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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

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- Transportation

This is the final report for *Advanced Energy Storage Systems for Enabling California's Smart Grid,* (contract number 500-09-027) conducted by Pacific Gas and Electric Company. The information from this project contributes to Energy Research and Development Division's Energy Technology Systems Integration program area.

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ABSTRACT

Pacific Gas and Electric Company designed and installed two sodium-sulfur battery energy storage systems at two different sites – their Vaca-Dixon Substation and the industrial Hitachi Global Storage Technologies facility (now HGST) facility in San Jose, California. This report documents the project team's experience in connecting these two systems to California's electric grid and testing their ability to provide grid support. The report includes an overview of the design of each battery system, battery testing results, and recommendations from the project team for deploying future battery energy storage projects.

The battery energy storage system at the Vaca-Dixon Substation provided ancillary services in California Independent Sytem Operator markets, and was tested for its ability to manage intermittent renewables from the nearby Vaca-Dixon Solar Station.

The Yerba Buena battery energy storage system at HGST's San Jose facility enhanced power reliability for customers served by the utility distribution circuit serving that facility. The battery system also allowed the HGST facility to be fully powered by the battery system in the event of an outage. Using the battery system to provide backup power helps reduce emissions from the diesel backup generator that would normally be operated during an outage. Battery capacity was also allocated to provide peak shaving that reduced electric feeder loading during high demand periods. Additional battery capacity was allocated to provide ancillary services in California Independent System Operator markets, but was not yet providing these services at the time of this report.

Keywords: Energy storage, sodium-sulfur, NaS, battery energy storage system, BESS, Vaca-Dixon battery, Yerba Buena battery

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EXECUTIVE SUMMARY

Introduction

Energy storage technologies have the potential to increase the reliability and dispatchability of California's energy supply. While wind and solar power plants help California to generate energy with little detriment to the environment, the intermittent and power-fluctuating nature of these resources require special attention when connecting them to the grid. Building a portfolio of energy storage options could help address these system challenges and balance the development of newer, distributed energy technologies with the continued development of well-established generation technologies.

Project Purpose

This report documents Pacific Gas and Electric Company's (PG&E) experience in connecting two sodium-sulfur (NaS) battery energy storage systems to California's electric grid and the subsequent testing and assessment of the ability of these systems to provide additional grid support functions under a contract with the California Energy Commission (Energy Commission). Included in this report are an overview of the two battery systems, summaries and results of the battery tests, lessons learned during implementation, and recommendations for deploying future battery energy storage projects based on the experience of the project team.

The NaS battery energy storage system (BESS) manufactured by Nichiyu Giken Kogyo Co. (NGK) Insulators of Japan is one of the most advanced battery storage technologies on the market because it has a high efficiency and long life span. PG&E deployed a two-megawatt (MW) BESS at its Vaca-Dixon Substation and a 4 MW BESS at the HGST facility in San Jose.

PG&E's Vaca-Dixon Substation is in close proximity to the Vaca-Dixon Solar Station. The solar station is capable of generating approximately 2.5 MW of peak power. Testing of the 2 MW BESS demonstrated the use of energy storage at the substation level to manage the intermittent and fluctuating generation from the solar station. The BESS will also be used to provide grid ancillary services and energy dispatch/storage services depending on customer demand.

The Yerba Buena BESS in San Jose served to enhance power reliability for customers on that circuit, and allowed the HGST facility to be fully powered by the battery – known as "islanding" – in the event of an outage. The use of the BESS system to provide multiple hours of backup power also helped reduce emissions from the facility's diesel backup generator, which would normally be operated during an outage. In addition to these functions, additional battery capacity was allocated to provide ancillary services that help support grid stability, as well as to supply energy in times of high demand and store energy in times of oversupply.

Project Results

Initial Testing

During the three-month testing period, the project team evaluated whether the systems met their specifications, followed programmed test schedules accurately, and determined their round-trip efficiency under a variety of test conditions.

Both systems performed well and met or exceeded their specifications. Both systems exhibited round-trip efficiencies of between approximately 73 percent and 79 percent, with efficiency measurements highly dependent on discharge power level, time of discharge, and time period during which battery was idle. Both systems performed safely and had 100 percent reliability (no unplanned outages) during these tests.

Technical Assessments

The project team conducted battery performance tests for a variety of functions. The following sub-sections provide a brief summary of the results.

Performance of the Yerba Buena BESS for Load Shaping and Power Quality:

PG&E performed tests to gather data to evaluate impacts from the Yerba Buena BESS. The results showed that the BESS simultaneously decreased peak load and potentially contributed to reduced system losses.

Power Quality Results for Current and Voltage Harmonics:
The test results showed that the BESS operated within acceptable current and voltage harmonic limits based on the electric industry standards and thus, meets PG&E's system operational standard requirements.

Performance of the Yerba Buena BESS for Reliability Enhancement:
The islanding function for the Yerba Buena BESS was tested under a number of scenarios to verify that the BESS could provide power following the loss of power on the utility circuit. The BESS successfully islanded the customer loads, but the transition from utility power to battery power may take longer when the battery is idle (neither charging nor discharging).

Islanding Experience Since Initial Testing:
The system successfully islanded customer loads numerous times under various conditions and for several sustained utility power outages. The goal for the Yerba Buena BESS was to quickly transition to a fully stable electrical island following detection of a utility power disturbance because even a very brief interruption in power caused problems for some equipment at HGST. The project team tuned the control settings to provide the most protection with a minimum of "nuisance islanding" events. Nuisance islanding is a term coined to describe those events that are very transient in nature that may not have been noticed by the HGST facility had the system not entered island mode. The result was a significant decrease in nuisance islanding.

Assessment of Yerba Buena BESS for Renewable Resource Integration:

PG&E conducted a simulation using historical solar PV output from the 2.5 MW solar PV system located at the Vaca-Dixon Substation combined with the BESS output to generate 4 MW over a six-hour duration. Another test combined a simulated solar PV output with the BESS output to generate 2 MW over a 10-hour duration. Overall, the simulation test showed that the combined BESS and solar PV output could generate the desired 2 MW output over 10 hours and effectively smooth the solar PV power.

For purposes of analyzing the effect of integrating wind energy with the Yerba Buena BESS, historical power output from the 18 MW Diablo Wind plant was taken and supplied as an input to the BESS so that the wind plant and BESS outputs could be combined into a desired smoothed output power to the utility. The results showed that the combined wind and BESS output effectively produced the desired smoothed output power.

In conclusion, the BESS was effective at smoothing renewable resources such as solar PV and wind energy.

Assessment of Vaca-Dixon BESS for Providing Ancillary Services in California ISO Markets:

The performance of the Vaca-Dixon BESS and the Yerba Buena BESS were evaluated for their ability to provide ancillary services in California Independent System Operator (California ISO) markets. Its findings included:

- Initial test data indicated that each of the BESS facilities have an on-site response of less than one second to go from one power level to another power level, within its capacity power and energy level limits. This time response capability is extremely fast when compared to any fossil, hydroelectric, or nuclear plant.
- When following California ISO signals to control the Vaca-Dixon BESS, and accounting for the time delay associated with existing California ISO/PG&E communications, the response time of the Vaca-Dixon BESS facility is less than one second. This time response capability is also extremely fast when compared to any fossil, hydroelectric, or nuclear plant.

Overall, the Vaca-Dixon BESS and the Yerba Buena BESS worked well and analysis of field test data showed that both systems can provide the following types of California ISO ancillary services:

a) Regulation-Up and Regulation-Down

b) Spinning Reserve

c) Non-Spinning Reserve

d) Voltage Support

The only California ISO ancillary service not included above is the black start ancillary service, which was not specified or built into the design for either BESS.

Technology Transfer Activities

Technology transfer activities throughout the course of this project consisted of tours, presentations, and other information-sharing events designed to inform the general public, project stakeholders, industry representatives, and key decision makers about the objectives and status of the Vaca-Dixon and Yerba Buena battery storage projects.

Overcoming Obstacles: Lessons Learned

The following items are the key challenges and lessons learned from this project:

- Organizational Challenges
  - Developing new roles and responsibilities for operating energy storage assets.
  - Addressing concerns about unfamiliar technology among utility personnel.
  - Complexities of a system sited at a third-party customer location.
  - Need for single project integrator to manage maintenance and repair processes.
  - Need for flexibility in contracts to allow for incorporating lessons learned during the process of system design and installation.
- Technological Challenges and Lessons Learned
  - Need to develop new communications and control pathways, hardware, and software to efficiently battery storage resources.
  - Higher than expected equipment failure rates, particularly in power conversion equipment, causing project delays.
  - Maintenance complexities requiring new processes and procedures for equipment repairs.
  - Unique safety risks and mitigation needs arising from possibility of a system fire.
- Financial Challenges and Lessons Learned
  - Significant parasitic loads and efficiency losses
  - Significant "hidden" costs, such as maintenance support, spare parts, and service contracts.
  - No market for many energy storage functionalities.
  - Need for greater clarity in financial and regulatory accounting for energy storage.

The project team worked to address these challenges and extensive lessons learned are documented in Chapter 5 of this report.

Project Benefits

This project provides benefits to the public in multiple ways:

- Technologies, procedures, organizational roles and responsibilities, and other innovations developed for this project will enable more cost-effective deployments of energy storage in the future.
- Data and lessons learned helped inform new storage procurements underway at PG&E in response to the California Utility Commission's Assembly Bill 2514 (Skinner, Chapter 469, Statutes of 2010) (AB 2514), instructing California utilities to procure over one gigawatt of storage over the next six years.
- This project validated that battery technology is effective at smoothing intermittent renewables and providing ancillary services in California ISO markets, both of which are important to providing grid stability as more renewable generation is connected to California's electric grid to meet its aggressive renewable portfolio goals.
- This project validated that battery technology is effective at maintaining a microgrid, which could be an important part of making the electric grid more reliable and resilient when normal utility power is unavailable.

CHAPTER 1: Overview

1.1 The Value of Energy Storage

The California electricity grid is continually changing in its scope and requirements as load, generation, distribution, and transmission metrics change over time. Until recently, California's electric grid was of limited complexity, with unidirectional energy flow from California electric utilities to California customers—almost entirely supported by centralized generation via large fossil-fueled, nuclear, and hydroelectric power plants. In the 21st century, distributed energy production and delivery infrastructures have become a growing part of grid infrastructure, creating new challenges for grid operators to maintain system stability and reliability.

California's utilities, regulators, industry stakeholders, and general public are increasingly looking to energy storage and its potential to address a range of technical and economic challenges facing the electric industry. The need to economically serve uncertain peak load growth and the increasing and large amount of renewable generation (principally from wind and solar), along with the need to improve grid reliability and resilience, have presented large opportunities for energy storage technologies in California.

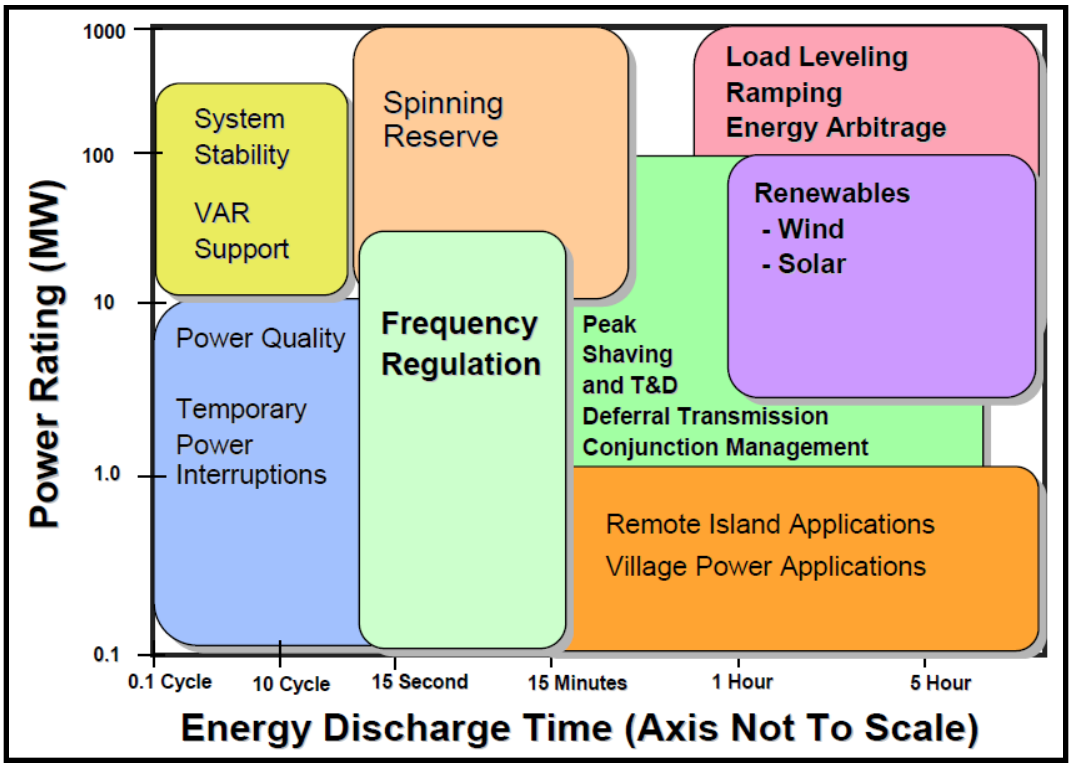
Widespread use of energy storage technologies will require a coordinated effort from technology developers and California utilities to ensure that such systems are designed to adequately address the needs of utilities, grid operators, project developers, and ratepayers. Energy storage systems may be large or small, centrally located or distributed, owned by end users or utilities, and provide a range of system and customer benefits. Figure 1 from the Electric Power Research Institute (EPRI) shows representative energy storage use cases characterized by the megawatt (MW) power rating of an energy storage plant versus its duration of plant discharge level, while Figure 2 illustrates the diversity of energy storage siting possibilities within the current California electric grid infrastructure.

Many technologies can store energy, including conventional lead-acid batteries, advanced batteries (such as a sodium-sulfur battery), super-capacitors, flywheels, pumped hydroelectric storage, and compressed air energy storage plants. In essence, different energy storage plants are appropriate for different needs, MW scales, discharge durations, locations, and applications.

1.2 Sodium-Sulfur Battery Technology

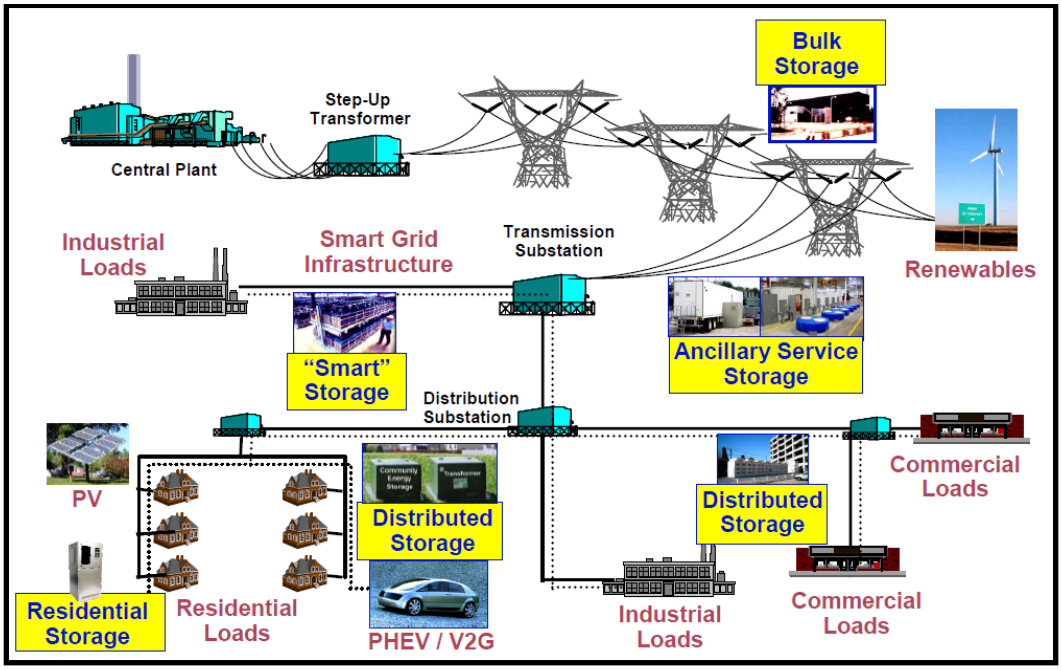
Sodium-sulfur (NaS) batteries are a commercial energy storage technology finding applications in electric utility distribution grid support, wind power integration, and high-value service applications on electric grid islands. NaS batteries employ molten sulfur as the positive electrode and molten sodium as the negative electrode, separated by a beta-alumina solid electrolyte, which acts as the medium to transfer Na ions in the battery. Operating temperatures for this type of battery are in the range of 570°F (300°C) to 660°F (350°C). The estimated life of a NaS battery is approximately 12 to 15 years when this type of battery experiences 4500 cycles at 90 percent depth of discharge.

Figure 1: Overview of Energy Storage Use Cases



Source: EPRI

Figure 2: Overview of Siting for Energy Storage Applications



Source: EPRI

The sodium-sulfur battery technology was jointly developed by NGK Insulators Ltd. and Tokyo Electric Power Company over the past 25 years. "NAS" is a registered trademark for NGK's sodium-sulfur battery system, even though "NaS" is a generic term for sodium-sulfur chemistry based on those elements' atomic symbols ("Na" and "S"). NGK currently offers NAS batteries in multiples of 1 MW/6 MWh units, with installations typically having a MW capacity level in the range of 2 to 10 MW. The largest single installation of this type of battery is the 34 MW Rokkasho wind-stabilization project in northern Japan that has been operational since August 2008. More than 300 MW of NAS batteries have been deployed globally, including those in the Japan, United States, Abu Dhabi, Germany, and France. In addition to the Pacific Gas and Electric Company (PG&E), customers in the United States include American Electric Power (AEP), Xcel Energy, New York Power Authority (NYPA), and Southern California Edison.

1.3 Project Purpose

Energy storage systems have the potential to improve the reliability and efficiency of electric delivery by providing power as needed to help balance peak loads, control the increasing costs of grid infrastructure equipment, and mitigate the intermittent nature of many types of renewable generation, such as wind and solar. Improvements and advances have been made to several types of electric energy storage technologies. However, electric utilities need more information and data about the use and value of electric energy storage systems before they can be in a position to confidently adopt such systems in sufficient quantities to bring cost-effective benefits to customers. For example, additional information and data are needed in the following areas:

- Applications to support distribution system capacity expansion and reliability.
- Applications to support energy management and renewable power optimization.
- The economic value of electric energy storage systems and how best to value and monetize their economic value in California energy markets.

The California Energy Commission's (Energy Commission's) Public Interest Energy Research Program funded projects to meet the need for relevant, real-world tests and data to advance the use and value of electric energy storage systems in California. To enable the full value of electric energy storage options to be realized in California, the Energy Commission funded projects involving field demonstration and monitoring, test and evaluation, costs and benefit assessment, and technology transfer.

One such demonstration is PG&E's Yerba Buena (Y-B) project, a 4 MW/27.8 MWh NaS battery energy storage system (BESS) deployed at the HGST Research and Development facility in San Jose, California near PG&E's Swift Substation. Owned and operated by PG&E, this BESS was designed to test the feasibility of achieving three major goals:

- Improve service reliability and power quality to electric customers.
- Support energy management through load shaping and participate in the California ISO energy and ancillary services markets.

- Leverage battery energy storage to increase renewables penetration and displace conventional generation currently used to integrate intermittent renewable plants (such as wind and solar).

1.4 Project Participants

The key participants in this project are PG&E, HGST[1], NGK Insulators, Ltd. (NGK), S&C Electric Company (S&C), EPRI, and the Energy Commission.

PG&E, a subsidiary of the PG&E Corporation, is one of the largest combined natural gas and electric utilities in the United States. Based in San Francisco, the company delivers energy to about 15 million people in Northern and Central California. For more information about PG&E, visit the following websites; www.pge.com and www.pgecurrents.com.

HGST is a high-tech company that develops advanced hard disk drives, solid state drives, external data storage solutions, and services to store, preserve, and manage critical data. It leases land and buildings on Yerba Buena Road in San Jose. The battery system is located adjacent to the HGST facility.

