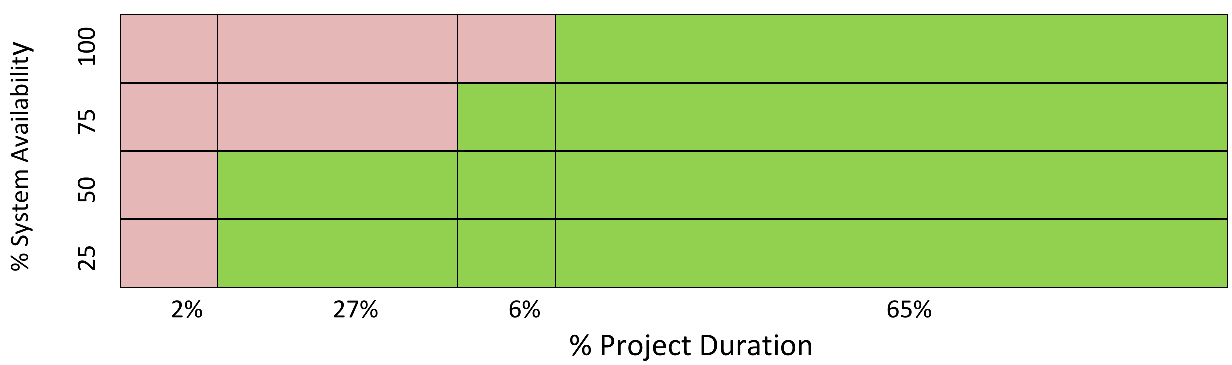


Figure 6-32- The percentage of the system available versus the total time of the project

As listed in Table 6-15 above, the duration with only 50% operational availability occurred when the PCS 1 transformer failed. This can be attributed to the fact that the BESS installation was specifically designed for this site. As a result, a large component such as the PCS transformer was custom-built and installed inside the PCS container. This required a change to a different type of transformer to be specially designed and constructed which contributed to the down time. Additionally, access to and removal/installation of the transformer caused additional down time. The takeaways are that site selection for future installations should take access to large or critical components into consideration and to the extent possible, should include non-custom built components.

6.6 Lessons Learned – Design through Commissioning

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

6.6.1 Commercial

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

6.6.2 Construction

Item/Event	Lessons Learned
Complex project with several subcontractor tiers. Onsite presence needed for shipments, unannounced visitors, on-the-spot decision making	• Perform project management and site management onsite. • People expect the prime contractor to be onsite.
Roof leaks and door gaps	• Perform leak checks of roof prior to equipment installation. • Inspect and seal doors prior to equipment installation.
Presence of insects and rodents	• Seal up doors. • Install traps. • Install sonic repellers.
No loading dock, no storage space	• Made scheduling a priority: deliveries, tasks, crew sizes, and trash disposal
Site security issues, break-ins	• Set up security procedures, track keys issued. • Perform daily check of all doors from outside prior to leaving site.
Relatively remote location, no mailing address	• Allocate resources and time for setting up basic infrastructure. • Plan to spend more time on receiving shipments, directing drivers to the site.
Unique aspects of site (location, access, weather, rodents, etc.)	• Plan for every project site being different and unique. • Take site aspects into account during pre-bid job walks. • Check weather daily and plan schedule accordingly.
Uneven floor and rack leveling	• Develop shim hardware and shimming methods to handle site conditions.

TSP CAISO interconnection of the Battery Energy Storage System (BESS)	• CAISO Interconnection Request (IR) required significant lead time to allow for processing Queue Cluster (QC) 4 • Only 2 windows for submitting IR Oct or March • Required PSLF Model to be submitted as part of the IR process • Significant costs associated with System upgrades, required up front Security Deposits to stay in the QC • Interconnection stipulated restrictions/limitations on BESS due to system topology and/or reliability requirements
Installation of System HVAC	• HVAC was specified for original BESS supplier and later applied to LG Chem. This required adoption of existing system capabilities. In retrospect it would have been valuable to consider an HVAC system that had direct interface with the BESS controls. • HVAC system was a source of roof leaks
Site Considerations	• Built within existing substation to accelerate project • Facility outside of substation would have different permitting requirements • Location and proximity to existing infrastructure needs to be evaluated (above and underground utilities) • Noise was not a significant issue due to the location, but if in a populated area it may be • Grid Protection Settings evaluation needs to be performed early in the development • Typical construction considerations e.g. construction power, storage, access, staging, interim battery storage (climate control)
Site Civil works	• Battery facility foundation used very dense rebar matt, required consideration when anchoring racks • Site seismic requirements should be considered (PCS units and battery components) • Thermal design for structure (insulation, air handling equipment, modeling, etc.) • Weight considerations for installation, movement of materials

66 kV to 12 kV Transformer Connection	• Point of demarcation needs to be clearly identified • Inter-company Clearance Procedure Requirements • Roles & Responsibilities for "Customer" and Transmission/Distribution System Owner • Lock out tag out procedure • Auxiliary power provided from a separate bus for TSP.
Fire Suppression System	• Limited guidance from fire codes and standards for lithium ion facilities. • Fire marshal reviews could be an issue for other locations • Vendors should demonstrate the effectiveness of the proposed fire suppression system through detailed analysis and laboratory tests • In the event of a fire, firefighting and post fire protocols need to be considered
Deployment of BESS equipment to site - importance of decisions that can impact the on-site commissioning and integration testing with an active grid.	• Deployment of BESS components to the site should be carefully considered and made part of the commissioning planning. • The potential for commissioning a partial ESS with the power conversion systems (PCS) while connected to the grid should be considered. The advantage of this approach is the potential earlier project completion since PCS and grid integration testing can occur while the remainder of the battery continues in production. The result is an incremental commissioning with a potential earlier project completion date.

6.6.3 Technical

Item/Event	Lessons Learned
Equipment installation and assembly challenges	• Provide more extensive training in advance. • Include more photos in manuals, have demos, have post-training tests. • Develop products with ease of installation in mind.

Initial understanding of and questions about software interface, software functions and behavior	• Include onsite training visit and training manual to introduce software.
Managing scope and requests	• Discuss and review SOW more frequently. • Have a more detailed design review toward the beginning of the project.
Subscale testing using the Mini-System	• Subscale testing provides excellent opportunities to test out both hardware and software in advance of full-scale deployment.
Computer, network, and communications configurations	• Identify specific configurations with team. • Clarify scope and resources for each piece of equipment and software since each piece may have multiple scopes and owners.
File sharing and access	• Set up file portal at project start. • Make sure that central file portal can be accessed by all team members. • Need to factor in extra efforts for posting/sending files separately if IT security prevents all team members from accessing files.
DC-bus engineering required more engineering than estimated	• Utilize additional resources for this type of work.
Onboard step-up transformer requires additional resources than an external transformer. Creates additional costs and risks.	• Avoid this configuration if possible.
Lack of familiarity with IEC61850 Server solution caused challenges in defining hardware and assembly information.	• Improve internal communications and processes.

DC bank switchboards damaged due to unit not being protected properly during shipment.	• Verify proper packaging before shipment from vendor.
Personnel were frequently requested to site for unplanned visits, causing resource issues, and additional costs.	• Include plan for site support during sales process.

6.6.4 Information Technology

Item/Event	Lessons Learned
General Management System Interface.	• Ensure early engagement of IT team. • Clearly define roles and responsibilities for IT team.

6.6.5 Preliminary Testing

Item/Event	Lessons Learned
Defined SAT procedure in advance of full-scale testing vs. in-process procedure during Mini-System testing	• Collaborating and defining all test procedures in advance helps the actual testing process later on. • Conduct training on system in advance so that software and hardware interfaces are understood clearly to enable seamless SAT.

SAT – Testing time and schedule	• Allow sufficient time not only to perform the test, but also for changeover, setup, shutdown, data collection, and data analysis.
SAT – Onsite support is beneficial for answering questions, collaborating real-time, and performing repairs	• Provide onsite support for customer during SAT. • Include onsite support on several fronts, including technical, electrician, and laborers.
Unexpected additional tasks, outages, and changes to test sequences	• Make plan flexible and not completely serial. • Be flexible and adjust as needed.
Lengthy approval and confirmation processes	• Communicate expected process and timing in advance, identify if there are scheduling and resource limitations.

6.6.6 Training

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

6.7 Events and Lessons Learned – Operations

Over the course of the formal testing period (scheduled from January 2015 through June 2016) the team will accumulate a number of insights. This TPR #2 and the Final Technical Report will report lessons learned and derived from the implementation and operation of the Test Plan. The following describes the categories and timing of significant events.

Categories

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

Reporting Aspects

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

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

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

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

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

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

On January 6, 2015, LG Chem traveled to the site to investigate the trip with remote support from ABB. LG Chem found one of the two dc circuit breakers in PCS inverter lineup 1 tripped, requiring a manual reset. As designed, this tripped circuit breaker was preventing the inverter lineup from being remotely reset or restarted (and was causing the aforementioned circuit breaker "unexpected status" fault code). On January 7, LG Chem used a circuit breaker checker tool from ABB in an effort to determine the cause of the trip, but the tool did not provide any useful information. Also during the visit, LG Chem noted the voltage of battery section 1 had dropped below the default minimum for the PCS to operate.

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

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

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

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

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

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

- Remote e-stop: The system had an existing on-site e-stop circuit designed to quickly and safely stop the system in the event of a major failure or emergency. Upon activation, this circuit was designed to send a signal to trip the PCS containers, and to open the master bank/rack auxiliary power circuit breaker after a three second delay, thereby shutting down the BBMSs, RBMSs, and MBMSs, and opening the rack main contactors for all four battery sections. However, this circuit could only be activated via a physical pushbutton in the control room. Had this circuit been controllable remotely, SCE could have used it to remove power from the BMS (albeit for all four battery sections), which would have immediately preserved the SOC without traveling to the site. At SCE's request, LG Chem and ABB added a second e-stop button outside the battery building, and added a remotely controllable software e-stop button to the SEC interface. This software button triggers the same circuit as the physical buttons, and can be used to remotely trip the system in the event of an emergency or similar situation in the future.

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

The lessons learned from this series of events include:

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

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

6.7.2 PCS Voltage Measurement Error (16 June 2015 – 23 June 2015)

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

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

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

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

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

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

	• Make arrangements with local contractors for maintenance and support when possible. This helps provide options in case of limited availability, as well as resolving logistics difficulties of having supplies delivered to/removed from an unmanned facility.

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

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

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

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

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

On 5/26/15, the third-party changed the gateway's configuration to use "buffered reporting" instead of "dataset polling". This appeared to greatly improve the performance of the gateway, since there were no interruptions to the data stream until 9/17/15. However, after 9/17, the gateway again lost communication with the eDNA server as much as several times per week, and the third-party resumed daily status checks.

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

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

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

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

over the entire operational period, data export became very cumbersome and time consuming due to limitations with the data export procedure and amount of memory available on the local data historian embedded computer	

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

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

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

Item/Event	Lessons Learned
The rack's only passive protective element prevented the rack from being charged at an unsustainable rate, after the control system failed to properly limit the	• Passive protective elements that are simple and completely independent from the primary control system are critical in protecting devices from severe damage, especially in the event the primary control system and associated safety features fail to provide the intended levels of safety and protection.

charge power based on real-time system operating conditions.	• Extensive system behavior and safety testing is important to ensuring control system hardware, software, and algorithms work properly under all possible operating modes and scenarios, and are capable of protecting the integrity of system components and the safety of personnel.

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

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

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

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

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

Item/Event	**Lessons Learned**
Battery section controller computer failed	• Use of a hardened computer, industrial PLC, or parallel devices with redundancy or failover, may have prevented a similar singular control system hardware failure from affecting a large portion of the system. • • Use redundant power supply
Computer clock unsynchronized; not	• Manufacturers should make use of complete commissioning procedures to ensure all configuration and startup aspects of a hardware/software

configured properly during commissioning	installation/replacement are addressed before the system is returned to the client for operation.
Computer frozen, likely due to battery section controller software patch not installed during commissioning	• Same as above. • Software issues discovered during testing and operation may be addressed by patches, and all appropriate patches should be included in commissioning procedures. When appropriate, patches should be replaced by subsequent software revisions/updates, and commissioning procedures should be updated.

6.7.7 Additional Lessons Learned During 2015

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

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

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

6.7.8 Hardware Replacements

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

Item/Event	**Lessons Learned**

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

Battery Protection Unit (BPU) Issues • Current Sensor Wire Error message appeared during starting or restarting of the battery system	• Root cause: Intermittent connection between the sense lead connector and current sensor • Corrective action: Replaced 11 affected BPUs • Component Manufacturing: Include manufacturing enhancements, such as using assembly jigs

	• System Design: Test and evaluate components more strictly during the design and product development process; include diagnostic messages that are more descriptive • Product Design: Develop new versions of BPUs with improved internal structure, more robust parts, and secure connections; including improved connector housing and dual-channel current sensor

6.8 Conclusions

This TPR #2 defers project wide conclusions until the Final Technical Report #3. The project has shifted in concept from 2 years of uninterrupted operation to debugging and intermittent operation while accomplishing the scope of the Test Plan requirements.

The primary conclusions at this point are:

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

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

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

The Final Technical Report #3 will report further conclusions derived from the implementation and operation of the Test Plan.

7. Storage System Performance Parameters

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

STORAGE SYSTEM PERFORMANCE PARAMETERS: Technical		
Metric	Value	Definition
Scheduled maintenance down time[4]	%	Ratio of the time that the energy storage system is down for scheduled maintenance divided by the total timeframe. Example: If the system was down for scheduled maintenance 50 hours out of 30 days (720 hours), then the "scheduled maintenance down time" would be 6.9% = (50/720*100).
Down time associated with State of Charge (SOC)[4]	%	Ratio of time that the energy storage system has been charged/discharged to the limit and is unable to respond to a signal divided by the total timeframe minus scheduled maintenance down time. Example: If the energy storage system was at the SOC limit for 5 hours and the system was down for scheduled maintenance 50 hours out of 30 days (720 hours), then the "down time associated with SOC" would be 0.7% = (5/(720-50)*100) .
Unscheduled down time[4]	%	Ratio of the unscheduled down time divided by the total timeframe minus scheduled maintenance down time. Example: If the system was down for 10 hours due to unscheduled incidents and down for 50 hours for

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

* To be reported at the start of operations.

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

STORAGE SYSTEM PERFORMANCE PARAMETERS: Technical		
Metric	Value	Definition
Number and duration of failure incidents	#, hrs/days	Date and time of the failure incidents including a description of the general cause and duration. To be tracked upon initiation of reliability testing starting Jan. 1, 2015

[4] Reliability testing to begin Jan 1, 2015

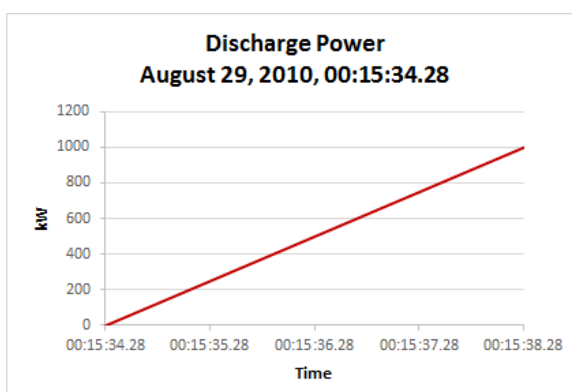
		Note: This is a summary list and the details of each of these failure incidents will be tracked and available for review.
Energy dispatched on day-to-day and lifetime basis	kWh	Energy dispatched on day-to-day basis accumulated for entire project. Example table: ENERGY DISPATCHED Date / kWh / Cumulative kWh August 1, 2010 / 557 / 557 August 2, 2010 / 330 / 887 August 3, 2010 / 129 / 1,016
Round-trip efficiency (RTE)	%	Ratio of total energy storage system output (discharge) divided by total energy input (charge) as measured at the interconnection point. Example: If the total output was 5,000 kWh, but the total energy input was 6,500 kWh, then the "round-trip efficiency" would be 76.9% = (5,000/6,500*100). Note: supplemental loads and losses (e.g., cooling, heating, pumps, DC/AC and AC/DC conversions, control power, etc.) consumed the 1,500 kWh.

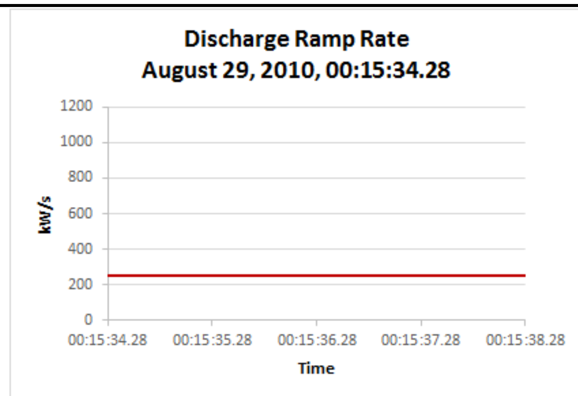
Example table (ENERGY DISPATCHED):

ENERGY DISPATCHED		
Date	kWh	Cumulative kWh
August 1, 2010	557	557
August 2, 2010	330	887
August 3, 2010	129	1,016

STORAGE SYSTEM PERFORMANCE PARAMETERS: Technical		
Metric	Value	Definition
Ability to follow Automatic Generation Control (AGC) signal (load following only) and Area Control Error (ACE) signal (regulation only)	N/A	Ratio of the kWh provided by the energy storage system divided by the kWh required by the AGC at each 4 second interval. Example: If the AGC or ACE signal requires discharge of 100 kWh but the energy storage system only provides 80 kWh during that 4 second interval, the ability to follow the AGC or ACE signal would be 80% = (80 kWh/100 kWh *100) *Note: This is a summary number and the details of each of these incidents will be tracked and available.*

Capacity degradation	0%	Ratio of energy capacity at the end of the time period divided by the capacity at the beginning. Example: If the total energy storage system capacity at the end of the project had a capacity of 4,000 kWh and at the start of the project was 5,000 kWh, then the "capacity degradation" would be 20% = ((5,000-4,000)/5,000*100). Note: for battery systems, this measurement is taken on the device DC bus. Otherwise it is at the interconnection point. Reliability testing to begin Jan 1, 2015

STORAGE SYSTEM PERFORMANCE PARAMETERS: Technical		
Metric	Value	Definition
Ramp rate (charge/discharge)	kW/sec Graph and Table	The change in power charged and discharged over time to meet the variations in power requirements. Graphically (with resolution of 100 milliseconds) demonstrate the energy storage system's sustainable maximum ramp rate (kW/sec). List the number of times that the energy storage system did not meet the requested ramp rate on a daily basis. Example Details: August 29, 2010, 15:34.28, Maximum Discharge 0kW to 1,000kW achieved in 4 seconds for a discharge ramp rate of 250 kW/s. Example of Associated Graphs: 

		Discharge Ramp Rate August 29, 2010, 00:15:34.28 1200 1000 800 600 400 200 0 kW/s 00:15:34.28 00:15:35.28 00:15:36.28 00:15:37.28 00:15:38.28 Time

STORAGE SYSTEM PERFORMANCE PARAMETERS: Economic		
Metric	Value	Definition
Engineering and design costs	$	The cost associated with engineering and design for the demonstration project implementation.
Capital cost (i.e., equipment capital and installation)*	$	Total installed first cost of fielded system, breaking out major categories including equipment (i.e., major equipment components, related support equipment, and initial spare parts) and costs associated with shipping, site preparations, installation, and commissioning.
Capital cost*	$/kWh & $/kW	Total installed first cost of fielded system, normalized by energy storage capacity and peak power output.
End of life disposal cost**	$	Total cost of dismantling and removing the fielded system, including (if applicable) decontamination long-term waste storage, environmental restoration and related costs.
End of life value of plant and equipment**	$	Resale or salvage value of plant and all associated equipment.
Operating cost (activity based, non-fuel, by application plus monitoring)	$/kW-month	Activity based, average monthly total of all direct and indirect costs incurred in using the system, excluding the cost of purchased electricity and including third-party monitoring if applicable.
Maintenance cost (by cost category)	$/kW-month	Activity based, average monthly cost of maintaining the fielded system.

* To be reported at the start of operations.

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

STORAGE SYSTEM PERFORMANCE PARAMETERS: Environmental Health & Safety		
Metric	Value	Definition
Operating temperature	20°C	Degrees Fahrenheit at which the energy system normally operates.

Flammability	°C	Material flammability ignition temperature and ignition energy.
Material toxicity	--	Qualitative discussion on materials toxicity.
Recyclability	%	Percent of the material from the energy storage system expected to be recyclable at the end of life. Example: If there are four tons of lead that can be recyclable from the original five tons installed, then the lead "recyclability" would be 80% = (4/5*100).
Other	N/A	List and describe any other EH&S issues.

Table 7-1 Storage System Performance Parameters

***** To be reported at the start of operations.

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

8. Impact Metrics

Limited data is available to date. Table will be updated with data for the Final Technical Report #3.

IMPACT METRICS: Electric Transmission Systems				
Metric	**Remarks**	**Value**		**Data Analysis**
		Project	**System[5]**	
Metrics Related Primarily to Economic Benefits				
Congestion		MW	MW	Information will be estimated or modeled based on CAISO system records of MW dispatched to relieve a transmission constraint and the associated cost.
Congestion Cost		$	$	
Transmission Line or Equipment Overload Incidents	The total time during the reporting period that project area line loads exceeded design ratings	0	0	Data will come from the Transmission Management System (legacy EMS) and from PMUs when available.
Transmission Line load	Real and reactive power readings for those lines involved in the project. Information should be based on hourly loads and obtained from SCE application	MW	MW	
		MVAr	MVAr	
Deferred Transmission Capacity Investments	Project area transmission capacity investments are not anticipated at this time.	0	0	Semi-annual variance analysis of transmission capital investment plan
Transmission losses		%	%	EMS load information, transmission planning model analysis.
Transmission power factor		PF	PF	
Metrics Related Primarily to Environmental Benefits				
CO_2 Emissions		Tons	Tons	Emissions impacts will be calculated based on other metrics and results; including transmission
Pollutant Emissions (SOx, NOx, PM-2.5)		Tons	Tons	

[5] This project only includes one single system, therefore “System” values are identical to “Project” values.

				losses, congestion and integration of wind generation resources.

Table 8-1 Impact Metrics Electric Transmission Systems

Impacts Metrics Storage Systems

IMPACT METRICS: Storage Systems				
Metric	**Remarks**	**Value**		**Data Analysis**
		Project	**System**	
Metrics Related Primarily to Economic Benefits				
Annual Storage Dispatch	July 1 thru Dec. 31 2014	1,014,027 kWh[6]	1,014,027 kWh[6]	Data will come from the storage system PCS.
Annual Storage Dispatch	Jan. 1 thru Dec. 30 2015	4,693,048 kWh[6]	4,693,048 kWh[6]	Data will come from the storage system PCS.
Average Energy Storage Efficiency	Excluding Aux. Loads	88.6%	88.6%	Information will be calculated based on data from the storage system PCS.
Average Energy Storage Efficiency	Including Aux. Loads	87.4%	87.4%	Information will be calculated based on data from the storage system PCS.
Ancillary Services Price	Operating reserves and frequency regulation	$/MWh	$/MWh	Information will be estimated or modeled based on CAISO system records of ancillary services prices.

Table 8-2 Impact Metrics Storage Systems

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

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

Table 8-3 Impact Metrics: Transmission Systems Baseline

Impact Metrics: Storage Systems Baseline

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

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

9. Appendices

9.1 Appendix A: Detailed Test Plans

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

Overview:

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

Primary Method of Performing Tests:

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

The BESS Site Energy Controller (SEC) regulates voltage to within +/-5%[7] of the set point. The +/- 5% dead-band will be adjustable in an upcoming software revision. If the voltage set point is 66 kV, then BESS voltage support capability will be in effect only when the Monolith bus voltage falls outside of 66 kV ±5% (i.e., [62.7 kV, 69.3 kV]), which may be a less likely event in the current system. However, if the voltage set point is 62.86 kV, then BESS voltage support capability will be in effect when the Monolith bus voltage is higher than 66 kV (set point voltage +5%), which is more likely to happen. In the first phase of the test, a sweeping test is proposed to evaluate BESS' voltage sensitivity in current system and to identify the best selection for voltage set point. The series of voltage set points to be tested are shown in Table 9-1.

