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FINAL PROJECT REPORT

DISTRIBUTED ENERGY STORAGE TO SUPPORT GRID OPERATIONS

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PREFACE

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

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Distributed Energy Storage to Support Grid Operations is the final report for this project (Contract Number 500-11-006, "Determining Best Location for Energy Storage to Maximize Effectiveness with Residential Renewable Generator Clusters") conducted by San Diego Gas & Electric. The information from this project contributes to Energy Research and Development Division's Energy Technology Systems Integration Program.

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ABSTRACT

This demonstration project focused on installing and operating distributed energy storage systems on the utility distribution network. The project comprehensively measured and quantified using energy storage systems to support grid operations. The major tasks for the project were to procure three energy storage units, select sites, establish baselines, install the systems, operate them, and collect and analyze the data.

The selected energy storage units used a lithium-ion based technology and were of a size suitable for serving one or multiple commercial or residential customers on the distribution system. These modular energy storage systems were called community energy storage units. The sites for the three applications selected for the demonstration were a utility test center, a group of small commercial customers (a strip mall), and a residence with a large solar photovoltaic system.

The energy storage units were tested under various modes of operation against the customer loads. The modes of operation demonstrated were:

- Constant Charge and Discharge
- Peak Shaving (Load Following)
- Arbitrage
- PV Smoothing
- PV Load Shifting
- Four Quadrant Operation
- Aggregated Constant Output
- Aggregated Peak Shaving
- Aggregated Arbitrage

The units were installed in the third quarter of 2013 and the demonstrations took place during the first six months of 2014. All planned demonstrations were conducted successfully. The average AC-AC round trip electric efficiency of the units was 80 percent.

The demonstration showed how utility-owned energy storage systems installed on the distribution network can be operated both individually and aggregated as a fleet of distributed resources to support grid operations.

Keywords: Energy Storage, Distributed Energy Storage Systems, Community Energy Storage Systems, Peak Shaving, PV Smoothing, Arbitrage, Energy Storage Dispatch, Demand Management

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EXECUTIVE SUMMARY

Introduction

This report, *Distributed Energy Storage to Support Grid Operations*, is the final report for Contract Number 500-11-006, "Determining Best Location for Energy Storage to Maximize Effectiveness with Residential Renewable Generator Clusters," an Energy Research and Development project funded by the California Energy Commission. San Diego Gas & Electric (SDG&E) has over 40,000 customer-owned renewable energy installations in operation, with a total connected capacity of over 200 megawatts (MW). The predominant type of customer-owned renewable energy installations are photovoltaic (PV) systems, which creates electric system operating challenges due to the intermittency of power production in areas of high penetration. The goal of this project was to identify solutions to eliminate or mitigate these operating challenges using distributed energy storage systems. In the project, these modular systems were called community energy storage (CES) systems because their charge/discharge rates and energy storage capacities were suitable for serving one or multiple commercial or residential customers.

Project Objectives

The project had five key objectives associated with the deployment and operation of CES systems on the distribution network.

1. Develop criteria for the installation of the energy storage systems.
2. Install the systems.
3. Develop techniques for managing and dispatching the systems.
4. Test the effectiveness of the systems.
5. Quantify additional benefits of the systems.

Project Outcomes

Some of the key findings and results learned from the testing phase of the project are listed below:

- The site selection process identified several potential circuits as candidates for installation of the CES units that met a majority of the identified selection criteria. However, identifying physical locations for the CES units proved to be the most challenging requirement. The dimensions of the CES units in relationship to the dimensions of the utility's existing right-of-ways significantly limited the potential sites for the units.
- The dispatching of multiple CES systems requires the development of a strategy and resources to optimally schedule the systems.
- Each unit could be scheduled and operated in the constant power mode, ramp rate control mode, and power management mode.

- The demonstration tested the ability of the CES units to operate under three different approaches for peak shaving operations, including: 1) managing power flow to a set import limit; 2) operating to a set power export limit; and 3) operating at constant power at the desired load reduction value for the peak shaving function.
- The CES systems were successfully scheduled and operated to capture and use excess PV generation at times when the customer would typically import power from the grid.
- The PV smoothing function using ramp rate control varied between the residential unit and strip mall unit.
- Demonstrations showed that the SDG&E Test Center unit was capable of successfully operating in all four power quadrants near the desired set points.
- The fleet average AC-AC round trip efficiency for the units was near 80 percent.
- The demonstrations showed that the three units could be programmed to operate in an aggregated fashion for the various modes of operation.

Project Benefits

This proof-of-concept CES demonstration is expected to produce several benefits for California's electricity ratepayers.

Microgrids and CES systems provide a locally controlled resource to address the challenges of new customer electric usage characteristics and to improve load management, power quality issues, bi-directional power flow on the distribution network, the environmental benefits of integrating renewable sources, and reliability of service.

This work also helps advance future deployment of energy storage systems by both California utilities and electric customers and can be part of a portfolio of energy solutions that help advance renewable energy standards in the state.

CHAPTER 1:
Project Objectives

The project had five key objectives associated with the deployment and operation of distributed community energy storage (CES) systems on the distribution network.

Develop criteria for the installation of energy storage systems

The criteria focused on the identification of locations on the distribution network where the modular CES units could provide benefits to utility operations. These addressed peak load management, high penetration PV, and stressed utility distribution equipment support.

1. Install energy storage systems

   Three CES units were purchased and installed in the service territory. Each unit was placed between a distribution transformer and one or more customers. The procurement process included the development of an RFP, development of selection criteria, equipment selection, site selection, installation, and start up.

2. Develop techniques for managing and dispatching energy storage devices

   Once installed, the units were operated in a manner to demonstrate benefits to distribution operations. Various modes of operation and methods for dispatching were developed. The units were dispatched individually and then in an aggregated manner.

3. Test the effectiveness of the energy storage devices

   The demonstration also evaluated the operational performance of the CES units. The performance metrics included usable energy capacity, maximum charge rate, maximum discharge rate, efficiency, and characterization of the various modes of operation.

4. Quantify additional benefits of the energy storage devices

   During the course of system operations, other modes of operation and distribution operations support were identified and implemented to help quantify these additional benefits. These may include arbitrage and congestion relief using CAISO day-ahead pricing information, PV load shifting to minimize export to the circuit, and PV/load smoothing.

CHAPTER 2:
Project Approach

2.1 CES Design

2.1.1 Specification

The project team developed a specification that defined the specific engineering and operating requirements for the CES units intended for installation on the San Diego Gas & Electric's (SDG&E) electric distribution system. The CES units were generally envisioned to be pad-mounted equipment located in a public setting and configured to meet all applicable standards required of other SDG&E pad-mounted equipment with respect to safety and environmental impact. Most functional and engineering requirements were described in the specification. However, in some instances, some specifics were application or site-sensitive and were addressed once a vendor was selected.

2.1.2 Equipment Selection

The specification was packaged into a Request for Proposal (RFP) and sent to battery vendors and power conditioning system vendors. The RFP focused on a turnkey installation approach for the CES units and requested vendors to provide costs for three CES options as presented in Table 1.

Table 1: RFP CES Discharge Rating Options

CES Discharge Ratings	
Continuous Nominal Discharge Rate (kW_{AC})	**Usable Discharge Capacity (kWh_{AC})**
25	25
25	50
25	75

Bidders were required to provide the following:

- System specifications
- Installation design
- Equipment delivery
- System installation
- All relevant CES control algorithms and application software to support required modes of operation

- Factory acceptance testing
- System start-up
- On-site acceptance testing and commissioning
- On-site training
- Manuals, as-built drawings and documentation
- Maintenance schedule
- Warranty
- Cost

The RFP provided a listing of the selection criteria that would be applied to evaluation of the proposal. The criteria were presented without indication of the priority or weighting for each particular criterion. The evaluation criteria are presented in Table 2:

Table 2: RFP Criteria Description

Criteria #	Criteria Description
1	Cost
2	Technical Merit of CES System
3	Proof of Performance
4	Safety/Environmental Issues
5	Staff Expertise and Experience
6	Compliance with Terms and Conditions
7	Realistic Project Schedule
8	Diverse Business Enterprise (DBE) Goals*

*Item #8: DBE Goals represents SDG&E's Supplier Diversity Program to implement a process that will aid, counsel, and assist, insofar as is legally permissible, the participation of certified Diverse Business Enterprise (DBE) firms in contracts for SDG&E properties, facilities, and services. The anticipated levels of participation for these services are fifteen percent certified Minority-Owned Business Enterprises, five percent certified Women-Owned businesses, and five percent Service Disabled Veteran-Owned Businesses. Bidders are encouraged to utilize

these businesses in fulfilling the work requirements of any Scope of Work, and are requested to identify them on Bidder's proposal. SDG&E's goal is 30 percent DBE spend.

2.1.3 Site Selection

The project team developed criteria for the basis of identifying eligible circuits for the project. The evaluated circuit characteristics included the following:

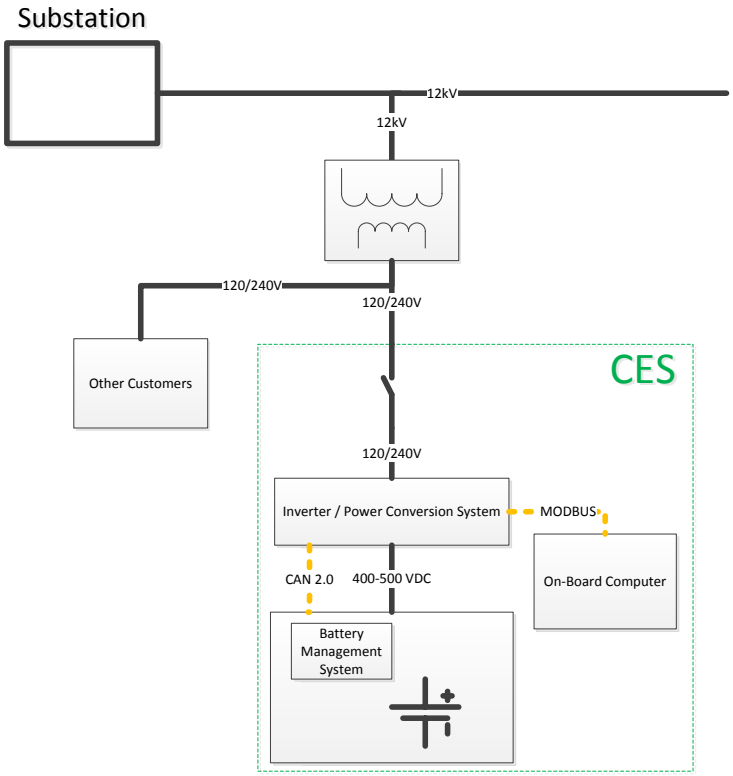
- Circuit Peak Load: Circuits where there is an opportunity to reduce the peak load at the substation transformer with the CES units operating either individually or in aggregate
- Distribution Transformer Peak Load: Circuits where there is an opportunity to reduce the peak load at one or more distribution transformers with the CES units
- Circuit Reliability: Circuits where there are reliability issues that have the potential to be improved with the addition of the CES units
- Circuit Power Quality: Circuits with poor power quality or low power factors that can potentially be improved through the operation of CES units installed on the circuit
- Circuit Voltage: Circuits with voltage drop issues where the application of the CES units installed at strategic locations on the circuit could improve the level of service to all customers served by the circuit
- Level of Customer-Owned Photovoltaic (PV) Penetration: Circuits with a high level of PV penetration (>15 percent of peak load) where the CES units can be used to provide smoothing and regulation
- Ease of CES installation: Circuits that can be improved by one of the means described above and have adequate space in the utility right of ways for the CES units.

The site selection process identified several potential circuits as candidates for installation of the CES units. However, identifying physical locations for the CES units proved to be the most challenging requirement. The dimensions of the CES units in relationship to the dimensions of the utility's existing right of ways significantly limited the potential sites for the units.

2.1.4 Installation

The specification defined the engineering and operating requirements for the CES units intended for installation on the SDG&E electric distribution system. The CES systems were envisioned to be pad-mounted equipment located in public settings and configured to meet all applicable standards required of other SDG&E pad-mounted equipment with respect to safety and environmental impact. A general schematic of a CES installation is presented in Figure 1.

Figure 1: CES Installation Schematic



2.2 Techniques and Algorithms for the Control of CES

The CES unit controls were specified to include communications connections and associated data protocols to support control and data transmittal for performance of administrative functions from a remote computer. Wide area communication interfaces for remote management applications, as well as any other communication interfaces (such as into home networks or for local management functions) were specified to be compliant with the emerging NIST Smart Grid cyber security requirements.

2.2.1 Control Functions

The CES unit controls were responsible for performing the following by priority in this order:

- Disconnect from the grid in the event of a grid outage (Anti-islanding per IEEE 1547)
- Protect itself (isolate for any internal fault)
- Remain within power constraints (transformer and CES unit)
- Remain within voltage constraints
- Remain within operating temperature constraints

- Isolate in response to system anomalies
- Charge / Discharge Real Power in response to CES programs or external commands
- Absorb / Provide Reactive Power in response to CES programs or external commands
- Communicate status and diagnostic data

2.2.1.1 CES Operating Mode Software Algorithms

The CES unit included all necessary software applications and supporting hardware to meet the specified unit functional requirements. Software algorithms, external data input capabilities, and user interfaces allow for user-specified variable input or set point values, as well as external data value streams required by programs directing the CES operations.

2.2.1.2 CES Monitoring and Control

A compatible CES management application was provided to permit remote or local monitoring and control from a remote utility-provided system controller (computer, server, etc.) used to manage distributed energy resources on the distribution network. All settings were viewable and settable including statuses, operating parameters, and log files. Basic access user names and password levels were required for system access.

The CES unit was to remain functional in the absence or loss of communication from the remote CES controller. The CES unit would continue the previous charge / discharge / standby operation for a set time period (variable setting, 15 minute default). On expiration of the time, the CES unit would go into a standby mode.

The CES unit controller had non-volatile memory. In the event of total loss of power (battery replacement or DC bus outage), the CES unit was to retain all current and logged information and was capable of restarting without reconfiguring. The design attempted to ensure that no single mode of failure could result in loss of power to the control and data acquisition module.

The control system had the provision for storing key operational data in a time-sequenced flat data file. This data was stored in non-volatile memory with a storage capacity sufficient for at least 30 days of data. The system also stored events, such as changes in operational mode, received commands, faults, and shutdowns. Each event was time-stamped.

Event and history logs were maintained by the CES to record routine performance data and key time-stamped events. The event log could be viewed locally or remotely by selecting time ranges or using standardized “event codes”. Once read, they may be further filtered by type of event or other criteria.

All data files were downloadable, either remotely or locally via a standard computer port or wireless connection.

2.3 CES Test Plans

The demonstration plan followed a phased approach based on the incremental introduction of components and variables. The project team began with more simple demonstrations and proceeded to more complex ones. The early demonstrations were designed around local control of individual devices. Later demonstrations introduced remote software and integration with data collection systems. Additional complexity was added based on the customer load and PV generation profiles. Later phases included operation of multiple CES units in fleet mode, and operating individual units in parallel but with individualized settings following a set schedule.

2.3.1 Individual Operation

Individual demonstrations were planned to exercise the operation of the CES systems in varying operating modes and at varying set points. Each demonstration was planned for multiple iterations. Additional iterations were planned and scheduled based on analysis of results of the initial tests. The various demonstrations addressed the following modes of operation:

- Constant Output: Constant charge and discharge on a daily schedule using the full usable range of the CES
- Peak Shaving: Use the CES for peak shaving (CES in Load Following controlling to the load at the distribution transformer). CES was at 90 percent SOC at the beginning of the Discharge Cycle
- Arbitrage: Charge and discharge CES based on day-ahead CAISO price
- Demand Response: Discharge system based on a day-ahead plan. Charge the system to a full state of charge during the following off-peak period
- PV Load Shifting: Charge the system at a variable load (representing PV generation) and discharge at a variable load to support the peak demand of the circuit
- PV Smoothing: At a 50 percent state of charge, support smoothing function to support PV load characteristics using revised settings
- Four-Quadrant Test: Demonstrate the operation of the CES in all four quadrants of the Real/Reactive power circle

2.3.2 Fleet Operation

Once all the individual demonstrations were complete, the subsequent demonstrations focused on aggregated fleet operations. A general objective was to demonstrate the ability to affect the operation of the three CES units as a fleet versus operating the units individually. These demonstrations also provided an opportunity to compare and contrast the behavior of the units and communication timing when commands are dispatched as a fleet. The following fleet operations were implemented for the project:

- Aggregated Constant Output: Constant output mode with all three units operating together

- Aggregated Peak Shaving: Peak shaving mode with all three units operating together
- Aggregated Arbitrage: Scheduled constant charge and discharge mode with all three units operating together to charge at lower prices and discharge at higher prices

The demonstration test matrix is presented in Table 3.

