Pacific Gas and Electric Company

EPIC Final Report

Program	**Electric Program Investment Charge (EPIC)**
Project ***Reference Name***	**EPIC Project 1.01 – Energy Storage End Uses** ***Energy Storage for Market Operations***
Department	*Electric Asset Management*
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List of Acronyms

5MM	5-Minute Market
AB	Assembly Bill
ADS	Automated Dispatch System
AGC	Automated Generator Control
BESS	Battery Energy Storage Systems
CAISO	California Independent System Operator
CDS	Central Dispatch Server
CIDI	Customer Inquiry, Dispute, and Information
CPUC	California Public Utilities Commission
DA	Day-Ahead
DCC	Distribution Control Centers
DCS	Dispatch Control System
DECS	Distributed Energy Control System
DOT	Dispatch Operating Target
ECN	Energy Control Network
EGI	Electric Generation and Interconnection
EPIC	Electric Program Investment Charge
EPRI	Electric Power Research Institute
ESOIR	Electric Safety Order Instituting Rulemaking
ESRFO	Energy Storage Request for Offers
ETRM	Enterprise Technology Risk Management
FMM	Fifteen-Minute Market
FR	Frequency Regulation
HE	Hour Ending
IIE	Instructed Imbalance Energy
IOU	Investor-owned Utility
IT	Information Technology
LESR	Limited Energy Storage Resources
LMP	Locational Marginal Price
MW	Megawatt
NAS	Sodium-Sulfur
NERC-CIP	North American Electric Reliability Corporation Critical Infrastructure Protection
NGR	Non-Generator Resource
NP	No-Pay
NRI	New Resource Implementation
OIR	Order Instituting Rulemaking
PG&E	Pacific Gas & Electric
POC	Proof-of-Concept
RegDn	Regulation Down
RegUp	Regulation Up

REM	Regulation Energy Management
RIG	Remote Intelligent Gateway
RT	Real-Time
RTDECS	Real-Time Distributed Energy Control System
SCADA	Supervisory Control and Data Acquisition
SIS	System Impact Studies
SMS	Storage Management System
SOC	State of Charge
STES	Short Term Electric Supply
TD&D	Technology Demonstration and Deployment
UIE	Uninstructed Imbalance Energy
O&M	Operations and Maintenance

1 Executive Summary

This report summarizes the project objectives, technical results and lessons learned for EPIC Project 1.01 Energy Storage End Uses, also referred to as Energy Storage for Market Operations, as listed in the EPIC Annual Report. The project was authorized on September 19, 2013 and concluded on September 13, 2016.

In 2010, California passed Assembly Bill (AB) 2514, which identified a number of areas in which energy storage systems could benefit Californians, particularly with regard to helping the state meet its ambitious Renewable Portfolio Standards.[1] However, the bill noted that "there are significant barriers to obtaining the benefits of energy storage systems." The California Public Utilities Commission (CPUC), identified nine key barriers to energy storage, including "Lack of Commercial Operating Experience," "Evolving Markets," "Lack of Transparency… in Wholesale Price Signals," "Lack of Well Defined Interconnection Processes," and "Lack of Cost-Effectiveness Valuation Method." [2]

To help address these barriers, EPIC 1.01 Energy Storage for Market Operations established the following objectives:[3]

- Utilize PG&E's recently deployed Vaca-Dixon and Yerba Buena Battery Energy Storage Systems (BESSs) to gain "real-world" experience and data from participation in the California Independent System Operator's (CAISO) new Non-Generator Resource (NGR) market model created specifically for Limited Energy Storage Resources (LESRs) such as batteries[4]
- Develop and deploy an automated communications and control solution to enable battery resources to automatically respond to CAISO market awards and thus make full use of their fast-response functionalities
- Quantify financial performance from participation in CAISO markets

Key Accomplishments

The following summarizes some of the key accomplishments of the project over the project duration:

- Successfully demonstrated the use of PG&E's Vaca-Dixon and Yerba Buena Sodium Sulfur (NAS) Battery Energy Storage Systems (BESSs) to provide energy and ancillary services in CAISO markets as the first battery storage resources in California to participate in the market
- Developed and deployed a scalable technology platform to automate the response of current and future PG&E battery storage resources to CAISO market awards via its Automated Dispatch System (ADS)

[1] California Assembly Bill (AB) 2514 – Energy Storage System Procurement Targets from Publicly Owned Utilities
[2] D.12-08-016, Decision Adopting Proposed Framework for Analyzing Energy Storage Needs, Aug. 2, 2012
[3] In the time since the Energy Storage for Market Operations Project commenced, both the CPUC and the California Independent System Operator (CAISO) have identified regulatory and market rule challenges for energy storage, particularly around metering, billing and market participation. EPIC 1.01 Energy Storage for Market Operations Project has been conducted to address the primary objectives listed here, and does not establish precedent for ongoing discussions on metering, billing and market participation rules and regulations.
[4] Non-Generator Resources have the capability to serve as both generation and load and can be dispatched to any operating level within their entire capacity range.

- Established organizational roles and responsibilities for the operation of PG&E battery storage resources as both market and distribution system assets
- Assisted PG&E's Electric Generation Interconnection (EGI) team in the development of new processes for interconnection review and approval of battery storage resources both connected to PG&E's distribution grid and providing CAISO market services
- Developed optimization models and workflow processes for efficient bidding of battery resources into the CAISO market
- Engaged with CAISO to identify and resolve implementation issues with the CAISO NGR model for Limited Energy Storage Resources based on operational experience
- Quantified financial revenues of the CAISO Day Ahead (DA) and Real-Time (RT) energy markets
- Achieved NGR model design improvements through the Energy Storage and Distributed Energy Resources (DER) initiative such as including state of charge in the day-ahead market bid parameters

Key Takeaways from Market Participation

The following findings are the key takeaways and lessons learned from this project:

- **CAISO Day-Ahead (DA) and Real-Time (RT) Energy revenues are not currently conducive to energy arbitrage.[5]**

  The economics of battery participation in energy markets are driven by the differentials between electricity prices at which the battery is charged versus those at which the battery is discharged. The project observed that these price differentials were not large enough on a consistent basis to offset the inherent round trip efficiency[6] of the BESSs, which averaged about 75 percent.

- **Frequency Regulation represented the best financial use of the BESSs.[7]**

  Frequency Regulation (FR) provided significantly higher revenues than Day-Ahead energy or Real-Time energy market participation. For the month of August 2015, when the 2 MW Vaca BESS was bid into the market every day for its full FR range, total revenues were approximately $2,000/MW. This remained the highest revenue month for FR until early 2016 when FR revenues were significantly higher, primarily driven by higher daily procurement of FR by CAISO. For the month of March 2016, the Vaca BESS operated exclusively for FR generated approximately $7,000/MW. Revenues began to return to lower levels in May 2016 as daily FR procurement decreased.

- **Spinning Reserve revenues can very modestly add to resource revenues.**

  Spinning Reserve (Spin) provides revenue for unused resource capacity that is available for quick dispatch if called by CAISO. The value of Spin was observed to be approximately $4/hour per MW.

[5] Energy arbitrage is the act of buying and selling energy, by charging and discharging the battery in this case, at electricity price differentials to generate revenue.

[6] AC energy output divided by AC energy input measured over a specified period of time at the point of electrical interconnection to the grid.

[7] Frequency Regulation (FR) is the power market that CAISO uses to compensate for the difference between Day-Ahead Energy and real-time demand. FR procures a small number of resources on call to receive continual instructions (on a 4-second basis) to increase or reduce their electric output in response to near instantaneous system needs to maintain the required frequency of 60 hertz.

Frequency Regulation, however, consistently represented a higher revenue use of resource capacity and Spin was not a significant revenue contributor during the project.

- **Overall, revenues from market participation seen during the project were less than those estimated by models filed with the CPUC and California Energy Commission (CEC).**

  To help inform cost-effectiveness evaluations, this project compared actual revenues from the battery system's participation in CAISO markets with those projected by models[8] filed with the CPUC and CEC and found actual revenues to be lower than the models' projections. This was driven primarily by lower prices for Frequency Regulation than those used by the models. See Section 6 Cost-Effectiveness Assessment for more details.

- **The NGR Regulation Energy Management (REM) Model is effective in managing BESS State of Charge (SOC) and simplifying operations.[9]**

  The NGR REM model, in which CAISO manages the resource SOC to 50%, has been effective in managing SOC, simplifying resource management, and ultimately improving financial performance as compared to the non-REM model.

- **Current market dynamics do not favor long-duration batteries.**

  Given that the most significant revenues are from FR, and that FR is a power rather than energy product (meaning that FR requires resources to provide power for short periods), a 30-minute BESS might be able to provide the same FR capabilities as a 7-hour system[10], with presumably less capital investment. [11]

- **Incentives to charge and discharge depend on the Locational Marginal Price (LMP) where the unit is located.**

  The location of an energy storage unit and the relative prices at its LMP drive the economics of when the resource will charge or discharge. Locational Marginal Prices differ based on the congestion and losses at different locations in the CAISO system, resulting in market participants responding to localized conditions and needs. While two different geographic locations might have equivalent amounts of renewable generation at a given time, there is a possibility that only one location has a negative LMP. If the storage resources are geographically outside the grid conditions driving negative LMPs, it may not make economic sense to charge. For example, even if there is over generation in Southern California, such a condition may not incentivize energy storage in Northern California to charge.

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[8] Models referenced were "Cost-Effectiveness of Energy Storage in California. Application of the EPRI Energy Storage Valuation Tool to Inform the California Public Utility Commission Proceeding R. 10-12-007," EPRI, B. Kaun Project Manager, June, 2013, and "Energy Storage Cost-effectiveness Methodology and Results," DNV GL Energy and Sustainability, August 2013, CEC 500-2014-068.

[9] The NGR model is the only CAISO model designed for energy storage and other energy constrained resources, recognizing that resources can operate seamlessly between positive and negative generation (unlike traditional positive generation only power plants). It allows smaller, energy-constrained resources to be treated on a comparable basis to traditional generation resources in qualifying for day-ahead capacity and continuous energy output when providing regulation services.

[10] Both the Vaca and Yerba Buena BESSs are 7-hour batteries.

[11] An important caveat is that it may be easier for the CAISO in the REM model to manage the SOC of a longer duration battery than a 30-minute system. As such, revenues documented in the report for the Vaca Dixon BESS as a REM resource should not be assumed to accrue fully to a 30-minute BESS.

<u>Market Participation Challenges and Resolutions</u>

Several challenges to CAISO NGR market participation were identified over the course of the project, and many of these challenges have been resolved through the joint efforts of PG&E and CAISO personnel to benefit current and future market participants. These included:

- **CAISO Day-Ahead State of Charge Assumptions**

  The CAISO currently makes an assumption about an NGR resource's state of charge at the start of the next day based on its prior DA award schedule. When the assumed SOC does not support the award, CAISO will mitigate the award. This award mitigation presented multiple issues that complicated the bidding of BESS services into markets and was a result of the SOC assumed by CAISO not accurately reflecting the true SOC of the resource (see Section 4.5.2.2). Over the course of the project, PG&E worked extensively with CAISO personnel on this issue.

  <u>Status</u>: Due to the efforts of this project, FERC recently approved the inclusion of SOC as a day-ahead bid parameter for CAISO's NGR Tariff. FERC clarified the need for such a change in an August 16, 2016 letter, stating "CAISO's proposal to allow non-generator resources to provide their initial state-of-charge as a bid parameter in the day-ahead market will allow resource bids to better reflect operational conditions accurately, which will help CAISO more precisely manage the resources participating in its markets."[12]

- **Abnormalities with CAISO NGR-related Software Systems**

  During the project, several issues were observed by PG&E that indicated a problem with the CAISO systems processing NGR-related awards, which were ultimately rectified by CAISO. These included spurious market awards and market awards not properly flowing through the Day Ahead and Real Time markets. PG&E identified these issues to CAISO via its Customer Inquiry, Dispute, and Information (CIDI) portal and CAISO has implemented fixes.

  <u>Status</u>**:** Due to the joint efforts of PG&E and CAISO personnel, the abnormalities identified during this project have been resolved.

- **Operational Limitations for Interconnection**

  Both the Vaca and Yerba Buena BESSs have operational limitations that were established as a result of PG&E's Distribution System Impact Study. These operational limitations restrict facility operations during specified periods. Currently, CAISO tariffs do not support changing the regulation ranges for the battery over different hours of the day. As such, the interconnection limits for some hours can limit the full range of FR that can be bid in all hours.

  <u>Status</u>: PG&E is continuing to work with CAISO to accommodate these kinds of seasonal, monthly or hourly interconnection limitations without adversely impacting the resources' ability to offer market products at other times.

- **SOC Management during Frequency Regulation outside the REM model**

  Managing the SOC of the resource providing Regulation Up (RegUp) and Regulation Down (RegDn) outside of the REM model is challenging due to lack of advanced notice whether the CAISO will call for significantly differing amounts of RegUp and RegDn in a given period. This could, and often did, result in the net SOC of the resource changing significantly over the hours where the resource is

[12] Docket No. ER16-1735-000

providing regulation. This further complicated the management of the resource's ability to fulfill its award obligations, and ultimately led to the full FR range of the resource not being utilized.

Status: PG&E has determined through this project that, given current market dynamics favoring frequency regulation, the REM model is the most effective use of the battery resources and is working with CAISO on improvements to enable more dynamic use of the REM model.

Recommendations

In light of some market operation lessons learned through the project and PG&E's expectation for the unique attributes of future BESS expected to come onto the system, PG&E recommends the following additional NGR enhancements:

- **Allow User-Specified REM Range**

  To mitigate the issues caused from operational limitations for interconnection (see "Market Participation Challenges" section above), PG&E recommends that CAISO allow a user-specified Regulation Energy Management (REM) operating range, enabling resources that are also dedicated for another purpose to participate in REM.

- **Reflect Operational Limitations in Optimization Constraints**

  Energy storage model enhancements that include daily limits on throughput and cycling, along with the ability to change these limitations on a day-to-day basis, would give Scheduling Coordinators the means to effectively manage constraints around warranty-based discharge limitations. CAISO could reflect these and other use limitations, such as throughput and cycle limitations, in the NGR model as optimization constraints in order to preserve the life of the assets and increase the cost effectiveness of storage resources.

Conclusion

This project successfully achieved all of its key objectives and, in doing so, has directly and indirectly addressed multiple barriers to energy storage for the benefit of current and future CAISO market participants. Through the work executed in this project and documented in this report, PG&E has gained substantial operational experience with battery storage, informed and enhanced CAISO models through identification and resolution of implementation issues, informed a new interconnection process, provided more transparency in the wholesale price signals and informed cost effectiveness understandings. Due to the achievements of the project, PG&E will continue to maintain the Automated Dispatch System as a platform to automate the response of current and future PG&E battery storage resources to CAISO market awards and plans to provide a new flexible ramping product[13] that CAISO plans to introduce in late 2016.

[13] The flexible ramping product is designed to provide additional revenues for fast ramping resources such as batteries.

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- Jason Pretzlaf: Project Engineer
- Steven Ng: Manager of Substation Engineering and Design
- Darrin Yoxtheimer: IT Project Manager
- Alva Svoboda: Manager of Market Design Integration
- Glenn Goldbeck: Manager of Short Term Electric Supply Planning and Strategy

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2 Introduction

This report documents the EPIC 1.01 Energy Storage for Market Operations project achievements, highlights key learnings from the project that have industry-wide value, and identifies future opportunities for PG&E to leverage this project.

The California Public Utilities Commission (CPUC) passed two decisions that established the basis for this project. The CPUC initially issued Decision 11-12-035, *Decision Establishing Interim Research, Development and Demonstrations and Renewables Program Funding Level*[14], which established the Electric Program Investment Charge (EPIC) on December 15, 2011. Subsequently, on May 24, 2012, the CPUC issued Decision 12-05-037, *Phase 2 Decision Establishing Purposes and Governance for Electric Program Investment Charge and Establishing Funding Collections for 2013-2020,*[15] which authorized funding in the areas of applied research and development, technology demonstration and deployment (TD&D), and market facilitation. In this later decision, CPUC defined technology demonstration as the installation and operation of pre-commercial technologies at a scale sufficiently large and in conditions sufficiently reflective of anticipated actual operating environments, to enable the financial community to effectively appraise the operational and performance characteristics of a given technology and the financial risks it presents.

The decision also required the EPIC Program Administrators[16] to submit Triennial Investment Plans to cover three-year funding cycles for 2012-2014, 2015-2017, and 2018-2020. On November 1, 2012, in A.12-11-003, PG&E filed its first triennial Electric Program Investment Charge (EPIC) Application at the CPUC, requesting $49,328,000 including funding for 26 Technology Demonstration and Deployment projects. On November 14, 2013, in D.13-11-025, the CPUC approved PG&E's EPIC plan, including $49,328,000 for this program category. Pursuant to PG&E's approved EPIC triennial plan, PG&E initiated, planned and implemented the following project: EPIC Project #1.01 – Demonstrate Energy Storage End Uses, also referred to as Energy Storage for Market Operations. Through the annual reporting process, PG&E kept CPUC staff and stakeholders informed on the progress of the project.

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[14] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/156050.PDF
[15] http://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/167664.PDF
[16] Pacific Gas & Electric (PG&E), San Diego Gas & Electric (SDG&E), Southern California Edison (SCE), and the California Energy Commission (CEC)

3 Project Summary

This report summarizes the project objectives, technical results and lessons learned for EPIC 1.01 Demonstrate Energy Storage End Uses, also referred to as Energy Storage for Market Operations, as listed in the EPIC Annual Report. The project was authorized on September 19, 2013 and concluded on September 13, 2016.

3.1 Energy Storage Barriers

In 2010, California passed Assembly Bill (AB) 2514, which identified a number of areas in which energy storage systems could benefit Californians, particularly with regard to helping the state meet its ambitious Renewable Portfolio Standards.[17] However, the bill noted that "there are significant barriers to obtaining the benefits of energy storage systems, including inadequate evaluation of the use of energy storage to integrate renewable energy resources into the transmission and distribution grid through long-term electricity resource planning, lack of recognition of technological and marketplace advancements, and inadequate statutory and regulatory support."

The California Public Utilities Commission (CPUC), in *Decision Adopting Proposed Framework for Analyzing Energy Storage Needs* (Decision 12-08-016),[18] identified nine key barriers to energy storage. Among these were the following:

- "Lack of Commercial Operating Experience"
- "Evolving Markets" and "Lack of Transparency… in Wholesale Price Signals"
- "Lack of Well Defined Interconnection Processes"
- "Lack of Cost-Effectiveness Valuation Method"

This project was designed to improve technical understanding of these barriers and to design innovative systems and processes to directly and indirectly address these barriers as follows.

3.1.1 Lack of Commercial Operating Experience

At the start of the project in 2013, PG&E had recently deployed the Vaca Dixon and Yerba Buena BESSs. These projects represented multiple firsts: the first BESSs to be deployed by PG&E, the first assets owned and operated by PG&E's Electric Asset Management organization (owner of PG&E's electric distribution infrastructure) to participate in CAISO markets, and the first assets operated by PG&E to provide both distribution system and market services. As such, the project aimed to develop new technological and procedural capabilities needed to enable efficient operation in CAISO markets.

3.1.2 Evolving Markets and Lack of Transparency in Wholesale Price Signals

In response to the concerns that lack of wholesale price transparency was a barrier to cost-effective BESS development, the California Independent System Operator (CAISO) had recently developed the Non-Generator Resource (NGR) market model specifically to accommodate the unique properties of

[17] California Assembly Bill (AB) 2514 – Energy Storage System Procurement Targets from Publicly Owned Utilities
[18] D.12-08-016, Decision Adopting Proposed Framework for Analyzing Energy Storage Needs, Aug. 2, 2012

BESSs.[19] However, no BESS resource had ever participated in the market, and the NGR model had never been utilized in CAISO's production environment by any commercial resource. The project aimed to address this barrier through active participation in the NGR market model.

3.1.3 Lack of Well-Defined Interconnection Processes

At the start of this project, PG&E's Electric Generation and Interconnection (EGI) team did not have an established process for reviewing and approving interconnection for battery systems sited on the distribution grid. This project used the Vaca-Dixon BESS interconnection process as a test vehicle for EGI's formalization of an interconnection process for battery storage.

3.1.4 Lack of Cost-Effectiveness Evaluation Method

A number of cost-effectiveness studies on battery storage have shown wholesale market participation to be a key differentiator of a battery system being cost-effective or not. For example, in reports produced by Electric Power Research Institute (EPRI) [20] and DNV-GL[21] that were filed to inform the California Public Utility Commission (CPUC) Energy Storage Order Instituting Rulemaking (OIR) Proceeding, R. 10-12-007, valuation models determined wholesale market participation to represent the bulk of the value of energy storage and the difference between a battery resource being cost-effective or not. EPIC Project 1.01 aimed to provide "real world" data that could be used to revisit these model calculations to compare with model-predicted values.