NGK, established in 1919 and headquartered in Japan, is a leading manufacturer and vendor of electric-power-related equipment including electric insulators, industrial ceramic and beryllium copper products, and engineering electric grid plant engineering services. NGK is also the world's primary supplier of sodium-sulfur battery plants. For more information on this company, see www.ngk.co.jp.

S&C is a global provider of equipment and services for electric power distribution and transmission systems. Founded in 1911, this Chicago-based company designs and manufactures switching and protection products for electric power transmission and distribution grid systems. Visit www.sandc.com for information on this company.

EPRI conducts research, development, and demonstration projects relating to the generation, delivery, and use of electricity for the benefit of the public. As an independent nonprofit organization, EPRI brings together scientists and engineers as well as experts from academia and the industry to help address and resolve challenges and/or technical issues in the electricity infrastructure industry.

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1 The company occupying the facility has changed names and ownership several times during the course of the project. The company's current name is HGST, with no relation to the company Hitachi. However, it previously was affiliated with Hitachi and called "Hitachi Global Storage Technologies." Therefore, various project documents refer to the facility as "Hitachi"or HGST.

The Energy Commission is the state's primary energy policy and planning agency. Established by the Legislature in 1974 and located in Sacramento, seven core responsibilities guide the Energy Commission as it sets California energy policy:

- Forecasting future energy needs.
- Promoting energy efficiency and conservation by setting the state's appliance and building energy efficiency standards.
- Supporting energy research that advances energy science and technology through research, development and demonstration projects.
- Developing renewable energy resources.
- Advancing alternative and renewable transportation fuels and technologies.
- Certifying thermal power plants 50 MW and larger.
- Planning for and directing state response to energy emergencies.

CHAPTER 2:
Vaca-Dixon BESS and Yerba Buena BESS Project Histories

The original project objective was to deploy a 6 MW/42 MWh NaS BESS and its associated equipment at a selected distribution system site. This included the installation of three, 2 MW NaS battery modules in enclosures and racks with supporting wiring; one power conditioning system building with inverter, switches, and monitoring equipment; an electric wired bus extension to the existing distribution customer substation with a transformer, switches, and protective equipment; and one power electronic transfer switch to enable site islanding.

The original schedule was for successful deployment to be completed by November 2010. PG&E evaluated six potential distribution sites (four customer-owned sites, one general distribution feeder site, and one PG&E-owned substation site) to determine the most appropriate location for a NaS BESS installation. The cost of installation was about the same for all six sites.

The site selection criteria included assessment of reliability and power quality benefits (from historical data and interviews with major customer account representatives), space availability, connectivity characteristics, and environmental and other considerations.

The assessment identified the Hitachi Global Storage Technologies facility (now HGST), located on Yerba Buena Road in San Jose, CA, and the Vaca-Dixon Substation as the most suitable sites to deploy a 6 MW NaS BESS. The HGST facility is a high profile research and development facility located at the end of PG&E's Swift 2102 circuit, with a high level of distribution system exposure and historical reliability and power quality issues. The Vaca-Dixon (V-D) site was chosen because of its proximity to the 2.5 MW Vaca-Dixon Solar Station and available space and transformer bank tie-ins at the Vaca-Dixon Substation. The decision was made to deploy a 2 MW/13.9 MWh NaS BESS at the Vaca-Dixon Substation and 4 MW/ 27.8 MWh NaS BESS at the Y-B site.

2.1 Vaca-Dixon BESS

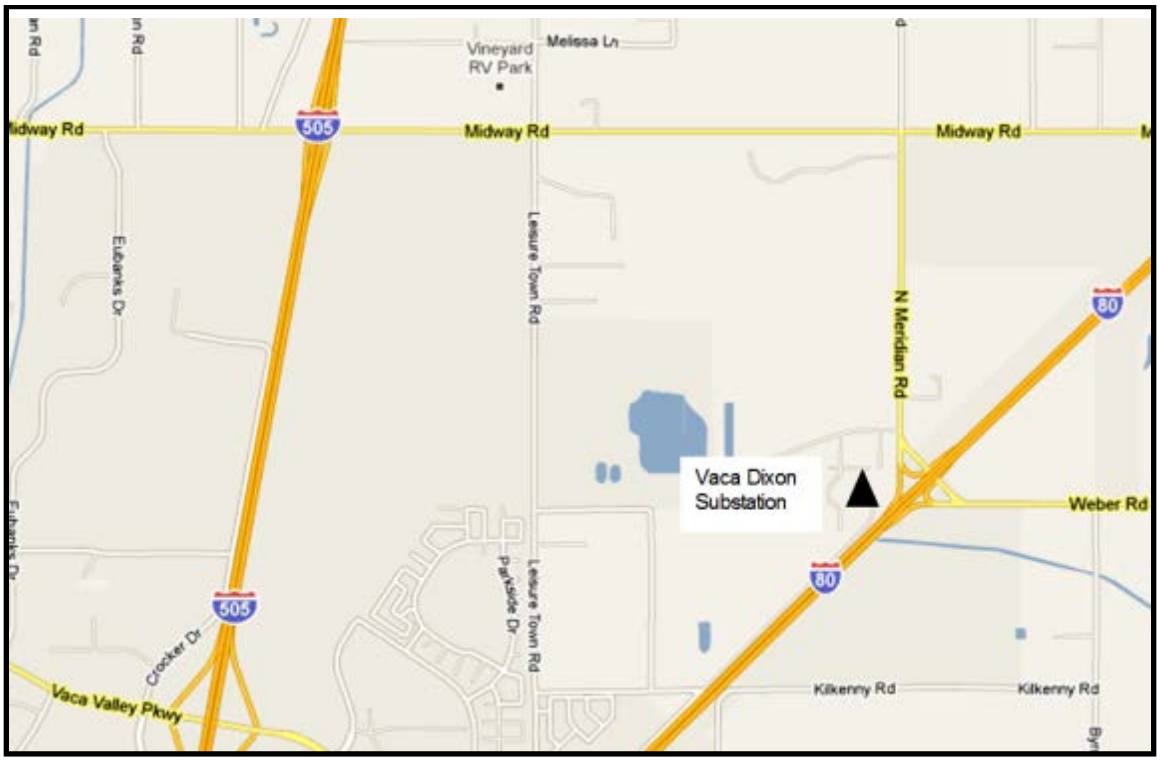
An Engineer-of-Record Report was completed for the V-D BESS under Task 2 of this project; its key information is summarized below.

On November 8, 2010, PG&E approved a capital expenditure of $10.5 million to carry out the V-D project. This project authorization was to be used for permitting, engineering and design, material procurement, and construction activities for the project. Engineering, material procurement, and construction were to be performed by entities external to PG&E. The V-D BESS was originally scheduled to be released to PG&E Electric Operations in July 2011.

2.1.1 Facility Location

PG&E's Vaca-Dixon Substation is located adjacent to Highway 80 between Vacaville, California, west of Sacramento and Dixon, California (Figure 3). The Vaca-Dixon Substation is a key substation on the 500 kV transmission system backbone. In addition, the Vaca-Dixon Substation is located near the Vaca-Dixon Solar Station, which generates up to 2.5 MW of solar photovoltaic (PV) power. There are also several wind turbine generators operating near the Vaca-Dixon Substation.

Figure 3: Vaca-Dixon Substation near Vacaville, California



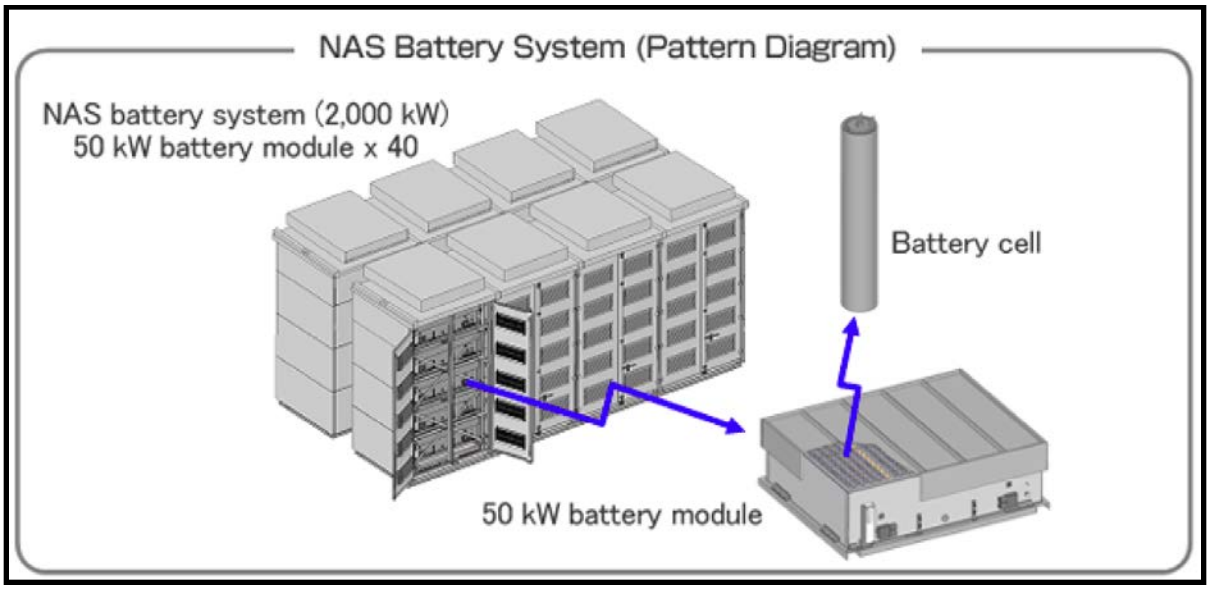
Source: Google Maps

The V-D NaS BESS is comprised of the batteries themselves, a storage management system that controls power flow to and from the battery modules, a transformer through which the BESS is interconnected to the electric grid, and balance-of-plant equipment. The sub-sections below provide a high-level overview of the NaS BESS components.

2.1.2 Sodium-Sulfur Technology

The system has an energy storage rating of approximately 13.9 MWh. Two, 1 MW containers each hold twenty, 50 kW battery modules, for a total of 40 battery modules; each module contains 352 individual NaS cells (Figure 4).

Figure 4: Illustration of NGK BESS



Source: NGK

2.1.3 Storage Management System

S&C provided the "PureWave®" Storage Management System (SMS) that converts alternating current (AC) grid voltage to the direct current (DC) voltage stored by the NaS battery when charging; and then when discharging, converts the battery's DC voltage to the AC grid voltage for the PG&E grid. The intelligent SMS provides power conditioning functions that are critical to the BESS's operation.

2.1.4 Step-Up Transformer

The voltage step-up transformer increases the 480-volt AC power provided by the SMS to 12.47 kilovolt (kV) required by the grid. The transformer includes overcurrent protection via fuses.

Figure 5 is a photo taken at the project site in January 2013. Two, 1 MW NGK NaS batteries are contained in the large containers shown, which are pad-mounted and parallel to each other. The large container on the left facing the two battery module cabinets is the SMS.

2.1.5 Balance-of-Plant

Balance-of-plant components include a voltage step-up transformer, auxiliary transformers, circuit breakers, switches, electric buses, support structures, control equipment, metering equipment, switchgear, and other equipment needed to operate and control the NaS BESS. Other details on this battery plant are provided in Chapter 5.

2.1.6 NGK NaS Battery Fire

In September 2011, the V-D NaS BESS installation was on schedule and on budget. However, later that year NGK informed PG&E that there had been a fire at one of its sodium-sulfur battery installations in Japan. NGK advised its customers to cease operations of their systems,

and advised PG&E not to commission the battery installation at the V-D site until the fire's root cause had been determined and until a determination was made on whether the design, construction and/or operational control modification to the battery modules and/or control system had to be made. PG&E followed this recommendation and halted the project pending the outcome of the NGK investigation.

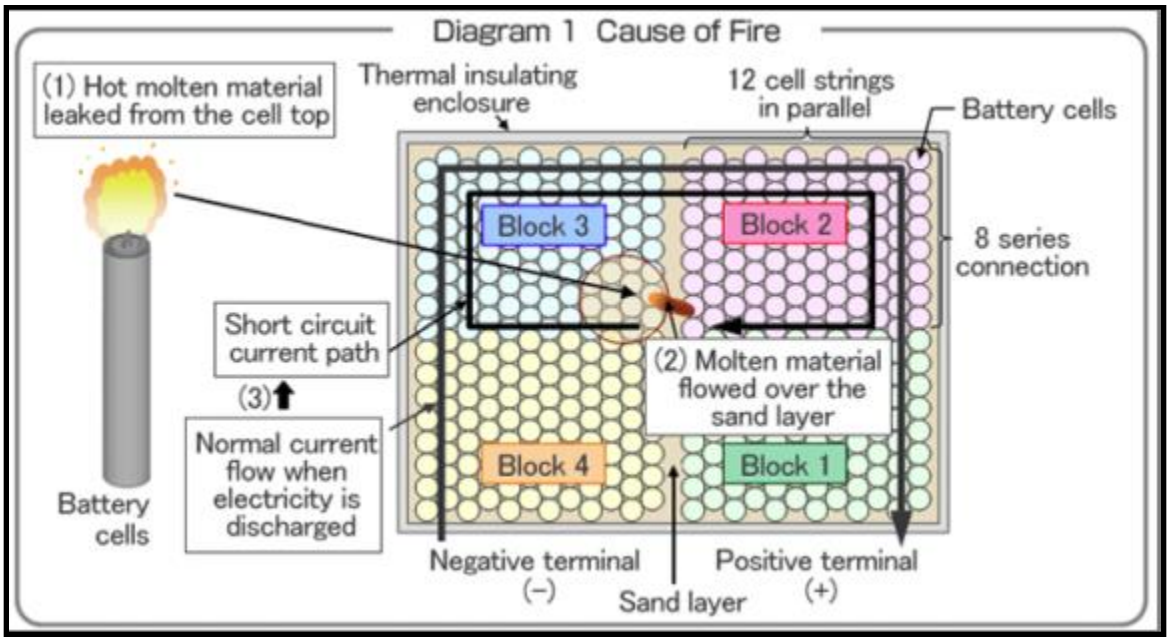
Figure 5: NaS BESS Installed at PG&E's Vaca-Dixon Substation

Photo Credit: David Fribush

In March 2012, NGK notified PG&E that it had located and corrected a design flaw that had led to the fire. In a public briefing dated June 7, 2012, NGK described the cause of the fire as follows (refer to Figure 6):

1. The molten material from a faulty cell flowed over the sand filler portion between blocks inside the battery module, which caused a short between battery cells in an adjoining block.
2. Because there were no fuses installed between the battery cells, the short-circuit current flowed continuously and emitted heat, which destroyed a number of other battery cells that caught on fire. This fire spread to the whole battery module in question.
3. The combustion of the particular battery module released flames and hot molten material melted battery cell casings inside battery modules installed above and below, which caused the fire to spread further.

Figure 6: Cause of Fire



Source: NGK

In that same briefing, NGK described the safety enhancement measures taken to prevent the spread of fire in future NGK NaS battery modules (Figure 7):

1. Fuses will be added between individual batteries in each module to prevent a short-circuit current from causing a fire.
2. Insulation boards will be placed between blocks in each battery module to prevent leaking molten materials from causing a short circuit.
3. Anti-fire boards will be placed between battery modules above and below to prevent fire from spreading to other battery modules.

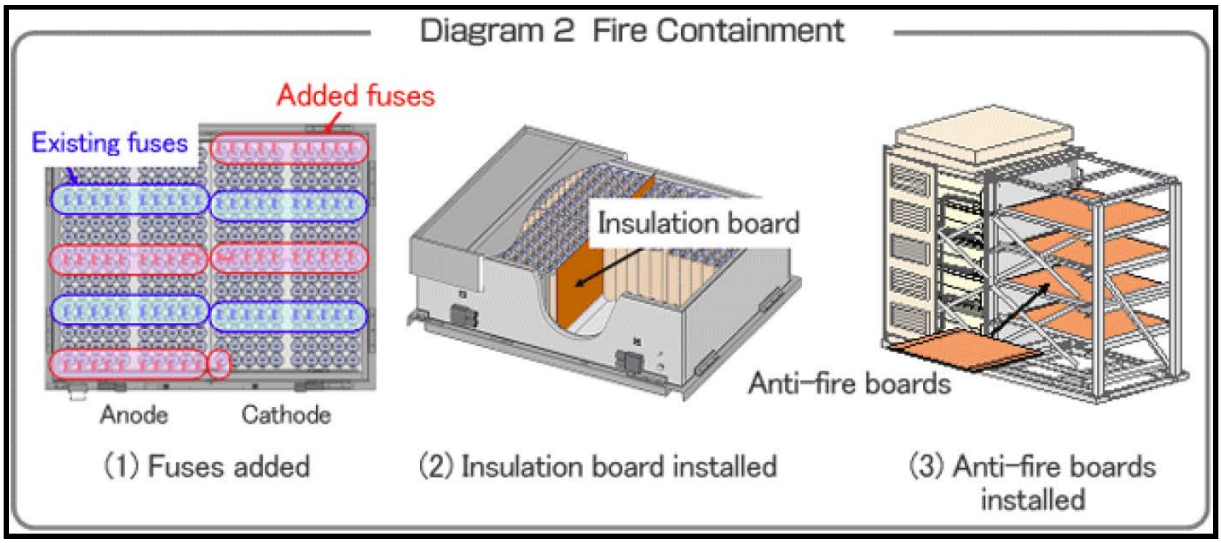
2.1.7 Installation

Replacement battery modules from NGK arrived at the V-D site in July 2012 (see Figure 8). The long delay caused by the fire and ensuing investigation, redesign, and the replacement module construction and transport time resulted in a significant overall change in the project schedule and the accrual of additional costs to the project.

The following photos of the V-D BESS (Figure 9 through Figure 16) were taken during the installation in June 2012 and January 2013.

The V-D BESS was commissioned in August 2012 for a final cost of $11.1 million.

Figure 7: Fire Containment



Source: NGK

Figure 8: Replacement Battery Modules at Vaca-Dixon BESS Site

EPRI's Robert Schainker stands next to replacement battery modules provided by NGK containing re-engineered fusing to reduce fire risks.
Photo Credit: David Fribush

Figure 9: Two 1 MW NaS Battery Containers at the Vaca-Dixon Substation

Photo Credit: Bill Steeley, EPRI

2.2 Yerba Buena Battery Energy Storage System

An Engineer-of-Record Report was prepared under Task 2 of this contract and is summarized below.

2.2.1 Initial Scope and Schedule

Preliminary engineering began in early 2010.

The Y-B BESS is located on a third-party property, which required a lease agreement with Hitachi[2] (sub-tenant), Celanese (original tenant), RREEF Property Trust (landlord), and PG&E. Although initial estimates were that the lease could be signed within a month, it took until August 2011 (18 months) before all parties had signed.

Construction was scheduled to begin in September 2011. However, that same month, NGK informed PG&E that there had been a fire at one of its battery installations in Japan (as detailed in Section 2.1.6 above). Based on NGK's advice, PG&E suspended the construction of the Y-B BESS.

2 Now HGST, as previously noted.

Figure 10: Installation of the Vaca-Dixon Battery Containers

PG&E's Dave Fribush and a colleague inspect the installation of the battery containers.
Photo Credit: Robert Schainker, EPRI

Figure 11: Switchgear at the Vaca-Dixon Substation Associated with the NaS BESS

Photo Credit: Robert Schainker, EPRI

Figure 12: NaS Battery Modules Within One of the 1 MW NaS Containers

Located at the Vaca-Dixon Substation, one NaS container holds 20 modules. Each module can deliver up to 50 kW of power.
Photo Credit: Robert Schainker, EPRI

As with the V-D BESS, the NGK battery fire in Japan caused PG&E to put the project on hold pending NGK's investigation of the incident and development of new modules containing enhanced fire mitigation measures.

2.2.2 Installation

In late March 2012, NGK notified PG&E that it had located and corrected the design flaw that led to the fire and would be sending replacement batteries.

Replacement battery modules from NGK arrived at the Y-B site in autumn 2012. The long delay caused by the fire and ensuing investigation, redesign, and transport time resulted in a significant overall change in the project schedule and the accrual of financing charges, as well as additional costs for re-starting the project and developing and deploying an enhanced fire safety plan and alarm system in conjunction with safety personnel from HGST.