Table 3: CES Test Plan Summary

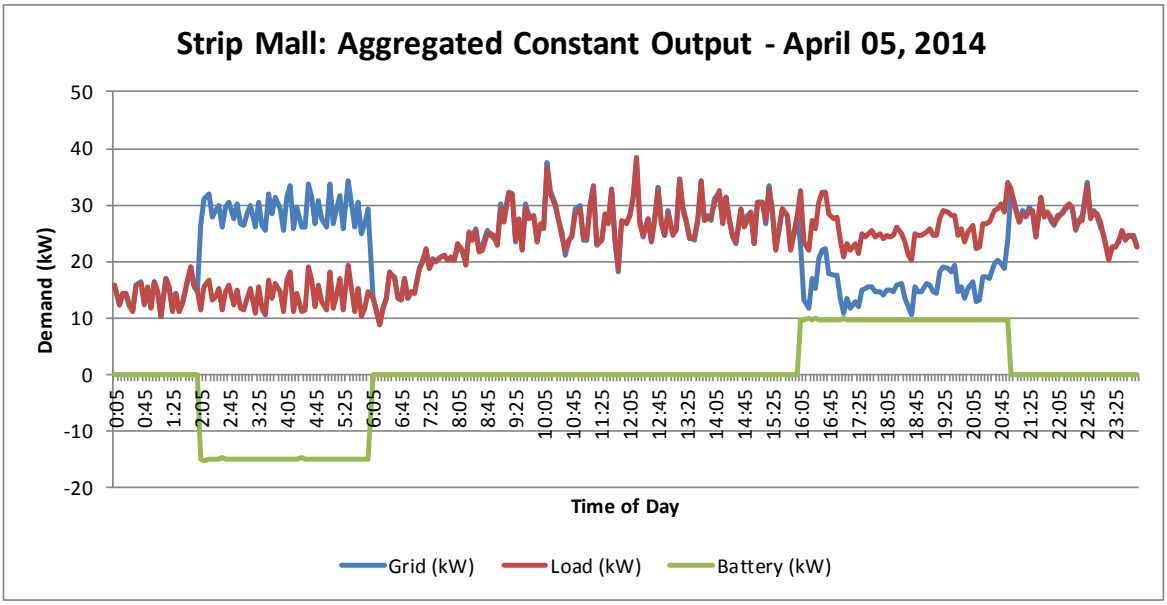
Mode of Operartion	Code	Test Center	Strip Mall	Residence
Constant Output	CO	X	X	X
Peak Shaving	PS		X	X
Arbitrage	A	X	X	X
Demand Response	DR	X	X	X
PV Load Shifting	PV			X
Smoothing	S		X	X
Ramp Rate	RR	X		
Aggregation: Constant Output	ACO	X	X	X
Aggregation: Peak Shaving	APS	X	X	X
Aggregation: Arbitrage	AA	X	X	X
Aggregation: Demand Response	ADR	X	X	X

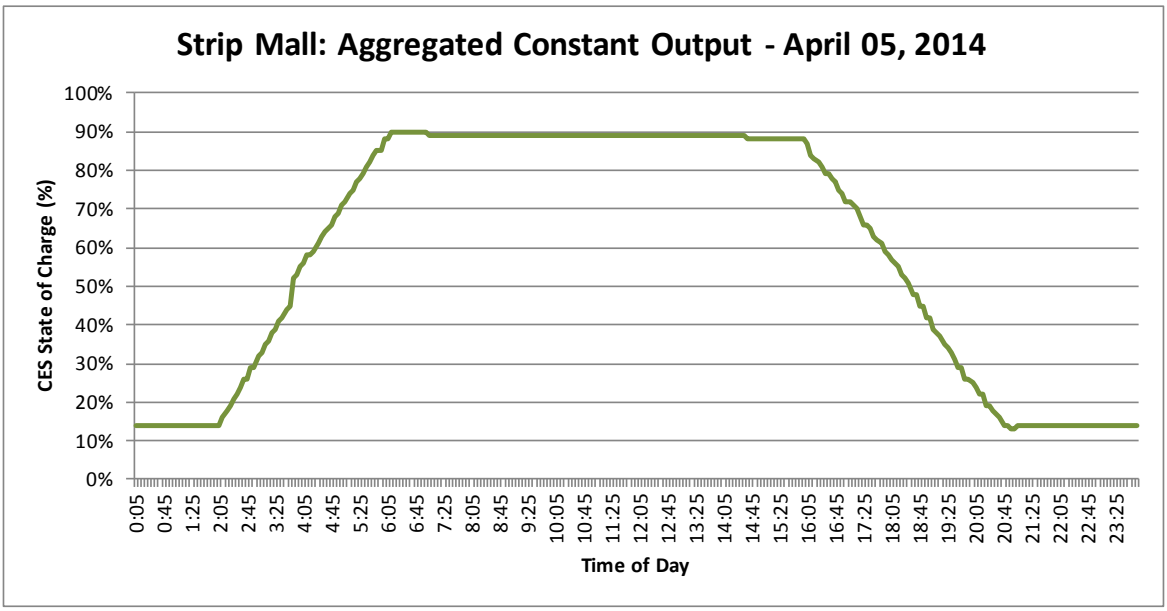
2.4 Testing and Results

Once the three systems were installed and the manual operations were conducted, it was discovered that there were operational difficulties with all three units. SDG&E worked with the vendor to have the systems modified to ensure consistent and reliable operations so that the testing phase could be executed. The units were not available for the demonstrations until March 2014. In order to conduct the required demonstrations within the period of performance of the contract, most of the tests were conducted over a two–and-a-half month period. The demonstrations were scheduled to take place on specific dates and operate under the site conditions occurring on those dates.

Data collection was conducted using the CES units' monitoring system. Data analysis was conducted using 5-minute data sets for each 24-hour period. A typical demonstration summary is presented in Figure 2.

Figure 2: Typical Demonstration Test Summary





Efficiency and Capacity Analysis

Cycle	Lower SOC	Upper SOC	Energy kWh
Charge Cycle	20%	80%	-48.3
Discharge Cycle	80%	20%	38.2

Efficiency 79.0%
Capacity: 63.7 kWh

CHAPTER 3:
Project Outcomes

3.1 CES System Selection

3.1.1 Vendor Selection

SDG&E assembled a team to review and evaluate the proposals that were submitted. The team consisted of five SDG&E electrical engineers, an SDG&E procurement administrator, and a technical consultant. The engineers and consultant conducted a technical review focusing on evaluation criteria 2-5 and 7. The procurement administrator conducted a review and evaluation of criteria 1, 6, and 8. The team assigned the weighting factors for the eight criteria and scored the four proposals that were technically responsive. The final scoring is presented in the following Table 4.

Table 4: RFP Scoring Summary

	Section	Vendor #1	Vendor #2	Vendor #3	Vendor #4
		Percent of Available Maximum Points			
1	Cost	46%	44%	100%	25%
2	Technical Merit of DESS System	60%	67%	71%	70%
3	Proof of Performance	75%	70%	65%	45%
4	Safety/Environmental Issues	83%	50%	83%	75%
5	Staff Expertise and Experience	60%	70%	70%	85%
6	Compliance with T&C's	100%	70%	50%	100%
7	Realistic Proj Schedule	75%	68%	68%	55%
8	DBE Goals	20%	100%	20%	40%
	Total Weighted Score	**309.05**	**310.15**	**372.7**	**281.5**

For this project, the highest ranked vendor was selected as the desired supplier and SDG&E entered into negotiations. Upon final negotiation, SDG&E issued a contract for three 25 kW, 50 kWh lithium-ion based CES units.

3.1.2 Equipment Specification

Table 5: Equipment Specification Comparison

Parameter	RFP	Selected System	Compliance Check
AC-Side Parameters			
Power (kW)	25	30 Discharging, 15 Charging	Yes
Energy (kWh)	50	72	Yes
Power (kVA)	30	30	Yes
Round Trip Efficiency (AC-AC)	85%	89%	Yes
Inverter	4 Quadrant	4 Quadrant	Yes
Nominal Voltage	120/240	120/240	Yes
Frequency Range	59.3 - 60.5 (per IEEE 1547)	59.3 - 60.5	Yes
Power Factor	0.0 - 1.0	0.0 - 1.0	Yes
IEEE 1547	Compliant	Compliant	Yes
Number of Cycles: 90% DOD	2,250	2,250	Yes
Number of Cycles: 10% DOD	150,000	150,000	Yes
Modes of Operation			
Mode #1	Peak Load Management	Peak Load Management	Yes
Mode #2	Frequency Regulation	Frequency Regulation	Yes
Mode #3	Constant Charge	Constant Charge w/ Reactive Power	Yes
Mode #4	Constant Discharge	Constant Discharge w/Reactive Power	Yes
Mode #5	Standby	Standby	Yes
Mode #6	Shutdown	Isolation	Yes
Mode #7	PV Smoothing	PV Smoothing	Yes
Enclosure			
Width (inches)	44	43	Yes
Length (inches)	42	90	No
Height (inches)	35	47	No
Protection Rating	Weather Proof, Dust Tight, 304 SS	NEMA 3R – Not Stainless	Yes
Environmental			
Ambient Operating Temperature	10°F to 120°F	–13°F to 140°F	Yes
Communications			
Protocol #1	Modbus	Modbus	Yes

Parameter	RFP	Selected System	Compliance Check
Protocol #2	DNP3	DNP3	Yes
Protocol #3	TCP/IP	TCP/IP	Yes

3.2 Energy Storage System Installation

3.2.1 Site Selection

Three sites were selected for the installation of the CES units. The team was not able to find a single circuit that could accommodate all three CES units as originally planned, so three individual sites on separate circuits were selected. The sites include SDG&E's Test Center, a residential site with a large photovoltaic system and a commercial site at a small strip mall.

3.2.1.1 SDG&E Test Center Site Description

The first CES unit was installed on an internal testing circuit at SDG&E's Test Center. The Test Center is composed of buildings for classrooms, offices, lineman training facilities, and smart grid technology demonstrations.

Figure 3: Test Center Installation

Photo Credit: San Diego Gas & Electric

Site Advantages:

Although the circuit the CES unit was installed on does not directly serve any customers, there were several advantages of this site for the research purposes of the demonstration. These included the ability to conduct system operations without directly impacting customer power quality, and adequate availability of space for installing the system. The installation location also supported the addition of infrastructure to add load banks that could be used to apply customized loads to the CES units for testing. Two 10 kW controllable load banks were used at the site to support the operations defined in the Test Plan.

Site Disadvantages:

The main disadvantage of the site was that there were no historical loads or dedicated loads for the CES unit to support. In addition, there were no renewable energy sources to support the CES modes of operation for PV smoothing. Only the load shifting modes of operation could be tested, using simulated dynamic loads with the load banks.

3.2.1.2 Residential Site with Large PV Site Description

The second CES unit was installed in a gated residential community on a transformer with one customer. The customer had a large residence (~10,000 ft2) with a 25 kW ground-mounted PV system.

Figure 4: Residential Installation

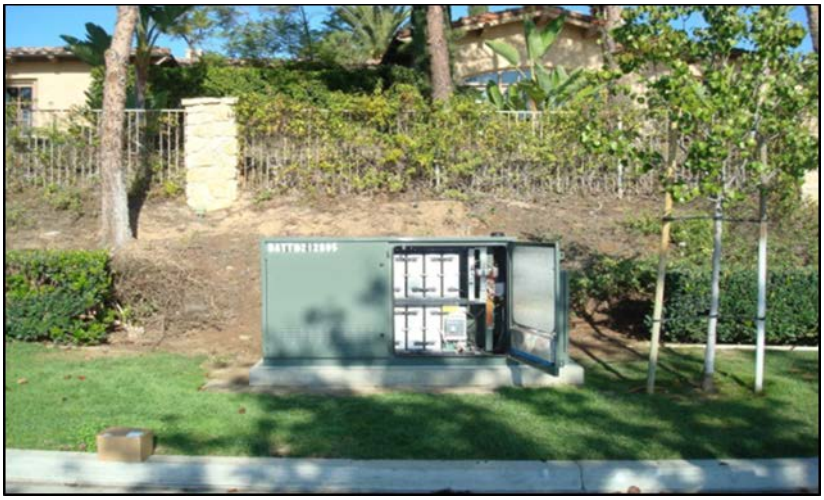


Photo Credit: San Diego Gas & Electric

Site Advantages:

The site had a residential customer with a large electric load and a large PV system. The AMI billing meter data aggregated at the transformer level provided a measurement of the net import and net export of electricity for this customer. The gated community has large right-of-ways for the utilities which provided adequate space for the CES unit to be located in an unobtrusive location relative to the residences in the community.

Site Disadvantages:

Unfortunately, the CES at this location only serves a single customer directly, meaning there was little load diversity at this site. The service of only one or two individual customers is not expected to be a typical application for a CES system due the high cost of the units. Another disadvantage presented itself because of a lack of utility SCADA enabled equipment on the distribution circuit. This meant there was limited historical data on the circuit segment, so any power quality information needed for the demonstration would need to be collected through some alternative temporary monitoring equipment.

3.2.1.3 Strip Mall Site

The third site was a cluster of small commercial customers in a strip mall. There were a total of six customers served by the distribution transformer and the CES unit. The types of customers were as follows:

1. Liquor Store
2. Supermarket
3. Restaurant
4. Hair Salon
5. Laundromat / Cleaners
6. Check Cashing Store

Figure 5: Strip Mall Installation

Photo Credit: San Diego Gas & Electric

Site Advantages:

The application of the CES on a service for six commercial customers appears to be in line with an anticipated "typical" CES installation. The site had adequate space for the CES unit near the existing ground-mounted distribution transformer in the utility right of way. The businesses being served by the system were expected to operate on a routine and predictable schedule with load profiles typical of commercial customers throughout the service territory. This load profile had a summer peak demand in the late afternoon due to higher cooling loads, and low night-time loads when the businesses were closed. The predicable load profile of the aggregated customers would support CES peak shaving and load shifting modes of operation.

Site Disadvantages:

The only disadvantage to the commercial site was the lack of customer-owned PV. This meant that the functions of renewable smoothing and PV load shifting would not be properly demonstrated at this site. However, similar operations could be tested for load smoothing due to large and quick changes in load caused by air conditioning or refrigeration systems. Similarly, load shifting operations could be demonstrated to create a flatter load profile at the distribution transformer.

3.2.2 Baseline Data

3.2.2.1 SDG&E Test Center

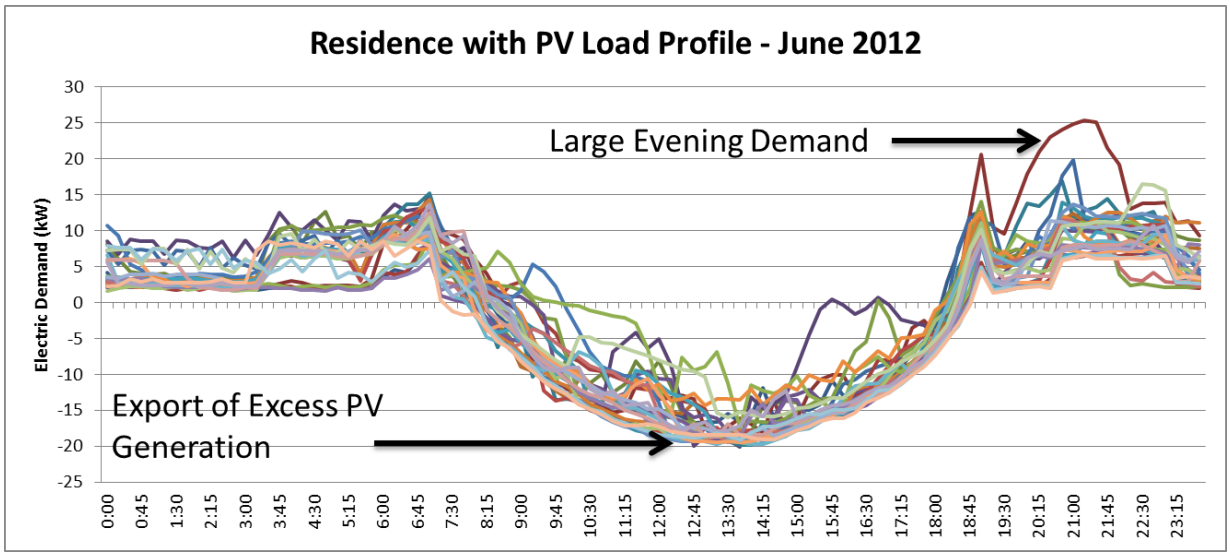
This installation was considered a smart grid technology test system and could be used to simulate various operations without impacting any actual customers. The circuit had provisions for the addition of several load devices such as load banks to simulate various load profiles. There were also provisions to interface additional monitoring equipment as needed to validate data collected from the DESS unit and to characterize power quality signatures of the unit as needed.

