December 2013

Sacramento Municipal Utility District PV and Smart Grid Pilot at Anatolia

Mark Rawson, Principal Investigator
Sacramento Municipal Utility District

Ed Sanchez, Project Manager
Sacramento Municipal Utility District

Powering forward. Together.

SMUD®

Department of Energy
DE-EE0002066

Sacramento Municipal Utility District
PV and Smart Grid Pilot at Anatolia

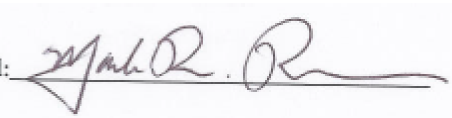
Mark Rawson
Principal Investigator
(916) 732-6364
mrawson@smud.org

Submitted By: Ed Sanchez
Project Manager
(916) 732-5572
esanche@smud.org

December 30, 2013

DUNS: 009235342
Sacramento Municipal Utility District
6201 S Street
Sacramento, CA

Grant Period: 12/31/2009 – 09/30/2013
Reporting End Date: 12/30/2013
Final Report

Signed: 

DE-EE0002066

Sacramento Municipal Utility District

PV and Smart Grid Pilot at Anatolia
Final Project Report

Acknowledgment: This material is based upon work supported by the Department of Energy and the California Energy Commission under Award Number DE-EE0002066.

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

Table of Contents

List of Figures and Tables

Figures:

Tables:

Executive Summary

Background
Under DE-FOA-0000085 High Penetration Solar Deployment, the U. S. Department of Energy funded agreements with SMUD and Navigant Consulting, SunPower, GridPoint, the National Renewable Energy Laboratory, and the California Energy Commission for this pilot demonstration project. Funding was $5,962,409.00. Cost share of $500,000 was also provided by the California Energy Commission.Our team met all key deliverables and objectives.

Project description
SMUD tested advanced lithium ion storage at both customer and distribution transformer locations in the Anatolia III Solar Smart Homes community in Rancho Cordova, CA, in the southeast portion of our service area.

One of the first integrated PV and energy storage projects in the U.S., the Anatolia venture accomplished many firsts, among them:

- A residential energy storage appliance received UL certification.
- A customer-sited, grid-connected energy storage appliance was permitted and installed.
- Load was shifted and smoothed at a residential scale.
- High resolution monitoring equipment was installed throughout a neighborhood's electrical system, from the substation to individual homes.

Goals and objectives
The project aimed to help resolve three challenges for utilities:

- The intermittency of PV generation.
- The impacts on reliability of large penetrations of PV.
- Growing utility system peak load.

Specific objectives were to:

- Demonstrate residential and transformer-level load-shifting 3,566 times.
- Demonstrate residential and transformer-level load-smoothing 2,051 times.
- Demonstrate utility control of a PV inverter via a smart meter.
- Set up dynamic pricing for customers with PV and energy storage.
- Develop and use a communication system for utility control of distributed energy storage.
- Define and assess the benefits of distributed energy storage to SMUD and its customers.
- Assess the strategic implications of this project for SMUD, with an eye toward developing new programs and managing high penetrations of distributed PV.

Conclusions
We learned some valuable things from our study.

- **Distributed energy storage can help manage high penetrations of PV –** We demonstrated energy storage functions that could control voltage, manage reverse power flow (reducing ramping), and shift load.

- **Some SMUD customers interested in managing their energy costs and energy storage can facilitate the use of energy storage –** Our residential energy storage offering was oversubscribed, indicating a strong interest. In a focus group, participants said they valued highly the idea of managing their energy costs with energy storage.
- **Distributed energy storage can add value for SMUD and its customers –** We quantified benefits of $88/kW to $215/kW for customer-sited and $67/kW to $176/kW for transformer-sited distributed energy storage.
- **The impact of PV on the feeder was low –** Even though almost all the 300 homes in the neighborhood had solar PV, we did not find issues at the substation or feeder level. We think this was due partly to large loads up the feeder from our neighborhood that absorb excess power, and partly to SMUD's distribution design standards.
- **Distributed energy storage can help reduce residential and transformer-level peak loads –** We studied timing of peak loads and dispatched energy storage to reduce peak levels.
- **A smart meter can be used to control a PV inverter, and most of the necessary protocols are in place to facilitate this –** After demonstrating this capability in the lab, we conducted a gap analysis between functionalities SMUD wanted and existing protocol. We found no gaps.
- **The project has strategic implications** for SMUD, other utilities and the PV and energy-storage industries in business and resource planning, technology deployment and asset management. These implications include:
  - At this point, no dominant business models have emerged and the industry is open for new ideas. We demonstrated two business models for using distributed PV and energy storage, and we brainstormed several dozen more, each with different pros and cons for SMUD, its customers and the industry.
  - Energy storage can be used to manage high penetrations of PV and mitigate potential issues such as reverse power flow, voltage control violations, power quality issues, increased wear and tear on utility equipment, and system wide power supply issues.
  - Smart meters are another tool utilities can use to manage high penetrations of PV. The necessary equipment and protocols exist, and the next step is to determine how to integrate the functionality with utility programs and what level of utility control is required.
  - Time-of-use rates for the residential customers who hosted energy storage systems did not cause a significant change in energy usage patterns. However, the rates we used were not optimized for PV and energy storage. Opportunities exist for utilities to develop new structures.

Looking forward

Using what we've learned, we have developed suggestions for further study. First, now that we have demonstrated utility control of a PV inverter in a lab setting, the next step would be real-world deployment in a residential neighborhood. Second, more configurations of energy storage should be tested, including customer control, backup power capabilities, four-quadrant control of voltage and power factor, automated back-feed prevention, and new smoothing algorithms. Finally, develop more effective smoothing algorithms and autonomous storage controls, and aggregation software for utility control of fleets of energy storage devices.

1. Introduction

The U. S. Department of Energy under DE-FOA-0000085 High Penetration Solar Deployment funded the Sacramento Municipal Utility District (SMUD) along with its project partners Navigant Consulting, SunPower, GridPoint, and the National Renewable Energy Laboratory to implement the Anatolia PV and Storage Demonstration Pilot for a total Project cost of $5,962,409 Cost share of $500,000 was also provided by the California Energy Commission.

- SMUD demonstrated advanced lithium ion storage at customer and distribution transformer locations in the Anatolia III Solar Smart Homes Community located in the southeast portion of SMUD's service territory in the city of Rancho Cordova, CA.
- The overarching goals of this demonstration were to:
  - Firm intermittency of PV generation
  - Mitigate reliability impacts of large penetrations of PV
  - Reduce utility system peak load

The grant was also used to conduct research on the value of energy storage sited on a customer residence and as a distribution asset. These funds allowed the design, integration, testing and application of energy storage appliances in a community with a high concentration of PV homes, homes that are of similar vintage, and at the end of a distribution circuit.

The combination of these characteristic made this a unique environment to validate the benefits of this technology for both the home owner and utilities. The technology was operated by SMUD to investigate the use of energy storage for renewable energy firming and load shifting along with assessing the impact of dynamic prices and critical peak prices over the course of the study. These funds supported high resolution telemetry at the homeowner's residence, at the transformer and substation along with metrological data to assess the impact of this technology on grid operations.

SMUD used the grant funds to procure fifteen Residential Energy Storage (RES) appliances and three Community Energy Storage (CES) appliances. The grant funds supported the design, integration, testing, siting and installation, and de-commissioning of these energy storage devices. The funds were also used for customer recruitment and support over the course of the demonstration. The funds were also used to support the system integration and development of a home energy portal and the data analysis that was conducted by the National Renewable Energy Laboratory and Navigant Consulting.

2. Performance Objectives and Deliverables

The project team set performance objectives and deliverables in the proposal and SOPO. Each objective and deliverable was reviewed for completion and per Table 1 and Table 2 all objectives were met and deliverables provided.

Table 1. Map of Performance Objectives

Objectives	Complete?	Discussion
Add energy storage as either RES (connected behind the meter) or CES (connected to distribution transformers).	Yes	15 RES and 3 CES units were installed.
Install communications so that the energy storage can be monitored and controlled by SMUD.	Yes	Communications was done via the customer's broadband connection for the RES units and via a cellular modem for the CES units.
Install a Utility portal that will allow SMUD to monitor PV output, energy storage, and customer loads, as well as coordinate the resources at a system aggregate level, or more granularly at the substation, feeder, or individual residence level.	Yes	The project team implemented a Utility portal that allowed us to view real time data and control energy storage devices by unit, transformer, fleet and feeder.
Deploy a Customer portal that will allow consumers to monitor their energy usage, PV output, and energy storage in real-time. In addition, consumers will receive energy conservation tips and other educational tools to help them change their energy use patterns.	Yes	The project team implemented the Customer portal and were able to send energy conservation related messages.
Determine pricing signals that will change the energy usage behaviors of customers.	Yes	The RES customer group was put on a Time-of-Use rate during the study.
Determine if customers who have PV and energy storage manage their energy usage differently when compared to those who do not.	Yes	The project team found no difference between groups. The project team suspect this is because customers were not given control of the units.
Control a PV/energy storage inverter with a smart meter from SMUD's AMI deployment.	Yes	The project team partnered with EPRI to conduct lab demonstrations of controlling an inverter with a smart meter.

Develop a functional specification for a smart meter/inverter interface that would enable management of distributed PV/storage system with AMI.	Yes	The specification was developed as part of task 4.06.
Help to build a strategy for integrating energy storage and PV that can be replicated throughout SMUD's service territory and the utility industry as a whole.	Yes	The project team discuss this in section 5.
Simulate the lower bandwidth communications of the AMI wireless mesh network to determine the limitations it could present in terms of data capacity and latency; and implement a prototype interface between a smart meter and PV inverter to demonstrate the simulated communications channel.	Yes	The project team partnered with EPRI to conduct lab demonstrations of controlling an inverter with a smart meter.

Table 2. Schedule of Deliverables

Task #	Deliverable	Complete?	When?	Documentation
1.01	Kick-off Meeting Agenda	Yes	6/14/2010	High Level Agenda for Kick OffV3.xls
1.01	Kick-off Meeting PowerPoint Presentation	Yes	6/18/2010	2010-06-17 HPS Kick off meetng.pdf, SMUD-DOE Kickoff Meeting – Technology Installation and Integration 20100611.pptx, SMUD metering_NREL-jbank.pdf, SunPower-SMUD-DOE Home Storage Demo Program Charter (as presented 6-18-2010).pdf
1.01	Kick-off Meeting minutes	Yes	6/21/2010	2010-06-21 HPS Kick Off Notes_v3.docx
1.02	CPR meeting, meeting record and recommendation for continuing project	Yes	11/8/2012	DOE CPR Nov 8 2012.pptx, 2012-11-01 CPR Meeting V12.pdf, CPR Meeting Summary.pptx
1.03	Final Meeting Agenda	TBD	TBD	This is still being scheduled with DOE
1.03	Final Meeting PowerPoint Presentation	TBD	TBD	This is still being scheduled with DOE

1.03	Written documentation of final meeting agreements and all pertinent information, for final meeting	TBD	TBD	This is still being scheduled with DOE
1.03	Schedule for completing closeout activities	Yes	7/31/2013	Closeout Schedule.docx
1.04	Monthly progress reports	Yes	Multiple	Multiple
1.05	Final report	Yes	9/30/2013	2013-09-30 Final Report.docx
1.06	Meeting Agenda - DOE program review	Yes	DOE Peer Review 5/26/201, High Penetration Solar Forum 3/1/2011, SunShot Grand Challenge Summit 6/13/2012, High Penetration Solar Forum 2/13/2013	Refer to workshop proceedings on SunShot Initiative homepage.
1.06	Meeting presentations - DOE program review	Yes	5/26/210, 3/1/2011, 6/13/2012, 2/13/2013	Prm2010_smud.pdf, highpenformum1-14_rawson_smud.pdf, 2012-06-07 SunShot Poster.pdf, 2012-02-13 SMUD High Pen Pres.pptx
1.06	Meeting Minutes - DOE program review	Yes	5/26/210, 3/1/2011, 6/13/2012, 2/13/2013	Refer to workshop proceedings on SunShot Initiative homepage.
1.07	Sub-agreements	Yes	Multiple	Multiple
1.08	Internal Technical Workshop - Meeting Agenda	Yes	12/2/2010	2010-12-10 Internal Meeting.pptx
1.08	Internal Technical Workshop - Presentations	Yes	12/13/2010	2010-12-10 Internal Meeting.pptx

1.08	Internal Technical Workshop - Meeting Minutes	Yes	12/16/2010	2010-12-13 Meeting Notes.docx
1.09	Final results workshop - meeting agenda	Yes	8/28/2013	Final Results Workshop – Morning.pdf, Final Results Workshop – Afternoon.pdf
1.09	Final Results workshop - Meeting Presentations	Yes	8/28/2013	Final Results Workshop – Morning.pdf, Final Results Workshop – Afternoon.pdf
1.09	Final Results Worskhop - Meeting Minutes	Yes	8/28/2013	Sent via email to SMUD team
2.01	Hardware specifications documents	Yes	Multiple	Final CPR 20 Jul 2012.pdf
2.01	Pre-Installation unit certification reports for all field deployable units	Yes	Multiple	Final CPR 20 Jul 2012.pdf
2.01	Post-Installation unit diagnostic reports for all field deployed units	Yes	Multiple	Final CPR 20 Jul 2012.pdf
2.02	Software specifications documents	Yes	Multiple	Final CPR 20 Jul 2012.pdf
2.02	Interface specification documents	Yes	Multiple	Final CPR 20 Jul 2012.pdf
2.02	An operational utility portal	Yes	Multiple	Final CPR 20 Jul 2012.pdf
2.02	An operational consumer portal	Yes	Multiple	Final CPR 20 Jul 2012.pdf
2.03	Data packet specification document	Yes	1/26/2011	Final_Monitoring_And_Testing_PlanV12.docx
2.03	Defined data packets	Yes	1/26/2011	Final_Monitoring_And_Testing_PlanV12.docx
3.01	Data for Analysis	Yes	N/A	Data hosted by NREL at https://pfs.nrel.gov and http://www.nrel.gov/midc/smud_anatolia/

3.02	Determinations of impact of PV/energy storage on feeders	Yes	12/30/2013	2013-12-30 Final Report.docx
3.02	Data for subsequent analysis	Yes	N/A	Data hosted by NREL at https://pfs.nrel.gov and http://www.nrel.gov/midc/smud_anatolia/
4.01	A summary report on the framework for assessing PV/storage benefits for the project	Yes	11/30/2010	PV-Storage Benefits Framework – Final – 11-30-2010
4.02	A testing and monitoring plan that covers each of the operating scenarios.	Yes	1/26/2011	Final_Monitoring_And_Testing_PlanV12.docx
4.03	Pricing models for each of the three customer groups	Yes	5/30/2012	Rates were implemented with customers in Q2 2012
4.03	Pricing model implementation plan	Yes	5/30/2012	Rates were implemented with customers in Q2 2012
4.04	Advanced Pricing Workshop - Agenda	Yes	6/27/2011	Advanced Pricing Workshop – 06-27.pptx
4.04	Advanced Pricing Workshop - Presentations	Yes	6/27/2011	Advanced Pricing Workshop – 06-27.pptx
4.04	Advanced Pricing Workshop - Meeting Minutes	Yes	7/26/2011	Meeting Minutes – Advanced Pricing Workshop – 07-26-2011.pptx
4.05	Report outlining output of data analysis	Yes	12/27/2012, 2/14/2013, 3/25/2013	2013-2-19 Q2 Data Report – Final.docx, 2013-2-19 Q3 Data Report – Final.docx, 2013-3-25 Data Report – Final.docx
4.06	Straw man functional specification for PV/smart meter interface	Yes	7/19/2013	2013-07-19 Functional Spec.docx
4.07	Recommended updates for strategies	Yes	12/30/2013	2013-12-30 Final Report.docx

4.08	Summary report on business model options and potential value tradeoffs	Yes	12/30/2013	2013-12-30 Final Report.docx
N/A	CPR Report	Yes	7/20/2012	Final CPR 20 Jul 2012.pdf

3. Key Findings

The project team structured the project around a set of strategic objectives and key research questions to focus the testing and analysis. This section reviews each question and the insights gained from the work.

Strategic Objective 1 – Understand how the integration of energy storage could enhance the value of distributed PV resources within the community

- *Does the location of energy storage significantly change the utility's ability to "firm" customer load and distributed PV capacity?*
  The answer to this question is yes, the location does change the ability to manage variations in load and PV capacity.

  The algorithms implemented in this demonstration smooth and dampen variations, rather than firm the PV production into a set load shape. Consequently for the remainder of this report, the term smoothing will be used instead of firming.

  While the RES and CES units employ the same smoothing algorithm – a moving average based algorithm that tries to dampen changes in power – the CES units see load (and thus volatility) aggregated from 5 to 15 houses. This means that spikes in load or rapid changes in PV output from one house are added to load from many houses and result in a relatively lower change at the transformer level. Thus, the CES unit is responding to relatively smaller changes in load and has an easier time responding by charging or discharging as needed.

  Evidence of this can be seen in the impact of the smoothing algorithm, Table 3 and Table 4 compare ramp rates with and without the smoothing algorithm applied in the CES and RES, respectively[1]. Table 3 shows that with the CES the smoothing algorithm reduced the mean and medium ramp rates at the transformer. In contrast, Table 4 shows the smoothing algorithm with the RES actually increased mean and median ramping[2].

Table 3. Summary Statistics of Smoothed and Unsmoothed Transformer Load Ramp Rates - CES

Statistic Parameter	Unsmoothed Load	Smoothed Load
Mean Ramp Rate (W/s)	55.9	50.6
Median Ramp Rate (W/s)	23.8	13.7
Standard Deviation of Ramp Rate (W/s)	74.9	78.8
Number of Data Points	99,250	

[1] For more information on the analysis that went into these tables, refer to the Q4 2012 Data Analysis Report

[2] It is suspected that this is because the algorithm drives an immediate charge in response to a discharge or vice versa and that this effect is more pronounced in the RES units because of the higher spikes

Table 4. Summary Statistics of Smoothed and Unsmoothed Customer Load Ramp Rates - RES

Statistic Parameter	Unsmoothed Load	Smoothed Load
Mean Ramp Rate (W/s)	13.3	19.6
Median Ramp Rate (W/s)	2.6	4.4
Standard Deviation of Ramp Rate (W/s)	50.5	60.3
Number of Data Points	147,431	

- *How much storage is necessary to accomplish the desired PV and load firming effects?*
  The answer to this question depends on the definition of firming. Per the discussion above, smoothing was tested in the project. With the smoothing algorithm deployed, the CES units discharged an average of 5.5 kWh/day on high solar variability days[3] and the RES units discharged an average of 1.9 kWh/day[4]. These values are lower than the unit's energy storage capacity – 34 kWh for the CES units and 7.7 kWh for the RES units. However, the smoothing algorithm used was only effective in smoothing ramps greater than 2.5 minutes in length[4]. Thus, a faster acting algorithm might require more energy storage capacity.

  If defining firming as the ability to turn PV into a firm, reliable resource, the requirements are higher. The exact amount depends on the utility's use of energy storage to firm PV.

  - If the intent was to firm PV output on any day of the year and in any weather conditions, an energy capacity of 6.2 to 6.8 kWh per kWp(DC) would be required to completely back up a PV system. This number was calculated from looking at the highest output for any PV system over the course of year and normalizing by capacity[5]. The average PV system size is 2 kW in the Anatolia neighborhood, so this would require a 12.4 to 13.6 kWh energy storage system.

  - If a utility had day ahead solar forecasting capabilities detailed enough to predict typical weather patterns (e.g. sunny, fully over cast, partly cloudy, etc.), the utility would know storage would not be required on clear days and could plan ahead for low PV output on fully over cast days. The energy storage equipment would be designed to firm PV output on partly cloudy days. The maximum amount of storage required to firm PV output on intermittent days would be ~2.5 kWh per kWp(DC) of PV capacity or 5 kWh for a 2 kW PV system in Anatolia. This amount is less than half of the amount required (6.2 to 6.8 kWh per kWp(DC)) if the storage is sized to back up PV in any conditions.