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

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

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

Table 9-1 Voltage Set Point Sweeping Test

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

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

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

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

Given the healthy local voltage profile, there is no particular preference on the time of day for conducting the test. Each test case will last, at a minimum, until bus voltage has stabilized at the command value. A duration of one hour is suggested to demonstrate BESS' ability to sustain the scheduled MVAr flow. It is ideal that capacitor banks will remain the same status during all the series of voltage set points in the test. However, if keeping the capacitor banks fixed may cause potential adverse impact to the system, the status of capacitor banks will remain the same during the test for the same voltage set point.

Data to be collected:

- Voltage profile at 66 kV Monolith substation bus
- Monolith substation capacitor bank status
- BESS parameters
    - Status
    - Voltage Set Point
    - State of Charge (%)[8]
    - Charge/Discharge rate (MW/MVAr)

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

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

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

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

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

9.1.2 Test 2 Steady State Voltage Regulation Under Any Mode

Overview:

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

Primary Method of Performing Test:

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

As this test will be conducted in conjunction with Test 3/4/5, it is recommended to perform this test after Test 3/4/5 have been conducted and data analyses have provided insight of how and how much the BESS affects the system parameters evaluated in each test. With this information from well-developed tests 1/3/4/5, this test can concentrate on demonstrating the capability of BESS in providing dynamic voltage support at local Monolith 66 kV bus.

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

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

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

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

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

Overview:

Test 3 was primarily designed to demonstrate BESS operation to mitigate congestion (Operational Use 3). Prior to the EKWRA project, two 66 kV lines between Cal Cement and Antelope substations and one 66 kV line between Goldtown and Antelope experienced congestion when high wind generation output exceeded available transmission capacity. If the pre-EKWRA configuration had remained in place, this test would have demonstrated Operational Use 3 by charging during periods of high line loading and discharging during periods of low line loading. Reduced line loads in the high load period would correspond to reduced transmission congestion while also reducing curtailment of wind generation requiring compensation. Reduction in line loading will also reduce transmission losses (Operational Use 2).

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

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

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

Primary Method of Performing Test:

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

The BESS SEC utilizes an algorithm[9] to compare the line loading of two selected transmission lines with the pre-defined range and then dispatch BESS to inject or absorb real power accordingly. The two selected transmission lines that carry the wind power to Windhub through Monolith substation are

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

[9] ABB, “Tehachapi Wind Energy Storage Project Control and Interface Concept”

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

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

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

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

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

Data to be collected:

- Transmission loads on the following 66 kV lines.
  - Monolith – Breeze lines 1 & 2
  - Monolith – Cummings line
  - Monolith – Loraine line
  - Monolith – Cal Cement line
  - Monolith – MidWind line
  - Monolith – ArbWind line
- Frequency at Monolith substation (PMU data)
- Monolith transformer 1 and 2 load
- Tehachapi wind generation profile for each wind plant (MW/MVAr)
- Storage dispatch event with its timing
- BESS parameters
  - Status
  - State of Charge (%)

- Energy Available
- Charging/discharging rate (MW/MVAr)

Step #	Who Does It?	Action	Additional Notes
	Which participant, either primary or secondary is responsible for the activity in this step?	Describe the actions that take place in this step in active, present tense.	Additional description of statement about the step to help support description. Comments about data collection requirements, special equipment features, unusual challenges, etc.
1	Advanced Energy Storage	In BESS HMI, configure "Test 3 Set Points" SP parameters as: • I_Calc_Lim1 = 91 • I_Calc_Lim1_Lower = 79 • I_Calc_Lim2 = 91 • I_Calc_Lim2_Lower = 79 • I_Limit_Lower_Deadband = 2 • I_Limits_Deadband = 2 • I_Line1_Lim1 = 70 • I_Line1_Lim1_Lower = 60 • I_Line1_Lim2= 70 • I_Line1_Lim2_Lower = 60 • T_Lim = 70[10]	The BESS will begin the test at approximately 50% SOC. The parameters "SOC Max (%)", "SOC Min (%)", "SOC (%)" will remain at default values. The parameters "P Ramp + [kW/sec]", "P Ramp – [kW/sec]", "P Charge [kW]", and "P Discharge [kW]" remain at default values to enable charge/discharge BESS at the maximum rate. The parameters are based on the selection of Monolith – Sub Tran Lines BREEZE1/Monolith – Sub Tran Lines BREEZE2 as Line 1 and Line 2. If BESS SEC has other

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

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

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

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

Overview:

The output of wind resources is variable and dependent on wind availability. Output is generally higher during off-peak periods than when load is at its peak. Storing off-peak energy for use during on-peak periods will increase the amount of available wind energy used and reduce the use of energy produced by other generating sources. This test will also demonstrate the ability of the BESS to firm and shape wind output to better follow its generation schedule. Benefit will be determined by estimating the difference in energy prices between off-peak charge and on-peak discharge. There might be additional value in reduced transmission losses and reduced emissions.

Primary Method of Performing Test:

---

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

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

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

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

Data to be collected:

- Transmission loads on the following lines.
    - Monolith – Breeze lines 1 & 2
    - Monolith – Cummings line
    - Monolith – Loraine line
    - Monolith – Cal Cement line
    - Monolith – MidWind line
    - Monolith – ArbWind line
- Monolith transformer 1 and 2 load
- Tehachapi wind generation profile for each wind plant (MW/MVAr)
- Storage dispatch event with its timing
- BESS parameters
    - Status
    - State of Charge (%)
    - Energy Available
    - Charge/discharge rate (MW/MVAr)
- CAISO price data

<table>
<tr><th>Step #</th><th>Who Does It?</th><th>Action</th><th>Additional Notes</th></tr>
<tr><td></td><td>Which participant, either primary or secondary is responsible for the activity in this step?</td><td>Describe the actions that take place in this step in active, present tense.</td><td>Additional description of statement about the step to help support description. Comments about data collection requirements, special equipment features, unusual challenges, etc.</td></tr>
<tr><td>1</td><td>SCE EMS</td><td>Place BESS in EMS Test 4 mode.</td><td></td></tr>
<tr><td>2</td><td>Advanced Energy Storage</td><td>In BESS HMI setting:
Set the “Maintain SOC Allowed for T1&T4” as ON.
Set the “Fully Charge BESS” and “Fully Discharge BESS” as ON.</td><td>The parameters such as “SOC Max (%)”, “SOC Min (%)”, “P Charge [kW]”, and “P Discharge [kW]” remain at default values to enable fully charge/discharge BESS at the maximum rate.</td></tr>
<tr><td>3</td><td>Advanced Energy Storage</td><td>Set the BESS Off-Peak Period Schedule as
<table>
<tr><td colspan="2">Day of Week</td><td colspan="2">Time</td></tr>
<tr><td>Start</td><td>Stop</td><td>Start</td><td>Stop</td></tr>
<tr><td>Monday</td><td>Monday</td><td>0000</td><td>0600</td></tr>
<tr><td>Wednesday</td><td>Wednesday</td><td>0000</td><td>0600</td></tr>
<tr><td>Friday</td><td>Friday</td><td>0000</td><td>0600</td></tr>
<tr><td>Saturday</td><td>Saturday</td><td>0000</td><td>0600</td></tr>
</table>
Set the BESS On-Peak Period Schedule as
<table>
<tr><td colspan="2">Day of Week</td><td colspan="2">Time</td></tr>
<tr><td>Start</td><td>Stop</td><td>Start</td><td>Stop</td></tr>
<tr><td>Monday</td><td>Monday</td><td>1200</td><td>1800</td></tr>
<tr><td>Wednesday</td><td>Wednesday</td><td>1200</td><td>1800</td></tr>
<tr><td>Friday</td><td>Friday</td><td>1200</td><td>1800</td></tr>
<tr><td>Saturday</td><td>Saturday</td><td>1200</td><td>1800</td></tr>
</table></td><td>BESS will be fully charged/discharged in four hours under the maximum rate. The on/off peak duration in this test is set as six hours to ensure the battery to be fully charged/discharged in case wind generation fluctuates significantly or other variations occur.</td></tr>
<tr><td>4</td><td>Grid Operations</td><td>Operate BESS in the configured mode for 4 weeks.</td><td>The test period can start on any Monday, Wednesday, or Friday,</td></tr>
</table>

			but will last for a period that contains at least 4 weekends (both Saturday and Sunday).
5	Grid Operations	Test complete	

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

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

Overview:

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

Primary Method of Performing Test:

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

The wind-park generation information is captured in SCADA and mapped back as an input to the SEC. As this test can be applied at any season, it is recommended to use the average wind speed during previous days as the parameter P_WT_Act_Coef[12] for the test periods. Depending on the test period, this value may vary.

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

Data to be collected for all tests:

- Total wind generation profile in Tehachapi (MW/MVAr)
    - P_WT_Act
- Storage dispatch event with its timing

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

- BESS parameters
    - Status
    - State of Charge (%)
    - Energy Available
    - Charge/discharge rate (MW/MVAr)
- Transmission loads on the following 66 kV lines
    - Monolith – Breeze lines 1 & 2
    - Monolith – Cummings line
    - Monolith – Loraine line
    - Monolith – Cal Cement line
    - Monolith – MidWind line
    - Monolith – ArbWind line

Step #	Who Does It?	Action	Additional Notes
	Which participant, either primary or secondary is responsible for the activity in this step?	Describe the actions that take place in this step in active, present tense.	Additional description of statement about the step to help support description. Comments about data collection requirements, special equipment features, unusual challenges, etc.
1	SCE EMS	Place BESS in EMS Test 5 mode	
2	Advanced Energy Storage	In BESS HMI setting: • Set the "P Ramp + [kW/sec]" and "P Ramp – [kW/sec]" to enable dispatch BESS at the maximum rate.	The BESS will begin the test at approximately 50% SOC.
3	Quanta Technology	Calculate "P_WT_Act_Coef" for the chosen test period.	P_WT_Act_Coef is a parameter to be configured in the system.
4	Grid Operations	Operate BESS in the configured mode for one week.	
5	Grid Operations	Idle BESS.	Ensure a moderate SOC (e.g., 30%) of the BESS before being idled
6	Grid Operations	Monitor the same system parameters for one week.	
7	Quanta Technology	Evaluate the data collected to determine if longer test period is needed or test parameters will be changed.	
8	Grid Operations	Repeat step 2 – 6 as needed.	
9	Grid Operations	Test complete	

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

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

Overview:

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

Primary Method of Performing Test:

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

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

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

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

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

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

Data to be collected:

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

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

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

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

Overview:

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

Primary Method of Performing Test:

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

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

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

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

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

Alternative method of performing test:

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

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

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

Data to be collected:

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

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

	the activity in this step?		collection requirements, special equipment features, unusual challenges, etc.
1	Grid Operations	In EMS Test Screen, turn off test modes and turn on Grid Functions.	
2	SCE GMS	Place BESS in appropriate mode allowing CAISO control.	
3	SCE Scheduling Coordinator	Bid into Energy and Ancillary Services market to provide spinning/non-spinning reserves.	
4	SCE GMS	Monitor CAISO ADS's dispatch signal or follow extracted CAISO ADS dispatch signal and dispatch BESS accordingly.	
5	BESS	Follow dispatch signal to inject real power.	Fully charged at start of test
6	SCE GMS	Monitor dispatch instructions and BESS power level and duration remained.	Intervene as necessary, e.g., toggle BESS from AGC/Dispatch mode
7	SCE GMS	Reassume control when award period ends.	
8	Grid Operations	Turn off Grid Functions and return BESS to prior mode. Test complete.	

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

9.1.8 Test 8 Follow A CAISO Market Signal For Energy Price

Overview:

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

Primary Method of Performing Tests:

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

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

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

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

Data to be collected:

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

Step #	Who Does It?	Action	Additional Notes
	Which participant, either primary or secondary is responsible for the activity in this step?	Describe the actions that take place in this step in active, present tense.	Additional description of statement about the step to help support description. Comments about data collection requirements, special equipment features, unusual challenges, etc.
1	Grid Operations	In EMS Test Screen, turn off test mode and turn on Grid Functions.	
2	SCE GMS	Place BESS in appropriate mode allowing CAISO control.	
3	Generation operations center operators	Monitor RTD-LMP prices and dispatch signals; generate base points in SCE GMS.	
4	SCE GMS	Issue the dispatch instructions.	
5	BESS	Absorb or inject real power in response to operator action.	Approximately 50% State of Charge at start of test
6	SCE GMS	Monitor dispatch instructions and BESS power level and duration remained.	Intervene as necessary, e.g., toggle BESS from AGC/Dispatch mode
7	Grid Operations	Turn off Grid Functions and return BESS to prior mode. Test complete.	

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

9.2 Appendix B: Analysis of Wind Generation Data

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

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

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

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

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

For each period in a given month, a capacity factor is obtained by dividing the total generation in MWh by the sum of individual peak generations of wind farms during the entire study period, then dividing by the number of hours in the calendar month. Generally, a capacity factor is the ratio of its actual output over a period of time, to its potential output if it were possible for it to operate at full nameplate capacity indefinitely[13]. The presented calculation uses peak generation instead of nameplate capacity. It is felt that the peak observed generation for each wind farm is a more credible measure of its capacity than its CAISO listed capacity, because wear and tear during their service lives has left some wind turbines in a degraded state and they are unlikely to attain their

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

original MW outputs. No adjustment is made for individual turbine outages due to mechanical causes.

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

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

Table 9-11 Wind Farm Capacity Factors - 2010

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

Table 9-12 Wind Farm Capacity Factors - 2011

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

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

Values are shown graphically in Figure 9-1.

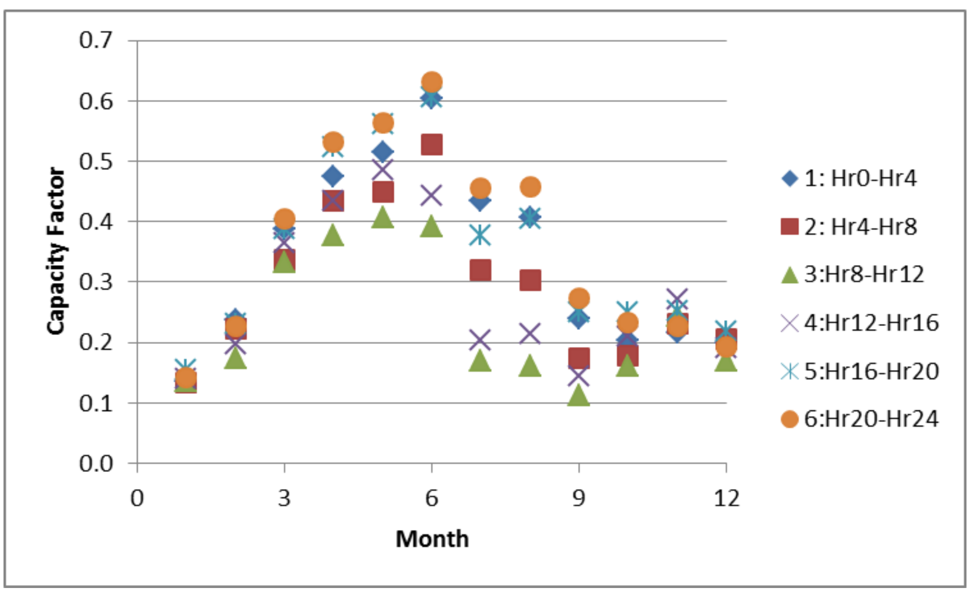


Figure 9-1 Wind Farm Capacity Factors – 2010 and 2011

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

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

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

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

9.3 Appendix C: Tehachapi Area Load Analysis

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

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

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

Table 9-15 Total 2010 GWh by Month and Period

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

Table 9-16 Total 2011 GWh by Month and Period

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

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

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

The average monthly loads during the 2010-2011 monitoring period are shown in Figure 9-2.

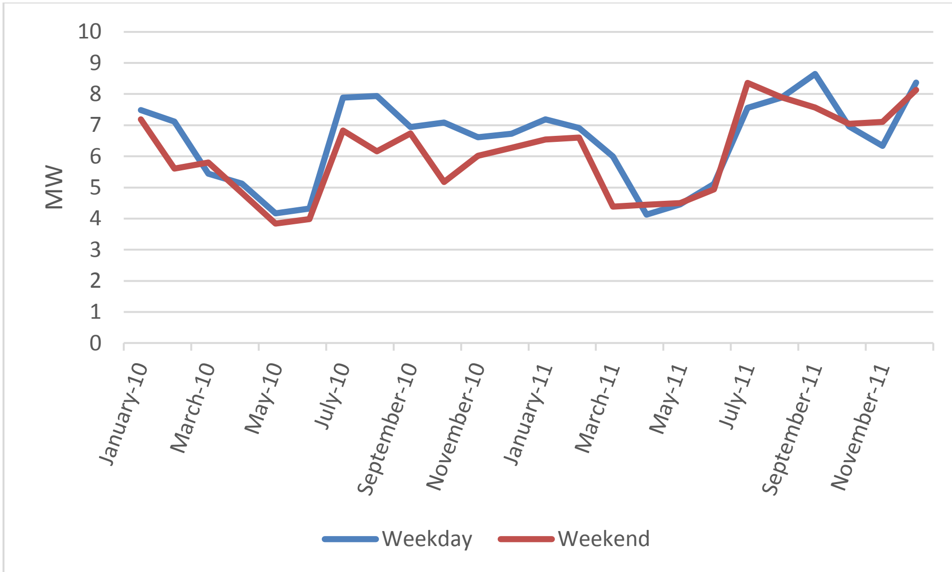


Figure 9-2 Monthly Average Loads at Monolith Substation

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

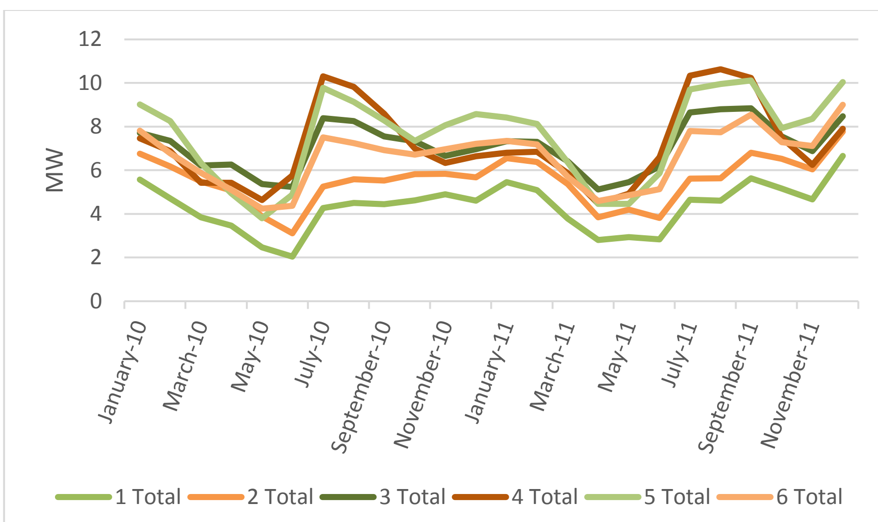


Figure 9-3 Monolith Average Load by Period

The principal observations about load variation are as follows:

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

9.4 Appendix D: Line Loading Analysis

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

The seven sub-transmission lines are listed below. The line names are from the eDNA system. In some cases, the names used in this plan differ, and the names used in this plan are listed as well, for cross reference.[14]

- Monolith – Sub Tran Lines BO-HA-LO-WB (Monolith – Loraine line)
- Monolith – Sub Tran Lines BREEZE1
- Monolith – Sub Tran Lines BREEZE2
- Monolith – Sub Tran Lines CAL-GOL-WIN (Monolith – MidWind line)
- Monolith – Sub Tran Lines CAL-ROS-WIN (Monolith – ArbWind line)
- Monolith – Sub Tran Lines CAL-WINDP (Monolith – Cal Cement line)
- Monolith – Sub Tran Lines CUMMINGS

Figure 9-4 to Figure 9-10 present the histogram of loading of seven sub transmission lines connected with Monolith substation.

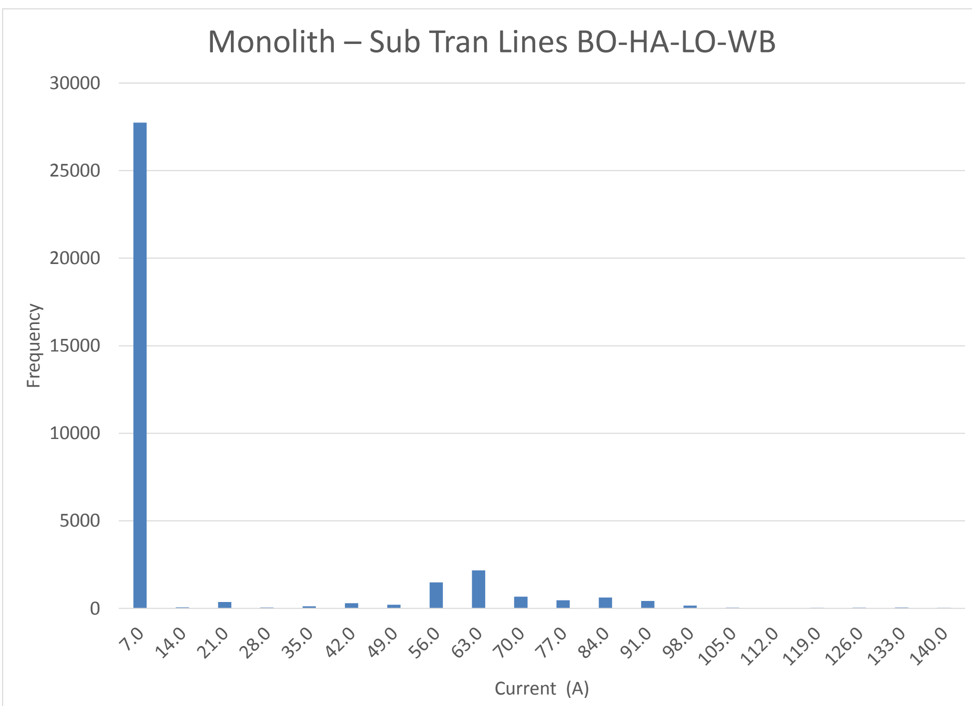


Figure 9-4 Distribution of Monolith – Sub Tran Lines BO-HA-LO-WB 2013 Loading

[14] This matching is based on current information available to Quanta Technology, some information are uncertain, the final matching needs confirmation from SCE