3.2.2.2 Residence

The circuit consisted primarily of residential customers and has a summer peak demand of approximately 7.2 MW. The circuit also had a connected customer-owned PV capacity of 958 kVA which represented 23.3 percent of the peak load of the circuit. This was considered a high level of PV penetration.

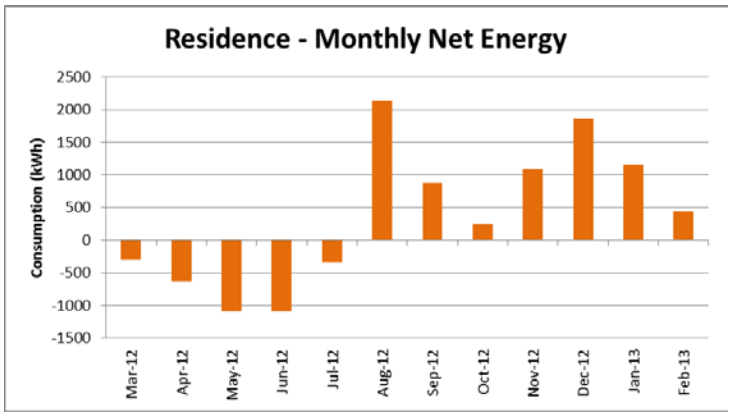
The following figure presents the daily load profile on the transformer that supported the single residence. Each line color represents a day of the month. The demand profile has peaks in the morning and the evening. In the middle of the day, the PV generation exceeded the demand of the residential loads and electricity was exported to the grid.

Figure 6: Residential Sample Load Profile



The data shows that during each month of the year, there were both net import and net export days. The data also indicates that during spring and early summer, the customer was a net exporter of electricity over the course of the month. Over the entire twelve-month period, the customer was a net importer of electricity. The following Figures present the monthly electric consumption data for a 12-month period.

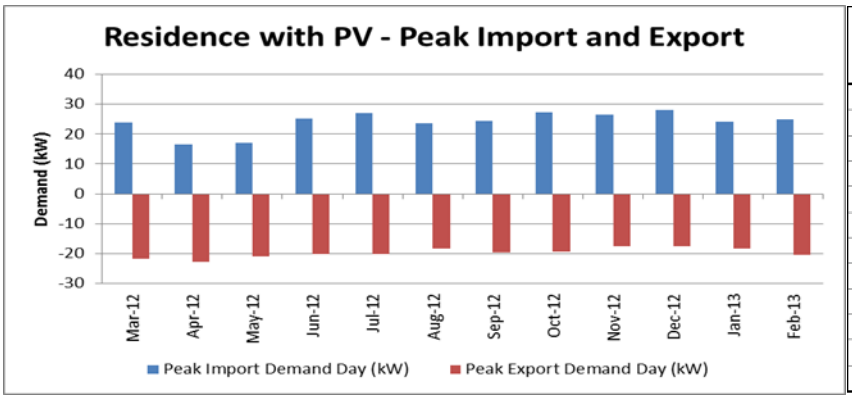
Figure 7: Residential Baseline Electric Consumption



Month	Peak Import Energy Day (kWh)	Peak Export Energy Day (kWh)	Average Energy Day (kWh)	Monthly Net Energy (kWh)
Mar-12	106.1	-70.2	-9.9	-305.5
Apr-12	86.5	-84.5	-21.0	-630.0
May-12	54.8	-94.2	-35.2	-1,090.4
Jun-12	43.5	-85.6	-36.6	-1,096.6
Jul-12	95.4	-103.5	-10.8	-334.0
Aug-12	164.3	-37.4	68.9	2,135.8
Sep-12	143.9	-17.0	29.3	878.4
Oct-12	111.5	-38.8	7.7	240.0
Nov-12	116.4	-18.8	36.3	1,089.8
Dec-12	151.1	-32.4	60.2	1,864.8
Jan-13	126.8	-32.0	37.4	1,159.4
Feb-13	129.4	-50.5	15.8	441.5
Total				**4,353.2**

During each month, the customer had a large swing in the peak import power demand and peak export power demand. The annual peak import demand was 28.0 kW in December and the peak export demand was 22.7 kW in April. The monthly peak demands are presented as follows.

Figure 8: Residential Baseline Electric Demand



Month	Peak Import Demand Day (kW)	Peak Export Demand Day (kW)
Mar-12	23.8	-21.8
Apr-12	16.6	-22.7
May-12	17.1	-21.0
Jun-12	25.3	-20.2
Jul-12	27.0	-20.2
Aug-12	23.5	-18.2
Sep-12	24.3	-19.7
Oct-12	27.4	-19.4
Nov-12	26.6	-17.4
Dec-12	28.0	-17.4
Jan-13	24.2	-18.4
Feb-13	25.0	-20.5

3.2.2.3 Strip Mall

The circuit consisted primarily of residential customers and had a summer peak demand of approximately 5.4 MW. The circuit also had a connected customer-owned PV capacity of 228 kVA which represented 6.7 percent of the peak load of the circuit. This was considered a moderate level of PV penetration for circuits in the SDG&E service territory at the time of the demonstration.

The data collected for the load profile was based on the consolidated customer AMI data that was collected in one-hour time periods. Table 6 presents the monthly energy consumption and peak demand summary for the distribution transformer.

Table 6: Strip Mall Site Baseline Energy

Month	Total Energy (kWh)	Peak Demand (kW)
Apr-12	16,028.4	37.4
May-12	17,908.5	43.4
Jun-12	18,157.2	46.0
Jul-12	19,943.4	50.1
Aug-12	22,232.1	51.0
Sep-12	20,970.1	52.0
Oct-12	18,395.7	50.0
Nov-12	15,368.5	42.9
Dec-12	14,999.7	33.4
Jan-13	14,850.5	34.1
Feb-13	13,533.7	32.8
Mar-13	15,428.0	35.3
Total	**207,815.8**	
Maximum	**22,232.1**	**52.0**

The data in Table 6 shows that the highest energy consumption in August and highest peak demand occurred in the month of September. The site annual peak demand was 52.0 kW.

The following Figures present the data in Table 6 graphically.

Figure 9: Strip Mall Monthly Energy Consumption

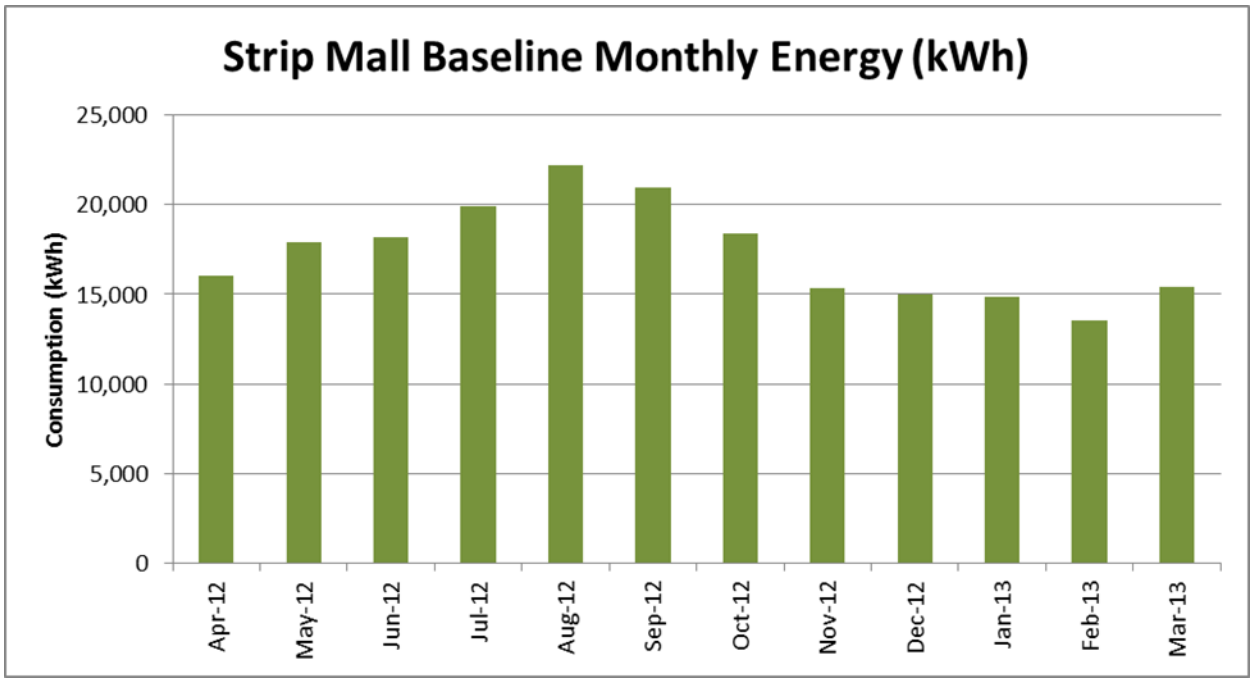
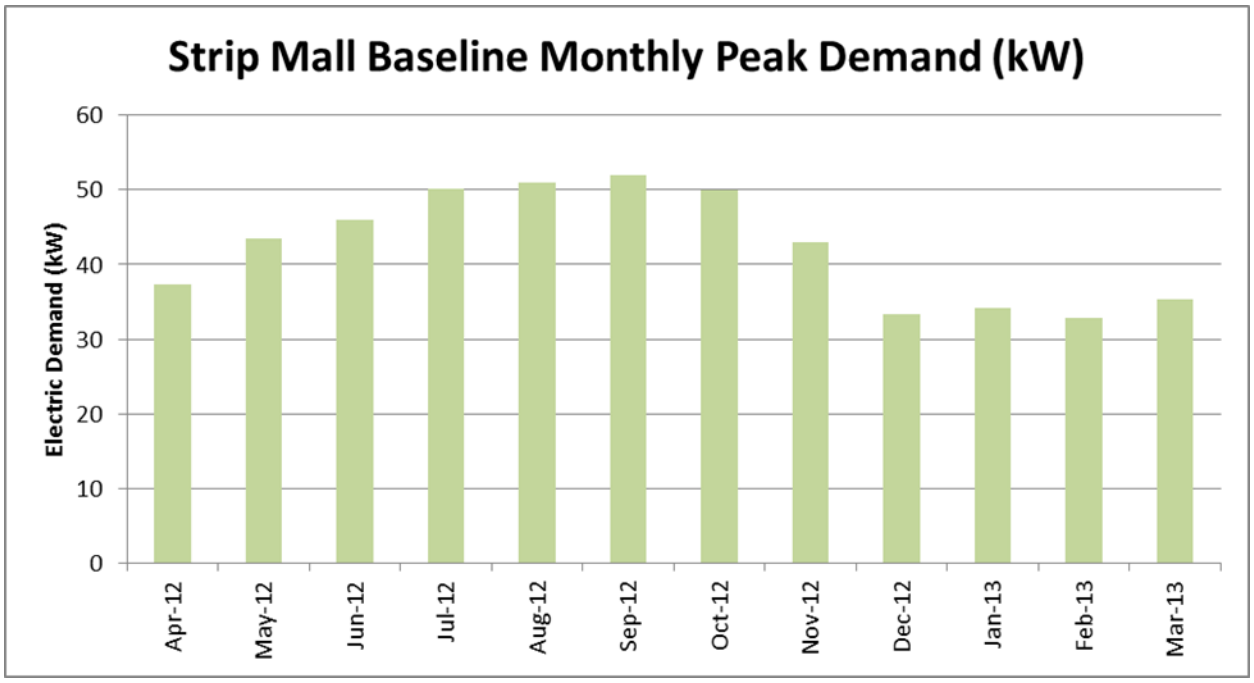
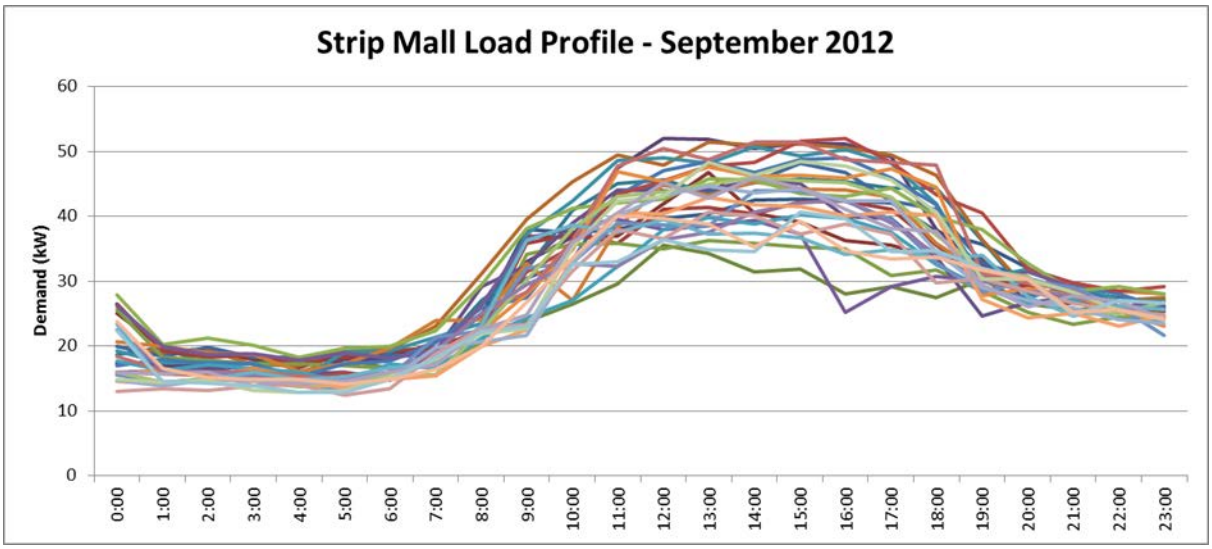


Figure 10: Strip Mall Monthly Peak Demand



A sample of the daily load profiles for a month is presented in Figure 11. Each line represents a day of the month. The profile shows that demand routinely increases between 7:00 a.m. and 11:00 a.m. as the businesses open and the cooling requirements increase. The peak load occurs between noon and 4:00 p.m. and then the load decreases until approximately 6:00 p.m., when the load was relatively flat for the night. This load profile was considered "typical" of commercial customers in Southern California.