Figure 13: Completed Installation of the Vaca-Dixon 2 MW NaS BESS

Photo Credit: David Fribush for PG&E

Figure 14: S&C's "PureWave®" Storage Management System at the Vaca-Dixon site

Photo Credit: David Fribush for PG&E

Figure 15: PG&E's Jon Eric Thalman Giving a Tour of the Vaca-Dixon NaS BESS

Photo Credit: David Fribush for PG&E

Following delivery of new NGK battery modules to the Y-B site, construction proceeded through the second half of 2012. The following photos (Figure 17 through Figure 30) were taken during the construction and installation of the Y-B BESS, which occurred between June 2012 and May 2013.

The Y-B BESS was formally commissioned at a dedication ceremony held on May 23, 2013, with initial testing and commissioning for its islanding functionality continuing through that year. The final cost for the Y-B BESS was $22.5 million.

Figure 16: PG&E and S&C Personnel Completing Final Items for the Vaca-Dixon NaS BESS

Photo Credit: David Fribush for PG&E

Figure 17: Yerba Buena NaS BESS Site Preparation (June 2012)

Photo Credit: William Steeley, EPRI

Figure 18: Further Site Preparation at Yerba Buena Site (June 2012)

Photo Credit: William Steeley, EPRI

Figure 19: Building Site Retaining Wall at Yerba Buena Site (August 15, 2012)

Photo Credit: Leonard Wilde for PG&E

Figure 20: Trenching and Laying Conduit for Power Cables at Yerba Buena Site (October 4, 2012)

Photo Credit: Leonard Wilde for PG&E

Figure 21: Pouring Concrete for Pad-Mounted Equipment at Yerba Buena Site (October 15, 2012)

Photo Credit: Leonard Wilde, for PG&E

Figure 22: Construction of Battery Cabinets at the Yerba Buena Site (January 2013)

Photo Credit: Leonard Wilde, for PG&E

Figure 23: Battery Module Loaded into a Cabinet at the Yerba Buena Site (January 8, 2013)

Photo Credit: David Fribush, for PG&E

Figure 24: Battery Module Installation into the Yerba Buena Battery Enclosure

Each battery module weighs approximately 8,000 pounds and fits into the battery enclosure with extremely tight tolerances.
Photo Credit: Leonard Wilde for PG&E

Figure 25: Installation of Diesel Generator at the Yerba Buena Site

The diesel generator is used to power the battery module heaters in the event of a prolonged utility power outage at the Y-B BESS site.
Photo Credit: Leonard Wilde for PG&E

Figure 26: Installing One of Two 480 V/21 kV Transformers at the Yerba Buena Site

Photo Credit: Leonard Wilde for PG&E

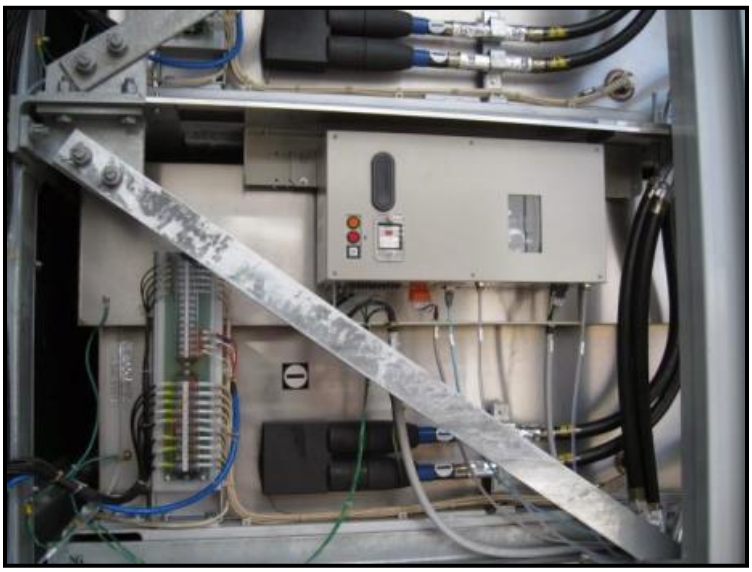
Figure 27: NGK Engineer Attaches DC Power Cables to Yerba Buena Battery Module

Photo Credit: Leonard Wilde for PG&E

Figure 28: Three of the Four 1 MW Pad-Mounted BESS Cabinet Enclosures at the Yerba Buena Site (April 30, 2013)

Photo Credit: David Kligman, PG&E

Figure 29: Yerba Buena NaS BESS SO_2 Monitoring Equipment (May 23, 2013)



The SO_2 monitoring equipment was one of the design modifications required by NGK for retrofitting safety enhancements into the Na BESS following the battery fire in Japan.
Photo Credit: David Kligman, PG&E

Figure 30: Yerba Buena NaS BESS Ribbon Cutting Public Event on May 23, 2013

Photo Credit: Robert Schainker, EPRI

CHAPTER 3:
System Commissioning and Initial Characterization

3.1 Commissioning Overview

System level commissioning at both the V-D BESS and the Y-B BESS facilities began following energization with heating the battery modules from ambient temperature, at which sodium and sulfur are solid, to their minimum operating temperature 572°F (300°C), at which sodium and sulfur are liquid. This heating process takes approximately five days and was overseen by an engineer from NGK. This procedure was conducted without incident on both systems.

The next commissioning procedure was for the battery to be fully discharged and charged five consecutive times. This procedure was conducted without incident on both the V-D and Y-B systems.

Following these two steps, the systems were turned over to PG&E for performance testing. PG&E's performance testing procedure was developed by J Henderson and Jason Pretzlaf, the Project Engineers, from PG&E's Applied Technology Services group. The primary goals of this procedure were to:

1. Verify that the system met or exceeded its manufacturer specifications and stayed within safe and normal tolerances while operating.
2. Provide data that could be used as a baseline to compare later operational performance of each BESS facility.

The Project Engineers developed this plan with guidance from NGK, S&C, and EPRI's Robert Schainker and Bill Steeley, the Engineers of Record for this contract and authors of the technical reports on battery performance.

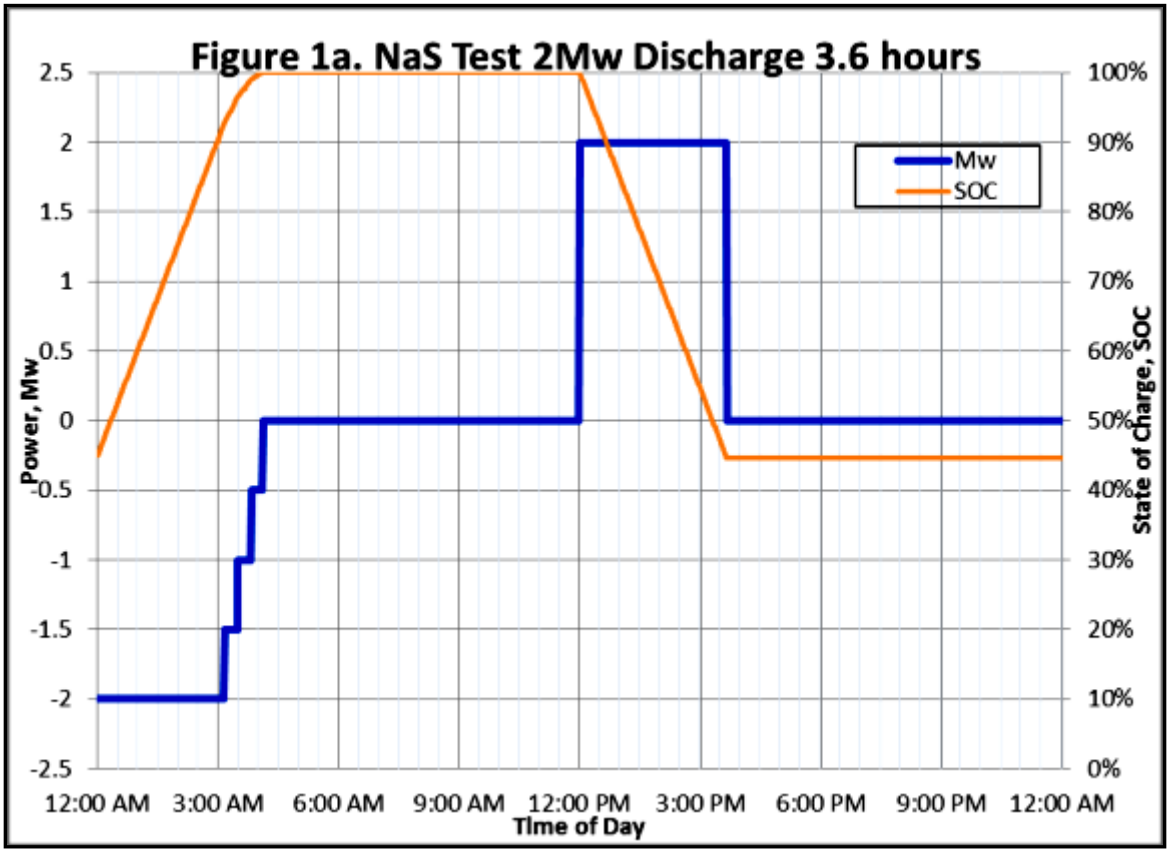
3.1.1 PG&E's System Characterization Tests

A series of operational profiles were developed to test the system's performance at various levels of power and time durations for charge and discharge. For example, Figure 31 shows a profile of what a 3.6-hour discharge at full power would look like with the blue line representing the system output in megawatts and the orange line representing the system's State of Charge (SOC).

The schedule represented by the blue line was input into the BESS control system and run on several consecutive days. The project team monitored the test to ensure that the system operated normally and safely, and that the batteries stayed within their normal operating temperatures, between 572°F (300°C) and 662°F (350°C). The electrochemical reaction for discharge is exothermic and endothermic for charge, so the batteries increase in heat on discharge and decrease in heat on charge. The tests were repeated at progressively longer

duration (4.6 hours, 5.6 hours, 6.6 hours, and 6.95 hours[3]). These durations were based on guidance from NGK. Then the same durations were run at successively higher power levels.

Figure 31: Example Test Profile



Source: Jason Pretzlaf, PG&E Applied Technology Services

The key parameters evaluated were:

- Did the system follow its programmed schedule accurately and consistently?
- Did the battery modules stay within normal operating temperatures? Note that automatic system protection curtailed and/or shut off the batteries immediately upon detection of abnormal (greater than 662°F [350°C]) temperatures.
- What was the round-trip AC to AC efficiency of the system,as measured at the revenue meter)?

3 Originally NGK had stated that 6.6 hours was the maximum discharge duration for the system, but later revised the rating to 6.95 hours provided the system stayed within its normal operating temperatures.

Thorough and detailed evaluations of the test procedure and results for both systems are documented in the Engineer of Record reports for both systems. Summaries of results of these tests for both systems are in Sections 3.1.2 through 3.1.4.

3.1.2 Vaca-Dixon BESS Initial Characterization Results

The V-D NaS BESS performed well and exhibited good reliability during the performance tests. AC round-trip efficiency depends on discharge power level and time of discharge. When the battery system is used for one charge-discharge cycle per day at full load (for example, 2 MW for the V-D BESS) and discharged for 6.6 hours, and its AC round-trip efficiency is based on charge and discharge times periods only, then its AC round-trip efficiency was measured at 79.3 percent.

However, if the AC round-trip efficiency is based on a full 24-hour time period, the AC round-trip efficiency decreases to 74 percent due to heater system losses accruing during the "idle" time period. Thus, the net effect of the heaters needed for this type of battery system reduces the battery system's AC round-trip efficiency by about 5 percent when analyzed over a 24-hour time period.

The original energy specification for the V-D BESS called for the unit to be discharged at the 2 MW level for 6.95 hours for a total system energy capacity of 13.9 MWh DC. The BESS discharged 13.95 MWh DC, achieving 100.4 percent of the specification's DC energy rating. The original power specification was 2.1 MW DC, which included the ability for an extra 0.1 MW of higher power pulse discharge for a limited number of times per year, if necessary. However, NGK later revised its operational guidance to remove pulse discharge capability, and S&C did not allow the user to command more than 2 MW DC power from the V-D BESS. Accordingly, the V-D BESS achieved 100 percent of its 2 MW DC power rating.

The tests showed that the V-D BESS discharged an average of 1940 kW (including overall BESS losses) over a duration of 6.95 hours, at which time, the system's SOC decreased to 5.3 percent for a total energy discharge of 13.2 MWh AC measured at the revenue meter.

The 24-hour AC round-trip efficiency of the V-D BESS for 6.95 hour discharge duration was 75.2 percent, which is slightly higher than the maximum AC round-trip efficiency value of 74.0 percent that was achieved for the 6.6 hour discharge duration.

The AC round-trip efficiency over 24 hours increases as the MW discharge level increases to 2 MW. This is mainly attributed to the heater load losses being averaged over a higher amount of discharged energy as the MW discharge power level increases.

For long-duration discharge cycles (that is, six hours or greater), the V-D BESS facility will have its highest AC round-trip efficiency when operated at or near full rated power output (that is, 75.2 percent for the 6.95-hour discharge). This is particularly useful when applying this type of battery system for peak load shaving duty, which will assist in extending the life of transmission and distribution system equipment (for example, transformers).

3.1.3 Yerba Buena BESS Initial Characterization Results

The Y-B BESS facility's original energy specification was that the facility could be discharged at the 4 MW level for 6.95 hours for a total system energy capacity of 27.8 MWh DC. The total energy discharge for the Y-B BESS was measured at 27.6 MWh DC, which resulted in the Y-B BESS performance to achieve 99.4 percent of its DC specification energy rating. The system's original power specification was 4.2 MW DC, which included the ability for an extra 0.2 MW higher power pulse discharge a limited number of times per year if necessary. However NGK later revised its operational guidance to not include this pulse discharge capability and S&C Electric did not allow the user to command more than 4 MW DC power from the system. Accordingly, the Y-B BESS performance achieved between 4000 kW and 4031 kW or 100 percent of its DC 4 MW power capacity rating.

The tests showed that the Y-B BESS facility could discharge an average of 3837 kW (including system losses) over a duration of 6.95 hours, at which time its SOC decreased to 5.8 percent for a total energy discharge of 25.7 MWh AC measured at the revenue meter.

The 24-hour AC round-trip efficiency for a 6.95 hour discharge achieved 73.0 percent which is slightly lower that the 73.7 percent achieved for its 6.6 hour duration discharge.

As expected, for the Y-B BESS, its AC round-trip efficiency over 24 hours increases as the MW discharge level increases to 4 MW. This is mainly attributed to the relatively fixed BESS heater load losses being averaged over a higher amount of discharged energy as the MW discharge power level increases.

The Y-B BESS total energy losses ranged from around 140 to 350 kW continuous, which is primarily comprised of battery module heater loads.

Both the V-D and Y-B BESS facilities performed safely and without incident during all the tests conducted during this project.

3.1.4 Comparison with Other USA-Based Utility-Deployed NaS Systems

Under Task 2 of the contract, EPRI prepared a report comparing PG&E's battery systems with other NGK NaS battery systems owned/operated by other utilities (namely NYPA, AEP, and Xcel Energy). Many NaS BESS lessons learned were summarized and documented in that report. For example, installed capital costs vary from $3,580 to $5,625/kW on the basis of discharge power capability, and varied from $600 to $810/kW for each hour of storage on the basis of energy discharge capability. The capital costs for other utility NaS battery systems do not strictly contain all the same cost items due to different accounting systems used by each utility. The AC-to-AC round-trip efficiencies vary from 68 to 81 percent (including all auxiliary power/energy requirements for the NaS BESS heaters and other parasitic loss sources).

CHAPTER 4:
Detailed System Studies Summaries

Several technical reports were created under this contract to document testing and assessment of the Y-B BESS for a number of different functionalities. These technical task reports were:

- An assessment of the performance of the Y-B BESS for providing load shaping and power quality improvement. (Task 3)
- An assessment of the performance of the Y-B BESS for providing reliability enhancement to electric customers. (Task 4)
- An assessment of the performance of the Y-B BESS for integrating renewable resources. (Task 5)
- An assessment of the performance of the V-D BESS for providing ancillary services assessment in California ISO markets. (Task 6)
- A report on PG&E's technology transfer activities with regard to the information gained from these demonstrations. (Task 8)

Summaries of these reports are provided in Sections 4.1 through 4.5.

4.1 Measuring the Performance of the Yerba Buena Sodium-Sulfur BESS for Load Shaping and Power Quality

4.1.1 Overview

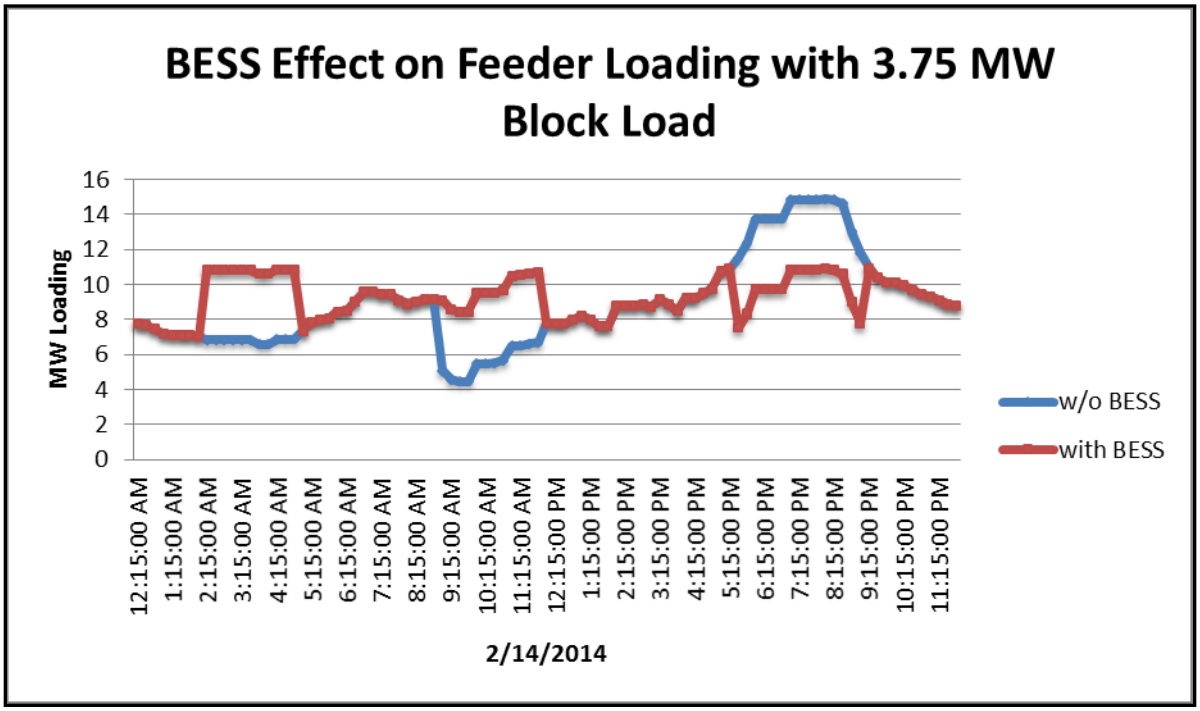
The Task 3 report included a facility description, brief project history, load shaping data and analysis, power quality data and analysis (addressing harmonics and flicker), results, general conclusions, and recommendations. This report was one of several reports documenting the performance of the Y-B BESS. The key purpose of this specific report was to document the power quality and flicker performance of the Y-B BESS.

4.1.1.1 Load Shaping Study Results

The Task 3 report provided EPRI's analysis of the data obtained from load shaping tests noted the following results.