3.2 Project Objectives

To address these barriers, the specific objectives of EPIC Project 1.01 Energy Storage for Market Operations were to:

- Utilize PG&E's recently deployed Vaca-Dixon and Yerba Buena Battery Energy Storage Systems (BESSs) to gain "real-world" experience and data from participation in the California Independent System Operator's (CAISO) new Non-Generator Resource (NGR) market model created specifically for Limited Energy Storage Resources (LESR)
- Develop and deploy an automated communications and a control solution to enable battery resources to automatically respond to CAISO market awards and thus make full use of their fast-response functionalities
- Quantify financial performance from participation in CAISO markets
- Conduct ancillary activities as necessary, such as interconnection processes and development of roles and responsibilities across PG&E's lines of business to enable efficient participation in the NGR market model

[19] The NGR model is the only CAISO model designed for energy storage and other energy constrained resources, recognizing that resources can operate seamlessly between positive and negative generation (unlike traditional power plants). It allows smaller, energy-constrained resources to be treated on a comparable basis to traditional generation resources in qualifying for day-ahead capacity and continuous energy output when providing regulation services.

[20] Cost-Effectiveness of Energy Storage in California. Application of the EPRI Energy Storage Valuation Tool to Inform the California Public Utility Commission Proceeding R. 10-12-007, Electric Power Research Institute, B. Kaon Project Manager, June, 2013.

[21] "Energy Storage Cost-effectiveness Methodology and Results," DNV GL Energy and Sustainability, August 2013.

- Establish recommendations and guidance for accounting standards applicable to energy storage based on lessons learned[22]

The project met the above objectives by working closely with CAISO to create novel processes to enable streamlined market operations. While the Energy Storage for Market Operations Project, as part of EPIC, did not establish legal precedent for PG&E on metering, billing or market participation rules, it did establish guidelines for previously unaddressed barriers that can influence CAISO, CPUC and Utility policy and regulations regarding energy storage.

3.3 Scope of Work and Project Tasks

To accomplish the objectives for EPIC 1.01 Energy Storage for Market Operations, the following key scope items were developed:

- Develop and deploy technology platform to enable fully automated resource response of PG&E's battery storage resources to CAISO market awards
- Develop organizational roles and responsibilities for efficiently operating battery resources in the CAISO market
- Quantify the value that battery resources can capture in the CAISO market
- Compare empirical financial results with model-based results filed with the CPUC

Table 3-1 below includes the tasks and milestones that were achieved by the project:

Table 3-1: Project Milestones

Task	**Milestone**	**Date Achieved**
Complete all work relating to the declaration of commercial operations for PG&E's existing Vaca-Dixon BESS and Yerba Buena BESS and preliminary testing of any necessary hardware, software, or equipment changes or upgrades necessary prior to commencement of commercial operations		
Prepare Vaca BESS for market operations	Completion of SCADA upgrades required prior to commencement of market operations with Yerba Buena BESS	July 2014
Complete PG&E Electric Generation and Interconnection process	Receipt of Permission to Operate for Vaca-Dixon NAS Battery by PG&E Electric Generation Interconnection	Vaca Dixon BESS: July 30, 2014 Yerba Buena BESS: Oct 13, 2014
Test production version of Real-Time Distributed Energy Control System (RTDECS), the software and IT architecture developed for Manage and control energy storage resources[23]	Completion of SCADA testing and deployment of new software application for managing energy storage at Vaca-Dixon Battery installation. This first release of the software enabled manual configuration of storage resource to follow market awards.	July 2014

[22] This was an initial objective at the early stages of project development. As the project progressed, the Technical Team moved to focus on the technological demonstration and market operations objectives. As such, this particular objective moved out of scope and no recommendations or guidance for accounting standards applicable to energy storage will be made.
[23] This project began prior to the EPIC project and was funded separately.

Task	Milestone	Date Achieved
Develop tool for determining bidding/scheduling strategies for the battery resources in CAISO markets	Development of optimization model that takes into account unique characteristics of battery storage systems	First model produced in July 2014, and continually iterated upon over course of project based on market performance and operational experience[24]
Begin operations of Vaca BESS as a CAISO market resource	Commencement of commercial operations of Vaca Dixon Battery in CAISO markets. Initial activities limited to self-scheduling resource in Day-Ahead energy market	August 2014
Expand Vaca BESS market participation to bidding resource (as opposed to self-scheduling)	Commencement of bidding Vaca BESS into CAISO Day-Ahead Energy market	September 2014
Expand Vaca BESS market participation to include frequency regulation	First tests of Vaca BESS providing frequency regulation in CAISO market	October 2014
Prepare Yerba Buena BESS for market operations	Completion of SCADA upgrades required prior to commencement of market operations with Yerba Buena BESS	August 2015
Commence market operations with Yerba Buena BESS	CAISO New Resource Implementation Process completed and Yerba Buena BESS declared commercial	January 2016
Develop a scalable technology solution to enable the resources to automatically respond to CAISO market awards, while meeting strict cybersecurity standards required by PG&E's Information Technology (IT) department and North American Electric Reliability Corporation Critical Infrastructure Protection (NERC-CIP) requirements		
Draft and complete ADS Automation IT Project scope	Scope completed, IT resources assigned and initial design plan drafted	August – November 2014
Develop IT project to develop ADS automation capability	Kickoff for IT project to develop and deploy communications pathway, IT architecture, and ancillary hardware/software to enable automated response to market awards via CAISO's Automated Dispatch System (ADS)	June 2014
Obtain approval of solution design and selection of vendors for ADS automation project	Successful Proof-of-Concept (POC) of ADS automation solution	June 2015
Complete testing of ADS automation solution in development environment	Solution blueprint approved, IT equipment procured, configured, and tested	October 2015
Commence ADS automation	Vaca BESS demonstrates fully automated	November 2015

[24] PG&E continues to test the bidding/scheduling strategies to test feasible charge/discharge cycles to help determine the highest values that can be realized from a NGR resource in the CAISO markets.

Task	Milestone	Date Achieved
with Vaca BESS	response to CAISO market dispatches	
Commence ADS automation with Yerba Buena BESS	Yerba Buena BESS demonstrates fully automated response to CAISO market dispatches	January 2016
Build organizational capacity to operate and manage battery storage resources		
Develop and socialize new responsibilities for PG&E Distribution Operations Personnel for operating a CAISO market resource in its jurisdiction	Auburn Distribution Operations (control center that has jurisdiction over area that includes Vaca BESS) approval of new roles and notification responsibilities for operating CAISO market resources	September 2014
Obtain approval of official roles and responsibilities for other PG&E Lines of Business for operating PG&E's battery storage resources	Official internal approval of Roles and Responsibilities for document for NAS batteries by six PG&E LOBs	Preliminary Approvals, October 2015 Final Approvals, October 2016
Receive Distribution Operations approval for commencement of market operations with Yerba Buena BESS	Utility Bulletin for NAS Battery Operations approved and Concord Distribution Control Center (has jurisdiction over area that includes Yerba Buena BESS) provides approval	January 2016
Project Close	**Completion of Final Report**	**Aug 2016**

The project has been focused on gaining real world experience and data from distribution-connected BESS participating in the CAISO market, as well as developing and deploying processes and communications internal to PG&E to enable automated responses from these resources. The scope of work activities did not include any efforts intended to establish precedent on metering, billing or market participation rules and regulations or the interpretation of existing rules and regulations.

4 Project Activities, Results and Findings – Market Operations

4.1 Preparatory Activities for Market Operations

The following activities were completed to enable market operations and the declaration of BESSs as commercial in CAISO markets.

4.1.1 Completion of PG&E Electric Generation Interconnection and CAISO New Resource Implementation Processes

All of the market activities documented for the project were predicated on the BESSs being declared commercial in the CAISO market. This process involved completing CAISO's New Resource Implementation (NRI) Process, a 45-step process that can take multiple years. At the start of the project, almost all of the NRI process had been completed for the Vaca BESS, and a majority of the NRI process had been completed for the Yerba Buena BESS; however, several issues related to metering, specific to CAISO participation, were still incomplete.

A key step to complete in the NRI process is to receive Permission to Operate from the Distribution System Owner. For PG&E, this process is managed by the Electric Generation and Interconnection (EGI) department. At the start of the project, EGI did not have a process for interconnecting a battery storage resource for market participation because there had never before been such a resource to interconnect. As such, the EPIC Technical Team assisted the EGI team as it developed such a process using the Vaca and Yerba Buena BESSs as its first battery storage resources.

As part of the resource deployments, the EGI team began by reviewing the System Impact Studies (SISs[25]) that had been completed for the two BESSs in 2011. In the preparation of an SIS, a utility engineer examines how an interconnecting resource can affect the distribution system and, if necessary, requires upgrades be made to the system to accommodate the resource. As the distribution system is a dynamic system that changes with time, a review of the 2011 reports was required that took into account the operations of BESSs as market resources.

For both systems, the SIS review revealed that under certain operating scenarios both BESSs could adversely impact the local area of the distribution grid to which they connected. As such, they gave the resource owner (PG&E's Electric Asset Management) two choices: (1) pay for upgrades to distribution equipment to mitigate the potentially adverse effects, or (2) accept the following operational constraints for the resources so that the adverse scenario would not be created:

- *Vaca BESS: From May 1 to October 1 between 1500 to 2300 hours, the battery system can charge no more than at 1.7 MW.*
- *Yerba Buena BESS: Year round between hours of 23:00 and 09:00 hours, the battery can discharge no more than 2.0 MW. From May 1 to September 1 between hours of 15:00 and 23:00 the battery can charge at no more than 2.5 MW.*

[25] System Impact Study for Generator Interconnection, Battery Energy Storage System (BESS) Interconnection, Pacific Gas and Electric Transmission Planning Department, July 2011 (Vaca BESS) and January 2012 (Yerba Buena BESS).

These operational constraints were evaluated and determined to have limited impact.[26] Specifically, both resources were limited from charging during the highest use periods of the year, which would be a financially inadvisable period to charge as electricity prices would be highest. The Yerba Buena BESS limitation was for discharging between hours (11 PM and 9 AM) when electric usage was lowest, which would also be financially inadvisable. Since paying for upgrades to remove these limitations would incur additional costs while only enabling operational scenarios of uncertain value, the operational constraints were accepted.

The EGI process also required the submission of documentation demonstrating that the proper system protection was in place to safeguard the distribution system from adverse effects in the event of faults or other abnormal equipment operations. As part of this review, the EGI team looked at the settings on protective relays that resided in the BESSs switchgear[27] that is expected to operate and isolate the BESS from the grid in an abnormal event such as an electrical fault.

This review revealed many complexities due to the unique properties of the BESS, particularly with the Yerba Buena BESS. Specifically, part of the EGI process is designed to ensure that when there is a loss of power on the grid, electrical systems connected to it (such as a battery) do not continue to operate as an electric island. This is to protect personnel who might be working on the de-energized circuit from harm due to the unexpected discharge of power onto the grid from an interconnected resource. However, a key functionality of the Yerba Buena BESS was that it would create an electrical island to support downstream loads in the event of a utility outage. As such, the EGI engineers had to closely investigate the relay settings and conduct special testing with the BESS's switchgear to ensure that should an islanding event occur, there was no chance that the system would attempt to discharge power back onto the grid prior to the grid being re-energized. A further complication is that the switch tripping mechanisms in the BESSs' switchgear were, under normal operations, triggered by the battery systems' relays and not by the protective relays, which usually detect abnormal events and execute switch operations. While these protective relays (SEL-351) were deployed at both BESSs, the switchgear and Storage Management System (SMS) were designed to detect abnormal events and operate faster than the SEL relays with EGI-proscribed settings. As such, additional testing needed to be conducted to confirm that the equipment did operate the switchgear to support system protection. This process was an iterative one that involved extensive cooperation between EGI engineers, the equipment manufacturer engineering team, and the Technical Team.

The Vaca BESS, which did not have the additional complication of islanding functionality, completed the new EGI process for energy storage and received Permission to Operate in July 2014. It began market operations in August 2014.

The Yerba Buena BESS took longer to complete the interconnection process due to the islanding-related complexities, and received Permission to Operate in October 2014. Several issues needed to be resolved prior to its completion of the NRI process and declaration of commercial operations as a market resource.

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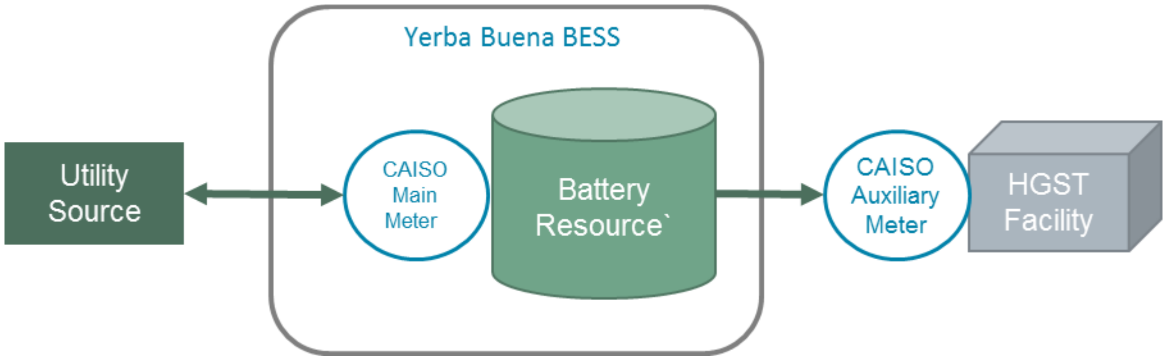
[26] As it turned out, this initial assessment was not fully accurate, but not known until the Yerba Buena BESS began market participation in January 2016. See Section 4.5.2.3 for a more detailed discussion of the impacts these limitations had on market operations.

[27] Equipment that contains switches that enable the battery system to be connected or disconnected from the electric distribution grid.

4.1.1.1 *Yerba Buena BESS Metering Challenges*

The Yerba Buena BESS sits on a distribution feeder with electric loads both upstream and downstream. The downstream load is that of a high-tech R&D facility for computer peripherals. As such, the resource needed two CAISO meters – one immediately upstream of the battery (Main Meter in Figure 4-1) and one downstream (Aux Meter) to determine the net output of the BESS at any given time.

Figure 4-1: Yerba Buena BESS Simplified Metering Schematic



As an example, if the BESS was discharging 0.5 MW and the neighboring high-tech R&D facility was consuming 2 MW, the main meter of the battery would read 1.5 MW (since the 0.5 MW would be going to feed the neighboring facility's load) and the Auxiliary meter would read 2 MW since that is the electric load of the facility. The two meter values would be subtracted (2 MW – 1.5 MW = 0.5 MW) to determine the net generation/load of the battery.

There were two complications for this setup:

1) This is an abnormal configuration for CAISO resources, which typically have a dedicated feeder between the generator and the point of interconnection, and
2) The Aux Meter had to be sited at the high-tech R&D facility, where an open meter socket was available.

The alternative would have been to perform prohibitively expensive excavation and construction to deploy the meter on the battery site.

To address the first issue, the EPIC Technical Team met with a group of CAISO stakeholders to discuss the issue and to go over site schematics. The CAISO metering vendor was then engaged to develop an implementation plan and requisite documentation of this subtractive metering arrangement. It was determined that the two meters would be connected electronically, with the Main Meter subtracting the Aux Meter's values in real time and then reporting that net value to the CAISO. This avoided the need for the CAISO to take and net two meter readings.

The key remaining issue was how the Aux Meter would communicate its values to the Main Meter. The physical location of the Aux Meter was in a building owned the high-tech R&D facility and housing its switchgear approximately 100 yards from the battery site, so distance was not an issue. However, connecting a fiber-optic cable between the two sites (the preferred method for meter communications) would have been expensive and disruptive to the high-tech R&D facility due to the need to de-energize all the equipment and trench a conduit between the two facilities. As such, the EPIC Technical Team proposed and led development of a wireless communications solution.

This work was relatively unprecedented, both for PG&E and the CAISO, and required extensive review and approvals.

4.1.2 Development of Operational Roles and Responsibilities for CAISO Market Participation

Unlike other market-participating resources in PG&E's portfolio, the Vaca and Yerba Buena BESSs were connected as distribution system assets on distribution system SCADA. Distribution assets are managed by PG&E's Distribution Operations from Distribution Control Centers (DCCs) to which they are connected. The Vaca BESS is connected to what was formerly the Auburn DCC (now Rocklin DCC) and the Yerba Buena BESS is connected to the Concord DCC.

As the Vaca BESS was prepared for commercial operations in the summer of 2014, the Technical Team, Auburn DCC, and Short Term Electric Supply (STES) Teams worked together to develop and socialize these new notification responsibilities. These required, for example, that a DCC Operator communicate with PG&E's Real-Time Generation Desk (a group in STES which manages direct communications with CAISO) for notifications about any changes to the resources' availability in the market and to schedule planned outages. Auburn DCC accepted these responsibilities, and market operations with the Vaca BESS commenced. During the first several months of commercial operations with the Vaca BESS, all parties worked to identify and address gaps in procedures until new notification responsibilities were working smoothly.

The Yerba Buena BESS represented a more complicated situation in that unlike the Vaca BESS, which was fully dedicated to market participation and was on its own distribution feeder, the Yerba Buena BESS was providing distribution system support on a feeder with many customers in addition to its market participation functions. As such, more work was required in providing operators from Concord DCC with technological capabilities and operational procedures for effectively managing the Yerba Buena BESS providing both distribution system and market services. The Technical Team and Distribution Operations coordinated on this effort, and the Yerba Buena BESS was cleared for market operations by the Concord DCC and declared Commercial in the CAISO markets in January 2016.

For both projects, this work included:

- Designing and refining SCADA screens to provide Distribution Operators with requisite visualization and control capabilities, particularly with regard to alarm notification and monitoring
- Creating new operational roles and responsibilities for Distribution Operators
- Assisting in the development of switching procedures for battery maintenance and troubleshooting
- Creating safety protocols for managing any battery-related safety incidents

4.2 CAISO Market Operations Activities

Market Operations commenced with the Vaca-Dixon BESS in August 2014 and continued through the project. Between this date and November 2015, market operations continued in what was termed “manual mode,” where the market awards were communicated by the STES team to the Project Engineer who then uploaded the award schedule into the BESS’s Dispatch Control System. While this process only took a few minutes, it did limit some market activities such as dynamic participation in the Real-Time and Spinning Reserve energy markets. Work to fully automate the response of the BESSs to market awards continued throughout this period (see Section 5 Project Activities, Results and Findings – Automated Dispatch System Solution) with full automation commencing in November 2015.

It is important to note at the start of the project the Vaca BESS was the first and only resource in the CAISO Non-Generator Resource market. Neither PG&E nor CAISO had any “real world” experience or data on managing an NGR resource. The primary goal of the project was not to optimize for highest revenues. Instead, the intent of the project was to achieve the objectives as noted in Section 3.2.

The majority of the results discussed in this report are from the Vaca BESS, which began market operations in September 2014. As mentioned previously, the Yerba Buena BESS did not begin market operations until January 2016.

4.2.1 Development of Optimization Model

Prior to commencement of CAISO market operations, it was necessary for PG&E’s Short Term Electric Supply (STES) Team to develop an optimization model.[28] This model would take into account the specific characteristics of the battery combined with forecasts of CAISO clearing prices and other data to produce a forward bid curve for the resource.

The first iteration of the optimization model was created in August of 2014. In building this model, the STES Team had to take into account a number of characteristics of the battery system. STES used these characteristics as inputs into the optimization, and its output would inform the bids that were entered into the CAISO market. The resource characteristics and constraints specific to the Vaca BESS are identified in Table 4-1.

[28] STES Team is responsible for bidding resources in the CAISO market and manages market participation.

Table 4-1: Vaca BESS Optimization Model Inputs

Vaca BESS Optimization Model Parameters	
Constraint	**Notes**
Max Energy Available: 12.5 MWh	The BESS met its design specifications, 2MW output (DC) for 6.95 hours, for total usable energy of 13.9MWh. However, a 10% minimum State of Charge (SOC) was set in order to minimize full depth of discharge.
Max Discharge Rate: 1.85 MW	While the DC discharge power of the battery is 2MW, the effective AC charge power is reduced due to DC/AC conversion and transformer losses, and heaters used by the system to keep it at a minimum operating temperature of 300° C.
Max Charge Rate: -2.15 MW	While the DC charge power of the battery is -2MW, the effective AC charge power is increased due to DC/AC conversion and transformer losses, and heaters used by the system to keep it at a minimum operating temperature of 300° C.
Charge Curtailment: As SOC reaches 92% SOC while charging, charge power is reduced incrementally by the Battery Management System	As the SOC of the battery reaches full SOC, it automatically reduces charge power as a battery cannot be overcharged without damage. This has implications for the amount of power/energy the STES Team can bid into the market as SOC reaches 100%.
Periodic Battery String Balancing	The Battery Management System (BMS) tracks SOC at the string level. The Vaca BESS has four strings. As the battery is charged and discharged over multiple days without reaching 100% SOC, the difference between SOCs of the individual strings grows. The BMS will provide an indication when the strings need to be fully balanced at 100% SOC, which takes a full charge of all strings. As SOC approaches 100% the BMS will "top off" charge of each string successively at very low power. The practical result is that the greater the string imbalance the longer it will take to reach 100% SOC for all strings, and the optimization model needed to account for these periodic string balancing charges.
Parasitic Losses from Battery Heaters	Even when the battery is idle, the system uses energy to maintain its minimum 300° C operating temperature. It does not, however, affect the battery's SOC since the energy is going to the heaters and not to charge the battery.[29]
Efficiency (AC energy output/AC energy input)	The optimization model must take into account the battery's efficiency to determine how much charge energy versus discharge energy to bid into the market. It will take more energy to charge the battery than the battery discharges, with effects on SOC and the amount of discharge energy available. The efficiency of the NAS battery technology greatly varies with how the systems are used and efficiency is measured; for the model a value of 75% was used.
Interconnection Limitation	From May 1 to October 1 between 1500 to 2300 hours, the battery system can charge no more than 1.7 MW.
Ancillary Services	• Energy and A/S in the same hour: Yes • Regulation: Yes • Spinning Reserve: Yes

[29] From a bidding/scheduling perspective, if the STES Team bids this energy into the Day Ahead market to hedge its exposure to real-time prices, then the CAISO's SOC prediction becomes a problem. This is because it will see the energy bid to hedge heater load financial exposure as charge energy increasing to the battery's SOC, which would often result in market awards being mitigated due to incorrect assumptions by CAISO about the battery's actual SOC.