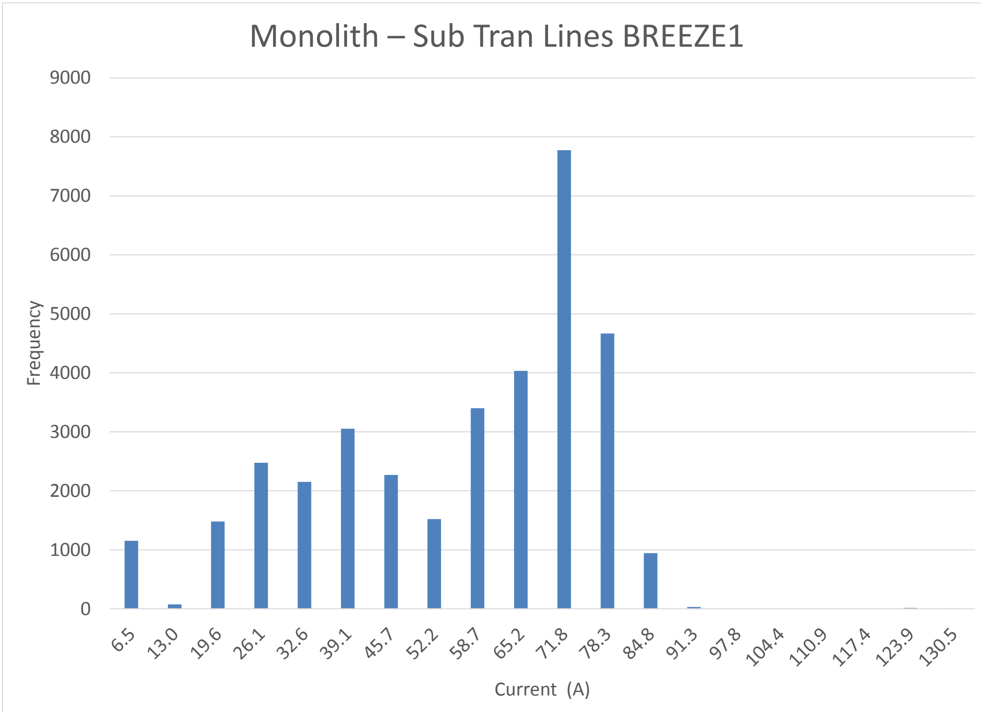


Figure 9-5 Distribution of Monolith – Sub Tran Lines BREEZE1 2013 Loading

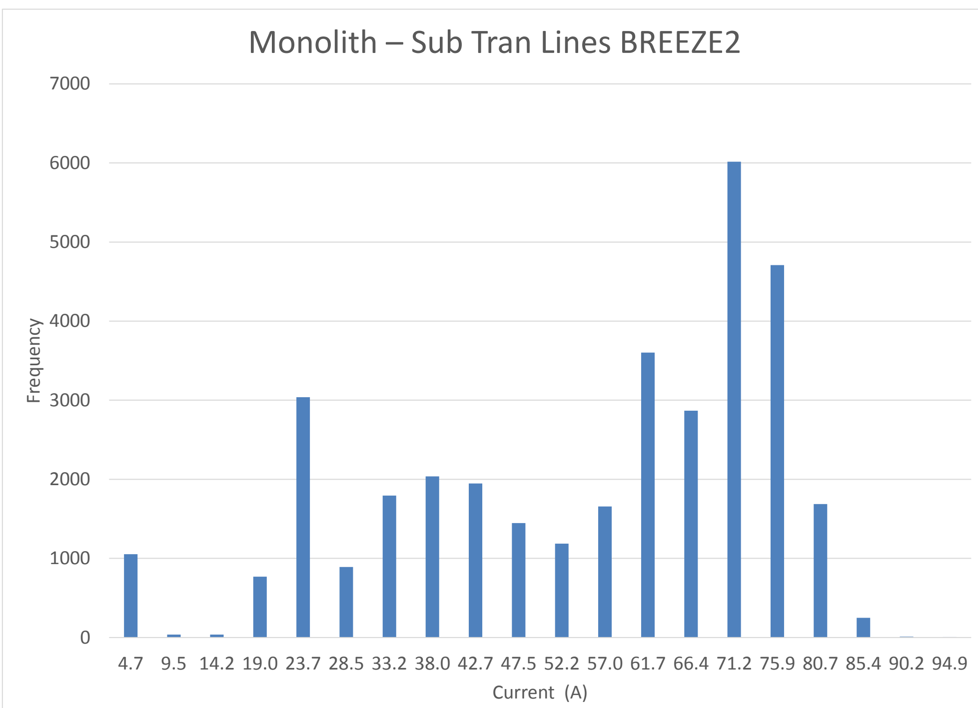


Figure 9-6 Distribution of Monolith – Sub Tran Lines BREEZE2 2013 Loading

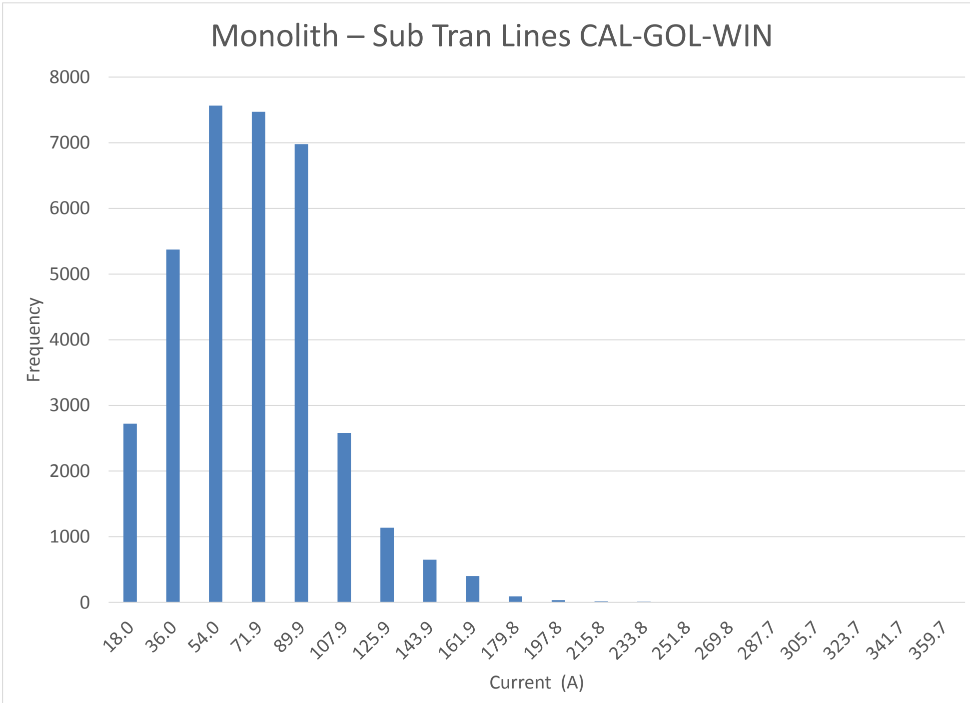


Figure 9-7 Distribution of Monolith – Sub Tran Lines CAL-GOL-WIN 2013 Loading

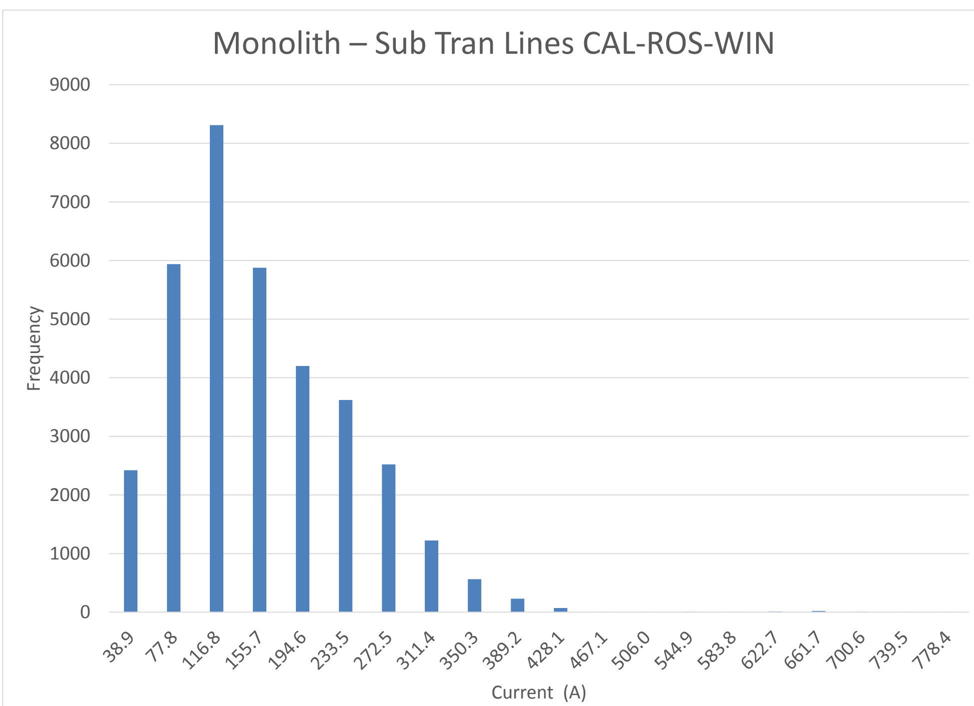


Figure 9-8 Distribution of Monolith – Sub Tran Lines CAL-ROS-WIN 2013 Loading

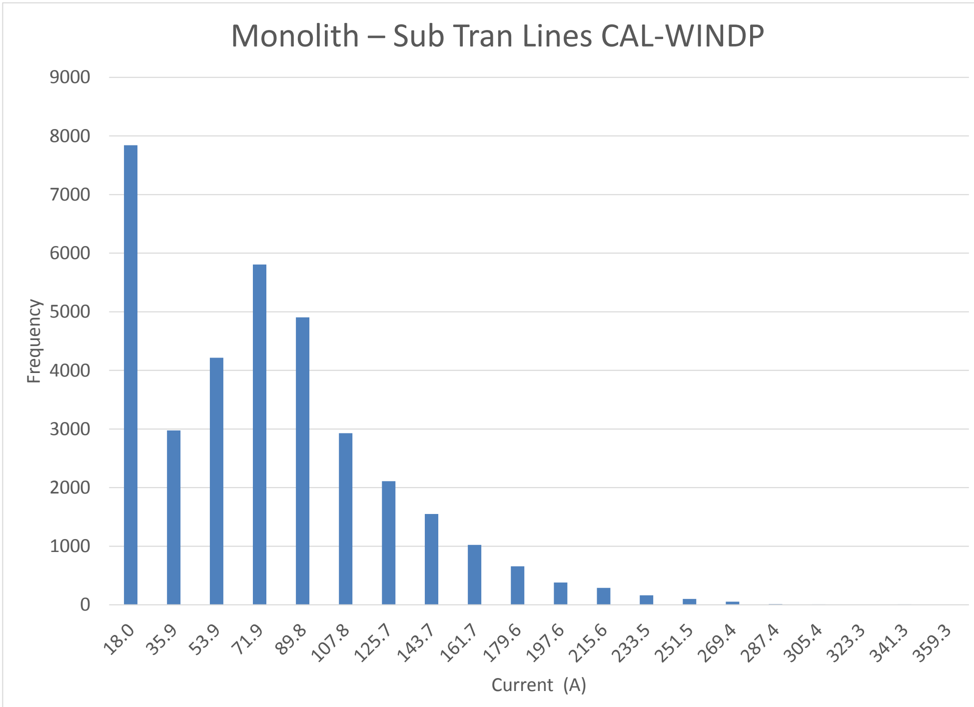


Figure 9-9 Distribution of Monolith – Sub Tran Lines CAL-WINDP 2013 Loading

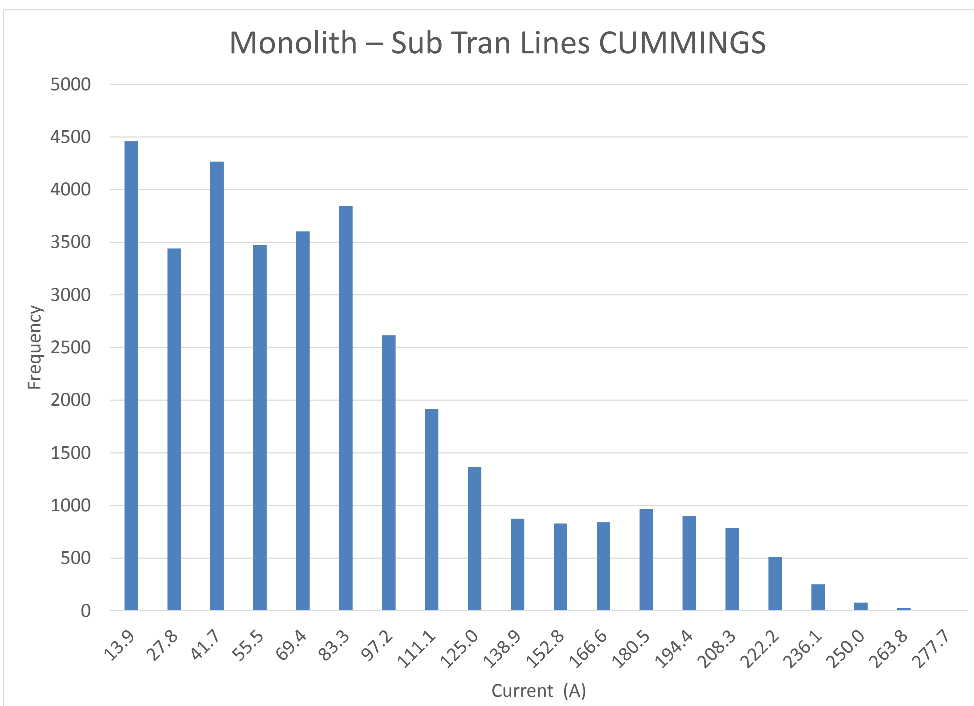


Figure 9-10 Distribution of Monolith – Sub Tran Lines CUMMINGS 2013 Loading

Among these seven lines, Monolith – Sub Tran Lines BO-HA-LO-WB has the smallest load, Monolith – Sub Tran Lines CAL-ROS-WIN has the largest load.

Electric system loads often vary by season, with some loads higher during one season and lower in others. Figure 9-11 to Figure 9-17 represent the 2013 load of the seven sub transmission lines. These plots show the temporal information as well as the variation of the loading over time. As exhibited in figure 9-17, the loading on Monolith – Sub Tran Lines CUMMINGS shows a clear seasonality – peaking in the spring and fall with lower loading during the winter and summer months. Other loads are relatively consistent over time as seen in figure 9-12 and 9-13 representing the loadings on Monolith – Sub Tran Lines BREEZE 1 and Monolith – Sub Tran Lines BREEZE 2. On these feeders the load is consistent all year except for the first quarter of the year. On the other hand, loading on Monolith – Sub Tran Lines BO-HA-LO-WB, Figure 9-11, presents large variation that are more of random nature with no relationship to seasonal fluctuation.