Figure 11: Sample Monthly Load Profiles



3.3 Development of Techniques for Managing and Dispatching Energy Storage Devices

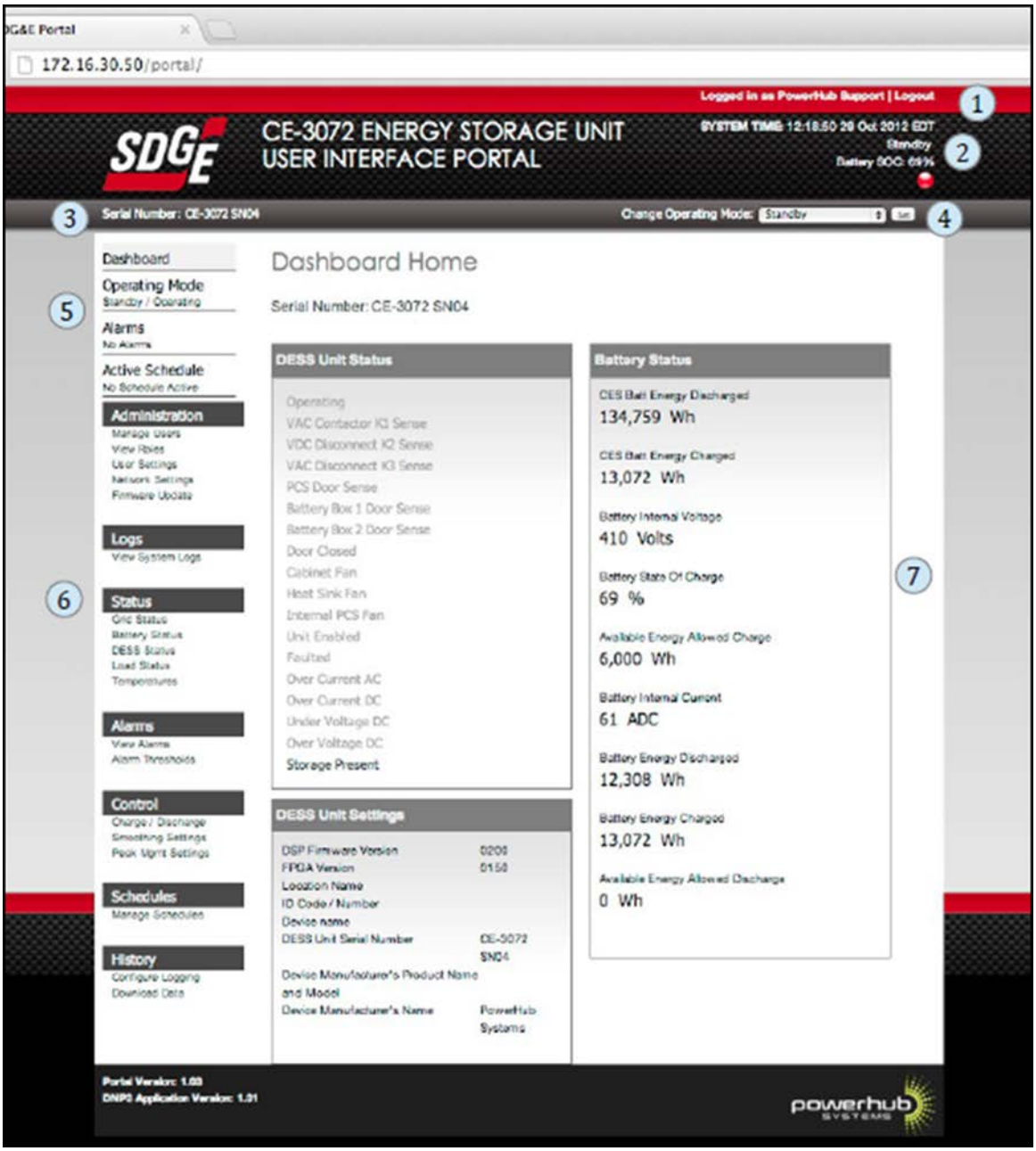
3.3.1 Vendor Controls

During the course of the demonstration project, the CES units had two successive user interfaces for monitoring and control. The initial user interface was specific to each CES unit, requiring the user to access the units through individual URLs and with a user name and password. The second interface was able to access the three units through a single user interface, which created an approach more conducive to fleet operations. The two interfaces are presented in this section.

3.3.1.1 Vendor Control System Overview

Once successfully logged into the system, the user was presented with a dashboard as presented in the folowing Figure 12

Figure 12: CES Original Control User Interface



The following table presents an overview of the key areas of the dashboard as identified by the corresponding numbers 1 though 7 in Figure 12.

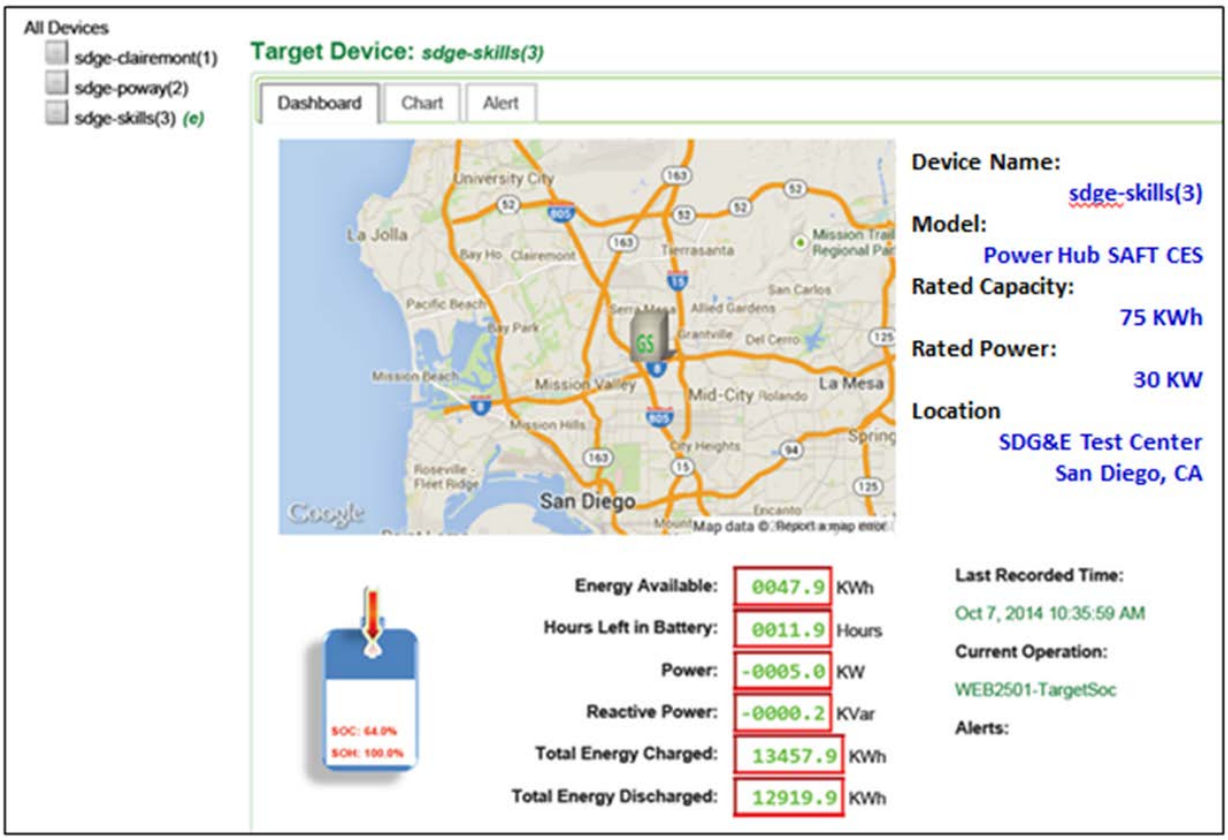
Table 7: CES Original Controller User Interface Functions

Location	Content
1	Logged user name and Log Out button
2	Time of day, current mode of operation, and state of charge
3	CES serial number
4	Mode selection menu
5	Current mode, alarms, and schedules
6	Administration and CES management
7	CES status information

3.3.1.2 Aggregated System Control

The aggregated user interface is presented in the following figure. The upper right shows the tree of CES units in the "fleet", and all could be accessed through a single user name and password. Figure 13 below shows the dashboard information for the Test Center with a map, high level specifications for the unit, and current CES status. This interface also provided for tracking CES operation through charts and unit alarms.

Figure 13: CES Aggregated Control User Interface



The interface also had a section for dispatching each unit, which must be done individually by navigating to the dispatch page of each unit. The available modes of operation were Power Ramp Rate Control, Constant Power, Target SOC, and Power Management. This interface was used to dispatch the units for some individual unit demonstrations and all of the aggregated demonstrations.

3.3.2 System Dispatch Tools

The baseline assumptions that drove the charge and discharge energy capacities and cycle times are presented in Table 8. The CES specification identified the nominal charge rate as 15 kW and the nominal discharge rate as 30 kW with a total usable storage capacity of 72 kWh. This information was used to set the schedules for the demonstrations that were conducted in this project.

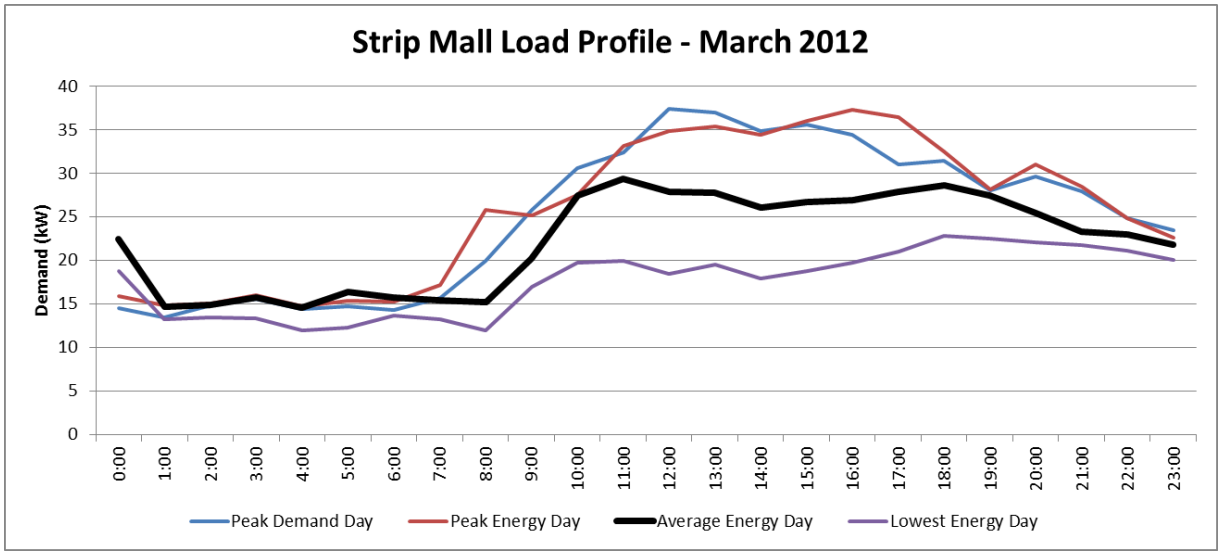
Table 8: CES Data Points

	Charge	Discharge
Max Rate	15.0 kW	30.0 kW
Max Energy	82.8 kWh	72.0 kWh
80% Capacity	66.2 kWh 4.4 hours	57.6 kWh 1.9 hours

3.3.2.1 Peak Shaving

In the Peak Shaving mode, the CES units used the power (kW) measurement of the energy from the source (import set point) as a feedback to control the charge and discharge of the battery. For individual CES unit operation, the import set point was set based on either the historical baseline load profiles or a site load forecast. For the controlled demonstrations, the set points were selected based on the anticipated peak load on the transformer, the power capacity (kW) of the CES unit, and the usable energy capacity (kWh) of the CES unit. This conceptual approach is presented in Figure 14.

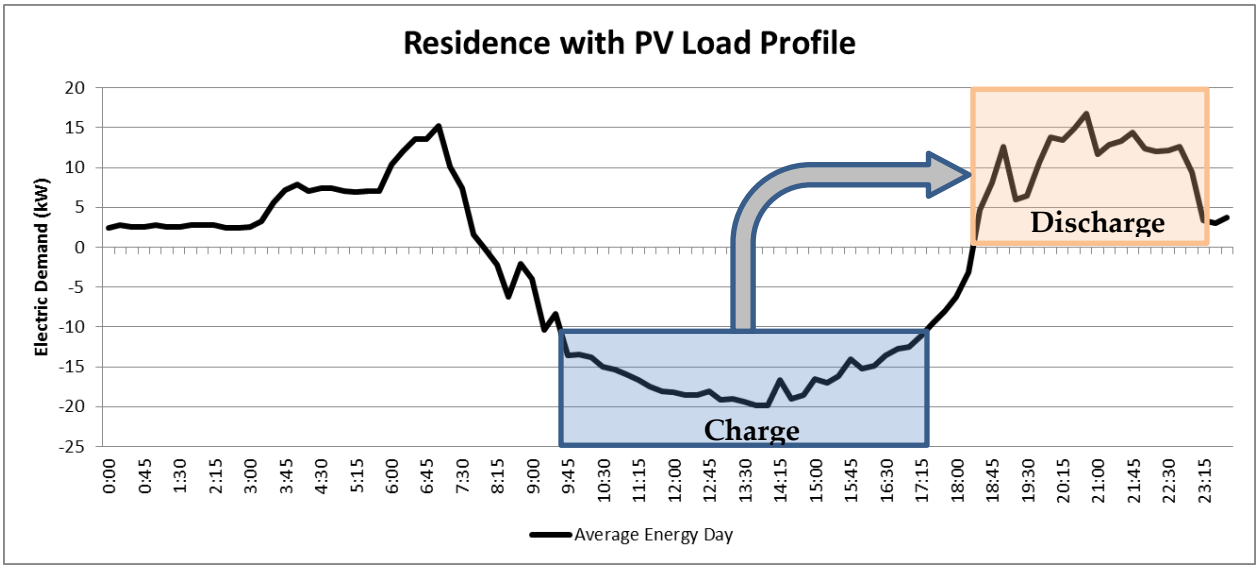
Figure 14: Strip Mall Peak Shaving Plan



3.3.2.2 PV Load Shifting

In the Load Shifting application, the Residential CES unit was scheduled to charge when the PV production exceeded the customer load. This was the time period when the PV system typically exported energy to the grid in a net metering scenario. At a time later in the day when the customer typically was importing the maximum amount of electricity from the grid, the CES unit was scheduled to discharge. This conceptual approach is presented in Figure 15.

Figure 15: PV Load Shifting



3.3.2.3 Arbitrage

As an example of the Arbitrage application, Table 9 on the next page presents one of the schedules developed for the Residential unit based on the CAISO day-ahead pricing schedule for a pricing node near the CES unit substation. The plan was developed by identifying the time and value of the lowest LMP price during the 24 hour period ($35.00 during the hour of 3:00 a.m.). The Differential column presents the difference between the rate for the specific hour and the cost of electricity for the hour with the lowest cost. The strategy was to charge the CES unit during the hours of the lowest prices and then to discharge during the hours of the highest prices. When these are identified, a schedule is developed for the hours of operation and the corresponding CES charge and discharge rates. The schedule shown in table 9 helps estimate the cost of electricity purchased from the ISO and then the estimated potential value (revenue) that would be generated by selling that electricity back into the ISO during a time of higher value. It also ensures that the schedule is based on the characteristics of the specific CES unit (maximum charge and discharge rates and usable storage capacity) and that the plan has an energy balance between the two cycles. For the schedule presented, the unit was dispatched at a 15 kW charge rate from 1:00 a.m. to 5:00 a.m. and a 15 kW discharge rate for two periods during the day that were each two hours long. The net potential savings from arbitrage for the day in Table 9 was $1.67. Note that this example presents a process that was executed for the purposes of the demonstration project. The data is from an arbitrary spring day which was neither a peak

demand day nor a high congestion day when the differentials would be expected to be much higher.