The following parameters were used for the Yerba Buena BESS:

Table 4-2: Yerba Buena BESS Optimization Model Inputs

Yerba Buena BESS Optimization Model Parameters	
Constraint	**Notes**
Max Energy Available: 27. 8 MWh	This represents the total battery energy available in the battery.
Max Energy Available for Market Operations: 15.3 MWh	PG&E has an agreement with the adjacent customer, a high-tech R&D facility, to maintain 6-hours (12 MWh) of backup energy for islanding the facility in the event of a utility outage. The remainder of the energy (55%) can be used for market operations.
Max Discharge Rate: 3.85 MW	While the DC discharge power of the battery is 4MW, the effective AC charge power is reduced due to DC/AC conversion and transformer losses, and heaters used by the system to keep it at a minimum operating temperature of 300° C.
Max Charge Rate: -4.25 MW	While the DC charge power of the battery is -4MW, the effective AC charge power is increased due to DC/AC conversion and transformer losses, and heaters used by the system to keep it at a minimum operating temperature of 300° C.
Charge Curtailment: As SOC reaches 92% SOC while charging, charge power is reduced incrementally by the Battery Management System	As the SOC of the battery reaches full SOC, it automatically reduces charge power as a battery cannot be overcharged without damage. This has implications for the amount of power/energy the STES Team can bid into the market as SOC reaches 100% (identical to Vaca BESS).
Periodic battery string balancing	The Battery Management System (BMS) tracks SOC at the string level. The Vaca BESS has four strings. As the battery is charged and discharged over multiple days without reaching 100% SOC, the difference between SOCs of the individual strings grows. The BMS will provide an indication when the strings need to be fully balanced at 100% SOC, which takes a full charge of all strings. As SOC approaches 100% the BMS will “top off” charge of each string successively at very low power. The practical result is that the greater the string imbalance the longer it will take to reach 100% SOC for all strings, and the optimization model needed to account for these periodic string balancing charges (identical to Vaca BESS).
Parasitic Losses from Battery Heaters	Even when the battery is idle, the system uses energy to maintain its minimum 300° C operating temperature. It does not, however, affect the battery’s SOC since the energy is going to the heaters and not to charge the battery (identical to Vaca BESS).[30]
Efficiency (AC energy output/AC energy input)	The optimization model must take into account the battery’s efficiency to determine how much charge energy versus discharge energy to bid into the market. It will take more energy to charge the battery than the battery discharges, with effects on SOC and the amount of discharge energy available. The efficiency of the NAS battery technology greatly varies with how the systems are used and efficiency is measured; for the model a

[30] From a bidding/scheduling perspective, if the STES Team bids this energy into the Day Ahead market to hedge its exposure to real-time prices, then the CAISO’s SOC prediction becomes a problem. This is because it will see the energy bid to hedge heater load financial exposure as charge energy increasing to the battery’s SOC, which would often result in market awards being mitigated due to incorrect assumptions by CAISO about the battery’s actual SOC.

Yerba Buena BESS Optimization Model Parameters	
Constraint	**Notes**
	value of 75% was used (identical to Vaca BESS).
Interconnection Limitation	• Year round between hours of 23:00 and 09:00 hours, the battery can discharge no more than 2.0 MW • From May 1 to September 1 between hours of 15:00 and 23:00 the battery can charge at no more than 2.5 MW.
Ancillary Services	• Energy and A/S in the same hour: Yes • Regulation: Yes • Spinning Reserve: Yes

The key differences between the two models is primarily the need to keep half the energy of the battery in reserve at the Yerba Buena BESS to provide islanding backup power to the adjacent R&D facility and the operational limitations for maximum charge and discharge power at that location during certain months and hours.

4.2.2 CAISO Market Participation and Settlements Overview

In order to understand the financial impacts, as well as the operational challenges and opportunities for optimizing BESS operations, this project participated in four CAISO markets: (1) Day-Ahead Energy, (2) Real-Time energy, (3) Frequency Regulation and (4) Spinning Reserves. A brief overview of these CAISO markets is provided below, in addition to the BESSs' participation and settlements findings.[31]

4.2.2.1 Day-Ahead (DA) Energy

The DA Energy market is where the California Independent System Operator (CAISO), based on forecasts of energy usage, procures the bulk of the energy it needs to meet California's electricity needs the following day. CAISO stacks the bids from all market-participating generators to determine a clearing price[32] for energy at which it expects to procure the majority of supply to meet that day's predicted electric load. While all resources receive the same clearing price for energy, each generator may face a different Locational Marginal Price (LMP)[33] for its DA energy once CAISO accounts for the marginal cost of congestion and losses at different locations in the CAISO system.

For example if Generator A bids $10/MW and the LMP for the resource is $25/MW, Generator A receives $25/MW since its bid was less than or equal to the LMP. Elsewhere, Generator B could also bid $10/MW, and the LMP it faces may be only $7/MW due to congestion and losses. Since Generator B bid higher than its LMP, which represents the clearing price at that location, Generator B would not receive an award and payment. The locational nature of LMPs can result in market participants responding to localized conditions and needs. For example, while two different geographic locations might have equivalent amounts of renewable generation at a given time, there is a possibility that only one location has a negative LMP as a result of regional oversupply of generation and grid conditions that lead to congestion. This results in only the energy storage within the region with a negative LMP to charge. If the storage resources are geographically outside the grid conditions driving negative LMPs, it may not make economic sense to charge even when there is too much renewable generation in a particular area.

[31] For those desiring further information, the CAISO has a number of resources on its website.
[32] Clearing price is the price point where supply and demand curves cross, sorted by lowest cost bids.
[33] LMP: A locational market-based price for managing transmission congestion.

This aspect of the CAISO DA market highlights the importance for STES, acting as Scheduling Coordinator, to optimize bid formulation for energy storage resources. To achieve financial returns in the DA energy market, resources must charge at LMPs lower than prices during discharge. Poorly formulated bids could lead to a resource never charging or discharging and STES has over a decade of experience performing a similar bid formulation optimization for PG&E's Helms Pumped Storage Plant.

CAISO publishes an award schedule that specifies those hours the next day when a given resource has an award. For the battery, this award schedule was uploaded to the battery's dispatch control software for performance the next day.[34]

Table 4-3 is an example award from October 2014, in which the battery received charging awards in seven hours and discharging awards in five hours. Positive values represent the BESS discharging (selling) energy and negative values represent the BESS charging (buying) energy.

Table 4-3: Single Day DA Award (October 2014)

	VACADX_1_NAS
HE[35]	**ENERGY (MW)**
1	0
2	0
3	0
4	-2.14
5	-2.14
6	-2.14
7	-2.14
8	-2.14
9	-2.14
10	-0.17
11	0
12	0
13	0
14	0
15	0
16	0
17	1.85
18	1.85
19	1.85
20	1.85
21	0.64
22	0
23	0
24	0

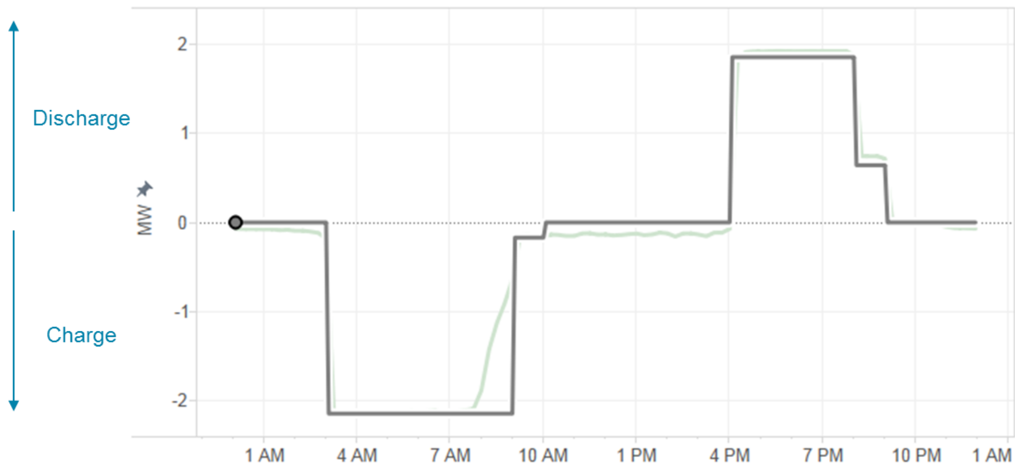
[34] Energy procured from resources in the Day Ahead (DA) market is by hour and constant over that hour.
[35] "HE" stands for Hour Ending, and encompasses the inclusive time period of one hour before the HE hour. For example, HE 15 includes all time periods between 2:00:00 PM and 2:59:59 PM.

The reason that awards range from -2.14MW to +1.85MW instead of the resource's nameplate values of -2.0MW to +2.0MW is due to DC/AC conversion, transformer losses, and parasitic losses from the battery heaters between the DC output and the output measured at the CAISO revenue meter.[36]

The award schedule was sent by the STES team to the Project Engineer, who then uploaded it into the battery's dispatch control software for performance on the scheduled day/times.

Figure 4-2 is a graphical representation of the DA award in
Table 4-3 above. The grey line represents scheduled battery output in megawatts (MW), with values below the x-axis corresponding to charge energy and values above the x-axis with discharge energy.

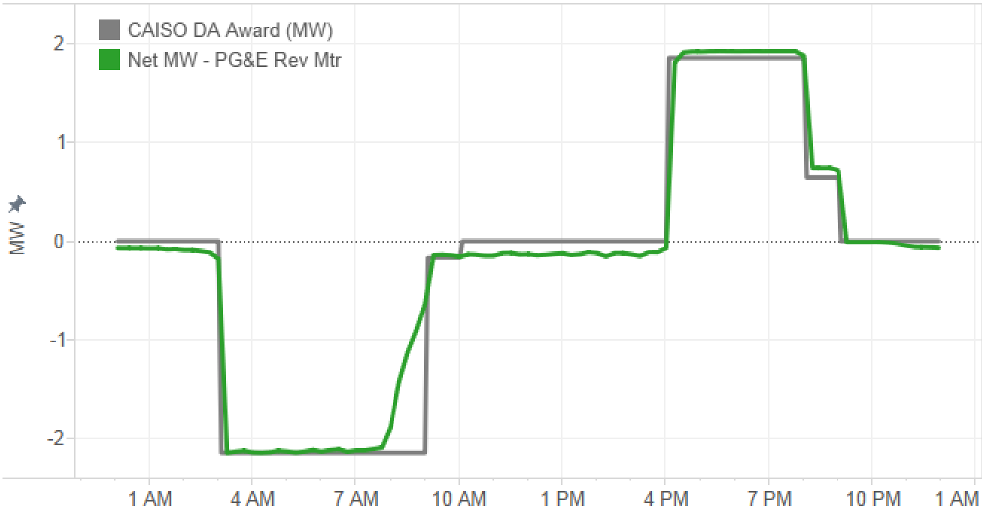
Figure 4-2: Day-Ahead Energy Award – Single Day, October 2014



The chart below plots scheduled (grey) vs actual (green) battery performance. The difference between the lines is primarily due to parasitic loads in the battery system and other losses, and curtailment of charge power as the battery nears 100% SOC. This is explained in greater detail in the Section 4.5.1 Resource-Specific Challenges.

[36] The Vaca BESS's Storage Management System uses measurements at its inverters to set and control its output level. However, parasitic loads and losses in between the inverters and the CAISO meter effectively alter the power range of the resource, in that less power is delivered to the grid on discharge and more power pulled from the grid on charge then what is measured at the inverters. This issue was corrected with the Yerba Buena BESS which measures and controls the set point at the point of electrical interconnection, which is also the location of the CAISO meter.

Figure 4-3: Vaca BESS Output plotted with DA Award – Single Day, October 2014



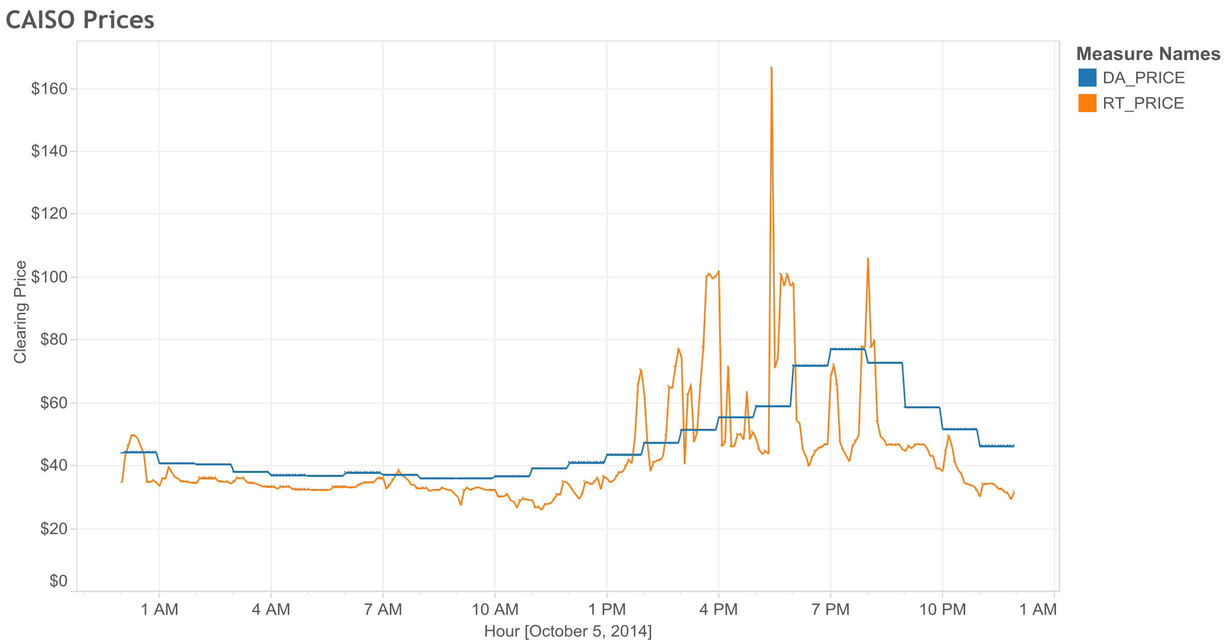
The differences between the green and grey lines represent deviations from the DA schedule, termed “uninstructed deviations”, and settled in the Real-Time (RT) market at the RT clearing price.

4.2.2.2 Real-Time Energy

CAISO’s Real-Time (RT) markets include the Fifteen-Minute Market (FMM) and 5-Minute Market (5MM), which the CAISO uses to manage the differences between the DA forecasted energy loads for California with actual energy loads. These differences are a function of inherent inaccuracies of forecasts, unexpected problems (such as a generator that trips offline), or other unforeseen events. Uninstructed deviations are settled in the 5MM.

5MM RT prices are considerably more volatile than DA prices. Figure 4-4 below visually demonstrates the difference in volatility between RT and DA system-wide prices for October 5, 2014.

Figure 4-4: CAISO DA and RT Prices – 10/5/14



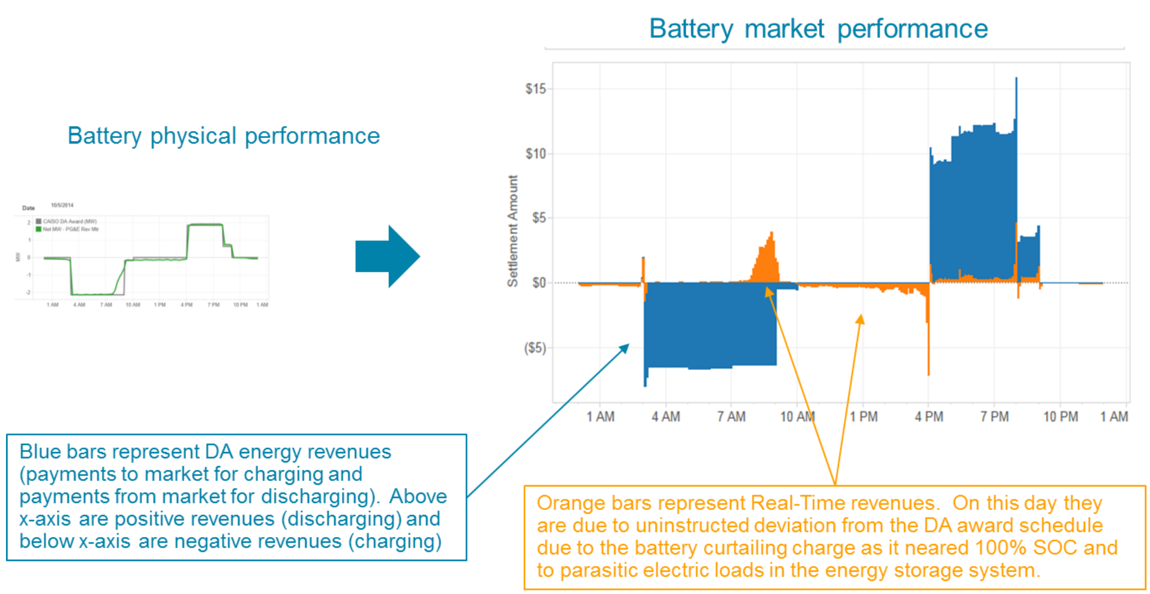
4.2.2.3 DA and RT Energy Settlement

The day's settlements are thus composed of two components:

- Revenues from DA awards
- Costs or revenues from uninstructed deviations from the DA award schedule settled at the real-time price for energy at the time of the deviation

This is illustrated in Figure 4-5 below.

Figure 4-5: Vaca BESS Illustrative Financial Settlement



The positive values seen for RT Energy (orange sections above the x-axis) at the end of the charging period represent uninstructed deviations from the DA schedule during which the battery used less energy than had been awarded in the DA market. This was due to charge curtailment, which slowed the battery's charging power as its SOC approached 100%. Since RT prices were lower during that period than when the battery ultimately discharged, the uninstructed deviation resulted in positive revenues. In addition to uninstructed deviations, bids can be placed into the FMM and 5MM as well to take advantage of economic opportunities.

4.2.3 Ancillary Services Markets Overview

In addition to participation in the DA and RT markets for energy, the project explored participation in the ancillary services of Frequency Regulation and Spinning Reserves.

4.2.3.1 Frequency Regulation (FR)

Frequency Regulation is a mechanism by which the CAISO manages the difference between energy forecasts in the 5MM with actual demand in real-time. This difference is called the Area Control Error, which is a small discrepancy due to the inherent nature of forecasts not being completely accurate[37]. To ensure that energy supply always meets energy demand, the CAISO procures a small number of resources to be on call to receive continual instructions (on a 4-second basis) to increase or reduce their electric output in response to near instantaneous system needs to maintain the required frequency of 60 hertz. As such, a resource providing Frequency Regulation is not actually supplying frequency but power, and due to the very rapid nature of the set points sent by the CAISO, faster responding resources are preferred and receive incremental revenue based on how accurately they follow the CAISO's four-second signal. The measurement of the accuracy of resources following this signal is termed "mileage," with higher mileage resulting in higher revenues. This is of potential advantage to a very fast-responding resource such as a battery system, so exploring this market was a key goal of the project. When the CAISO sends a set-point that increases the electric output of a generator, it is termed Regulation Up (RegUp). When it sends a set-point that decreases the electric output of a generator, it is termed Regulation Down (RegDn). A resource may offer both services provided it is capable of both increasing and decreasing its output.