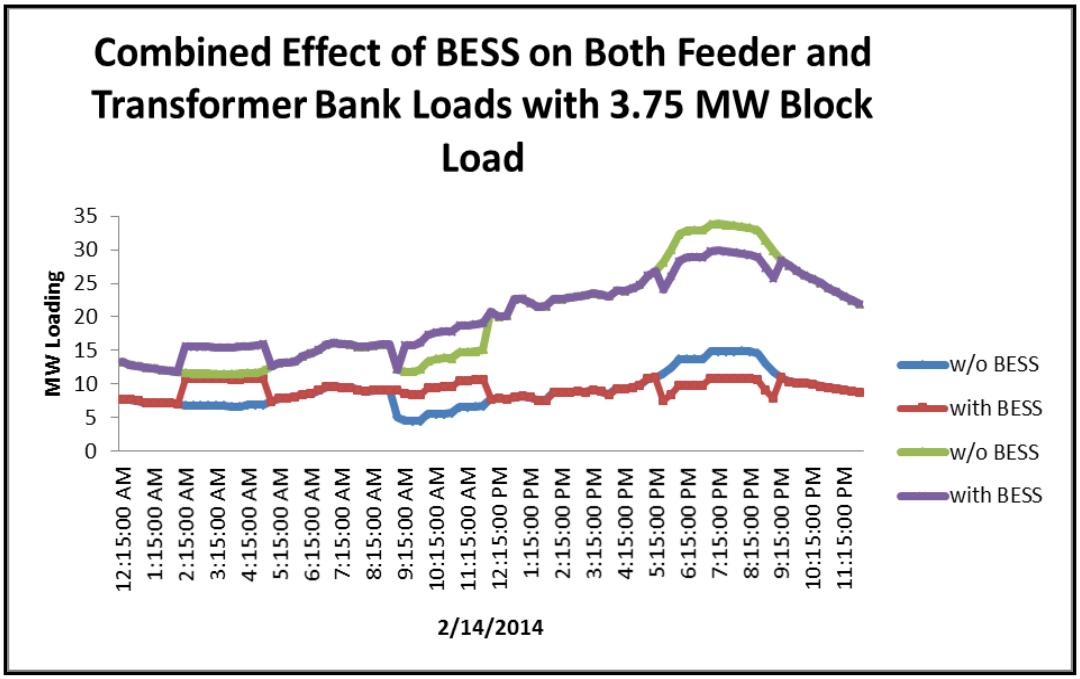
As shown in Figure 32 through Figure 34, operating the Y-B NaS BESS at full power 3.75 MW for a block of multiple hours (assuming typical parasitic load and losses of 250 kW) not only decreased peak system feeder loading but should also reduce system losses through load leveling.

Figure 32: 4 MW Block Loading Effect on Yerba-Buena BESS Feeder



Source: Jason Pretzlaf, PG&E Applied Technology Services

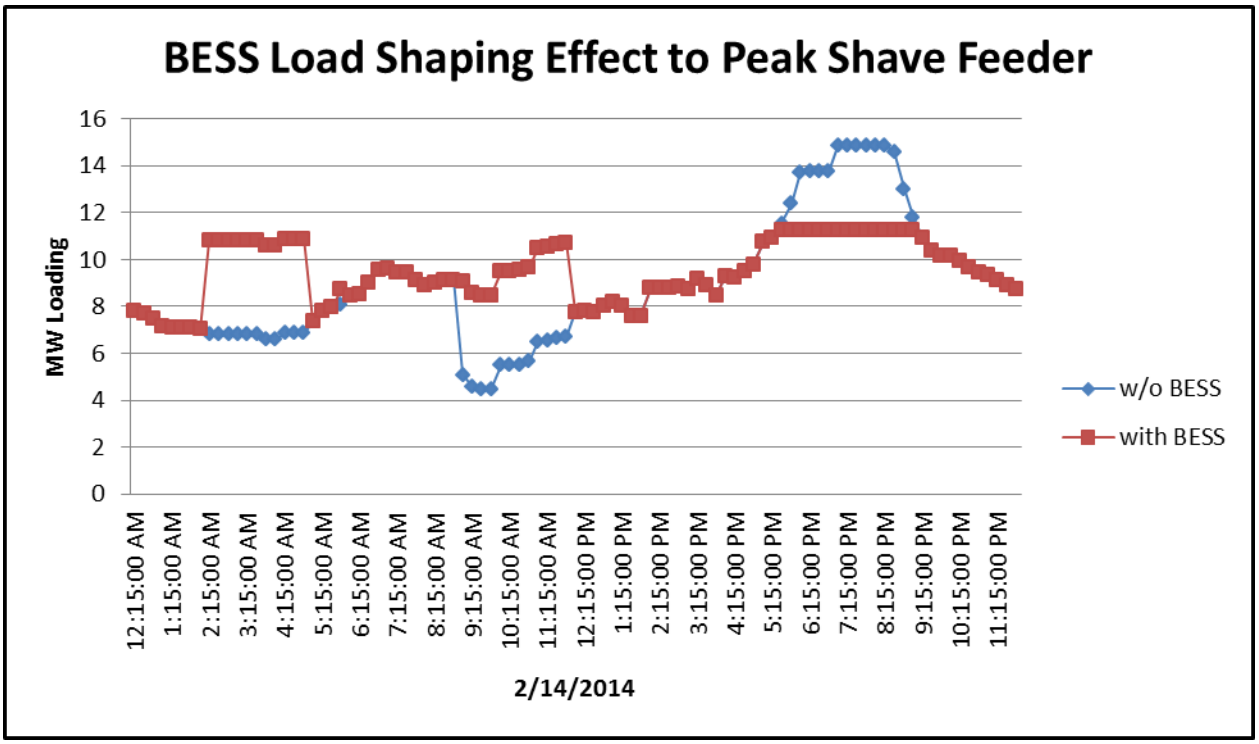
Figure 33: Y-B BESS Block Loading Effect on Both Feeder (Blue and Red) and Transformer Bank (Green and Purple)



Source: Jason Pretzlaf, PG&E Applied Technology Services

As with the block loading mode, the peak shaving mode of operation can also be used to cap the peak system feeder loading to a desired level. In addition, the peak shaving mode should reduce system losses through load leveling. For this function, a special NaS BESS control algorithm is required to discharge and charge the BESS at varying levels. This functionality has been included into the dispatch control software developed during this project.

Figure 34: 4 MW Peak Shaving Effect on Y-B BESS Feeder



Source: Jason Pretzlaf, PG&E Applied Technology Services

4.1.1.2 Distribution System Impact Study Results

PG&E conducted System Impact Studies (SISs). The May 2014 SIS stated that when the Y-B NaS BESS was placed online in 2013 as a distribution asset, no substation work was required since charging and discharging the BESS was limited to operate under optimal conditions that would not degrade the safety and reliability of Swift Bank #1 and its feeders.

Steady-state power flow analyses concluded that the BESS operations would not overload Swift Bank #1 under any loading scenario. Instead, any power generated will back-feed into the transmission system. The SIS noted that the existing line equipment on the Swift 2102 circuit might be overloaded if the BESS charging capability were not limited.

The SIS also concluded that proper voltage regulation by the Swift Bank #1 might be affected by the generation interconnection, and that the load tap changer control might need to be replaced if the BESS does not limit its discharging during minimum loading conditions.

From the distribution SIS results, it is not anticipated that interconnection of the Y-B NaS BESS will result in overloading existing banks or feeders under any normal operating condition during the summer and/or the winter. However, an operational restriction was placed on the resource to limit its discharge to 1.5 MW or less from 2300 to 0600 hours year-round to prevent potential back-feeding to its substation transformer.

4.1.1.3 Power Quality Results for Current Harmonics and Flicker

Power quality tests were conducted on the Y-B NaS BESS to determine if the unit complies with the harmonic distortion and flicker limits stated in the Institute for Electrical and Electronic Engineers 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems (IEEE 1547).

IEEE 1547-2003 states that the total demand distortion (TDD) must not exceed five percent of the unit's rated current capacity for all harmonics for each phase, and that the TDD must not exceed four percent for those harmonics less than the 11th harmonic for each phase. At full load, the TDD is equal to the Total Harmonic Distortion (THD).

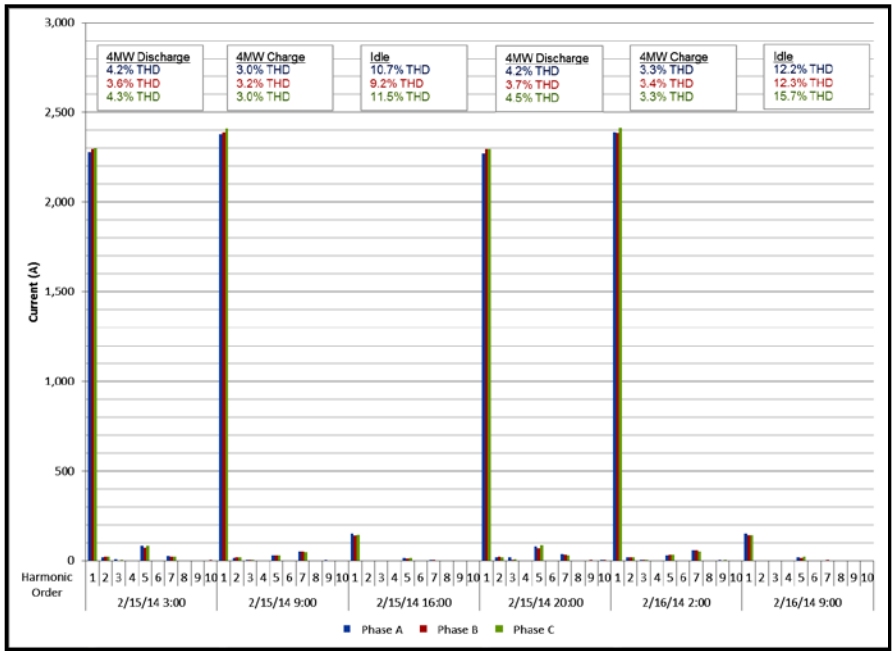
In Figure 35, the THD of the root mean square (RMS) current during both rated maximum discharge periods (that is, 4 MW) was less than five percent for each electricity phase. In Figure 36, the THD for the RMS voltage during both maximum discharge periods ranged from 3.6 percent to 4.5 percent across all three electric phases, which meets the Institute of Electrical and Electronics Engineers (IEEE) standard of five percent for each electric phase. Also, no individual current or voltage harmonic less than the 11th harmonic is greater than four percent of the fundamental frequency. The THD values during the idle periods are high but not significant because the fundamental current that they are based upon is low. Therefore, the THD values during idle periods are insignificant (that is, each phase has less than five percent THD). There is no IEEE standard for "idle" condition THD. IEEE 1547 also states that the measured device (the AC output of the BESS) shall not create objectionable flicker that causes a modulation of the light levels of lamps sufficient to be irritating to humans or cause equipment misoperations.

The Percentile Short Term (Pst) flicker and Instantaneous Flicker Level (IFL) are based on the IEEE Recommended Practice, *Adoption of IEC 61000-4-15:2010, Electromagnetic compatibility (EMC)--Testing and measurement techniques--Flickermeter--Functional and design specifications* (IEEE 1453). Pst flicker is a metric for how much a fluctuating AC voltage causes noticeable incandescent light flickering and IFL is a metric which quantifies the voltage fluctuation at a given instant.

Figure 37 and Figure 38 show that the results for both Pst flicker and IFL have values below one (which is the accepted limit), as measured and recorded on both the step-up transformer banks. Maximum measured values approached 0.7 for Pst and 0.42 for IFL for very short periods of time during two full discharge-charge cycles.

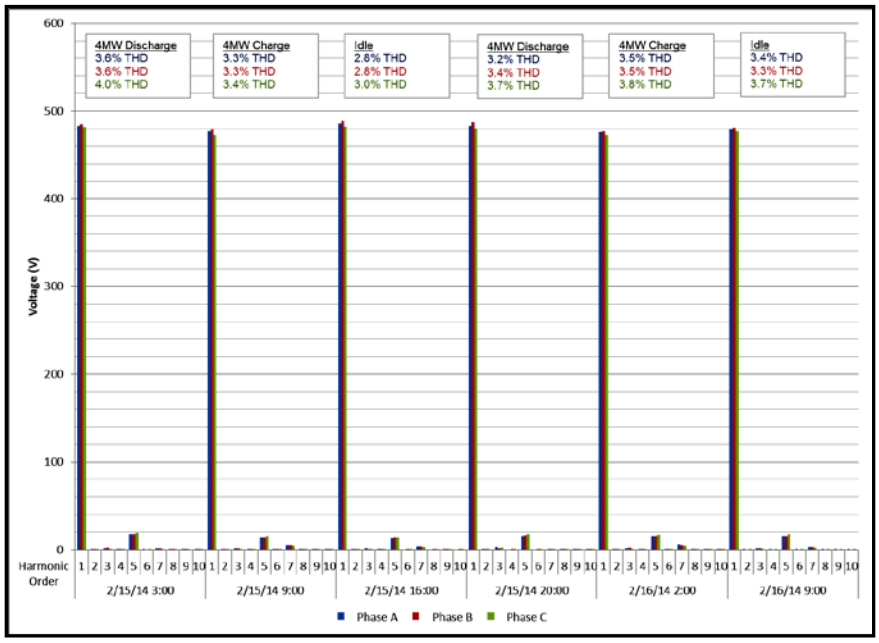
In conclusion, the Y-B NaS BESS operated within acceptable current and voltage harmonic and flicker limits based on IEEE 1547 and thus meets PG&E's operational standard requirements.

Figure 35: Yerba Buena NaS BESS Current Harmonic Magnitude & THD



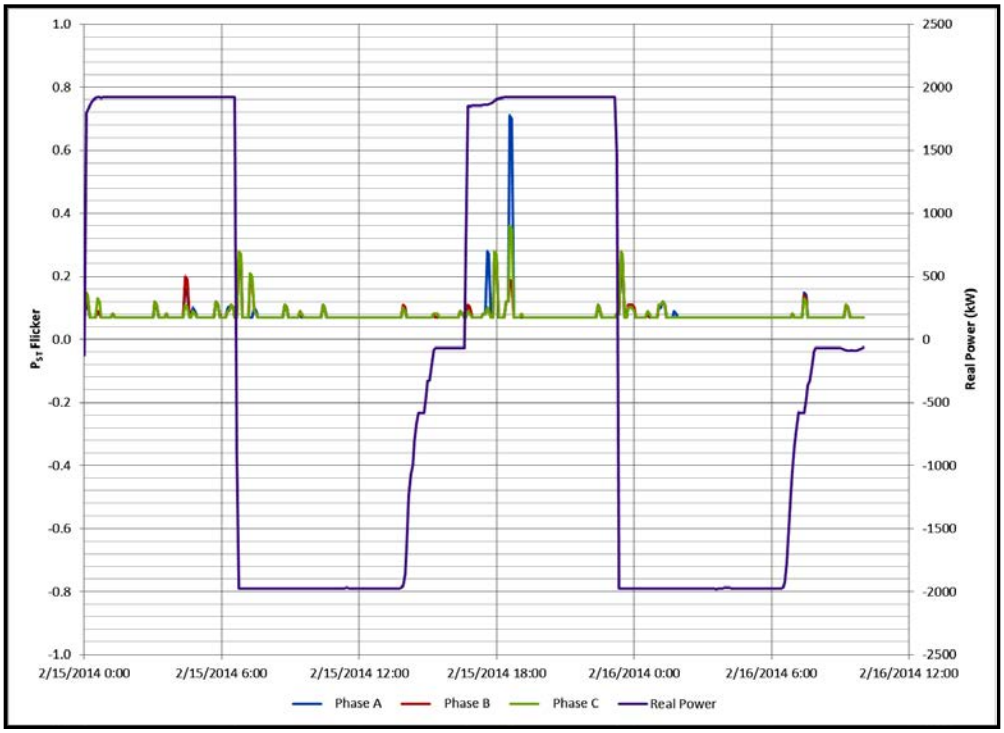
Source: Jason Pretzlaf, PG&E Applied Technology Services

Figure 36: Yerba Buena NaS BESS Voltage Harmonic Magnitude & THD



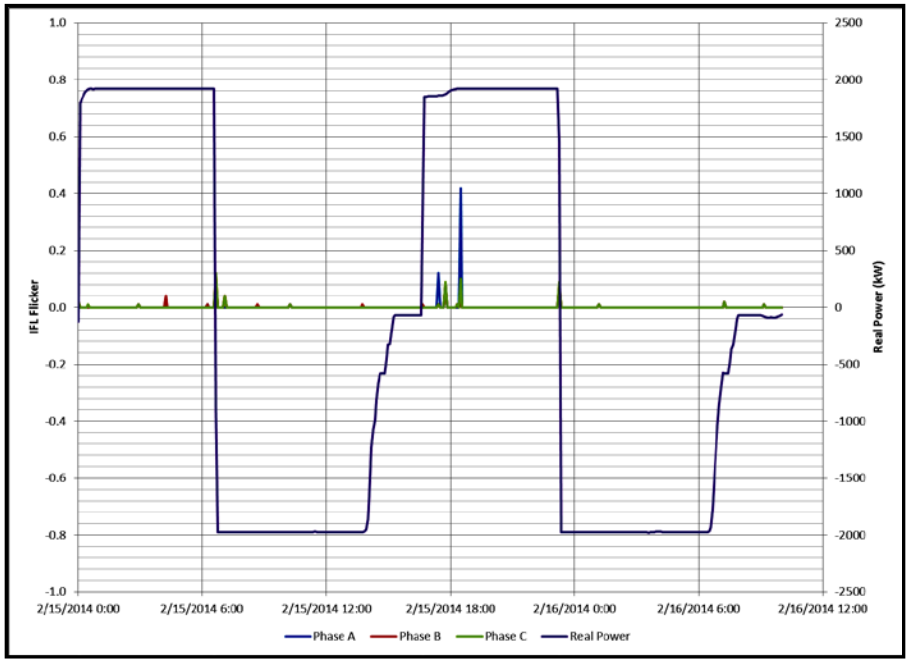
Source: Jason Pretzlaf, PG&E Applied Technology Services

Figure 37: Yerba Buena NaS BESS Pst Flicker



Source: Jason Pretzlaf, PG&E Applied Technology Services

Figure 38: Yerba Buena NaS BESS IFL Flicker



Source: Jason Pretzlaf, PG&E Applied Technology Services

4.2 Yerba Buena BESS Reliability Enhancement Assessment

4.2.1 Overview

The EPRI report on Y-B BESS customer reliability enhancement summarizes data and analysis pertaining to reliability during the operation of a 4 MW, 27.8 MWh NaS BESS at a PG&E customer site in San Jose, California. The battery purchased from NGK is owned and operated by PG&E.

The EPRI reliability report included a facility description, brief project history, test procedures and results, general conclusions, and recommendations. The key purpose of this report was to document analyses and assessments evaluating the reliability enhancement benefits of the Y-B NaS BESS for its islanding functionality.

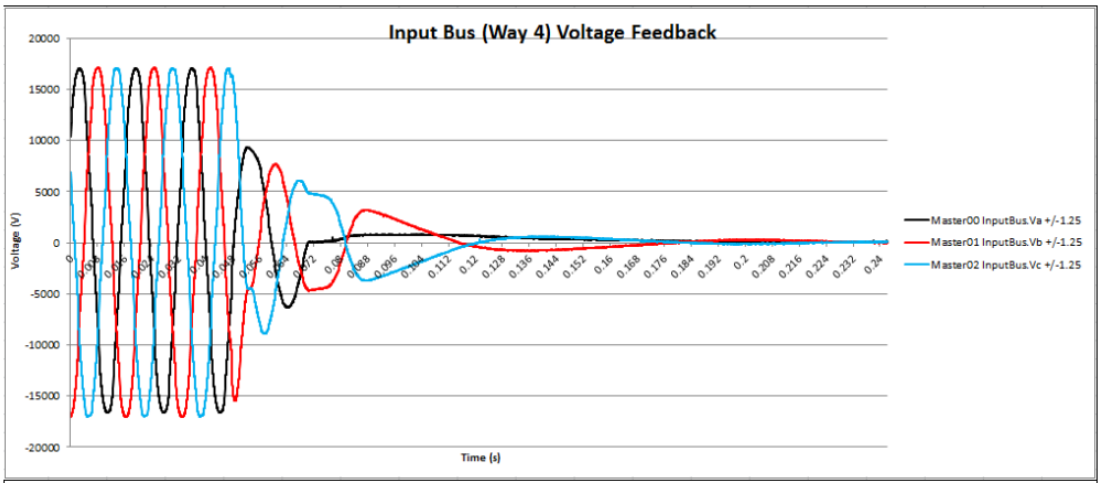
4.2.2 Results and Conclusions

In September 2013, PG&E and S&C carried out commissioning testing for voltage source mode (islanding) of the Y-B NaS BESS Storage Management System™ (SMS) and summarized their results in a test report[4]. The commissioning test plan consisted of three islanding scenarios:

1. Islanding with no load.
2. Islanding with no critical loads and no spinning loads.
3. Islanding with all available spinning and non-spinning loads (Note: spinning loads, such as those from electric motors, represent more of a challenge for islanding).