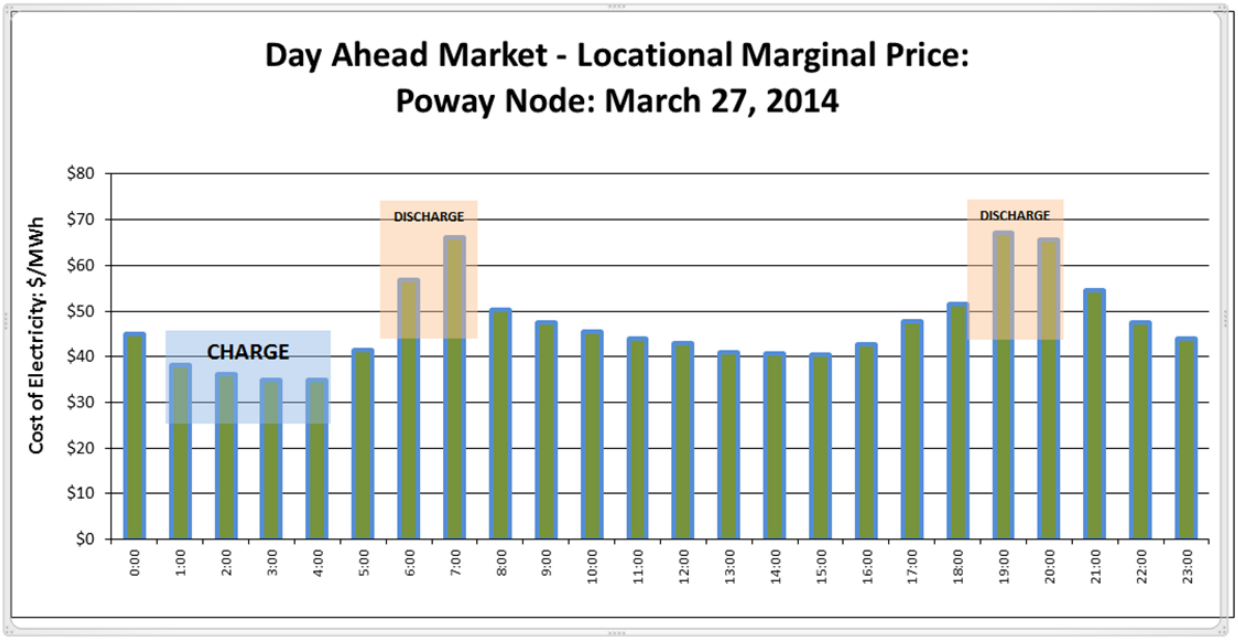
Table 9: Residential Day-Ahead Operating Plan Based on CAISO Pricing

POWAY NODE 1 Locational Marginal Prices ($/MWh)

			CES Plan		
Day Ahead Pricing			Mode	Charge	Discharge
Thursday, March 27, 2014				15	15
Time	**$/MWh**	**Differential**		kW	kW
0:00	$44.94	($9.94)		$ -	$ -
1:00	$38.18	($3.18)	Charge	$ 0.57	$ -
2:00	$36.11	($1.12)	Charge	$ 0.54	$ -
3:00	$35.00	$0.00	Charge	$ 0.52	$ -
4:00	$35.04	($0.04)	Charge	$ 0.53	$ -
5:00	$41.45	($6.46)		$ -	$ -
6:00	$56.77	($21.78)	Discharge	$ -	$ 0.85
7:00	$66.10	($31.11)	Discharge	$ -	$ 0.99
8:00	$50.38	($15.38)		$ -	$ -
9:00	$47.49	($12.49)		$ -	$ -
10:00	$45.57	($10.57)		$ -	$ -
11:00	$44.00	($9.00)		$ -	$ -
12:00	$43.06	($8.06)		$ -	$ -
13:00	$40.99	($6.00)		$ -	$ -
14:00	$40.73	($5.74)		$ -	$ -
15:00	$40.39	($5.39)		$ -	$ -
16:00	$42.82	($7.83)		$ -	$ -
17:00	$47.73	($12.74)		$ -	$ -
18:00	$51.47	($16.47)		$ -	$ -
19:00	$67.28	($32.28)	Discharge	$ -	$ 1.01
20:00	$65.74	($30.74)	Discharge	$ -	$ 0.99
21:00	$54.58	($19.58)		$ -	$ -
22:00	$47.57	($12.58)		$ -	$ -
23:00	$43.92	($8.93)		$ -	$ -
Max $/MWh	$67.28		**Hours**	4.0	4.0
Min $/MWh	$35.00		**kWh**	60.0	60.0
Avg $/MWh	$46.97		**Cost**	$2.16	
			Revenue		$3.84
			Arbitrage	**$1.67**	

Figure 16 graphically presents the operational plan for the Residential unit, with a four-hour charge period capturing the lowest-cost energy of the day and two discharge periods during the highest-cost time periods of the day, thereby maximizing the value of the arbitrage operations.

Figure 16: Residential Day-Ahead Operating Plan Based on CAISO Pricing

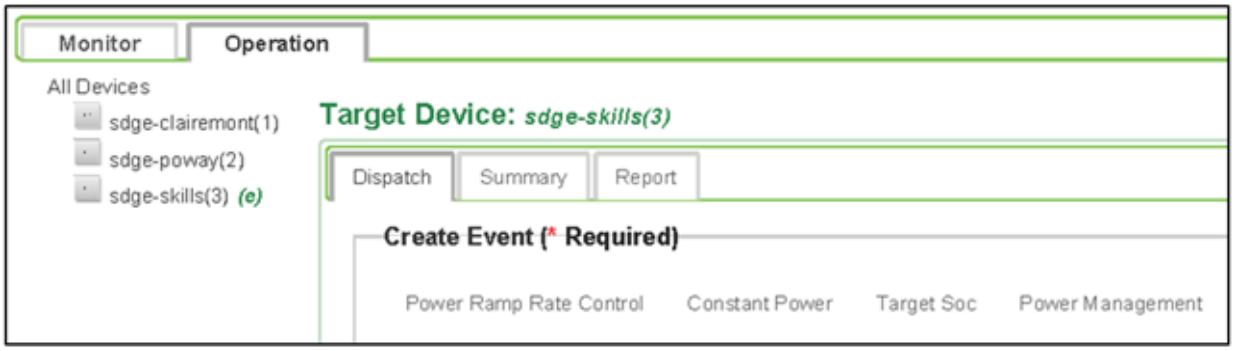


3.3.3 CES Effectiveness

3.3.3.1 System Scheduling

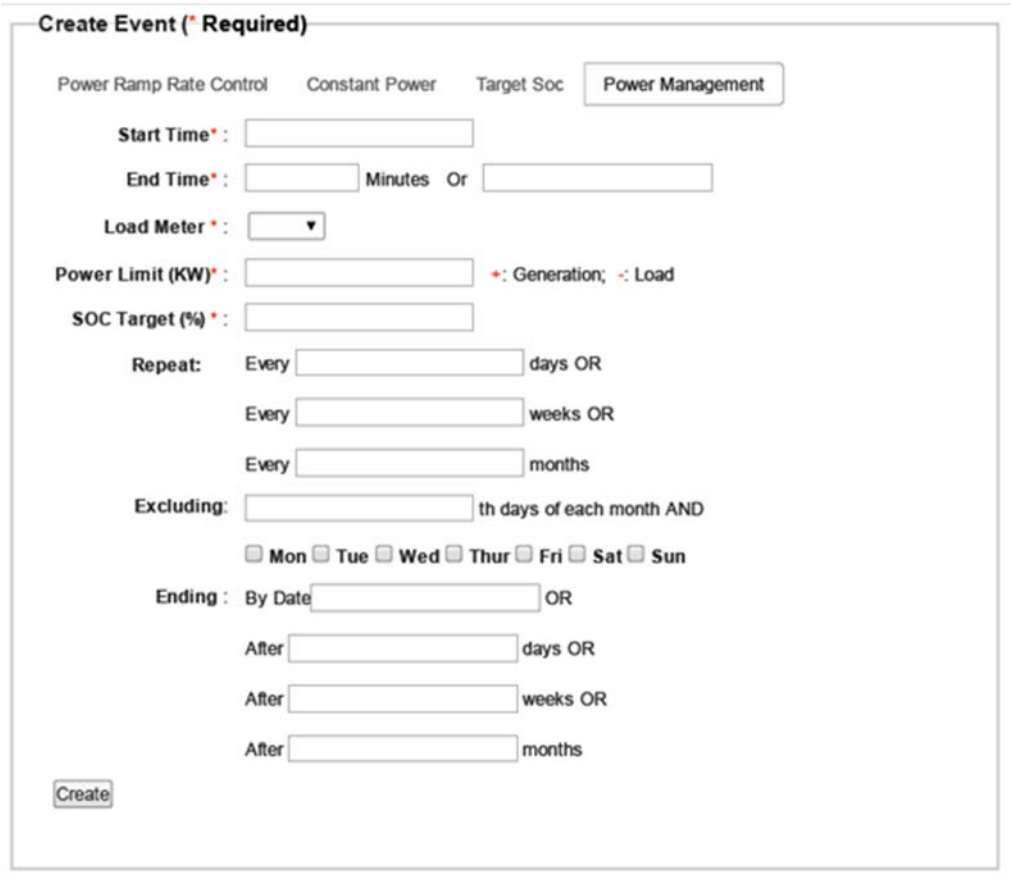
All demonstrations were scheduled using the CES web-based user interface. This required a single login to be able to access all three units. To schedule a unit, the user selected the Operations tab, then the Site Name, then the Dispatch tab to create an event. The options for the CES units were: Power Ramp Rate Control, Constant Power, Target SOC, and Power Management. Each option had its own list of set points that had to be populated for the selected unit. The initial dispatch menu is presented in Figure 17.

Figure 17: CES Dispatch Control Options



The Figure 18 below presents the setting options to dispatch a unit for Power Management, which was used to conduct the Peak Shaving and Import Control demonstrations.

Figure 18: Controller Power Management Dispatch Settings



3.3.3.2 Modes of Operation

Demonstrations were conducted for all the modes of operation presented below.

a. Constant Charge and Discharge

b. Peak Shaving (Load Following)

c. Arbitrage

d. PV Smoothing

e. PV Load Shifting

f. Four Quadrant Operation

g. Aggregated Constant Output

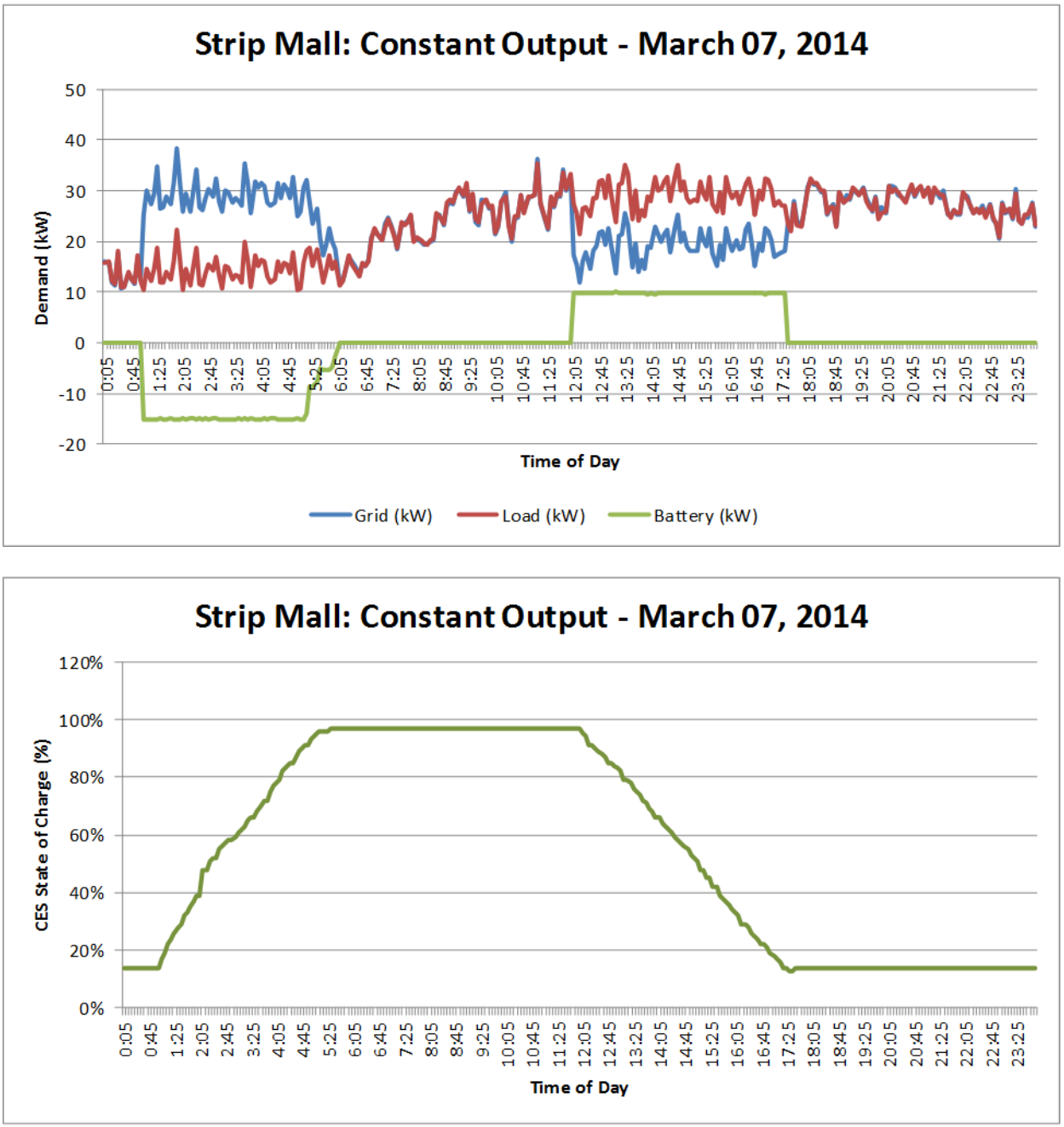
h. Aggregated Peak Shaving

i. Aggregated Arbitrage

The following section presents a few highlighted results of these demonstrations.

Figure 19 below presents an example of a constant power demonstration on the Strip Mall unit. The unit charges at 15 kW starting at 1:00 a.m. and stops charging at 6:00 a.m. when the state of charge reaches 97 percent. The unit then discharges at 10 kW starting at noon. The discharge cycle ends at about 5:30 p.m. when the state of charge reaches about 18 percent.

Figure 19: Strip Mall Typical Constant Output Operations



The following Figure 20 shows the Strip Mall unit operating in Power Management mode to limit the load on the distribution transformer to 25 kW. This demonstrated that the CES unit could operate in a load following strategy to absorb all the customer demand in excess of the import set point. The unit was able to limit the load to 25 kW for a period of 6 hours during this demonstration.

Figure 20: Strip Mall Peak Shaving Operations

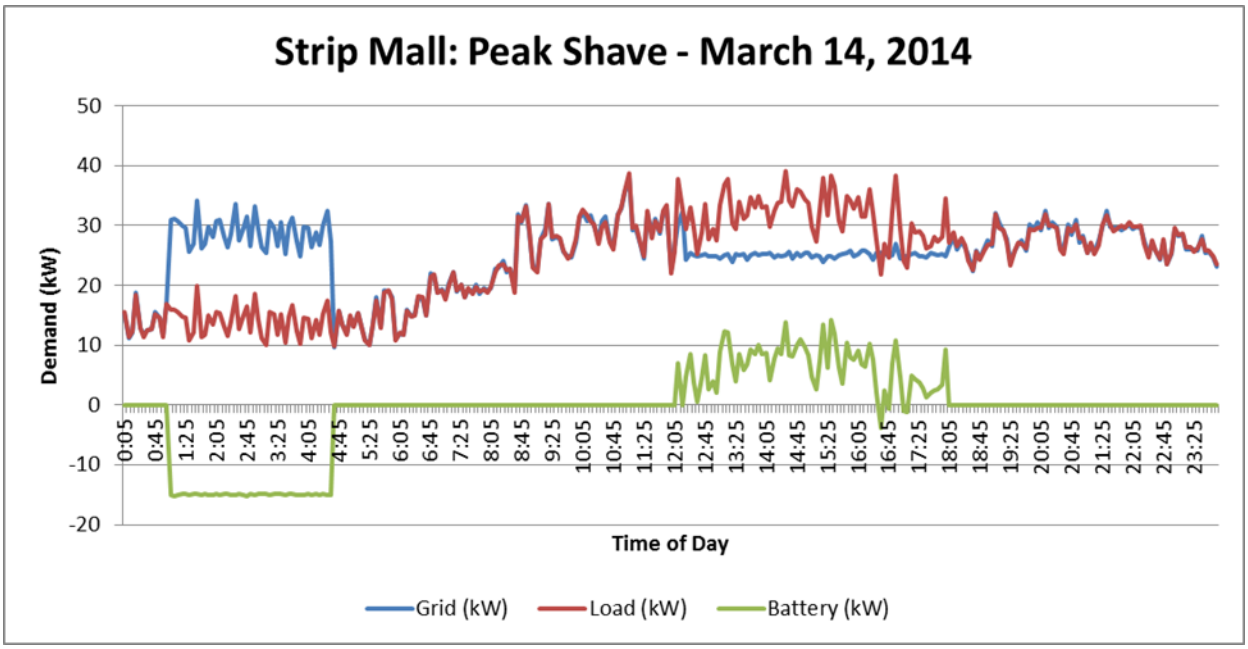


Figure 21 below presents a different approach to Power Management that was demonstrated on the Residential unit. In this case, the unit was dispatched in a manner to limit the level of export that typically occurs when the PV system output exceeds the demand of the customer. This figure shows that the export was controlled to a level of 15 kW when the export would have been about 24 kW without the CES unit.