[37] Glossary of CAISO terminology

4.2.3.2 Frequency Regulation Award Example

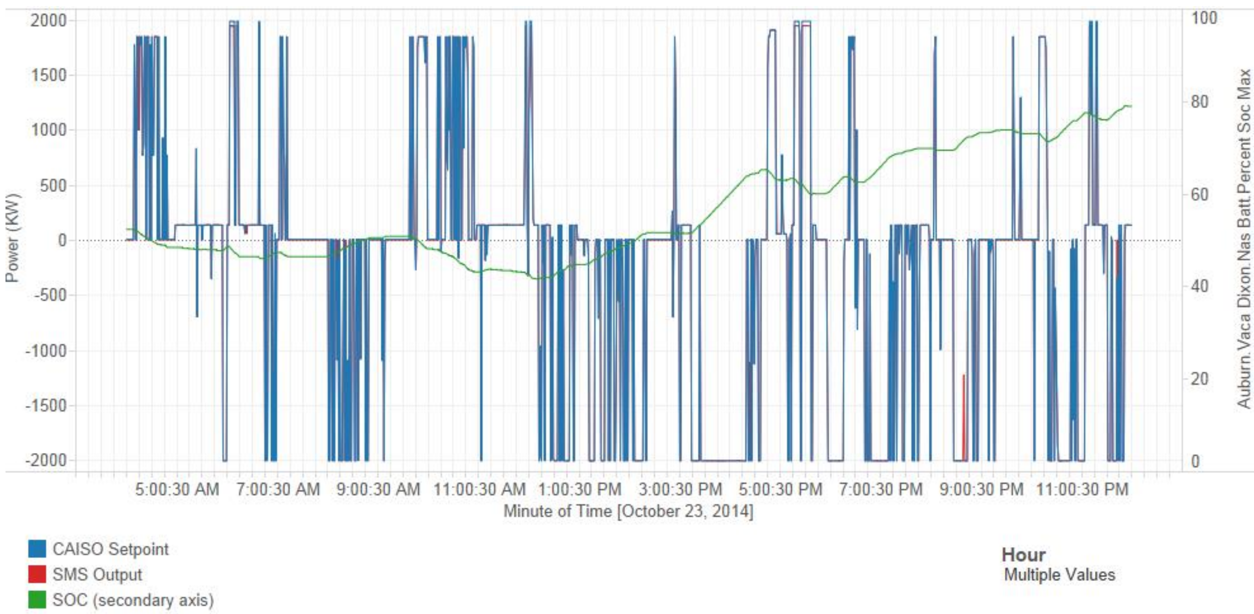
Table 4-4 shows the Day Ahead FR award for the Vaca BESS for performance on a day in October 2014. The resource was awarded 2.14MW of charging energy from 12:00AM to 3:00AM, then 2.14MW RegDn and 1.85MW RegUp from 3:00AM to midnight.

Table 4-4: DA FR Award Schedule, Vaca BESS – Single Day October 2014

VACADX_1_NAS			
HE	**ENERGY**	**REGDOWN**	**REGUP**
1	-2.14	0	0
2	-2.14	0	0
3	-2.14	0	0
4	0	2.14	1.85
5	0	2.14	1.85
6	0	2.14	1.85
7	0	2.14	1.85
8	0	2.14	1.85
9	0	2.14	1.85
10	0	2.14	1.85
11	0	2.14	1.85
12	0	2.14	1.85
13	0	2.14	1.85
14	0	2.14	1.85
15	0	2.14	1.85
16	0	2.14	1.85
17	0	2.14	1.85
18	0	2.14	1.85
19	0	2.14	1.85
20	0	2.14	1.85
21	0	2.14	1.85
22	0	2.14	1.85
23	0	2.14	1.85
24	0	2.14	1.85

On the day of performance, the CAISO AGC system dispatched the battery within the awarded FR range by sending a set point every four seconds. The output of the battery is depicted in Figure 4-6.

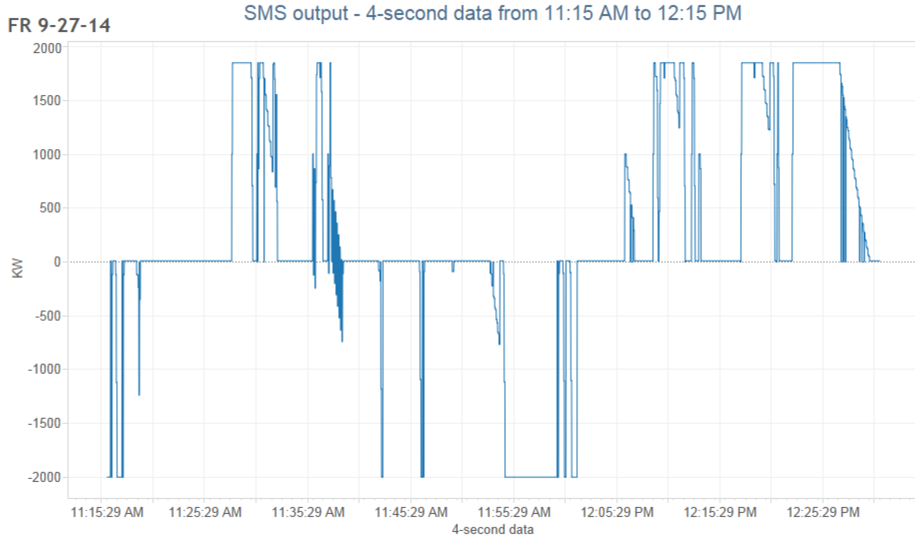
Figure 4-6: Vaca BESS Response to AGC Signal (1-minute data) – Single Day October 2014



The blue line represents the battery output over the course of the day, measured at one-minute granularity. One-minute data (as opposed to four-second data) was normally captured in order to manage the amount of data to be stored on data historian servers. Values above the X-axis represent battery discharge and below the X-axis represent battery charge. Since the awarded energy over these hours was 0MW, values below the X-axis are RegDn awards and above the X-axis are RegUp awards. The actual battery output was more volatile than shown in this graph as the set-point can change every 4 seconds.

For illustrative purposes, Figure 4-7 is a graph of battery response for FR on a day in September 2014 at one-second granularity, showing how the Dispatch Operating Target (DOT) of the resource can be moved substantially from one four-second interval to the next.

Figure 4-7: Vaca BESS Response to AGC Signal – 4-second Data – Single Day September 2014



Another important note in Figure 4-6 is the green line representing the SOC of the system. On this particular day, the CAISO called for more RegDn (charging) than RegUp (discharging) over the course of the day. As such, the SOC of the battery increased from approximately 50% to 80%. Since the change in SOC over the awarded period of FR cannot be known in advance, this adds additional complexity in the bidding/scheduling of the resource. For the example in Table 4-4, the move to 80% SOC would mean that the resource would only be available to charge 2.5MWh the next day vs. 6.25MWh if the battery had remained at 50% SOC.

4.2.3.3 Frequency Regulation Settlement

Frequency Regulation revenues are based on the following components:

- **Regulation Up and Regulation Down Capacity**

  A payment for being available to provide RegUp or RegDn at the awarded interval

- **Real-Time (5-min) Instructed Imbalance Energy (IIE)**

  Revenue (or costs) from energy discharged/charged during the period that was instructed by the AGC system

- **Real-Time (5-min) Uninstructed Imbalance Energy (UIE)**

  Revenue (or costs) from energy discharged/charged during the period that was not instructed by the AGC system; for the Vaca BESS, this is primarily due to parasitic loads and losses as described earlier

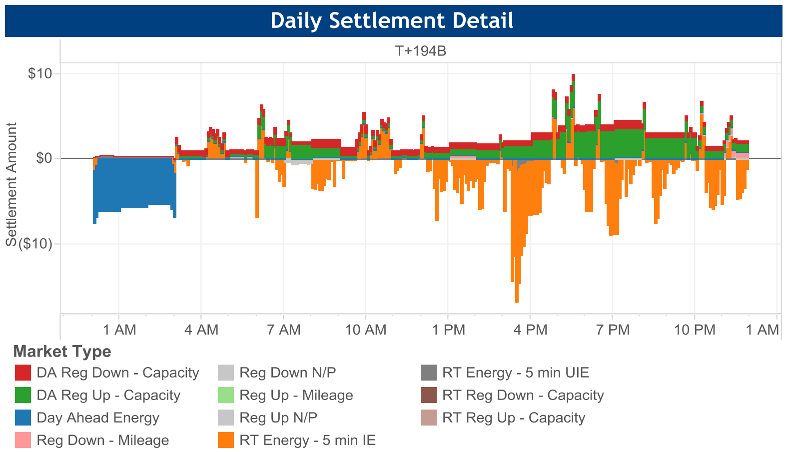
- **Mileage**

  Additional revenue based on how accurately the BESS follows the CAISO four-second instructions

- **RegUp and RegDn No-Pay (NP)**
- A reduction in revenue for periods in which the resource was called to provide regulation but did not respond, which was most likely due to SOC issues

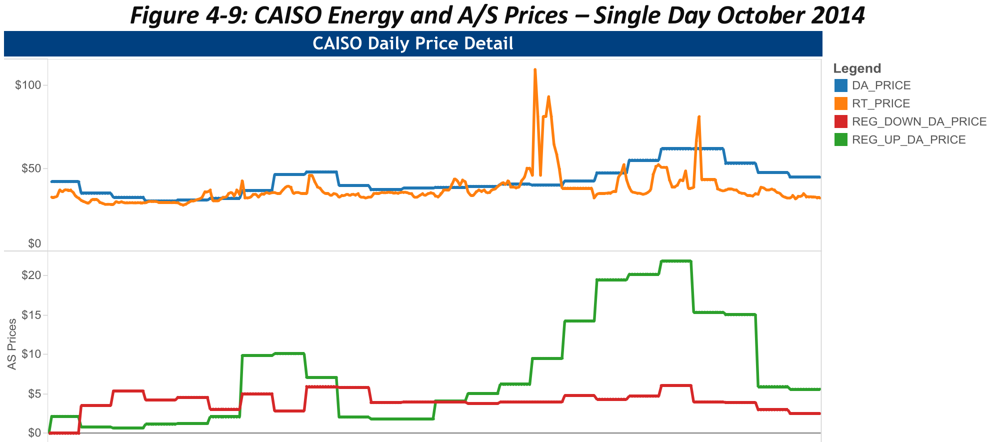
Figure 4-8 is a graphical representation of the revenue components described above from a day in October 2014 by five-minute interval.

Figure 4-8: Vaca BESS Financial Settlement Data – Single Day October 2014



For reference, clearing prices for energy and FR capacity on an exemplary day in October 2014 are shown in Figure 4-9.

Figure 4-9: CAISO Energy and A/S Prices – Single Day October 2014



When following AGC instructions, the resource is exposed to RT Energy (5MM) prices. That is, if the CAISO AGC signal sends a DOT to charge, then the resource is buying energy from the market at the RT price. If the CAISO AGC signal sends a DOT to discharge, then the resource is selling energy at the RT price. This exposure can be significant if RT Energy price spikes are observed while charging.

4.2.3.4 Spinning Reserves (Spin)

Spin is a mechanism by which the CAISO procures additional capacity from the market to provide energy if needed due to unexpected differentials in available supply and demand that exceeds the ability of FR-awarded resources. Spin resources must be synched to the grid to be available to provide energy on short notice. A battery, while not having a physically spinning component like a traditional generator, can be classified as a spin resource due to its fast response capabilities. Spin resources only provide energy when they are called by the CAISO during an interval for which the resource receives a Spin award. As of the writing of this report, the only Spin product in the CAISO market is to provide (discharge) energy.

Spinning Reserve revenues are based on the following components:

- Spin Capacity: A payment for capacity held in reserve to provide Spin
- Real-Time Energy: Revenues (or costs) for energy provided (or reduced/consumed) if Spin is called by the CAISO

The following is an example of Spin awards for the Vaca BESS for a day in December 2015. 1.85MW of Spin was awarded in the Day-Ahead market for all hours, indicating that the resource should be available to be called on for 1.85MW in all hours. If the resource is called, instructions will come through in the 5MM for each 5-min interval. That is, while the Spin capacity award is an hourly award, the resource is called on a 5-minute basis. There were no energy awards (or bid) for all hours except HE14, in which there was an energy award of -1.25MW of charge energy. Since the resource is still capable of dispatching 1.85MW when charging at -1.25MW (the resultant dispatch would be 0.6MW), this award is still valid.

Table 4-5: DA Award Schedule for Spin – Vaca BESS – Single Day December 2015

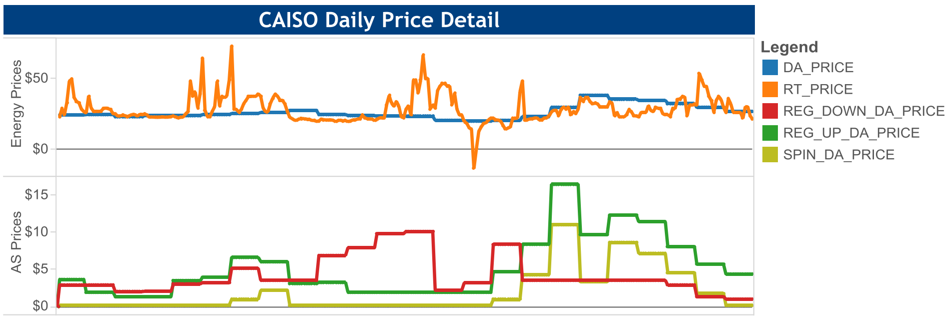
	VACADX_1_NAS	
HE	**ENERGY**	**SPIN**
1	0	1.85
2	0	1.85
3	0	1.85
4	0	1.85
5	0	1.85
6	0	1.85
7	0	1.85
8	0	1.85
9	0	1.85
10	0	1.85
11	0	1.85
12	0	1.85
13	0	1.85
14	-1.25	1.85
15	0	1.85
16	0	1.85
17	0	1.85
18	0	1.85
19	0	1.85
20	0	1.85
21	0	1.85
22	0	1.85
23	0	1.85
24	0	1.85

On that day, no actual Spin energy was called by CAISO. That is, the resource was available and valid but not called on to provide energy to the grid, which is typical as Spin resources are contingent resources.

4.2.3.5 Spin Settlement

Spin prices along with energy prices for a day in December 2015 are shown in Figure 4-10.

Figure 4-10: Spin Settlement – Vaca BESS – Single Day December 2015



Providing Spin comes at the opportunity cost of other products a BESS can provide to the grid. As Frequency Regulation was a higher-revenue use of the resource, STES did not bid Spin-only resources following confirmation that the ADS automation system was able to properly enable Spin participation. Over the limited period during which only 1.85 MW of Spin was bid into the market, Spin hourly prices ranged between $0 and $10 per MW per hour.

4.3 Market Participation Testing Plan

Over the course of the project, STES methodically explored market participation with the Vaca BESS for Energy, Frequency Regulation and Spin. This section highlights results from this testing.

4.3.1 Vaca-Dixon BESS – Market Operations

4.3.1.1 Day-Ahead (DA) Energy Market (September 2014 – December 2014):

The primary goal of this period was to begin an exploration of participation in the Day-Ahead Energy markets and to verify proper functioning of technical systems. This exploration was focused on the following tasks:

- Iterate the optimization model to ensure that it was accurately reflecting the battery's unique characteristics
- Iterate workflow processes to ensure a smooth end-to-end workflow from STES bidding the resource into the market to the resource performing per its market awards
- Verify technical performance of resource in following award schedule
- Gain experience with the NGR market model and financial performance of the Vaca BESS when providing energy and identifying any issues with participation
- Ensure that new roles and responsibilities developed for Distribution Operations personnel were working correctly, as this was the first time Distribution Operators had responsibility for overseeing a resource in the CAISO markets

4.3.1.2 Initial Exploration of Real-Time (RT) Energy Participation (January 2015 - April 2015):

During this period, the Technical Teams explored Real-Time energy participation, pending the deployment of technology for automatically responding to CAISO dispatches that was the primary technical component of the project (see Section 5).

As such, an alternative strategy was explored in which the battery was bid in for FR at very low levels (0.1 MW) so that the battery would remain on AGC control. When in AGC control, energy awards are a component of the Dispatch Operating Target (DOT) sent by CAISO. For example, if the resource has a 0.1MW FR award, a concurrent bid of 1.5 MW for energy could be awarded. At the interval of the award, the CAISO DOT would sum the current FR value sent by CAISO and the energy award. If at the interval the CAISO EMS requested 0.1MW RegUp, the resulting set point sent via the AGC signal would be 0.1MW + 1.5MW DA Energy = 1.6MW. As such, RT Energy awards could effectively be executed via the AGC signal, which eliminated the need for manually uploading the energy award schedule. An example schedule can be seen in Table 4-6. The "Energy" column denotes the planned RT Energy bids, which were placed into the market that day when the FMM market opened for these intervals.

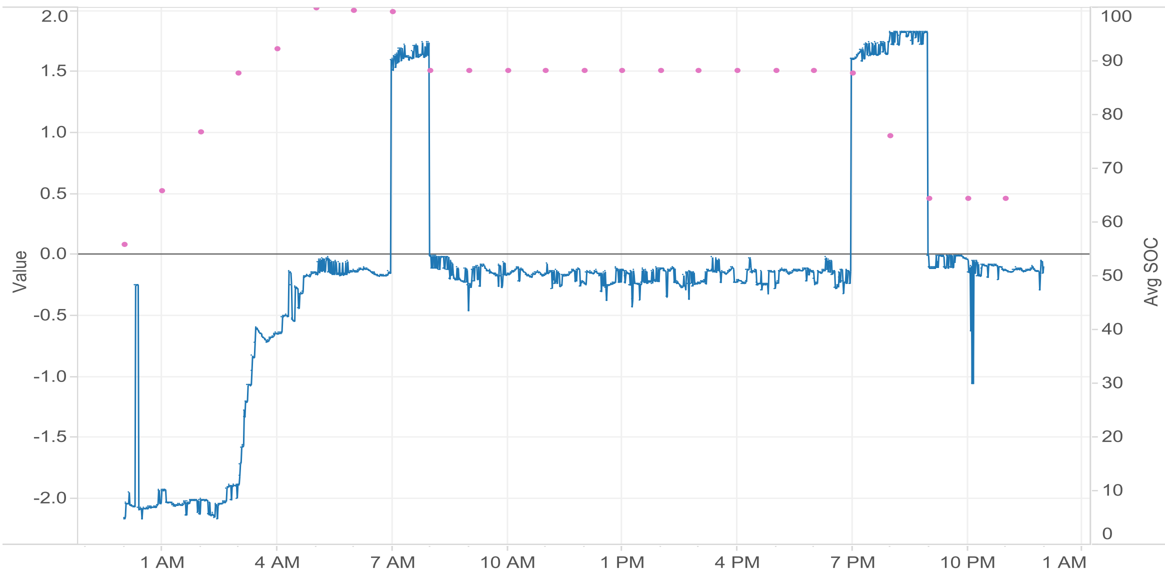
Table 4-6: Example of RT Energy Market Participation Using Low-level FR Bids

VACADX_1_NAS			
HE	**ENERGY**	**REGDOWN**	**REGUP**
1	0	0.1	0
2	-2.1	0.04	0.1
3	-2.14	0	0.1
4	-2.14	0	0.1
5	-2.14	0	0.1
6	0	0.1	0.1
7	0	0.1	0.1
8	1.85	0.1	0
9	0	0.1	0.1
10	0	0.1	0.1
11	0	0.1	0.1
12	0	0.1	0.1
13	0	0.1	0.1
14	0	0.1	0.1
15	0	0.1	0.1
16	0	0.1	0.1
17	0	0.1	0.1
18	0	0.1	0.1
19	1.85	0.1	0
20	1.85	0.1	0
21	0	0.1	0.1
22	0	0.1	0.1
23	0	0.1	0.1
24	0	0.1	0.1

The alternative strategy functioned as intended; it was observed that the energy and FR awards both were reflected in the DOT set point sent by CAISO, effectively passing the 5MM instructed energy award to the resource via the AGC signal.

Table 4-11 shows the output of the battery that day. The “bumpiness” of the output graph reflects the 0.1MW FR award and the CAISO AGC system sending set points that reflected the summation of the RT Energy award and the AGC set point for FR.

Figure 4-11: Vaca BESS Output – Single Day March 2015



While this method of using low-level Frequency Regulation bids to enable RT Energy market participation did work, several issues were identified that ultimately led to its abandonment. The first was that it is not guaranteed that the resource will get an FR award. If not, the system will not get any DOT from the CAISO’s AGC system, so the RT Energy award will not be sent to the resource. The second is that at low power levels, the Vaca BESS is not very accurate when measured at the CAISO meter. This is not a function of the batteries themselves, but rather a combination of the variable nature of the parasitic heater load in idle hours, combined with limitations in the battery power conversion system. The CAISO tracks how accurately a resource follows its AGC signal, and if not sufficiently accurate, CAISO will de-certify the resource as an FR resource and require it be re-tested. Upon advisement by STES personnel in April 2015 that the resource was indeed in danger of being de-certified for Frequency Regulation, this alternative strategy was discontinued.[38]

4.3.1.3 Sustained Frequency Regulation (May 2015 – October 2015):

During this period, a more thorough investigation of participation in the Frequency Regulation market was performed using the full certified range of the battery (-2.14MW to +1.85MW). The results seen in

[38] While the CAISO de-certified the resource for FR in October, 2014, a re-certification test was completed in November, 2014, after which the battery could resume participation in the FR market (the de-certification process takes a number of months from CAISO review of data to notice of de-certification).

this period validated that FR participation was a significantly higher value usage of the resource than energy arbitrage.

4.3.1.4 ADS Automation Solution Testing (November 2015 – December 2015):

After sustained FR participation, the ADS Automation Solution (see Section 5) was ready to begin testing. This enabled the resource to receive CAISO five-minute market award instructions and to respond to such awards automatically without requiring the Project Engineer to manually upload schedules. Practically, this meant that STES could bid both energy and ancillary services into the RT market.

4.3.1.5 All Market Products (January 2016 – June 2016)

With the ADS Automation Solution testing successful, STES began bidding for all market products, including DA Energy, RT Energy, Frequency Regulation, and Spin. This period also saw the Yerba Buena BESS begin commercial operations in the CAISO market on January 21, 2016 (See Section 4.3.2 Yerba Buena BESS Market Operations).