- *Can an integrated PV/energy storage system provide service reliability benefits for customers?*

Service reliability can be thought of in two ways:

[3] Refer to the Q2 2012 Data Analysis Report for the definition of high solar variability days.
[4] Refer to the Q1 2013 Data Analysis Report for detail on how these numbers were calculated.
[5] Refer to the Q4 2012 Data Analysis Report for more information on this analysis

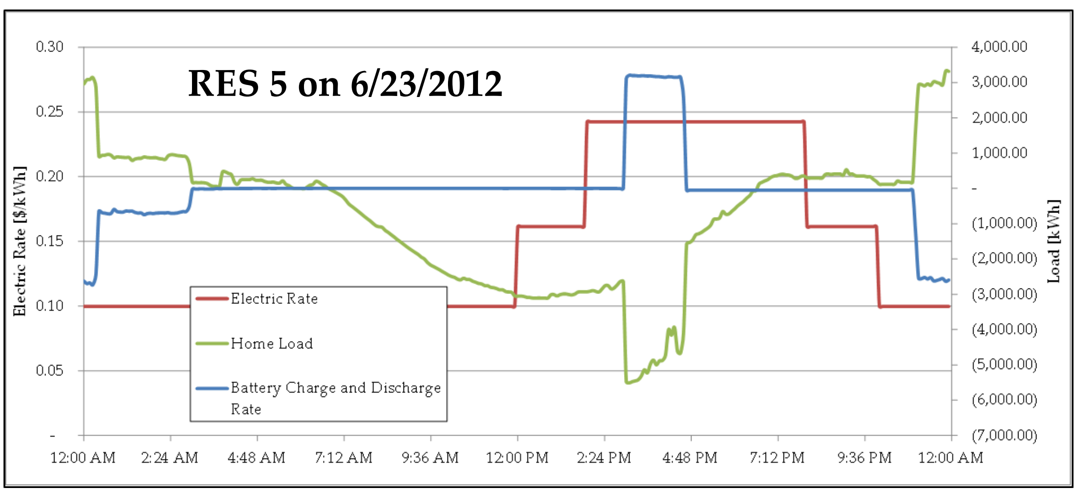
– Reducing the impact of outages by providing back up power.
– Reducing voltage fluctuations.

In terms of mitigating outages, the answer is yes, but current interconnection standards prevent this. IEEE 1547 governs the interconnection of distributed energy resources and mandates that inverters trip offline in the event of a grid outage. The primary driver of this is to ensure that a grid connected distributed energy resource is not producing energy and energizing lines when utility repair crews are active. IEEE 1547 is currently being updated and this might change in the future. In theory, an automatic transfer switch could be designed into a PV/energy storage system to remove the system from the grid in the event of an outage. However, this would require the addition of equipment and controls software to manage loads, PV generation and battery charging that are not common now and that were not tested in the study.

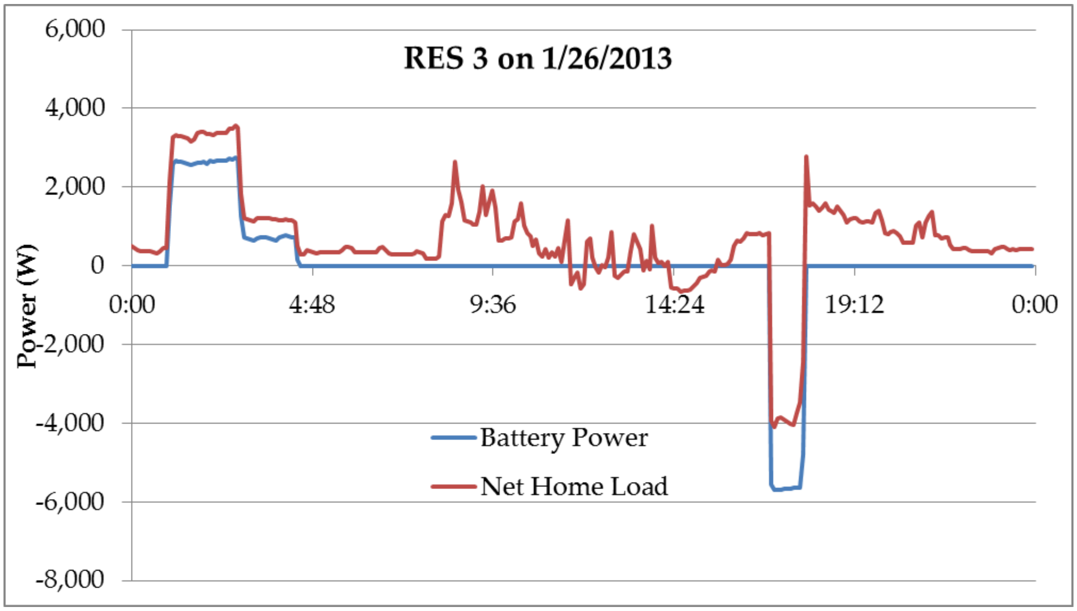
For reducing voltage fluctuations, the answer is likely yes if volt/var control was enabled. However, (a) the penetration of PV on this feeder isn't high enough to actually see voltage issues (as confirmed in NREL's 2009 study of the neighborhood[6]) and (b) this functionality was not designed into the demonstration units. A recommendation for further study from this report is to test this functionality as part of a demonstration.

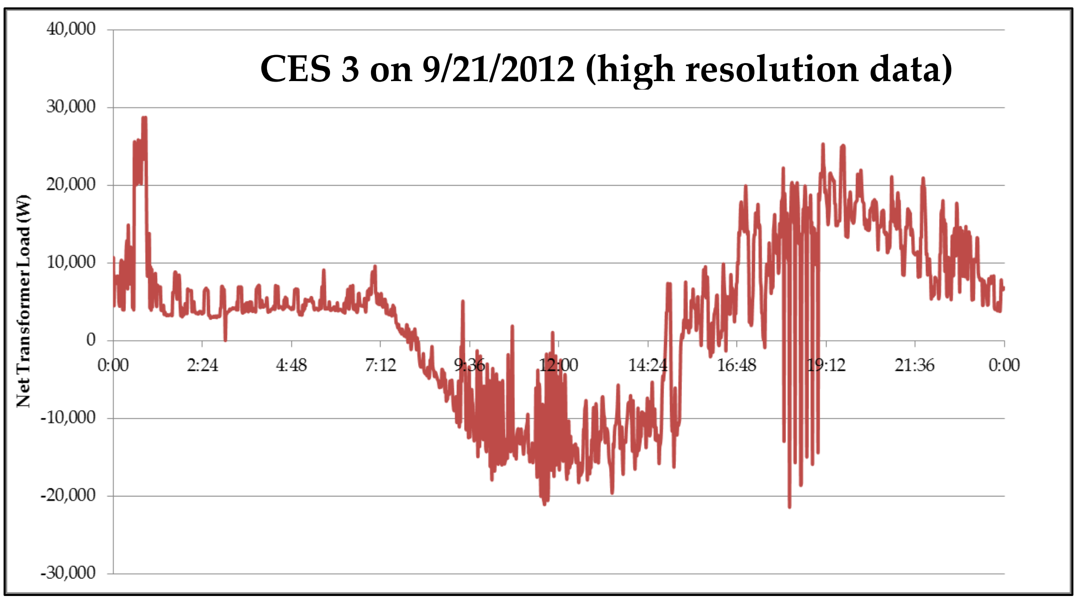
Strategic Objective 2 - Determine if the addition of energy storage could add value for the utility

- *Can energy storage in a high penetration solar deployment help support SMUD's "super-peak" from 4 PM to 7 PM, particularly when PV output drops off after 5PM?*
  Yes, SMUD proved many times that energy storage in both the RES and CES configuration can reduce peak loads. SMUD ran load shifting 2,847 times with for the RES units and 719 times for the CES units and sample plots from actual tests are shown below.



[6] The 2009 report is entitled *Impact of SolarSmart Subdivisions on SMUD's Distribution System*, July 2009, NREL/TP-550-46093


RES 3 on 1/26/2013
Power (W)
6,000
4,000
2,000
0
-2,000
-4,000
-6,000
-8,000
0:00
4:48
9:36
14:24
19:12
0:00
Battery Power
Net Home Load


CES 3 on 9/21/2012 (high resolution data)
Net Transformer Load (W)
40,000
30,000
20,000
10,000
0
-10,000
-20,000
-30,000
0:00
2:24
4:48
7:12
9:36
12:00
14:24
16:48
19:12
21:36
0:00

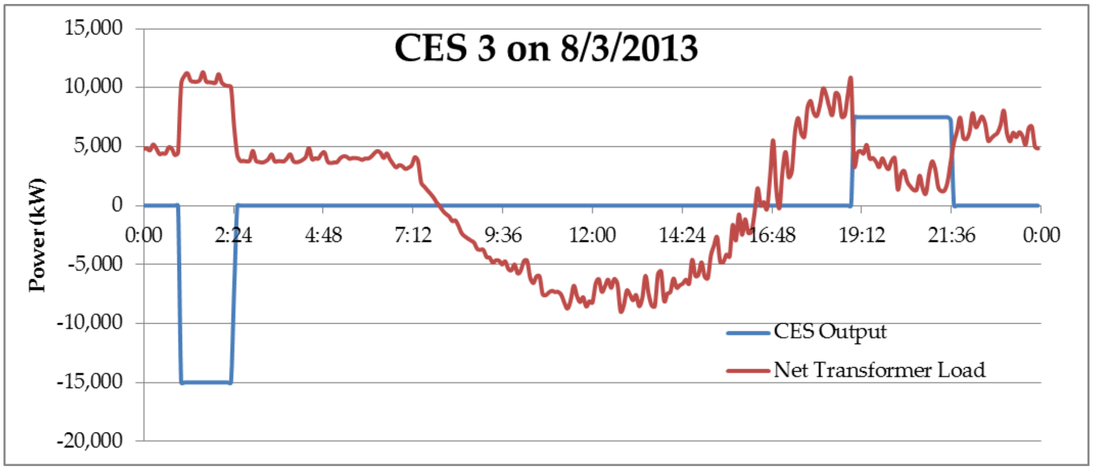


Figure 1. Samples of Energy Storage Reducing Peak Loads

However, one key finding of the study was that the neighborhood summer peak in Solar Smart communities is later than SMUD's summer system peak of 4 to 7 PM. The figure's below show the time of transformer peaks in the neighborhood – by month – against the system peak period. As a result, using energy storage to reduce peak during SMUD's system peak might not result in peak reduction in the neighborhood's peak.

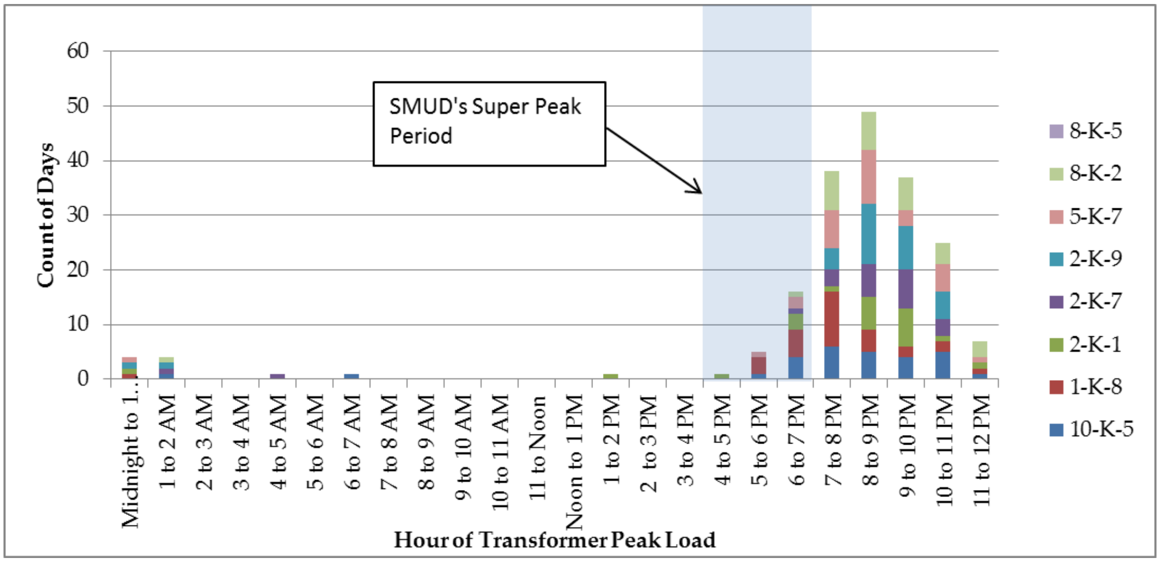


Figure 2. Hour of Each Transformer's Daily Peak Load - June 2012

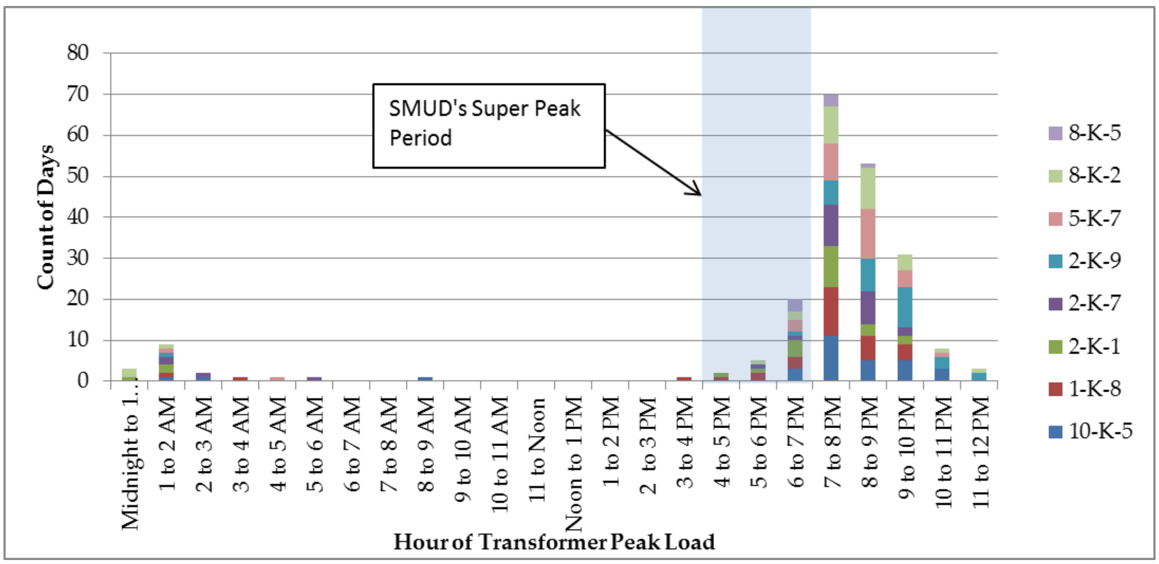


Figure 3. Hour of Each Transformer's Daily Peak Load - July 2012

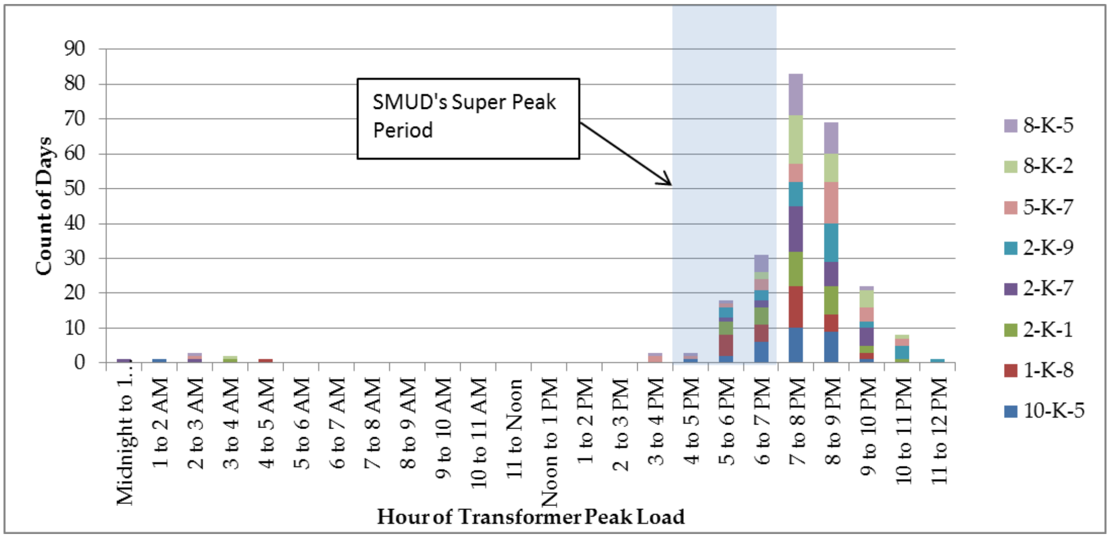


Figure 4. Hour of Each Transformer's Daily Peak Load - August 2012

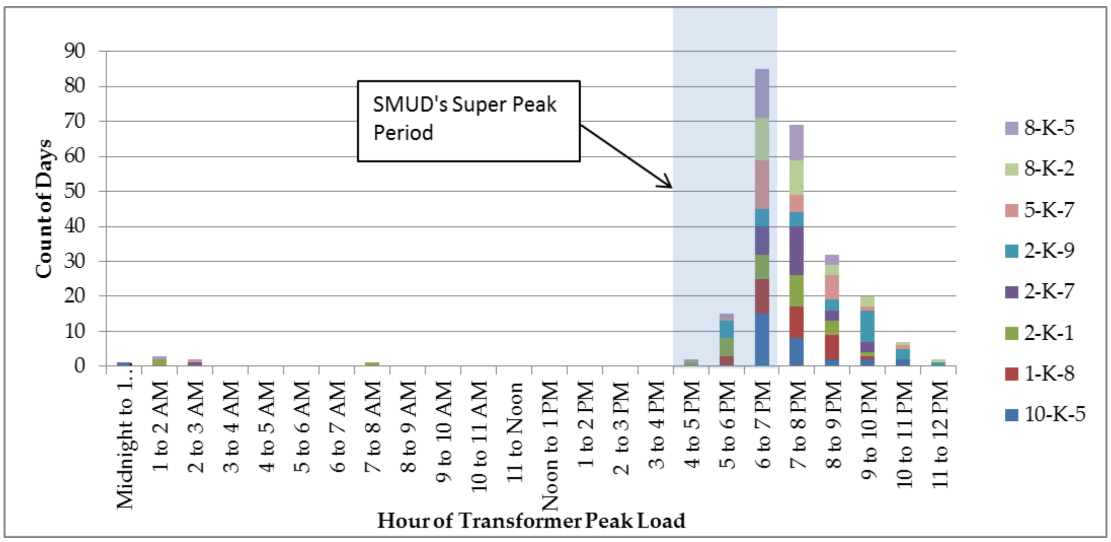


Figure 5. Hour of Each Transformer's Daily Peak Load - September 2012

The project team also looked at the feeder level for information on timing of peaks. The distributions of the peak load occurrences at the neighborhood and feeder levels are given in Figure 6. Source data for these graphics are drawn from over a year of SMUD's SCADA Data. The upper plot gives the distribution over time of when the substation experienced its peak load value. Here the time points are binned into half hour periods on the horizontal axis and the count is given on the vertical. The lower plot presents the same results for the Anatolia Neighborhood. Additionally, the PV production region is blocked out in yellow while SMUD's Super Peak Period is given in red.

In Figure 6, the majority of the observed peak loads occur after the Super Peak region. Once again demonstrating that the loads in this area in general do not coincide with SMUD's Super Peak period.

The majority of the peak load periods also occur at the tail end of the daylight hours when very little power is being generated by the PV in the neighborhood indicating that the PV in the Anatolia neighborhood is not significantly shifting the peak load time. At the substation level where the installed PV capacity represents a smaller percentage of the total load a similar trend is seen with the PV having little effect in shifting the load.

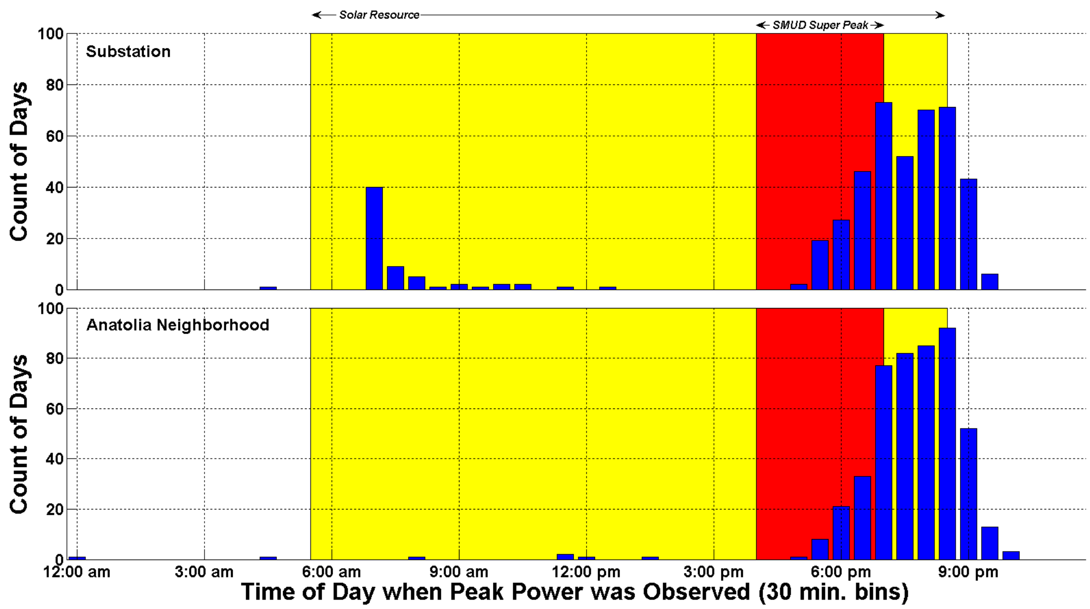


Figure 6. Peak Load Distributions at Substation and Neighborhood Level

In order to better demonstrate how the PV in the Anatolia Neighborhood is affecting the afternoon peak load a specific example is presented in Figure 7. May 18, 2013 was a particularly clear day with a very clean irradiance profile with a high amount of total solar energy available due to the proximity to the Summer solstice. Additionally, the load is relatively light as it occurs in the spring before a lot of air conditioning load becomes prevalent. The high PV output and lower load conditions provides a worst case example for the PV being able to affect the load peak time.