The following sub-cycle data was recorded during these tests:

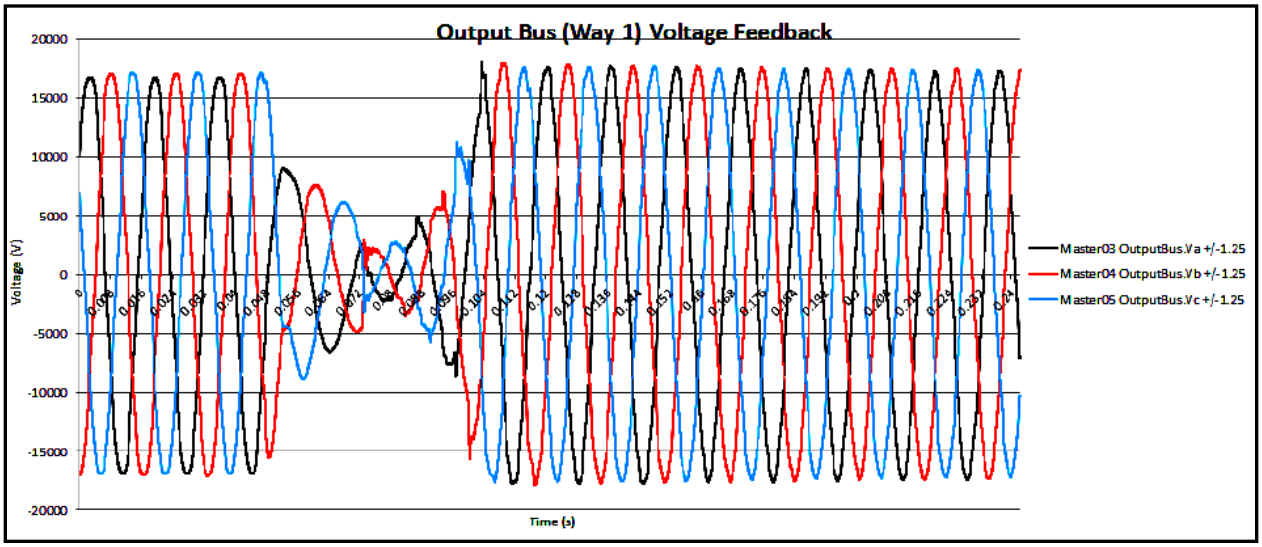
Figure 39: Yerba Buena BESS Transition to Islanding with No Load



Source: S&C Electric Company

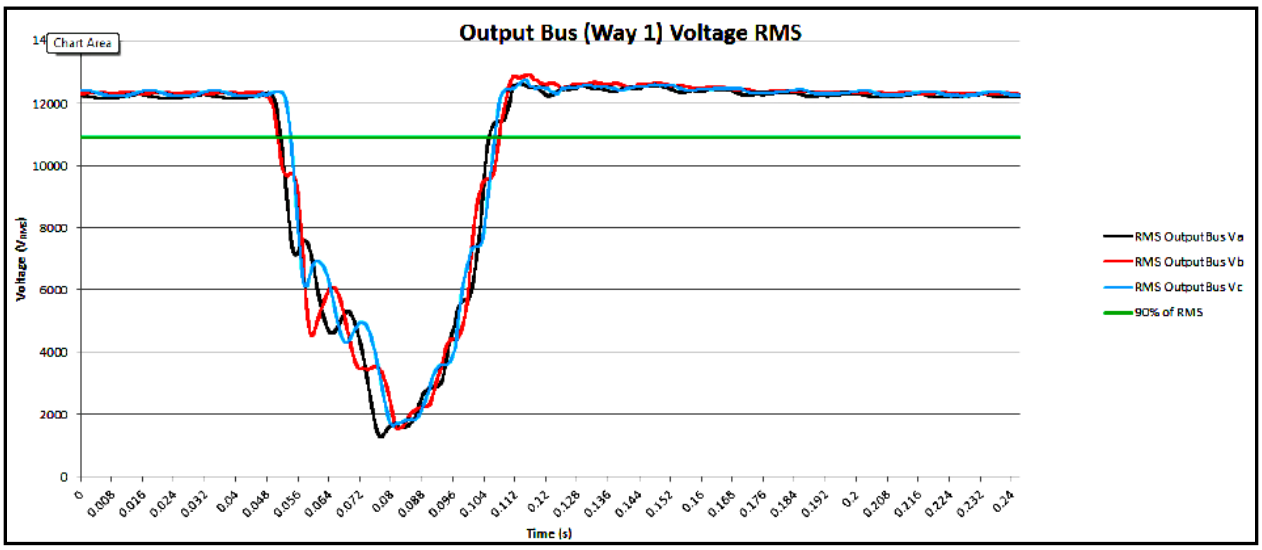
4 Pacific Gas and Electric Company. *PG&E Yerba Buena SMS Voltage Source Operation Test Report 09/14/2013*, S&C Electric Co., TR-10215, November 2013.

Figure 40: Yerba Buena BESS Transition to Islanding with Non-Spinning Loads



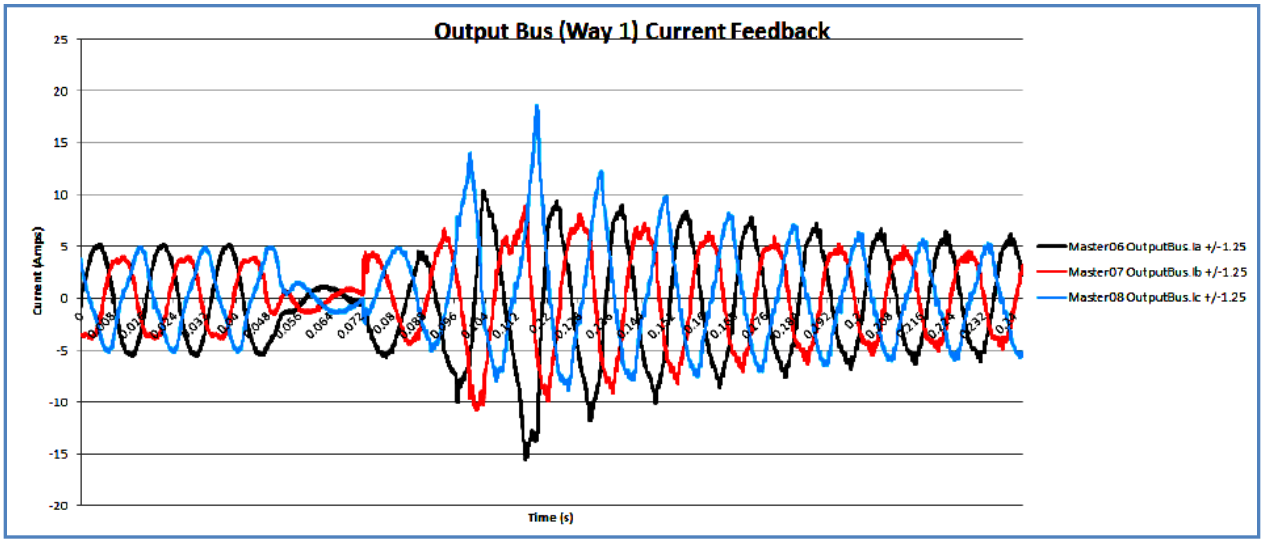
Source: S&C Electric Company

Figure 41: Yerba Buena BESS Transition to Islanding with Non-Spinning Loads



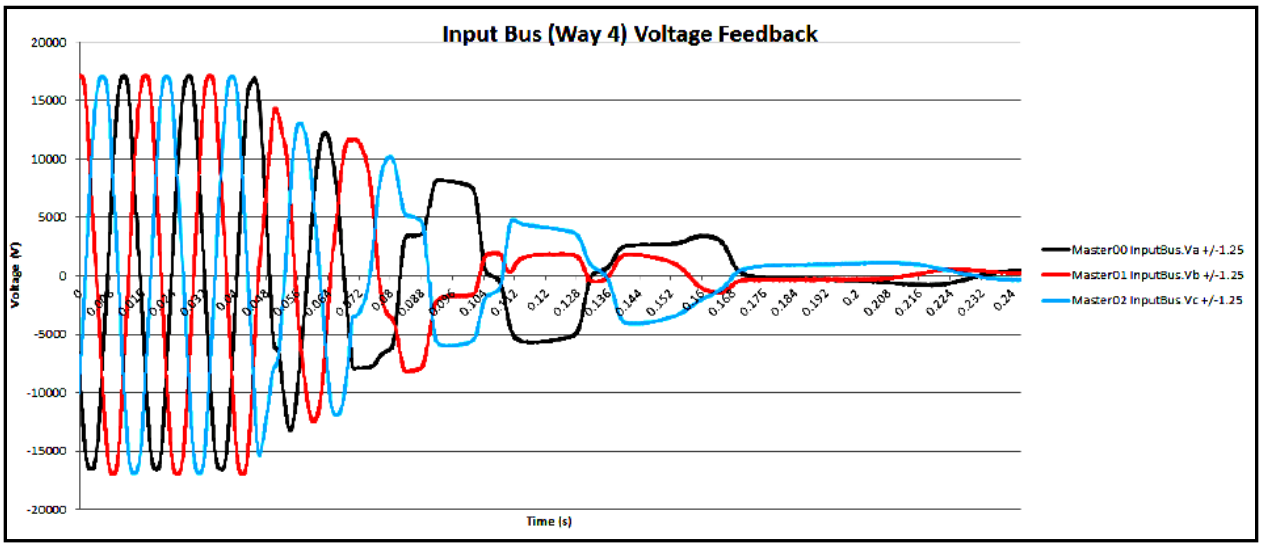
Source: S&C Electric Company

Figure 42: Yerba Buena BESS Electricity Current Feedback During Transition to Islanding with Non-Spinning Loads



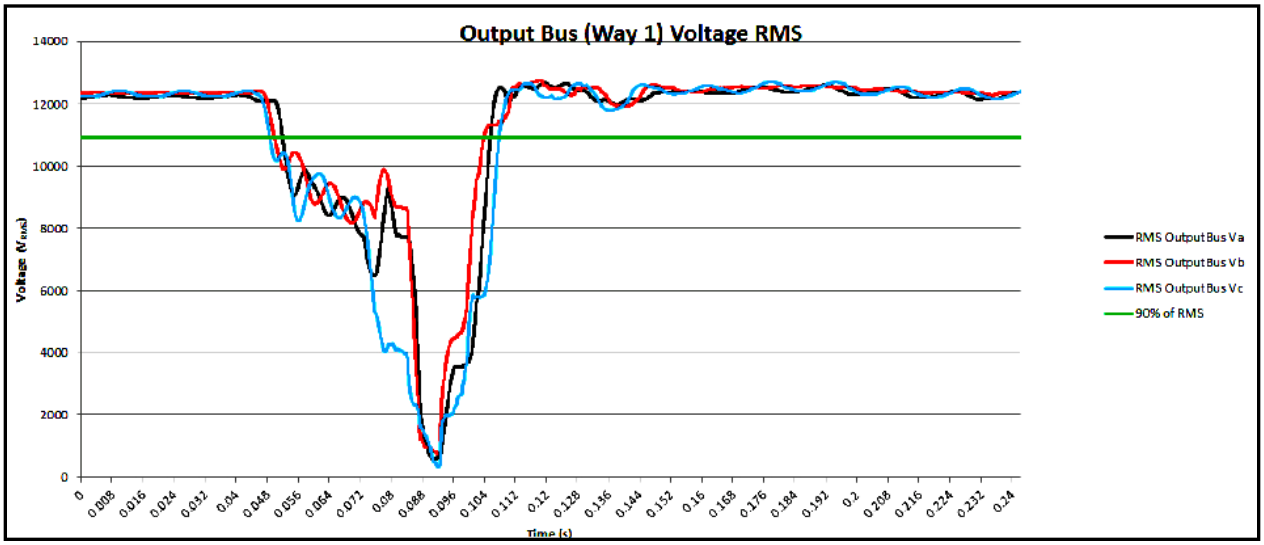
Source: S&C Electric Company

Figure 43: Yerba Buena BESS Transition to Islanding with Spinning and Non-Spinning Loads



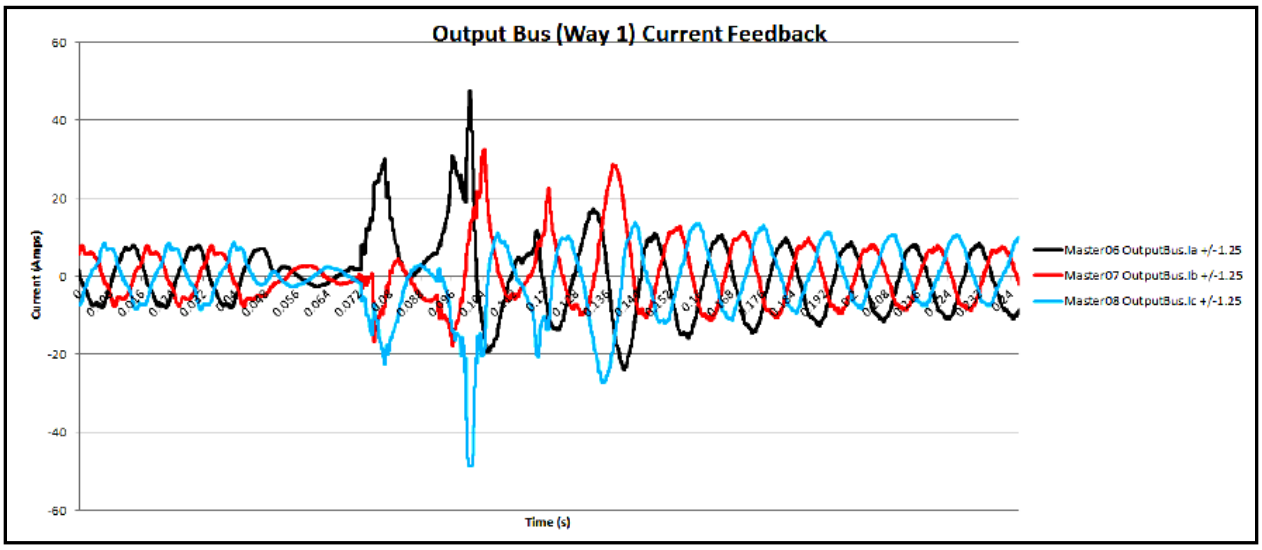
Source: S&C Electric Company

Figure 44: Yerba Buena BESS Transition to Islanding with Spinning and Non-Spinning Loads



Source: S&C Electric Company

Figure 45: Yerba Buena BESS Electricity Current Feedback with Spinning and Non-Spinning Loads



Source: S&C Electric Company

Based on the S&C test report, the following conclusions were reached by EPRI:

- The SMS successfully islanded the customer loads available during commissioning.
- The SMS successfully picked-up the loads in less than four cycles when the system was in READY mode.
- The SMS took longest to transition to islanding when starting from an idle state.

4.2.3 Islanding Experience Since Testing Cited in EPRI's Report

PG&E gained significant new data from operations, which are summarized below. The specification for the Y-B BESS was that it would transition to a fully stable electrical island within four cycles following detection of a disturbance on the distribution feeder. While this is exceptionally fast for a mechanical switch, even this very brief interruption in voltage and power caused some problems for some equipment at HGST. Most importantly, the HGST facility has two chiller systems that, among other duties, are necessary to keep some sensitive high-tech equipment functioning properly. The island transition caused one of these chiller systems to drop offline if the island transition occurred when the battery system was idle. (Less impactful effects such as a short flicker in the lights could also be observed even with such a brief transition time). At the engineering design stage of the project, S&C recommended a static switch instead of a mechanical switch for creating the electrical island; however, this recommendation was not implemented due to the high cost of a solid state, static switch. Subsequently, both PG&E and HGST agreed that a sub 4-cycle island transition time was sufficient.

The system was initially set to island if voltage or frequency on the feeder was measured at more than plus or minus 10 percent of nominal, sampled every half-cycle. If the duration of the voltage/frequency event was transitory and power and voltage never went to zero on the feeder, then the system would transition back from the island mode to the utility power source after a few seconds. The downstream loads for these events see two interruptions that are approximately 4-cycles each within a few seconds.

In the first full month of island operations, these settings resulted in the system islanding 12 times. Two of these events were sustained feeder interruptions: one event lasted 12 seconds after a relay failure and the other event was a sustained 35-minute outage due to a line-to-line fault. The remaining 10 events were very transitory and most were not noted as events in PG&E's outage logs. During four of these events, the system was discharging at the time and no disturbance was reported by HGST staff. During one of these events the system was charging and no disturbance was reported by HGST staff. However, for the remaining seven events, HGST saw some disturbance and the temporary tripping off of one of its chiller systems.

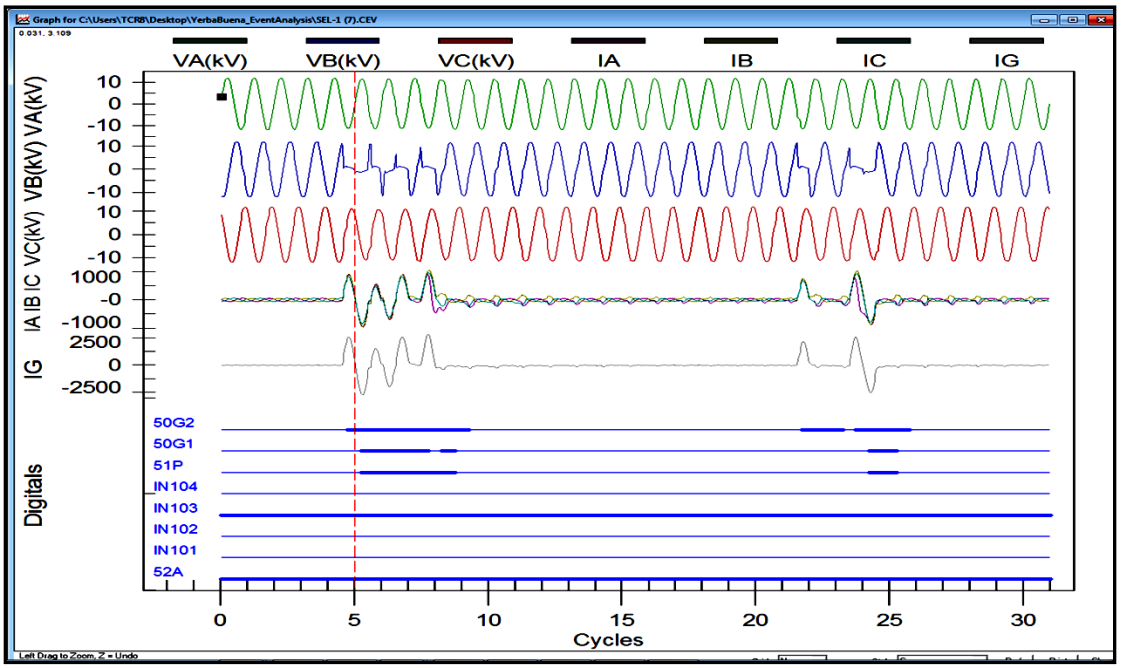
The term "nuisance islanding" was coined for these types of events as a very transient voltage or frequency excursion that may or may not be even noticed by the HGST facility had the system not entered island mode. This began a lengthy and iterative process by the project team, HGST, and S&C to determine how the island settings might be optimized to minimize nuisance islanding while still protecting the facility from sustained PQ events. Since this was "real-world" testing, it was necessary to wait for events to happen before investigating and developing intelligence based on the results. Throughout 2014, the following changes were made to the Y-B BESS islanding settings:

- Islanding for frequency violations was turned off, as transient frequency excursions were not likely to cause a problem for the HGST facility.

- The minimum duration of a voltage violation to trigger islanding was increased from one half-cycle to one full cycle.
- The minimum islanding time was changed from 9 seconds to 30 minutes. This change was made in response to the nuisance islanding that often occurred in clusters due to PG&E's circuit reclosing logic.

There were two significant failures related to islanding. One incident involved the failure of a power supply to the motor-operated switch that should have returned the system to normal mode after islanding. This incident was investigated and traced to an improperly sized backup battery, which was resolved by substantially increasing the capacity of the backup battery. The second islanding failure was due to a ground fault from a blown underground elbow in close proximity to the HGST facility (see Figure 46). This incident caused one of the inverters to trip offline, which left the system with insufficient power capacity to support the HGST facility during the sustained feeder outage.