Of particular interest during this period was to test Spin participation (see Section 4.2.3.4 for additional information on Spinning reserves). Spin is generally used as an opportunity to gain some revenues for hours in which the battery is not being used for other functions with higher economic value, such as Frequency Regulation. Since resources providing Spin can be called at any time during their Spin award periods, it was required that the ADS Automation Solution be in place prior to testing the batteries for providing this product.

4.3.1.6 REM Model Testing (Vaca-Dixon BESS) (March 2016 – April 2016):

The NGR market model contains a Regulation Energy Management (REM) option in which the CAISO will manage the SOC of the resource to stay near 50% when performing Frequency Regulation. This option is intended for energy storage resources with very limited energy capacity, for which SOC management is more critical. Throughout the project, the Vaca BESS was modeled as a non-REM resource, where the resource operator is responsible for managing its SOC. As detailed in other sections of this report, SOC management can be quite complex. Therefore, it was prudent to test how the REM option worked. This required a change to the master file for the resource, which is filed with CAISO and specifies a resource's operating parameters and other values. STES submitted the requisite change to the Vaca BESS master file on February 26, 2016. Processing of the change by CAISO takes about one week. On March 3, 2016, STES attempted bidding in the Vaca BESS as a REM resource; however, the effort was not successful. A Customer Inquiry, Dispute, and Information (CIDI) ticket was filed, and CAISO's investigation revealed issues within its software which prevented bidding of the Vaca BESS as a REM resource. On March 10, 2016, CAISO notified PG&E that a fix had been implemented to its software and the Vaca BESS successfully began participation as a NGR REM resource.

4.3.2 Yerba Buena BESS Market Operations

On January 21, 2016, the Yerba Buena BESS was declared commercial in the CAISO NGR market and began market participation. The resource is unique in that it is both participating in the CAISO market as well as providing services to the distribution grid. For its distribution grid functions, 45% of the energy capacity of the battery (approximately 12.5MWh) is held in reserve to support an adjacent customer facility in the event of a power quality problem or outage on the feeder.

The system's full power (+/- 4MW) and 55% of its energy capacity (15.3 MWh) can be used for CAISO market participation. The system is currently used to provide Frequency Regulation in those hours in which it is not bound by an interconnection operational limitation (see Section 4.5.2.2). Table 4-7 shows a representative schedule for the resource:

Table 4-7: Yerba Buena BESS Schedule Reflecting Operational Limitations

SWIFT_1_NAS			
HE	**ENERGY**	**REGDOWN**	**REGUP**
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	3.98	3.6
11	0	3.98	3.6
12	0	3.98	3.6
13	0	3.98	3.6
14	0	3.98	3.6
15	0	3.98	3.6
16	0	3.98	3.6
17	0	3.98	3.6
18	0	3.98	3.6
19	0	3.98	3.6
20	0	3.98	3.6
21	0	3.98	3.6
22	0	3.98	3.6
23	0	3.98	3.6
24	0	0	0

The Yerba Buena BESS has not been moved into the REM model because its SOC must be maintained at a value other than 50% to support its requirements as a distribution system resource.

4.4 Market Results and Observations

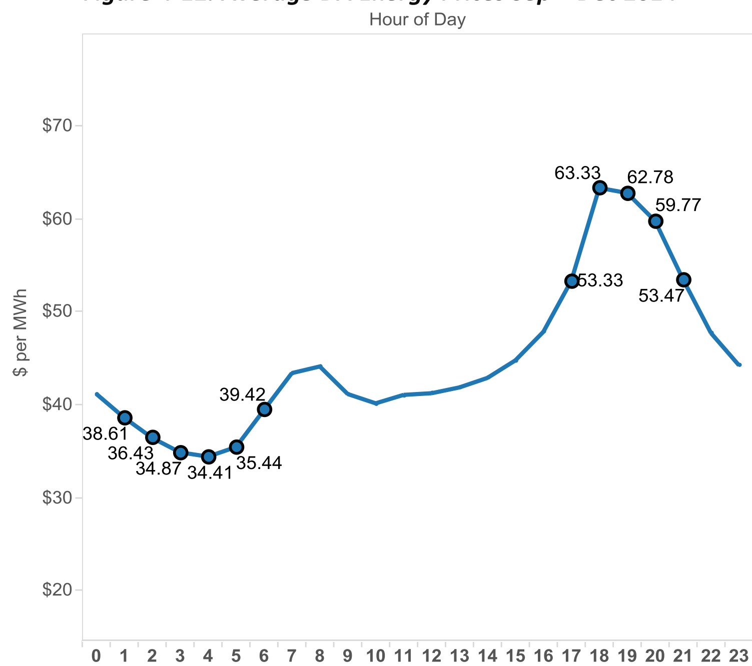
The testing periods documented above revealed the following data and insights about market participation.

4.4.1 CAISO Day-Ahead Energy Financial Results

Financial results during this period revealed that participation in the Day-Ahead energy markets was essentially a break-even proposition. This is because revenues for market participation are a function of the difference between prices during periods when the battery is discharging versus prices when the battery is charging. However, the differences in DA Energy prices in the CAISO market between higher-price and lower-price hours are not consistently large enough to offset energy losses from the inherent round trip efficiency (AC in to AC out) of the battery system, which averaged about 75 percent. For example, if the BESS was discharged at full power (1.85MW) for 5 hours, it dispatched 9.25MWh of energy. To charge it back to the same SOC required 9.25MWh/0.75 (efficiency correction), which equals 12.3MWh.

The average DA prices over a 3-month period from the start of the project, during which the Vaca BESS was primarily bid for DA Energy, are shown in Figure 4-12:

Figure 4-12: Average DA Energy Prices Sep – Dec 2014



The average price over discharging and charging hours was $58 and $36, respectively. Based on the following calculation, the daily average resource revenue was expected to be $94/day:

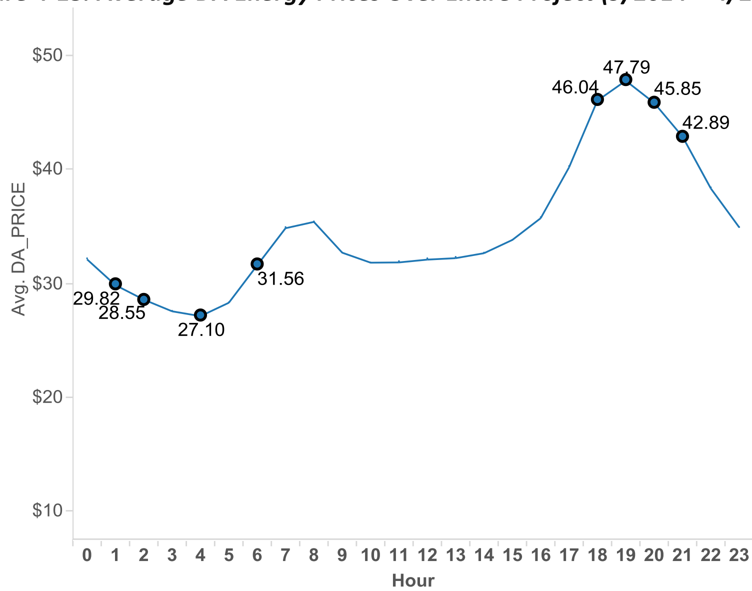
$$(9.25MWh\ X\ \$58/MWh) - (12.3MWh\ X\ \$36/MWh) = \$94/\text{day}$$

This assumes, however, that the resource was bid for its full energy capacity every day during that period and that the average round-trip efficiency is 75%, which is not always the case, as well as that the hours bid for charging and discharging always correlated with the highest and lowest prices that day, which would require perfect foresight[39].

DA Energy prices did not exhibit enough difference between high and low priced hours to offset the efficiency losses of the BESS for energy arbitrage throughout the project. Figure 4-13 shows the hourly average DA prices for the entire Project, demonstrating that the arbitrage value further declines with a longer timeframe (as compared to Figure 4-12).

[39] Detailed studies of the efficiency of the Vaca and Yerba Buena BESSs were conducted under a grant from the California Energy Commission, and found that the efficiency of this technology ranged between 65% and 80%, and is highly dependent on the number of hours the battery is idle during the day since the battery must be kept at an operating temperature of 300 degrees Celsius. This report can be found at http://www.energy.ca.gov/2015publications/CEC-500-2015-060/CEC-500-2015-060.pdf

Figure 4-13: Average DA Energy Prices Over Entire Project (9/2014 – 4/2016)

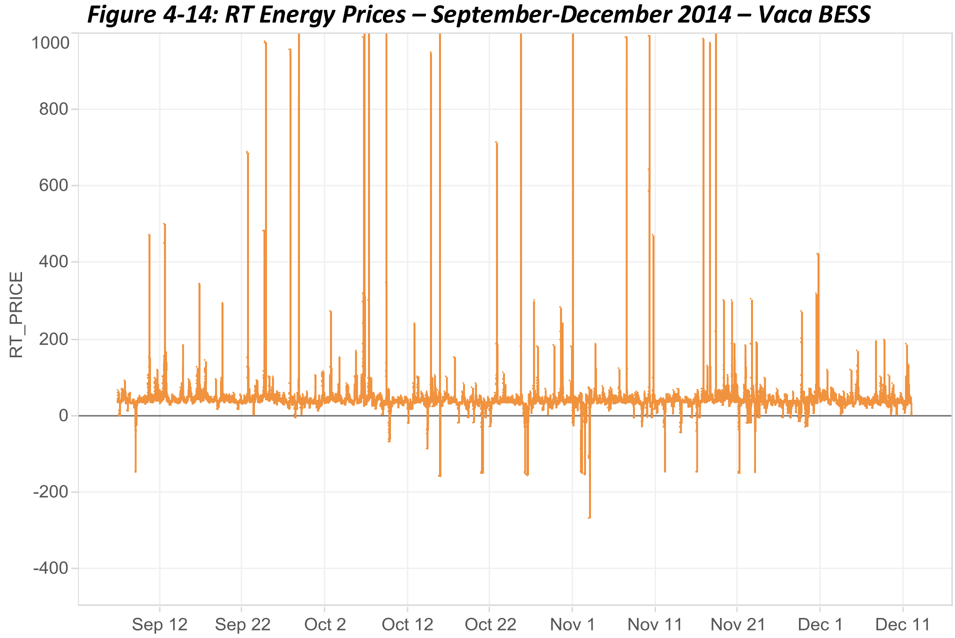


4.4.2 CAISO Real-Time Energy Financial Results

Real-Time energy participation potentially represented better opportunities for a BESS because RT prices are more volatile. As with DA Energy, the difference between costs for charging and revenues for discharging are the key factor in battery financial performance.

Figure 4-14 depicts RT Energy prices for the same time period as Figure 4-12, which depicts DA Energy prices. As can be seen, there are numerous price spikes in the positive direction in which prices reached around $1,000/MWh. There are also numerous days during which negative prices are observed.

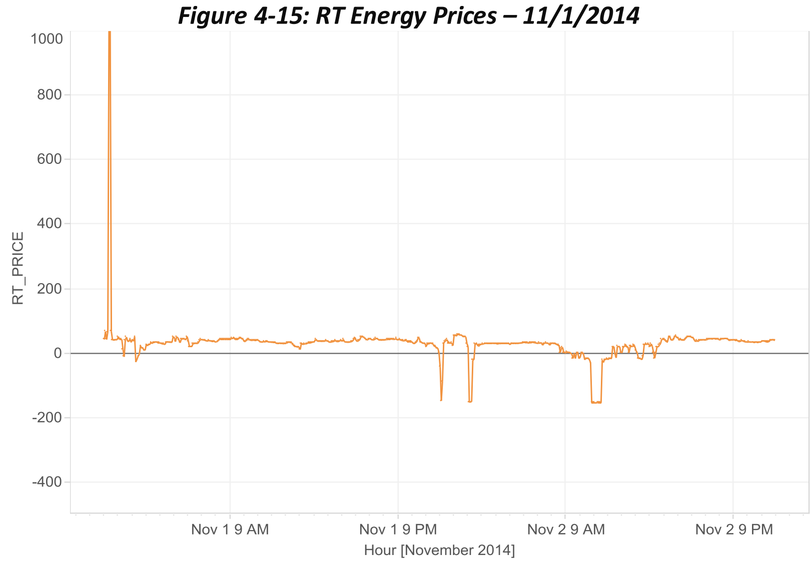
Figure 4-14: RT Energy Prices – September-December 2014 – Vaca BESS



The price spikes, either in the positive or negative direction, tend to be short-lived, and it is not possible to know in advance when they will occur due to volatility of the market.

For example, a closer look at November 1, 2014 in Figure 4-15 reveals the following price curve over the course of the day:

Figure 4-15: RT Energy Prices – 11/1/2014



Over the course of the day, there is relatively low volatility aside from one $1,000 positive price spike for approximately 15 minutes and one $80 negative price for approximately one hour. Assuming perfect foresight in bidding where the battery was able to discharge during the positive price spike and charge during the negative prices, the 2 MW battery resource would have earned a total of $410. During the rest of the day, the resource revenue would be no better than DA Energy market participation, and possibly worse. One alternative option is using standing high priced bids so awards only occur when pricing is very advantageous. However, price spikes and dips are not sufficiently common, resulting in the resource sitting idle most of the time. Explained next, there are higher-value options to maximize market revenue with the resource.

4.4.3 Frequency Regulation Financial Results

Frequency Regulation proved to be the best financial use of the BESS resource with higher revenue than any other type of market participation.

A detailed discussion of financial results from Frequency Regulation during the project can be found in Section 6: Cost-Effectiveness Assessment

4.4.4 Spin Reserve Financial Results

The value of Spin was approximately $4/hour per MW if fully dedicated. As Spin is rarely actually called, this amounts to revenue that the resource receives for sitting idle but being available for quick dispatch if necessary.

The optimization model will favor FR since it represents the highest revenue potential but will add Spin during periods when there are no higher-value products to offer. For example, in certain hours in

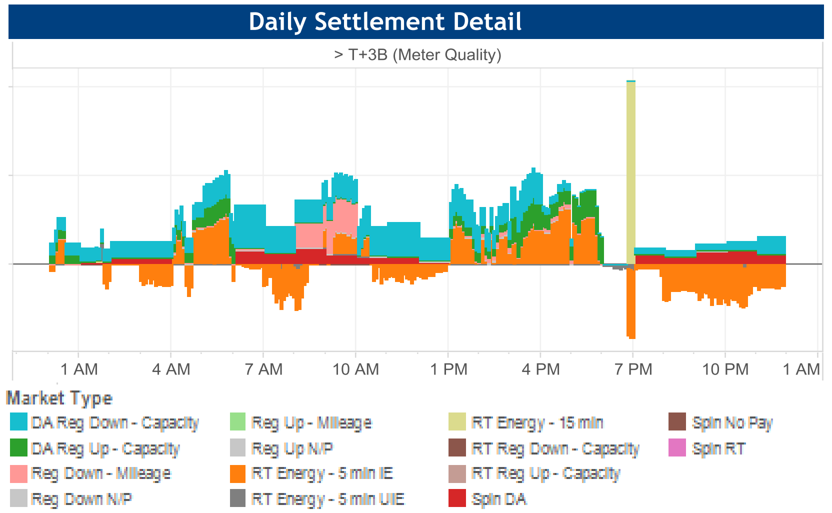
Table 4-8, the Vaca BESS was only bid in for FR in one direction. This was usually done to manage the SOC of the resource. That is, using RegDn only will tend to increase the SOC over time with the opposite true using RegUp only. When the full regulation range of the resource is not otherwise awarded, Spin can be awarded as well for remaining capacity.

Table 4-8: Combination of Spin and FR – Vaca BESS – Single Day January 2016

VACADX_1_NAS				
HE	**ENERGY**	**REGDOWN**	**REGUP**	**SPIN**
1	0	1.3	1.32	0
2	0	1.3	0	1.32
3	0	1.3	0	1.32
4	0	1.3	0	1.32
5	0	1.3	1.32	0
6	0	1.3	1.32	0
7	0	1.3	0	1.32
8	0	1.3	0	1.32
9	0	1.3	0	1.32
10	0	1.3	0	1.32
11	0	1.3	0	1.32
12	0	1.3	0	1.32
13	0	1.3	0	1.32
14	0	1.3	1.32	0
15	0	1.3	1.32	0
16	0	1.3	1.32	0
17	0	1.3	1.32	0
18	0	0	1.32	0
19	0	0	0	0
20	0	1.3	0	1.32
21	0	1.3	0	1.32
22	0	1.3	0	1.32
23	0	1.3	0	1.32
24	0	1.3	0	1.32

Revenues for a single day in January 2016 are shown in Figure 4-16.

Figure 4-16: Vaca BESS Settlement – Single Day January 2016



When bid during periods when the BESSs did not have a higher-value function to perform, Spin accounted for very modest additional revenues of approximately $60/MW per day.

4.4.5 Current Market Dynamics Advantageous to Short-Duration Batteries

Given that Frequency Regulation yields the most significant revenue and requires power output over short periods rather than energy capacity, a 30-minute BESS would conceptually be able to provide the same FR capabilities as a 7-hour system[40] with presumably less capital investment. This conclusion may change if increased renewable penetration in California leads to sustained periods of over-generation during the day, resulting in CAISO regions with low or negative LMPs. In this scenario, FR financial viability could be overshadowed by energy capacity market products, requiring longer duration batteries.

4.4.6 REM Model Effective in Managing Resource SOC

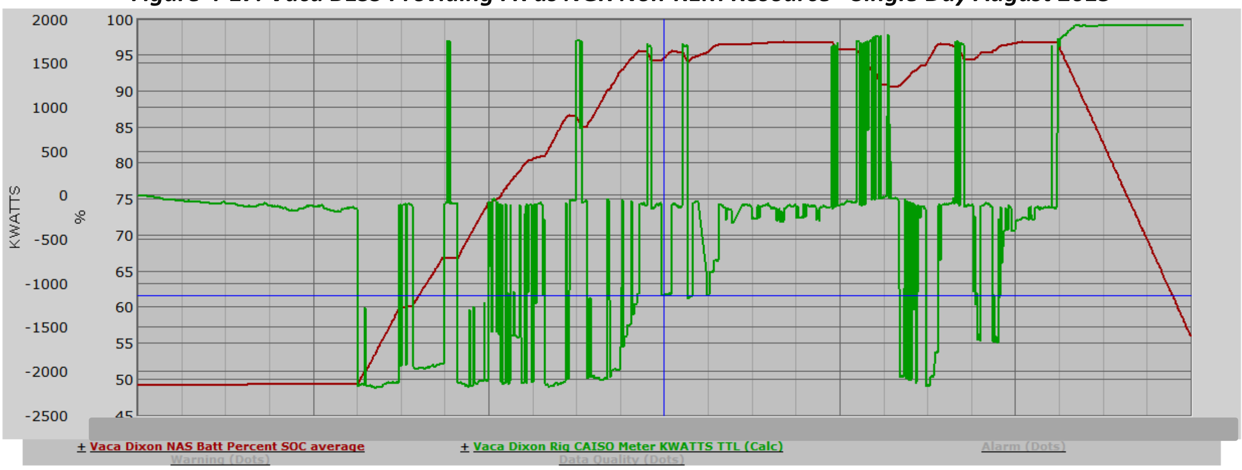
With the caveat that there has so far been little experience with the NGR model, initial observations indicate that the NGR REM model has been effective in managing resource SOC and ultimately improving financial results. The challenges associated with managing SOC outside of the REM model are detailed in Section 4.5.2.1.

Below are examples of the Vaca BESS AGC dispatch and SOC as a Non-REM (Figure 4-17) and REM (Figure 4-18) resources. The green line denotes battery output and the red line SOC percentage. As seen in Figure 4-17, the CAISO EMS dispatched the battery primarily for RegDn between 4 AM and noon, resulting in its SOC moving from 50% to nearly 100%. This resulted in the battery curtailing charge power due to its high SOC, and thereby being limited in its ability to provide further RegDn. Based on

[40] Both the Vaca and Yerba Buena BESSs are 7-hour batteries.

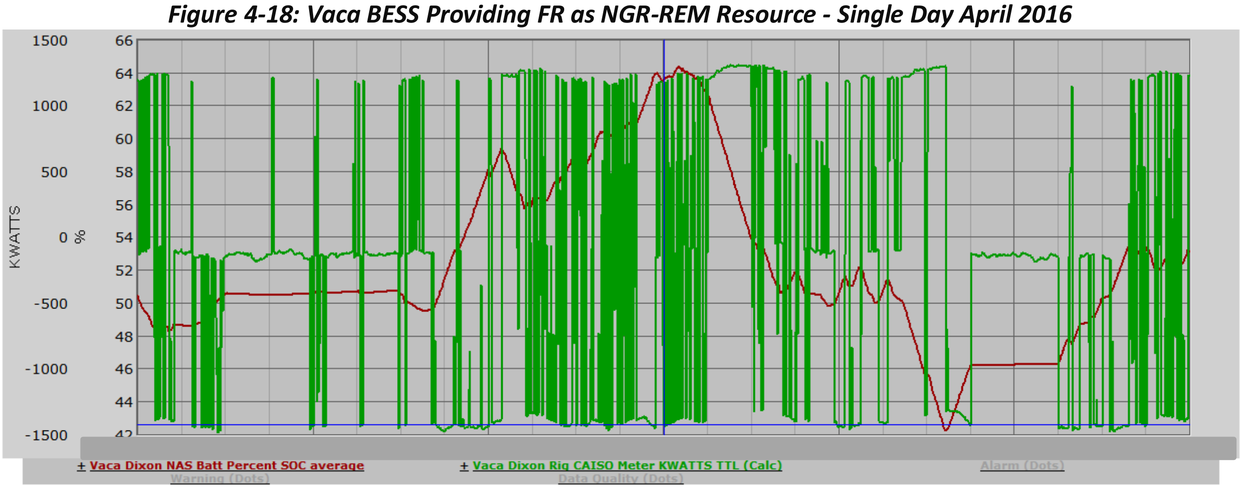
results like this, STES began leaving blocks of hours open at different points of the day so that a real-time energy bid could be provided to manage SOC (SOC in red trend line).