In Figure 7, the blue trace is the measured load at the neighborhood level, it demonstrates the typical midday trough due to the PV generation and a clear load peak in the evening at about 9:00 pm. This peak load time is slightly later than normal but not atypical in the measured data. The red trace is the estimated total daily PV power output; it was constructed from the irradiance measurement using a few scaling factors to account for the installed capacity, panel tilts, and orientations. This estimate represents a best guess and is not perfectly accurate due the variance in house orientation, tilt angle and the geographic diversity of the irradiance. The black trace gives the estimated load as derived by adding the PV production to the measured load flow. Here the peaks of the estimated load and the measured power flow line up exactly indicating that the PV is having no effect on either reducing the peak or shifting it for this day. This is as expected because the peak is occurring nearly two hours after sunset when the PV has stopped producing power. Several other days were considered in this fashion with similar results.

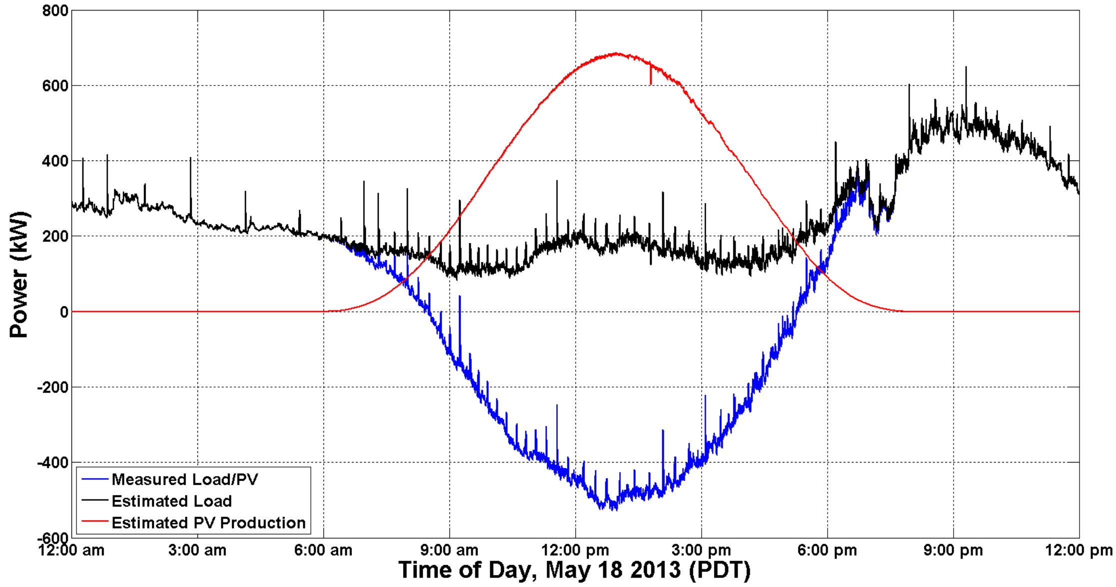


Figure 7. Load and PV Profiles for May 18 2013

In order to estimate the amount of energy storage needed to perform peak shaving in the Anatolia Neighborhood, the feeder level power flow measurements were used to establish how much energy was being consumed and exported on a daily basis. The power measurements during midday when the PV was producing and the neighborhood was a net supplier were integrated to establish how much energy was feeding to the substation on a daily basis. Additionally the power measurements from periods when the Neighborhood was a net consumer were integrated separately. These integrals were performed on each of the 642 daily profiles available in the feeder level data set. Histograms of these results are given in Figure 8, the top plot is the total energy supplied during the period while the neighborhood is a net exporter and the bottom plot is total energy consumed while the neighborhood is a net importer.

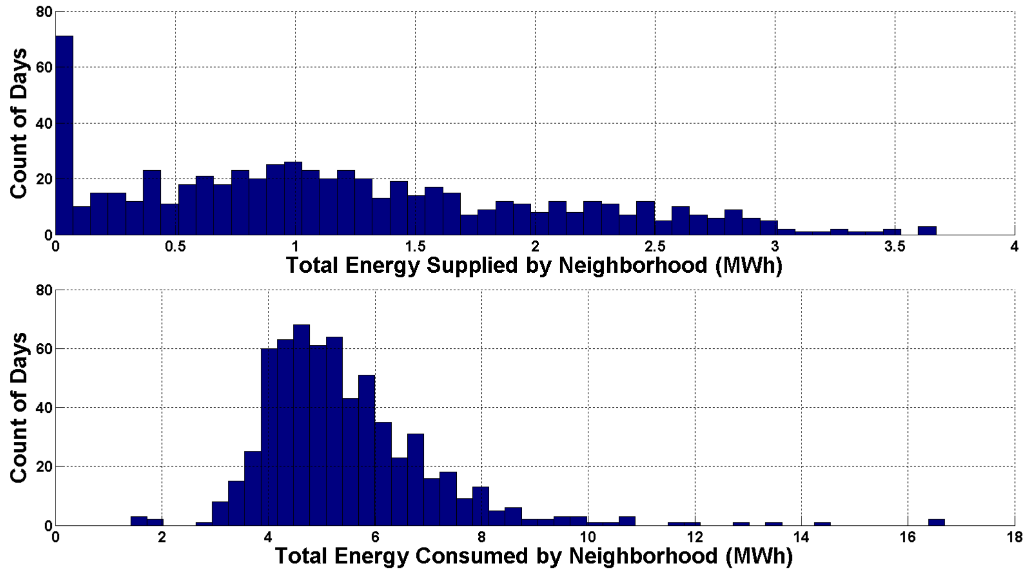


Figure 8. Total Energy Supplied and Consumed by Anatolia Neighborhood on a Daily Basis

The amount of energy supplied by the neighborhood is quite variable ranging from 0 up to 3.7 MWh per day with the average at 1.2 MWh. During the 642 days analyzed, 22 of them demonstrate no periods of reverse power flow with the neighborhood acting as a net consumer the entire day. The majority of these 22 days occurred in the winter months when the solar resource was at a minimum.

The daily energy consumption for the neighborhood resulted in a much more tightly packed distribution with total daily consumption ranging from 1.4 MWh to 16.7 MWh with the majority of days densely packed around the average of 5.5 MWh. Once again these numbers represent the total energy consumption when the neighborhood was a net consumer, generally during the non-daylight hours. Across the entire data set only one day, June 5th, 2012, was found in which the neighborhood was a net supplier for the entire day, producing 300 kWh, for all other days in the data set the total energy consumed exceeded the total supplied. However, there were several other days observed which were very close with total daily consumption of less than 250 kWh.

Based on the results of this analysis, in order to provide benefits for peak shaving at the neighborhood level, total energy storage sized in the range of 500 kWh to 1 MWh would be able to capture most of the exported energy on average and be able to fully discharge during the peak period without exceeding the load.

The project team then simulated the impact of this. The May 18th load profile from Figure 7 was adjusted to include a hypothetical 1 MWh energy storage device implementing peak shaving to demonstrate this effect. Here an ideal energy storage device is implemented without accounting for any efficiency losses. The storage is charging during the daylight hours while the neighborhood is exporting power and discharging in the late afternoon and evening while the neighborhood load is peaking as indicated by the red trace of Figure 9. The blue trace is the original measurement data and the black trace adds the energy storage action to it. Both the solar peak (midday trough) and the load peak in the evening are reduced, reducing both the excess power that the utility must sink and the power that it must supply during peak hours.

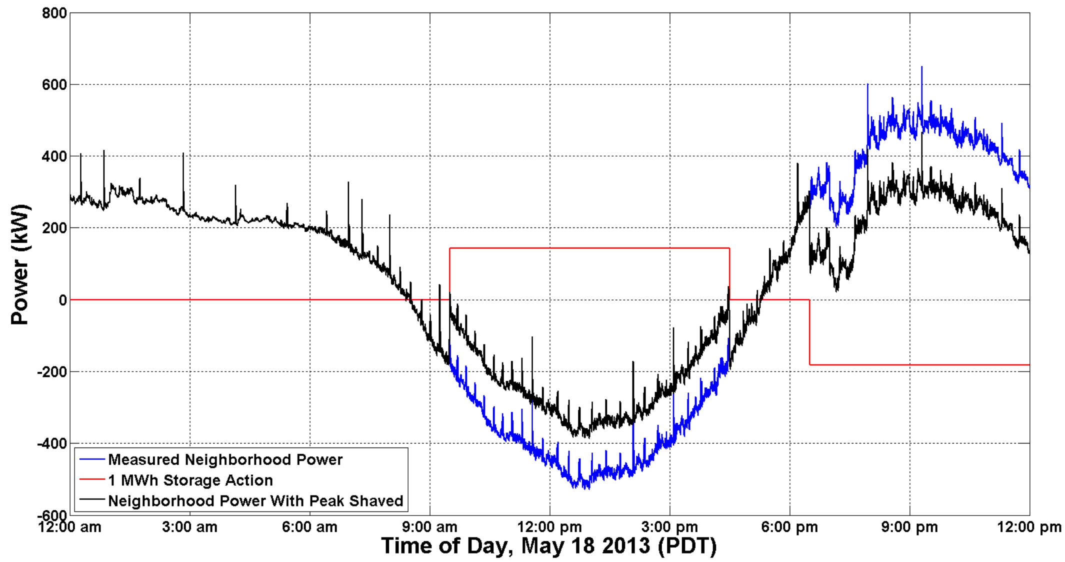


Figure 9. May 18th 2013 load Profile with Hypothetical 1 MWh Storage

The Anatolia neighborhood is still currently under development with full build out of the homes expected to reach three times what is currently built in the area. Given that these new homes would have similar design and construction this would have the effect of increasing the power flows by a factor of three over what was measured over the course of this project. Previous studies by NREL have shown that this full build out poses minimal operational impacts to the utility but the increased power flows would need to be included for any energy storage sizing. Based on measurement data, the Anatolia Neighborhood peak load only represents about 10% of the peak load at the substation and thus is having minimal impact on the demand seen there and the Anatolia PV never produced enough power to cause the substation to back feed over the span of data collection for this project. As the neighborhood builds out, it is unlikely this will change as it would still represent a small portion of the total load supplied by the substation.

- *Does the location of energy storage significantly affect the ability of the utility to manage the resource?*
  Yes, the location of a distributed energy storage system affects the ability of the utility to manage the resource in two areas: Asset Management and Operations.

  In regards to Asset Management, the two locations tested – utility sited at a transformer and customer sited in a residential home – have pros and cons. The table below maps them out. One key observation from the table is that from an Asset Management perspective, both configurations have pros and cons and neither is better than the other.

Table 5. Asset Management Impacts of Location

CES (Utility sited)	RES (Customer sited)

Pros	• Asset is utility sited and does not require any customer contact beyond installation • Asset does not impact customer bill easing billing and avoiding cost of battery round trip inefficiencies • Asset can be sized to service multiple homes • Home owner liability and risk is reduced	• Unit can be housed in customer's garage and sheltered from elements • Unit can aide in lowing customer bills depending on rate structure and dispatch schedule of batteries • Can be configured to reduce outages and provide a UPS source (NA in this project)
Cons	• Distribution crew is required for all maintenance activities • Unit is installed outside and exposed to elements	• Equipment trouble shooting requires schedule coordination with homeowner • Customer bears impact of system inefficiency and might complain about higher bills • Increased risk and liability issues

In terms of Operations, SMUD tried different solutions for each configuration and the findings are as follows:

- SMUD used the customer's broadband connection to control the RES units. SMUD encountered several issues with this solution. The first was electromagnetic interference (EMI) between the storage device and broadband cabling. This required time consuming trouble shooting and repair. The second was the broadband connection was found to be intermittent in this neighborhood. When communication with the devices was lost, it interrupted the data feeds. Thus, using customer's broadband is not recommended going forward. In the future, SMUD could leverage its AMI/HAN infrastructure that has been deployed or its direct load control infrastructure (DRMS) to operate customer sited energy storage systems, but this would require broadband or WiFi.
- For the transformer sited CES units, SMUD used cellular modems for operating the units. This was also not a highly reliable solution because outages with the local cellular service would cause communications and monitoring interruptions. If SMUD were to scale up a deployment of this configuration, they'd likely use their secondary Silver Springs network deployed for distribution automation purposes or their fiber optic SCADA system.

To conclude, each configuration would likely use a different operating system if rolled out at a larger scale.

- *How variable is PV output within a community or distribution feeder, and what is the potential operating impact for the utility?*

Power Spectral Density Plots have been previously used to assess the variable nature of loads and the solar resources in the Anatolia community[7]. Fourier analysis is used to transform the time series measurement data into the frequency spectra. The total power of each frequency component is then

[7] J. Bank and B. Mather, "*Analysis of the Impacts of Distribution Connected PV Using High-Speed Datasets*", *IEEE Green Technologies Conference. April 4-5 2013, Denver CO p. 153-159*

easily attained and variable features in the measurements can then be seen as spikes in power at the corresponding frequency. Here this analysis technique is used to observe the nature of solar resource variability and how that affects the total feeder power flow.

Since the PV is installed on the customer rooftop level, both the distribution transformer and SCADA power measurements include the PV generation and the load netted together. In order to assess the impacts of solar resource variability, cloudy and clear days are compared. Here data sets from early April are used to limit the influence of variable load effects most commonly seen in the summer and because the spring months generally demonstrate the most variability in the solar resource.

Seven clear days and seven cloudy days from between April 1st and April 18th 2013 were selected for analysis. One second global horizontal irradiance measurements from the north side of the neighborhood were compiled and the resulting power spectra were computed for this data. Figure 10 presents these results, with the clear days plotted in red and the cloudy days in black.

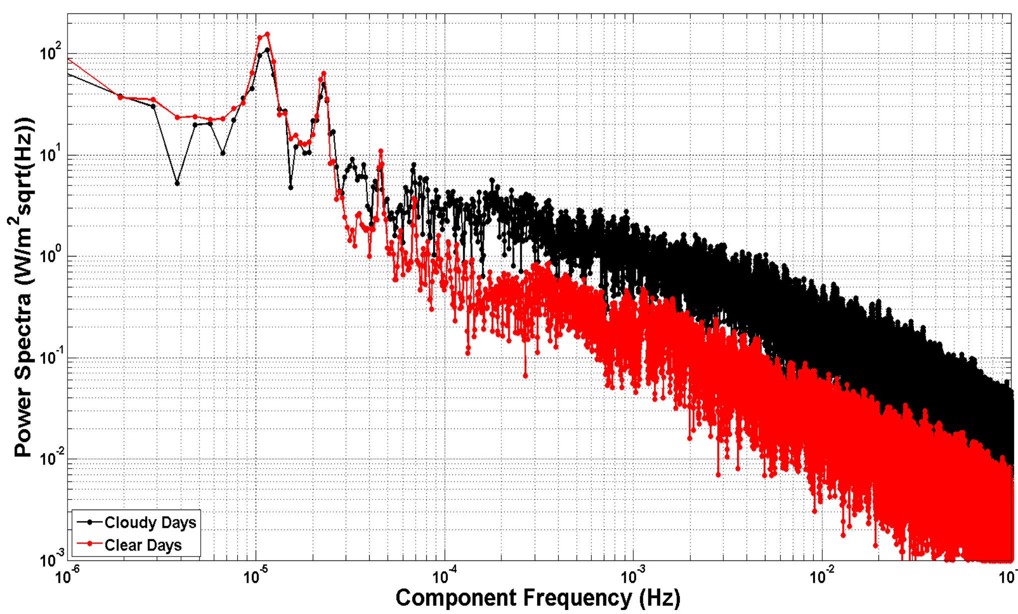


Figure 10: Solar resource power spectral density for clear and cloudy days in early April

The 24, 12 and 6 hour components of the daily solar profile are prevalent on the left hand side of the plot in both trends and contain most of the power in the signal. To the right of these points the two spectra become markedly different though. The cloudy days demonstrate significantly higher power throughout the 2.7 hour ($f \approx 10^{-4}$ Hz) to 10 sec ($f \approx 10^{-1}$ Hz) band. This indicates significantly higher resource variability on the cloudy and overcast days as expected. Neither spectrum has any prominent spikes in this region though, indicating the random, aperiodic nature of the cloud passage through this area.

The effect of the PV variability can be seen at the neighborhood level through the feeder level SCADA measurements. In Figure 11 the spectra of the feeder real power measurements is plotted in black for the cloudy days and in red for the clear days. The cloudy days demonstrate more power in the 2.7 hour ($f \approx 10^{-4}$ Hz) to 20 sec ($f \approx 5*10^{-2}$ Hz) band than the clear days do.

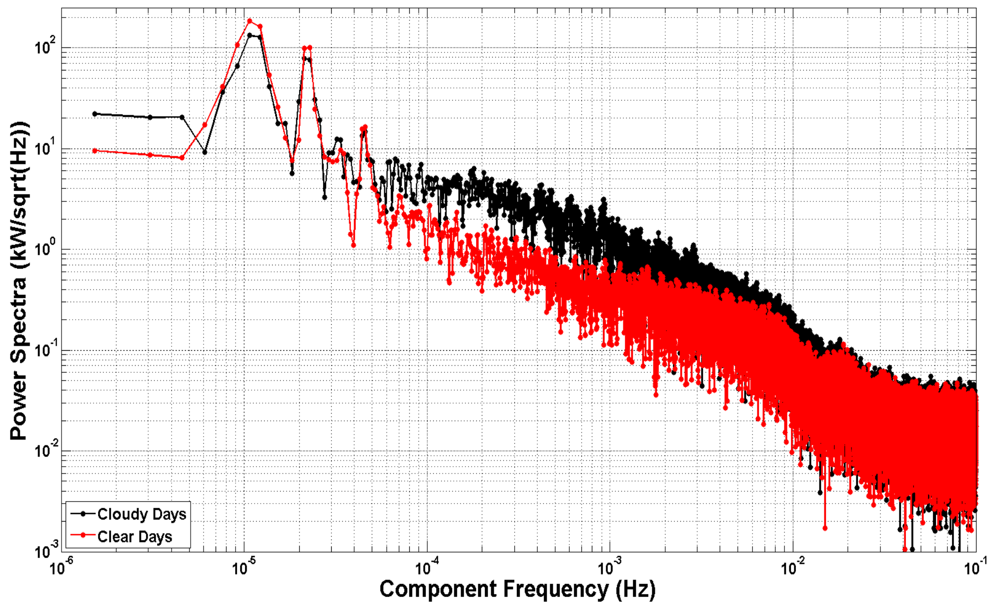


Figure 11: Power spectra of feeder real power flow on clear and cloudy days in early April

Given the small area covered by this neighborhood, less than half a square mile, the irradiance throughout should be highly correlated and non-diverse. With all the PV panels experiencing very similar solar resource, the variability in irradiance should be well correlated with the variability in total power of the neighborhood. Up to a point this is seen in Figure 10 and Figure 11, while the clear (low PV variability) and cloudy (high PV variability) days show drastic difference between the irradiances in Figure 10, these differences are still present in Figure 11 but are not as pronounced.

While the available resource is non-diverse across the neighborhood several other factors are at play which can serve to limit the variability of the PV seen at the system level. The solar panels throughout the area are all roof mounted on the homes and thus do not all have the same orientation, with most ranging from south-east facing to south-west. This diversity in PV panel orientation serves to lessen the impacts of non-diverse global horizontal irradiance as each panel is receiving slightly different incident irradiance. Additionally the load in the neighborhood is being netted against the PV generation before the measurement point and thus PV makes up a smaller percentage of the total signal power, reducing its prominence in the spectra of Figure 11. Despite these smoothing effects the utility is seeing increased variability in power flows at the feeder level as a result of the variability in the solar resource.