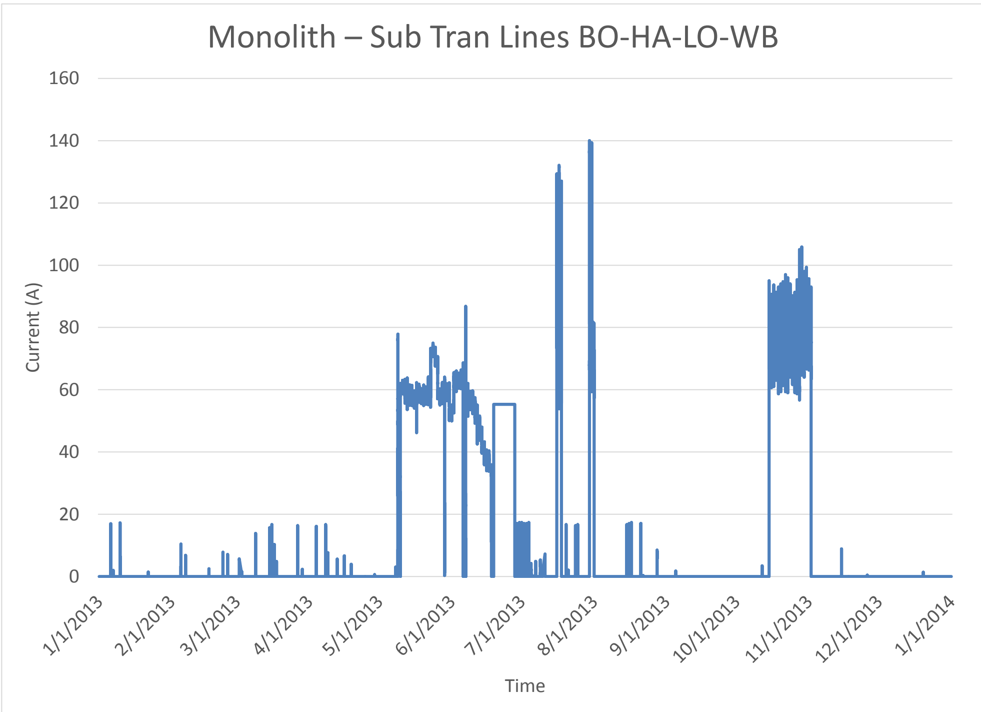


Figure 9-11 Monolith – Sub Tran Lines BO-HA-LO-WB 2013 Loading

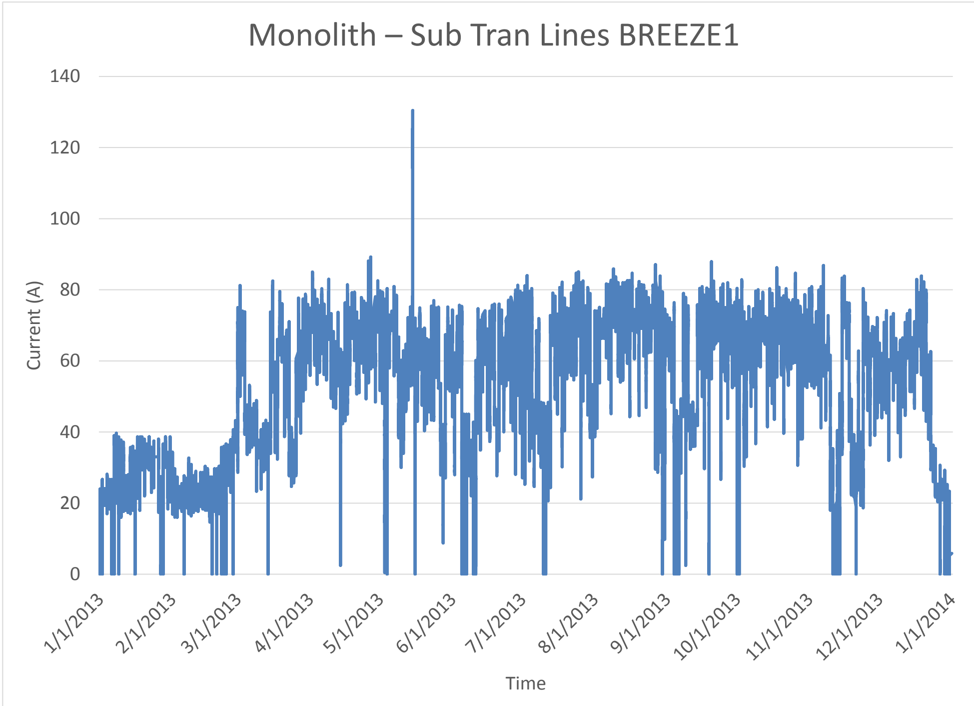


Figure 9-12 Monolith – Sub Tran Lines BREEZE1 2013 Loading

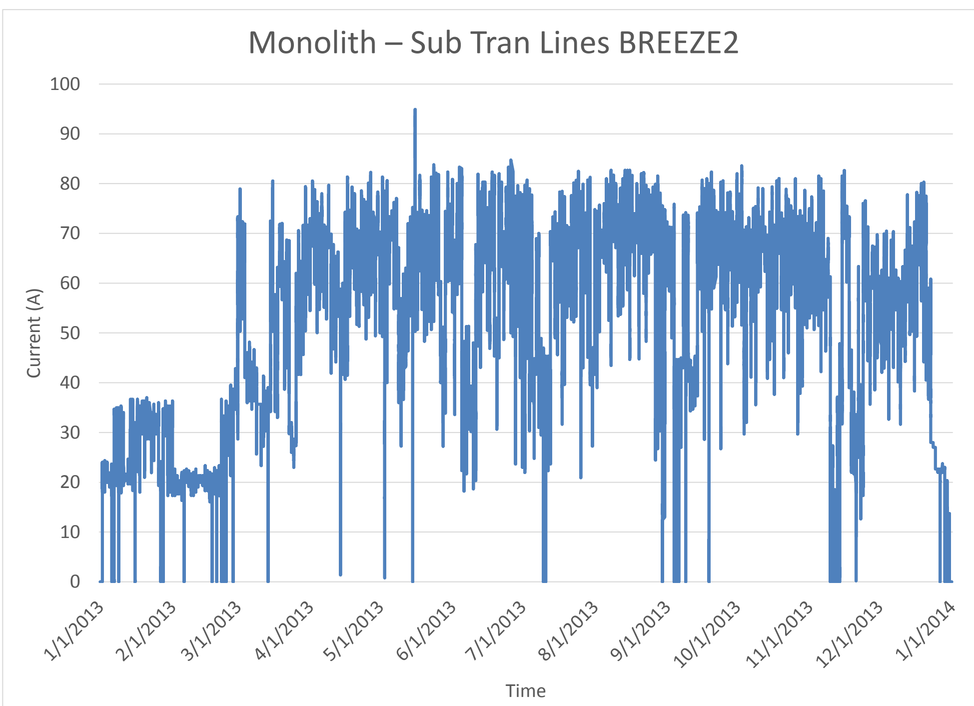


Figure 9-13 Monolith – Sub Tran Lines BREEZE2 2013 Loading

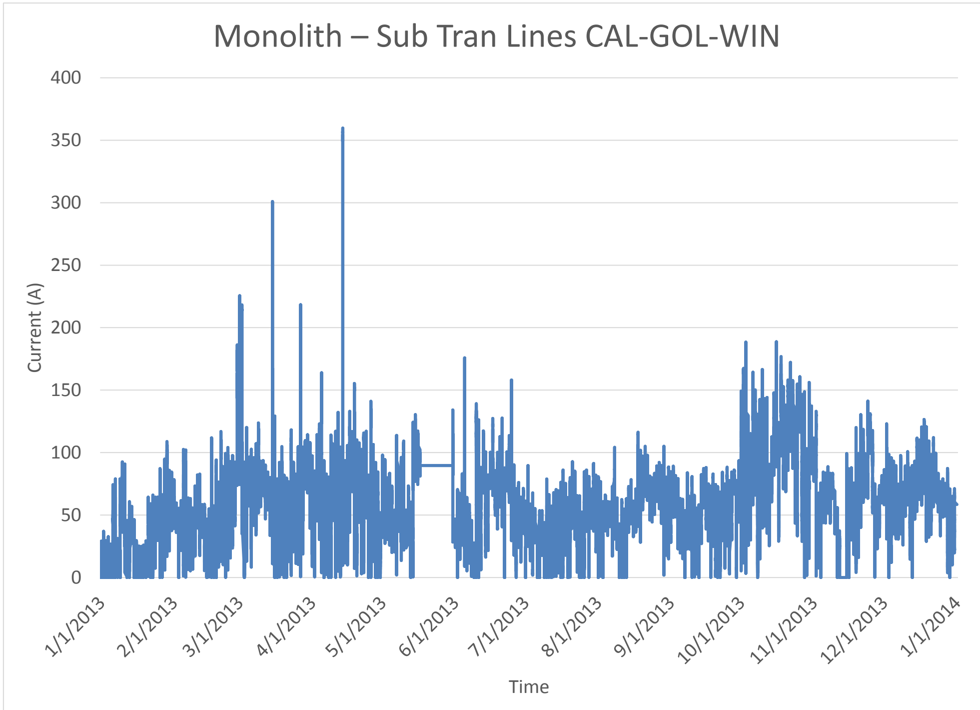


Figure 9-14 Monolith – Sub Tran Lines CAL-GOL-WIN 2013 Loading

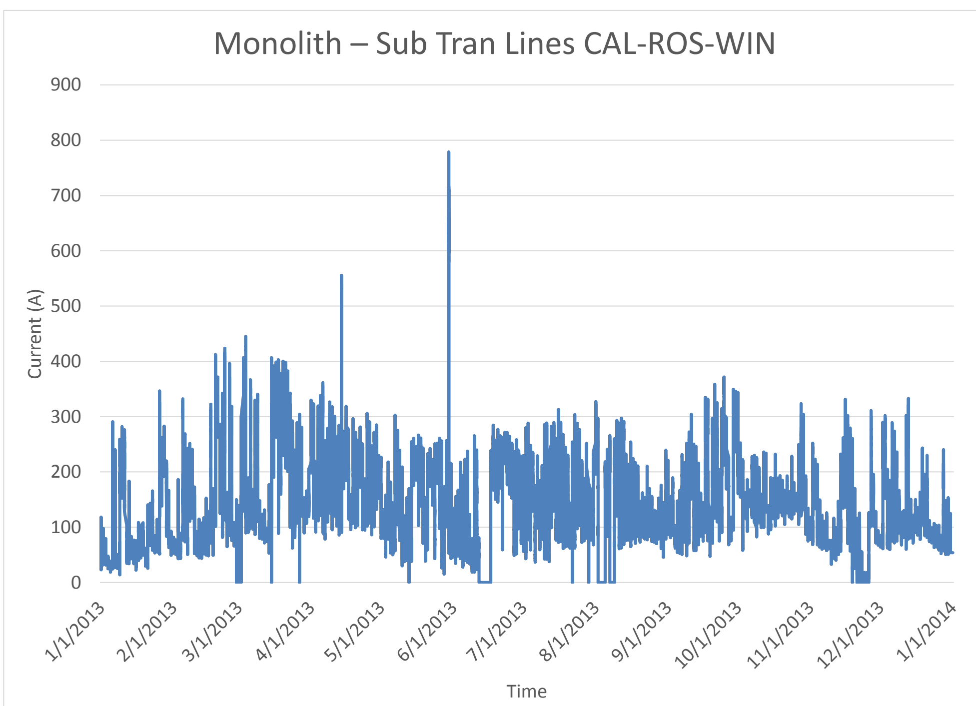


Figure 9-15 Monolith – Sub Tran Lines CAL-ROS-WIN 2013 Loading

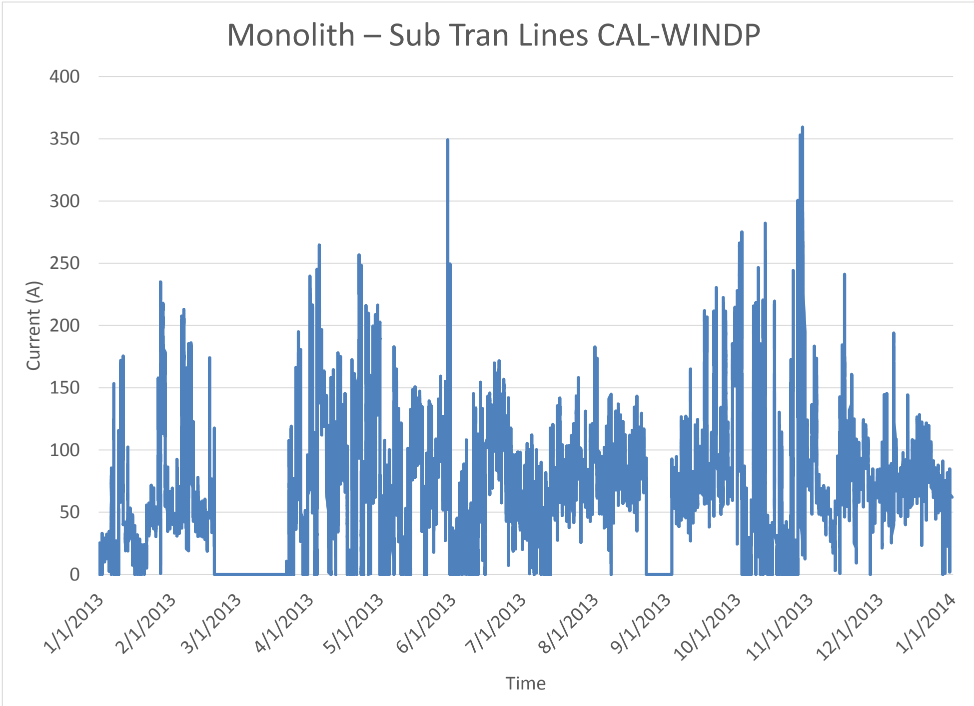


Figure 9-16 Monolith – Sub Tran Lines CAL-WINDP 2013 Loading

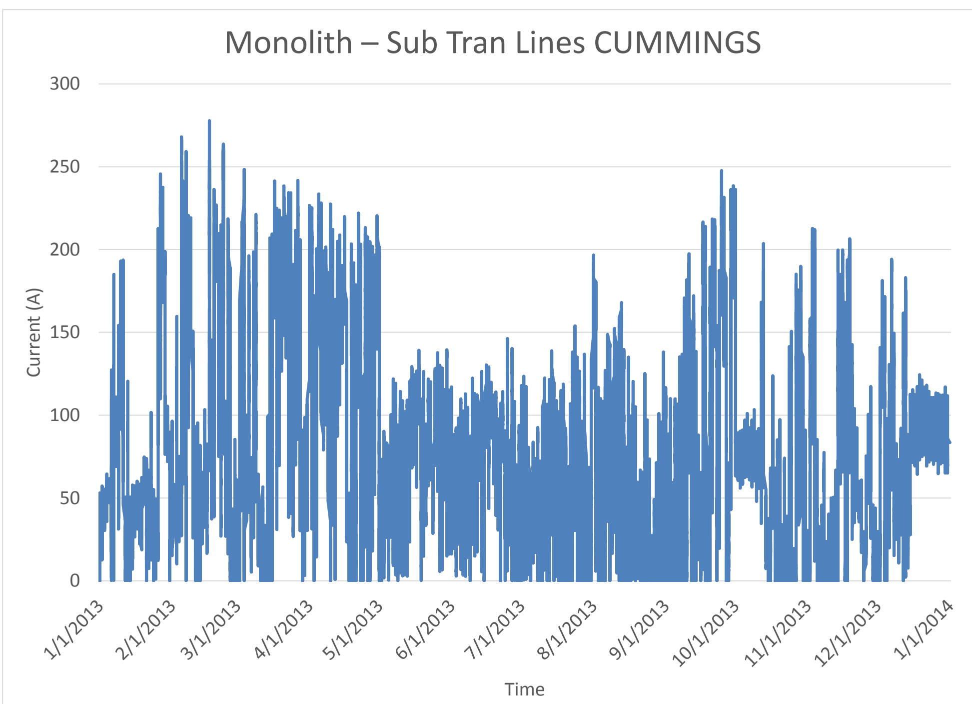


Figure 9-17 Monolith – Sub Tran Lines CUMMINGS 2013 Loading

9.5 Appendix E: Schedule of TPR/Impact Metrics Reporting

Report	Due Date
TPR/Impact Metrics #1	12/31/14
TPR/Impact Metrics #2	12/31/15
Final Technical Report/Impact Metrics #3	09/30/16

9.6 Appendix F: Static and Dynamic Analysis for TSP Project Using GE-PSLF Software

Sizing and Location Selection of the Battery Storage

The studies performed in Tehachapi area are based on two software tools: General Electric - Positive Sequence Load Flow (PSLF) and Power System Computer-Aided Design (PSCAD). The PSLF model is a WECC system wide network database used for bulk power system analysis. The 2009 High summer WECC base case was used for the steady-state contingency analysis and dynamic simulations to size the battery and select its location in the Antelope-Bailey system.

The area wind generation static and dynamic characteristics were added to the base case based on data collected from SCE EMS system. Wind generation was modeled as Type 1 wind farms, i.e., using shunt capacitors to support the wind farm. Different power cases with different dispatch for the wind generation were created to assess the system operating condition with and without the battery.

Static contingency analysis using load flow was then performed for the Tehachapi area on the cases prepared for the study (i.e. different area load/wind generation mix). Two critical contingencies were identified during the analysis. One of the identified contingencies was a major concern for SCE, SCE already had a RAS system for this contingency by area wind energy generation curtailment.

A dynamic analysis was then conducted using PSLF dynamic module to assess the critical contingencies and size the battery to mitigate this contingencies without wind generation curtailment. A three phase fault is simulated at time equal to 1 second and cleared after 4 cycles by disconnecting one of the critical lines. Figure 18a and b show the output power and the terminal voltage behavior of different wind farms in the system before and after the critical contingency without the energy storage. It's clear that the system is unstable and within an un-damped oscillatory state.

The size and location of the storage are selected based on the solution to contingency problems mentioned above. The BESS size was selected to be 8 MW up to 4 hours and the STATCOM should be capable of providing 20 MVAr up to 4 seconds in order to mitigate the aforementioned problems. Figure 19 shows the system frequency before and after the critical contingency without the energy storage. The abnormal frequency excursions are the result of system instability. Figure 20 shows the system frequency with the energy storage installed in the system. The figure shows that the system is stable after the contingency and the oscillations are damped. Figure 21 shows the voltage profile and the power output of a number of wind farms before and after the critical contingency with energy storage and reactive power support. As can be seen in the figure, the wind farms maintain their pre contingency power output without any oscillatory behavior.

The PSLF analysis showed that the installation of the energy storage with a STATCOM function will provide the best support at the Cal-Cement 66 kV station; however, due to the physical space available, the Cal-Cement Substation was ruled out and Monolith Substation was identified by the PSLF steady state and dynamic analysis.

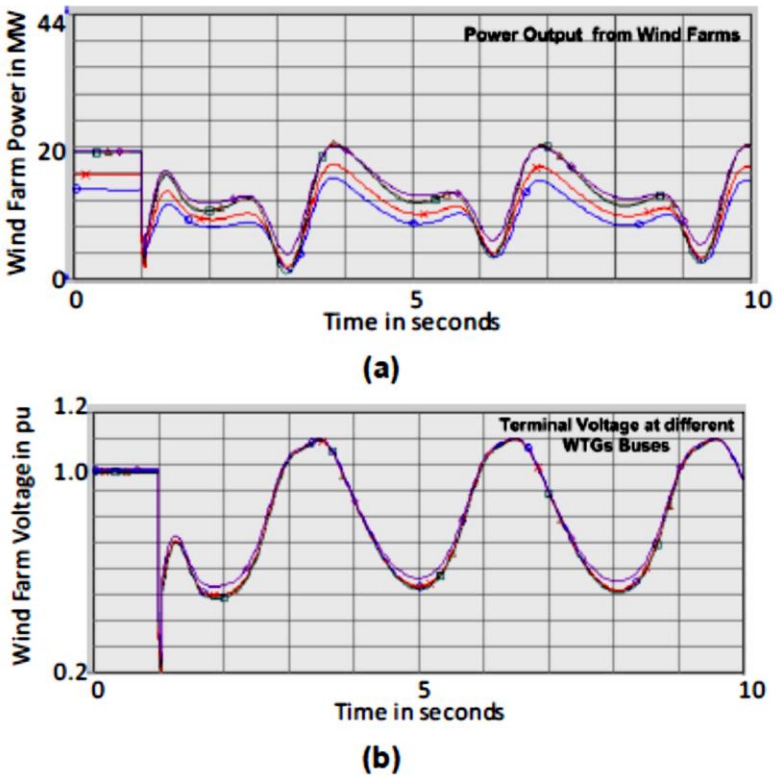


Figure 9-18 Power output (a) and voltage profile (b) at different wind generation buses before and after the contingency without the energy storage (the contingency is initiated at 1 sec).

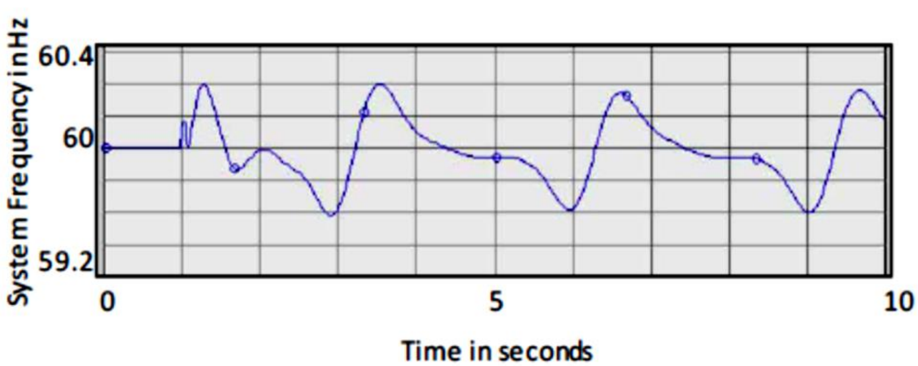


Figure 9-19 System frequency without the energy storage before and after the contingency

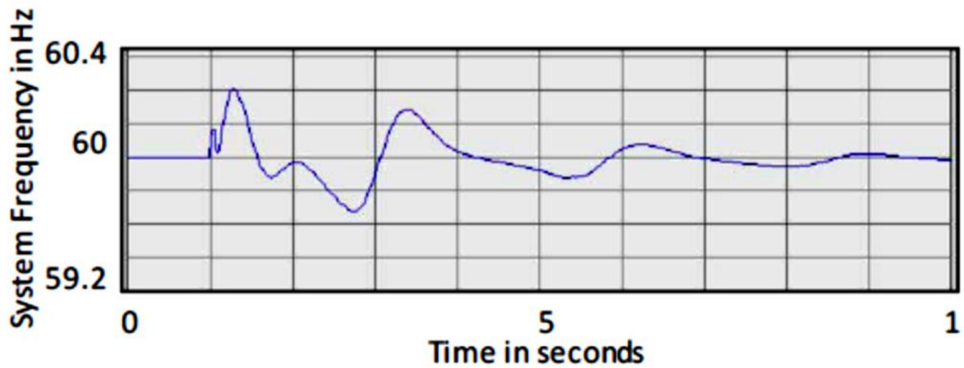


Figure 9-20 System frequency with the energy storage during the contingency

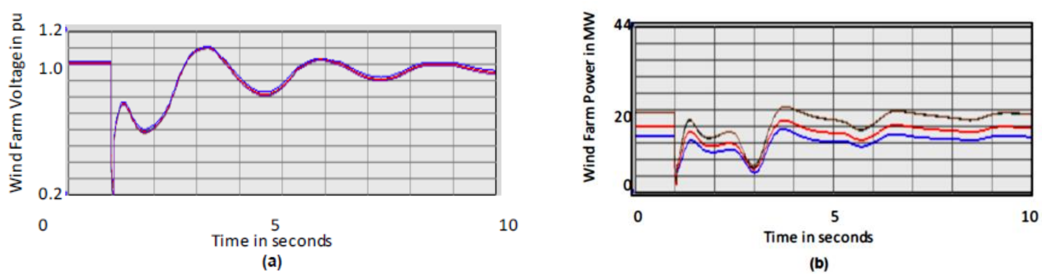


Figure 9-21 Voltage profile (a) and the wind farms output power (b) before and after the Contingency with energy storage (the contingency is initiated at 1 sec)

Use of PSLF in Measurement and Verification

Dynamic and static simulations will be conducted using PSLF to validate some system responses. The following are some beneficial capabilities of the BESS – STATCOM that may be evaluated with PSLF modeling:

- Provides system voltage support by injecting or absorbing real and reactive power after a disturbance or system contingency.
- Provides voltage support and improves the voltage recovery after a transient by 10-15%. (The percentage value depends on the fault type and location.)
- Provides wind generators terminal voltage (Type1-induction generators) support by providing VAR support to ride through low voltage excursions during remote faults.
- Provides regulation ancillary services.
- Provides black-start functionality.
- Provides additional spinning reserves.
- Can be used for energy price arbitrage.
- Reduces the need for curtailments of wind farms.
- Enhances system frequency regulation.

9.7 Appendix G: Analysis for TSP Project Using RTDS

Dynamic Voltage Support Testing

A real time digital simulator (RTDS) was used to test the dynamic voltage support function (also described as 'voltage clamp' in ABB nomenclature) of the PCS. The voltage support function was requested to test the ability of the TSP system to autonomously stop following a P & Q setpoint, and begin injecting reactive power to boost system voltage when the 66 kV bus voltage at Monolith Substation drops below a defined setpoint. When the voltage recovers, the PCS curtails the reactive power and resumes following the P and Q setpoint.

What is RTDS and how is it being used to test dynamic voltage support

A RTDS system is a hardware platform for running an electro-magnetic transients program (EMTP) in real time. One of the differences between EMTP and other power system simulation tools, is that EMTP calculates the instantaneous voltages at all of the nodes (or busses) and the currents between all of the nodes (or busses) at every simulation time step. Typical real time EMTP simulations build the waveform by calculating all of the instantaneous voltage and currents every 50 microseconds, which is about one degree on a single 60 hertz cycle.

In order to test external equipment, the RTDS has several different types of input/output cards that can be used to bring signals into or send out of the EMTP simulation. In this application, the simulated voltage and currents in the PCS and at Monolith substation are scaled down to a low voltage (+/-10V) analog signal and connected directly to the PCS 100's analog to digital converter via several D-subminiature connections in the front of the device. Similarly, the firing pulses that the PCS would send to the insulated-gate bipolar transistors (IGBT) are sampled by the RTDS via a low voltage digital input card.

For many applications, such as testing microprocessor based protective relays, a time step of 50 microseconds is sufficient, however converter systems such as the PCS 100 send out firing pulses that are only a few microseconds in duration. Additionally, converter controller systems typically have very fast control loops that may become unstable if the delay between time steps is too long.

To solve this problem, the RTDS has the capability to run part of a model with a much smaller time step (about 2.5 microseconds) and interface the small time step model with the large time step model. The interface between the small and large time step models is done with a special interface transformer model that decouples the two solutions. The decoupling does introduce some error (added series inductance and shunt reactance) but still captures overall system behavior. However, the interface transformer has a feature to scale up the output of a single PSC 100 unit to represent the power injected by both PCS container units (8 MVA).

Test Setup

The ABB PCS 100 lab unit was first run in an open loop mode for initial input signal calibration, verifying the polarity of current transformers and voltage transformers in the model match what the controller expects, and system phase rotation.

Next, the ABB PSC 100 lab unit was placed in a closed loop mode with an ideal voltage source. In this mode SCE verified the PSC 100 lab unit could run in all four quadrants (inject and absorb real and reactive power).

Lastly, the ABB PSC 100 was integrated into the Windhub 66 kV sub-transmission network model and subjected to system disturbances.

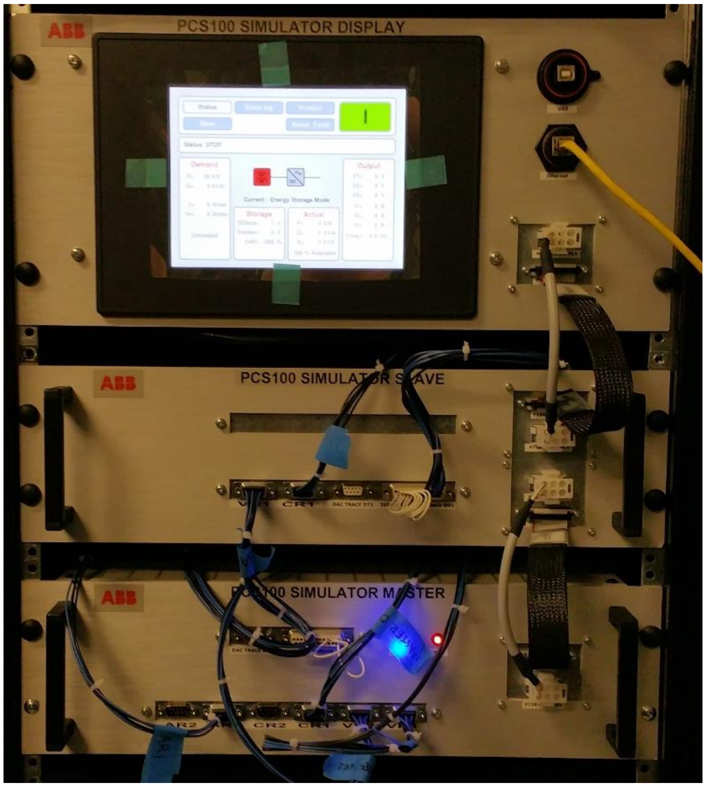


Figure 9-22 ABB PSC 100 Lab Controller

<u>What Was Tested</u>

The wind generation in Windhub system is made up of type 1 and type 2 wind generators, which draw a significant amount of reactive power during system events that depress the system voltage. SCE simulated faults and the resulting line clearing on several transmission lines in the Windhub system and verified the response of the PCS 100 unit. This type of testing is important to verify correct operation of the system, but also there is no guarantee of a system event while the PCS is configured to operate in with the dynamic voltage support mode enabled.

Results for a Three Phase Fault on a Sub-Transmission Line near TSP

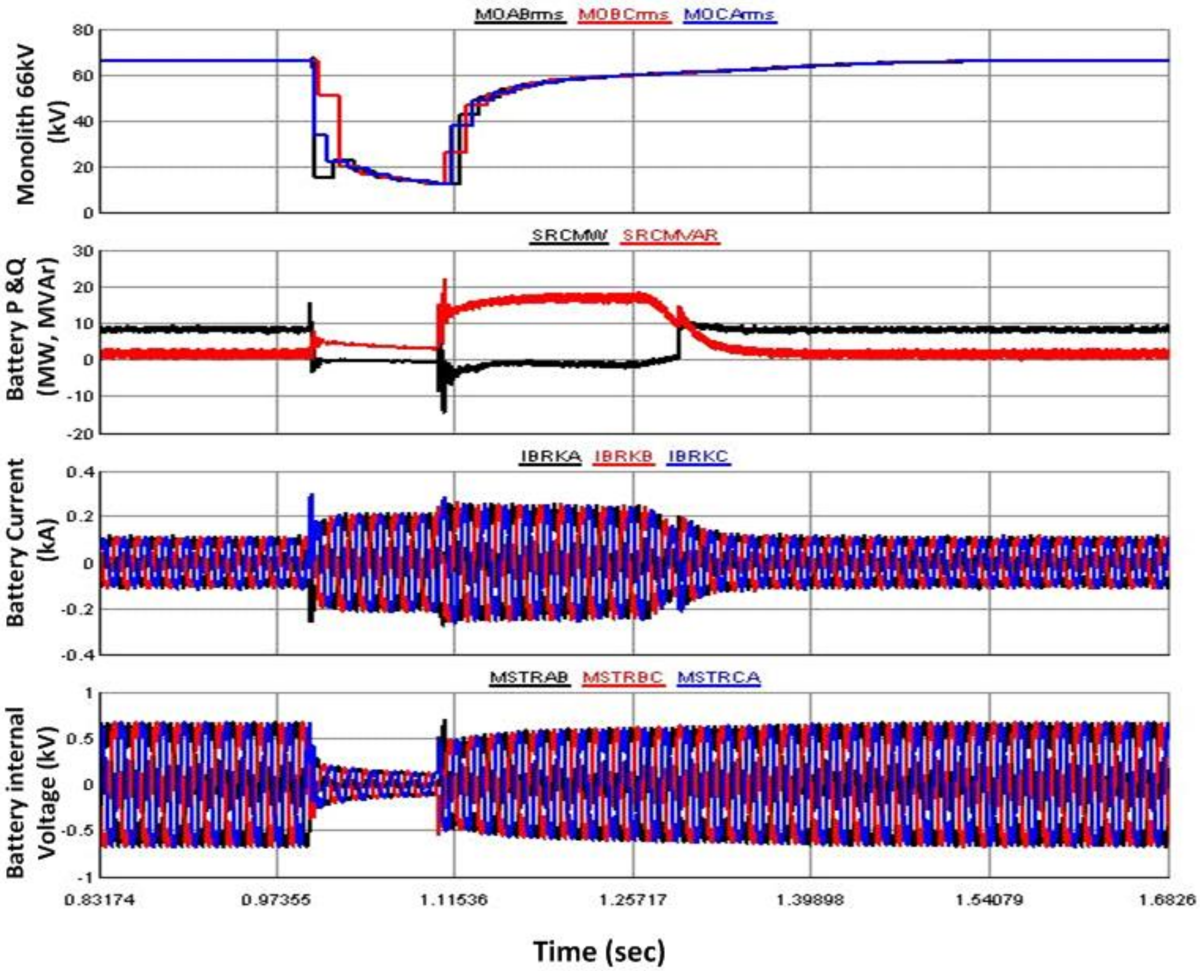


Figure 9-23 Bus Voltage, Power, and Interconnection Current and Voltage

The first graph shows the RMS voltage at the 66 kV bus the TSP is connected to, the second graph shows the real and reactive power output of the TSP, and the third and fourth graphs show the current and voltage at the TSP interconnection point.

It can be seen that during the period when the voltage is depressed due to a six cycle fault and the reactive power draw from the wind machines, the PCS switches into a reactive power injection mode to help the voltage recover. Once the voltage has returned to normal, the reactive power curtails and the PCS returns to the previous normal operation.

9.8 Appendix H: System Acceptance Test Results

Tehachapi Wind Energy Storage Project
System Acceptance Test Report
Project Report No. TC-13-269-TR01
Revision No. 00
Final Report, July 2014

Electric Vehicle Technical Center
An ISO 9001 Registered Facility
Prepared by:

Grant Davis, PE
Advanced Energy Storage
Southern California Edison

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

This report was prepared by the Advanced Technology Department of Southern California Edison (SCE).

Neither SCE, nor any of its affiliates, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness, of any information, apparatus, or product or process disclosed herein or represents that its use will not infringe any rights. Reference herein to any specific product, process, or service by trademark, name, and manufacturer or otherwise does not constitute or imply endorsement, recommendation, or favoring opinion of same by SCE or any of its affiliates. The views and opinions of the authors expressed herein do not necessarily state or reflect those of SCE or any of its affiliates. Any recommendations, opinions or findings stated in this report are based on circumstances and facts upon which this report is based as they existed at the time SCE performed the evaluation. Any changes in such circumstances and facts upon which this report is based may adversely affect any recommendations, opinions or findings contained in this report.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Introduction

The Tehachapi Wind Energy Storage Project (TSP) is a 32 MWh, 9 MVA (8 MW, 4 MVAr) battery energy storage system (BESS) located at Monolith Substation in the Tehachapi Wind Resource Area, near Tehachapi, CA. The project is jointly funded by Southern California Edison (SCE) and the United States Department of Energy (DOE), and was awarded through the American Recovery and Reinvestment Act (ARRA).

SCE contracted with LG Chem to design, construct, and maintain the system for a two-year measurement and validation (M&V) period. During the M&V period, BESS and transmission system data will be collected to analyze the project's effect on the regional transmission network, as well as gain experience and knowledge about the operation of a large BESS.