Figure 21: Residential PV Export Management

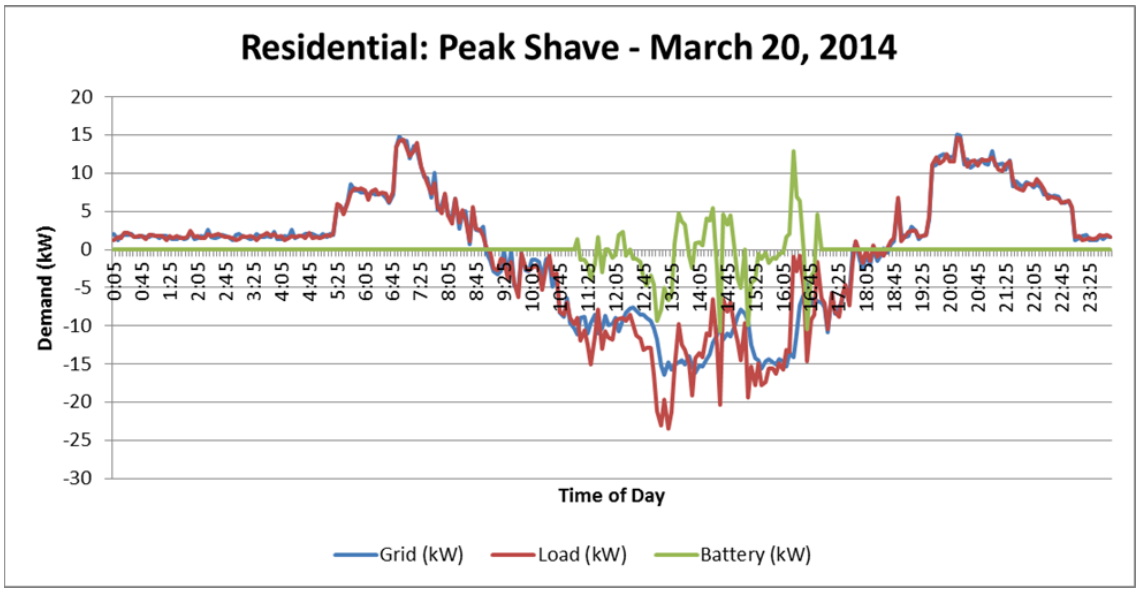


Figure 22 below presents an example of the PV Shifting demonstration using the Residential CES unit. The demonstration showed that the CES units could be scheduled and operated in a manner to capture the PV generation that would typically be exported to the grid, and then use that renewable energy to provide electricity to the load when the customer would typically import power from the grid. This approach limits the back-feed of PV generation to the grid and allows the customer to use the PV energy at a later time of the day or evening. Charging was scheduled to occur when the export exceeded 10 kW, and then discharge would commence in the evening during the peak load of the customer.

Figure 22: Residential PV Shifting Operations

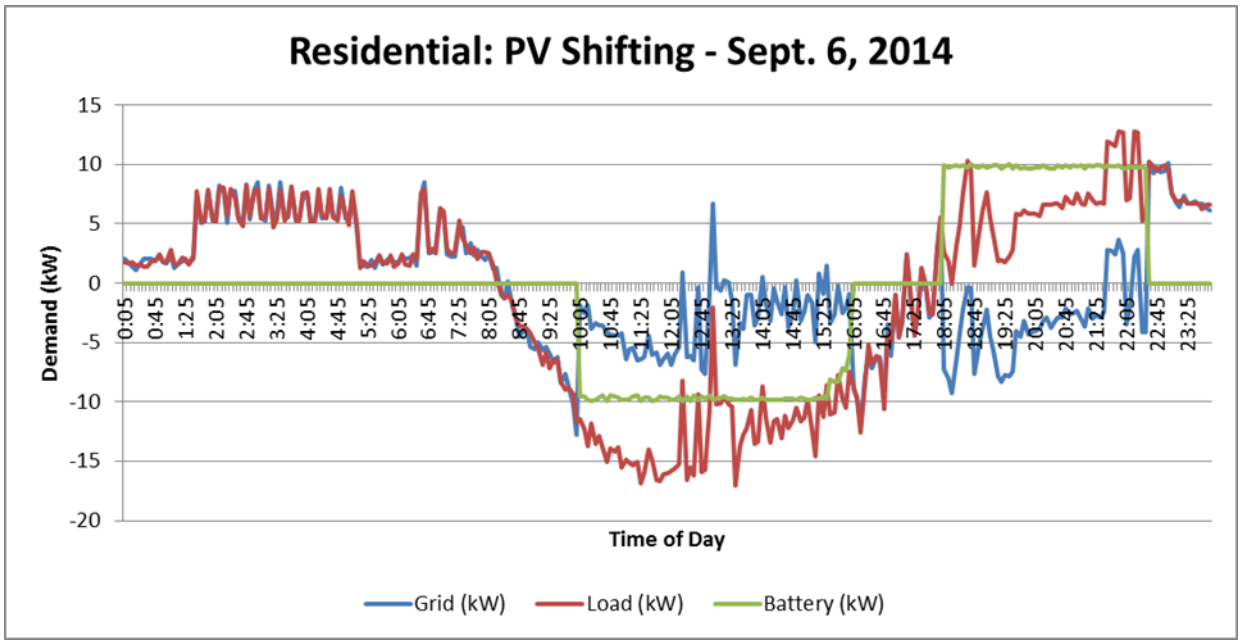


Figure 23 below shows the results of a day of the PV Smoothing demonstration conducted using the Residential CES unit. The PV Smoothing operation between 11:00 a.m. and 12:00 p.m. shows that the variability, as measured at the grid, was less than the variability of the load and PV generation. At approximately 3:35 p.m. there was a spike in load. The CES unit absorbed the entire spike and even produced a slightly lower than average load on the grid at the peak of the spike. The data shows that the unit was clearly reacting to the variability of the PV generation.

Figure 23: PV Smoothing Operations

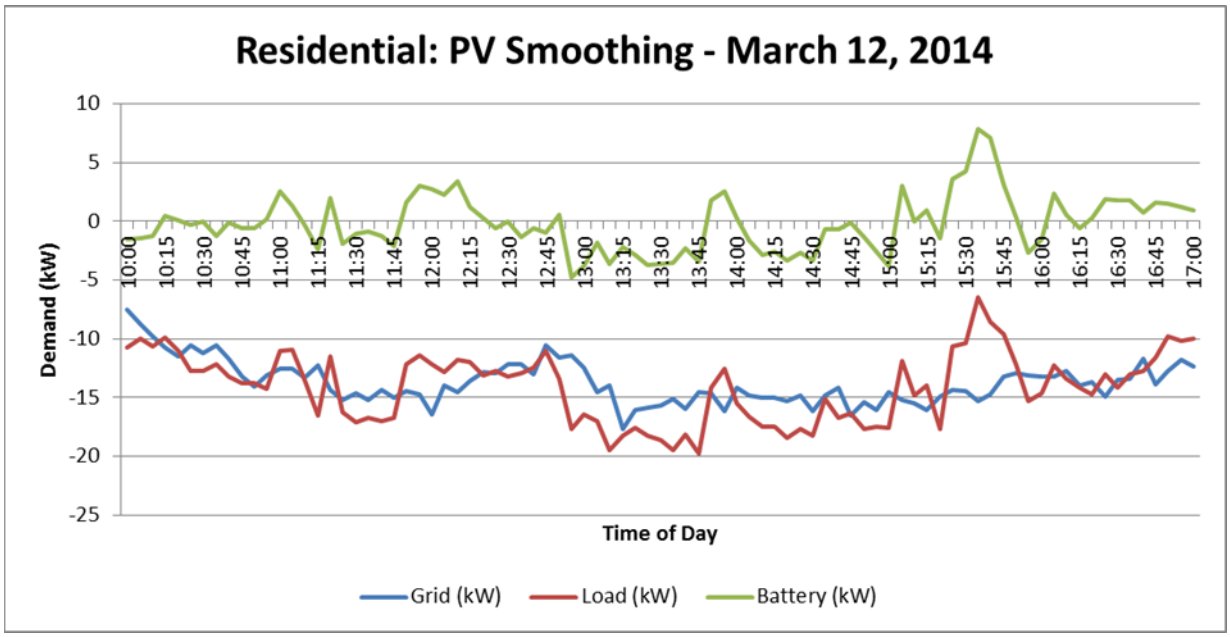
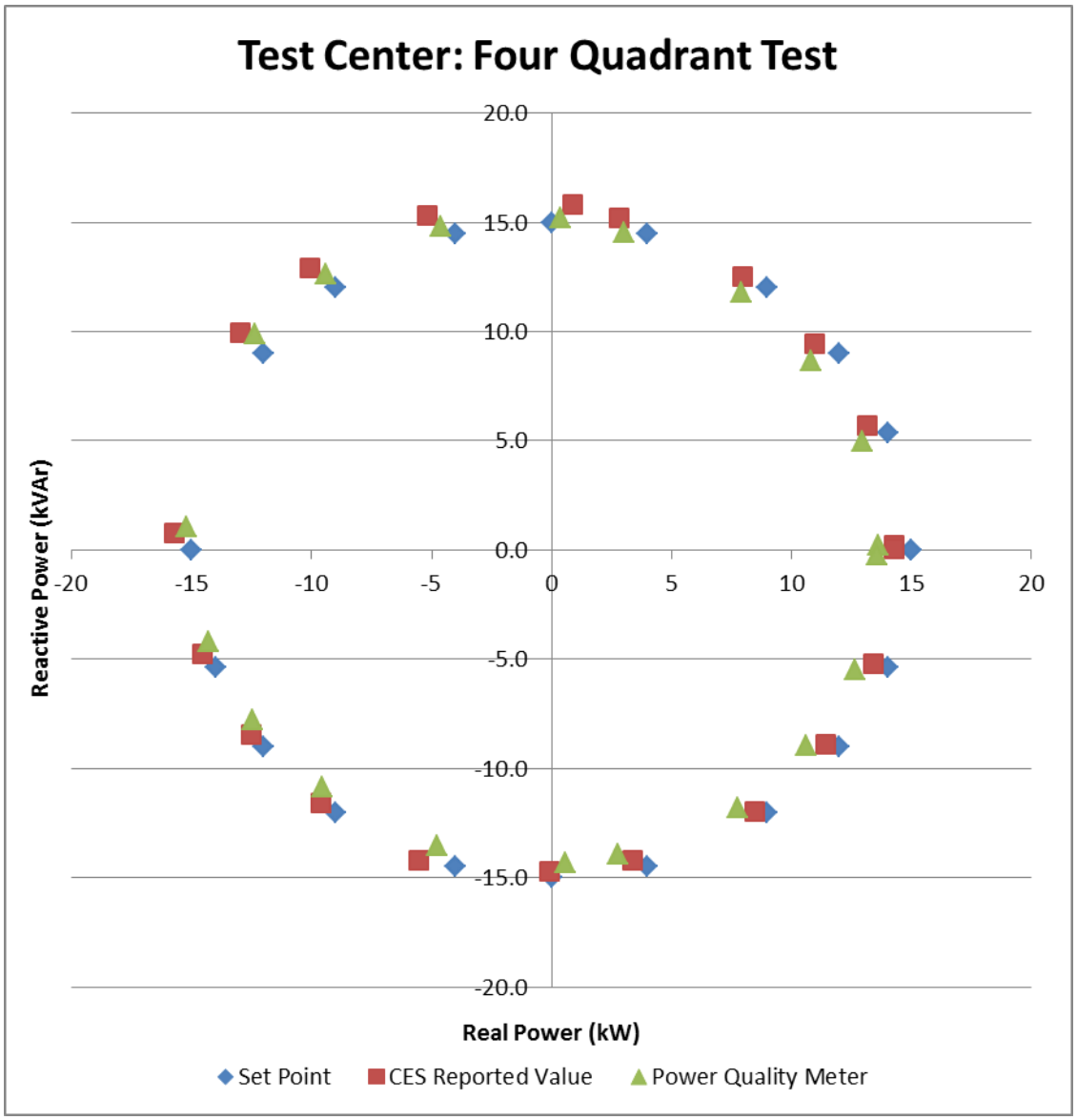


Figure 24 on the next page presents the results of the Four Quadrant demonstration. The manufacturer specification has a nominal charge rate of 15 kW and a nominal discharge rate of 30 kW. To better visualize the four quadrant operation of the CES units, the test was conducted at the 15 kVA power circle. In other words, the apparent power (kVA) was constant for each instance. The four-quadrant demonstration was conducted by varying the real power (kW) from -15 kW to + 15 kW and varying the reactive power (kVAr) from -15 kVAr to +15 kVAr in combinations that all reflect the 15 kVA apparent power rating. This demonstration tested the ability of the CES units to operate at a variety of the maximum real and reactive power set points that may be required to support distribution system operations. Part of this demonstration was to also validate the accuracy of the values being monitored by the CES unit. To conduct this valuation, a power quality meter was installed on the AC-side of the CES unit. The power quality meter values are represented in Figure 24.

The demonstration showed that the unit was capable of successfully operating near the desired set points around the 15 kVA power circle. An analysis was conducted to validate the accuracy of the unit being able to operate at the programmed set points. On average, the operating real power was slightly lower than the programmed value by 0.7 kW. The quadrant where real power operation was the least accurate was Quadrant I, where the average value was 1.0 kW

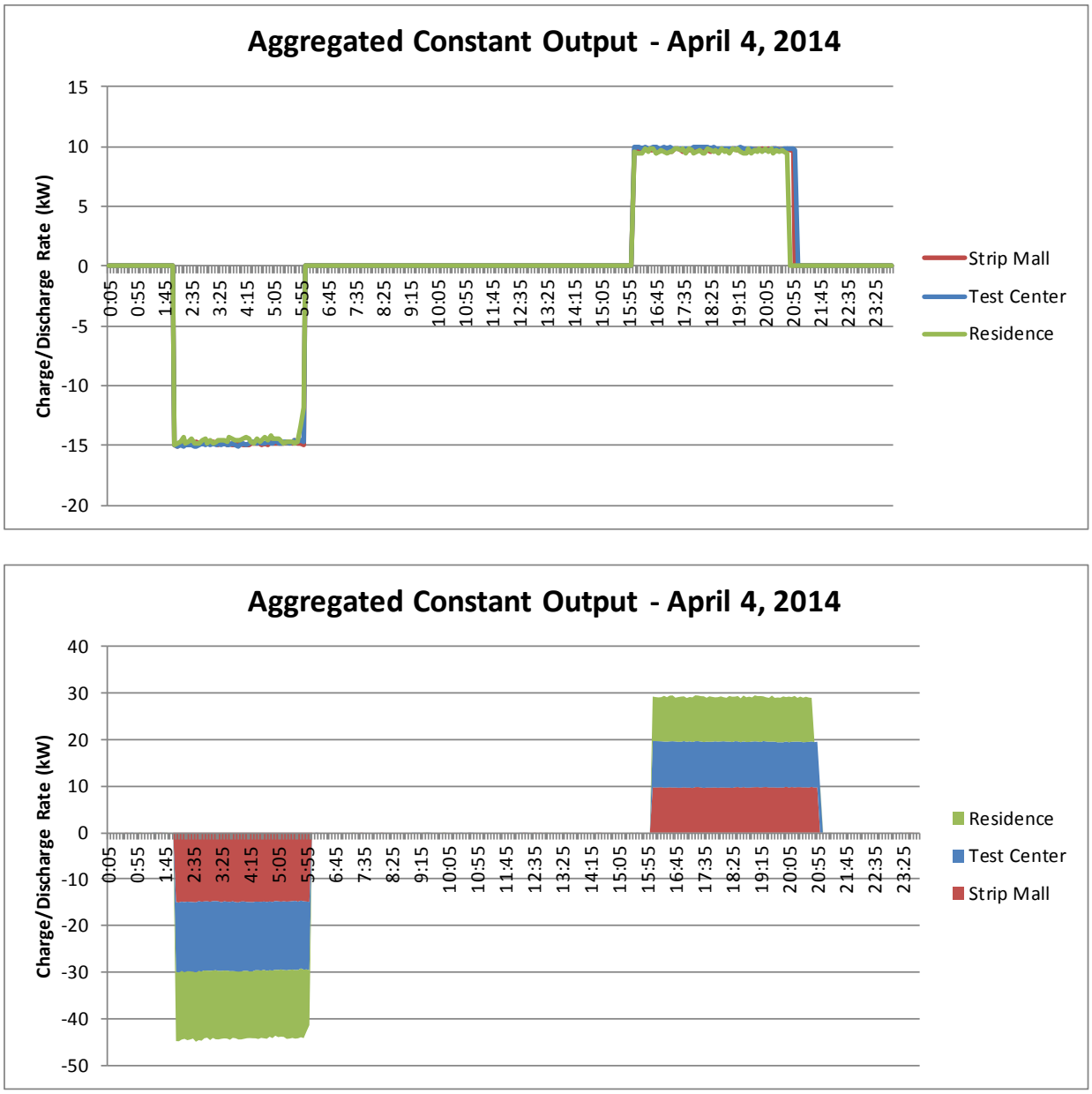
lower than the programmed value. On average, the operating reactive power was slightly higher than the programmed value by 0.5 kVAr. The quadrant where reactive power operation was the least accurate was Quadrant II, where the average value was 0.9 kVAr higher than the programmed value. The quadrant where reactive power operation was the most accurate was Quadrant IV, where the average value was 0.1 kVAr higher than the programmed value.