The voltages for this April clear and cloudy day data set demonstrate some increased variability but not as pronounced as that of the power flow. The power spectral density plot for the secondary voltage at transformer 8K5 is given in Figure 12.

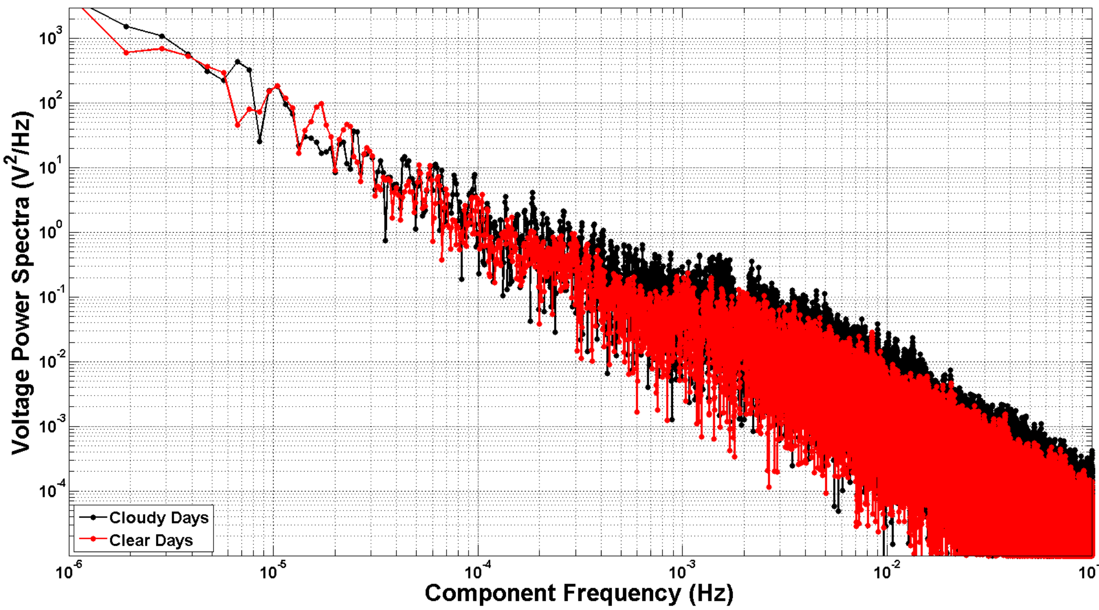


Figure 12: Power spectra of transformer 8K5 secondary voltage on clear and cloudy days

Once again the power spectra for the cloudy days are plotted in black and the clear days are plotted in red. Here the cloudy days demonstrate slightly more variability across the spectra but not nearly as prominent as the differences seen in Figure 10 and Figure 11. In fact, this particular transformer showed the largest differences between clear and cloudy data sets with most of the other metered transformers (total of twelve) seeing nearly identical power spectra for clear and cloudy days. Thus for this circuit, the variability in solar resource is having little effect on the variability in customer voltage. Additionally, the voltages measured at the feeder level showed no appreciable differences in variability. This is most likely because the PV penetration is relatively low (about 18%), the PV is close to the substation and the circuit has been designed with the Anatolia Solar community in mind.

Another effect the variable nature of the solar resource can have is to introduce increased activity of voltage regulation equipment on the circuit. If the solar resource variability is influencing the circuit voltage the switched capacitor banks and load tap changers (LTC) can see an increase in number of operations as they try to regulate the voltages on the circuit in response to passing clouds and other transients. Increased number of operations can shorten their lifespan, thus high penetrations of PV have the potential to reduce the useable life of voltage regulation equipment. To investigate this interaction, the number of LTC tap changes during the daylight hours for each day between June, 7 2012 and June, 30 2013 was compared against the relative variability of the solar resource for that day. These results are presented in the scatter plot of Figure 13.

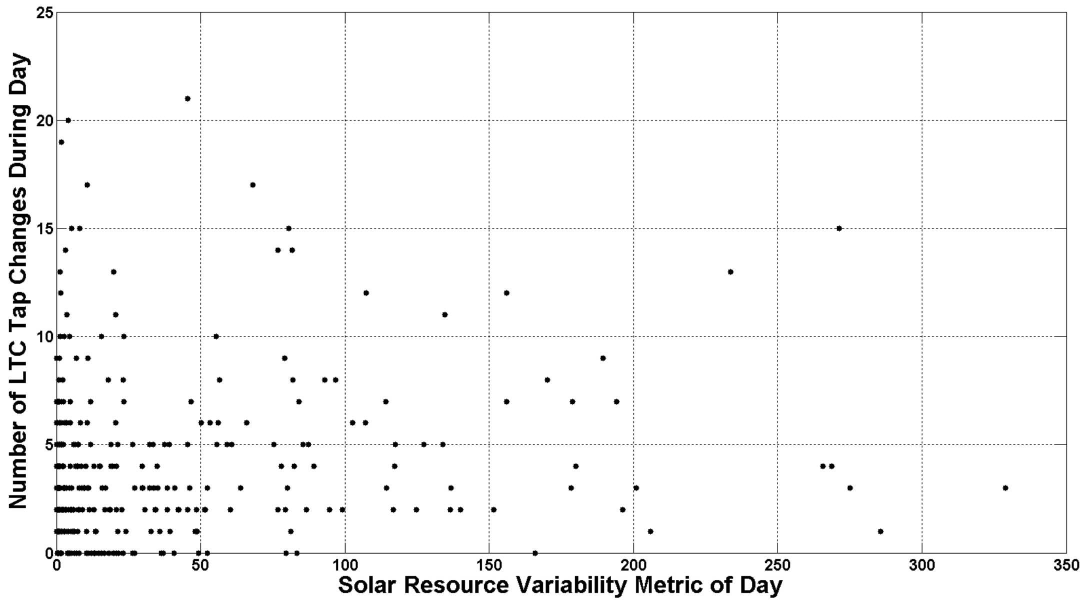


Figure 13: Scatter plot of LTC tap changes as a function of resource variability

In Figure 13, the independent axis corresponds to the relative solar resource variability, computed by taking the variance of the point to point one second changes for the irradiance data collected at the north side of the Anatolia neighborhood, higher numbers here indicate increased variability in the irradiance. The dependant axis corresponds to the number of tap changes on the substation transformer during the daylight hours. Each point in the scatter plot corresponds to one day in the source data set. If the PV was having an influence on the LTC, highly variable days would result in more tap changes producing a strong positive correlation. Figure 13 does not indicate this strong correlation, reinforcing the previous point that the voltages on this circuit are relatively immune to fluctuations in the solar resource for a variety of reasons.

Strategic Objective 3 - Determine how to leverage SMUD's AMI investment to manage a distributed PV/energy storage resource

- *Can a smart meter be used to monitor and control a PV system, and to what extent?*
  During the study, SMUD proved this was possible via a desk top demonstration[8]. SMUD partnered with the Electric Power Research Institute (EPRI) and conducted testing at EPRI and SMUD labs. SMUD leveraged the Smart Energy Protocol (SEP) version 1.1 communications protocol to test the following functions:
    - Setting – On/Off
    - Control – Output Level
    - Control – Cancel Event
    - Read – Current Output Level
    - Read – Historical Output

  When SMUD started this project, SEP 1.1 was the most up to date protocol available and SMUD tested all available functions for PV inverters. Subsequently, SEP 2.0 has been released and contains the

[8] Refer to the task 4.06 deliverable for full documentation of the testing that was run and the results.

additional functions shown in Table 6. SMUD conducted a gap analysis between what monitoring and control functionality SMUD would like and what was available in SEP 2.0 and did not find any gaps. Thus, a smart meter could be used to monitor and control a PV system in every aspect required by SMUD.

Table 6. Additional PV Inverter Control Functions Contained in SEP 2.0.

Read
Voltage
VARs
Power Factor
Current Settings
Event Duration
Event Success
Inverter Fault and Last Gasp Codes
Control
Voltage
VARS
Power Factor
Setting
Automated Control Mode

- *What are the practical challenges associated with using AMI for managing PV?*
  As discussed above, SMUD tested and proved the use of a smart meter to control a PV inverter. Before rolling out this functionality in a real world setting or across the service territory, SMUD needs to consider the following practical challenges:

  - Several functions could compete for AMI network bandwidth – SMUD is considering many different uses of its AMI network such as DR control, communications, electric vehicle charging management and monitoring that will be competing for bandwidth. SMUD conducted a preliminary assessment of the impact of using the network for controlling PV systems. The impact was small, but needs to be assessed against all the other potential uses.
  - Deciding on a level of utility control – SMUD found that all the technology and protocols exist to meet SMUD desired functionality of a PV smart meter interface. However, many of these functions could be done by the inverter autonomously. The California Public Utilities Commission and California Energy Commission have an open proceeding on this, but SMUD needs to decide its preferred path forward.
  - Developing a roll out schedule considering PV industry dynamics – The PV industry is changing rapidly and deploying new technologies and business models that could change how SMUD controls inverters. SMUD needs to regularly track these changes and assess their impact on control of inverters

- *What are the technical requirements for integrating inverters and smart meters, and what codes, standards and reference designs must be developed?*
  When SMUD was awarded this project in late 2009, very little work had been done by industry stakeholders in this area (e.g. equipment vendors, utilities, standards making organizations, etc.). In the four years since then, several efforts have begun to define technical requirements for advanced inverters and their integration with utility communication systems. These efforts include:
  - Smart Energy Protocol (SEP) 2.0 – this is a technical requirements document developed by the ZigBee Alliance that defines a protocol for communication between a smart meter and a PV inverter
  - SunSpec Alliance – A working group of PV industry stakeholders has created open information standards to help facilitate interoperability between different vendor's PV components. As part of this, they created a standard for advanced inverters.
  - CEC/CPUC Candidate DER Capabilities Working Group– In an effort to update California's Rule 21 Distributed Energy Resource interconnection standard, the California Public Utilities Commission (CPUC) and California Energy Commission (CEC) started a working group to define mandatory requirements for PV inverters interconnecting in California. Their work is ongoing, but some mandatory requirements included automated volt/var control, ability to change real power output based upon utility signals and a low voltage/frequency ride through capability.
  - Inverter Manufacturers – Several European countries have been using advanced inverters for several years and vendors are now offering these in the US.
  - OpenADR – The *OpenADR* protocol has been developed in the past decade to serve as a flexible, open protocol for Automated Demand Response (ADR). However, it has several functions that could be leveraged for utility control of inverters.

  As a result of all this work, the project team believes that the required codes, standards and reference designs are already in place.

Strategic Objective 4 - Determine if capacity firming and advanced pricing signals will influence the energy usage behaviors of customers

- *Do the customers who have capacity firming capability (energy storage) behave differently than those who do not?*

Customers with PV and energy storage do not use more total daily energy or draw more peak demand than customers with only PV. Figure 14 shows some minor deviations, but this is likely due to the small sample size of the treatment group (i.e. the RES customers).

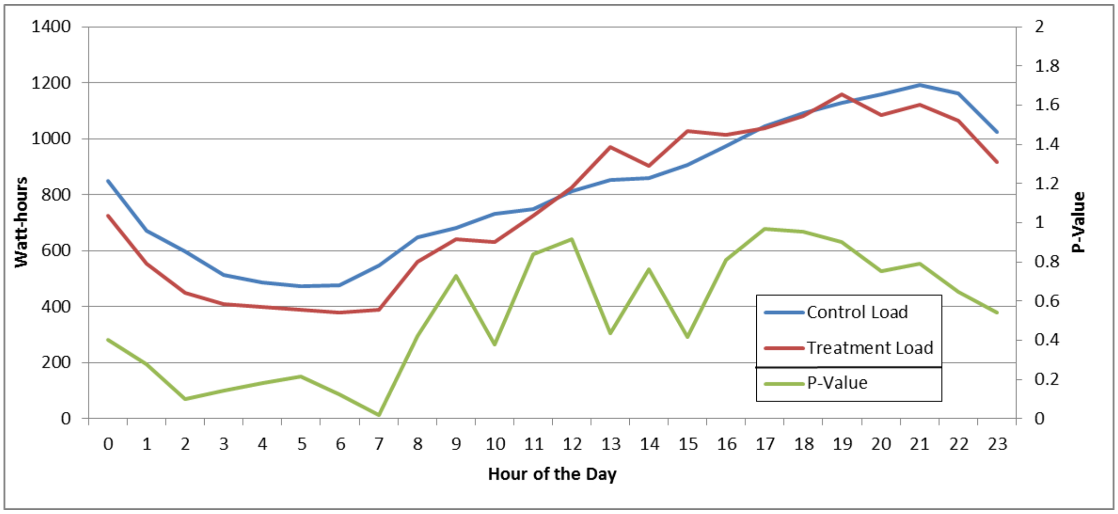


Figure 14. Average Daily Load Shape for Customers with PV and Energy Storage (Treatment Group) versus Customers with only PV (Control Group).

Before comparing meter data between the two groups, Navigant looked into whether the control group is representative of the treatment group. Navigant compared the average PV capacity per home, the proportion of customers leasing their PV, and the distribution of PV capacities (Figure 15). The average PV capacity and the distribution of PV capacities are similar between the two groups.

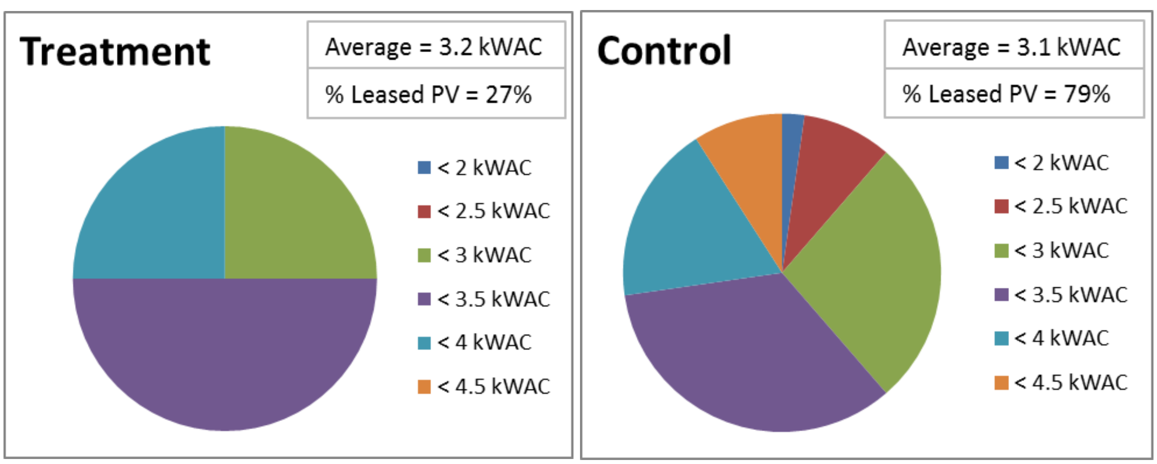


Figure 15. Comparison of Representativeness between the Treatment Group and the Control Group.

Navigant also verified the quality of meter data before reviewing any results. The analysis team ultimately removed ~4% of the data as having possibly erroneous meter reads and/or data gaps.

Navigant also limited the data to May 1st through May 9th, and May16 th through June 1st in order to avoid days in which the units were in smoothing and would likely display erratic loads.

To compare the meter data between the two groups, Navigant tested the average daily energy consumption, the average daily peak demand, and the hourly difference between the two groups. The energy load at 7 am is the only significant difference, although the demand at 2 am is almost significant because this is when the RES units were charged.

Table 7. Statistical Results Comparing Behavioral Differences Between Customers with PV and Energy Storage (Treatment Group) and Customers with Only PV (Control Group).

Statistical Test	Treatment Group Average	Control Group Average	P-Value
Average Daily Energy Consumption	18.5 kW	19.6 kW	0.86
Average Peak Demand	1,506 w	1,535 w	0.90
Average Load at 7am	391 w	547 w	0.06

Given the limited number of sites and the short time-period of interest, the project team cannot confidently propose that this trend will continue, or that this trend has occurred during other time periods or trials. However, the findings fit with the expectations based upon customer feedback received.

- *Do the customers with the RES behave differently than those with CES?*
  The original intent was to recruit residential customers on CES connected transformers to be part of the study by agreeing to have higher resolution monitoring and installing a customer portal. SMUD was not successful in this because of lack of interest, even with monetary incentives. SMUD used a very thorough approach of direct mailing, email and phone calls, and only recruited two customers to participate.

  Given this lack of interest, SMUD can make the assumption that customers connected to a transformer with energy storage would not be aware (or interested) in its presence and likely would not change their behavior because of its presence. The comparisons from the previous question are then valid for this group of customers as well.

- *How does energy storage impact the customer's ability/desire to respond to pricing signals?*
  The intent was to (a) allow customers control of their energy storage units and (b) implement a Critical Peak Price (CPP) rate of $0.75/kWh for 12 hours a year to test customer response to pricing signals. However, SMUS was unable to implement these for the following reasons:
  - SMUD did not allow for customer control of the RES units because the RES appliance interface and GridPoint software required extensive development and the schedule did not permit additional modifications. Further, SMUD did not feel comfortable giving customers control of brand new technology.
  - SMUD Customer and Rates department did not want to place such a small number of customers on a special rate because of the large effort required in doing so and that SMUD was

in the midst of a customer pricing study in which customers had already been placed on this rate.

As a result, SMUD did not test the customer's response to real time pricing signals.

However, SMUD did switch the RES customers from a tiered rate structure to a time of use rate structure that included an off-peak, on-peak and super-peak rate structure. The off-peak rate was ~$0.10/kWh and $0.25/kWh during super-peak. A billing analysis of before and after the rate was implemented found little change in RES customer energy usage during peak times. This suggests that (a) the super-peak rate was not high enough to elicit a response and (b) since the customers could not control the units, they did not respond to changes in rates. This finding was confirmed by a post-demonstration survey of the RES participants in which eight out of nine survey participants said the time of use rate had little to no impact on the way they used energy.

4. Value of PV and Energy Storage

4.1 Framework

In order to assess the business implications of this technology for SMUD and other interested parties, Navigant calculated the value of the distributed energy storage configurations deployed. Navigant also looked at value accruing to both the utility and its customers. Navigant used the Energy Storage Computational Tool (ESCT) that Navigant developed for the DOE's Office of Electricity[9] to calculate the benefits of different energy storage technologies and applications.

The ESCT characterizes energy storage projects by identifying key characteristics of the deployment (i.e. by identifying the location, type of market, owner and type of energy storage asset deployed) and by identifying how that deployment will be used (i.e. the applications it will it be used for). Different applications will lead to various benefits whose monetary value can be quantified using sets of equations and appropriate inputs. Figure 16 depicts the overall methodology that the tool employs to determine the monetary value of an energy storage deployment. The final set of benefits are brought into net present value terms and normalized by power capacity, resulting in $/kW metrics.

[9] More information about the ESCT is available at http://www.smartgrid.gov/recovery_act/program_impacts/energy_storage_computational_tool

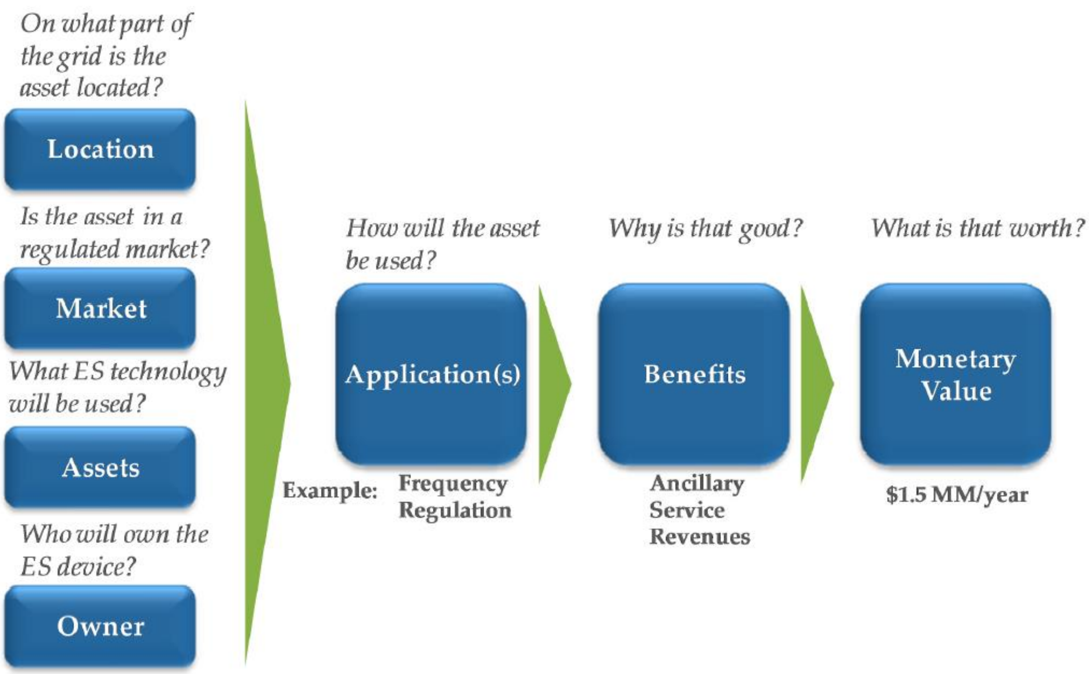


Figure 16. Description of How the ESCT Works

4.2 *Configurations Analyzed*

The first four characteristics that must be defined in the ESCT are location, market, assets and owner. The project team confined the analysis to what was deployed and looked at the three configurations shown in Table 8. The two locations chosen – on the distribution system and at an end user – match the CES and RES locations, respectively. SMUD is in effect a regulated utility, so Navigant used a regulated market. For assets, Navigant used the exact configurations tested. Configurations 1 and 2 match the CES and RES deployments, respectively. SMUD technically did not test configuration 3, but had planned to at the beginning of this study, so Navigant analyzed it.