The BESS is composed of a 6,300 square foot facility housing 604 lithium ion battery racks, which are divided into four separate 8 MWh battery sections. The battery sections are connected to two 4.5 MVA (4 MW, 2 MVAr) power conversion system (PCS) containers located adjacent to the battery facility. The PCS containers feed a 12.47/66 kV transformer, which is connected directly to the region's transmission network via the substation's 66 kV transfer bus. LG Chem was responsible for delivering the batteries and battery management system (BMS), while ABB was subcontracted by LG Chem to deliver the PCS containers and associated controls.

SCE, LG Chem, and ABB jointly developed "Contract Data Requirements List (CDRL) 19, System Acceptance Test Plan", which defined 12 separate tests to assess the system's operational readiness in meeting the project's contractual requirements for substantial acceptance. Once system commissioning was complete, CDRL 19 was used by LG Chem, ABB, and SCE to perform System Acceptance Testing (SAT). SAT occurred from July 7 through 11, 2014, and from July 14 through 18, 2014.

This document describes the results and analysis from SAT.

Procedure and Instrumentation

"CDRL 19, System Acceptance Test Plan (version AN)" describes the specific instrumentation, monitoring points, prerequisites, control settings, and procedures for all 12 tests. Reference CDRL 19 for details.

Depending on the test, electrical measurements were taken at the two 12.47 kV and/or one 66 kV monitoring points. The two 12.47 kV monitoring points (voltage and current) were each located in one of the PCS containers, on the high side of the 480/12.47 kV transformer. The one 66 kV monitoring point (voltage only) was located on the substation's 66 kV transfer bus. All three monitoring points reported measurements to the PCS control software via the BESS' communication network. For the purposes of SAT, an OPC data logger application was used to record data points available in the PCS control software, including measurements from the power meters, control points/statuses from the PCS, and data from the battery system. In addition, all normally available/recorded data points were captured in SCE's networked data historian. Table 9-18 shows the instruments and their corresponding accuracy, while Table 9-19 shows the cumulative accuracy (all accuracies are expressed as a percentage of the measured value).

Point	Description	Make	Model	Accuracy	Notes
66 kV	Power meter	Janitza	UMG604	Voltage: 0.2 % Current (L): 0.2 % Current (N): 0.6 % Power: 0.4 % Energy: 0.5 %	Does not include accuracy of external transducers
66 kV	PT	GE	JVT-350	0.3 % @ 69 kV	
12.47 kV	Power meter	Janitza	UMG604	Voltage: 0.2 % Current (L): 0.2 % Current (N): 0.6 % Power: 0.4 % Energy: 0.5 %	Does not include accuracy of external transducers
12.47 kV	CT	GE	120-401	0.3 % @ 400 A, 0.6 % @ 40 A	Assuming burden of 0.1 A or less
12.47 kV	PT	ABB	VIZ-11	0.3 % @ 690--13800 V	Assuming burden of 200 VA (Z burden) or less

Table 9-18 Instruments and Accuracies

Point	Description
66 kV	Voltage: 0.5 %
12.47 kV	Voltage: 0.5 % Current (L): 0.5 % Current (N): 0.9 % Power: 1.0 % Energy: 1.1 %

Table 9-19 Cumulative Accuracy

Results and Analysis

CDRL 19 Section 6, Test Plan for BESS Power Accuracy

The purpose of this test was to verify the output accuracy of the BESS at several real and reactive power set points.

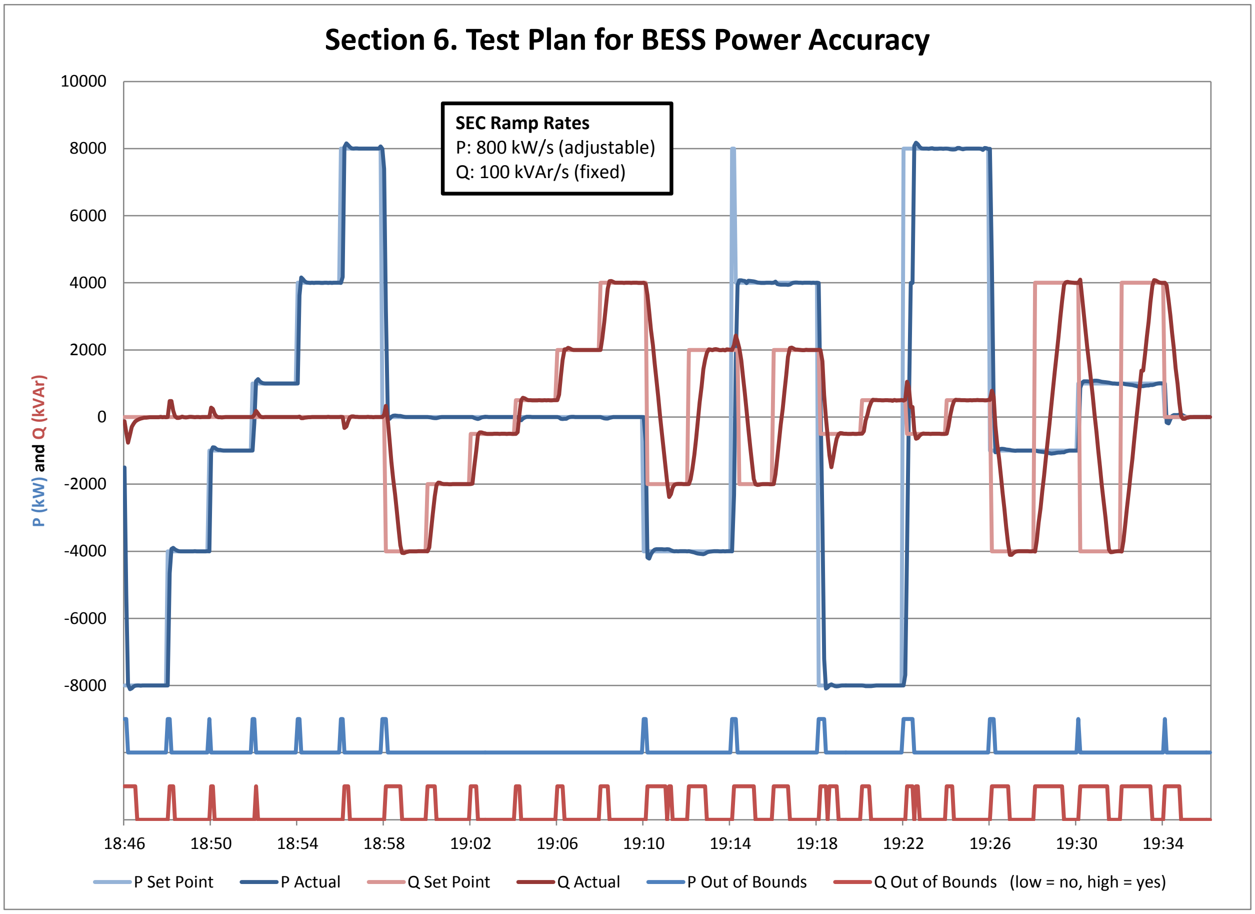


Figure 9-24. CDRL 19 Section 6, Test Plan for BESS Power Accuracy

In Figure 9-24 above, the light blue line is the real power set point, while the dark blue line is the real power actually measured. The separate blue high/low line at the bottom of the plot area shows when the measured real power was not within the expected accuracy (+/- 240 kW) of the set point. The only times at which the real power was not within +/- 240 kW of the set point were during transition periods caused by changes in the real power set point. For this test, the BESS' real power ramp rate was set at 800 kW/s. Therefore, when the real power set point was changed, the BESS followed the real power ramp rate and created a transition period where the measured real power was not within +/- 240 kW of the set point. This is the expected behavior.

Similarly, the light red line is the reactive power set point, while the dark red line is the reactive power actually measured. The separate red high/low line at the bottom of the plot area shows when the measured reactive power was not within the expected accuracy (+/- 120 kW) of the set point. The only times at which the reactive power was not within +/- 120 kW of the set point were during transition periods caused by changes in the reactive or real power set points. For this test, the BESS' reactive power ramp rate was fixed at 100 kVAr/s. Therefore, when the reactive power set point was changed, the BESS followed the reactive power ramp rate and created a transition period where the measured reactive power was not within +/- 120 kW of the set point. This is most evident in the last few reactive power set point changes near the right of the plot area, where the set point was changed from one extreme to another. This created a long transition period as the BESS changed from +4 MVAr to -4MVAr at 100 kVAr/s, and is the expected behavior. However, the reactive power was not within +/- 120 kW of the set point during most changes in the real power set point as well. For example, a change in only the real power set point usually caused the reactive power to be more than +/- 120 kW from the reactive power set point. This was due to the inherent nature of the PCS components, where changes in real power output also created changes in the overall reactance of the system at the measurement point. In all cases, the reactive power returned to within +/- 120 kW of the set point after the transition period, and is acceptable behavior.

The BESS passed this test.

CDRL 19 Section 7, Test Plan for BESS Reactive Power Tests

The purpose of this test was to verify the BESS could deliver different combinations of full real and/or reactive (+/- 4 MVAr and/or +/-8 MW) power capacity for at least one hour blocks of time.

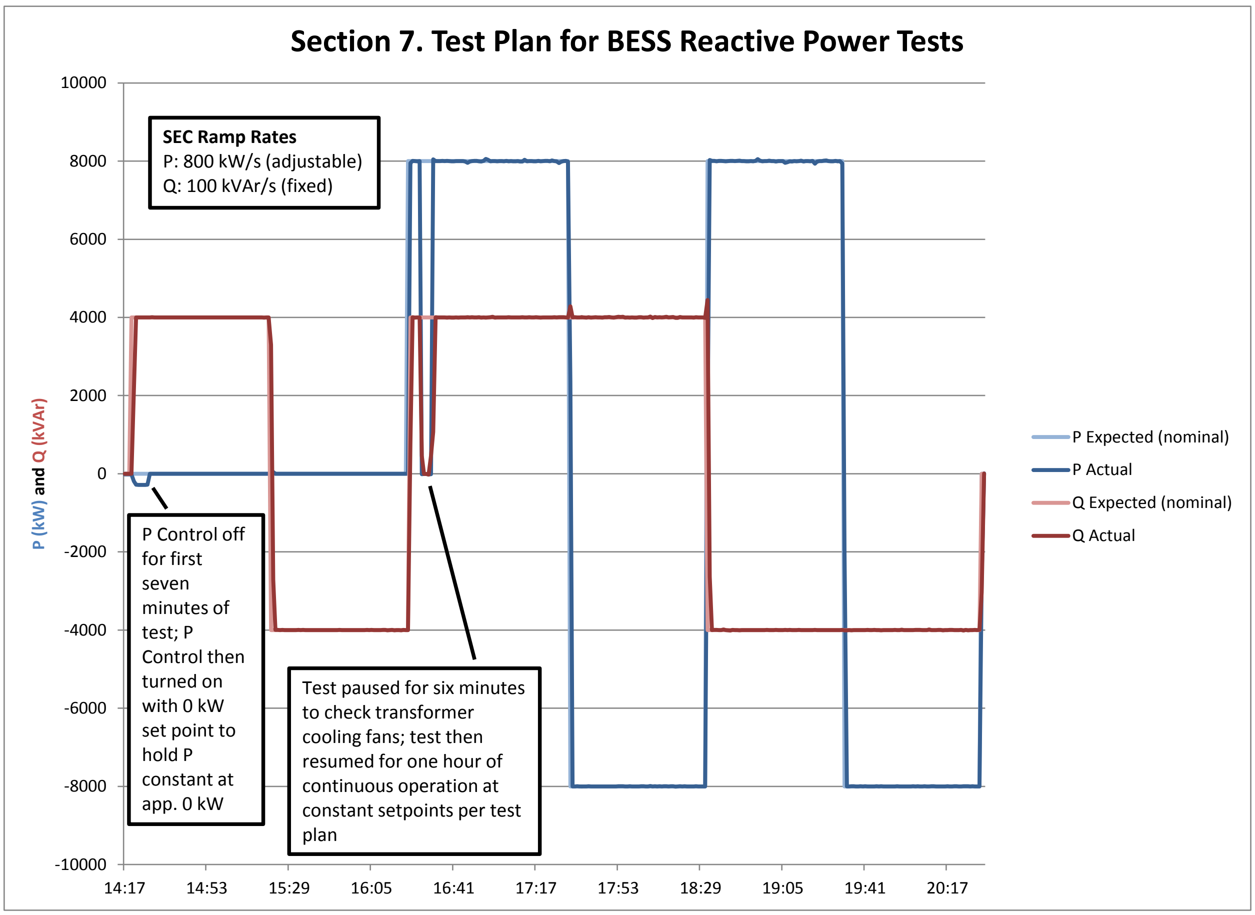


Figure 9-25. CDRL 19 Section 7, Test Plan for BESS Reactive Power Tests

In Figure 9-25 above, the light blue line is the expected real power (nominal, without considering ramp rates or interruptions), while the dark blue line is the measured real power. Similarly, the light red line is the expected reactive power (nominal, without considering ramp rates or interruptions), while the dark red line is the measured reactive power. The BESS delivered each combination of full real and/or reactive power capacity as expected for each block of time. The only differences between the expected real/reactive power and the measured real/reactive power were due to the reasons described below.

At the beginning of the test, real power control (P Control) was not turned on in conjunction with reactive power control (Q Control), which resulted in the BESS not holding the real power output to the set point (0 kW). The concurrent 4 MVAr dispatch caused a relatively small real power dispatch in the opposite direction, as noted in the extreme left of the plot area. As soon as real power control was turned on, the BESS held real power output to the set point (0 kW), and continued the 4MVAr dispatch.

- Near the middle of the test, the PCSs were shut down to manually measure the surface temperature of the 480/12.47 kV transformer cooling fans[15]. This resulted in the real and reactive power dropping to zero for approximately six minutes before resuming the test. After the test was resumed, the BESS provided the remaining real/reactive power combinations as expected for at least one uninterrupted hour each.

The BESS passed this test.

CDRL 19 Section 8, Test Plan for BESS Capacity

The purpose of this test was to verify the BESS could deliver 32 MWh of energy over approximately four hours of continuous discharge at 8 MW.

[15] This topic is discussed in the conclusion.

Test Plan for BESS Capacity

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

Table 9-20 CDRL 19 Section 8, Test Plan for BESS Capacity

In Table 9-20 the average energy delivered over three discharge cycles was 32.03 MWh, the average power was 7.99 MW, the average power factor was 1.00, the average duration was 4 hours, zero minutes, and the average state of charge (SOC) range was 93.44 percent. These results, along with the corresponding percent error from nominal values, and underlying measurement errors, represent the expected performance of the BESS.

Energy values were calculated by manually integrating 30-second power data recorded during each discharge cycle. The results are in agreement with energy recorded directly from the power measurement instrumentation (energy calculated internally by the instrument), which are shown in Table 9-21.

Cycle	Manually Integrated Energy (MWh)	Instrument Calculated Energy (MWh)	% Difference
1	31.95	31.97	0.06
2	32.04	32.03	0.03
3	32.08	32.10	0.06

Table 9-21 Comparison of Manually Integrated and Instrument Calculated Energy

The BESS passed this test.

CDRL 19 Section 9, Test Plan for BESS Ramp Rate Test

The purpose of this test was to verify the BESS could provide approximately 10-minute real power charge and discharge ramps between 0 and +/- 8 MW (these longer duration ramps are in addition to the shorter duration ramps recorded in other tests; see CDRL 19 Section 6).

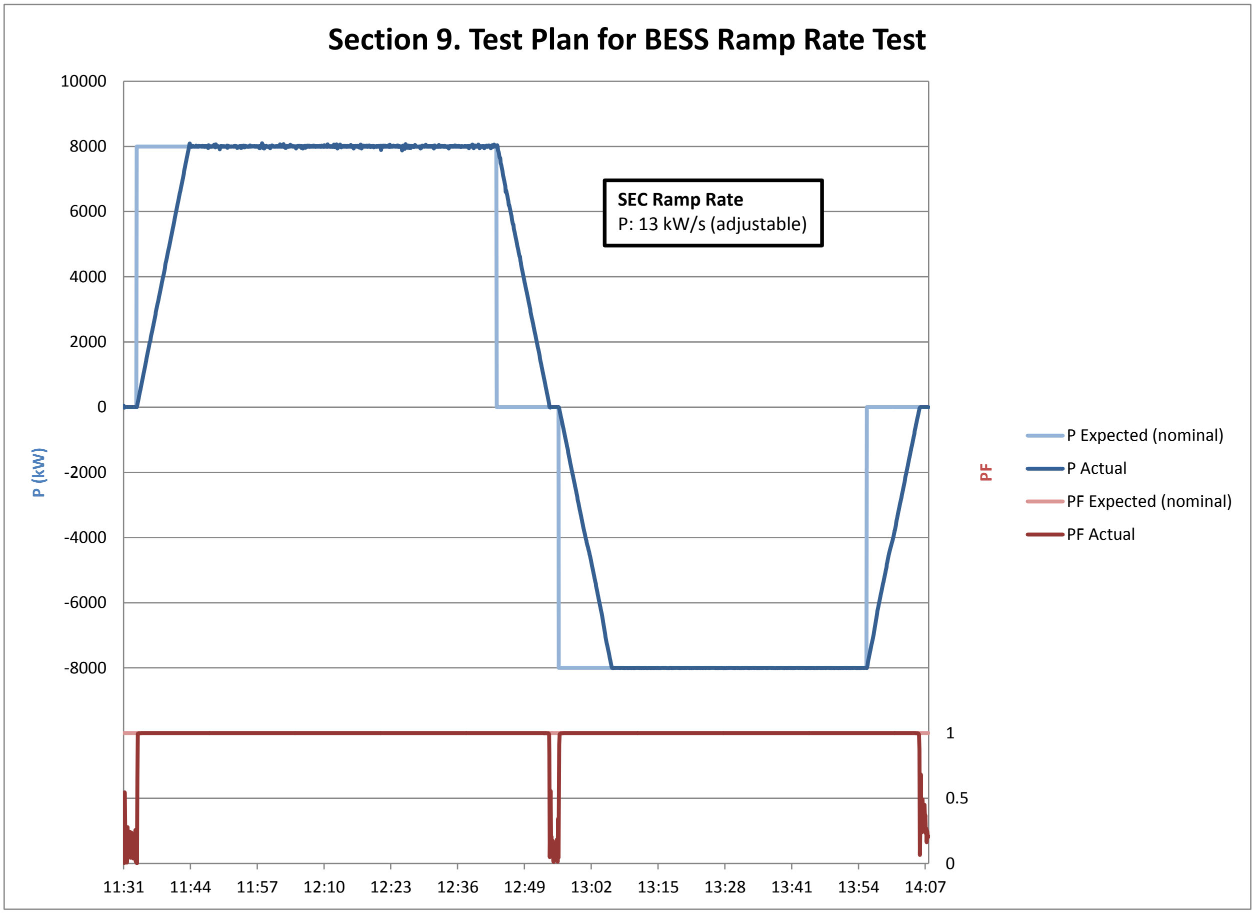


Figure 9-26 CDRL 19 Section 9, Test Plan for BESS Ramp Rate Test

In Figure 9-26 above, the light blue line is the real power set point (expected, nominal real power without considering the ramp rate), while the dark blue line is the measured real power. Similarly, the light red line is the expected power factor, while the dark red line is the measured power factor. The BESS provided the approximately 10-minute real power charge and discharge ramps between 0 and +/- 8 MW as expected, and maintained a near unity power factor throughout each ramp and steady-state output period. The power factor was always unity, except when the BESS was regulating real power output near 0.

The BESS passed this test.

CDRL 19 Section 10, Test Plan for Balancing Function Test

The purpose of this test was to verify the BESS could balance the four battery sections to within 1 percent state of charge (SOC) of each other while the system was discharged from a slightly unbalanced condition.

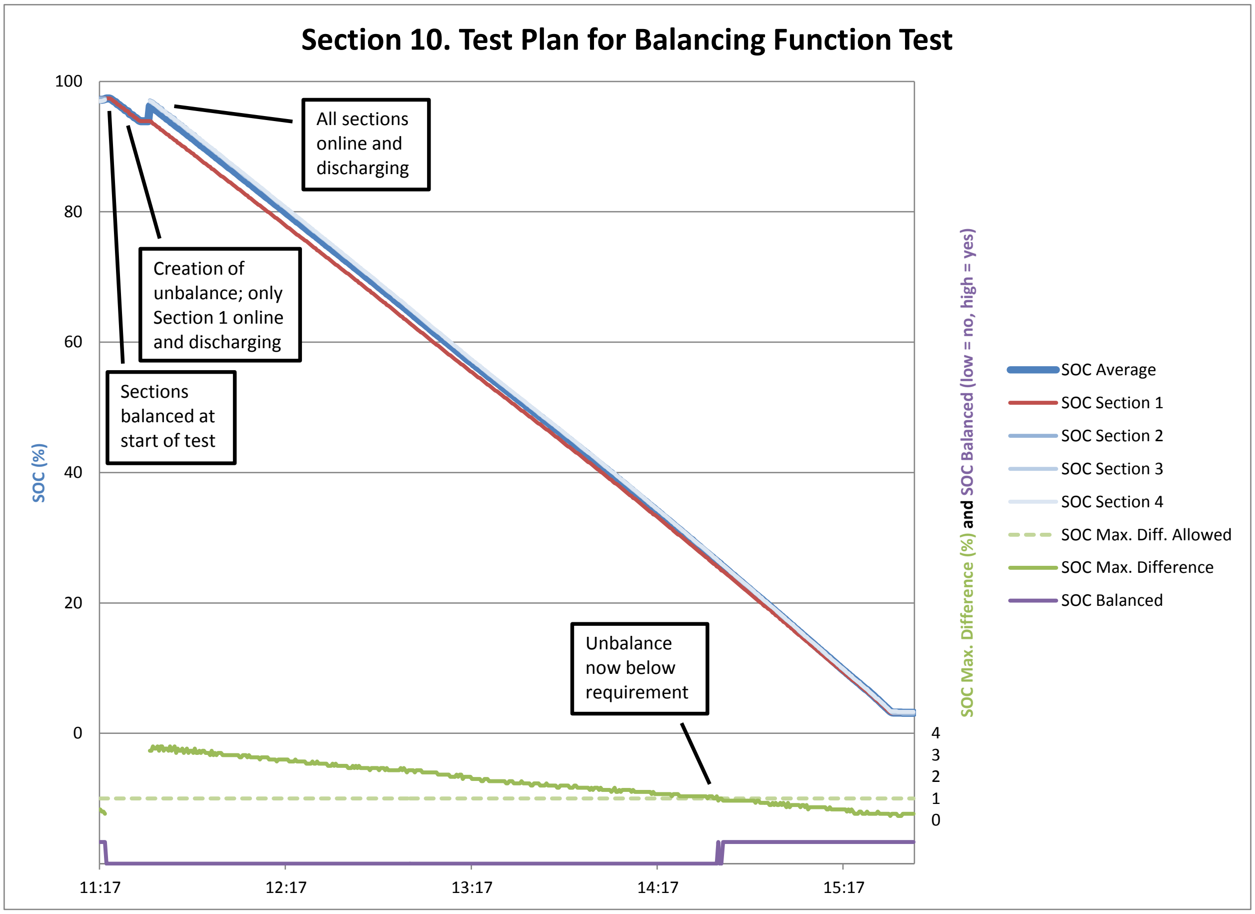


Figure 9-27 CDRL 19 Section 10, Test Plan for Balancing Function Test

In Figure 9-27 above, the thick dark blue line is the average SOC of the four battery sections, while the three lighter blue lines are the individual SOCs of battery sections 2, 3, and 4. The red line is the SOC of battery section 1. The dashed green line is the targeted maximum allowed percent SOC difference between each of the battery sections (1 percent), while the solid green line is the actual maximum percent SOC difference between each of the battery sections throughout the test. Lastly, the purple high/low line at the bottom of the plot area indicates if the battery sections are all within the targeted maximum allowed percent SOC difference (i.e., balancing during the discharge was successful).

The test started with all battery sections balanced (at approximately the same SOC), and near a complete charge. Then, the corresponding PCS lineups for battery sections 2, 3, and 4 were shut down, and only section 1 was discharged to approximately 94 percent SOC. The PCS lineups for the other three sections were then restarted, creating an unbalance of approximately three percent SOC. The BESS was then discharged at maximum power. The BESS slowly balanced the four battery sections over the discharge, as shown by the convergence of the red and blue lines. By approximately 20 percent SOC, all four battery sections were within 1 percent SOC of each other.