Figure 24: Four Quadrant Test Results



Several aggregated dispatch demonstrations were conducted for the project. These included Aggregated Constant Output, Aggregated Peak Shaving, and Aggregated Arbitrage. Figure 25 presents an example of the Aggregated Constant Output demonstration. All three units were dispatched to charge and discharge at the same times and at the same levels. The charge cycle was scheduled to start at 2:00 a.m. and charge at a rate of 15 kW. The discharge cycle was scheduled to start at 4:00 p.m. at a rate of 10 kW for five hours. The lower portion of Figure 25 presents the aggregated discharge capacity of the three units, which resulted in a load reduction of nearly 30 kW during the late afternoon hours.

Figure 25: Aggregated Constant Output Demonstration



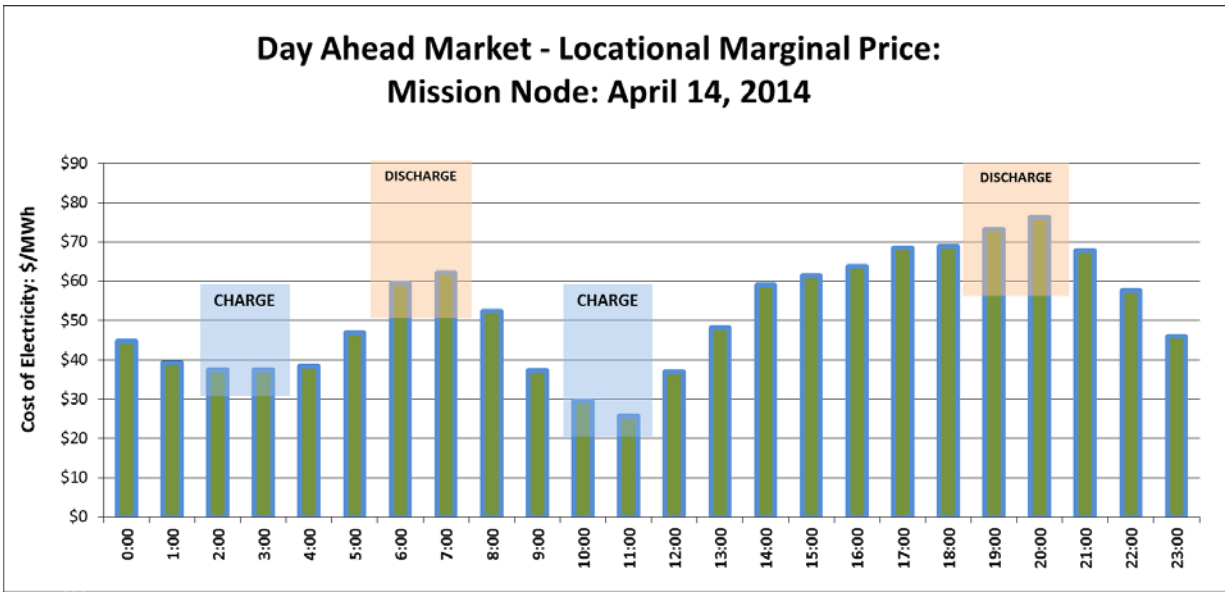
During the Aggregated Arbitrage demonstration period, the node selected for the pricing signals had two peak pricing periods, one in the morning and one in the evening, consistent with a typical residential load. All the CES units were scheduled to charge and discharge twice a day in order to maximize the value of energy that could be used for the arbitrage operations. Table 10 and Figure 26 below present the operations for a typical Aggregated Arbitrage operation.

Table 10: CAISO Day-Ahead Locational Marginal Pricing with CES Plan

Mission NODE 1 Locational Marginal Prices ($/MWh)

			CES Plan		
Day Ahead Pricing			Mode	Charge	Discharge
Monday, April 14, 2014				20	20
Time	**$/MWh**	**Potential**		kW	kW
0:00	$44.70	($19.01)		$ -	$ -
1:00	$39.39	($13.71)		$ -	$ -
2:00	$37.49	($11.81)	Charge	$ 0.75	$ -
3:00	$37.50	($11.82)	Charge	$ 0.75	$ -
4:00	$38.38	($12.70)		$ -	$ -
5:00	$46.98	($21.30)		$ -	$ -
6:00	$59.52	($33.83)	Discharge	$ -	$ 1.19
7:00	$62.23	($36.54)	Discharge	$ -	$ 1.24
8:00	$52.40	($26.72)		$ -	$ -
9:00	$37.24	($11.55)		$ -	$ -
10:00	$29.56	($3.88)	Charge	$ 0.59	$ -
11:00	$25.68	$0.00	Charge	$ 0.51	$ -
12:00	$36.97	($11.28)		$ -	$ -
13:00	$48.28	($22.59)		$ -	$ -
14:00	$58.98	($33.29)		$ -	$ -
15:00	$61.46	($35.77)		$ -	$ -
16:00	$63.75	($38.07)		$ -	$ -
17:00	$68.47	($42.78)		$ -	$ -
18:00	$68.90	($43.21)		$ -	$ -
19:00	$73.25	($47.56)	Discharge	$ -	$ 1.46
20:00	$76.36	($50.67)	Discharge	$ -	$ 1.53
21:00	$67.85	($42.17)		$ -	$ -
22:00	$57.63	($31.95)		$ -	$ -
23:00	$45.94	($20.26)		$ -	$ -
Max $/MWh	$76.36		**Hours**	4.0	4.0
Min $/MWh	$25.68		**kWh**	80.0	80.0
Avg $/MWh	$51.62		**Cost**	$2.60	
			Revenue		$5.43
			Arbitrage	**$2.82**	

Figure 26: CAISO Day-Ahead Locational Marginal Pricing with CES Plan



The information in Table 10 on the previous page was used to develop a dispatch plan for the CES units. For this set of demonstrations, the CES units were placed in the Target State of Charge mode. This mode is similar to the Constant Output mode except that instead of relying on the internal system upper and lower state of charge limits, the cycles end when the specified target state of charge is reached.

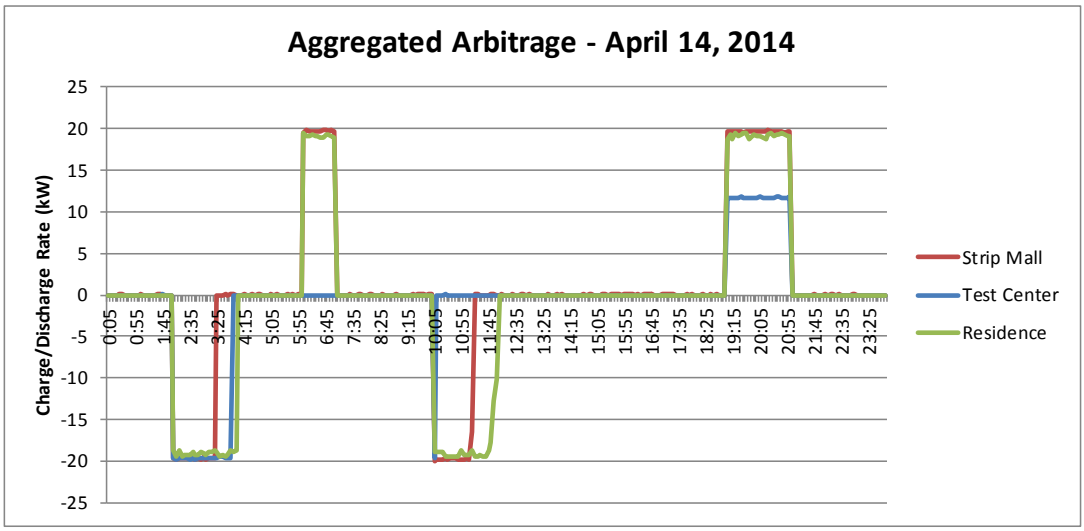
Table 11 below presents the dispatch schedule for the three CES units for the Aggregated Arbitrage test on April 14, 2014.

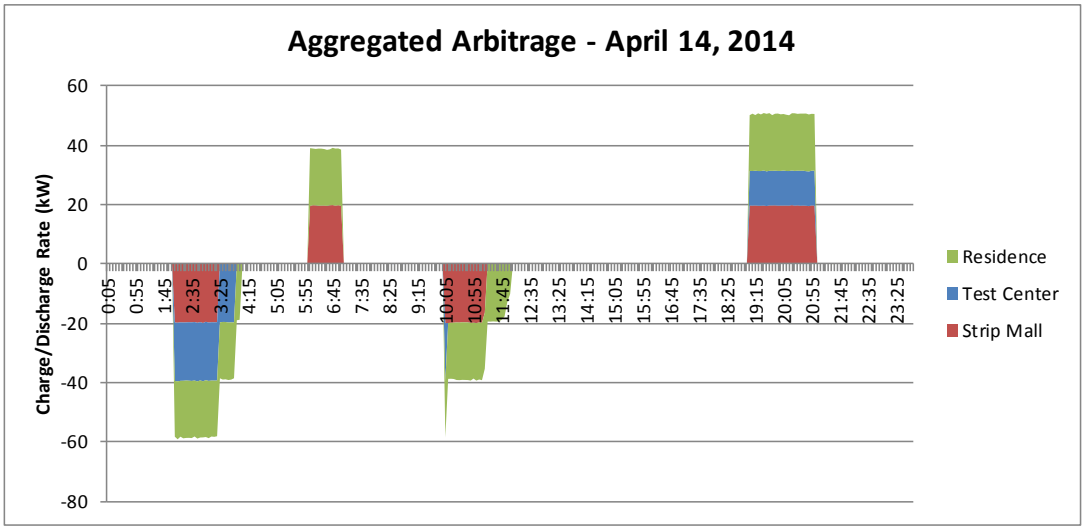
Table 11: Aggregated Arbitrage Dispatch Schedule

	Charge					Discharge				
Site	**Mode**	**Start Time**	**Stop Time**	**Limit (kW)**	**Target SOC**	**Mode**	**Start Time**	**Stop Time**	**Limit (kW)**	**Target SOC**
Strip Mall	Target SOC	2:00	4:00	20	95%	Target SOC	6:00	7:00	20	20%
	Target SOC	10:00	12:00	20	95%	Target SOC	19:00	21:00	20	20%
Residence	Target SOC	2:00	4:00	20	95%	Target SOC	6:00	7:00	20	20%
	Target SOC	10:00	12:00	20	95%	Target SOC	19:00	21:00	20	20%
Test Center	Target SOC	2:00	4:00	20	95%	Target SOC	6:00	7:00	20	20%
	Target SOC	10:00	12:00	20	95%	Target SOC	19:00	21:00	20	20%

Figure 27 below presents the operation of the aggregated units for April 14. The data shows that for both charge cycles, the Strip Mall unit reached the target state of charge before the end of the two-hour charge period. The data also shows that the Test Center unit did not discharge as anticipated. The Residential Unit operated as anticipated.

Figure 27: Aggregated Arbitrage Operations



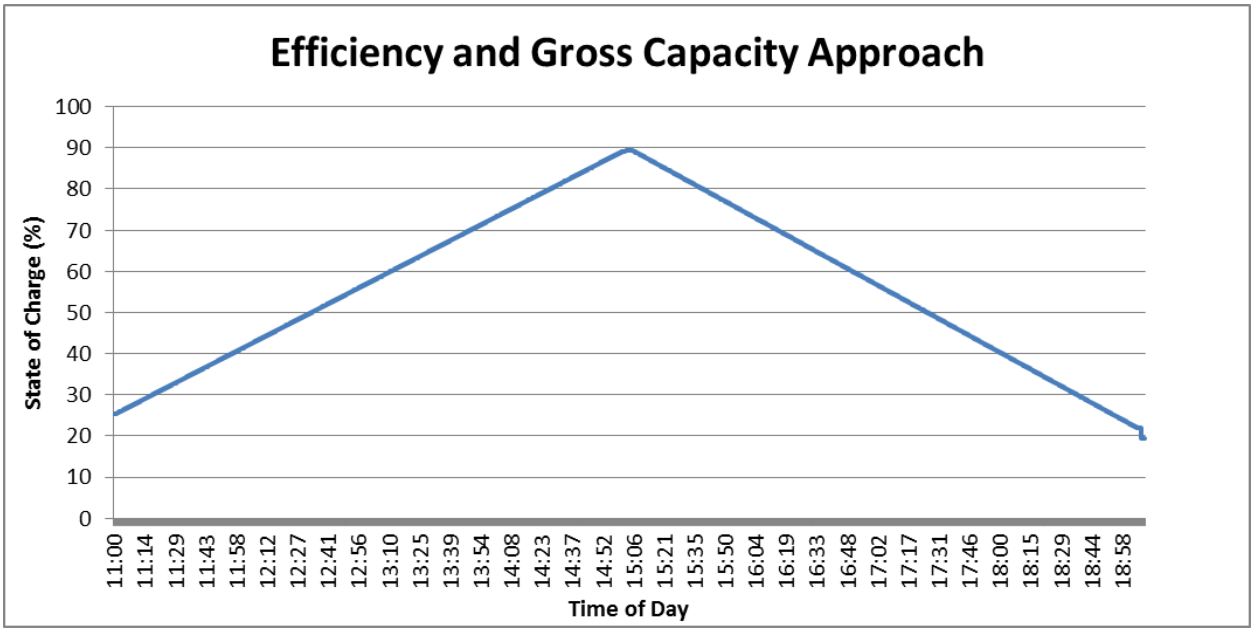


In order to maximize the savings, the units were dispatched at 20 kW, which is slightly higher than the manufacturer recommend charge rate of 15 kW but well within the 30 kW rating of the CES inverter. During this set of demonstration tests, the Test Center unit tripped offline on April 14 and the Residential unit tripped offline on the April 15 - 17. Also, there was a scheduler error that resulted in the units being programmed to discharge from 6:00 a.m. to 7:00 a.m. instead of discharging during the 6 o'clock and 7 o'clock hours (i.e. 6:00 a.m. to 8:00 a.m.). These factors resulted in the achievement of a lower level of Arbitrage benefits than anticipated.

3.3.3.3 System Capacity and Efficiency

The CES units were charged and discharged during multiple constant output demonstrations. During each demonstration, the state of charge (SOC) for the units was closely monitored for round trip operation. During a charge cycle, the SOC of a CES unit increased as energy was being stored in the unit. Energy (kWh) stored in the CES was calculated by accumulating the instantaneous charge rate over the charge duration. During a discharge cycle, the SOC of the CES unit decreased as energy was taken out from the unit. Energy taken out from the CES was calculated by accumulating the instantaneous discharge rate over the discharge duration. Efficiency is calculated as the ratio of energy taken out to energy injected into the CES for the same state of charge ranges. The efficiency analysis was conducted for the same SOC range for both the charge and discharge cycle, as presented in Figure 28.

Figure 28: AC-AC Efficiency and Gross Capacity Approach



The AC-AC round trip efficiency was calculated as the ratio of the energy transferred during the discharge cycle between a SOC of 80 percent and 30 percent to the energy transferred during the charge cycle between a SOC of 30 percent and 80 percent. Note that this approach does not take into account any standby energy losses or trickle charge requirements of the units between operating cycles.

The gross storage capacity of the units was calculated by scaling the discharge energy from the SOC range of analysis to 100 percent SOC.

Figure 29 below presents the AC-AC round trip efficiency of the three units for data collected during the Aggregated Constant Output Demonstrations described in a previous section of this report. The efficiencies varied between 73 percent and 87 percent, with an overall average of 80 percent. It should be noted that the observed average efficiency was less than the expected 85 percent that was specified by the vendor.