Figure 46:Sub-Cycle SEL Relay Log Showing Voltage Anomalies, Most Likely Due to Impending Failure of an Underground Elbow on the B Phase of the 2102 Feeder



Source: Steven Ng, PG&E

In response, a change was also made to inverter breaker settings to allow them to ride through these types of faults without tripping offline.

After the above changes were made, a significant decrease in nuisance islanding was observed at the Y-B BESS customer site. There has been only one islanding event since the last changes were made in November 2014 and March 2015, which appeared to have been due to a transformer failure on an adjacent feeder and therefore was a legitimate islanding event.

HGST reported a significant improvement in their operations, and they will work with PG&E to adjust the settings if necessary.

4.3 Renewable Resource Integration

To effectively characterize the capabilities of the Y-B BESS, PG&E developed the Y-B NaS Battery Test Plan. Based on this test plan, EPRI assessed the Y-B NaS BESS for its ability to improve renewable resource integration through firming and shaping a portion of the output of renewable generation sources (for example, from solar PV and/or wind energy).

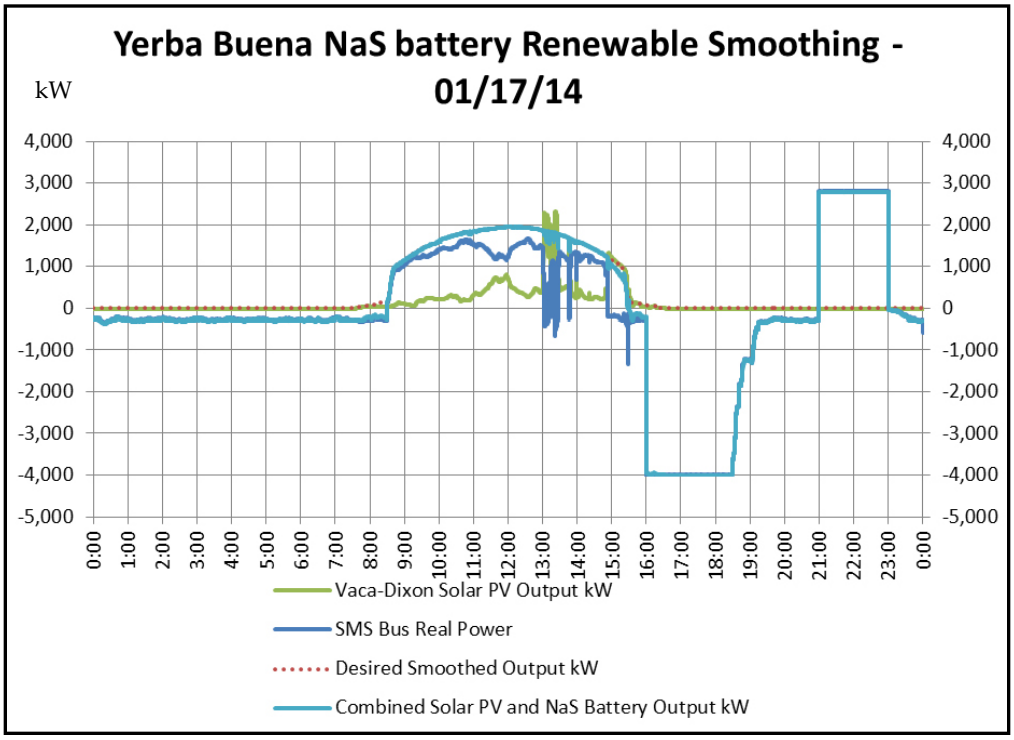
4.3.1 Summary of Results and Conclusions for the EPRI Report on Renewable Resource Integration

The ability of the Y-B BESS to smooth the output of a solar PV system to the desired solar bell-shaped load curve was undertaken. The solar PV output power used was from historical output data of a 2.5 MW-rated solar PV system that is located near the PG&E's Vaca-Dixon Substation. These values were input into the NaS BESS and the summation of the solar PV power with the NaS BESS SMS bus real power can be seen for the time period from 8:30 to 13:30 in Figure 47, resulting in the desired bell-shaped output power curve with a maximum power of 2 MW.

The BESS idle times and discharge times without solar PV (from the time period from 21:00 to 23:00) show an offset between the desired output and the actual output of around 130 kW, which can be attributed to the NaS BESS heater load. In addition, there was a NaS BESS charge and discharge cycle at rated power that occurred between the time period 16:00 and 23:00 without solar PV contribution. However, the combined solar PV and BESS output for the time period 8:30 to 13:30 can be seen to effectively form a bell-shaped output power curve with a maximum power of 2 MW, as was desired.

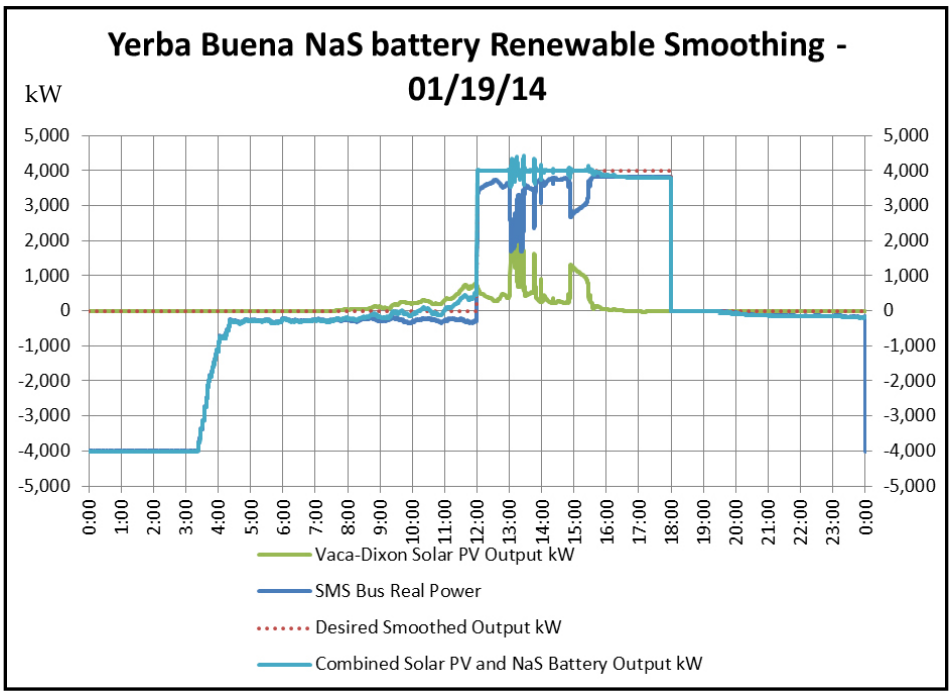
In another example of renewable smoothing, the project team took the same solar PV output with the NaS BESS output to generate 4 MW over a six-hour duration. The result is shown in Figure 48 for the time period 12:00 to 18:00. In general, the combined NaS BESS and solar PV output was able to generate the desired 4 MW output over six hours, with a couple of exceptions. The first exception occurred for the time period 12:00 to nearly 16:00 as a result of data logging resolution intervals not being synchronized. Specifically, there were times when the SMS captured data during a setpoint transition that made it appear as if the battery did not track the setpoint requested. From around 16:00 to 18:00, without any solar PV contribution, the offset between the desired output of 4 MW and the actual NaS BESS output of around 3.8 MW was due to the NaS BESS's heater load. These exceptions withstanding, the NaS BESS was able to effectively smooth the solar PV power over the first four hours and provided rated power of around 3.8 MW for the remaining two hours to generate a block-shaped output power for the desired six hours.

Figure 47: Yerba Buena NaS BESS Combined with Solar PV for Bell-Shaped Load



Source: Jason Pretzlaf, PG&E Applied Technology Services

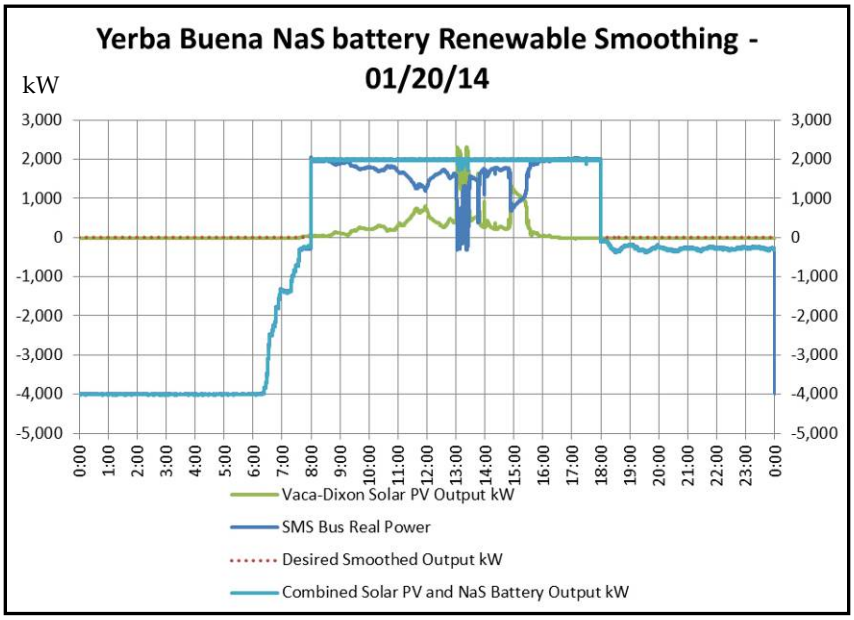
Figure 48: Yerba Buena NaS BESS Output combined with Solar PV for Block Loading at 4 MW



Source: Jason Pretzlaf, PG&E Applied Technology Services

As an additional example of renewable smoothing, the project team took the same solar PV output with the NaS BESS output to generate 2 MW over a 10-hour duration. This was done and is shown in Figure 49 for the time period 8:00 to 18:00. Overall, the combined NaS BESS and solar PV output was able to generate the desired 2 MW output over 10 hours and to effectively smooth the solar PV power.

Figure 49: Yerba Buena NaS BESS Output Combined with Solar PV for Block Loading at 2 MW



Source: Jason Pretzlaf, PG&E Applied Technology Services

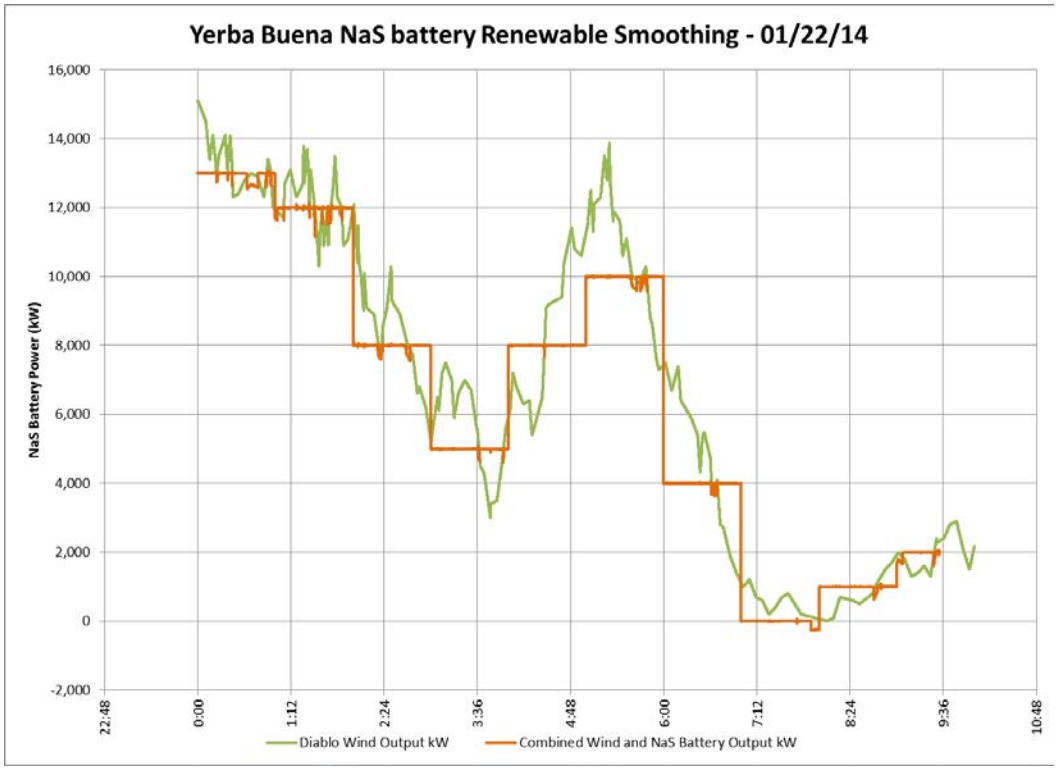
For purposes of analyzing the effect of integrating wind energy with the Y-B NaS BESS, historical power output from the 18 MW-rated Diablo Wind Plant was taken and supplied as an input to the NaS BESS so that the wind plant and BESS outputs could be combined into a desired smoothed output power to the utility. The results from this work effort can be seen in Figure 50, where the combined wind and NaS BESS output curve effectively produced the desired smoothed output power that was requested.

In conclusion, the NaS BESS was effective at smoothing renewable resources such as solar PV and wind energy provided it did not operate in the SMS 120 kW deadband. In addition, the NaS BESS SMS could perform frequency regulation in response to Supervisory Control and Data Acquisition (SCADA) setpoint requests that replicate data requests which would come from the California ISO.

4.4 Ancillary Services Assessment

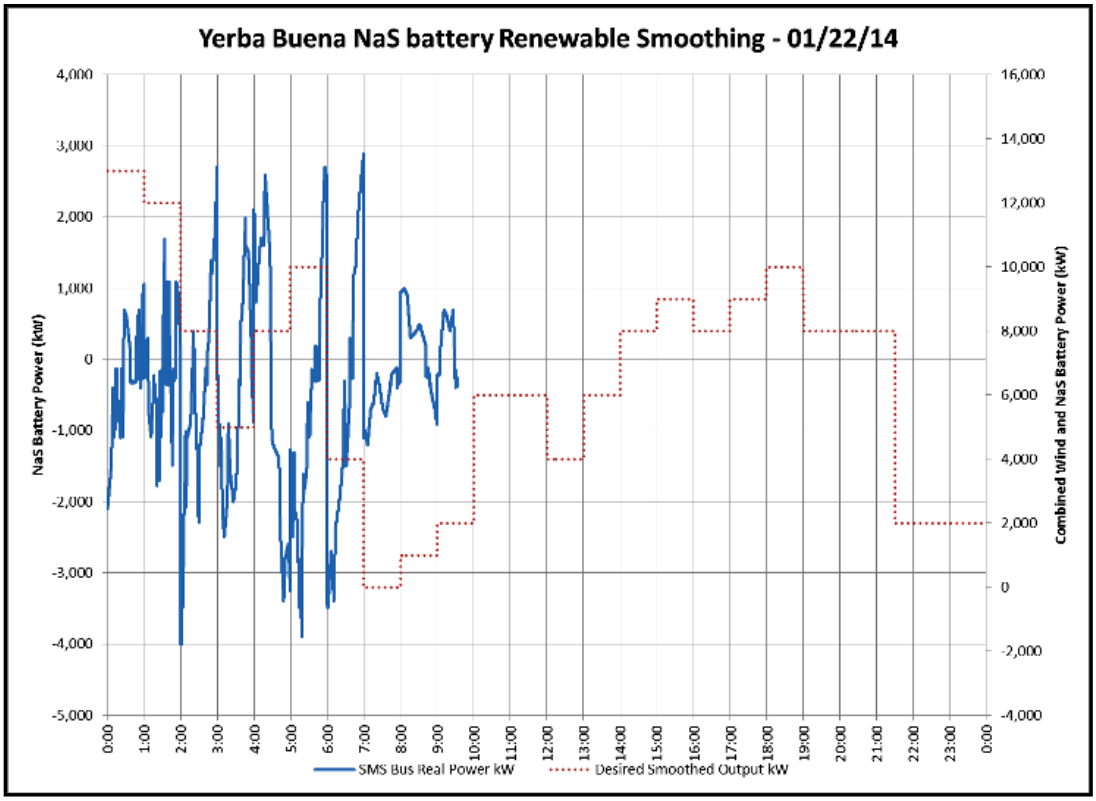
EPRI analyzed the ability of the V-D and Y-B BESS facilities to provide ancillary services in the California ISO market. The V-D system began commercial operations in California ISO markets in August 2014. As of March 2015, the Y-B BESS was not yet operational in California ISO markets; this capability is expected to be available in summer 2015. Since both BESS facilities used identical NaS technology and power conversion equipment, for illustrative purposes the V-D BESS's performance data was used for ancillary service evaluation below.

Figure 50: Chart Showing Scaled Wind-Farm Output (Green) Firmed to Constant Hourly Blocks (Orange)



Source: Jason Pretzlaf, PG&E Applied Technology Services

Figure 51: Excerpt of Battery Output Analysis Results to Derive the Resultant Firmed Hourly Output

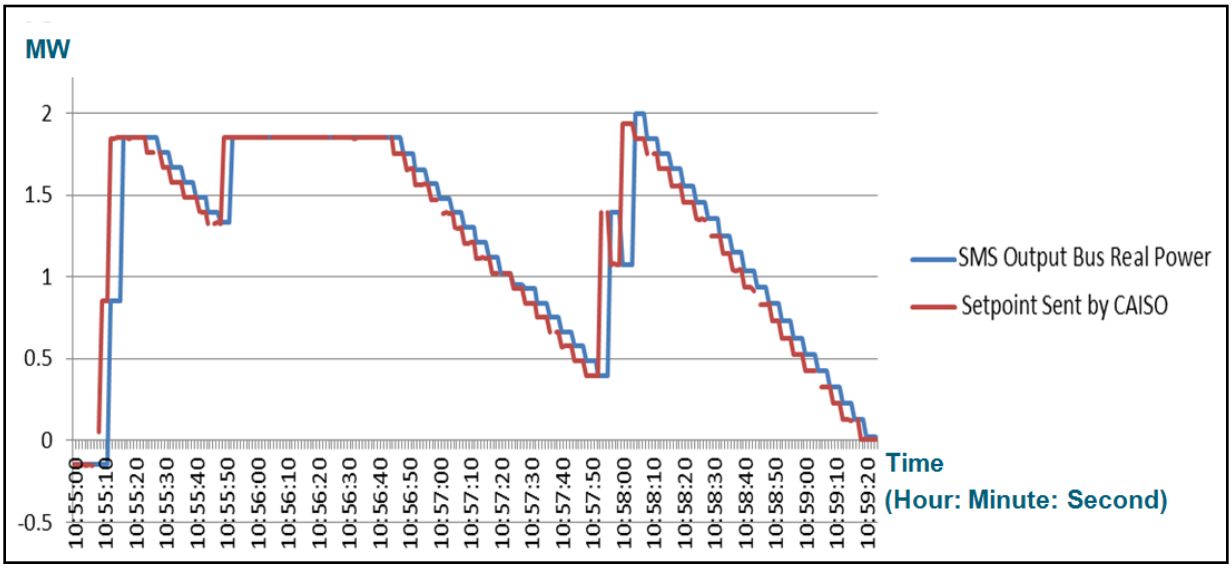


Source: Jason Pretzlaf, PG&E Applied Technology Services

4.4.1 Regulation Up and Regulation Down Ancillary Service Analysis

Figure 52 and Figure 53 show that the V-D NaS BESS performed regulation up and regulation down duty when it received real-time regulation signals from the California ISO, which occurred on a four-second time interval. The total time interval for the communication signal from California ISO to get to the V-D BESS, and then respond to this signal was less than one second. Figure 52 and Figure 53 together with other test data show the MW level of the V-D BESS over the time period from full charge to full discharge within the power and energy ratings of V-D BESS. Figure 52 covers a four-minute time period of continuous regulation-up duty and regulation-down ancillary service duty, whereas Figure 53 covers a six-hour time period of continuous regulation-up and regulation-down ancillary service duty.