The BESS passed this test.

CDRL 19 Section 11.1, Test 1, Steady State Voltage Regulation

The purpose of this test was to verify the BESS could provide up to +/- 4 MVAr of reactive power to maintain the substation's 66 kV bus voltage within +/- 5 percent, while also maintaining the state of charge (SOC) of the batteries.

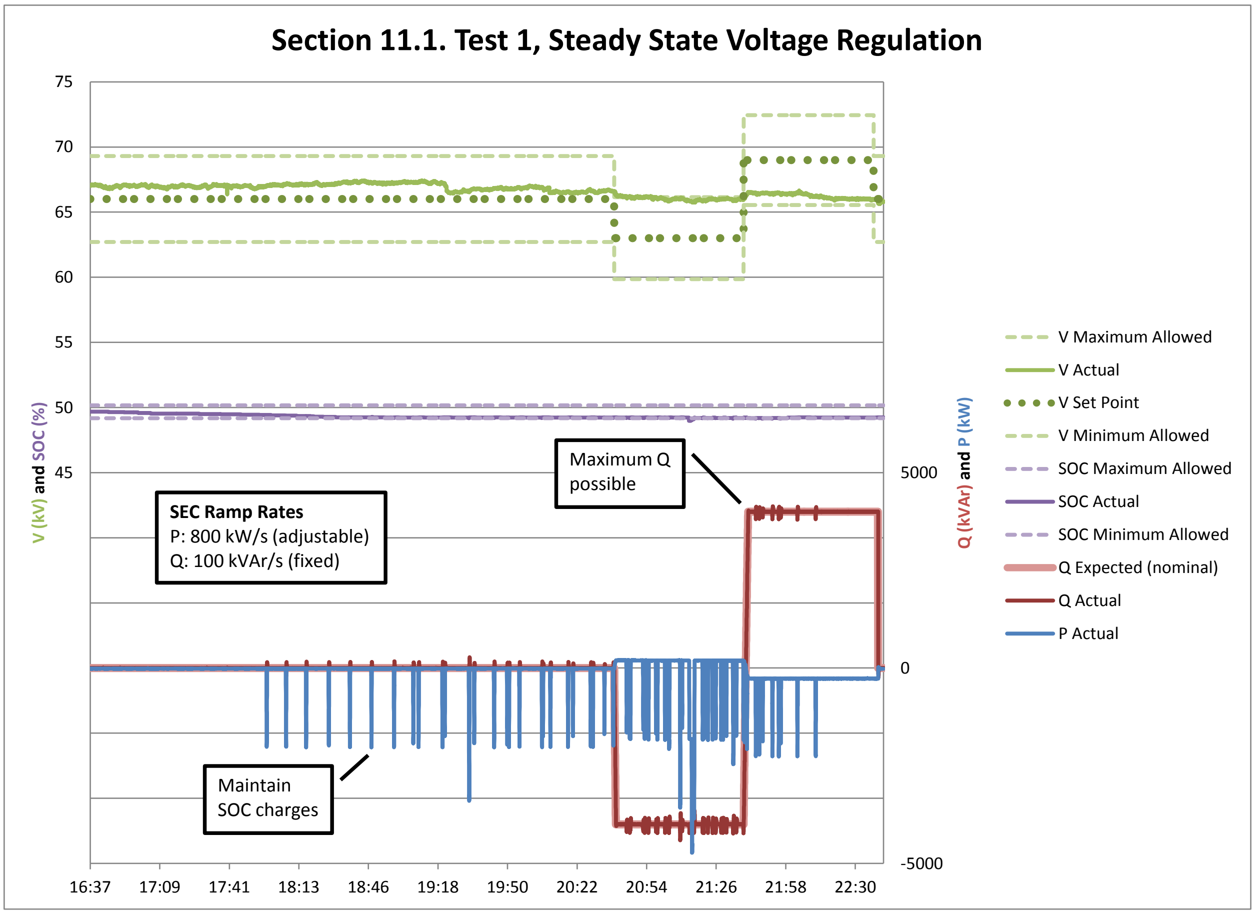


Figure 9-28 CDRL 19 Section 11.1, Test 1, Steady State Voltage Regulation

In Figure 9-28 above, the green lines are the set point, maximum allowed, minimum allowed, and measured 66 kV bus voltages, as shown in the chart legend. Similarly, the purple lines are the maximum allowed, minimum allowed, and measured SOCs, the red lines are the expected (nominal) and measured reactive powers, and the blue line is the measured real power.

For the first four hours of the test, the voltage set point was set at 66 kV, and the measured voltage remained well within the maximum/minimum allowed voltages. As a result, the system remained idle, except for an occasional real power charge to maintain the battery SOC (as seen in the measured SOC dropping to the minimum allowed SOC, and the subsequent pulses of real power). For the fifth hour of the test, the voltage set point was intentionally lowered to 63 kV, which placed the measured voltage above the maximum allowed voltage. This triggered a full -4 MVAr dispatch in an attempt to lower the bus voltage. As shown in the measured voltage, this action may have very slightly lowered the 66 kV bus voltage from where it otherwise would have trended. Similarly, for the sixth and final hour of the test, the voltage set point was intentionally raised to 69 kV, which placed the measured voltage below the minimum allowed voltage. This triggered a full +4 MVAr dispatch in an attempt to raise the bus voltage. As shown in the measured voltage, this action may have very slightly raised the 66 kV bus voltage from where it otherwise would have trended.

Due to existing conditions and characteristics of the substation's 66 kV bus, the first four hours of the test didn't demonstrate the BESS' voltage regulation function. Similarly, the behavior for the last two hours of the test was intentionally induced, and the BESS still had negligible impact on the bus voltage. Regardless, the BESS exhibited the expected behavior for the existing conditions and characteristics of the bus.

The BESS passed this test.

CDRL 19 Section 11.2, Test 3, Charge during High Line Load/Discharge during Low Line Load

The purpose of this test was to verify the BESS could charge during periods of high line loading and discharge during periods of low line loading16 per the algorithm defined in system documentation and implemented in the control software.

[16] The BESS is upstream of bottlenecks in transmission system capacity.

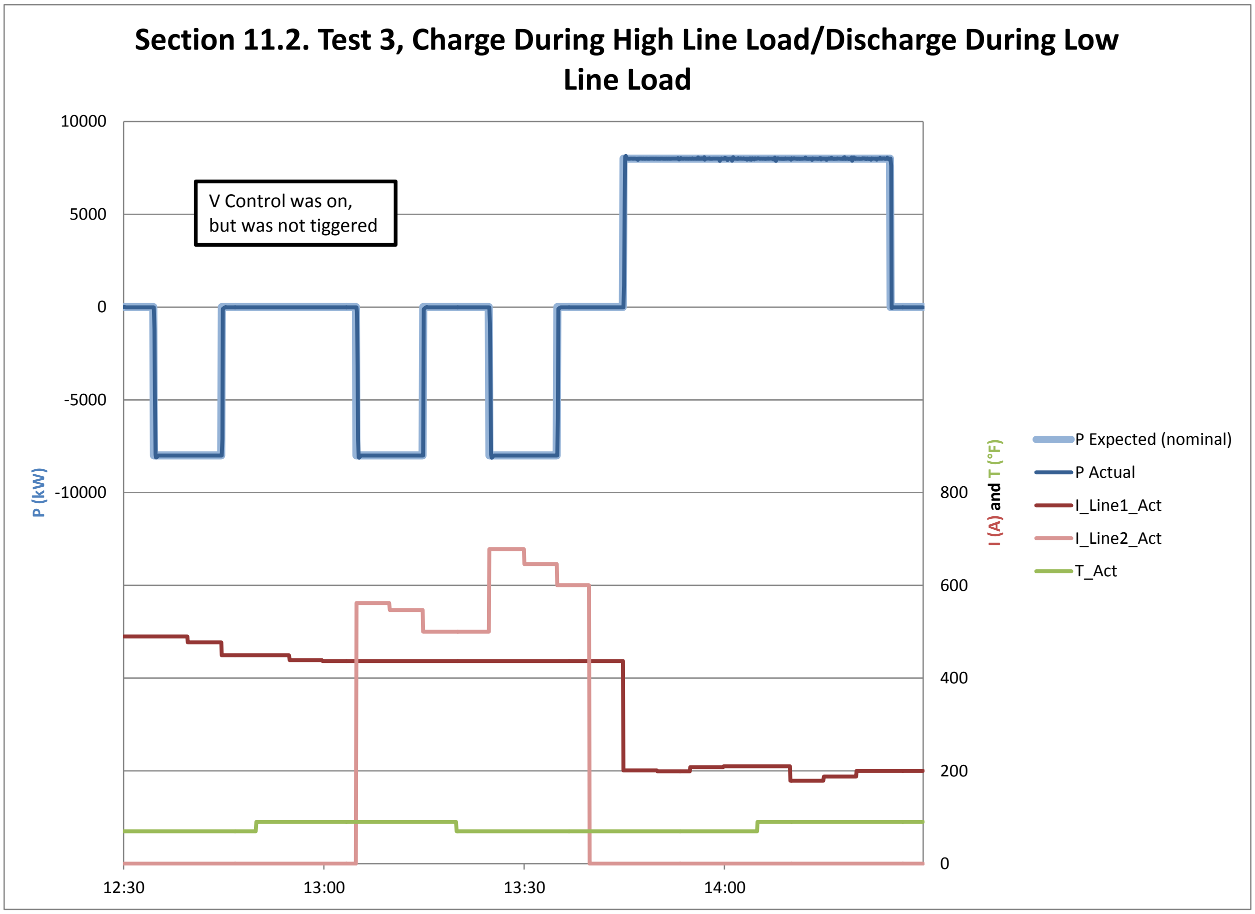


Figure 9-29 CDRL 19 Section 11.2, Test 3, Charge during High Line Load/Discharge during Low Line Load

In Figure 9-29 above, the blue lines are the expected (nominal) and measured real powers, the red lines are I_Line1_Act and I_Line2_Act (line currents, representing line loading) entered for the test, and the green line is T_Act (ambient temperature) entered for the test, as shown in the chart legend. As shown by the blue lines, the BESS charged and discharged as expected throughout the test. Even though Test 2, Steady State Voltage Regulation under Any Mode was also enabled, it was not triggered due to the existing conditions and characteristics of the substation's 66 kV bus (see CDRL 19 Section 11.1).

The BESS passed this test.

CDRL 19 Section 11.3, Test 4, Charge Off-peak/Discharge On-peak

The purpose of this test was to verify the BESS could discharge during on-peak periods and charge during off-peak periods.

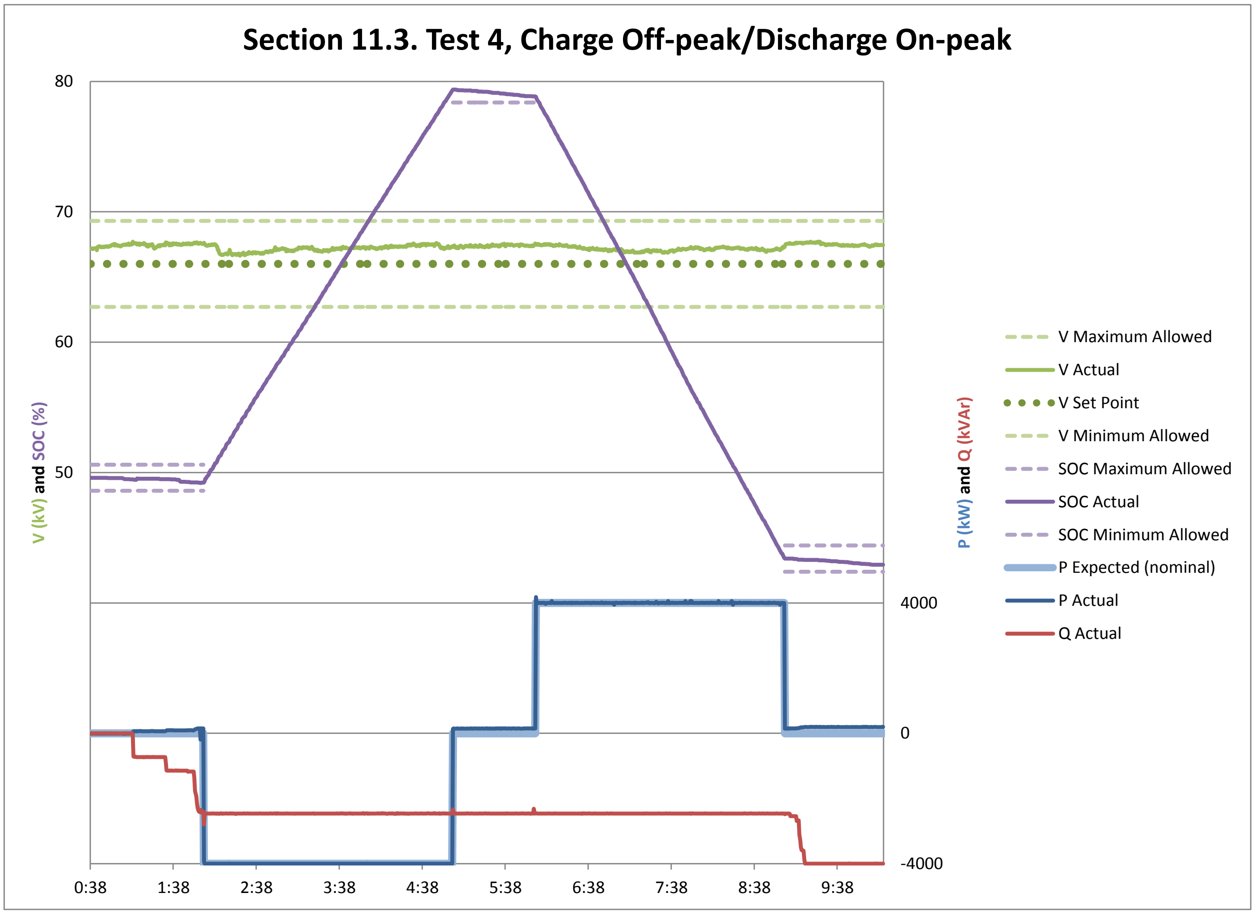


Figure 9-30 CDRL 19 Section 11.3, Test 4, Charge Off-peak/Discharge On-peak

In Figure 9-30 above, the green lines are the set point, maximum allowed, minimum allowed, and measured 66 kV bus voltages, as shown in the chart legend. Similarly, the purple lines are the maximum allowed, minimum allowed, and measured state of charges (SOCs), the blue lines are the expected (nominal) and measured real powers, and the red line is the measured reactive power.

As shown by the blue and purple lines, the BESS charged and discharged as expected over approximately three hour periods, with a one hour rest between the two periods, per the on/off peak schedule set in the control software.

Test 2, Steady State Voltage Regulation under Any Mode was also enabled, and was triggered in stages as shown by the red line near the beginning of the charge ramp, and again near the end of the discharge ramp. Voltage regulation was triggered even though the measured voltage did not appear to exceed the maximum or minimum allowed voltage limits shown by the green lines. This behavior was not expected, and should be further investigated by LG Chem and ABB[17].

[17] This topic is discussed in the conclusion.

With the exception of the unexplained voltage regulation behavior, the BESS passed the core component of this test.

CDRL 19 Section 11.4, Test 5, Charge and Discharge as Needed for Grid Purposes

The purpose of this test was to verify the BESS could charge and discharge as needed for grid purposes by accurately following wind turbine generation data, and dispatching proportionate real power ramps in the opposite direction to smooth the wind generators' output.

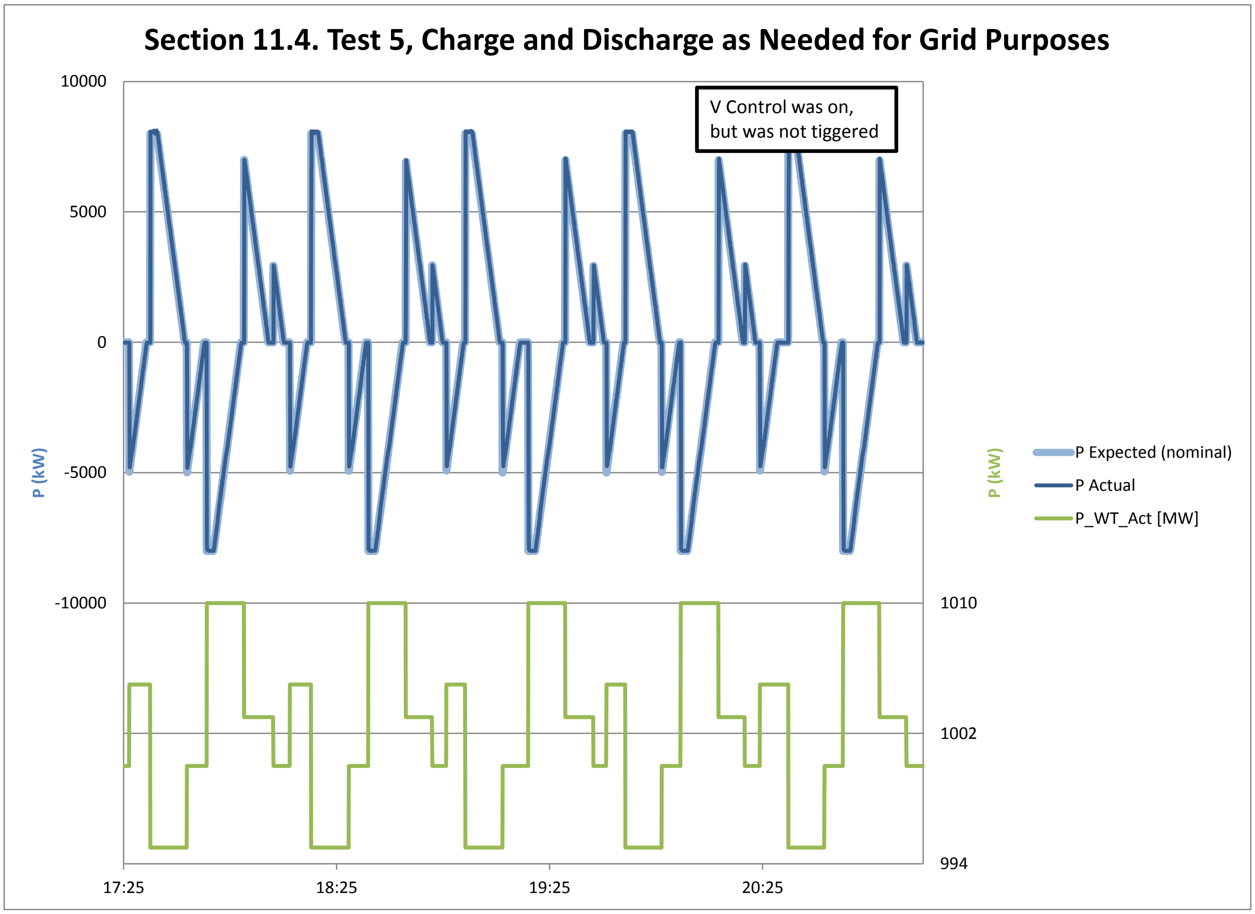


Figure 9-31 CDRL 19 Section 11.4, Test 5, Charge and Discharge as Needed for Grid Purposes

In Figure 9-31 above, the blue lines are the expected (nominal) and measured real powers, and the green line is P_WT_Act [MW] (wind turbine generation) entered for the test. As shown by the blue lines, the BESS dispatched proportionate real power ramps as expected throughout the test. Even though Test 2, Steady State Voltage Regulation under Any Mode was also enabled, it was not triggered due to the existing conditions and characteristics of the substation's 66 kV bus (see CDRL 19 Section 11.1).

The BESS passed this test.

CDRL 19 Section 11.5, EMS–GMS Transition

The purpose of this test was to verify the BESS exhibited the expected behavior when transitioning between EMS and GMS operation under different scenarios, per the interlocks and behaviors defined in system documentation and implemented in the control software.

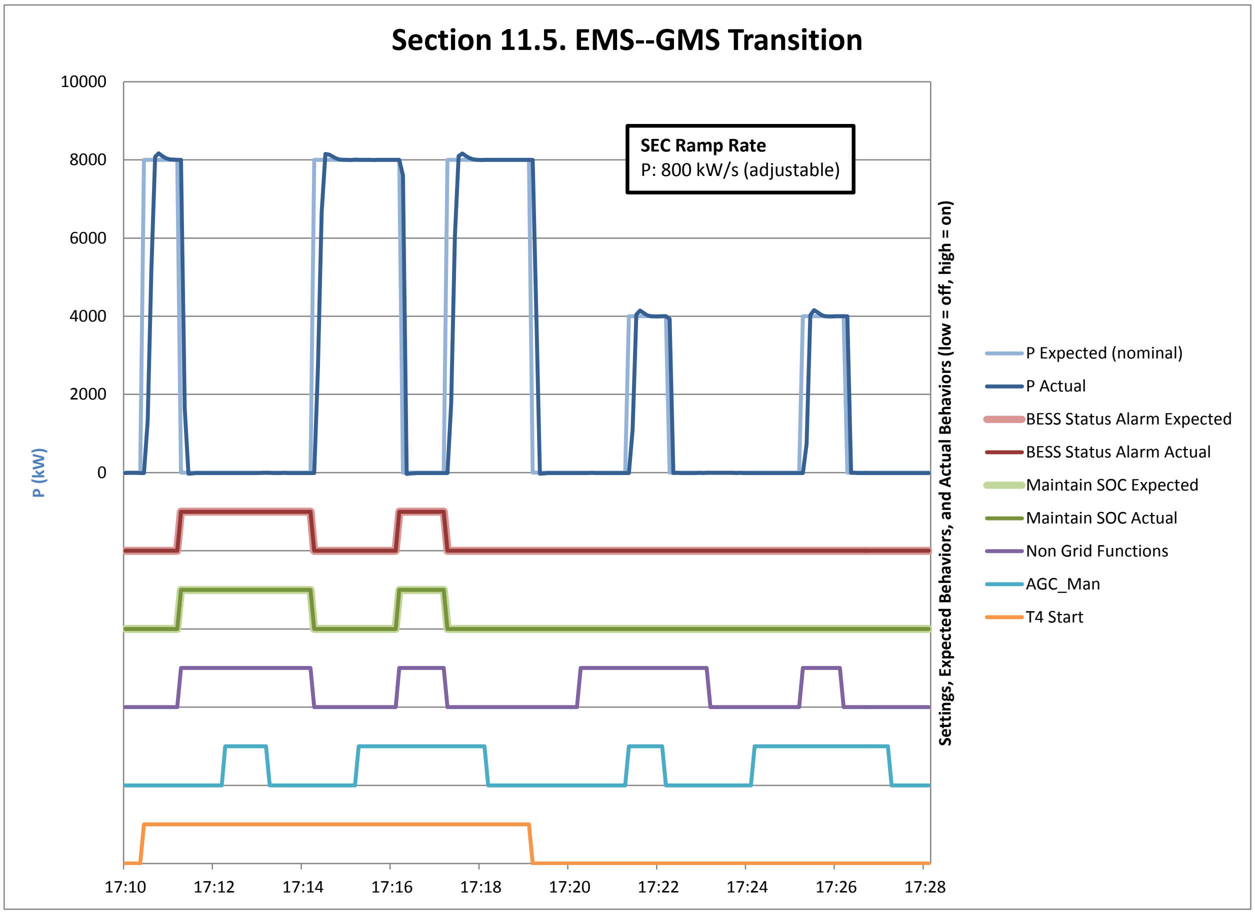


Figure 9-32 CDRL 19 Section 11.5, EMS–GMS Transition

In Figure 9-32 above, the blue lines are the expected (nominal) and measured real powers, the red high/low lines are the expected and observed BESS Status Alarm statuses (on/off), and the green lines are the expected and observed Maintain SOC statuses (on/off), as shown in the chart legend. Also, the purple, teal, and orange high/low lines are the Non Grid Functions, AGC_Man, and T4 Start control points entered for the test (on/off), respectively.

As shown by the blue, red, and green lines, the BESS charged, generated BESS Status Alarms, and maintained SOC as expected throughout the test.

The BESS passed this test.

CDRL 19 Section 11.6, EMS and GMS Communication Fault Handling

The purpose of this test was to verify the BESS exhibited the expected behavior when encountering EMS and GMS communication faults under different scenarios, per the interlocks and behaviors defined in system documentation and implemented in the control software.