Table 8. Configurations Analyzed for Benefits

Configuration #	1	2	3
Location	Distribution System	End User	End User
Market	Regulated	Regulated	Regulated
Assets	30 kW/34 kWh Li-Ion Systems	5 kW/7.7 kWh Li-Ion Systems	5 kW/7.7 kWh Li-Ion Systems
Owner	Utility	Utility	End User

Navigant also used data measured and calculated during the study to inform the benefits analysis. This included:

Round Trip Efficiency- In the quarterly data analysis reports, SMUD had been tracking the RES and CES round trip efficiencies. The RES unit efficiencies have been between 80% and 90%, varying strongly with weather. The CES unit efficiencies have been in the mid to upper 80%.
Equipment Lifetime – Since this was only a 1.5 year demonstration, SMUD did not have enough time to observe how the energy storage cells age. Thus, SMUD worked with the equipment vendors to develop estimates of system lifetimes and arrived at 15 years. Note that this might require cell replacement to reach 15 years. However, given that Navigant performed a net present value analysis of the benefits and are using discounted cash flows, the financial difference between at 10 and 15 year life is small.

4.3 Applications

The ESCT framework contains eighteen different applications for energy storage, but Navigant focused on those relevant to SMUD and the configurations SMUD tested. SMUD did not look at applications related to ancillary services because the focus of the study was on functionality that could help integrate high penetrations of DG PV on a feeder and ancillary services are grid level functions.

4.3.1 Configuration 1 – CES

The first configuration represents the CES units tested, but scaled up in number to represent a realistic deployment. The community studied currently has 33 transformers, so Navigant assumed full deployment of CES units across three communities similar to the one studied. Thus, Navigant simulated 100 CES units. Navigant looked at the following applications individually and bundled together:

Electric Energy Time Shift - The Electric Energy Time-shift application involves storing electricity when the price of electricity is low and discharging that electricity when the price of electricity is high. SMUD demonstrated this capability many times during the study and also demonstrated the ability to flexibly schedule the units throughout the year to respond to seasonal changes in power prices, weather, and sunset timings.

Voltage Support - The Voltage Support application involves using energy storage assets to provide distributed or centralized voltage support. Storage is well suited for this application because it is quick to respond, can be sited where it is needed, and can effectively provide voltage support during contingency conditions. Voltage support could be provided by dispatching real or reactive power. In the study, SMUD did not test the unit's reactive power capabilities, but did demonstrate load smoothing with real power dispatch. This could have the effect of improving voltage in the event of severe PV ramping events.

Distribution Upgrade Deferral - Upgrade deferral is the process by which utilities delay the need to replace or enhance equipment within the grid, usually by using a power source or load management to reduce the peak load served by the equipment to below the equipment's rated power. The Distribution Upgrade Deferral application involves installing energy storage in order to delay distribution system upgrades. The value of this application is derived from the fact that storage can be used to provide enough incremental capacity to defer the need for a large 'lumpy' investment in distribution equipment.

4.3.2 Configuration 2 – RES

The second configuration represents the RES units SMUD tested – customer sited systems with utility control. Navigant scaled up the number of units to represent a wide scale deployment by SMUD. The Anatolia neighborhood currently has approximately 300 homes and Navigant assumed one third had an RES unit to arrive at 100 units in one neighborhood. Navigant then looked at three neighborhoods having this level of deployment. Given that the units are owned by the utility, the same applications apply as configuration one. The differences in value will be a function of the performance characteristics of the units and the amount of storage relative to the local electrical system.

4.3.3 Configuration 3 – RES with Customer Ownership

The final configuration is one that SMUD considered testing but ultimately did not pursue because of schedule and budget constraints – customer control of customer sited energy storage systems. Again, Navigant looked at a larger scale deployment – 100 homes in a neighborhood similar to Anatolia. For applications, Navigant focused on things customers would likely do with their units – control their energy bills and enhance power quality. Since SMUD's residential customers (and a majority of residential customers in the US) do not have demand charges, Navigant focused on energy charges.

Time of Use Energy Cost Management - For the Time-of-use (TOU) Energy Cost Management application, energy end users (utility customers) would use energy storage devices to reduce their overall costs for electricity. They would accomplish this by charging the storage during off-peak periods when the electric energy price is low, then discharge the energy during times when on-peak Time of Use (TOU) energy prices apply. SMUD demonstrated this many times during the study by operating the energy storage as a customer would. The 15 RES customers were put on a TOU rate as part of this study and SMUD charged the units during off peak hours and discharge them during Super Peak hours.

Electric Power Reliability - The Electric Service Reliability application involves using energy storage to ensure highly reliable electric service. In the event of a short or extended service disruption, the energy storage can be used to provide power to critical loads. SMUD did not test this function during the demonstration because current grid interconnection rules (IEEE 1547) require distributed generation to trip offline in the event of an outage. However, SMUD received several participant questions about this and has discussed the concept with energy storage equipment vendors, so Navigant analyzed its benefits.

4.4 Benefits

As discussed above, Navigant modeled the benefits of the energy storage configurations SMUD actually deployed. To inform the analysis, Navigant made extensive use of monitored data from the project and forecasts from various departments within SMUD. The following sections describe data Navigant used for the calculations and the resulting benefits.

4.4.1 Common Data Sources

For the analysis, SMUD used data from other planning efforts. Key data includes:

Power Prices: Navigant used hourly price forecasts for the next 15 years as modeled by SMUD's Resource Planning And Pricing Department. In the months outside of super-peak (October through May), the difference between on-peak and off-peak was low – typically \$10/MWh. In the super-peak months, it averages \$16/MWh, but gets as high as \$56/MWh. These relatively low differentials are driven by low natural gas prices that are expected to persist in the near future.

Capacity Prices: SMUD Resource Planning And Pricing Department also provided their capacity price forecasts, shown in Figure 17. Prices are very low now because California has an excess supply of capacity. While they are expected to rise in 2018 because of the need for new capacity, $90/kW-Yr is lower than many other parts of the country.

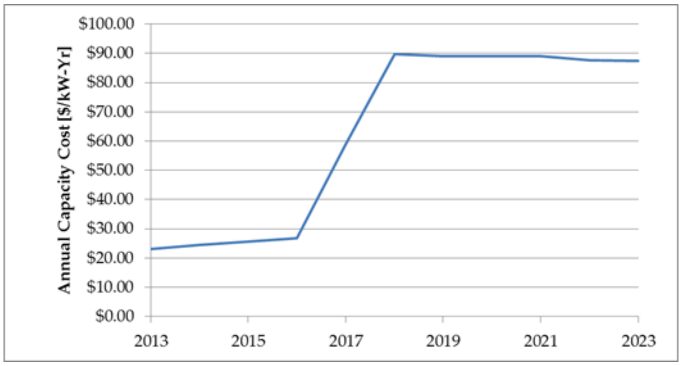


Figure 17. SMUD's Capacity Price Forecast

Deferred Distribution Costs – In 2011, SMUD had a study commissioned to look at various options for different types of energy storage[10]. As part of this study, SMUD distribution engineers looked at feeder needed upgrades and estimated what the required costs and how much energy storage could defer them. SMUD arrived at a likely value of $100/kW-Yr for three years and an upper value of $158/kW-Yr for five years. Refer to the full report for details of the calculations.

Voltage Control Costs – Also as part of 2011 study, SMUD estimated the value of voltage support to be $3/kVAR with an upper value of $8/kVAR. This was based upon the cost of shunt capacitors – the most common technology currently providing voltage support.

Emission Price Forecasts – SMUD's Resource Planning And Pricing Department provided the carbon price forecast shown in Figure 18. It is based upon internal SMUD estimates that account for resource mix, policies and other external variables. Navigant focused on carbon exclusively as SMUD's fossil fleet is entirely natural gas fired, so NOx and SOx emissions are relatively low or negligible.

[10] *Benefits Analysis of Energy Storage: Case Study with the Sacramento Utility Management District*, 2011, EPRI report 1023591

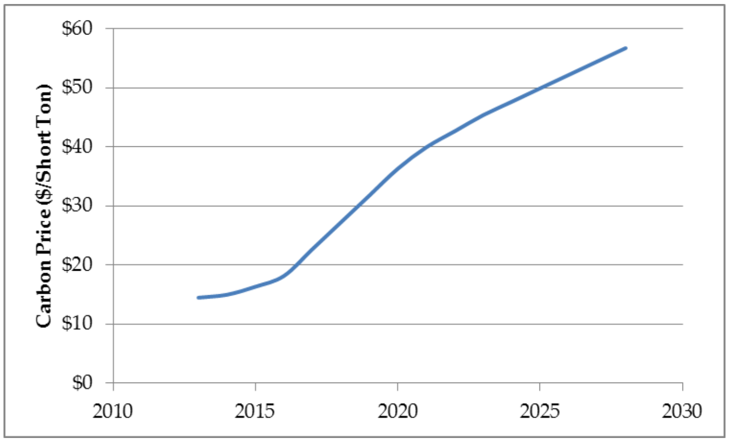


Figure 18. SMUD's Carbon Price Forecast

Distribution System Characteristics – For all of the calculations of impacts to the distribution system, Navigant used data on the neighborhood where SMUD did actual testing. Key characteristics were:

- Approximately two miles of distribution line between substation and neighborhood transformers;
- Peak load of 1.3 MVA based upon the feeder monitoring;
- Voltage of 12.47 kVA; and
- Impedance of 0.245+j0.208 ohms/mile based upon equipment data from SMUD.

Financial Inputs – In order to calculate the net present value of benefits, Navigant used SMUD's current cost of capital – 6.17% as a proxy for the discount rate and a generic 2% assumption for inflation.

4.4.2 Configuration 1 – CES

For this configuration, Navigant analyzed three applications: Electric Energy Time-Shift, Voltage Control and Distribution Upgrade Deferral. These applications result in several different benefit streams and Navigant calculated each benefit as follows:

Reduced Electricity Cost – the calculation Navigant used is: Total Energy Discharged for Energy Time-Shift (MWh) x [Avg. Variable Peak Generation Cost ($/MWh) – Avg. Variable Off-Peak Generation Cost ($/MWh) /Energy Storage Efficiency (%)] and thesource for each variable is :

- Total Energy Discharged for Energy Time Shift – Navigant looked at hourly pricing data and weather patterns and assumed the energy storage units would be used to shift energy from mid-May to mid-October. This comes to 152 days per year. Based upon SMUD's super peak period (4 to 7 PM), Navigant assumed a three hour discharge. Navigant also looked at hourly prices and assumed the units would be charged at night whenever prices were lowest, over a three hour period. Using operating parameters from the study, Navigant assumed the units are charged to 90% State of Charge (SOC) and discharged to 20% SOC. This equates to 23.8kWh of discharge for one unit or 2.38 MWh for the 100 unit fleet.
- Variable Generation Costs – As discussed above, SMUD's Resource Planning And Pricing Department provided hourly power price data. Navigant calculated the average price differential between peak and off-peak prices from mid-May to mid-October and used those.

- ES Efficiency – Navigant used the value of round trip efficiency discussed above based upon measurements from the equipment.

Deferred Generation Capacity – This benefit assumes a utility can monetize capacity savings either through lower capacity payments or offsetting construction of a new peaking facility. Given the size of the configuration relative to a typical peaking plant, Navigant are assuming the former. The calculation Navigant used is Capacity Price ($/kW-Year) ÷ 8760 hours/year x 1000kW/MW x Peak Reduction (MW) x Number of Hours of Peak Reduction (Hours) and the following data sources:

- Capacity Price – Navigant used the data discussed above on capacity price forecasts.
- Peak Reduction – The assumed 100 units have a total discharge capacity of 2.38 MWh and spreading that out over three hours comes to a peak reduction of 0.79 MW.
- Number of Hours of Peak Reduction – Navigant assumed that the discharge for Electric Energy Time Shift is during peak hours, so the total hours is 152 days times three hours per day = 459 hours.

Reduced Electricity Losses – The benefit captures the fact that SMUD is shifting usage to off peak periods and reducing peak load on the feeder. Since losses are proportional to the square of the current, reducing peak load on circuits will result in fewer overall losses. The equation for this calculation is complex and involves several parts. Please refer to the ESCT user's guide[11] for a full description, but Navigant used the measured neighborhood peak load and impedance data from SMUD to calculate the value of this benefit.

Improved Power Quality – This benefit captures the impact of the Voltage Support Application discussed in 4.3.1. The value is calculate by multiplying the energy storage systems reactive power capacity times the capital cost of conventional voltage support discussed in 4.4.1. Note that Navigant assumed the energy storage units could provide Voltage Support either via reactive or real power capabilities. If using real power capabilities (the unit's smoothing function), that would take away from storage capacity used for Electric Energy Time Shift. To assess the magnitude of this, Navigant looked at the average energy storage discharge on high solar volatility days when the units were in smoothing mode (this is discussed above in section 3). Navigant took this average discharge by day and multiplied by the number of high volatility days observed from mid-May to mid-October (the period Navigant is assuming for Electric Energy Time Shift) and subtracted that from the annual discharge from Electric Energy Time Shift. This came to 8 MWh/year less of Electric Energy Time Shift.

Deferred Distribution Investments – The benefit only accrues during the years the investment is deferred and is calculated by:

Benefit = Distribution Capacity Deferred (kVA) x Capital Cost of Deferred Distribution Capacity ($/kVA). For the capacity deferred, Navigant used the output of the 100 energy storage units during Electric Energy Time Shift - .79 MW – and used a simplifying assumption of a power factor of one. Navigant used the distribution capital cost assumptions discussed in 4.4.1.

[11] The user's guide is available at http://www.smartgrid.gov/recovery_act/program_impacts/energy_storage_computational_tool

Reduced Emissions – This benefit captures emissions savings by shifting generation from peaking plants to baseload plants that have presumably lower emissions. This is certainly the case in SMUD's service territory as they do not have any baseload coal resources. The calculation is:

Benefit = Energy Discharged for Energy Time-Shift (MWh) x [Emissions Factor for Generation on the Margin (tons/MWh) – Emissions Factor for Base Generation (tons/MWh)/ Storage System Round-trip Efficiency (%)] x Value of Emissions ($/ton)

SMUD's Resource Planning And Pricing Department provided emissions factors for their on peak and off peak fossil resources and Navigant used the emissions forecast discussed in 4.4.1 above to calculate the value.

Figure 19 shows the resulting value of each of these benefits. It shows the cumulative impact by adding in benefits. The biggest benefit is Deferred Distribution Benefits when using the energy storage for Distribution Upgrade Deferral. SMUD's 2011 value study cited that most of SMUD's distribution system is well built and will likely not need upgrading in the near and mid-term. Thus, the most representative near term value of configuration one is $70/kW-Year.

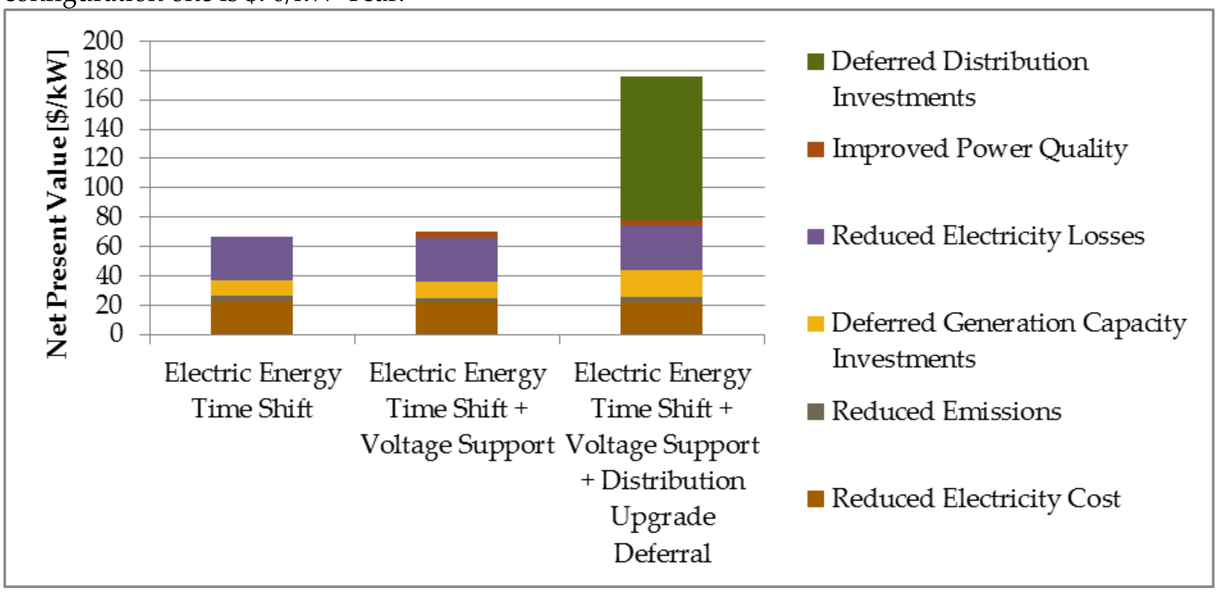


Figure 19. Benefits of Configuration One, Broken Out by Application

4.4.3 Configuration 2 – RES

The applications and benefits for this configuration are the same as configuration one because the utility still owns the asset and would operate them in the same manner. The difference lies is the actual equipment used and the location of deployment. The differences are as follows:

- Navigant simulated 300 units RES units in three neighborhoods instead of 100 CES units spread over three neighborhoods. Using the actual unit size (7.7 kWh capacity) and discharging from 90% to 20% SOC, this comes to a 1.62 MWh/day discharge capability all in one neighborhood.
- Navigant also analyzed a three hour discharge for this configuration, which comes to .54 MW peak.

The results are shown in Figure 20, by application. The results are very similar to configuration one except the magnitude is higher. Some of this is because of normalization by a smaller total system size and some of it is due to more energy storage being installed in one neighborhood. Again, Deferred Distribution Investments is the largest value, but will not likely be applicable to most high penetration solar neighborhoods.

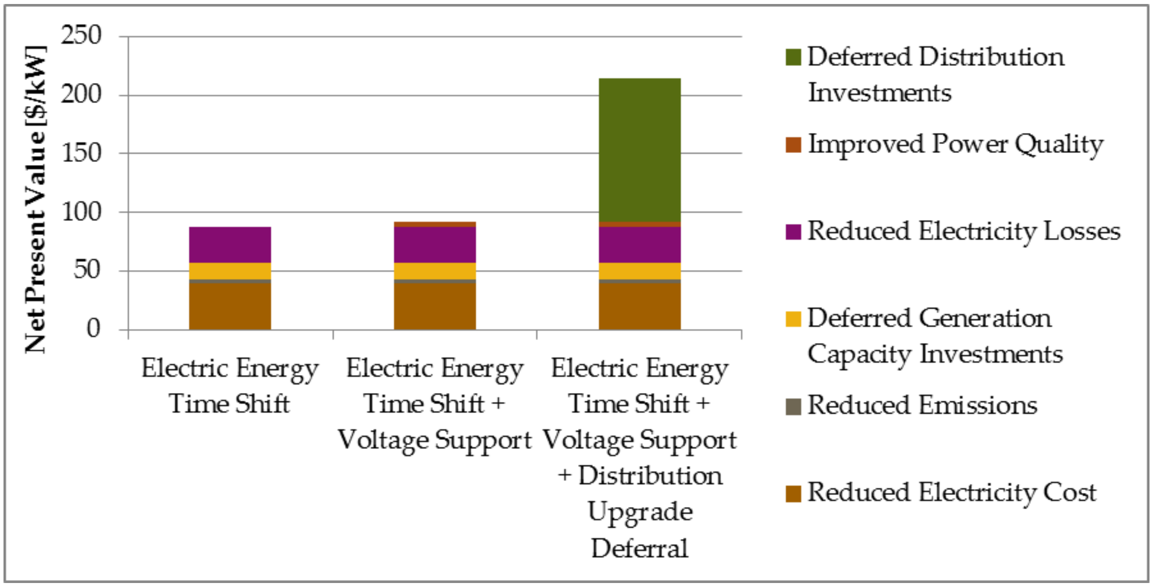


Figure 20. Results of Configuration Two, Broken Out by Application

4.4.4 Configuration 3 – RES with Customer Ownership

For this configuration, Navigant analyzed two applications: Time-of-Use Energy Cost Management and Electric Service Reliability. As discussed above, SMUD did not demonstrate Electric Service Reliability but several customers asked about the capability and the project team understands that equipment vendors might be developing products with the capability. Note that this is the first configuration in which some of the benefits directly accrue to the customer whereas the benefits of configuration one and two only apply to SMUD.