Figure 52: Vaca-Dixon NaS BESS MW Up/Down Response Time Responding to California ISO Four-Second Automatic Generation Control (AGC) Signals over Four Minutes



Source: David Fribush for PG&E

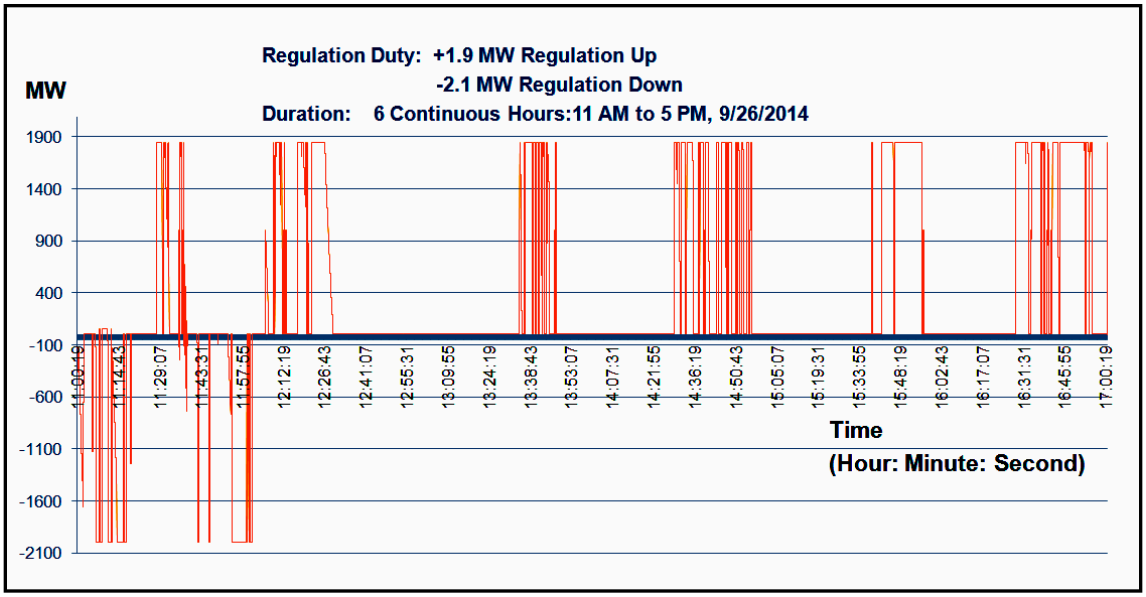
Thus, the PG&E NaS BESS facilities have full load (at charge and/or discharge MW load levels) which is an extremely fast time response (less than one second) when compared to a wide variety of other power plants (such as natural gas, coal, or nuclear fueled plants which have a regulation time response characteristic of tens of minutes to multiple hours). According to Federal Electric Reliability Commission and California ISO rules, if the PG&E NaS BESS facilities are put into regulation-up and/or regulation-down service, they should be able to obtain extra pay-for-performance revenue when compared to a wide variety of other plants that have much slower regulation/ramping time response performance characteristics.

4.4.2 Spinning and Non-Spinning Reserve Ancillary Service Analysis

PG&E did not perform tests based on California ISO input signals under this contract. Therefore, to assess the spinning reserve and non-spinning reserve performance capability of the BESS facilities, an analysis was performed on test data results that showed the performance of the BESS facilities responding to input test signal MW step changes.

The first such test data is shown in Figure 52 and Figure 53, where California ISO regulation up and regulation down signals were sent to the V-D NaS BESS. The time interval from the start time of the California ISO control signal to a specified up or down MW level (within the BESS's MW capability of +/- 2 MW) to the time the BESS completed its response to the California ISO signal was less than one second. Since the California ISO rules for the maximum time interval for such a response is 10 minutes, the V-D NaS BESS satisfied the California ISO spinning reserve requirement.

Figure 53: Vaca-Dixon NaS BESS MW Regulation Up/Down Response to California ISO Four-Second AGC Signals over Six Continuous Hours



Source: David Fribush for PG&E

For non-spinning reserve, the California ISO requirement is to respond to the California ISO MW load requirement (within the BESS's MW load capability of +/- 2 MW) after a pre-specified time delay, which is specified by the owner of the plant and used by the California ISO when sending signals to the BESS. Since non-spinning reserve is a less demanding and less valuable market product than spinning reserve and the battery resources require virtually no start-up time (that is, less than one second), PG&E elected not to certify the resource for non-spinning reserve.

Considering a NaS BESS duty cycle at a distribution feeder to a "large" customer, EPRI used the islanding response data and other market response data to determine that the PG&E NaS BESS facilities can respond to California ISO spinning reserve control signals. PG&E is planning to test this capability in mid-2015.

4.4.3 Voltage Support Performance Ancillary Service Capability Analysis

Voltage support performance assessment of the Y-B PG&E NaS BESS facility located at the HGST customer site in San Jose, California was conducted by operating this facility via a local controller to have its output power operate at specified real and reactive setpoint power levels. It should be noted that California ISO does not currently provide voltage support market revenue awards so this product was not used in practice at the California ISO during this project.

Figure 54 shows such an operational test conducted for approximately 31 minutes from about 7:44 am to 8:15 am on February 22, 2014. The red segmented line shows reactive NaS BESS

kilovolt-amperes reactive (kVAR) output power levels responding to red-dot input kVAR setpoint power levels; and, the blue segmented line shows real kW output power levels responding to blue dot input kW setpoint power levels. The green segmented line is the corresponding power factor for each of the real and reactive power levels' segmented lines.

The real and reactive kW and KVAR power output levels can be set independently (which is a California ISO requirement for the voltage support ancillary service market) and the response time for the Y-B NaS BESS was less than one minute (which is also a California ISO requirement for the voltage support ancillary service market). The actual voltage support response time was less than one second after a setpoint is sent to the Y-B NaS BESS.

The graph in Figure 54 was obtained via local control of the Y-B BESS. If California ISO provides voltage support market revenue awards in the future, this control signal could come from the California ISO. If that were the case, the overall Y-B BESS performance response characteristics must include the latency time delays associated with the total hardware, software, and communication system at the California ISO and at the local BESS facility level. This latency time period is embedded into the results shown in Figure 54, where the total overall response time period is less than one second.

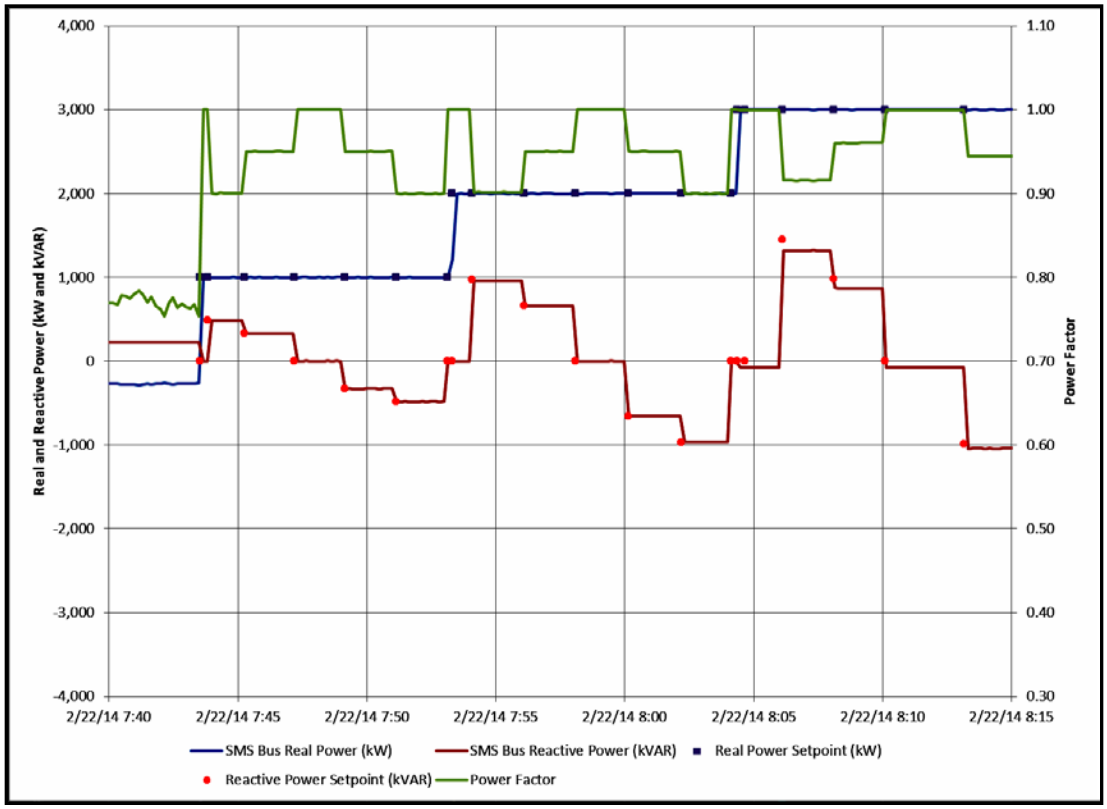
4.4.4 Black Start Capability Performance Ancillary Service Capability Analysis

The existing Y-B and V-D NaS BESS facilities were not specified or built for black start duty. Even so, black start capability could be specified and built based on commercially available components. Depending on an economic benefits-to-cost analysis, such a black start capability may be built in the future.

Based on current California ISO requirements, black start duty is a 24x7 duty cycle, and such a plant must be on-line within 10 minutes after it gets a control signal from the California ISO and a black start plant must provide a specified amount of power for a minimum of 12 hours. Thus, any BESS designed and built for black start duty will likely have a much larger rating (in power and energy) than that which is needed for one or more of the other California ancillary services discussed herein. As a result, adding black start duty to any California battery energy storage facility will likely be difficult to justify on an economic basis unless there are some unique emergency power requirements that must be satisfied and other black start technology options cannot be implemented (for example, the use of commercially available emergency diesel generators may cause unacceptable air quality or climatic impacts).

EPRI recommended that PG&E further investigated the costs and benefits of adding black start capability to these NaS BESS facility types. After discussing this option with S&C, PG&E determined that such a capability is technically feasible but its cost would be extremely high.

Figure 54: Vaca-Dixon NaS BESS Real and Reactive Power Performance



Source: Jason Pretzlaf, PG&E Applied Technology Services

4.5 Technology Transfer Activities

The key purpose of EPRI's technology transfer report was to document the ways that the knowledge gained, experimental results, and lessons learned from both of PG&E's NaS BESS facility projects have been communicated to key California state decision makers and other stakeholders. A summary of the EPRI report on PG&E's technology transfer activities on their NaS BESS projects are presented below.

The following items are the general results of the discussions which occurred before, during, or after the tours and presentations associated with the technology transfer activities of the V-D and the Y-B NaS BESS demonstrations:

- Proactive technology transfer activities (conference and industry storage-related panels, tours, and presentations) are excellent means to inform the public, regulators, and energy storage stakeholders of the project results.
- The general public understands the need for energy storage facilities in California once it is informed and/or thinks about the intermittent and power fluctuation nature of solar and wind renewable generation resources.

- The general public does not understand how the California electric grid works and how the California electricity market works. They are interested in obtaining information and learning about these topics.
- Safety concerns associated with the NaS technology (and other battery systems) came up frequently during discussion sessions.
- Most people participating in tours and conferences about the PG&E NaS BESS demonstrations did not understand how the chemistry of the NaS battery cells actually works; however, they do understand the importance of these or any other BESS facilities having high round-trip efficiency, long battery cell life, and low operating costs.
- Most people did not understand why it takes so long for battery plants to be installed throughout California, even though they understand that cost-benefit and technology assessment analyses need to be performed before building these plants in California.
- One common question expressed by battery suppliers concerned the current and expected future California ISO market rules for estimating the future economic benefits of any battery system when used for duty cycles such as for capacity, frequency regulation, black start, VAR support, synchronous spinning reserve, non-synchronous spinning reserve, and ramping (up-ramp versus down-ramp).
- People who attended these technology transfer events expressed that they learned important information and were pleased they came to the events.

CHAPTER 5:
Challenges, Solutions & Lessons Learned

Bringing these battery systems online involved overcoming numerous challenges which are likely to be experienced by other utilities deploying energy storage technologies. A description of the challenges, actions taken to meet those challenges, and lessons learned are summarized below.

The challenges are broadly categorized as organizational, technological, financial, and regulatory challenges. While most of the challenges have elements of more than one category, they are grouped by the category in which the challenge has the biggest impact.

5.1 Organizational Challenges:

5.1.1 Developing New Roles and Responsibilities for Operating Storage Assets

The fact that a battery energy storage system can be both a generator and a load, and provide services to both distribution and transmission infrastructure, represented an integration challenge for PG&E. While PG&E has extensive experience operating pumped hydroelectric resources that also operate as a generator and a load, these resources are owned and operated by the PG&E Utility-Owned Generation group who has extensive experience operating generating assets and this Line of Business (LOB) acts essentially like an independent power producer.

In the case of battery pilot projects, the resources are PG&E distribution assets and the owner is the PG&E Electric Operations LOB. Typically, a distribution resource would be operated by Distribution Operations. In the case of the pilot projects, the day-to-day operations were conducted by the project team engineer from the Applied Technology Services group. Yet, the BESS facilities are also participating in California ISO markets, which is a function managed by PG&E's Short Term Electric Supply (STES) group under the Energy Supply LOB. STES is the operator who would bid the resources if they are participating in the California ISO markets. These realities also brought up the questions such as who is responsible for maintaining the resources when used for different functions, who would notify the various groups and California ISO, how the resource performance would be tracked and accounted for, and other questions about how to use a resource that did not clearly fit within a PG&E utility precedent.

The challenge was to create new roles and responsibilities that covered the gamut of resource operations that would be acceptable by all parties within PG&E.

5.1.1.1 Actions Taken by the Project Team

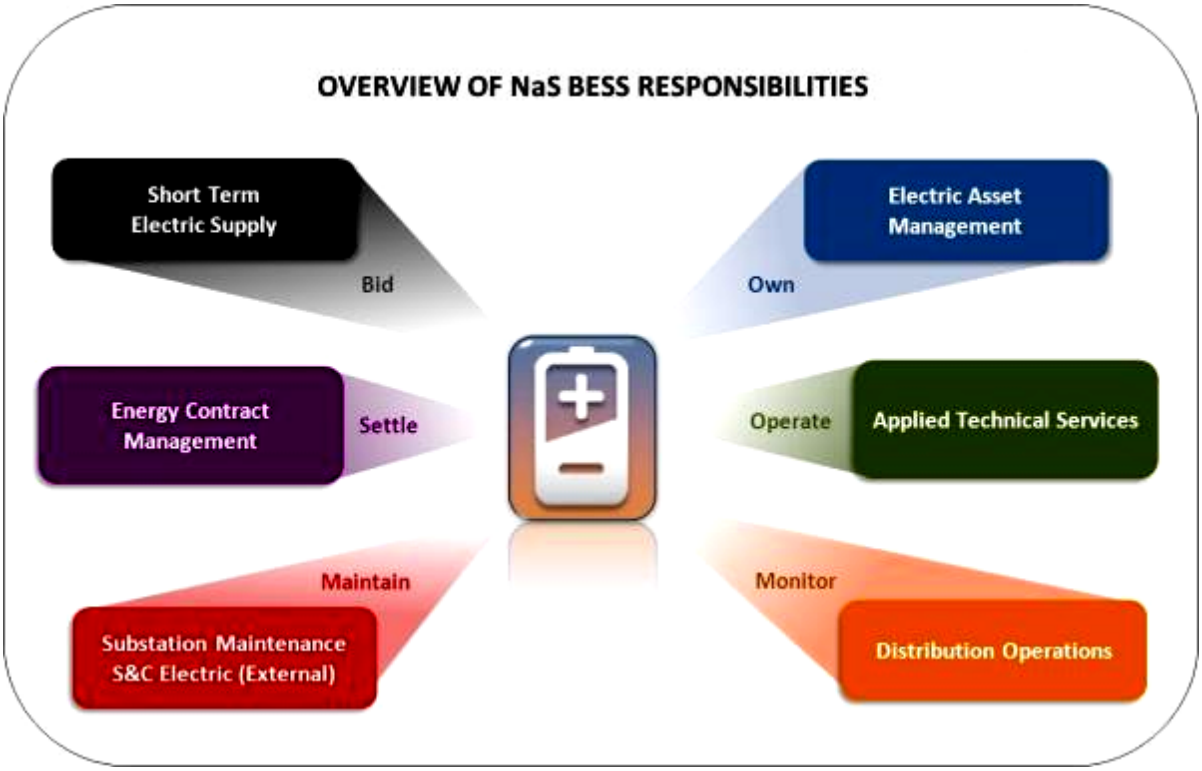
Early in the project, the project team began to work with the various LOBs and the personnel who would be directly involved in BESS resource operations. Extensive meetings and discussions were conducted with the Distribution Operations group at the Auburn Control Center to review and address the question of who will operate the resource, as it was

unprecedented that a resource in its control area would be operated by non-Distribution Operations personnel.

The project team worked with personnel across disparate groups and LOBs to get input, build working relationships, develop buy-in, and create a Roles and Responsibilities document agreed to by all referenced LOBs for operating the NaS BESS facilities.

Below is a diagram that shows the breakdown on the roles and responsibilities for the NaS BESS facilities by PG&E department and position.

Figure 55: Overview of the PG&E NaS BESS Roles and Responsibilities



Source: David Fribush for PG&E

- Electric Asset Management is the asset owner who has overall responsibility for the operation and evaluation of BESS assets.
- Applied Technology Services handles the day-to-day operations of the battery via programming the batteries' control systems, evaluating BESS performance on a variety of technical metrics, and maintaining battery health.
- STES schedules/bids the BESS assets into California ISO markets and is the primary contact for outage notification.

- Distribution Operations monitors the BESS assets via SCADA systems, provides clearances when requested, responds to SCADA alarms, and alerts STES about outages and service restorations.
- Energy Contract Management is responsible for settling market payables/receivables with the California ISO from battery operations.
- Substation Maintenance is primarily provided by S&C through a service contract with PG&E. Maintenance responsibility includes acting as a first responder to alarms and equipment trouble and conducting monthly visual inspections.

5.1.1.2 Results

The roles and responsibilities described in Section 5.1.1.1 accounted for virtually all scenarios experienced with battery operations; each group effectively performed their function. One successful example was the management of new notification processes between Auburn Distribution Operations and PG&E's Real-Time Generation Desk by both groups. A particular challenge was the coordination of system repairs between the system vendor (primarily S&C), PG&E Substation Maintenance, the project team, and third parties (particularly HGST), especially when repairs required electrical clearances and outages. Initial working relationship challenges lessened over the duration of the project, as all parties gained experience with the processes to manage and operate the BESS facilities in an effective manner.

5.1.1.3 Lessons Learned and Recommendations

The project team and offers the following lessons learned and recommendations from the project:

- Operating and maintaining energy storage resources requires utilities to develop new roles and responsibilities that cross traditionally separate business and organizational functions.
- Developing new roles and responsibilities can be a difficult and time-consuming process. Early, frequent, and iterative engagement with all involved personnel is important from project inception through deployment and operations of a BESS facility.
- Once precedent is established in a utility environment, it is vastly easier to repeat (and concurrently more difficult to change). Pilot projects should allow ample time to work out issues with roles and responsibilities early on in the project.

5.1.2 Addressing Concerns about Unfamiliar Technology

At multiple times during the deployment and testing of the various system components, as well as during operations and maintenance of the completed system, field personnel raised concerns about the reliability and safety of equipment they felts was unproven.

Relative to the typical utility equipment found on a distribution system, this perception is actually quite reasonable, and the project certainly saw far more than its statistical fair share of

component failures, maintenance complications, and other issues that did more to bolster this perspective than refute it.

Additional time and effort in understanding and addressing field personnel concerns delayed completing project milestones and incurred financial costs from those delays, and sometimes required upgrades/replacements of equipment to meet PG&E and CAISO requirements. Some examples are a requirement for additional backup power for protection relays, the installation of additional metering, and the addition of additional safety equipment.

5.1.2.1 Actions Taken by the Project Team

The project team spent extensive time working with field personnel to understand their concerns, answer questions, escalate issues to system vendors, coordinate between parties, and wherever possible develop solutions to address as many concerns as possible.

When it was not possible to address all concerns, the project team engaged with high-level utility managers to obtain exceptions or issue "hold harmless" letters to field personnel. Overall, the project team addressed a high percentage of field personnel concerns, but the perception that these systems are unproven remains.

5.1.2.2 Lessons Learned and Recommendations:

- Field personnel should be consulted at the project scoping stage to develop more of a sense of ownership and address concerns when they are easiest and least expensive to address.
- Standard utility substation equipment should be used where possible, such as switchgear and transformers.
- Particular attention should be made to ensuring that component vendors understand utility SCADA equipment and make their products compatible and meet or exceed electric utility standards.