Figure 29: Fleet AC-AC Efficiency

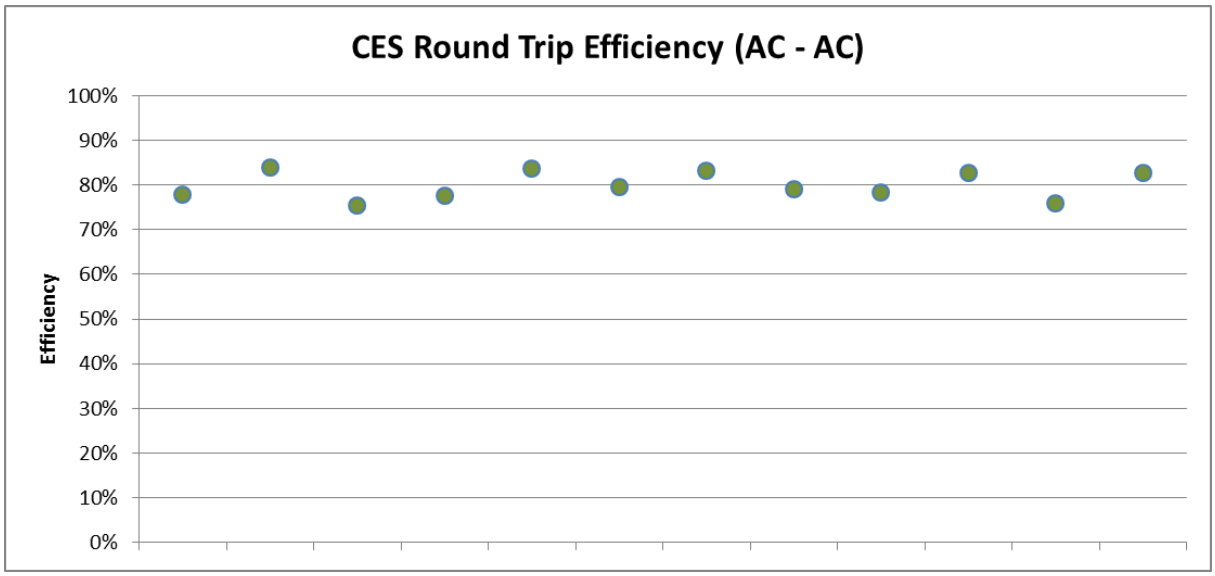
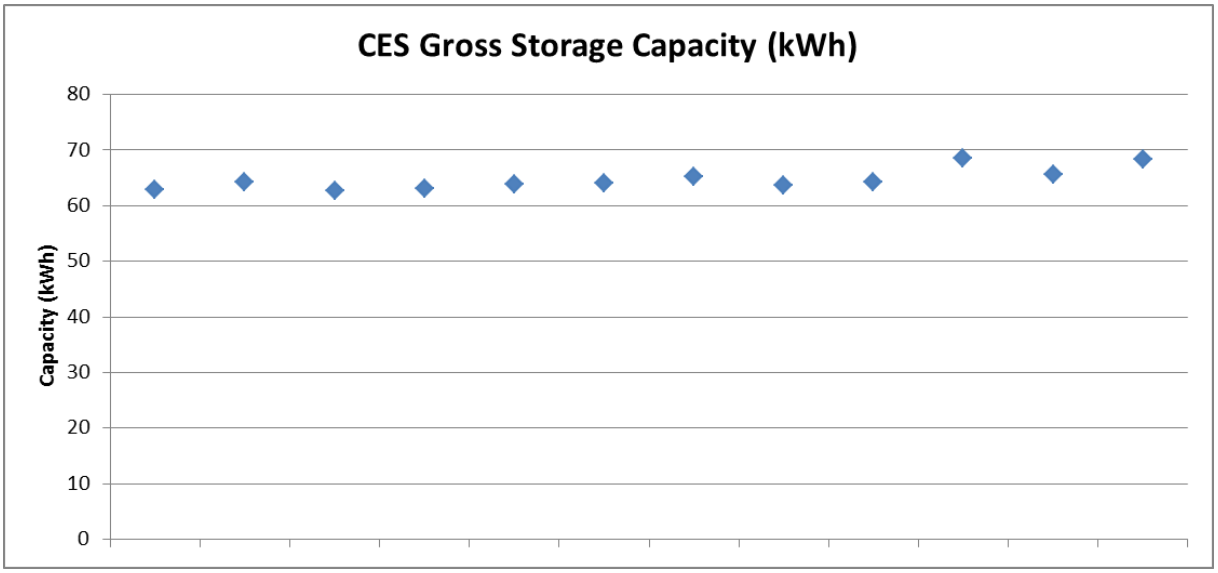


Figure 30 below presents the estimated gross storage capacity of the three units based on data collected during the same demonstrations. The capacities varied between 62 kWh and 79 kWh, with an overall average of 64.7 kWh.

Figure 30: Fleet Gross Storage Capacity



Chapter 4:
Lessons Learned and Key Findings

A summary of the key findings and lessons learned from the project are as follows:

Design and Installation:

- Locating the sites for multiple energy storage units in existing urban utility right-of-ways on individual circuits was challenging.

Controls:

- Using the Constant Power mode, the CES internal controls would terminate the charge or discharge operations when the maximum or minimum state of charge was reached. The set points are the same for all the units, but the data showed that the limits were not consistent.
- A CES unit was successfully scheduled and operated to capture the excess PV generation that would typically be exported to the grid, and to use that renewable energy to provide electricity to the customer when they would typically import power from the grid.
- The demonstrations showed that the three CES units could be programmed to operate in an aggregated fashion.
- Although a single user interface was provided for the fleet of CES units, aggregated operations required the operator to program each unit individually. This resulted in some inconsistent aggregated operations due to errors in setting the schedule.
- The active, dynamic dispatching of multiple energy storage units required the development of a strategy and resources to optimally schedule the systems.

Operations:

- The units' average AC-AC round trip efficiency of 80 percent proved to be less than the expected 85 percent specified by the vendor.
- The units' average gross storage capacity was 64.7 kWh.
- During the early project time period that included the Peak Shaving demonstrations, the Residential unit had operational issues and could not execute the dispatch plan on a regular basis.
- Each of the units could be scheduled and operated using three different approaches for Power Management and Peak Shaving operations. These were1) constant discharge, 2) control to a maximum import set point, and 3) control to a maximum export set point.
- The Arbitrage tests showed less benefit than anticipated due to the use of the Constant Power mode of operation. The process could be improved by lowering the discharge rates, reducing the hours of discharge in the plan, or dispatching the units using the Target State of Charge mode. The on-peak to off-peak price differential during the demonstration period made it very difficult to obtain significant economic value from arbitrage. During a peak demand day or a high congestion day, the differentials would be expected to be much higher.
- The demonstrations showed two approaches for aggregated load reductions coincident with the utility's peak demand: Constant Output and Peak Shaving. The data showed that the demand reduction quantity was more consistent with the Constant Output approach, as it does not rely on the characteristics of the load being served by the respective CES unit.
- The Residential unit successfully demonstrated its ability to conduct PV Smoothing using the Ramp Rate mode of operation.
- The demonstration showed that the Test Center unit was capable of successfully operating near the desired set points around the 15 kVA power circle for the Four Quadrant tests.
- Some demonstrations did not produce the anticipated results due to units tripping offline intermittently.

Chapter 5:
Public Benefits to California

The lessons learned and key findings from this proof-of-concept community energy storage demonstration are expected to produce benefits for California's electricity ratepayers. Community energy storage technology may provide benefits associated with the use of distributed energy resources and their control strategies. These benefits, associated with a utility's management of its distribution network operation, include:

Reliability:

- Load management on distribution equipment that is at capacity or has other operational limitations
- Improved power quality with local Distributed Energy Resources
- Management of 2-way power flow due to high penetration of customer-owned renewable generation
- Management of rapid changes in customer load caused by intermittency of renewable generation

Economics:

- Peak load management at a local level
- Export management of excess customer PV generation to local operations
- Levelization of loads
- Optimized congestion reduction based on day-ahead pricing signals from the CAISO

Environmental:

- Grid operations support in areas of high renewable energy generation
- Improved ability to accommodate higher levels renewable generation due to the improved grid operations support

An additional pathway this research project supports is the operation and improvement of microgrid systems. With the prolific deployment of PV and electric vehicles, and with energy storage systems being installed at the distribution level of the electricity system infrastructure, microgrids provide a locally controlled resource to address issues related to the new electric usage characteristics of customers, bi-directional power flow on the network, power quality issues, and reliability of service.

This project demonstrated specific scenarios for operating energy storage systems under real operating situations while serving actual utility customers. This work helps advance future deployment of energy storage systems by both California utilities and electricity customers. Given proper design, integration, and controls, energy storage can be part of the portfolio of energy solutions that help advance renewable energy standards in the state.

GLOSSARY

Term	Definition
AC	Alternating Current
AMI	Automated Metering Infrastructure
CAISO	California Independent System Operator
CEC	California Energy Commission
CES	Community Energy Storage
DBE	Disadvantaged Business Enterprise
DC	Direct Current
DESS	Distributed Energy Storage System
DNP	Distributed Network Protocol
DOD	Depth of Discharge
EPIC	Electric Program Investment Charge
IEEE	Institute of Electrical and Electronics Engineers
ISO	Independent System Operator
kV	Kilovolts
kVA	Kilovolt-Amperes (apparent power: the magnitude of a given combination of real and reactive power)
kVAr	Kilovolt-Amperes Reactive (reactive power)
kW	Kilowatt (real power)
kWh	Kilowatt-Hour (energy)
LMP	Locational Marginal Pricing
MW	Megawatt
MWh	Megawatt-hour
NEMA	National Electrical Manufacturers Association
PCS	Power Conditioning System
PV	Photovoltaic

RD&D	Research, Development and Demonstration
RFP	Request for Proposal
SCADA	Supervisory Control and Data Acquisition
SDG&E	San Diego Gas & Electric
SOC	State of Charge
SS	Stainless Steel
TCP/IP	Transmission Control Protocol / Internet Protocol
URL	Uniform Resource Locator
V	Volts
VDC	Volts: Direct Current

APPENDIX A:
Technology Transfer and Outreach Activities

Technology transfer in this demonstration project is a priority at SDG&E. The deployment, operation and management of community energy storage systems on the distribution network will contribute to advancements in the energy industry and produce a variety of benefits and consumer options for California's electricity ratepayers.

The key topics for technical transfer have been as follows:

1. Developing criteria for the installation and integration of energy storage systems
2. The procurement process
3. Installation of energy storage systems (lessons learned)
4. Developing techniques for managing and dispatching energy storage devices
5. Testing the effectiveness of the energy storage devices
6. Quantifying additional benefits of the energy storage devices
7. Operation and improvement of microgrid systems
8. Customer energy management solutions

Table 12 presents a summary of specific technology and outreach activities conducted by the project team.

Table 12: Technology Transfer & Outreach Activities

Date	Location	Topic	Presented by	Audience Served
June 2013	Web Conference	CEC CES 500-11-006 Presentation	SDG&E and Horizon Energy Group	CPR Stakeholders Meeting
Oct 2013	San Diego, CA	Plug-In 2013	SDG&E	The Plug-in 2013 conference brought together automotive industry experts and researchers to discuss the state of the industry, and what it will take to get more PEVs on roadways.
January	SDG&E Energy Innovation	NAATBatt Annual	SDG&E	NAATBatt International is a not-for-profit trade association

2014	Center	Conference		of companies, associations and research institutions commercializing advanced electrochemical energy storage technology for emerging high tech applications
Date	**Location**	**Topic**	**Presented by**	**Audience Served**
February 2014	CEC Sacramento, CA	CEC Technical Advisory Committee (TAC) meeting	SDG&E	California Energy Commission, PG&E, SCE
May 2014	SDG&E San Diego	Advanced Energy Storage Overview	SDG&E	SDG&E Technology Solutions & Reliability Group
May 2014	Newark, NJ	CEATI CESIG Spring Meeting	SDG&E	CEATI – Centre for Energy/Advancement through Technology Innovation CESIG – Customer Energy Solutions Interest Group
June 2014	San Diego	Lessons Learned	Green Energy Corp	Capitalizing on Grid-Scale Energy Storage Conference
July 2014	SDG&E – San Diego	SDG&E DER Lunch & Learn: Community Energy Storage	SDG&E	SDG&E Internal Departments, Engineers & Management
August 2014	SDG&E – San Diego	Community Energy Storage	Green Energy Corp	SDG&E Engineers, Department Managers and Staff
September 2014	Chicago	Energy Storage in Microgrids	Green Energy Corp	The Second Annual Microgrids Conference
September 2014	Kyoto, Japan	NEDO Energy Storage Demonstration	SDG&E	NEDO, Sumitomo and other Industry Engineers

		Discussions		
October 2014	SDG&E – San Diego	Future of Microgrids	Horizon Energy Group	SDG&E Engineers, Department Managers and Staff
Date	**Location**	**Topic**	**Presented by**	**Audience Served**
December 2014	CEC Sacramento, CA	CEC Energy Storage Workshop	SDG&E	CEC – California Energy Commission
January 2015	SDG&E Energy Innovation Center	UL Renewables Workshop	SDG&E	UL, a global independent safety science company that has championed progress for 120 years
January 2015	San Diego Conference	A Utility Perspective on Energy Storage	SDG&E	Annual Electric Energy Storage Conference – Marcus Evans
January 2015	SDG&E – San Diego	Distributed Energy Storage Demonstration	SDG&E and Green Energy Corp-	SDG&E Engineers, Department Managers and Staff
January 2015	Web Conference	Final Project Technical Presentation	SDG&E and Horizon Energy Group	CEC, Other Colleagues and Stakeholders
March 2015	SDG&E Smart Grid Website	CEC Distributed Energy Storage to Support Grid Operations – Final Report & PPT	Posted on SDG&E Smart Grid Website	Internal and Public Access - http://www.sdge.com/smart-grid-deployment-plan

APPENDIX B:
Next Steps

- **Updated Specifications**

The lessons learned from this project are leading to improvements in engineering specifications for advanced energy storage systems. Major changes planned for the specification include: clearer descriptions of operational modes, clearly-defined requirements for efficiency, definition of "unit useful life" defined in number of charge/discharge cycles and depth of discharge, and explicit Factory Acceptance Tests.

- **Smaller Footprint**

One of the major challenges for the installation of CES units is their relatively large dimensions and footprint. Finding sites for these devices can be very challenging, particularly in residential neighborhoods. SDG&E needs to investigate installations of CES units that have smaller footprints. Possible options are: subsurface (as opposed to pad-mounted) installations, smaller electrical sizes (15 kVA, instead of 25 kVA), and battery chemistries that have higher densities.

- **Islanding Capabilities**

One of the capabilities of the CES units used for this project that was not explored was "islanding", the ability of the unit to serve a small amount of load for a limited time in the event of a grid outage. This capability should be considered for future installations where some of the load being served by the CES is considered sensitive and/or critical.

- **Better Factory Acceptance Testing**

Previous acquisitions of storage systems required the supplier to provide a Factory Acceptance Test (FAT) plan based on an outline provided by SDG&E. This led to inconsistencies in testing protocols and definitions of FAT tests that were not ideal. SDG&E is transitioning to a FAT protocol that is written by SDG&E itself and includes step-by-step test procedures.

- **Battery Management Approaches**

The CES units for this project had the capability of being operated remotely by accessing the CES User Interface. As SDG&E looks to install more units from different vendors, this may become unwieldy.

Future applications will require that the CES systems have clearly defined control parameters and an interface that allows a master controller or a Distributed Energy Management System (DERMS) to operate dozens or hundreds or units simultaneously.

- **Integration Into SDG&E's Smart Grid Communication System**

Operation of the CES units for this project involved the use of cell-phone modems that have an associated monthly usage fee from the carrier. Given that SDG&E is developing its own Smart

Grid Communication System, the existing CES units will be retrofitted and future installations will be built with radios that are compatible with the new systems.

- **Market Participation**

One of the capabilities of the CES units used for this project that was not explored was "Market Participation", which involves the aggregation of many devices and bidding services such as Spinning Reserve, Non-spinning Reserve and Frequency Regulation into the CAISO Market. If the number of CES units reaches the threshold required by the CAISO, it would be interesting to explore the ability of aggregated CES units to provide these types of services.