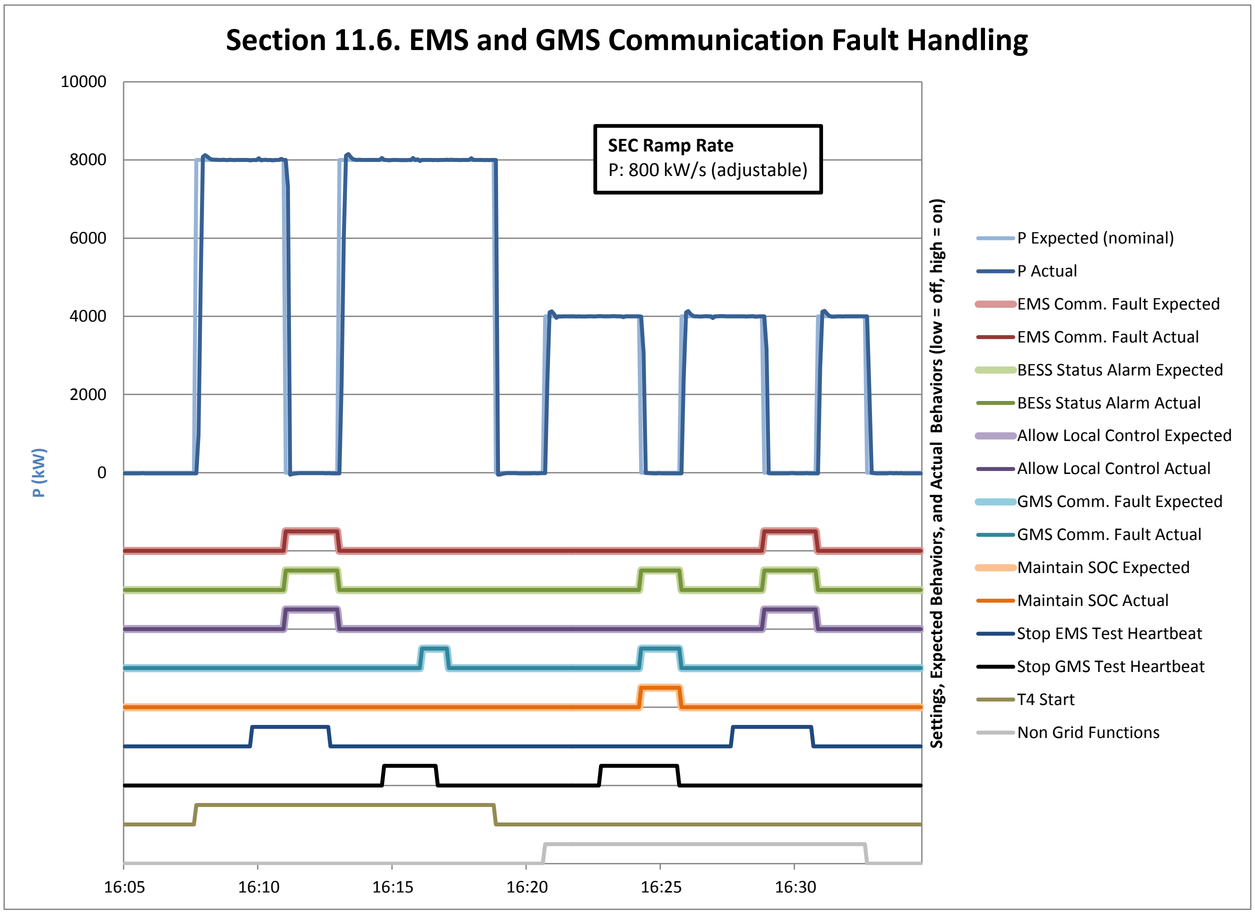


Figure 9-33 CDRL 19 Section 11.6, EMS and GMS Communication Fault Handling

In Figure 9-33 above, the blue lines are the expected (nominal) and measured real powers, the red high/low lines are the expected and observed EMS Communication Fault statuses (on/off), the green high/low lines are the expected and observed BESS Status Alarm statuses (on/off), the purple high/low lines are the expected and observed Allow Local Control statuses (on/off), the teal high/low lines are the expected and observed GMS Communication Fault statuses (on/off), and the orange high/low lines are the expected and observed Maintain SOC statuses (on/off), as shown in the chart legend. Also, the navy blue, black, tan, and gray high/low lines are the Stop EMS Test Heartbeat, Stop GMS Test Heartbeat, T4 Start, and Non Grid Functions control points entered for the test (on/off), respectively.

As shown by the blue, red, green, purple, and teal lines, the BESS charged, generated EMS and GMS Communication Faults and BESS Status Alarms, allowed local control, and turned on Maintain SOC as expected throughout the test.

The BESS passed this test.

CDRL 19 Section 12.1, Manual and CAISO Power Dispatch

The purpose of this test was to verify the BESS could dispatch real power using GMS commands.

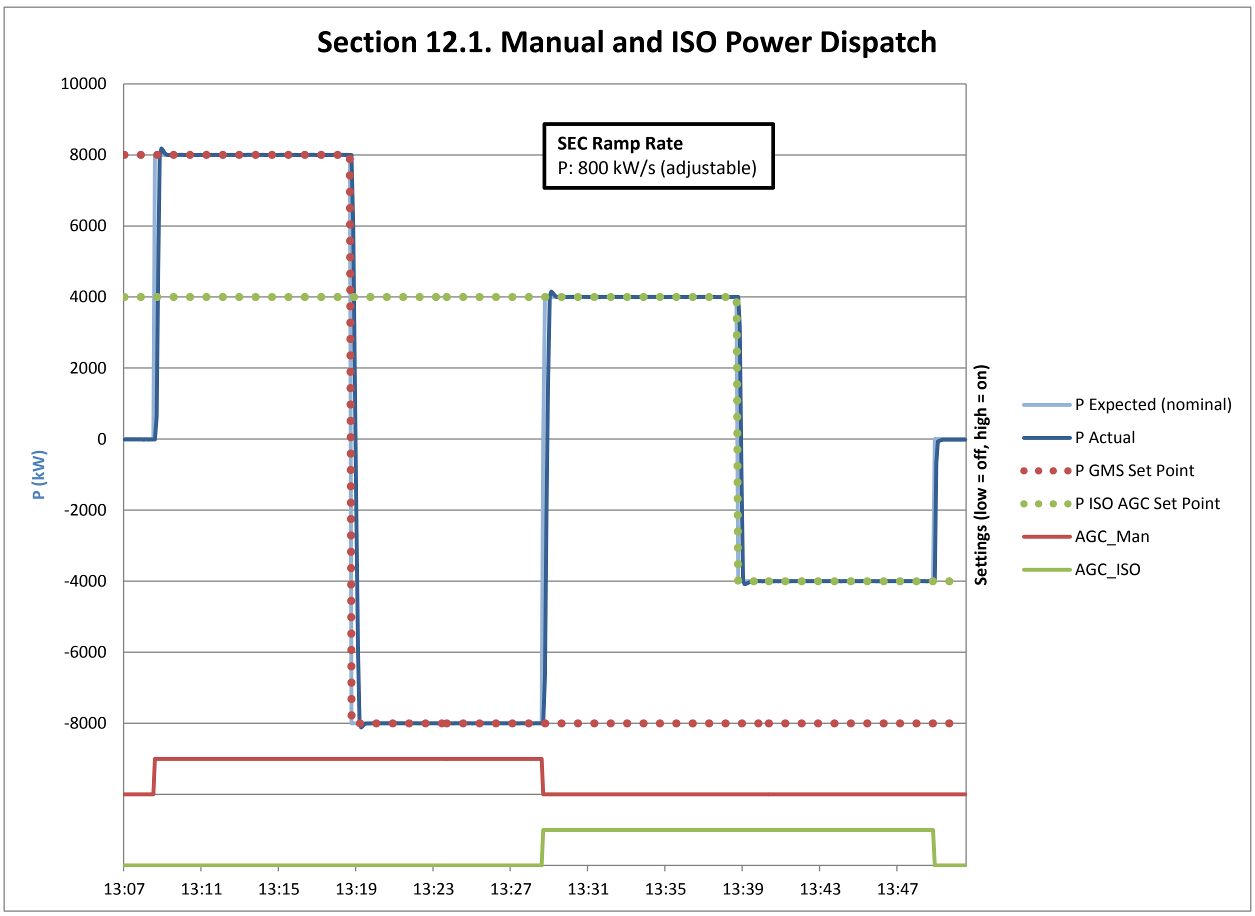


Figure 9-34 CDRL 19 Section 12.1, Manual and CAISO Power Dispatch

In Figure 9-34 above, the blue lines are the expected (nominal, without considering the real power ramp rate) and measured real powers, the red and green dotted lines are the P GMS Set Point and

P CAISO AGC Set Point entered for the test, respectively, and the red and green solid high/low lines are the AGC_Man and AGC_CAISO control points entered for the test (on/off), respectively.

As shown by the blue lines, the BESS charged and discharged as expected throughout the test.

The BESS passed this test.

Conclusion

Throughout SAT, the BESS largely exhibited the expected behavior and passed each test. With the successful completion of SAT, SCE hereby confirms that the Performance Tests have been satisfactorily completed and the Performance Guarantees have been achieved, as set forth in Exhibit O of the project contract and further established in "CDRL 19, System Acceptance Test Plan", and required by section (iv) of the definition of "Substantial Completion".

However, there are a number of open items, both related to behaviors and issues observed during SAT, as well as other items, all of which must be addressed by LG Chem and ABB prior to final acceptance. Notable items related to behaviors and issues observed during SAT are described below, and all items (SAT-related and otherwise) will be provided to LG Chem in separate documentation.

Notable Items Related to Behaviors and Issues Observed During SAT

As mentioned in CDRL 19 Section 7, one of the PCS containers had a 480/12.47 kV transformer cooling fan motor failure near the beginning of SAT, in addition to an identical failure shortly before the start of SAT. During SAT, all 12 of these fans were replaced in both PCS containers as a precautionary measure, and the tests were completed without any further failures. ABB reported they are investigating the cause of the failures, and SCE is waiting on their findings.

During CDRL 19 Section 11.3, Test 4, Charge Off-peak/Discharge On-peak (see CDRL 19 Section 11.3), the voltage regulation function was triggered, even when the measured voltage didn't appear to exceed the maximum or minimum allowed voltage limits. This behavior was unexpected and should be investigated by ABB. SCE would like a detailed description of the voltage regulation algorithm, including an explanation of its operation, and its sensitivity to voltage transients and other potential causes for it to trigger.

Per CDRL 19, SCE is waiting for an updated system communication diagram from ABB (ABB document number 3AUP000A110-R3) showing the current equipment IP addresses provided to ABB and verified by SCE during SAT.

The ABB local data historian was unable to recall logged data (or wasn't logging data at all) during SAT. ABB should fix the local data historian and confirm it automatically records all data as long as the OPC server is running and the data historian is powered on.

The OPC server configuration applet currently resides on the ABB local computer, requiring both the local computer and ABB local data historian be powered on in order for the ABB and SCE data historians to receive and log data. The OPC server configuration applet should be moved and configured to run on the ABB local data historian, so daily operation of the system is no longer dependent on the ABB local computer.

Appendix A

Report Approvals and Revisions: SAT Report approved and signed July 2014

Report Distribution:

SCE, LG Chem

9.9 Appendix I: CDRL 19, System Acceptance Test Plan

CDRL 19, System Acceptance Test Plan

Customer	**Southern California Edison**
Project	**8MW/32MWh Tehachapi Wind Energy Storage Project**
Customer Contact	**Mr. Blake Chalson (Contracts Manager / +1 626 940 9861)**
Date of Submission	**January 29, 2014**
LG Chem Ltd. Contact	**Kevin Fok (Sales Manager)** +1 248 825 1043 / kfok@lgchem.com LG Chem Power, Inc. 1857 Technology Dr., Troy, MI 48083, USA
	Jaehong Park (Project Manager) +82 10 9955 7749 / jaehongpark@lgchem.com LG Chem Ltd. 20, Yeouidodong Yeoungdeunpogu, Seoul, 150-721, Korea

Revision History

Date	Revision	Writer	Contents
Oct 08, 2013	AA	ABB : DMPC /LGC : Gyongjin Oh	Preliminary Release
Dec 12, 2013	AB	ABB : Igor Hot /LGC : Gyongjin Oh	Revised per SCE provided comments
Dec 13, 2013	AC	LGC : Gyongjin Oh	Revised Battery Fully charge and discharge
Dec 13, 2013	AD	LGC : Kevin Fok	Edits
Jan 29, 2014	AF	SCE : Grant Davis, Daryl Coleman, Loic Gaillac, Andy Paylan	Additions, corrections, and clarifications throughout
Feb 10, 2014	AG	ABB : Igor Hot	General Revision
Feb 13, 2014	AH	SCE : Grant Davis	Review
Feb 24, 2014	AI	ABB : Igor Hot	Minor Updates
Feb 27, 2014	AJ	SCE : Grant Davis	Review, minor updates to address SEC functionality, added power accuracy test
March 14, 2014	AK	ABB : Igor Hot	Minor Updates
April 07, 2014	AL	SCE : Grant Davis	Review
June 17, 2014	AM	SCE : Grant Davis	Review, formatting, minor updates suggested by ABB

Table of Contents

SAFETY

This document contains important information regarding the configuration and operation of the PCS equipment for ESS applications. All operations on the PCS should be carried out by a trained technician familiar with the contents of this document.

DANGER!
This symbol indicates an imminent danger resulting from mechanical forces or high voltage. A non-observance leads to life-threatening physical injury or death.

WARNING!
This symbol indicates a dangerous situation. A non-observance may lead to serious or life-threatening physical injury or death.

CAUTION!
This symbol indicates a dangerous situation. A non-observance may lead to physical injury or cause damage to the equipment.

NOTICE!
This symbol emphasizes important information. A non-observance may cause damage to the equipment or other adverse effects.

IMPORTANT!
This symbol indicates useful information. Not to be used to indicate dangerous situations.

Work performed on any part of the equipment must be by a trained technician familiar with servicing this product.

Ensure power is isolated and locked off before attempting any work on this equipment.

Ensure the Equipment Under Test (EUT) and electrical equipment is properly grounded before attempting any work on this equipment.

Follow all applicable safety procedures enforced by the company / facility where the testing is to be performed.

Many parts in this equipment, including printed circuit boards operate at lethal voltages. DO NOT TOUCH components or connections that have voltage present.

This equipment is a high energy device and requires strict precautions to be taken. Stored charge is present after the device is switched off.

Normal operation of this equipment requires all protective covers to be in place and doors secured closed.

Ensure proper PPE, including safety glasses, outerwear and Electrical Hazard safety footwear, are worn at all times while working on the equipment.

When the PCS100 ESS is powered down, lethal voltages (up to 1050Vdc) will remain in the energy storage element and the complete PCS100 ESS should be considered alive.

INTRODUCTION

This document provides the System Acceptance Test Plan for Southern California Edison's (SCE's) Tehachapi Storage Project (TSP) 32MWh battery energy storage system (BESS) installed at Monolith Substation near Tehachapi, California. The BESS consists of 32MWh of Li-ion batteries and an 8MW/4MVAr/9MVA bidirectional power conversion system (PCS). The PCS is designed to connect to a 12.47kV, 3-Phase, 60 Hz bus, and is divided into two 4.5 MVA units. Each PCS unit is controlled by a PCS controller, and is connected to two battery sections.

To allow for a central interface between the BESS and Southern California Edison, ABB implemented a site energy controller (SEC). The basic function of the SEC is to interpret the remote command functions (end user commands) and relay this information to the individual PCS units. In addition to accepting remote commands and providing status information, the SEC employs built-in logic to successfully run the system acceptance tests. The SEC aggregates the electrical parameters measured by each of the PCS power meters to act as a central interface for status reporting. The measured SEC values and/or separate data logger(s) will be used to serve as the validation mechanism for the system acceptance tests defined in this document. The accuracy of the power meters, inclusive of the current transformers (CTs), potential transformers (PTs), burden due to conductor runs from PTs and CTs to the power meters, and power meters themselves, will be provided, along with current calibration certificates. In addition, accuracy will be provided when aggregated electrical parameters are used to determine the performance of the system.

REFERENCES

TECHNICAL & CONTRACTUAL DOCUMENT REFERENCES

The tests described in this document shall demonstrate that the BESS conforms, at a minimum, to the technical requirements set forth in the following documents.

Item	Doc. Owner	Description	Document No.	Revision / Date
1	SCE	Technical Specification	TSP BESS SOW	v2-2 - FINAL
2	LG Chem	Technical Plan and Approach	CDRL 5.0	v1.0
3	ABB DMPC	Technical Proposal	PE-2161	c1-Conformed
4	SCE & LG Chem	Contract, Performance Tests & Performance Guarantees	Exhibit O	Executed

Table 9-22, Technical & Contractual Document References

DESIGN DOCUMENT REFERENCES

The containerized PCS has been designed, fabricated, and assembled based on a Master List of Documents (3AUP000A110-G). The current revisions in the document list will be available for Buyer review prior to the commencement of the scheduled test. The table below only includes the documents which will be referenced during the procedures detailed within this document.

Item	Doc. Number	Description	Revision / Date
1	3AUP000A110-R3	Communication Diagram – System Overall	TBD
2	3AUP080A108-V1	Control and Interface Concept	TBD
3	3AUP000A108-V2	DNP3/Modbus TCP/IP interface	TBD
4	3AUP080A108-V3	IEC61850 & Local Historian Data	TBD

Table 9-23, Design Document References

REQUIRED DATA ACQUISITION, RECORDING EQUIPMENT, AND INVERTER SYSTEM PERFORMANCE POWER ACCURACY

The following data acquisition and recording equipment is required for the test. Ensure all equipment is calibrated. During the test, fill in the serial number and calibration due dates. Do not use equipment without current calibration certificates.

To allow for a comprehensive and accurate analysis of the test results for each test outlined in this document, test data will be recorded with data logger(s), in addition to the local Data Historian.

The BESS inverter system power accuracy per PCS100 ESS technical specifications shall be +/-3% of the power set point.

Item	Description	Man. / Model	Quantity	Serial Number (Cal. Date / Due Date)
1	Local Historian	ABB / COM600	1	n/a
2	PQM	Janitza / UMG604	2 @ 12.47kV	PCS100 - Unit 1, SN:7001/9226 Calibration Date: Nov 3, 2013 PCS100 - Unit 2, SN:7001/9224 Calibration Date: Nov 3, 2013
3	PQM	Janitza / UMG604	1 @ 66kV	SEC, SN: 7001/9227 Calibration Date: Nov 3, 2013
4	CT	GE-ITI / Model 120, Catalog Number 120-401, Current Ratio 400:5	6	PCS100 - Unit 1, SN: 003525712, 003525711, 003525710 PCS100 - Unit 2, SN: 003552258, 003552254, 003552253
5	PT	ABB / Model VIZ-11, Primary Voltage 13800/13800Y, Secondary Voltage 120, Ratio 115:1, Highest Accuracy 0.3 % Z	4	PCS100 - Unit 1, SN: 41301546, 41301547 PCS100 - Unit 2, SN: 41301548, 41301549
6	Data Logger Software Installed on Commissioning PC	L.H. Controls /OPC Data Logger, Ver 1.72f	1	N/A

Table 9-24, Required Data Acquisition & Test Equipment

REQUIRED PROGRAMMING AND CONFIGURATION SOFTWARE

The following programming and configuration software (including specific versions) is required for the test. Ensure all software is up-to-date. During the test, fill in the actual version of the software.

Item	Description	Man.	Required Version	Actual Version
1	Compact Control Builder AC 800M	ABB	5.1.0/1 (Build 5.1.100.13)	
2	Panel Builder 800	ABB	5.1/0 (Build 353)	
3	GridVis software used for configuration and monitoring of PQMs	Janitza	3.1.1	
4	ProSoft Configuration Builder	ProSoft	4.1.0 (Build 4)	

Table 9-25, Required Programming and Configuration Software

REQUIRED COMPONENT SOFTWARE AND FIRMWARE

The following component software and firmware (including specific versions) is required for the test. Ensure all software and firmware is up-to-date. During the test, fill in the actual version of the software and firmware.

Item	Component Description	Man. / Model	Required Version	Actual Version
1	PLC - Processor Module - SEC	ABB / PM860	Firmware: FW866 5.1.100.13 2011-04-17 (BasicHwLib 5.1-0) Application: Rev TBD	
2	PLC - Processor Module - PCS100	ABB / PM856	Firmware: FW866 5.1.100.13 2011-04-17 (BasicHwLib 5.1-0) Application: Rev TBD	
3	CEX - Modbus TCP Module	ABB / CI867	Firmware: FWCI867 5.1.0111.0 (CI867ModbusTcpHwLib 2.0-30)	
4	HMI - Operator Interface - SEC	ABB / PP840	Application: Rev TBD	
5	HMI - Operator Interface - PCS100	ABB / PP835	Application: Rev TBD	
6	PCS100 - Lineup #1 Controller	ABB / PCS100 Master Controller	Firmware: R2I3	
7	PCS100 - Lineup #2 Controller	ABB / PCS100 Master Controller	Firmware: R2I3	
8	COM600	ABB / COM600HRH22TPNNNND	SW Ver: 4.0	
9	Section Controller	LGC / Battery System Controller	Section Controller SW Ver: TBD	
10	Battery Management System	LGC / Battery System Controller	BMS Firmware Ver: TBD BMS Hardware Ver: 1.0	

Table 9-26, Required Component Software and Firmware

TEST PREREQUISITES

The prerequisites for acceptance testing are:

- All commissioning tasks are completed.
- The BESS is ready for coordinated control, and all SEC local control functions have been tested (Q Control, V Control, P control, Standby Mode, SOC Control, and Maintain SOC Control).
- The SEC/SCE communication interfaces (EMS DNP3/Modbus TCP/IP and GMS DNP3/Modbus TCP/IP) are tested and fully functional.[18]

Set the following on the SEC Reference screen for all tests, unless specified otherwise by a specific test:

- SOC Max [%] = 100
- SOC Min [%] = 1.5
- SOC DB [%] = 0.5
- V [kV] = 66
- P Charge [kW] = -8000
- P Discharge [kW] = 8000
- P Ramp + [kW/sec] = 800
- P Ramp - [kW/sec] = 800
- Fully Charge BESS = Off
- Fully Discharge BESS = Off
- Maintain SOC Allowed for T1&T4 = On
- V Ctrl Selected for T3, T4 or T5 = On
- Critical Testing = On

IEC61850 INTERFACE AND LOCAL HISTORIAN

All logged signals should be recorded throughout the acceptance testing by the IEC61850 and Local Data Historian. Signals should be properly logged in the local historian and transferred to the SCE IEC61850 historian. Signals should be verified for accuracy and scaling per the IEC61850 & Local Historian Data document (3AUP080A108-V3).

[18] If any of these interfaces are not functional at the time of testing, the corresponding SEC EMS and/or GMS Test mode will be used for system acceptance testing.

TEST PLAN FOR BESS POWER ACCURACY (DAY 1)

The purpose of this test is to verify the output accuracy of the BESS at several real and reactive power set points. Active and reactive power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s).

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC, in order to have adequate charge and discharge capacity throughout the test.
- Using P Control and/or Q Control (Local Control), set the following in succession on the Reference screen. Wait at least one minute after each setting and then verify the actual output.

Step	**Real**	**Reactive**	**Description**
1	-8 MW	0 MVAr	Maximum active charge
2	-4 MW	0 MVAr	Mid-range active charge
3	-1 MW	0 MVAr	Small active charge
4	1 MW	0 MVAr	Small active discharge
5	4 MW	0 MVAr	Mid-range active discharge
6	8 MW	0 MVAr	Maximum active discharge
7	0 MW	-4 MVAr	Maximum reactive consume
8	0 MW	-2 MVAr	Mid-range reactive consume
9	0 MW	-0.5 MVAr	Small reactive consume
10	0 MW	0.5 MVAr	Small reactive supply
11	0 MW	2 MVAr	Mid-range reactive supply
12	0 MW	4 MVAr	Maximum reactive supply
13	-4 MW	-2 MVAr	Mid-range active charge, reactive consume
14	-4 MW	2 MVAr	Mid-range active charge, reactive supply
15	4 MW	-2 MVAr	Mid-range active discharge, reactive consume
16	4 MW	2 MVAr	Mid-range active discharge, reactive supply
17	-8 MW	-0.5 MVAr	Maximum active charge, small reactive consume
18	-8 MW	0.5 MVAr	Maximum active charge, small reactive supply
19	8 MW	-0.5 MVAr	Maximum active discharge, small reactive consume
20	8 MW	0.5 MVAr	Maximum active discharge, small reactive supply
21	-1 MW	-4 MVAr	Small active charge, maximum reactive consume
22	-1 MW	4 MVAr	Small active charge, maximum reactive supply
23	1 MW	-4 MVAr	Small active discharge, maximum reactive consume
24	1 MW	4 MVAr	Small active discharge, maximum reactive supply

The BESS shall exchange real and reactive power at the set points above, with an error no greater than +/- 3 percent of rated output (+/- 240 kW and +/- 120 kVAr).