These applications result in several different benefit streams and Navigant calculated each benefit as follows:

Reduced Electricity Costs – As discussed in 4.3.3, the primary benefit for customers owning the energy storage is shifting from high rates to low rates on a time of use rate. In this case, Navigant used the actual rate the RES customers were on - ~$.25/kWh on Super Peak from 4 to 7 PM, ~$.16/kWh on Peak, and ~$.09/kWh off Peak for June through September. Navigant assumed the customers would charge at night and discharge for three hours during Super Peak. The exact calculation is: Benefit = Total Energy Discharged for TOU Energy x [On-Peak Retail Price of Electricity ($/MWh) – Off-Peak Retail Price of Electricity ($/MWh) /Storage System Round-trip Efficiency (%)]. With the capacities of the storage systems, the total discharge per year for one customer would be 0.46 MWh.

Reduced Electricity Losses, Deferred Generation Capacity Investments, Deferred Distribution Investments, and Reduced Emissions – This benefit is calculated in the same manner as discussed in 4.4.2 except that Navigant used 100 RES systems in one neighborhood instead of 100 CES units across three neighborhoods.

Reduced Customer Outages – As discussed in SMUD's previous study of the value of PV[10] , assessing the value customer's place on being able to service critical loads during an outage is difficult. The best information available for residential customers is from a 2009 Lawrence Berkeley National Laboratory (LBNL) study[12]. The LBNL report surveyed many other studies that asked residential customers about their willingness to pay for a service that provided power during utility outages. From this, the LBNL team developed values for different regions of the country and different outage lengths. Please refer to the full report for more detail, but the values ranged from $1.4 to $6.9/kW.

Assessing the value per event is the first part of the calculation. The second piece is calculating an assumed number of events per year. SMUD publishes it's SAIDI and SAIFI statistics online and Navigant used those to develop CAIDI statistics for several different years. Using this data, the calculation is: Benefit = Duration of Power Quality Events Per Year (hours) x Average Un-Served Load (kW) x Value of Service ($/kWh). Navigant ran this calculation using different levels of CAIDI, un-served load and Value of Service that Navigant found.

Figure 21 shows that the largest benefit accrues to the customer and is related to electricity costs savings. The value of reduced outages is very small. This is due to (a) SMUD has a very reliable grid and has fewer outages than many other utilities and (b) the value of service numbers reported are currently low. However, the most recent of these studies was done several years ago and Navigant suspects that as residential customers rely more and more on electronic devices (e.g. tablets, computers, smart phones, etc.) the reported values will go up. Also, if customers were to compare the value to the cost of a portable generator, the value could be several thousands of dollars.

---

[12] Sullivan Et. Al. *Estimated Value of Service Reliability for Electric Utility Customers in the United States*, June 2009, LBNL-2132E

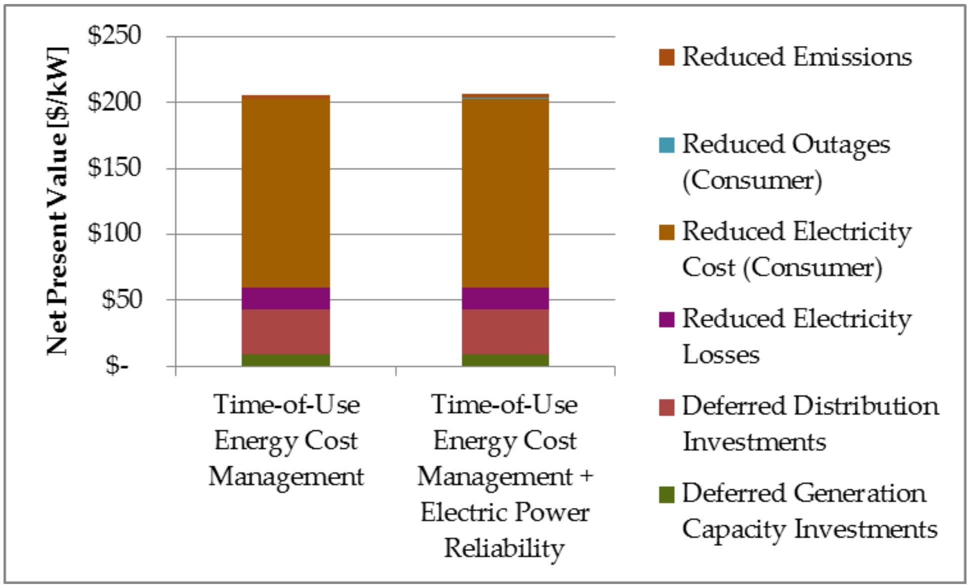


Figure 21. Results of Configuration 3, Broken Out by Application

4.5 *Summary*

Figure 22 compares the value of each configuration. Configuration 2 – SMUD owned but customer sited – has the highest value, but recall most of the value is in deferring distribution upgrades and that is not likely to be applicable in most circumstances in the near term for SMUD. In the next section – strategic implications for SMUD – Navigant examined how value might change under different scenarios of energy prices, capacity prices, etc.

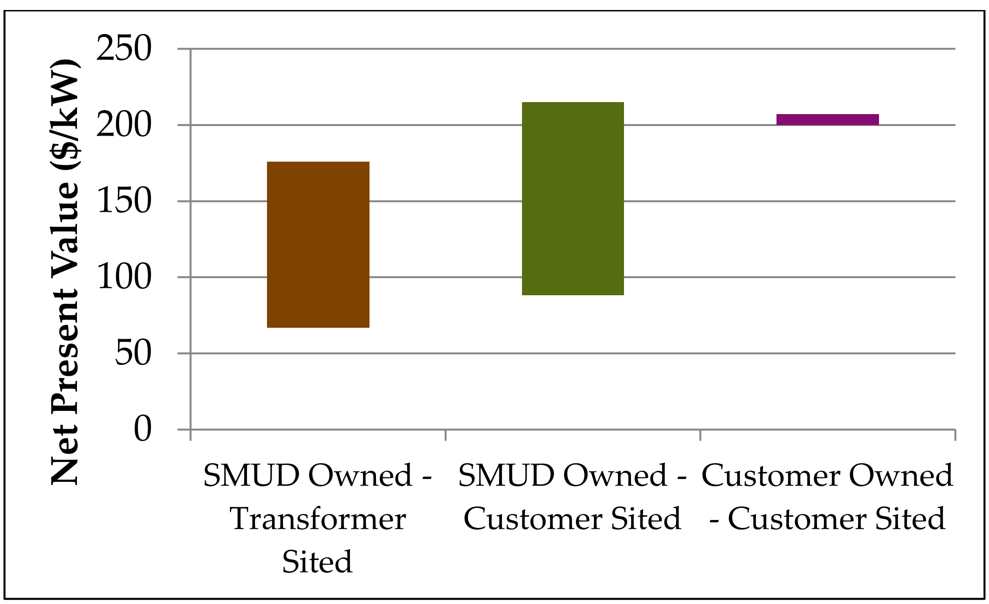


Figure 22. Comparison of Value by Configuration

5. Strategic Implications for SMUD

This section assesses the implications of this project on how SMUD views and manage distributed energy storage in high penetration PV applications. The project's implications on how SMUD may integrate energy storage are discussed first and then how SMUD can use storage to manage high penetrations of distributed PV is discussed.

5.1 *Integrating Energy Storage*

5.1.1 New Business Models Using Distributed Storage

Before developing programs and incentives for distributed energy storage, SMUD must select a business model or models to adopt. As part of the project Navigant tried two models – discussed below – but many more are possible. To date, the energy storage industry has not decided on a common solution, so the intent of this section is to develop a comprehensive list of possible options and discuss the pros and cons of each.

Business Model Elements

Business models to deploy distributed energy storage and PV can take many forms. To compare different ideas, Navigant looked at several different variables, discussed below and summarized in Table 9.

- Location – The energy storage could be located at the customer or SMUD's property. SMUD tried both during the project.
- Owner – During the project, SMUD only demonstrated SMUD ownership, but the customer or a third party could own the system. All three ownership options have been proven out in the distributed PV space.
- Interconnection – An energy storage system could be connected to the PV system or directly to the grid. In the project, the PV systems were already installed, so SMUD did not have the option to connect to PV and storage together as an integrated system.
- Financing – Beyond the system owner buying the equipment up front, SMUD could participate in financing to help support the industry. SMUD could provide a loan for customers or third parties to buy the equipment and to support the technology, the loans could be at subsidized rates. SMUD could also lease the equipment at market or subsidized rates.
- Utility Control – The project was constrained to 100% utility control, but equipment vendors are selling products for 100% customer control as well. A third option could be primarily customer control with occasional control by the utility. This would be similar to air conditioning demand response programs in which a customer controls their air conditioner most of the year, but the utility can either cycle the unit or reduce the temperature set point if needed for an agreed upon compensation.
- Compensation – SMUD could chose to provide compensation to customers or third party system owners to: support a high potential technology that is not yet cost effective, incent certain usage behaviors, or incent customers to install certain monitoring or control equipment. This could be done through an upfront incentive, payment for specific services (such as VAR support) or a fixed, re-

occurring payment that does not vary by usage. All three of these options have parallels in other industries and have been demonstrated commercially.

Table 9. Summary of Distributed Energy Storage and PV Business Model Variables

Business Model Variables					
Location	**Owner**	**Interconnection**	**Financing**	**Utility Control**	**Compensation**
Customer	Utility	Direct to Grid	SMUD Provides Loan	SMUD 100% Controls Asset	Upfront Incentives
Non-Customer	Customer	Direct to PV	SMUD Leases to Customer	Owner 100% Controls Asset	Regular Fixed Payments
	Third Party		SMUD Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
			Customer Owns		Upfront + Payment by Service
			Third Party Owns		

Next, Navigant brainstormed all possible combinations of these variables. During this process, Navigant made several assumptions:

- Customer ownership with 100% utility control doesn't seem likely as the customer would not be engaged. SMUD received feedback from study participants that they did not get a lot of value out of energy storage when they cannot control it.
- If SMUD is leasing or providing a loan for customer's to own energy storage, they are doing so at a subsidized rate and will not also provide upfront incentives. However, they might provide performance based incentives for customers to use the energy storage in a certain way.
- For customer sited systems which SMUD owned, SMUD would want control at least some of the time.

While these assumptions did reduce the number of potential business models, the list of possible models is large at 54 possible business models. A full summary is contained in 7.Appendix C and shows all possible variations of the variables listed in Table 9.

Comparison of Business Models

After developing a comprehensive list of business models for distributed energy storage and PV, Navigant looked at the pros and cons of each model to three stakeholder groups: SMUD, SMUD's customers, and companies involved in PV and energy storage. Navigant broadly defines the last stakeholder group as Third Party and it includes equipment vendors, system integrators, installation contractors and financial entities involved in distributed energy storage and PV.

Each of these stakeholder groups is important to SMUD and SMUD's strategic directives direct it to consider each one in the development of new programs. The tables below look at the pros and cons of each business model variable on each of these groups and 7.Appendix C contains a detailed description of the pros and cons of each business model.

SMUD is currently developing a business case for a solar and storage program. The pros and cons developed in this report will inform the models selected.

Table 10. Pros and Cons of Possible Locations for Distributed Energy Storage (ES) and PV

	SMUD		Customer		Third Party	
Location	Pros	Cons	Pros	Cons	Pros	Cons
Customer	Opens up possibility of customer ownership and this enables more business models	Accessing/repairing equipment will require coordination with customer	Customer can own and control ES to manage energy costs; Customer can feel involved in program	ES equipment operation and maintenance can impact customer; ES equipment could take up space in customer's home; Customer bears safety risk	Third Party has the opportunity to develop direct customer relationships and possibly sell other services	Third Party has to recruit customers to host ES and this could require lots of overhead
Non-Customer	Accessing equipment does not required coordination with customer; If SMUD owns, asset can be moved to maximize value	Does not provide a way to engage customers	Customer not impacted by day to day operations and no customer liability risk for safety issues	ES could be located next to transformer on customer's property; Customer might not feel involved in program	Third Party could install more ES per site; likely lower recruitment costs	No customer interaction to sell other services

Table 11. Pros and Cons of Different Ownership Structures

	SMUD		Customer		Third Party	
Owner	Pros	Cons	Pros	Cons	Pros	Cons
SMUD	SMUD can control equipment; Easy for SMUD to monetize benefits	If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	Customer does not need to maintain for finance equipment	Customer does not feel involved and might not be able to control energy costs	Does not require third party to develop ownership and financing models and this may be difficult in a relatively new industry	No involvement in business model beyond equipment manufacture and installation
Customer	SMUD customers feel engaged in program; SMUD does not need to maintain equipment	Energy storage might not be used in a way that benefits SMUD; SMUD cannot control equipment if needed; Monitoring and control equipment and systems could be required	Customer can control ES to capture benefits and manage energy costs	Customer responsible for maintenance and bears safety liability; Customer might need to finance	Does not require third party to develop ownership and financing models and this may be difficult in a relatively new industry	No involvement in business model beyond equipment manufacture and installation

Third Party	Industry feels engaged in programs; SMUD does not need to maintain equipment	Energy storage might not be used in a way that benefits SMUD; SMUD cannot control equipment if needed; Monitoring and control equipment and systems could be required	Customer not responsible for maintenance; Financing not required	Customer does not feel involved and might not be able to control energy costs	Allows for industry participation beyond just manufacture and installation; Third party can control as needed to earn revenue	In the near term, financing might be difficult to obtain for relatively new industry

Table 12. Pros and Cons of Interconnection Options

	SMUD		Customer		Third Party	
Interconnection	Pros	Cons	Pros	Cons	Pros	Cons
Direct to Grid	Direct connection to grid can allow energy storage to be used for grid support functions; Likely easier to integrate with existing SMUD communications and control systems	Extra equipment or software might be needed to monitor PV system output	ES performance and maintenance not tied to PV system	Customer cannot use ES to store PV system output for later usage; Two inverters might be required and this would be more expensive	ES performance and maintenance not tied to PV system	Two inverters might be required and this would be more expensive
Direct to PV	Likely easier to monitor PV system output	Grid support functions might be more difficult	Customer can use ES to store PV output and dispatch during times of high demand or high electricity costs	Might not be able to earn incentives or payment for grid support functions	PV and ES could be sold as a bundled product with only one inverter	Might not be able to earn incentives or payment for grid support functions

Table 13. Pros and Cons of Financing Options

	SMUD		Customer		Third Party	
Financing	Pros	Cons	Pros	Cons	Pros	Cons
SMUD Provides Loan	SMUD could specify required monitoring, communications and control equipment in order to get a loan	SMUD needs to develop a loan program, which might be a new business area	No upfront costs for ownership	Customer has to take on debt	N/A	N/A
SMUD Leases to customer	SMUD could specify required monitoring, communications and control equipment in order to get a lease	SMUD needs to develop a lease program, which might be a new business area	No upfront costs for ownership	Lease could be viewed as a lien against a home	N/A	N/A
SMUD Owns	SMUD can control the equipment	SMUD must rate base all the equipment and program costs	No upfront costs for ownership	Customer might not be able to control operation	No upfront costs for ownership	Third Party might not be able to control
Customer Owns	SMUD does not take on the equipment costs, but could still get benefits	SMUD might not be able to specify required equipment or operation	Customer can manage as desired	Potentially large upfront costs	N/A	Third Party might not be involved
Third Party Owns	SMUD does not take on the equipment costs, but could still get benefits	SMUD might not be able to specify required equipment or operation	No upfront costs for ownership	Customer might not be able to control operation	Third party can control operation	Third Party must obtain financing

Table 14. Pros and Cons of Different Levels Of Utility Control

	SMUD		Customer		Third Party	
Utility Control	Pros	Cons	Pros	Cons	Pros	Cons
SMUD 100% Controls Asset	SMUD retains control of asset	SMUD does not support third party involvement in operation	Hassle free for customer	Customer cannot manage energy costs	N/A	Third Party cannot operate to maximize their revenue
Owner 100% Controls Asset	SMUD does not need to set up and pay for communications and control systems	SMUD cannot control the ES equipment and it might not be used in a way that benefits SMUD	Customer can manage energy costs	SMUD might not be able to access or control the equipment to help with troubleshooting or control the equipment to provide reliability benefits	Third Party can operate to maximize revenue	N/A
Owner Mostly Controls Asset, with Occasional Utility Control	SMUD would be able to control if needed and specify communications and control equipment	SMUD cannot control the ES equipment all the time and operate it to fully benefit SMUD	Customer can manage energy costs but SMUD can access the equipment to help with troubleshooting or control the equipment to provide reliability benefits	Customer cannot control all the time	Third Party can operate to maximize revenue	Third Party cannot control all the time

Table 15. Pros and Cons of Different Compensations Schemes

	SMUD		Customer		Third Party	
Compensation	Pros	Cons	Pros	Cons	Pros	Cons
Upfront incentives	Simple to implement and does not require monitoring equipment or verification processes	ES might not be used as efficiently as possible	Reduces first cost and no ongoing monitoring required to get performance based incentives	Customer not incented to use system efficiently to manage energy costs	Reduces first cost and no ongoing monitoring required to get performance based incentives	Third Party not incented to use system efficiently to maximize revenue
Regular Fixed Payments	Simple to implement and does not require monitoring equipment or verification processes	ES might not be used as efficiently as possible	Simple program and no ongoing monitoring required to get performance based incentives	Potentially high first costs; Customer not incented to use system efficiently to manage energy costs	Regular payments provide stable revenue stream	Third Party not incented to use system efficiently to maximize revenue; potentially high first costs
Payment by Service	SMUD can design compensation schemes to ensure ES is used effectively and benefits SMUD	Monitoring and communication equipment required to verify performance; Overhead costs required to operate and maintain and program	Customer can operate ES to maximize return on investment and manage energy costs	Potentially high first costs	Third Party can operate ES to maximize revenue	Potentially high first costs

Upfront + Payment by Service	SMUD can design compensation schemes to ensure ES is used effectively and benefits SMUD	Monitoring and communication equipment required to verify performance; Overhead costs required to operate and maintain and program	Reduces first cost and customer can operate ES to maximize return on investment and manage costs	N/A	Reduces first cost and Third Party can operate ES to maximize revenue	N/A

5.1.2 Technology Readiness

SMUD considers many factors when assessing a technology's readiness for inclusion in programs or a wider deployment. This section discusses what was learned from this project in the context of what factors SMUD uses to assess a technology.

- **Fit with Strategic Directives** – Distributed energy storage and PV can help SMUD with the following strategic directives:
    - Empower customers with solutions and options that increase energy efficiency, protect the environment, reduce global warming, and lower the cost to serve its region. (Strategic Directive 1-B)
    - SMUD's rates shall be designed to balance and achieve the following goals
        - Meeting customer energy requirements (Strategic Directive 4)
        - Maintain a high level of customer relations (Strategic Directive 5)
    - Be an environmental leader through community engagement, continuous improvement in pollution prevention, carbon reduction, energy efficiency and conservation (Strategic Directive 7)
    - Meet greenhouse gas reduction goals by 2050 (Strategic Directive 9)
    - Integrate emerging technologies into SMUD's customer offerings (Strategic Directive 18)
- **Benefit to Customers** – This technology can benefit SMUD's customers in several ways:
    - Electric Power Reliability – SMUD did not test the backup power capability of the energy storage units. However, if a product was offered in the future that complied with all relevant regulations, distributed energy storage could be used to provide higher electric reliability to SMUD's customers.
    - Ability to Manage Energy Costs – Distributed energy storage coupled with PV would give customers another tool to manage their energy costs. They could charge the unit during times of low cost and discharge during times of high cost.
    - Overall Rate Reduction – If SMUD can deploy distributed energy storage and capture all the benefits, the value would eventually be passed onto SMUD customers through lower rates.
- **Cost Effectiveness** – As discussed above, the benefits range from a Net Present Value $60 to $200/kW of unit capacity. Contrasting this against current installed costs of several thousands of $/kW suggest they

are not cost effective right now. However, future developments could change and likely improve the cost effectiveness of distributed energy storage systems.