Figure 4-17: Vaca BESS Providing FR as NGR Non-REM Resource - Single Day August 2015



The Vaca BESS was moved into the REM model in March 2016. As seen in Figure 4-18, under the REM model the CAISO EMS keeps the battery's SOC close to 50%.

Figure 4-18: Vaca BESS Providing FR as NGR-REM Resource - Single Day April 2016



As of the writing of this report, the Vaca BESS is still participating as a REM resource, and doing so significantly simplifies the bidding of the resource into the market since the STES Team does not have to actively manage the resource's SOC.

4.5 Market Participation Challenges

Several challenges to CAISO market participation were identified over the course of the project. These included challenges specific to the characteristics of the battery resource itself, as well as issues with the CAISO market system specific to NGR market participation.

4.5.1 Resource-Specific Challenges

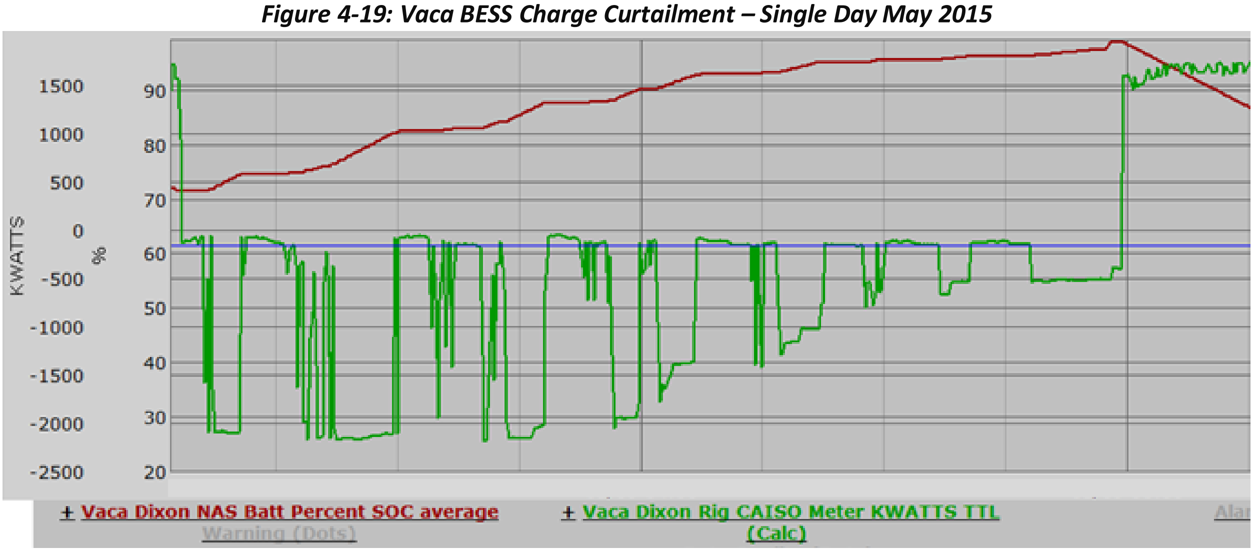
Battery technologies have unique properties that complicate bidding the system into the market, including charge curtailment, string balancing and parasitic loads.

4.5.1.1 Charge Curtailment

As a battery reaches 100% SOC, its charge rate is curtailed. Since a battery cannot be overcharged without damage, its Battery Management System will typically slow the rate of charge as SOC approaches 100%. In the case of the NAS battery technology, non-linear curtailment begins at approximately 92% SOC but can vary based on the differences between the SOCs of individual strings that make up battery modules. This meant it was not possible to submit DA bids during hours where curtailment occurred that accurately reflected battery operations since the charge rate could change significantly. This also exposes the battery to real-time prices through uninstructed deviations from the award schedule, though our experience was that these deviations were minor and could even be positive if RT Energy prices were lower than DA Energy prices, as is often the case. For Frequency Regulation, charge curtailment becomes an issue when curtailing begins if providing Regulation Down, since charge power is reduced during curtailment.

An example is shown below in Figure 4-19. The red line denotes SOC and the green line denotes battery power output. The battery is performing FR and getting pulsed for RegDn by the CAISO AGC system, resulting in SOC increase. At approximately 90% SOC, the charge power is automatically curtailed, which can be seen in the reduced amplitude of the green line as the SOC keeps increasing. The result here is that while the BESS is being commanded by the CAISO AGC system to charge at full power, the BESS can only charge at reduced power due to its high SOC. See Section 4.5.2.1 for a further discussion of SOC management challenges.

Figure 4-19: Vaca BESS Charge Curtailment – Single Day May 2015



4.5.1.2 String Balancing

The battery is composed of a number of individual strings. As the battery is operated over a period of time, the SOC of these strings slowly diverge. At some point, the BMS indicates that a full charge is needed to bring all strings to the same 100% SOC. As the strings are balanced, charge power is curtailed, and the process can take several hours. The key challenge this creates is that STES needs to track and manage string balancing while altering its bids to ensure sufficient charging awards for multiple hours. At the start of the project, string balancing was conducted weekly; however, it has since been reduced to approximately monthly.

4.5.1.3 Parasitic Loads

Battery temperature must be maintained for safety and optimal performance of the system, resulting in parasitic loads. While some lithium-ion batteries need to be cooled, sodium-sulfur batteries need to be kept at a high operating temperature. In the case of the Vaca and Yerba Buena BESSs, the minimum operating temperature is 300°C (572°F), which is maintained via heaters encased in the individual battery modules. This requires, on average, 60kW per MW of battery capacity when the battery is idle or charging. When discharging at or near full power, the battery naturally heats up, so heater use is significantly reduced. This energy use is highly variable, complicating the bidding of the resource into the market[41].

Managing the financial impact of parasitic loads due to the battery heaters remained a challenge throughout the project, particularly for hours in which the battery was idle since the heater would be the largest load. If the heater load is not bid in the DA market, its energy use is settled at the RT Energy price, exposing the resource to price spikes. Early in the project, a strategy was explored to bid the parasitic loads into the DA market to hedge against the potential financial impacts of real-time price spikes during idle hours. However, due to the impact this had on CAISO SOC assumptions (see Section 4.5.2.2 CAISO Day-Ahead State of Charge Assumptions), this strategy was eventually abandoned.

4.5.2 Operational Challenges

4.5.2.1 State of Charge (SOC) Management

There are two options for an NGR resource:

(1) Select the Regulation Energy Management (REM) option, or

(2) Select the Non-REM option

The REM option is intended for short-duration energy storage resources, for which the CAISO manages the SOC of the resource near 50%, and the non-REM option is intended for longer duration energy storage resources where the SOC is managed by the resource operator. As a long-duration (seven-hour) resource, the Vaca-Dixon battery was initially put into the non-REM option.

It became apparent during this period that managing the SOC of the resource during FR participation was challenging, because it is impossible to know in advance whether the CAISO Energy Management System (EMS) will call for differing amounts of RegUp and RegDn, resulting in the SOC moving lower with more RegUp and higher with more RegDn.

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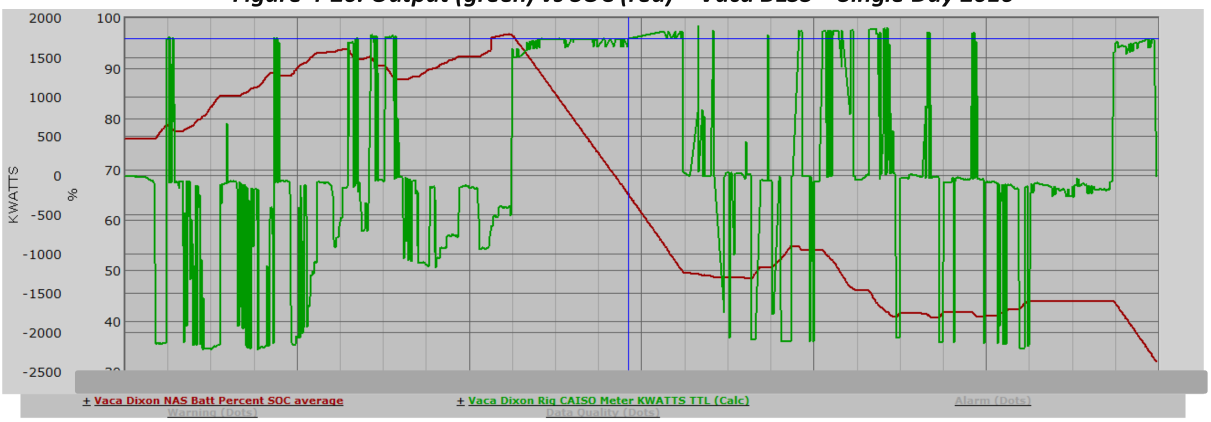
[41] It should be noted that parasitic loads are not specific to sodium-sulfur batteries. While this technology needs to be heated, other battery chemistries such as Lithium-Ion will need to be cooled, or a flow battery will require pumping energy to move fluid through its system.

Figure 4-20 shows an example from a day in January 2016 for which the battery received symmetrical FR awards (RegUp and RegDn values) in all hours. The green line denotes AC power output of the battery and the red line denotes SOC. As can be seen, the SOC varies significantly over the course of the day. Starting at 70%, it then receives more RegUp instructions than RegDn instructions, which takes its SOC close to 100%. It then receives more RegDn than RegUp, and its SOC moves down to 30% SOC at the end of the day. This complicates bidding the resource in the market since the optimization model needs the SOC as an input at the end of the day in order to determine the next day's optimal bids.

Figure 4-20: Output (green) vs SOC (red) – Vaca BESS – Single Day 2016



To better manage SOC during extended FR periods, the STES Team began a workflow to reserve some blocks of hours during the day where it would not place FR bids so as to use those blocks to manage the SOC. An example award schedule is shown in

Table 4-9 below from July 2015; there are blocks of hours with no FR award during which Real-Time energy bids could be placed so as to manage SOC. If the SOC at the start of the block was higher than expected, the STES team could bid in some hours of discharge. If the SOC at the start of the block was lower than expected, the STES Team could bid in some hours of charge. This enabled more accurate inputs into the optimization model and more economic bidding of the resource. However, the financial implication was that the resource did not receive FR capacity payments in those hours reserved for SOC management.

Table 4-9: Managing SOC for FR through Open Hours

HE	ENERGY	REGDOWN	REGUP
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	-2.14	0	1.61
7	-0.33	1.81	1.85
8	0	2.14	1.85
9	0	2.14	1.85
10	0	2.14	1.85
11	0	2.14	1.85
12	0	2.14	1.85
13	0	2.14	1.85
14	0	2.14	1.85
15	0	2.14	1.85
16	0	2.14	1.85
17	0	2.14	1.85
18	0	2.14	1.85
19	0	2.14	1.85
20	0	2.14	1.85
21	0	2.14	1.85
22	0	0	0
23	0	0	0
24	0	0	0

The STES team became comfortable with SOC management over time. This was facilitated by the deployment of the ADS Automation solution, which enabled the use of RT Energy bids to manage SOC. Additionally, the team began to utilize the unidirectional FR to manage SOC, so if the resource SOC needed to be raised, for example, it could be bid in for just Regulation Down for multiple hours. Every time the BESS received a real time instruction it would only be to charge, which would raise the SOC. However, since FR is almost entirely awarded in the DA market and it is impossible to know with certainty which way the CAISO EMS will move the resource's SOC each hour of the next day, this method involves considerable educated guesswork.

Table 4-10: Managing SOC through Asymmetrical FR Bids

VACADX_1_NAS			
HE	**ENERGY**	**REGDOWN**	**REGUP**
1	0	1.3	0
2	0	1.3	0
3	0	1.3	0
4	0	1.3	0
5	0	1.3	0
6	0	1.3	0
7	0	0	1.32
8	0	1.3	1.32
9	0	1.3	1.32
10	0	1.3	0
11	0	1.3	0
12	0	1.3	0
13	0	1.3	1.32
14	0	1.3	1.32
15	0	1.3	1.32
16	0	1.3	1.32
17	0	1.3	1.32
18	0	0	1.32
19	0	0	1.32
20	0	0	1.32
21	0	1.3	1.32
22	0	1.3	1.32
23	0	1.3	1.32
24	0	1.3	0

Both methods are effective; however, it is still required that STES closely monitor SOC and take appropriate actions if necessary.

SOC management for the Vaca BESS has improved considerably with its entry into the NGR REM model in March 2016. In this model, the CAISO maintains the SOC of the battery near 50%. The Yerba Buena BESS, which must be kept at a higher SOC than 50% due to its distribution system needs, cannot be placed into the REM model currently. However, the Technical Team is investigating options for how this might be effectuated. See Section 4.3.1.6 for further discussion of the REM model and SOC management.

4.5.2.2 CAISO Day-Ahead State of Charge Assumptions

The CAISO system makes an assumption about an NGR resource's state of charge at the start of the next day based on its prior DA award schedule. For example, if the resource received an award to discharge 12 MWh and charge 10 MWh in the prior day, it would assume that the SOC was approximately 80% at the end of the day,[42] which it would consider the starting SOC for the following day. The CAISO system then uses that starting SOC value to validate market bids/awards. When the assumed SOC does not support the award, it will mitigate the award. For example, if the assumed SOC is very low and there is a discharge award at the start of the next day, it will mitigate the award because it assumes the resource will be unable to discharge given its low SOC. Likewise, it will mitigate a charge award if the assumed SOC is very high. This award mitigation presented a number of issues:

- At the start of market participation, it was not possible to begin bidding the resource into the market until the CAISO made a manual override in its system to specify a starting SOC. This is because prior to the first day of market operations, the resource had no previous-day DA awards.
- Parasitic loads offered the greatest challenge for bidding the resource and CAISO SOC assumptions. Bidding the battery heater use into the DA market to hedge against exposure to RT Energy prices for energy distorted the CAISO SOC assumptions, often resulting in mitigated awards. As noted above, the battery heaters require, on average, 60kW of power per 1 MW of battery to keep the battery at its operating temperature when the battery is idle. This heater load is registered at the battery's CAISO meter. For the 2 MW Vaca BESS, even if fully cycled (6 hours of discharge followed by 8 hours of charge) there are 10 idle hours over which the battery heaters will consume approximately 1.3MWh of energy. To reduce exposure to RT Energy price spikes during these periods, the STES team at first began bidding the heater usage into the Day-Ahead energy market where prices are considerably more predictable. However, this ended up causing issues with the CAISO's SOC assumption because the CAISO system assumes that this energy was increasing the SOC of the system even though it was actually being consumed by the battery heaters. As such, the CAISO's assumed SOC would increase by 1.3MWh each day until it assumed the day's ending SOC was 100%. At that point, it would mitigate awards for charging energy at the start of the next day even though the battery's actual SOC was much lower than 100%.
- Charge curtailment and string balancing could cause errors in the CAISO SOC assumption due to the fact that battery power can change significantly over the course of curtailment. For example, the battery power may be non-linearly curtailed from -2 MW to -0.5 MW in its last hour of charging. If -2MW had been awarded in that hour, the CAISO would assume the SOC to increase 2MWh, whereas the actual SOC may have increased 1 MWh.

Over the course of the project, the STES Team discussed with CAISO personnel the issues experienced because of the SOC assumptions. The STES Team advocated for making SOC a biddable parameter, and due to these efforts, the FERC recently approved the inclusion of SOC as a day-ahead bid parameter for CAISO's NGR Tariff. FERC clarified the need for such a change in an August 16, 2016 letter, stating "CAISO's proposal to allow non-generator resources to provide their initial state-of-charge as a bid parameter in the day-ahead market will allow resource bids to better reflect operational conditions accurately, which will help CAISO more precisely manage the resources participating in its markets"[43].

[42] It is not clear how the CAISO's model accounts for efficiency losses that would affect SOC.
[43] Docket No. ER16-1735-000

4.5.2.3 Operational Limitations for Interconnection

Both the Vaca and Yerba Buena BESSs, as part of their interconnection agreements, have operational limitations during certain months and hours of the year. The Vaca BESS's limitations do not effectively have any impact on battery operations but the Yerba Buena BESS's limitations with respect to Frequency Regulation do. The limitations for Yerba Buena are the following:

- Year round between hours of 23:00 and 09:00 hours, the battery can discharge no more than 2.0 MW
- From May 1 to September 1, between hours of 15:00 and 23:00, the battery can charge at no more than 2.5 MW

CAISO tariffs require that a resource awarded FR must make its entire FR range available to CAISO during awarded periods. The certified FR range for the Yerba Buena BESS is -4.0MW to +3.6MW. Even if the STES team only bids in and receives a DA FR award of, for example, +/- 2.0MW in a given hour, the CAISO will automatically re-bid the rest of the FR range into the Real-Time FR market. Thus, the resource could be called for more than +/- 2.0MW during a FR period. Since the BESS has an interconnection-mandated limitation of 2.0MW or 2.5MW during the days/hours specified above, the result is that the Yerba Buena BESS cannot be bid for FR in those hours where there is a limitation because CAISO could call on the resource for a MW output that exceeds the limitation.

There were only two options available:

- Only bid the resource for FR in hours when there were no operational limitations below that range (Table 4-11)
- Reduce the FR range for the resource via a change in the resource's master file for all hours to a maximum value allowed by the operational limitation (Table 4-12)

Table 4-11: Option A – Only Bid FR in Hours with No Operational Limitation

SWIFT_1_NAS			
HE	**ENERGY**	**REGDOWN**	**REGUP**
1	0	0	0
2	0	0	0
3	0	0	0
4	-0.1	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	3.98	3.6
11	0	3.98	3.6
12	0	3.98	3.6
13	0	3.98	3.6
14	0	3.98	3.6
15	0	3.98	3.6
16	0	3.98	3.6
17	0	3.98	3.6
18	0	3.98	3.6
19	0	3.98	3.6
20	0	3.98	3.6
21	0	3.98	3.6
22	0	3.98	3.6
23	0	3.98	3.6
24	0	0	0

Table 4-12: Option B - Reduce Regulation Range of Resource in All Hours

SWIFT_1_NAS			
HE	**ENERGY**	**REGDOWN**	**REGUP**
1	0	3.98	2
2	0	3.98	2
3	0	0	0
4	0	0	0
5	0	3.98	2
6	0	3.98	2
7	0	3.98	2
8	0	3.98	2
9	0	3.98	2
10	0	3.98	2
11	0	3.98	2
12	0	3.98	2
13	0	3.98	2
14	0	3.98	2
15	0	3.98	2
16	0	3.98	2
17	0	3.98	2
18	0	3.98	2
19	0	3.98	2
20	0	3.98	2
21	0	3.98	2
22	0	3.98	2
23	0	3.98	2
24	0	3.98	0

STES ultimately determined that Option B was more economically advantageous, and the max power for RegUp for the Yerba Buena resource has been reduced to 2.0MW as of July 2016. However, the STES Team had a meeting with representatives from CAISO in April 2016 during which this issue was raised, and alternative options are currently being explored to enable more dynamic management of these interconnection limitations within the CAISO tariff.

4.5.2.4 Issues Identified in CAISO NGR-related Software Systems

During the project, several issues were observed by the STES team that indicated a problem with the CAISO systems for processing NGR-related awards, which were ultimately rectified by CAISO. These included:

- Spurious market awards appearing in the FMM despite the fact that no bids had been placed in the FMM
- Market awards not properly flowing from one market to the next - that is, an award in the Day-Ahead market should flow into the FMM and then the 5MM but were not flowing.

Both of the above issues were sporadic in nature. Once identified, the STES team filed Customer Inquiry, Dispute, and Information (CIDI) tickets with CAISO. An example of one CIDI ticket from March 2015 is below:

> *A new Inquiry Ticket has been entered into the system by [PG&E STES Team] for Pacific Gas & Electric Company….*

Inquiry Ticket Number: 00165125
Subject: 03/18/2015 -Anomalous FMM and RTD awards for Vaca Dixon Battery (VACADX_1_NAS)

Description:
Vaca Dixon battery (VACADX_1_NAS) received 1.75 MW FMM awards for HE 1-5, 6-7, 9-18, 22-24. Resource was not bid in for those hours and should not have received any market awards. Resource received RT Dispatch awards of -2 MW for HE 1-5 whereas it should have received -2.14 MW awards.

These anomalies were observed several times throughout the project and CIDI tickets were filed. For several issues, the CAISO technical team investigated and determined that the root cause was a shortcoming in the software system that was brought to the attention of their software vendor. The vendor investigated the issues and in all cases implemented fixes to address them. While all parties worked to resolve issues in as timely a manner as possible, the full time from identification of issue to CIDI notification, CAISO's investigation, software vendor investigation, remedy implementation, and requisite testing post implementation was at least two to three months. While battery operations continued throughout the project, financial settlement data is not fully accurate for a number of months due to these issues. Disputes have been filed with CAISO for these settlements inaccuracies, but the process is still ongoing as of September 2016.