5.1.3 Complexities of a System at a Third-Party Site

While energy storage resources can provide benefits to third parties, such as the islanding functionality that the Y-B system provides HGST, siting a system adjacent to an external party comes with complexities and risks.

For this project, there was an extensive 18-month delay due to protracted lease negotiations with the superior tenant and landowner of the property on which the battery was to be sited. The fire at the NGK battery in Japan raised understandable concerns by HGST safety and facilities personnel. Construction and maintenance activities were sometimes disruptive to HGST personnel. It took time and an iterative process to hone the system's islanding settings to minimize "nuisance" islanding events. There also were a few occasions in which the system did not island successfully, which impacted the facility.

5.1.3.1 Actions Taken by the Project Team

The project team developed a successful and constructive working relationship with HGST facility staff by understanding their concerns, answering questions, escalating issues to system

vendors when necessary, coordinating between multiple parties who operate and maintain the resource, coordinating construction activities that impacted HGST facilities or staff, adjusting the system's islanding settings through empirical experience, and developing solutions to address as many concerns as possible.

In response to HGST's concerns following the fire at the NGK battery in Japan, PG&E installed additional fire safety upgrades (sulfur-dioxide monitoring and alarming, additional fire detection and alarming) and developed a comprehensive, site-specific plan with HGST personnel.

5.1.3.2 Lessons Learned and Recommendations:

- Installing equipment at a customer or third-party site can expose utilities to a number of risks throughout project design, deployment, and operations. A thorough risk-reward assessment should be conducted to ensure that risks do not significantly outweigh benefits.
- Early and frequent engagement with third-party personnel is essential; they should be treated as project partners.
- When installing a project on land owned and/or occupied by a third-party, additional safety measures may be requested by third parties. Comprehensive due diligence should be conducted by utility safety personnel and third parties on potential safety issues at the outset of the project to ensure each party understands risks and mitigation measures.
- Project schedules should be shared with and reviewed by third-party personnel to ensure that work is conducted in a way that minimizes impact to the third party.
- Installing equipment on a customer or third-party site could add uncertainty into project planning. Project plans should allocate additional time and funding to address customer concerns/requests and unanticipated needs during the course of a project.

5.1.4 Need for Single Project Integrator

PG&E purchased the batteries separately from the other BESS components (inverters, transformers, switchgear) necessary for a fully functioning integrated system. S&C was the construction contractor for the project, but not the full system integrator. There were some situations where responsibilities amongst PG&E, S&C, and NGK were not clear.

Even if S&C and NGK had been consolidated as one project integrator, there is still a point of handoff to the utility. For example, telecommunication issues often fell into a grey area at the point of intersection between the utility and a third party, where one entity was responsible for installing a conduit and running fiber optic cable through it, but another entity was responsible for terminating the fibers. When a fiber optic cable or connection failed, it was difficult to arrange for troubleshooting and determine who is responsible for the repair, including costs. In this example, the cause was eventually identified as a faulty fiber strand, which was S&C's responsibility. A spare strand had been installed for this eventuality and was utilized.

5.1.4.1 Lessons Learned and Recommendations:

- Utilities should strongly consider contracting with a "one-stop shopping" single integrator for all system components that will be responsible for managing the various vendors and subcontractors.
- Points of hand-off between one party and another should be clearly demarcated at the scoping stage of the project
- Technical points of handoff (such as a telecommunication integration point) should be clearly delineated and determined with consideration to how troubleshooting problems during or following deployment will be conducted.

5.1.5 Need for Flexibility in Contracts

These NaS BESS demonstrations utilized a new technology and any new technology changes over time rather quickly. Since these types of projects in a utility setting can take multiple years to deploy, it is highly recommended that contracts be written in a flexible manner to allow for technology improvements and lessons learned to be incorporated during the project.

An example of a contract lacking flexibility was the specification of all the telecommunications hardware for the system. During the deployment of the V-D BESS, the project team began developing a new Dispatch Control System (DCS) for energy storage resources. There was no guarantee of success and so the battery project had to continue as originally specified. By the time the Y-B BESS was being deployed, however, the new DCS architecture and an early release of software had been completed. This new architecture eliminated the need for some hardware that was originally specified to be deployed at Y-B. The project team approached S&C to see if the originally specified equipment could be eliminated; however, the hardware had already been purchased by S&C and could not be returned. A change order would have been more costly than moving forward with the original design.

5.1.5.1 Lessons Learned and Recommendations:

- A balance needs to be struck between specifying system details in advance – so both parties know exactly what they are getting – with the need for flexibility as knowledge is gained along the way. Contracts should not necessarily specify the exact types of technology or equipment, especially for secondary or supporting systems (for example, telecommunications). Instead, the contract could specify expected performance requirements, including compatibility with interconnected systems. Exact equipment types and model numbers could be determined closer to deployment dates to ensure that they are most compatible with the project needs at that time.
- When possible, incentives should be incorporated into contracts to encourage project participants to employ new knowledge and technologies and on-going lessons learned to reduce overall costs while improving project performance. Contracts could include incentives to all parties for ideas or changes that would improve the project's technological, financial, and other performance, with a particular attention

to long-term ownership and improved performance of the asset. A process will be required for evaluating and approving/denying suggested changes and for compensating the respective parties if the change is successfully implemented.

5.2 Technological Challenges

5.2.1 Developing New Communications and Control Pathways, Hardware, and Software

The many different functions that battery energy storage systems can provide presents operation and integration challenges for utilities, necessitating new communications and control pathways, hardware, and software. The challenges are further exacerbated by the strict Information Technology (IT) cyber-security policies that exist in utility environments to insulate operational equipment from external communications (see Section 5.2.2).

This project faced numerous IT challenges and cumulative delays from IT-related issues. Many of these delays were to get devices to talk to each other and provide remote access to those who need it. The project team made significant progress in developing new IT architectures, hardware, software, visualization tools, and remote access. By setting a successful precedent, future storage projects can avoid the same delays and many of the costs associated with developing and deploying these capabilities the first time.

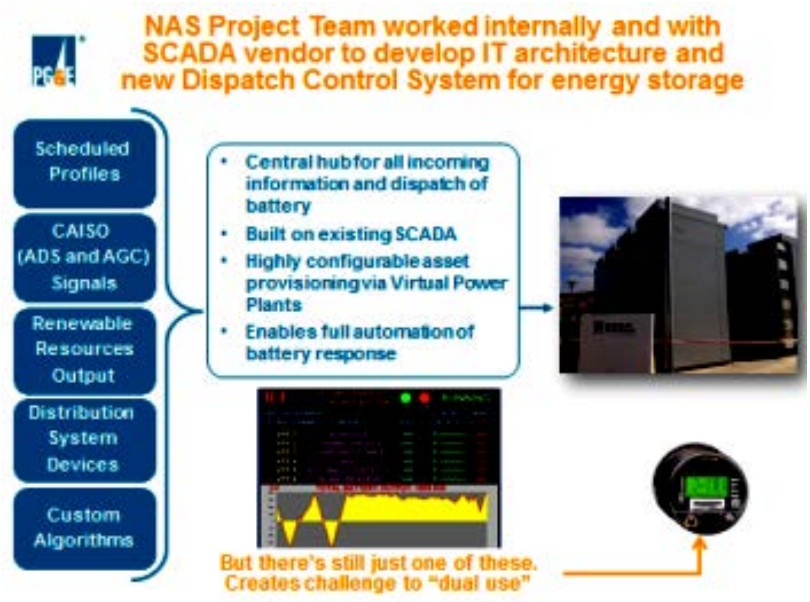
5.2.1.1 Actions Taken by the Project Team

In October 2012, the project team began development of a DCS application for controlling and automating the response of energy storage resources via PG&E's existing SCADA system. This development began with the recognition of the need to aggregate data in one point to enable the multiple functionalities of a battery system, greater operational flexibility, and better integration with existing utility visualization and control systems.

The project team presented the project to its SCADA vendor, DC Systems, who expressed a strong interest in co-developing the product called RT Stored Energy Control System (RTsecs). The project team worked closely with DC Systems and PG&E IT personnel to provide the product specifications, IT architecture, and other technical details and requirements for the overall battery system. All battery functions are controlled via the RTsecs application, which interfaces with the S&C Electric Storage Management System, which in turn, interfaces with the battery system and other resource components.

In August 2013, PG&E began beta-testing the DCS application at the Y-B BESS facility. In May 2014, following successful testing and product iteration at the Y-B facility, the DCS was deployed in production at the V-D BESS facility. The DCS was successfully used for operating the battery systems for multiple functionalities, including daily scheduling, peak shaving, renewable smoothing, and California ISO market operations at the V-D BESS. (Note: California ISO market operations will commence for the Y-B BESS facility in mid-2015).

Figure 56: Presentation Slide Describing RT Stored Energy Control System, Developed by the Project Team and DC Systems



Source: David Fribush for PG&E

5.2.2 Difficulty and Delays in Obtaining Necessary IT Support

There are two diametrically opposed forces at work with regard to IT and utilities. One force is the emergence of devices, energy storage systems among them, which require new IT communications pathways for effective operations. This force pushes for more open communications between devices, information sources, operators, and general connectivity. The other force is the threat of cyber-security attacks against utilities, which can negatively impact the grid and its equipment. This force pushes for closing communication channels, restricting visibility of devices, and isolation. The result was that new communications pathways were often at odds with existing and trending utility IT policies. There were extended delays in getting new IT communications pathways approved and enabled.

An example of this type of delay was the process for getting remote access to the energy storage resources for the Project Engineer. Remote access control would save the Project Engineer a minimum half-day of travel for each site. Two years elapsed from the time requests were made to PG&E IT to when the necessary communication pathways and middleware software were approved and deployed. Two key reasons for this long delay were:

- Extensive reviews required by IT and risk management personnel and need for deployment of new software within the secure IT network.
- Need for communications channels that crossed between lesser security network infrastructure and highest security network infrastructure.

5.2.2.1 Actions Taken by the Project Team

The project team assiduously worked to provide IT decision-makers with requested information, brokered meetings with vendors, developed detailed and extensive communications describing proposed projects, and helped identify high and low security risks.

5.2.2.2 Lessons Learned

- Deploying energy storage resources will likely require utilities to deploy new communications pathways for visibility and control. It is important that those deploying these systems, especially for the first time, begin conversations with relevant IT personnel as early as possible to begin the vetting process and identify solutions that have the least risk of lengthy delays.
- Good working relationships and/or a project champion within the IT group can significantly help the process. Project management should get input from IT personnel in developing the work scope to achieve the project goals.
- Deploying as a pilot project (and emphasizing as such) can help ease approval by IT personnel who may be more willing to allow new communication solutions for pilot projects.

5.2.3 Higher than Expected Failure Rates, Particularly In Power Conversion Equipment

Equipment failures were expected because of the complexity and new uses of battery energy storage systems to perform grid functions. This type of equipment typically has a high rate of failures at the beginning and end of life.

Since commissioning, both the V-D and Y-B BESS resources have experienced multiple forced outages in their power conversion equipment and switchgear. (The batteries themselves – that is, the DC side of the BESS facilities – have had very few and minor failures).

5.2.3.1 Actions Taken by the Project Team

The project team worked closely with the project, engineering, and IT teams from S&C to help provide diagnostic information, coordinate root cause investigations and repair work with substation maintenance and third parties, secure necessary clearances to support maintenance work and contracted repair work, and generally endeavored to identify failure causes and implement fixes.

5.2.3.2 Lesson Learned

- Expect system failures and ensure that sufficient personnel, funding, and protocols are in place to mitigate issues when they occur.
- During the engineering design phase, consider how equipment will be maintained and design the system for efficient service and repair equipment.
- When possible, use utility standard components for power conversion, such as voltage step-up/down transformers and other equipment to reduce system-level failure rates.

5.2.4 Unique Safety Risks and Mitigation Needs

The fire at NGK's installation in Japan illustrated the fact that battery technologies carry unique risks for utilities. A fire at a NaS battery is difficult to put out because water cannot be used. Essentially, a fire must be left to burn itself out[5].

5.2.4.1 Actions Taken by the Project Team

The project team worked in close coordination with PG&E's safety experts, engineers, local fire departments, and NGK to develop specific site and resource safety plans and joint response protocols. For the Y-B BESS, extensive safety plan development was conducted in coordination with HGST safety personnel, and additional mitigation was put in place to address their concerns. Numerous and thorough trainings were conducted with all involved personnel, including multiple site walks with local fire battalion personnel.

In addition to the safety upgrades provided by NGK, as detailed earlier in this report, PG&E installed secondary fire and sulfur dioxide detection and visual and audio alarms for additional protection of anyone in proximity to the BESS equipment.

5.3 Financial & Regulatory

5.3.1 Parasitic Loads and Efficiency Losses Are High and Constrain Use Cases

Measuring round-trip AC-to-AC BESS efficiency involved making a number of judgment calls. The key determinant of round-trip efficiency was the energy consumed by the battery modules' heaters, which maintain a temperature of at least 300 degrees Celsius. A very detailed analysis of system efficiency can be found in the Engineer-of-Record reports for Task 2. Overall, the AC efficiency of the BESS was between 60 and 80 percent, depending on how it was used and cycled over a given period of time. This is in line with most other commercially available BESS resources.

Losses of 20 to 40 percent represent a financial challenge for energy storage resources, as well as a regulatory challenge because resources that consume more energy than they generate could negatively impact the overall electric grid if they are not properly deployed and operated. For market participation, losses of 20 to 40 percent require the market to provide compensating price differentials for the resource to be economically operated. For the duration of this project, the California ISO market energy prices were fairly flat and ancillary services capacity prices were low, creating a challenging financial picture for energy storage. It is expected that as some existing fossil fuel generation plants are retired in the coming years, and more intermittent renewables come online, electricity prices may become more volatile and therefore attractive, since the market economics of batteries rely on price differentials and not absolute prices.

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5 In the case of the NGK system, a special vermiculite sand compound is to be sprayed on the fire-damaged equipment to contain it – but only after the fire has burnt itself out.

5.3.1.1 Actions Taken by the Project Team

The project team extensively studied system efficiency and heater use and endeavored to develop operational profiles that reduce the use of battery heaters. However, it was not possible to significantly minimize the use of heaters, as the cells must be kept at a high minimum temperature.

5.3.1.2 Lessons Learned

All commercially available energy storage resources have a significant parasitic load that cannot be extensively mitigated – sodium batteries must be heated, lithium-ion batteries must be cooled, and flow batteries must be pumped. Future energy storage procurements should consider the environmental setting of the system when choosing a storage technology. For example, it may not make sense to put heated technologies in wintry climates and cooled technologies in the middle of the desert. Similarly, project developers should consider how the resource is operated when evaluating different energy storage technologies since it can have significant impacts on system efficiency.

5.3.2 Significant "Hidden" Costs

Battery energy storage systems are complex devices and servicing them requires specialized expertise that can likely only be provided by a specialized vendor. As such, the cost of service contracts, maintenance support, and spare parts over the life of the battery energy storage resource must be considered.

Unexpected costs were experienced during the Y-B BESS project in supporting maintenance work conducted by S&C. PG&E has more stringent standards for electrical clearances and grounding of equipment for maintenance work than the industry standards and code requirements that S&C follows. For example, S&C personnel would normally use a grounding switch on their switchgear as sufficient grounding protection for working on the system, but PG&E standards require visual confirmation of open circuits. Since the grounding switch did not provide a visual open, a more complex grounding process was necessary involving the removal of electrical elbows and two different grounding crews for high and low voltage sides of system equipment.

Additionally, the Y-B site has a diesel backup generator to provide electrical power to the NaS BESS heaters during a utility outage if the BESS is offline and unable to supply the heaters from its own stored energy. While this generator should only run in very rare occasions where there is a loss of utility power and the system is drawn down to a zero state of charge, there were several times the generator ran during maintenance work due to the way the equipment had to be cleared and grounded. This method had both financial and emissions impacts.

5.3.2.1 Actions Taken by the Project Team

The project team worked extensively with S&C and PG&E substation maintenance personnel to develop equipment modifications to enable easier grounding, and developed new maintenance processes that mitigate the use of the diesel generator during maintenance.

5.3.2.2 Lessons Learned

The cost of a long-term service contract must be part of the financial evaluation of BESS projects since the specialized skills required to service this equipment are unlikely to be held by the asset owner. Service contracts should also include the cost of spare parts, which are likely to be specialized and expensive.

Substation maintenance personnel should be brought into the engineering design of the project to ensure that it is designed for utility processes for clearances and grounding of equipment.

5.3.3 Many Storage Functionalities Don't Have a Market

The financial case for energy storage almost always relies on providing multiple benefits, such as providing energy and ancillary services, distribution system support, and smoothing for intermittent renewables As demonstrated in this project, battery resources are fully capable of providing multiple benefits yet currently there are no direct financial markets for many of these services, such as smoothing an intermittent renewable resource. Even with projected decreases in the cost of energy storage, more direct compensation for providing multiple benefits will be necessary to make energy storage projects financially positive investments.

5.3.4 Accounting for Storage

Where there are markets for energy storage services, the regulatory mechanisms for compensation may not be fully realized. For example, the Y-B BESS facility can provide both market and distribution services, but in practice there is no established way for accounting for this dual use. The Y-B BESS has a California ISO meter that always runs, so any functions performed for distribution support will still be read by the California ISO meter and the resource will be charged (or credited, in the case of generation) accordingly. This dual use creates complexities in settlements with the California ISO and rate recovery because market assets aren't fully rate-based, but distribution assets are fully rate-based. Currently the California ISO and other stakeholders are examining this issue and hopefully will develop new rules and procedures that will better enable asset owners to take advantage of the dual-use capabilities of battery systems.

CHAPTER 6: Conclusion

The six-year journey from the initial purchase of the NGK NaS batteries to the writing of this report is testament itself to the challenges of bringing these projects online and generating the real-world results that are documented in this report and the detailed Task Reports developed under this contract.

The root of these challenges lies in many areas, but perhaps, at its most fundamental level, it is the challenge of doing something very new. Hopefully, the lessons learned and precedents set during this project will make future energy storage deployments much easier and faster.

This project successfully demonstrated that battery energy storage systems can indeed provide multiple benefits to California's distribution grid and electricity markets. Many questions remain as to how well these benefits can be practically realized by those deploying battery storage, at what cost, and at what quantifiable and paid benefit. These broader challenges will also require innovative solutions to organizational, technological, and financial challenges. But if there is any place in the world that best embodies innovative solutions, it is California.

The project team thanks the many people at PG&E who have helped make this project a success, and especially our project partners at S&C, NGK, HGST, and the Energy Commission.

GLOSSARY

Term	Definition
AC	Alternating Current
AEP	American Electric Power
AGC	Automatic Generation Control
BESS	Battery Energy Storage System
DC	Direct Current
DCS	Dispatch Control System
Energy Commission	California Energy Commission
EPRI	Electric Power Research Institute
HGST	The high-tech company adjacent to the Yerba Buena BESS (formerly Hitachi Global Storage Technologies)
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEEE 1547	IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems
IEEE 1453	IEEE Recommended Practice--Adoption of IEC 61000-4-15:2010, Electromagnetic compatibility (EMC)--Testing and measurement techniques--Flickermeter--Functional and design specifications
IFL	Instantaneous Flicker Level
IT	Information Technology
kV	Kilovolt
kVAR	Kilovolt-Ampere Reactive
LOB	Line of Business
MW, MWh	Megawatt, Megawatt-hour
NaS or NAS	Sodium Sulfur ("NAS" is a registered trademark for NGK's sodium-sulfur battery system)
NGK	Nichiyu Giken Kogyo Co. (that is, Japanese manufacturer of sodium-sulfur battery systems and other products, for example,spark plugs and insulators)

NYPA	New York Power Authority
PG&E	Pacific Gas and Electric Company
Pst	Percentile Short Term Flicker
RMS	Root Mean Square
S&C	S&C Electric Company
SCADA	Supervisory Control and Data Acquisition
SCR	Short Circuit Ratio
SMS	S&C's "PureWave®" Storage Management System
SIS	System Impact Study
SOC	State of Charge
STES	Short Term Electric Supply
TDD	Total Demand Distortion
THD	Total Harmonic Distortion
V-D	Vaca-Dixon
Y-B	Yerba Buena

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