System Cost Declines

The units used in the project cost several thousand dollars per kW. These costs are in line with current distributed energy storage prices reported by EPRI study[13]. The report showed residential scale Li-Ion systems at between $7,500/kW and $13,000/kW and community scale Li-Ion systems at between $1,800/kW and $5,500/kW.

However, the equipment SMUD purchased represented some of the first units from manufacturers, so the costs are not representative of high volume manufacturing prices. Further, recent press releases and statements by battery manufactures indicate goals of cell prices dropping 50% by 2020 because of innovation and scale up. Thus, distributed energy storage prices will likely decline going forward.

Power Market Conditions

As discussed in 4.4.1, a combination of low natural gas prices and abundant supply of capacity in California are creating low market prices for energy and capacity. For the value analysis above, SMUD used most likely projections that foresee these conditions persisting. Future unforeseen jumps in natural gas prices or limiting of capacity supply capacity would significantly change power market conditions and distributed energy storage would have more value. Likewise, higher emissions costs would increase the value of distributed energy storage. Figure 23 and Figure 24 below show the impacts of two future scenarios:

A. Capacity prices rise to the upper end of those shown in Figure 17, carbon prices trade at the high end shown in Figure 18 and power prices double their current levels.
B. Capacity prices rise to current levels in other parts of the country (PJM-ISO is currently at ~$160/kw-Year), carbon prices trade at the high end shown in Figure 18 and power prices triple their current levels.

Scenario A drives up value by ~35% and Scenario B increases value ~90%. These two scenarios illustrate that while distributed energy storage is not cost effective for SMUD now, it may be in the future under certain changes in power market prices.

[13] *Energy Storage System Costs, 2011 Update*, EPRI, February 2012

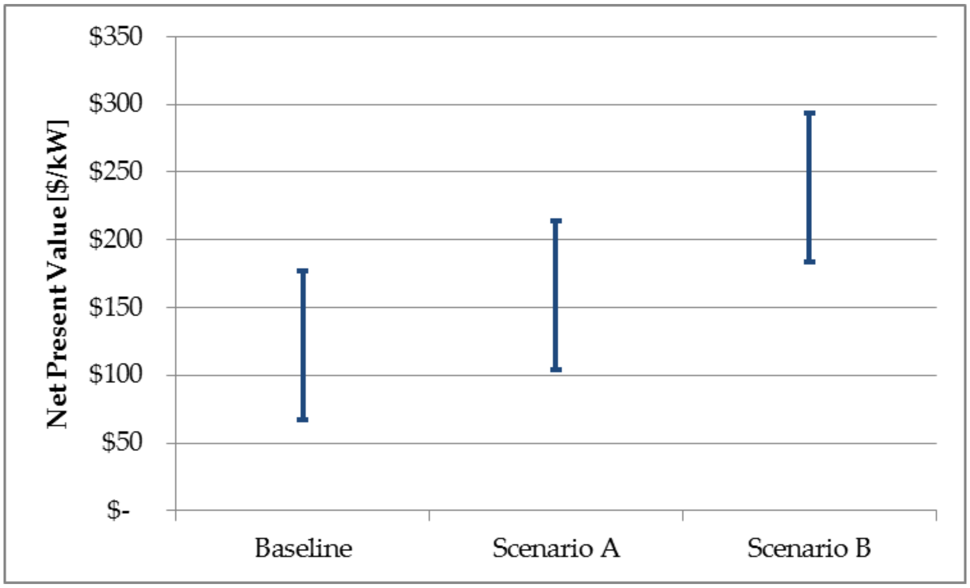


Figure 23. Impact of Scenarios on Value of Configuration One – Community Energy Storage Owned by SMUD

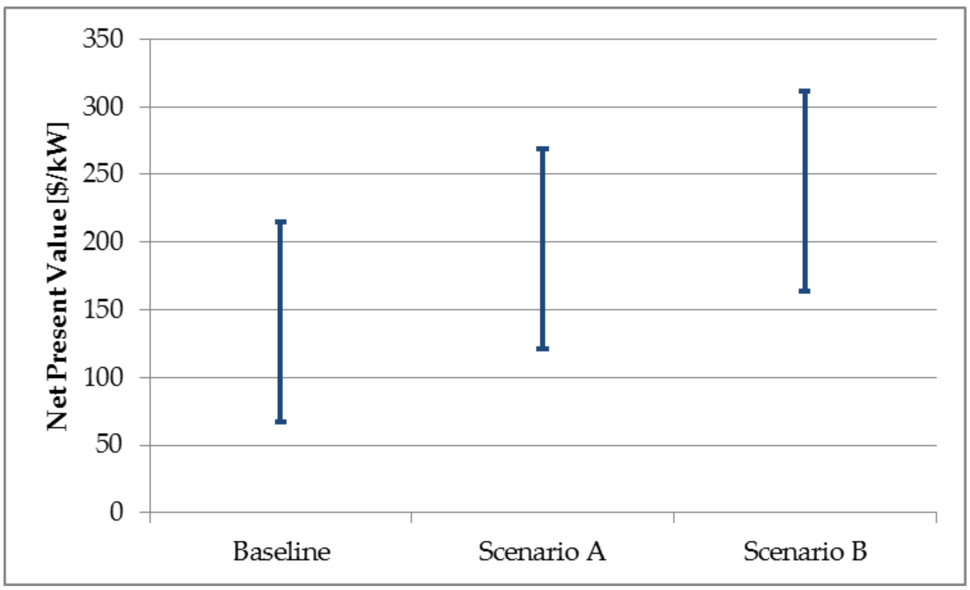


Figure 24. Impact of Scenarios on Configuration Two – Residential Energy Storage Owned by SMUD

The project team did not look at the impact of unforeseen changes in rate structures on configuration three because they vary much slower than power market prices and SMUD's rate structure is undergoing changes (as discussed below in section 5.2.3).

- **Reliability** – Table 16 contains an availability analysis of the test units throughout the test period and Table 17 shows a binning analysis of this data.

•

Table 16. Availability Analysis of RES and CES Unites

Availability							
Unit	Q2 2012	Q3 2012	Q4 2012	Q1 2013	Q2 2013	Q3 2013	Totals
RES1	88%	100%	97%	100%	100%	100%	82%
RES2	88%	64%	88%	100%	100%	44%	93%
RES3	89%	100%	98%	48%	0%	100%	66%
RES4	20%	0%	90%	100%	100%	100%	69%
RES5	89%	37%	88%	100%	100%	100%	84%
RES6	85%	14%	0%	34%	14%	100%	42%
RES7	35%	100%	15%	23%	100%	44%	61%
RES8	87%	100%	99%	100%	100%	44%	95%
RES9	86%	100%	100%	97%	100%	100%	93%
RES10	89%	100%	95%	100%	24%	100%	75%
RES11	34%	47%	0%	34%	0%	100%	35%
RES12	89%	100%	99%	93%	100%	44%	94%
RES13	85%	100%	100%	66%	11%	100%	64%
RES14	7%	100%	100%	32%	98%	44%	57%
RES15	88%	100%	93%	87%	91%	97%	87%
CES 1	100%	74%	100%	50%	45%	100%	80%
CES 2	100%	100%	80%	59%	71%	20%	73%
CES 3	75%	74%	71%	59%	87%	100%	76%

Four of the units had availability over 90%, the other units had low availability for a variety of reasons:

- Component failures;
- Firmware upgrades; and
- Delayed maintenance and troubleshooting because of difficulty coordinating a visit with a site owner or scheduling the right staff from the project team.

In addition, SMUD was very cautious in operating the units and immediately shut them down if a customer experienced any issues. In one instance, SMUD shut down the entire fleet when there was a safety concern with one unit.

Table 17. Binning Analysis of Availability

Total Availability Over Test Period	Count of Units
>90%	4
80% to 90%	4
70% to 80%	3
60% to 70%	4
<60%	3

- **Technical Risk –** Through the demonstration project, SMUD obtained a good understanding of what the technical risks are with distributed energy storage and PV and how to manage them. See the lessons learned section of this study for a longer discussion of the issues encountered.
- **Controls and Integration with Utility Systems –** The unit and fleet level controls were designed specifically for the project and met the needs of this demonstration project. Before integration into SMUD's operating systems, the unit and fleet level controls would have to go through more optimization and testing to meet SMUD's needs.
- **Market Risk –** Market risk is a broad category that includes sub-categories like customer acceptance, viability of business models, matureness of supply chain, presence of trained installation work force and codes/standards to facilitate installation. While a detailed assessment of each of these items is outside the scope of work, SMUD demonstrated and learned several things during this project that can help SMUD assess the market risk.
    - **Customer Acceptance –** Potential business models for deploying distributed energy storage with PV could include customer sited energy storage. During the project, SMUD received lots of interest from Anatolia residents in hosting an energy storage system. This suggests that customer acceptance could be high with the right business model.
    - **Viability of Business Models –** Section 5.1.1 contains a longer discussion of potential business models for distributed energy storage with PV and suggests that no winning business models have developed yet. However, we demonstrated two business models in the project – utility owned, sited and operated, and utility owned, utility operated and customer sited. This suggests that some business models are possible.
    - **Matureness of Supply Chain –** The project partners SilentPower and PowerHub are offering commercial products, as are other vendors. This suggests that a supply chained has developed to support some level of an industry.
    - **Presence of Trained Installation Workforce –** The project team was able to work with local electrical contractors to install the equipment and they did not require any extra training beyond what the technology partners offered in directions. This should not be a barrier to broader adoption.
    - **Codes/Standards –** For safety, SMUD required certification of the RES units to UL 1741, which means a safety certification is in place. The project team then worked with the city of Rancho Cordova to obtain building permits for installation. They did not have an existing process in place and it is suspected most cities do not. The creation of a

template or sample building permitting process for distributed energy storage would help support the industry.

Observations – The technologies SMUD deployed functioned as expected and met all the demonstration project objectives. The project team has identified some areas for further work – cost, reliability and controls and integration - prior to a large scale roll out.

5.2 *Managing High Penetrations of PV*

5.2.1 Managing New and Existing Distribution Networks

High penetrations of distributed PV on a feeder or across a utility's service territory can potentially impact utility operations and require equipment upgrades. Potential issues include:

- Voltage control violations
- Power quality issues (e.g. flicker)
- Reverse power flow
- Increase wear and tear on utility equipment (such as cap banks and LTC's)
- Real and reactive power imbalances
- Frequency issues if a utility cannot "see" large MW's of behind the meter PV
- System wide power supply due to daily morning and evening ramping of PV

The potential impact of high penetration varies significantly and is influenced by feeder design, location of the PV, magnitude of PV installations, load, existing equipment and solar resource variability. While the Anatolia neighborhood has a high penetration of PV (almost 100% of homes have PV), the feeder that serves the neighborhood has several large loads closer to the substation. This effectively reduces the relative penetration of PV. As a result of this and SMUD's standard methods for designing distribution networks, we have not seen any of the issues above[14].

However, the project team demonstrated many functionalities of energy storage that could mitigate the issues if they arise in neighborhoods similar to Anatolia or any other neighborhood. Table 18 shows how these functionalities could help. Thus, while SMUD might not have high penetration PV problems now, SMUD demonstrated several uses of energy storage for mitigation.

[14] *Impact of SolarSmart Subdivisions on SMUD's Distribution System*, July 2009, NREL/TP-550-46093

Table 18. Mapping of Tested Energy Storage Functionality Against Potential High Penetration PV Issues

Tested Functionality	Issue Addressed	Mitigation
Perform Smoothing of Combined PV and Load	Voltage control issues; Increased wear and tear on utility equipment; power quality issues	Energy storage could be added to a community with a high penetration of PV and put in smoothing mode to balance out fluctuations in PV output that can cause these issues
Shifting Load	Reverse power flow; System wide power supply because of ramping	Energy storage could be deployed to charge or discharge to mitigate these issues
Charging or Discharging on Utility Command	Reverse Power Flow	If energy storage were deployed in a community that experienced reverse power flow, SMUD could charge the energy storage to absorb the excess PV production

5.2.2 Leveraging Smart Meter Network

SMUD demonstrated the ability to control a PV inverter via a smart meter and then examined the practical challenges associated with using Advanced Metering Infrastructure (AMI) for managing PV. SMUD first looked at other competing uses for AMI network bandwidth. SMUD then looked at scenarios for PV penetration against the size of SMUD's AMI network. Next, SMUD compared AMI with customer broadband as a means for control. Finally, SMUD looked at some emerging trends that could impact utility control of inverters.

5.2.2.1 Overview of Potential Field and Customer Applications

To put residential PV based communications in the context of the overall uses (current and potential) of the AMI network, it is useful review the many possible applications that may need to leverage the AMI network. A variety of network based applications are likely to require communications throughout the service territory. To understand how PV related applications fit into the picture, it is useful to look at the spectrum of applications that are likely to require communications.

Applications vary in their communications requirements, focus and criticality to SMUD, but they will overlap geographically. Many future applications will be considered *field* communications, and have more traditionally been handled by Distribution Operations in utilities. Others are customer focused or at least require two way communications to the customer AMI meter. All these applications can potentially share network resources—and costs,--to make them individually more cost effective.

The overlap, interactions and priorities of the various applications will need to be reviewed, and some of them need to be understood better before network sharing can safely and effectively be achieved. Some network sharing is already being done with the AMI network (see Table 19 below under Meter Focused in the Application Focus Area column), and these applications will vie for use of the network.

SMUD's *Smart Grid Vision, Strategy and Roadmap*, Phase 1, enumerates many network based applications that are currently being piloted, and others that are envisioned for the future. SMUD has a strategy of using at least 3 distinct SMUD *controlled* field networks for different applications (AMI, Distribution Automation, Substation Automation—note that portions of the these networks use 3rd party carrier circuits, but the networks are still effectively defined and controlled by SMUD for cyber security reasons). SMUD also uses customer provided broadband for some applications (e.g., OpenADR pilot and some Home Area Network (HAN) communications pilots).

Table 19 below shows a partial listing of these various applications, and which of the three networks they are likely to be targeted for. Note that there will likely be Distribution Automation (DA) applications that will need to leverage AMI network, so there is not necessarily a clean functional division to these networks.

This type of analysis, with more detail about the specific network traffic characteristics of each application, can be used in planning and design of future network expansion, or at some point in the future, a wholesale upgrade of network infrastructure. For purposes here, it is assumed that the current Silver Springs Network (SSN) infrastructure will be in place at least through 2020, and that it can be upgraded to accommodate the most important applications for SMUD. One key thing to note is that the Infrastructure Management category (see Utility Area column in Table 19) can come to place a significant burden on network bandwidth, even if only periodically. One type of activity is likely to require firmware updates to enable different functions, which can require a significant amount of network bandwidth, and can impact operational and customer communications if not managed well.

Looking at the spectrum of applications and traffic requirements is one key to effective strategic network planning. Note that the green shaded areas indicate applications that are focused on PV functions, including monitoring and managing residential customer sited PV, but also the potential periodic updates (e.g., for protocol updates or compatibility) as well as for DA centric applications such as voltage stabilization and VAR support. SSN indicates that it should not be a problem from a bandwidth perspective supporting residential PV communications via ZigBee and SEP 2.0.[15] However, this support needs to be considered in the context of other applications that are likely to vie for use of AMI network and the specific timing of each.

If a large number of these applications plan to use the AMI network (e.g., say several DR programs, including HAN communications to smart devices, etc. as well as some storage monitoring applications as well as PV applications), then the analysis should look at all the applications together and make the determination. Table 19 below shows a list of possible applications for the AMI network—and the DA and Substation Automation (SA) networks—based on a review of some material made available by SMUD.

[15] Mentioned in conversation with Obadiah Bartholomy, 9-4-13.

Network	Utility Area	Application Focus Area	Application	Notes
AMI Network: SSN Network 900MHz mesh with AT&T cellular backhaul	**Customer Centric Applications (Primarily Residential)**	Meter focused	Meter data (interval) for billing	These applications are the primary focus of AMI. These are meter-centric applications, and successful execution is necessary for the AMI business case.
			Automated connect/disconnect	
			Meter event notifications (e.g., tamper)	
			Advanced meter data (load research, etc.)	
			Other operational data…	
		HAN focused (DR and EE)	DLC programs (Smart tstat, load switches)	These are focused on HAN communications and leveraging the HAN for DR, EE, and customer commuications
			Smart Appliances	
			Pricing programs	
			Other…	
		PV focused	Monitoring status to provide customer information	These are focused on PV monitoring, management, and being able to provide information to customers
			Remote control/monitoring functions	
			Seasonal and conditionalpolicy management	
		Storage focused	Load shifting, energy storage	Storage monitoring/management and customer communications
			Other…	
		EV focused	Smart Charging (storage, etc.)	EV monitoring/management and customer communications
			Other…	
	Infra-structure Management	Daily/ Continuous	Daily: meter event notifications (network connectivity)	Network, HAN, PV, EV, Storage telemetry and monitoring that is needed on a daily basis
			Network infrastructure status monitoring	
			Status monitoring for apps (HAN, PV, Storage, EV)	
		Periodic (e.g., Firmware Updates)	Meters (900MHz module, Zigbee module, metering chip?) e.g., SEP 1.1 to 2.0 migration.	Periodic maintenance that requires network bandwidth: firmware updates to various network attached functions (e.g., upgrade from SEP 1.1 to 2.0 and beyond)
			Network (wireless access points)	
			HAN (zigbee modules for all HAN equipment, PCTs, smart appliances, etc.)	
			PV (smart inverter control chips)	
			Storage (storage control chips)	
			EV (smart charging control chips)	
	DA Centric Applications	CVR support	End-of Line voltage	Distribution automation functions which leverage information available via the AMI network (e.g., EoL voltage)
		OMS support	Outage detection (last gasp)	
		Power Quality	Inverter control for AC voltage stabilization and dynamic VAR Support (remote vs. local automation): PV and Storage	
DA Network: field radios to SONET backhaul	**Distribution Operations Centric Applications**	Reliability	VVO/CVR/FLISR-- wireless communication network	These are DA functions that leverage field commuications totally independent of the AMI network: these typically use the DA SCADA network infrastructure.
		Efficiency	CVR/VVO	
		Power Quality	Cap bank control and VAR support	
		Equip. health	Monitoring for condition based maintenance	
		etc.	Many other potential applications	
SA Network: frame relay over SONET to sub-stations	**Substation Operations Centric Applications**	Switching, manage-ment, security, safety, etc.	Numerous	These are substation automation functions that require high speed communications and often high bandwidth (e.g., IP security camera) to and from substations.

Table 19. Network centric view of applications required communications throughout SMUD's service territory

5.2.2.2 *Residential Solar: Initial Network Scale Characterization*

Given the context above, SMUD drilled down one level deeper and started to characterize the possible breadth of PV communications by looking at an estimated number of PV endpoints in the future.

Based on initial information on expected solar penetration from SMUD, Navigant has developed the following table of rough estimates of solar penetration for two future time periods. The total numbers were provided by SMUD, and the residential / C&I breakout was reverse engineered from the data in Table 21.

	2020	2030
	MW	MW
Residential	51	250
C&I	299	1,450
Total	**350**	**1,700**

Green indicates initial information provided by SMUD

Table 20. Distributed Solar Penetration Estimates

The MW penetration estimates in Table 20 were used to project the possible number of residential distributed PV endpoints (rooftops) in the same two time periods (see Table 21 below). Three different cases are shown. The Expected case was derived from a potential estimate provided by SMUD of 50K residential rooftops by 2030, with a speculated average capacity of 5kW. Given 51MW of approximate PV, that leads to almost 10,300 rooftops in 2020. To get the high and low estimates, a 40% variation in MW deployed was used, as well as a 20% variance in the average size of a residential PV installation. This yields a high estimate of 18K residential PV rooftops in 2020 that might need to be managed via a network—in this case using the AMI network. This is a lot of rooftops, but only 3% of the 600K AMI metering end-points in 2020.

Note that the percentage of existing AMI column assumes the full population of AMI meters to be 600K AMI meters deployed throughout the service territory.