As of September 2016, the CAISO-specific issues identified above appeared to have been resolved and have not been observed since.

5 Project Activities, Results and Findings – Automated Dispatch System Solution

At the start of the project, PG&E had recently deployed two NAS Battery Energy Storage Systems (BESSs) as pilot projects at the Vaca-Dixon substation and at the end of the Swift 2102 distribution feeder on Yerba Buena Road in San Jose. Both BESSs were deployed with the intention that they participate in the CAISO energy and ancillary services markets[44].

In July of 2012, prior to the start of this Project, and during the deployment of the Vaca-Dixon BESS, the NAS Battery Pilot Technical Team recognized that PG&E would need to develop or acquire a dispatch control solution in order to take advantage of the multiple functionalities of the battery system. While the Storage Management System (SMS) provided by the equipment vendor did enable different modes by which the battery system could be operated to test these functionalities, it was never intended by the vendor that this be the primary control software. Rather, the vendor had supplied the requisite ability for its SMS to communicate to PG&E SCADA, as is standard for other distribution system equipment.

Discussions began internally with regard to the functionalities and IT architecture for a new battery Dispatch Control System (DCS). The following were key design considerations for this solution:

[44] When the BESS pilot deployments were first proposed and designed, 2009 – 2011, the CAISO had not yet developed the Non-Generator Resource market model for resources such as battery storage. That process continued on a parallel path, led by CAISO but with significant input from PG&E's Short Term Electric Supply group and other industry participants.

- Build on existing SCADA with a scalable architecture and a platform-based approach
- Be the central hub for all incoming information and dispatch of battery
- Enable all intended battery functionalities
- Enable full automation of all intended battery functionalities
- Display a common interface for all energy storage applications and
- Meet cybersecurity requirements

Building on existing SCADA was a key consideration because of the ability to leverage existing infrastructure and communication capabilities as well as the cybersecurity and other standards that existed for distribution-connected equipment. As such, the Technical Team initiated discussions with PG&E's SCADA vendor to develop an application that would make use of the base underlying SCADA to monitor and control the battery system in providing different functions. The development of the Real-Time Distributed Energy Control System (RTDECS) application was commissioned in August 2013 after one year of development, and the first beta version was deployed at the Yerba Buena BESS two months later.

From the beginning of the pre-EPIC RTDECS development process, it was intended that the solution enable fully automated response to CAISO market awards for Energy, Frequency Regulation, and Spin. However, getting to that point would require three key components. The first requirement was developing a communication pathway between the CAISO ADS portal, where market awards are published, and PG&E's battery resource that was fully compliant with rigorous internal and external cyber-security requirements. The second requirement was deploying the necessary hardware and software for fetching ADS dispatches from the CAISO ADS portal, parsing those instructions, and sending them along the communication pathway to the respective end resource. The final requirement was to ensure that RTDECS was capable of receiving and responding to dispatches from CAISO's Automated Dispatch System (ADS).[45]

Concurrent with the development of the ADS Automation Solution outlined below, market operations commenced in September 2014, utilizing RTDECS "Manual Market Operations Mode". This mode required the Project Engineer to upload the CAISO award schedule to the RTDECS software once it was received from PG&E's Short-Term Electric Supply team.

5.1 Market Operations — Automated Dispatch System Solution Goals and Objectives

The overall goal of the IT project was to automate the acquisition of ADS instructions and pass them to the RTDECS system so as to demonstrate full automation of resource response to CAISO market awards. Scoping of the Information Technology (IT) project to develop the ADS Automation solution began in February 2014.

The specific deliverables of the IT Project were to:

- Develop, validate, approve, and deploy a communication pathway between the CAISO ADS file location and the resource

[45] RTDECS development was fully funded separately from this EPIC project.

- Deploy and test software as well as, if necessary, hardware for acquisition of ADS information and transmittal to the resource DCS
- Demonstrate full automated resource response to CAISO market awards for both energy and ancillary services

The following were the guiding principles for the IT Project:

- Implement a solution architecture that will be the foundation for future storage deployments efforts
- Leverage architecture and design patterns already approved by PG&E IT that will support security requirement for the PG&E application
- Deploy a robust, industry-strength API proxy and policy enforcement point component which provide management of APIs for this phase and future efforts
- Develop an IT architecture that could be used for future storage deployments as recently mandated by the California State Legislature (AB 2514)

5.1.1 Communication Pathway

The initial intent of the project for developing a communication pathway between the CAISO's ADS portal on its Energy Control Network (ECN), where market award are published, and the RTDECS system at the individual battery sites was to explore the use of the same communication pathway used for communications between the CAISO's Automated Generator Control (AGC) system and the Remote Intelligent Gateway (RIG) sited at each battery. This is the pathway by which the CAISO instructs resources to follow its frequency regulation signal and which had been deployed at both the Vaca-Dixon and Yerba Buena battery sites.

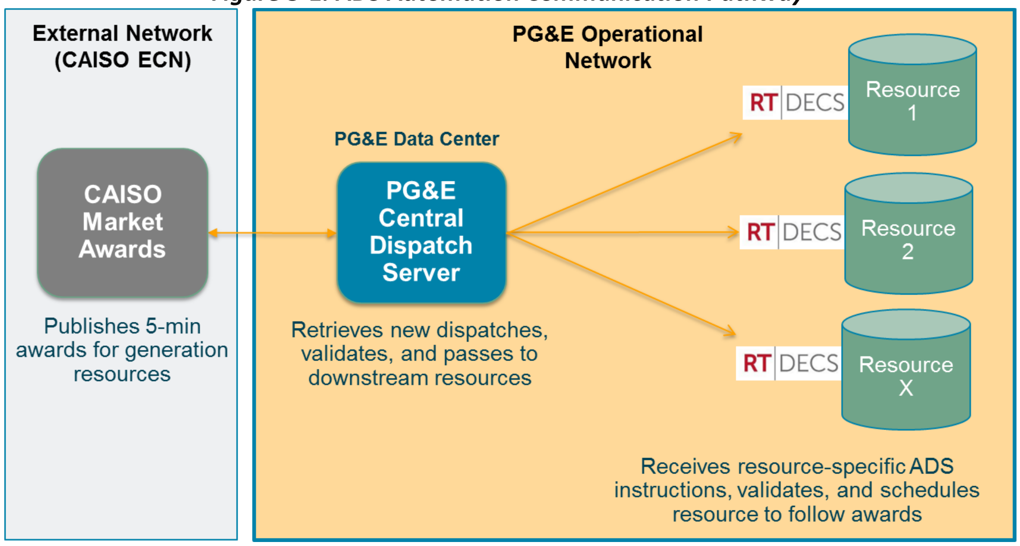
The Technical Team thus initially proposed an architecture in which the locally-sited RTDECS software would utilize the same communication pathway as the RIG to reach the CAISO ECN and directly poll the ADS web services portal for market awards of the battery resource it controlled. This proposal was explored in depth by PG&E IT network personnel, and it was ultimately rejected for a number of reasons, including:

- File transfers are not supported by the RIG communication architecture. File transfer was required because the ADS portal publishes awards as XML files, which must be retrieved and parsed. The existing ECN-RIG connection was only designed to support the direct exchange of real-time data between the AGC system and RIG.
- The RIG communication architecture could not be re-configured to deliver the required functionality because its architecture would not meet internal cybersecurity requirements
- The decentralized nature of the RIG communication architecture, in which each DCS at end resources would communicate directly with the CAISO ADS system, would make maintenance and troubleshooting more complex. It also would not support an ability of PG&E to alter award instructions if necessary in exceptional dispatch situations when there might be a need to deviate from the market award.

As such, the Technical Team abandoned this approach and began considering another architecture in which a central system on PG&E's network would communicate to the CAISO ADS portal to pull down the market awards (in XML files) for all resources, parse those files into a common format, and send files downstream to each individual resource's dispatch control system.

In this configuration, a server dubbed the Central Dispatch Server (CDS) located in a PG&E data center would host the software that pulled in the ADS dispatches and send them to the downstream resources. A simplified schematic of this architecture is shown in Figure 5-1.

Figure 5-1: ADS Automation Communication Pathway



While fairly simple in theory, the actual implementation of such a pathway was not a simple undertaking due to the stringent cybersecurity requirements at the utility to comply with both its own standards and North Electric Reliability Corporation Critical Infrastructure Protection (NERC-CIP) protocols.

The first iteration of this architecture was submitted in July of 2014 for review by PG&E's Enterprise Technology Risk Management (ETRM) group for review but was ultimately rejected due to cybersecurity concerns. The Technical Team continued to iterate with ETRM and Network Specialists on ways to implement this pathway that did pass ETRM review. In February of 2015, a design was reached that did pass provisional review which became the basis for the final architecture.

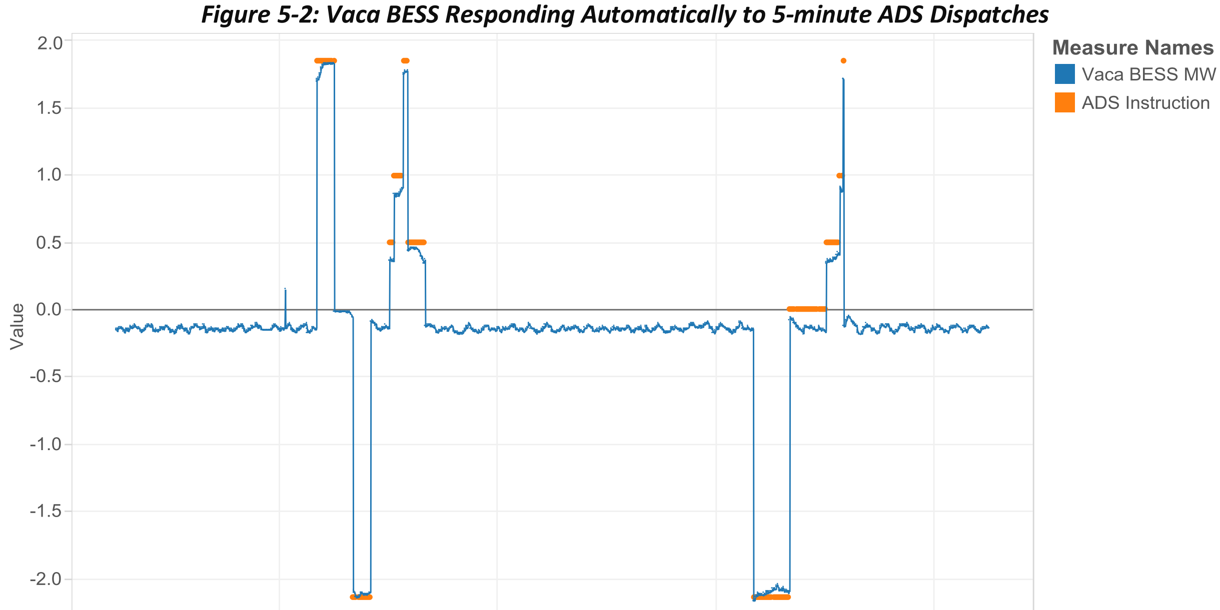
During this time, the Technical Team also explored options for the software to be hosted on the Central Dispatch Server and looked at both building the software internally and procuring an off-the-shelf solution from an external vendor. Discussions were held with numerous vendors to determine the suitability of their solutions in function, security, ability to be customized to meet PG&E standards, and the manner in which they had to be deployed. The Technical Team shortlisted several vendors, observed demonstrations of their products, and eventually chose a vendor to provide this software.

The Technical Team began working with the vendor and the RTDECS vendor on a Proof-of-Concept (POC) test. The solution required that the software parse the XML file it pulled down from the CAISO ADS portal and send it to the RTDECS software for execution. POC testing began in April of 2015 and iterations continued through July of 2015 when the POC was declared successful.[46]

[46] Testing was done in a Quality Assurance environment, so no resources were actually controlled during POC testing.

With the POC was successful, a Solution Blueprint was created that detailed every element of the communication pathway. This included such elements as the specific hardware appliances that would be deployed to provide required cybersecurity protections, specific protocols for how the different devices would communicate, and configuration requirements. Once created, the Solution Blueprint went through extensive internal review, further iteration, and was approved in August 2015. The procurement, deployment, and configuration of equipment began and continued through October 2015. On November 5, 2015, the communication pathway went live with the CDS software fetching ADS dispatches for the Vaca-Dixon BESS and sending them to the RTDECS software on a server locally sited at the BESS. With only minor troubleshooting, the Vaca BESS began responding to ADS dispatches automatically that same day. Figure 5-2 depicts the successful following of ADS dispatches (denoted by orange lines) by the battery. Any vertical gaps between the orange and blue lines represent parasitic loads from the battery heaters. Also, the ADS instructions (orange lines) are only present where there was a market award in that interval.

Figure 5-2: Vaca BESS Responding Automatically to 5-minute ADS Dispatches



5.1.2 Precedent and Scalability

A guiding principle of this project was that the ADS Automation Solution deployed needed to be scalable to future energy storage resources. The Technical Team operated diligently to ensure that every element of this solution was indeed scalable. This included working hand-in-hand with PG&E's Utility Owned Generation group, which manages many hydro-electric generating plants. The automation solution deployed is capable of managing CAISO ADS award files for numerous resources. Future utility energy storage systems on PG&E's network, using the RTDECS Dispatch Control System, need minimal setup to utilize this system.[47]

[47] PG&E secured an unlimited license for use of RTDECS for any resource on its system. RTDECS was procured via funding outside of the EPIC program. Funding from this project was used for its testing and configuration of ADS automation capabilities.

A fundamental goal of the EPIC program is to demonstrate technologies that, if successful, can be moved into production and funded by the utility. The ADS Automation Solution has been moved into production with funding secured for its maintenance and operations into the future.

6 Cost-Effectiveness Assessment

At the start of this project no battery systems had participated in the CAISO NGR market, and no empirical data existed on financial performance. Therefore, a goal of this project was to compare the actual financial performance of PG&E's Vaca-Dixon and Yerba Buena BESSs in CAISO markets to model-predicted values filed with the California Public Utilities Commission and California Energy Commission by the organizations Electric Power Research Institute (EPRI)[48] and DNV GL[49], respectively.

Batteries, with their exceptionally fast response times, are often rightly credited with their ability to provide multiple functions in fast succession or simultaneously. As such, they have the ability to instantaneously switch between providing different market products (Energy, FR, or Spin) as the prices of those products change. For example, FR may provide the best revenue in one interval whereas Energy may provide the best revenue in the next.

The reality, however, is that switching between those products involves mutually exclusive tradeoffs with imperfect information. The mutually exclusive tradeoff is that a resource can only receive a market award for one power/energy unit in any given time interval. The key imperfect information is that forward prices are unknown.

As such, operating a battery involves making the best guess about which of these products are likely to garner the highest revenues – not just in the next time interval but in some future interval - because a unit of energy charged or dispatched in interval X is one less unit of energy available in interval Y when prices may be higher or lower.

This makes using models to predict market values somewhat problematic to the extent that:

- They tend to assume "perfect" bids that would require more certainty about forward prices than is realistic
- They do not necessarily capture operational challenges such as managing SOC, resource-specific limitations, and the many other challenges detailed in Section 4.5 Market Participation Challenges

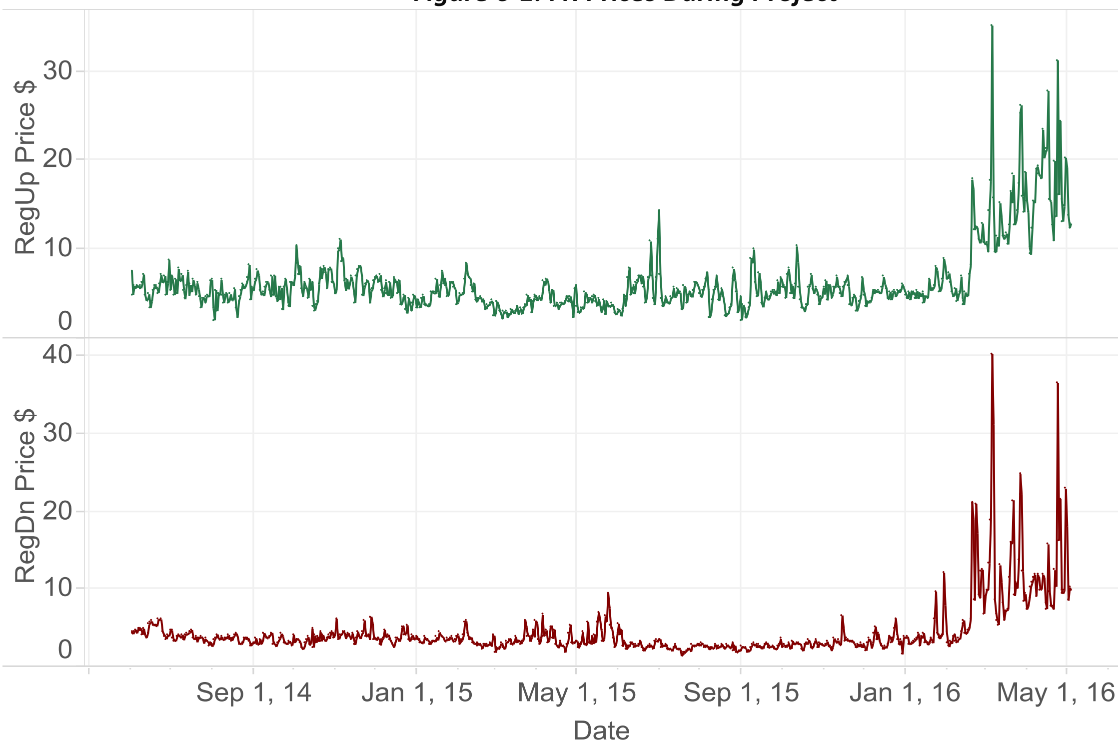
Over the course of the project, the highest value product for the batteries was in providing Frequency Regulation. As such, it was economically advantageous to bid full battery capacity for FR over Energy or Spin.

Figure 6-1 depicts FR prices for RegUp and RegDn from the start of the project (September 2014) through the writing of this report (July 2016).

[48] Cost-Effectiveness of Energy Storage in California. Application of the EPRI Energy Storage Valuation Tool to Inform the California Public Utility Commission Proceeding R. 10-12-007, Electric Power Research Institute, B. Kaun Project Manager, June, 2013.

[49] "Energy Storage Cost-effectiveness Methodology and Results," DNV GL Energy and Sustainability, August 2013.

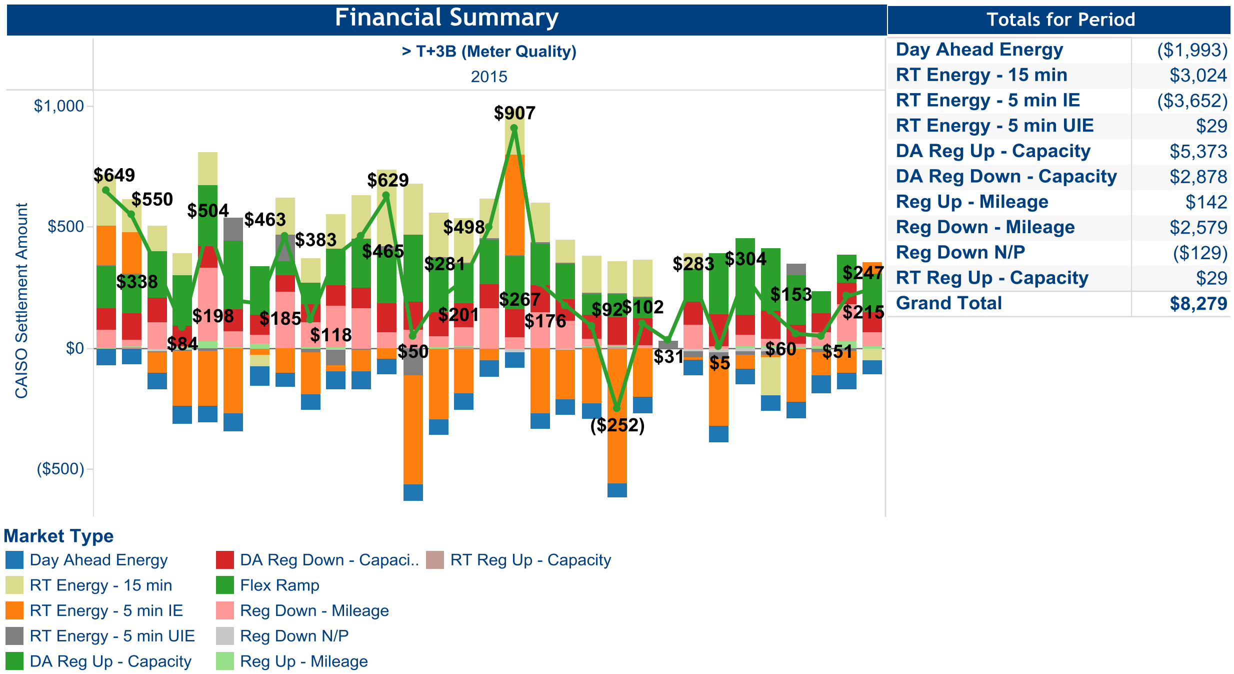
Figure 6-1: FR Prices During Project



As shown in the figure above, prices were extremely flat for most of this period until February 2016 when average prices increased significantly. This increase is driven by higher daily FR procurement amounts from CAISO, likely due to a combination of factors including high water levels after a relatively wet winter. In the case of a wet winter, hydro-electric resources, which normally provide a significant portion of California's ancillary services capacity, will opt for energy production rather than ancillary services.