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST PLAN FOR BESS REACTIVE POWER TESTS (DAY 2)

The purpose of this test is to verify that the BESS can deliver 4MVAr of reactive power and 8MW of real power as measured at the 12.47kV monitoring point. Active and reactive power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s).

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC, in order to have adequate charge and discharge capacity throughout the test.
- Using Q Control (Local Control) with a 4MVAr Q set point, the BESS shall supply 4MVAr for one hour (no active power will be exchanged).
- Using Q Control (Local Control) with a -4MVAr Q set point, the BESS shall consume 4MVAr for one hour (no active power will be exchanged).
- Using P Control (Local Control) with an 8MW P set point and Q Control (Local Control) with a 4MVAr Q set point, the BESS shall discharge at 8MW and supply 4MVAr for one hour.
- Using P Control (Local Control) with a -8MW P set point and Q Control (Local Control) with a 4MVAr Q set point, the BESS shall charge at 8MW and supply 4MVAr for one hour.
- Using P Control (Local Control) with an 8MW P set point and Q Control (Local Control) with a -4MVAr Q set point, the BESS shall discharge at 8MW and consume 4MVAr for one hour.
- Using P Control (Local Control) with a -8MW P set point and Q Control (Local Control) with a -4MVAr Q set point, the BESS shall charge at 8MW and consume 4MVAr for one hour.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST PLAN FOR BESS CAPACITY (DAYS 3, 4, AND 5)

The purpose of this test is to verify that the BESS can deliver 8MW of active power and 32MWh of energy over a 4 hour period as measured at the 12.47kV monitoring point.[19] Active power and energy measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s).

The test shall be performed in the following manner:

- The BESS shall begin each cycle at 30% +/- 0.5% SOC.
- Using P Control (Local Control) with Fully Charge BESS On, the BESS shall charge at 8MW and unity PF, automatically scaling back as it nears full charge, until the SOC reaches 100% (or a level considered to be equivalent to a complete charge as defined by LG).
- After an optional rest (P Control off and Maintain SOC on) of up to 1 hour, using P Control (Local Control) and Fully Discharge BESS On, the BESS shall discharge at 8MW and unity PF, until the SOC reaches 1.5% (or a level considered to be equivalent to a complete discharge as defined by LG).
- After an optional rest (P Control off and Maintain SOC on) of up to 1 hour, using SOC Control (Local Control) with a 30% SOC set point and a 0.5% dead band, the BESS shall charge at maximum available charge power and unity PF, until the SOC reaches 30% +/- 0.5%.
- After an optional rest (P Control off and Maintain SOC on), the cycle shall be repeated two additional times within 72 hours.

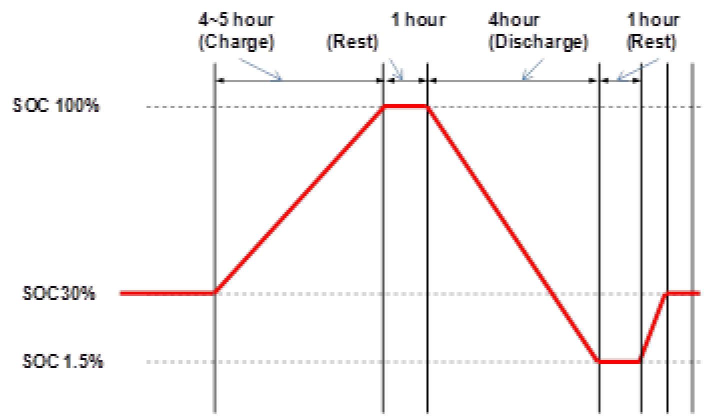


Figure 9-35, BESS Capacity Charge and Discharge Profile

The BESS shall provide a minimum of 8MW of AC active power and 32MWh of AC energy during each cycle.[19]

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

[19] Energy capacity is subject to revision per mutual agreement between SCE and LG Chem.

TEST PLAN FOR BESS RAMP RATE TEST (DAY 6)

The purpose of this test is to verify that the BESS can provide approximately 10-minute active power charge and discharge ramps from 0MW to 8MW. Active power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s).

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC, in order to have adequate charge and discharge capacity throughout the test.
- In addition to Section 4, Test Prerequisites, set the following on the Reference screen:
  - P Ramp + [kW/sec] = 13
  - P Ramp – [kW/sec] = 13
- Using P Control (Local Control) with an 8MW P set point, the BESS shall ramp linearly from 0MW to an 8MW discharge at unity power factor over approximately 10 minutes, and then sustain an 8MW discharge for one hour.
- After the one hour discharge, using P Control (Local Control) with a 0MW P set point, the BESS shall ramp linearly from an 8MW discharge to 0MW over approximately 10 minutes.
- After an optional rest (P Control off and Maintain SOC on) of up to 1 hour, using P Control (Local Control) with a -8MW P set point, the BESS shall ramp linearly from 0MW to an 8MW charge at unity power factor over approximately 10 minutes, and then sustain an 8MW charge for one hour.
- After the one hour charge, using P Control (Local Control) with a 0MW P set point, the BESS shall ramp linearly from an 8MW charge to 0MW over approximately 10 minutes.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST PLAN FOR BALANCING FUNCTION TEST (DAY 7)

The purpose of this test is to verify that the BESS can balance the four battery sections to within 1% SOC of each other while the system is discharged from a slightly unbalanced condition.

NOTE: The purpose of the SOC balancing function is to keep the SOC of all four battery sections within 1% SOC of each other during a discharge. The SOC balancing function is not intended to correct SOC imbalances if the four battery sections are at significantly different SOCs prior to the start of a discharge.

The test shall be performed in the following manner:

- Using P Control (Local Control) with a -8MW P set point, the BESS shall charge at 8MW and unity PF, automatically scaling back as it nears full charge, until the SOC reaches 100% (or a level considered to be equivalent to a complete charge as defined by LG).
- After an optional rest (P Control off and Maintain SOC on) of up to 1 hour, shut down the PCSs for battery sections 2, 3, and 4. Only the PCS for battery section 1 shall be online.
- Using P Control (Local Control) with an 8MW P discharge set point, the BESS shall discharge at maximum power possible with battery section 1.
- Stop the discharge once battery section 1 reaches 97% SOC. Start the PCSs for battery sections 2, 3, and 4. All PCSs shall be online.
- After an optional rest of up to 30 minutes, using P Control (Local Control) with a 4MW P discharge set point, the BESS shall discharge at maximum power possible until the four battery sections are within 1% SOC of each other, and then discharge at 4MW until the SOC reaches 1.5% (or a level considered to be equivalent to a complete discharge as defined by LG).

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST PLANS FOR EMS TESTS

TEST 1, STEADY STATE VOLTAGE REGULATION (DAY 8)

The purpose of this test is to verify that the BESS can provide up to 4MVAr of reactive power injection/absorption to maintain the Monolith 66kV bus voltage within +/- 5%, while also exchanging real power as needed to maintain the battery SOC throughout the test. Active and reactive power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s), and voltage measurements will be obtained by the 66kV Janitza PQM.

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC.
- Using Test 1 (EMS Test) with a 66kV V set point, the BESS shall provide up to 4MVAr of reactive power injection/absorption, and shall maintain the Monolith 66kV bus voltage within +/- 5% for at least 6 hours.

The 66kV bus voltage tolerance may be exceeded only if the BESS is operating at its maximum reactive power capacity of 4MVAr, and 4MVAr is still not sufficient to maintain the voltage within the tolerance. The BESS shall also exchange real power as needed to maintain the battery SOC within +/- 1% of the SOC at the start of the test.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST 2, STEADY STATE VOLTAGE REGULATION UNDER ANY MODE, AND TEST 3, CHARGE DURING HIGH LINE LOAD/DISCHARGE DURING LOW LINE LOAD (DAY 9)

The purpose of this test is to verify that the BESS can charge during periods of high line loading and discharge during periods of low line loading, while concurrently providing up to 4MVAr of reactive power injection/absorption to maintain the Monolith 66kV bus voltage within +/- 5%. The BESS should also exchange real power as needed to maintain battery SOC during periods of inactivity. Active and reactive power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s), and voltage measurements will be obtained by the 66kV Janitza PQM.

NOTE: Test 2 is not explicitly selected on the SEC EMS Test screen like Test 1, Test 3, Test 4, or Test 5. Instead, Test 2 (which provides voltage regulation and may be operated in conjunction with one of the other tests) is enabled by turning on the V Control selection on the Reference screen.

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC.
- In addition to Section 4, Test Prerequisites, set the following on the Reference screen:
  - I_Calc_Lim1 = 646
  - I_Calc_Lim2 = 610
  - I_Calc_Lim1_Lower = 320
  - I_Calc_Lim2_Lower = 300
  - I_Limit_Lower_Deadband = 10
  - I_Limits_Deadband = 10
  - T_Lim = 80
  - I_Line1_Lim1 = 486
  - I_Line1_Lim2 = 450
  - I_Line1_Lim1_Lower = 200
  - I_Line1_Lim2_Lower = 180
- Set the following on the EMS Test screen:
  - I_Line1_Act [A] = 490
  - I_Line2_Act [A] = 0
  - T_Act [F] = 70
  - I_Line1_Act_Coef = 1
  - I_Line2_Act_Coef = .31
- Using Test 3 (EMS Test), the BESS shall provide up to 4MVAr of reactive power injection/absorption, and shall maintain the Monolith 66kV bus voltage within +/- 5%.
- Set the following in succession on the EMS Test screen. Wait at least five minutes after each setting, and then record the actual behavior.

Step	Setting	Expected Behavior
1	I_Line1_Act = 477	System charges
2	I_Line1_Act = 449	System maintains SOC
3	T_Act = 90	System maintains SOC
4	I_Line1_Act = 439	System maintains SOC
5	I_Line1_Act = 437	System maintains SOC
6	I_Line2_Act = 562	System charges
7	I_Line2_Act = 547	System charges
8	I_Line2_Act = 500	System maintains SOC
9	T_Act = 70	System maintains SOC

10	I_Line2_Act = 678	System charges
11	I_Line2_Act = 646	System charges
12	I_Line2_Act = 600	System maintains SOC
13	I_Line2_Act = 0	System maintains SOC
14	I_Line1_Act = 201	System discharges
15	I_Line1_Act = 199	System discharges
16	I_Line1_Act = 208	System discharges
17	I_Line1_Act = 210	System discharges
18	T_Act = 90	System discharges
19	I_Line1_Act = 179	System discharges
20	I_Line1_Act = 188	System discharges
21	I_Line1_Act = 200	System discharges

The BESS shall charge, discharge, and maintain SOC per the expected behavior above, and the Test 3 algorithm in Section 6.7 of the Tehachapi Wind Energy Storage Project Control and Interface Concept document (3AUP080A108-V1, revision TBD). The 66kV bus voltage tolerance may be exceeded only if the BESS is operating at its maximum reactive power capacity of 4MVAr, and 4MVAr is still not sufficient to maintain the voltage within the tolerance. The BESS shall also exchange real power as needed to maintain battery SOC within +/- 1% of the SOC at the start of a maintain SOC period.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST 2, STEADY STATE VOLTAGE REGULATION UNDER ANY MODE, AND TEST 4, CHARGE OFF-PEAK/DISCHARGE ON-PEAK (DAY 10)

The purpose of this test is to verify that the BESS can discharge during on-peak periods and charge during off-peak periods, while concurrently providing up to 4MVAr of reactive power injection/absorption to maintain the Monolith 66kV bus voltage within +/- 5%. The BESS shall also exchange real power between on/off-peak periods as needed to maintain battery SOC. Active and reactive power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s), and voltage measurements will be obtained by the 66kV Janitza PQM.

NOTE: Test 2 is not explicitly selected on the SEC EMS Test screen like Test 1, Test 3, Test 4, or Test 5. Instead, Test 2 (which provides voltage regulation and may be operated in conjunction with one of the other tests) is enabled by turning on the V Control selection on the Reference screen.

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC.
- In addition to Section 4, Test Prerequisites, set the following on the Reference screen:
    - P Charge [kW] = -4000
    - P Discharge [kW] = 4000
    - Off Peak Period = Mo-Fr 0900-1200
    - On Peak Period = Mo-Fr 1300-1600

NOTE: The Off Peak and On Peak periods may be adjusted to accommodate actual test times, as long as the two periods are at least three continuous hours each, with a continuous one hour break between.

- Using Test 4 (EMS Test), the BESS shall provide up to 4MVAr of reactive power injection/absorption, and shall maintain the Monolith 66kV bus voltage within +/-5%.

The BESS shall charge at 4MW from 9:00 to 12:00, maintain SOC from 12:00 to 13:00, and discharge at 4MW from 13:00 to 16:00. The 66kV bus voltage tolerance may be exceeded only if the BESS is operating at its maximum reactive power capacity of 4MVAr, and 4MVAr is still not sufficient to maintain the voltage within the tolerance. The BESS shall also exchange real power between on/off-peak periods (inter-on/off-peak period) as needed to maintain battery SOC within +/- 1% of the SOC at the start of the inter-on/off-peak period.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST 2, STEADY STATE VOLTAGE REGULATION UNDER ANY MODE, AND TEST 5, CHARGE AND DISCHARGE AS NEEDED FOR GRID PURPOSES (DAY 11)

The purpose of this test is to verify that the BESS can charge and discharge as needed for grid purposes by accurately following wind turbine generation data. Whenever wind power quickly increases or decreases, the BESS will charge or discharge in the opposite direction to cancel out the non-compliant power ramp. This test will also verify that the BESS can concurrently provide up to 4MVAr of reactive power injection/absorption to maintain the Monolith 66kV bus voltage within +/- 5%. Active and reactive power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s), and voltage measurements will be obtained by the 66kV Janitza PQM.

NOTE: Test 2 is not explicitly selected on the SEC EMS Test screen like Test 1, Test 3, Test 4, or Test 5. Instead, Test 2 (which provides voltage regulation and may be performed in conjunction with one of the other tests) is enabled by turning on the V Control selection on the Reference screen.

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC.
- In addition to Section 4, Test Prerequisites, set the following on the Reference screen:
    - P_WT_Act Allowed Ramp + [kW/sec] = 17
    - P_WT_Act Allowed Ramp - [kW/sec] = 17
- Set the following on the EMS Test screen:
    - P_WT_Act [MW] = 1000
    - P_WT_Act_Coef = 1
- Using Test 5 (EMS Test), the BESS shall provide up to 4MVAr of reactive power injection/absorption, and shall maintain the Monolith 66kV bus voltage within +/- 5%.
- Set the following in succession on the EMS Test screen and then record the actual behavior.

Step	Setting	Expected Behavior
1	P_WT_Act [MW] = 1005	System follows P ramp and charges at approximately 5MW, and then ramps to 0MW over approximately five minutes
2	P_WT_Act [MW] = 995	System follows P ramp and discharges at 8MW for two minutes, and then ramps to 0MW over approximately eight minutes
3	P_WT_Act [MW] = 1000	System follows P ramp and charges at approximately 5MW, and then ramps to 0MW over approximately five minutes
4	P_WT_Act [MW] = 1010	System follows P ramp and charges at 8MW for two minutes, and then ramps to 0MW over approximately eight minutes
5	P_WT_Act [MW] = 1003	System follows P ramp and discharges at approximately 7MW, and then ramps to 0MW over approximately seven minutes
6	P_WT_Act [MW] = 1000	System follows P ramp and discharges at approximately 3MW, and then ramps to 0MW over approximately three minutes

- Repeat the sequence at least five additional times.

The BESS shall charge and discharge per the expected behavior above. The 66kV bus voltage tolerance may be exceeded only if the BESS is operating at its maximum reactive power capacity of 4MVAr, and 4MVAr is still not sufficient to maintain the voltage within the tolerance.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

EMS–GMS TRANSITION (DAY 12)

The purpose of this test is to verify that the BESS exhibits the expected behavior when transitioning between EMS and GMS operation under different scenarios. Active power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s).

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC.
- In addition to Section 4, Test Prerequisites, set the following on the Reference screen:
    - Maintain SOC Allowed for T4 = Off
    - V Ctrl Selected for T3, T4, or T5 = Off
    - Off Peak Period = Mo-Fr 2359-0001
    - On Peak Period = Mo-Fr 0001-2359
- Set the following on the GMS Test screen:
    - P_GMS_SetPoint [kW*10] = 400
- Using Test 4 (EMS Test), the BESS shall discharge at 8MW.
- Set the following in succession on the indicated screens and then record the actual behavior.

Scenario	**Step**	**Screen**	**Setting**	**Expected Behavior**
EMS running test and GMS idle	1	EMS Test	Non Grid Functions = On	BESS Status Alarm, Maintain SOC on
	2	GMS Test	AGC_Man = On	Same
	3	GMS Test	AGC_Man = Off	Same
	4	EMS Test	Non Grid Functions = Off	BESS Status OK, system discharges at 8MW
EMS and GMS running tests	5	GMS Test	AGC_Man = On	Same
	6	EMS Test	Non Grid Functions = On	BESS Status Alarm, Maintain SOC on
	7	EMS Test	Non Grid Functions = Off	BESS Status OK, system discharges at 8MW
	8	GMS Test	AGC_Man = Off	System continues discharging at 8MW
EMS and GMS idle	9	EMS Test	T4 Start = Off	System idles
	10	EMS Test	Non Grid Functions = On	Same
	11	GMS Test	AGC_Man = On	System discharges at 4MW
	12	GMS Test	AGC_Man = Off	System idles
	13	EMS Test	Non Grid Functions = Off	Same
EMS idle and GMS running test	14	GMS Test	AGC_Man = On	Same
	15	EMS Test	Non Grid Functions = On	System discharges at 4MW
	16	EMS Test	Non Grid Functions = Off	System Idles
	17	GMS Test	AGC_Man = Off	Same

The BESS shall discharge or idle per the expected behavior above.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

EMS AND GMS COMMUNICATION FAULT HANDLING (DAY 12)

The purpose of this test is to verify that the BESS exhibits the expected behavior when encountering EMS and GMS communication faults under different scenarios. Active power measurements will be obtained by the 12.47kV Janitza PQMs and/or data logger(s).

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC.
- In addition to Section 4, Test Prerequisites, set the following on the Reference screen:
  - Fully Charge BESS = On
  - Maintain SOC Allowed for T4 = Off
  - V Ctrl Selected for T3, T4, or T5 = Off
  - Off Peak Period = Mo-Fr 2359-0001
  - On Peak Period = Mo-Fr 0001-2359
- Set the following on the Control Mode screen:
  - SEC Control Point Selection = Remote
  - P Control = On
- Set the following on the GMS Test screen:
  - AGC_Man = On
  - P_GMS_SetPoint [kW*10] = 400
- Using Test 4 (EMS Test), the BESS shall discharge at 8MW.
- Set the following in succession on the indicated screens. Wait a maximum of five minutes after each setting and then record the actual behavior.

Scenario	Step	Screen	Setting	Expected Behavior
EMS running test with EMS comm. Fault	1	EMS Test	Stop EMS Test Heartbeat = On	EMS Communication Fault, BESS Status Alarm, Allow Local Control Actual Value Yes, system idles
	2	EMS Test	Stop EMS Test Heartbeat = Off	EMS Communication OK, BESS Status OK, Allow Local Control Actual Value No, system discharges at 8MW
EMS running test with GMS comm. fault	3	GMS Test	Stop GMS Test Heartbeat = On	GMS Communication Fault, system continues discharging at 8MW
	4	GMS Test	Stop GMS Test Heartbeat = Off	GMS Communication OK, system continues discharging at 8MW
GMS running test with GMS comm. fault	5	EMS Test	T4 Start = Off	System idles
	6	EMS Test	Non Grid Functions = On	System discharges at 4MW
	7	GMS Test	Stop GMS Test Heartbeat = On	GMS Communication Fault, BESS Status Alarm, Maintain SOC on
	8	GMS Test	Stop GMS Test Heartbeat = Off	GMS Communication OK, BESS Status OK, system discharges at 4MW
GMS running test with EMS comm. fault	9	EMS Test	Stop EMS Test Heartbeat = On	EMS Communication Fault, BESS Status Alarm, Allow Local Control Actual Value Yes, system idles
	10	EMS Test	Stop EMS Test Heartbeat = Off	EMS Communication OK, BESS Status OK, Allow Local Control Actual Value No, system continues discharging at 4MW

The BESS shall discharge and idle per the expected behavior above.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST PLAN FOR GMS TESTS

MANUAL AND ISO POWER DISPATCH (DAY 12)

The purpose of this test is to verify that the BESS can dispatch active power using GMS commands. Active power measurements will be obtained by the 12.47kV Janitza PQMs.

The test shall be performed in the following manner:

- The BESS shall begin the test at approximately 50% SOC.
- Using AGC_Man (GMS Test) with an 8MW P GMS Set Point, the BESS shall discharge at 8MW for ten minutes.
- Using AGC_Man (GMS Test) with a -8MW P GMS Set Point, the BESS shall charge at 8MW for ten minutes.
- Using AGC_ISO (GMS Test) with a 4MW P ISO AGC Set Point, the BESS shall discharge at 4MW for ten minutes.
- Using AGC_ISO (GMS Test) with a -4MW P ISO AGC Set Point, the BESS shall charge at 4MW for ten minutes.

Test Date	Completed (Y/N)	Completed by (Initials)	Recorded Test Data File Name	Test Note ID (Fill in reference to the notes in Appendix A – Test notes)

TEST REVIEW (DAYS 13 AND 14)

Days 13 and 14 are reserved for reviewing and organizing test results, and for completing any necessary retests.

APPENDIX A – TEST NOTES

FILL IN NOTE ID -
NOTE:

FILL IN NOTE ID -
NOTE:

FILL IN NOTE ID -
NOTE:

9.10 Appendix I: Glossary of Abbreviations

ACE	Area Control Error
ADS	Automatic Dispatch Signal
AGC	Automatic Generation Control
ARRA	American Reinvestment & Recovery Act
BBMS	Bank Battery Management System
BESS	Battery Energy Storage System
BMS	Battery Management System
BPU	Battery Protection Unit
BSC	Battery Section Controller
CAISO	California Independent System Operator
CSWE	Current Sensor Wire Error
DAS	Data Acquisition System
DFR	Digital Fault Recorder
DOE	Department of Energy
eDNA	Corporate Depository of Electrical Measurements
EKWRA	Eastern Kern Wind Resource Area
EMS	Energy Management System
EPM	Energy Procurement Management (SCE)
GWh	Gigawatt-hour
GMS	General Management System
GUI	Graphical User Interface
Hz	Hertz
HVAC	Heating Ventilation Air Conditioning
I&CS	Interoperability and Cyber Security Plan
IR	Interconnection Request
kV	Kilovolt
kVA	Kilovolt Ampere
kVAr	Kilovolt Ampere Reactive
kWh	Kilowatt-hour
M&V	Measurement and Validation
MBMS	Module Battery Management System
MBRP	Metrics and Benefits Reporting Plan
MP	Measuring Point
MVA	Megavolt Ampere
MVAr	Megavolt Ampere Reactive
MW	Megawatt
MWh	Megawatt-hour
PF	Power Factor
PMU	Phasor Monitoring Unit
PPS	Protective Power Sharing
PQM	Power Quality Meter
PSLF	Positive Sequence Load Flow
QC	Queue Cluster or Quality Control

RA	Resource Adequacy
RAS	Remedial Action Scheme
RIG	Remote Intelligent Gateway
RBMS	Rack Battery Management System
RTDS	Real Time Digital Simulator
SAT	System Acceptance Test
SCADA	Supervisory Control and Data Acquisition
SCE	Southern California Edison
SEC	Site Energy Controller
SFM	Schedule Follow Mode
STATCOM	Static Synchronous Compensator
T&D	Transmission and Distribution
TPR	Technology Performance Report
TSP	Tehachapi Wind Energy Storage Project
V	Volt
Vac	Volt Alternating Current
Vdc	Volt Direct Current
WECC	Western Electric Coordinating Council