In a sample month in 2015, the Vaca battery was bid into FR for approximately 18 hours per day, with 6 hours reserved for RT Energy bids to manage the SOC of the resource. The net revenues for this period were $8,279, as shown in Figure 6-2.

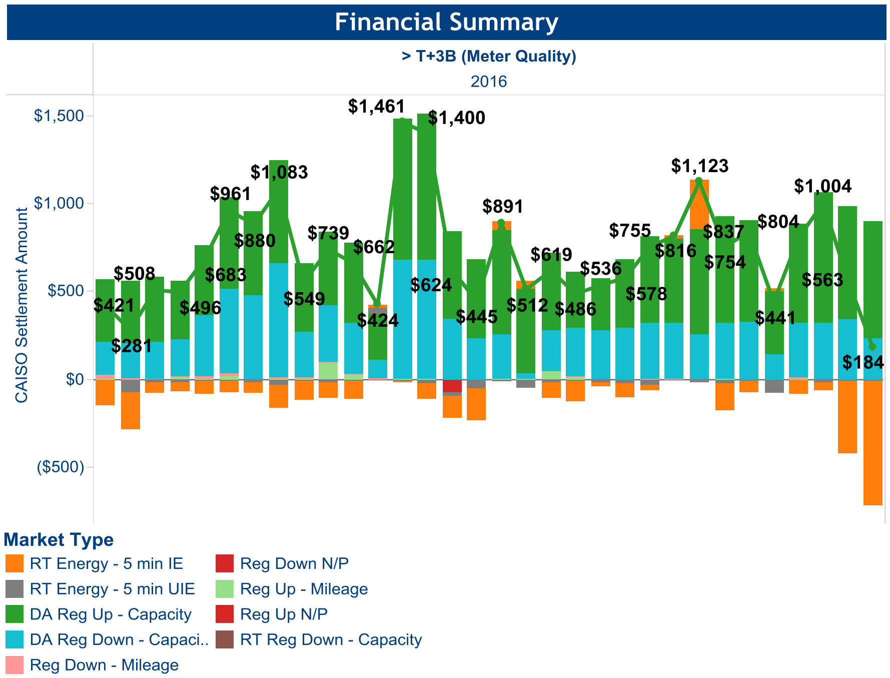
Figure 6-2: Vaca BESS Settlements – Sample Month 2015



Below in Figure 6-3 is a sample month of data from 2016 of the Vaca BESS performing FR as a REM resource in all hours of every day. Operated as a REM resource, where CAISO manages the SOC to 50%, the resource was bid into FR for 24 hours every day to achieve revenue of $22,597 for the month. In this period, the Vaca system was also operating at 65% of the FR range that was offered in mid-2015.[50] Extrapolated to the full range, this represents approximately $34,800 for this month.

[50] This is not due to a resource-specific limitation but rather due to issues that have been experienced with ancillary services re-testing for the resource with CAISO.

Figure 6-3: Vaca BESS Settlements – Sample Month 2016



Totals for Period	
RT Energy - 5 min IE	($2,865)
RT Energy - 5 min UIE	($574)
DA Reg Up - Capacity	$15,733
DA Reg Down - Capacity	$9,976
Reg Up - Mileage	$304
Reg Down - Mileage	$85
Reg Down N/P	($48)
Reg Up N/P	($24)
RT Reg Down - Capacity	$11
Grand Total	**$22,597**

Table 6-1 summarizes the results from these two scenarios, with the sample 2015 month representing the more common FR prices and the sample 2016 month representing more exceptional prices:

Table 6-1: Vaca BESS Settlements for FR

	Sample Month 2015	**Sample Month 2016**
Market Model	NGR Non-REM	NGR REM
Days	31	31
Hours per day of regulation	18	24
Regulating Range	-2.14 MW to 1.85 MW (4MW total range)	-1.3 MW to 1.3MW (2.6MW total range)
Average RegUp Price ($/MW/hr)	$4.67	$15.94
Average RegDn Price ($/MW/hr)	$2.42	$11.41
Regulation Capacity Revenues	$8,251	$39,552[51]
Mileage Revenues[52]	$2,721	$598
Energy Revenues	($2,592)	($5,291)
Other Revenues	($100)	($94)
Total Monthly Revenues	$8,279	$34,765
Annualized Revenues	$99,000	$417,000

[51] All dollar values this column scaled to make regulation ranges equivalent

[52] An interesting observation is that mileage values were higher in the month when the resource provided fewer hours of regulation. Possible reasons for this could be a significant difference in the mileage price or the accuracy of the resource, however there is no evidence to believe the resource was more or less accurate in either period. The Technical Team is continuing to monitor this but does not have a definitive explanation as of the writing of this report.

These are obviously significantly different numbers for a resource providing essentially the same services at two different months over a 20 month period.

The fully installed cost of the 2 MW / 14 MWh Vaca BESS was approximately $11,000,000, which equates to $783/kWh or $5,500/kW. Regardless of whether any month above is used, Table 6-2 below shows this resource is not cost effective in the current CAISO market where FR is the highest-value product.

Table 6-2: Vaca BESS Market Revenues and NPV

Scenario	Annualized FR Revenues	NPV[53]
Sample Month 2015: Representative of majority of project months	$99,000	($9,545,490)
Sample Month 2016 Representative of most recent 3 months	$417,000	($7,184,953)
Weighted blend of revenues	$146,700	($9,191,409)

Table 6-3 depicts the required $/kW price for a BESS in order for it to be cost effective (NPV greater than $0) with these market revenues. Note that this accounts for *capital costs only*, excluding operations and maintenance (O&M) costs, decommissioning and disposal costs, and any other variable costs.

Table 6-3: Breakeven Cost Calculation

Scenario	Annualized FR Revenues	Breakeven Installed Cost ($/kW)
Sample Month 2015: Representative of majority of project months	$99,000	$393
Sample Month 2016: Representative of most recent 3 months	$417,000	$1,656
Weighted blend of revenues	$146,700	$583

Both EPRI and DNV GL modeled a number of different scenarios with varying resource types and sizes as well as varying assumptions about what market prices will be for frequency regulation in the coming years. Their analyses demonstrated Frequency Regulation as the highest revenue product as well. Both DNV GL and EPRI assumed a high-power, low energy system (20MW, 5MWh). This equates to a 15-minute battery at full discharge. This is indeed a feasible product as the CAISO offers within its Non-Generator Resource model a Regulation Energy Management (REM) option.

Table 6-4 depicts the $/kW cost representing the maximum resource cost for a cost-effective resource based on their analyses.

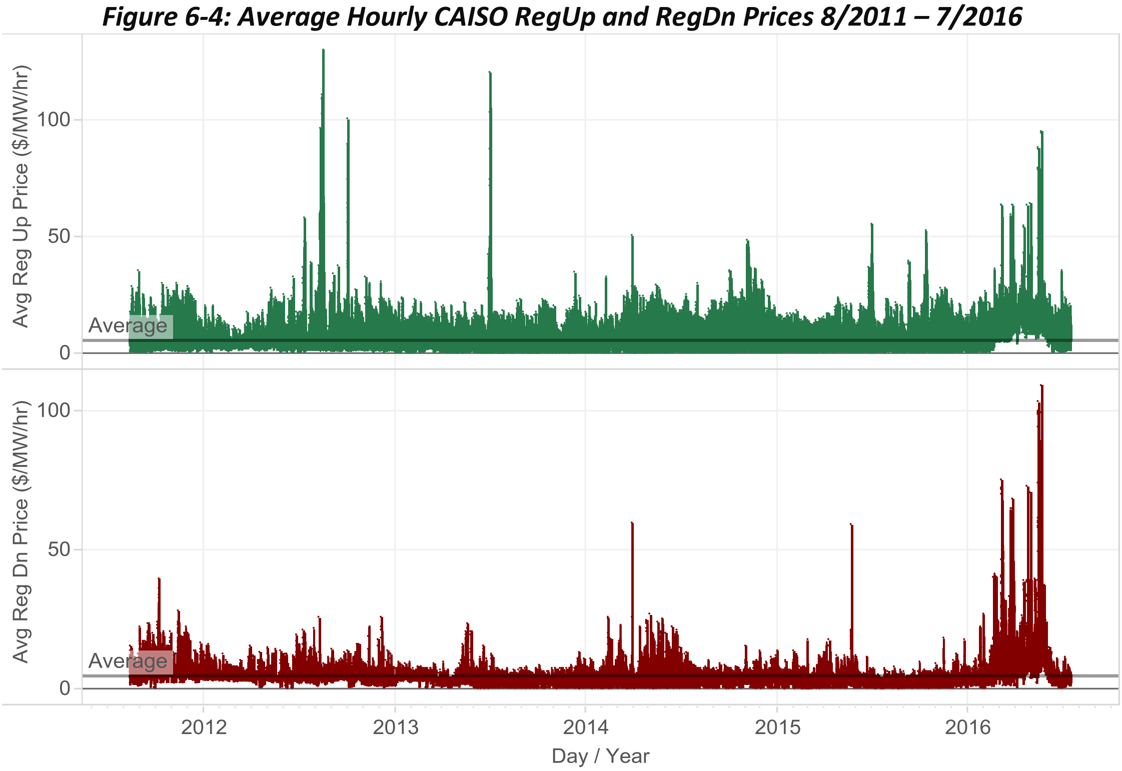
[53] Analysis assumes 12 years asset life, 7% cost of capital

Table 6-4: Resources Modeled by EPRI and DNV GL

	Resource modeled by DNV GL[54]	Resource modeled by EPRI[55]
Power (MW)	20	20
Duration (hours)	0.25	0.25
Capital Cost	$17,600,000	$15,560,000
Cost of capital	6.18%	11.50%
Asset life	20[56]	20
Breakeven installed cost ($/kW)	$880	$778

These breakeven $/kW prices for a cost-effective resource are in line with this project's empirical data if FR prices continue to stay at the values seen from February 20, 2016 through May 2016. While the past cannot predict the future, Figure 6-4 depicts historical FR prices from August 2011 through the July 2016. As can be seen, prices in June and July 2016 have begun returning to levels seen during the majority of this time period.

Figure 6-4: Average Hourly CAISO RegUp and RegDn Prices 8/2011 – 7/2016



It is expected that the CAISO market will change in the coming years with significantly more renewable regeneration coming online bringing the prospect of very low or negative sustained energy prices. This

[54] See p. 23 of cited DNV GL report.
[55] See p. 5-3 of cited EPRI report. $15.56M capital cost calculated from stated values of $3,112/kWh.
[56] While these are 20-year resources compared to the 12-year life use for calculations relating to the Vaca BESS, the overall effect of these lifespan differences on these analyses is small.

may improve the financial proposition for longer duration batteries, like the Vaca Dixon and Yerba Buena BESSs, participating in the DA and RT Energy markets. Later this year, CAISO also plans to release a Flexible Ramping product, which may provide additional revenues for long duration batteries.

One final caveat regarding the REM model and resource duration: PG&E's positive experience to date with the use of the CAISO's REM model has been that it enables the 7-hour Vaca BESS to provide maximum regulation while minimizing the energy cost risk involved to maintaining a median state of charge. Since being put into the REM model in March, 2016, Vaca Dixon's SOC has been kept close to 50% over periods of hours rather than minutes. This should not be seen as positive evidence, however, that the REM model would enable batteries with very short cycle times (such as the .25 hour cycles posited in the EPRI and DNV GL cost-benefit studies) to be kept at median charge without sacrificing a significant fraction of their regulating capability and corresponding revenue streams.

7 Key Accomplishments and Recommendations

7.1 Key Accomplishments

The following summarize some of the key accomplishments of the project over its duration:

- Successfully demonstrated the use of PG&E's Vaca-Dixon and Yerba Buena NAS BESSs to provide energy and ancillary services in CAISO markets. These are the first utility-owned battery storage resources participating in the NGR market
- Developed and deployed a scalable technology platform to automate the response of current and future PG&E battery storage resources to CAISO market awards via its Automated Dispatch System (ADS)
- Established organizational roles and responsibilities for the operation of PG&E battery storage resources as both market and distribution system assets with potential to be leveraged by other electric utilities
- Assisted PG&E's Electric Generation Interconnection team in the development of new processes for interconnection review and approval of battery storage resources both connected to PG&E's distribution grid and providing CAISO market services
- Developed optimization model and workflow processes for efficient bidding of battery resources into the CAISO market
- Engaged with CAISO to identify and resolve implementation issues with the CAISO NGR model for Limited Energy Storage Resources based on operational experience
- Quantified financial revenues of the CAISO Day Ahead (DA) and Real-Time (RT) energy markets
- Achieved NGR model design improvements through the Energy Storage and Distributed Energy Resources initiative such as including state of charge in the day-ahead market bid parameters.

PG&E continues to collaboratively work with CAISO on additional improvements to the NGR model as both organizations gain experience with how these resources operate in the market.

7.2 Market Recommendations

This report reflects the operational lessons particular to the Vaca and Yerba Buena BESSs. In the future, the unique properties of other BESS technologies that enter the market may need to be reflected in market design models. In light of some of the lessons learned through market operations and these future considerations, PG&E has identified two market model enhancements that warrant further consideration: (1) Allow users to specify the Regulation Energy Management (REM) operating range, and (2) reflect operational limitations in optimization constraints.

7.2.1 Allow User-Specified REM Range

Allowing a user-specified Regulation Energy Management (REM) operating range would allow resources that are also dedicated for another purpose to participate in REM.

PG&E's testing of the NGR model with its Vaca-Dixon and Yerba Buena BESS has found that CAISO does an excellent job managing the state of charge (SOC) of a resource on REM at 50%. While this may be an ideal solution for a fully dedicated CAISO REM resource, this approach is not suitable in situations when a portion of the resource is dedicated for another purpose. For example, half of PG&E's Yerba Buena BESS (4 MW) is dedicated to the customer's on-site usage and the other half to market participation. Interconnection limitations also exist that limit the output of the battery during certain months and hours (see Section 4.5.2.3 Operational Limitations for Interconnection). PG&E anticipates future resources serving both distribution and market functions may face similar limitations. To unlock the full value of energy storage, PG&E recommends that CAISO allow REM bids to specify different operational ranges for different hours and a target SOC that can be different than 50%.

7.2.2 Reflect Operational Limitations in Optimization Constraints

Based on PG&E's experience with the 2014 Energy Storage RFO and conversations with storage manufacturers, many energy storage warranties specify annual discharge limitations in order to preserve the life of the battery for the full span of the warranty. Depending on the contract structure, these annual limitations may be a constraint that Scheduling Coordinators must manage. Energy storage model enhancements that include daily limits on throughput and cycling, along with the ability to change these limitations on a day-to-day basis, would give Scheduling Coordinators the means to effectively manage these constraints. CAISO could reflect limitations such as throughput and cycle limitations in the NGR model as optimization constraints. PG&E also recognizes that new technologies may include unique attributes that may either provide more flexibility or require further limitations. Market models should be able to respect these unique attributes in order to preserve the life of the assets and increase the cost effectiveness of various storage resources.

7.3 Technology Transfer Plan for Applying Results into Practice

A primary benefit of the EPIC program is the technology and knowledge sharing that occurs both internally within PG&E and across the other IOUs and the CEC. In order to facilitate this knowledge sharing, PG&E will share the results of the EPIC 1.01 Energy Storage for Market Operations project in industry workshops and through public reports published on the PG&E website. Below is information sharing forums where the results and lessons learned from this EPIC project were presented and discussed:

Information Sharing Forums Held:

1. Energy Storage North America 2014 Annual Conference (Santa Clara, CA), September 2014
2. EPIC Workshop (San Diego, CA), August 2015
3. Energy Storage North America 2015 Annual Conference (San Jose, CA), October 2015
4. Meeting with CAISO personnel (Vacaville, CA), April 2016
5. CPUC/CAISO Multiple-Use Applications Conference (San Francisco, CA), May 2016
6. EPIC Summer Workshop (Westminster, CA), June 2016

7.4 Data Access

Upon request, PG&E will provide access to data collected that is consistent with the CPUC's data access requirements for EPIC data and results.

7.5 Project Metrics

The following metrics were identified for this project and included in PG&E's EPIC Annual Report as potential metrics to measure project benefits at full scale. Given the proof of concept nature of this EPIC project, these metrics are forward looking.

D.13-11-025, Attachment 4. List of Proposed Metrics and Potential Areas of Measurement	Report Reference
1. Potential energy and cost savings	
i. Nameplate capacity (MW) of grid-connected energy storage	See Table 4-1 and Table 4-2
3. Economic benefits	
a. Maintain / Reduce operations and maintenance costs	See Sections 4.2 and 5 for a discussion of market activities and ADS automation solution
6. Other Metrics (to be developed based on specific projects through ongoing administrator coordination and development of competitive solicitations)	
a. CAISO NGR financial settlements	See Section 4.4 for a detailed discussion of market results
7. Identification of barriers or issues resolved that prevented widespread deployment of technology or strategy	
a. Description of the issues, project(s), and the results or outcomes	See full scope of work with tasks and associated milestones in Section 3.3
b. Increased use of cost-effective digital information and control technology to improve reliability, security, and efficiency of the electric grid (PU Code § 8360)	See Section 5 regarding ADS Automation Solution
c. Dynamic optimization of grid operations and resources, including appropriate consideration for asset management and utilization of related grid operations and resources, with cost-effective full cyber security (PU Code § 8360)	See Section 4
l. Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services (PU Code § 8360)	See Section 0
8. Effectiveness of information dissemination	
d. Number of information sharing forums held	See Section 7.3

D.13-11-025, Attachment 4. List of Proposed Metrics and Potential Areas of Measurement	Report Reference
9. Adoption of EPIC technology, strategy, and research data/results by others	
c. EPIC project results referenced in regulatory proceedings and policy reports	Yerba Buena BESS project discussed at 5/3/2016 CAISO/CPUC Joint Energy Storage Workshop on Multi-Use-Applications • PG&E experience with NAS batteries also referenced in Energy Storage Request for Offers (ESRFO) and Energy Storage Order Instituting Rulemaking (ESOIR) proceeding comments by PG&E

8 Conclusion

This project successfully achieved all of its key objectives and, in doing so, has directly and indirectly addressed multiple barriers to energy storage for the benefit of current and future CAISO market participants. Through the work executed in this project and documented in this report, PG&E has gained substantial operational experience with battery storage, informed and enhanced CAISO models through identification and resolution of implementation issues, informed a new interconnection process, provided more transparency in the wholesale price signals and informed cost effectiveness understandings. Due to the achievements of the project, PG&E will continue to maintain the Automated Dispatch System as a platform to automate the response of current and future battery storage resources to CAISO market awards and plans to provide a new flexible ramping product[57] that CAISO will introduce in late 2016.

Informed and Enhanced the CAISO NGR Market Model through Identification and Resolution of Implementation Issues

The project helped CAISO identify and resolve multiple implementation issues with the NGR market model and enhance that model in ways that will significantly benefit future market participants.

Informed New Interconnection Processes

This project helped PG&E's Electric Generation and Interconnection (EGI) team derive learnings to inform new processes for interconnecting battery energy storage resources to the distribution grid with the ability to provide market and distribution services, including islanding.

Provided More Transparency in Wholesale Price Signals and Informed Cost-Effectiveness Understandings

The project gained significant real-world data on the financial performance of battery energy storage resources providing energy and ancillary services in CAISO markets that can better inform an assessment of market benefits in cost-effectiveness valuations of future battery storage procurements. Over the course of the 18 months of market participation during this project, the financial revenues from battery participation in CAISO markets were limited. If revenues from market participation are to be the key driver of evaluating the cost-effectiveness of battery storage, it is recommended to be conservative in the forecasting of those revenues. With California Assembly Bill 2514 and its requirements that utilities

[57] The flexible ramping product is designed to provide additional revenues for fast ramping resources such as batteries.

procure 1.3 gigawatts of energy storage, California ratepayers could expect to pay billions of dollars for the deployment and operations of these resources. In making its decisions, the CPUC and California State Assembly have relied on models showing CAISO market revenues to be the primary benefit driver for the cost-effectiveness of storage resources.[58]

New Operational Experience Gained with Battery Storage

PG&E has gained substantial experience operating battery energy storage resources providing distribution and market services including enhancing capabilities for control of market-participating, utility-owned, and distribution-connected resources. The ADS solution has enabled BESSs to participate in market operations by minimizing manual operations and optimizing market operations to maximize financial returns. After this project, PG&E plans to continue maintaining and improving the Automated Dispatch System as a platform for automating the response of current and future PG&E battery storage resources to CAISO market awards. In addition, PG&E plans to provide the new CAISO flex ramp product to market after introduction in late 2016.

This experience has ultimately informed new battery storage procurements and the project's learnings will enable more efficient and cost-effective integration of future battery storage resources into utility and market operations as PG&E strives to reach energy storage procurement targets.

[58] See EPRI and DNV GL reports filed with CPUC and sited in Section 6 Cost-Effectiveness Assessment.