		2020			2030			
	kW/ House	# roof-tops	MW	% existing AMI	#roof-tops	MW	% existing AMI	Pena-tration Est.
High Est.	4	18,015	72	3.0%	87,500	350	15%	140%
Expected	**5**	**10,294**	**51**	1.7%	**50,000**	**250**	8%	**100%**
Low Est.	6	5,147	31	0.9%	25,000	150	4%	60%

Table 21. Estimated Number of Communication End Points for Residential PV

The 3% of AMI endpoints requiring additional information does not seem that it should be difficult for the existing AMI network infrastructure to handle. However, the characteristics of the required communication are somewhat undetermined at this point, and fundamental questions such as how much intelligence is used locally at the PV installation to make automated decisions, versus how much communication to a central location is required, will drive requirements for bandwidth, latency and other required network characteristics.

5.2.2.3 *Comparison of 900MHz Mesh AMI Network and Consumer Broadband*

The section above shows that the impact to SMUD's AMI network would likely be small. However, control via AMI is not SMUD's only option for controlling PV inverters. In this project, SMUD demonstrated control of energy storage appliances via the customer's broadband connection and broadband provides an alternate communication pathway. To start the analysis of different options, Navigant started with a comparison between the basic attributes of the 900MHz wireless mesh infrastructure (Silver Spring Networks infrastructure) and customer broadband for use in communication to smart inverters.

Table 22. Comparison of SSN AMI Network and Customer Broadband for Inverter Control

Comparison Area	900MHz Mesh Utility AMI Network	Customer Broadband
Bandwidth	Varies by deployment architecture, but is likely asymmetric with *download* (to the home) being faster than *upload*.	Varies by location and service offering, and is typically asymmetric with *download* (to the home) being faster than *upload*. Typical download bandwidths range from 5Mbps to 40Mbps, and upload speeds range from 256Kbps to 10Mbps.
Latency	Varies by deployment architecture, but is likely asymmetric with *download* (to the home) being faster than *upload*. Latency is also likely to be higher than that of typical broadband. Latency is likely to be too long for some fast control functions.	Varies by location and service offering, but can range from 10ms one-way to 100ms or more one way, with the lower end of this range typical for areas with dense broadband connectivity. Note that TCP/IP networks do not guarantee latency. Latency is likely to be too variable for some fast control functions.
Control	Utility maintains control and can prioritize traffic (Quality of Service) within the limits of the technology.	Customer has control over some factors such as bandwidth provision and keeping the home routing equipment turned on. Internet service provider (ISP) has control over other factors such as QoS, bandwidth limiting, and in some cases restricting traffic types.
Cost	Utility bears this. Cost depends on deployment density.	Customer bears: $21 to $50/month for residential service is typical. Inverter traffic would "ride for free."
Location	Deployment can be focused where needed in the utility service territory.	Dependent on customer penetration and service availability from broadband service providers.
Co-existence with Other	Utility controls the applications chosen to use the network (e.g., meter reading, end-of-	Applications from other customers share portions of the network infrastructure, and

Applications	line voltage reading, meter disconnect, etc.) These applications can interfere with one another if network is not designed properly or unexpected circumstances occur on the network.	can impact communications at times of high usage.
Availability of Channel	ISM Band, unlicensed communications can be subject to additional radio interference if other users in the locale choose to use the band. This can reduce available bandwidth and even cause erratic communications in some circumstances.	Service outages can occur from damage to the physical infrastructure due to construction, weather and other issues. Customers can also turn off their in-home routing equipment, causing connectivity to cease. Response time and repair time are not in control of the utility.
Security	Private network is likely a smaller target relative to customer broadband because it is a smaller network, a smaller geographic footprint and has less entry points. Additionally, the utility takes great lengths to ensure cyber security is paramount.	A range of end-end security mechanisms can be applied. Many of these are well developed and mature and in use for services such as on-line banking. The nature of public internet, however, is that malicious actors can be located virtually anywhere and may obtain access to customer targeted traffic.

5.2.2.4 Trends of Interest

The viability of and functionality of utility control of PV inverters will be impacted by two emerging trends – microinverters and third party leasing models. Microinverters could add functionality to control of PV inverters and third party ownership could complicate utility control of inverters if the third party wants to control the PV inverters as well. The discussion below provides an overview of both issues.

Micro-inverters

Microinverters are not a new concept; however, they had a breakthrough year in 2011 and are the most disruptive technology in the industry today. Microinverters are installed on the back of each panel, matching its rated capacity. The main benefit of microinverters is that their use results in an overall higher energy yield because they prevent one panel's failure or degradation from affecting the overall system's energy harvest (as is the case with most string architectures). With microinverters, each panel is effectively individually monitored, thus removing the need for DC cabling. This architecture distributes the overall risk of failure among the number of panels in the installation, and relies on information technology to identify and isolate the problem panel. By contrast, central inverters have a single point of failure, which can lead to longer periods of downtime if that inverter fails. With Multiple Power Point Tracking (MPPT) at the panel level, instead of the string level, microinverters are ideally suited for the residential and small commercial market segments, where a higher risk of shading is possible. The downside of microinverters is that they are typically two to three times more expensive than string inverters and have lower efficiencies (even though they do typically result in a better overall energy harvest).[16]

[16] See "Inverters for Renewable Energy Applications." Research Report, Navigant Research. Q3, 2012. Dexter Gauntlett and Kerry-Ann Adamson, Ph.D., which contains significantly more detail on the solar inverter markets and players.

As if 2013, 38% of residential installations in the US now use microinverters. Approximately 50% of these installations are in California. Microinverters have been used in smaller installations (e.g., 2kW and below) but have been moving up into larger installations. The majority of these installations use detached architecture where the inverters are installed separately during installation; however, the market is moving quickly to fully integrated AC modules.

Whereas string inverters have an 8-10 year lifetime, the lifetime of microinverters is not well understood at this point. Microinverter lifetimes could turn out to be considerably shorter, given that they are positioned on the roof, and subject to daily heating and cooling cycles and other weather elements. This is a significant financial risk for leasing companies, as they can be required to replace this equipment upon failure. This fact is not lost on the investment community who are funding the leasing business. This unknown is slowing down the market adoption of microinverter based installations, and some smaller leasing companies are declining to work with microinverter installations due to fear of the risk exposure.

Residential Third Party Ownership Trends

Another recent phenomenon within the distributed PV market space is the solar lease model, whereby companies such as SunRun, SolarCity, and Sungevity finance solar PV arrays for customers. Such companies own the systems under a power purchase agreement (PPA) or lease, but offer customers fixed rates that typically lock in power costs at just below utility grid power. Since most utility rates go up over time, these solar PV customers – who may also employ net metering – pay less for electricity than those continuing to buy utility power. Contributing to these programs' popularity, many of these companies enable homeowners to install solar for little or no money down when the programs are combined with state incentives. In 2012, for example, the best SunRun deal in Oregon enables qualifying residential customers to pay $6,000 upfront and then receive $6000 in state and federal tax credits, in $1500 increments over the following four years.

These solar leasing options represented more than half the residential solar sales in California in 2011. The market share of solar PV leases is expected to exceed 75% for distributed installations in 2012. Solar leasing options – also known as solar power service agreements – are available in a dozen states and are causing a major shift in the demographics of today's typical solar PV customer. Median income zip codes are actually driving solar adoption. In the last three years in California, two-thirds of home solar installations have been in zip codes with median annual household incomes of less than $85,000 –not the wealthiest areas of the state. Moreover, the number of projects in lower income zip codes (666) was more than double the number in highest income zip codes (309) in 2011.

Almost all of these lease systems are monitored, as they need to perform within a certain performance parameters by contract to meet the PPA or lease. Various mechanisms are used for monitoring, including cellular network connectivity and consumer provided broadband. Customer broadband installations, while leveraging the connectivity paid for separately by the customer, has caused issues in cases where the broadband service is terminated by the customer, or where the in-home router gets unplugged for periods, etc.

Another issue that has plagued leasing companies is the wide range of vendor proprietary protocols needed to access information from the solar installation. A variety of different inverter vendor equipment can be selected by installers sometimes without respect to communication needs that will be required for management. This issue is being addressed by industry standards initiatives such as the SunSpec Alliance described above.

5.2.3 Rate Structures

Early in the project, SMUD held a rates workshop to discuss issues associated with high penetrations of PV, how energy storage might impact rate structures and consumer behavior under different rates structures. One goal of the study was to collect data on energy usage, PV output and usage of energy storage devices to inform rate making processes. However, during the course of the study, SMUD started a rate making process in which they are migrating all customers to time of use rates in the next five years, independent of technology adoption (e.g. PV, energy storage, etc.)[17]. Thus, SMUD will not be pursuing special rates for energy storage customers in the near term. However, customers are free to respond to rates with technology they may adopt and SMUD is considering a deep discount for off peak hours that could benefit customers with energy storage.

In order to incent customers to use customer owned distributed storage in a way that benefits SMUD as a whole, rate design is not an option. Thus, SMUD will have to consider different incentive mechanisms to influence customer behavior. The team brainstormed ideas, some of which SMUD has been studying in other programs. The ideas include:

- Annual program participation incentives allowing for utility control. This would be similar to a demand response program for air conditioners in which the utility pays a residential customer an annual incentive for occasionally being able to control air conditioners.
- While the new rate structures have not been finalized, SMUD is rolling out a Critical Peak Pricing (CPP) program in 2018. A CPP rate typically has a very high energy charge for a limited number of hours per year, but this would likely incent a customer to dispatch their energy storage during this time.
- SMUD could provide event based incentives if customers use energy storage in a certain way. SMUD has experimented with this concept for demand response programs and had very favorable findings.
- To gain insight into what behind the meter energy storage systems are doing, SMUD could provide upfront incentives in return for installing monitoring equipment.
- SMUD could create a residential storage program parallel to its commercial auto DR program in which SMUD enters into contracts with commercial customers to deliver a minimum load during events. A similar program for residential customers would incent them to dispatch energy storage during peak times.

The SMUD team is taking these ideas into consideration for future program design. The key to successful implementation of any of these concepts is customer engagement and a lesson learned from the project suggests that some customers may be interested in new programs. At the outset of the project, SMUD flagged customer recruitment and engagement on the RES deployment as a high risk. However, the program was oversubscribed and customers showed lots of interest. Thus, as SMUD moves forward and considers new ideas for incenting certain behaviors with owners of energy storage SMUD can expect some customers to be highly engaged.

[17] The new rate structures have not been finalized yet, so cannot report on them.

6. Lessons Learned

The project involved many steps and touched several different areas of utility operations. During the project, the project team documented key lessons learned along the way and organized them in the categories shown here.

6.1 *Billing*

- SMUD was not able to implement a CPP rate because Customer/Billing pushed back on the difficulty of doing so for such a small group.
- Putting the RES customers on TOU rates was labor intensive and took longer than expected but once they were on the rate, it was easy to manage.
- As part of their participation in this demonstration of a new application of energy storage, SMUD promised to pay the customer for any excess electricity usage resulting from the testing. SMUD suspects this might have resulted in less behavioral changes than they might normally see.
- New rates or engagement techniques are need for these customers to influence behavior as they think they are using the most energy when their PV systems are producing. This is not the case as SMUD found summer transformer peaks after 7 PM in this neighborhood. One idea might be to send text messages and emails if a customer goes over a certain pre-defined amount of usage in a month.
- At the conclusion of the project, none of the RES customers wanted to stay on the TOU rate. The customers that participated in the study were very low users of electricity to begin with, so they stayed in the lower part of SMUD's tiered rate structure. Switching to a TOU rate resulted in higher bills for some of them.

6.2 *Customer Interaction*

6.2.1 Customer Experience

- The RES customers valued participation and being involved in research effort sponsored by the DOE. They felt part of something big and that made an environmental impact. Many were also interested in trying something new.
- However SMUD did receive some complaints: child tampering that required resets; equipment noise when the RES were operating in smoothing mode; one customer requested SMUD to shut down their RES unit during a party; frequency and duration of visits for troubleshooting; and problems with internet related to an EMF issue between the RES unit and their broadband internet equipment.
- At the beginning of this project, SMUD identified the possibility of taking up too much customer broadband as a risk. This was never a problem during the project and SMUD did not receive any complaints about this.
- The project team established a detailed customer escalation process involving SMUD and Gridpoint, but customers ended up calling the team directly because the project team had established such a strong rapport.

6.2.2 Customer Recruitment

- Marketing and recruitment of CES customers was difficult. SMUD tried direct mailing, emails and phone calls and only signed up two participants. SMUD also offered a $50 gift card and suspect this was not enough to incent participation.
- SMUD had over subscription to host RES. This was due to many things: the project team had a recruiting event in the neighborhood and potential hosts got to speak with vendors and ask questions; SilentPower brought actual unit out so they could see it; and SMUD offered a $500 incentive for participating.
- While SMUD received lots of interest in RES participation, close, frequent contact was required to finally sign RES customers.
- During recruitment, the most common questions received from prospective site hosts were: "Can I buy it, can I control it, does it provide backup power, what benefits does it provide me or SMUD, and how will the installation impact me?" Answers to these questions will be integrated into future demonstration recruitment materials and could inform marketing materials if SMUD were to roll out a program like this.

6.3 *Monitoring and Communications*

- Relying on customer broadband for RES communication and control was not reliable and resulted in interference issues. SMUD used a lot of store and forward technology because SMUD anticipated that this might be an issue. In the future, SMUD should complete a pre-installation internet qualification to reduce instances where internet connectivity and stability interfere with system communication.
- This was SMUD's first time installing high resolution monitoring equipment on underground feeders and thus no design standard existed within SMUD. SMUD experienced several equipment issues with this: during the installation of monitors phasing got mixed up and required re-work, one piece of equipment had power problems, some of the communications equipment wasn't mapped correctly into SMUD's SCADA system, and some re-work required doing an outage which created scheduling difficulties. These findings are already informing how SMUD will do this in the future.
- Connection with the CES units via a cellular modem was lost regularly in the beginning of the project, but improved over the last two years as the cellular provider expanded coverage in the neighborhood. In the future, SMUD will make sure to test the cellular network early on.
- On the CES, SMUD had to move monitoring equipment to not be behind energized equipment. This improved the ease of trouble shooting and maintaining the monitoring equipment.
- The equipment vendors would have preferred direct access to the raw data from the OnDemand RES units. For the project, all raw data was fed to a central location. Though rare, there were instances where access to data was delayed due to a password, firewall or other security measure changes. This creates the potential for delays in accessing critical data for system monitoring or troubleshooting.
- Data transmission through the cellular network and the internet proved reliable with operational units regularly reporting more than 97% of their data points per day. The primary sources of data loss with these units were related to server uptime and RES or CES unit reliability. Software and firmware upgrades to monitoring equipment and storage units throughout the course of the project helped to alleviate these issues. The distribution transformer meters have configurable data reporting rates up to 60 points per second but bandwidth limitations through the cellular channels limit this to about 10 points per second in operation. The reporting rate for this project was set at 1 point per second based on the study parameters and the available resolution of the other collected data sets.

6.4 *Integration*

6.4.1 Storage Devices

- The project team engaged the City of Rancho Cordova Permitting Office early in project. SMUD also pro-actively engaged local fire service regarding the technology as they did not have any experience with it. Both of these steps helped expedite plan check and approvals.
- At the project proposal stage, SMUD had not decided to require the RES to be safety certified by UL. Once this decision was made after reviewing the RES unit design and battery characteristics in detail, this requirement as determined. This added substantial time to the project schedule. In the future, SMUD will allow more time for UL and IEEE compliance testing as this delayed the project.
- Equipment maintenance and trouble-shooting efforts were more complex than the project team expected and the project team did not have a test environment for trouble shooting. This will inform how SMUD does demonstrations in the future.
- The project team learned many lessons about operating and maintaining the CES units: the vendor had cooling fan issues throughout the project; the battery management module had issues; at SMUD's recommendation following deployment, the vendor went away from a lifting bar to a strap for lifting the CES during installation; had to replace whole circuit board because of capacitor issue; SD cards failed during the project; the vendor had to replace a modem; and the vendor had to replace batteries because they went offline for too long and became unrecoverable. All of these findings will inform equipment design and operation for future products.
- The project team also learned many lessons about operating and maintaining the RES units: if voltage goes outside of range for the battery, it drops offline (this is still under investigation); SMUD had EMF interference between an RES unit and customer broadband equipment; the RES vendor had a manufacturing defect that caused SMUD to shut down all the RES units; the vendor had battery management module issues; and child proofing the equipment is necessary as there were kids turning off the equipment. To help with this, Silent Power, the RES vendor, will allow more qualification & testing time for specific battery types. We will expand testing into a broader range of operating conditions to ensure better performance and longevity from the batteries.
- Silent Power will allow more time for lab testing of hardware and software prior to deployment. This testing will include a broader sampling of operating conditions to better reflect real-world operating conditions and include all operational and communication paths to be used by Silent Power and its partners during the actual deployment.
- Silent Power Next-Generation product will allow for remote installation of code updates for all system components including the User Interface, Inverter, Charger and Shunts. This will further reduce in-home service calls and allow all RES units to be kept up to date with the latest software revisions without extensive travel and logistics.

6.4.2 Communications and controls

- The storage scheduling software provided by GridPoint was easy to navigate by SMUD. However, storage unit programming was done event by event and time consuming to use. SMUD could have used more fleet level controls. Also it was not as user configurable like other operations tools.

- The project team did not have enough monitoring when something broke or malfunctioned. This would have reduced the trouble shooting time.
- The project team could have used a more definitive register map for error codes. SMUUD received a large volume of error codes from the storage equipment and control systems, and this sometimes was a distraction.

6.5 Data Management and Analysis

- 10 second resolution was required to see the effects of smoothing. They could not be seen with five minute data.
- Spreadsheet tools were not adequate in handling sub-one minute data. The project team needed to develop database tools.
- The lack of time synching between data measurements was a time consuming issue to deal with. However, the project team was using equipment that was already installed (e.g., SCADA), so the project teamcould not change the time synching.
- Because the project team was integrating several sources of data and some were legacy, the project team did not have a single data repository for all the data. This might have sped up the analysis.
- The variety of high resolution data sources on the Anatolia circuit generated an immense about data over the study period of this project. The integration of metering from several different partners also resulted in a variety of data storage formats and transmission methods. These ranged from point-by-point one second data at the distribution transformer level to 5 and 15 minute resolution data collected at the households and forwarded to data concentrators on an hourly or daily basis. These varied sources resulted in several issues related to processing as sources from differing metering location types generally did not use common formats, requiring a large amount of post processing. Most of this was unavoidable however due the varied nature of measurement quantities and locations.

7. Recommendations for Further Study

During the course of the study, the project team noted several items for further study. At the end of the project, they developed several more ideas for consideration. This section reviews each idea.

- Advanced control and communications architectures integrating the solar measurement locations with the battery systems and/or the PV inverters to provide firming.
- System modeling activities exploring the impacts of increased PV deployments and benefits of larger amounts of deployed RES and CES units. What amount of battery storage is required to produce the desired benefits?
- Integration of the high resolution measurement data with distribution modeling packages to assist with system identification, improved time series load modeling and better weather / irradiance modeling.
- Continued analysis of the data sets collected on this project. To this point a large amount of work remains to fully process the large amount of measurement data which was collected over the course of the project.
- Implement utility control of advanced inverters via AMI. The concept was explored in task 4.06 and the project team thinks the next step is pilot testing.
- Deploy customer controlled storage to further explore customer behavior and technology impacts.
- Use findings from this study on current smoothing algorithm to develop and deploy new ones.
- Deploy storage at feeder/substation to contrast results for load shifting and smoothing with deployment at transformer and customer's homes.
- Deploy storage devices that can deploy four quadrant control for voltage and power factor management.
- Develop a white paper on how to do grid interconnected storage and have the device serve as back-up power for the customer.
- Look at a business model of swapping out batteries over time, but keeping appliance in the same place. This could be a way of extending equipment lifetime by swapping out degraded cells.
- Deploy rate structures that incent customers to use energy storage that benefits the utility and customers.
- Implement reverse power flow (e.g. backfeed) prevention at the CES. A mode could be designed in which the unit charges when it senses backfeed. Research would be needed on typical backfeed levels in order to size the energy storage correctly.
- Implement islanding capabilities with CES units in order to provide customer uninterrupted utility service. This would likely require additional equipment beyond what was tested in the project, but could add value to customers.
- Deploy more capabilities for remote shutdown and restart of the CES and RES units. This capability would have saved the project team considerable time and effort in the study.
- Conduct research on what form factor and location of RES units would be most appealing to residential customers.

Appendix A. Final Testing Results

Summary of Data Collection

We deployed high resolution monitoring throughout the neighborhood's electrical system, as shown in Figure 25. This allowed us to establish a baseline of the neighborhood and assess the impact of a high penetration of PV and the impact of energy storage. This appendix reviews the key testing metrics we tracked.

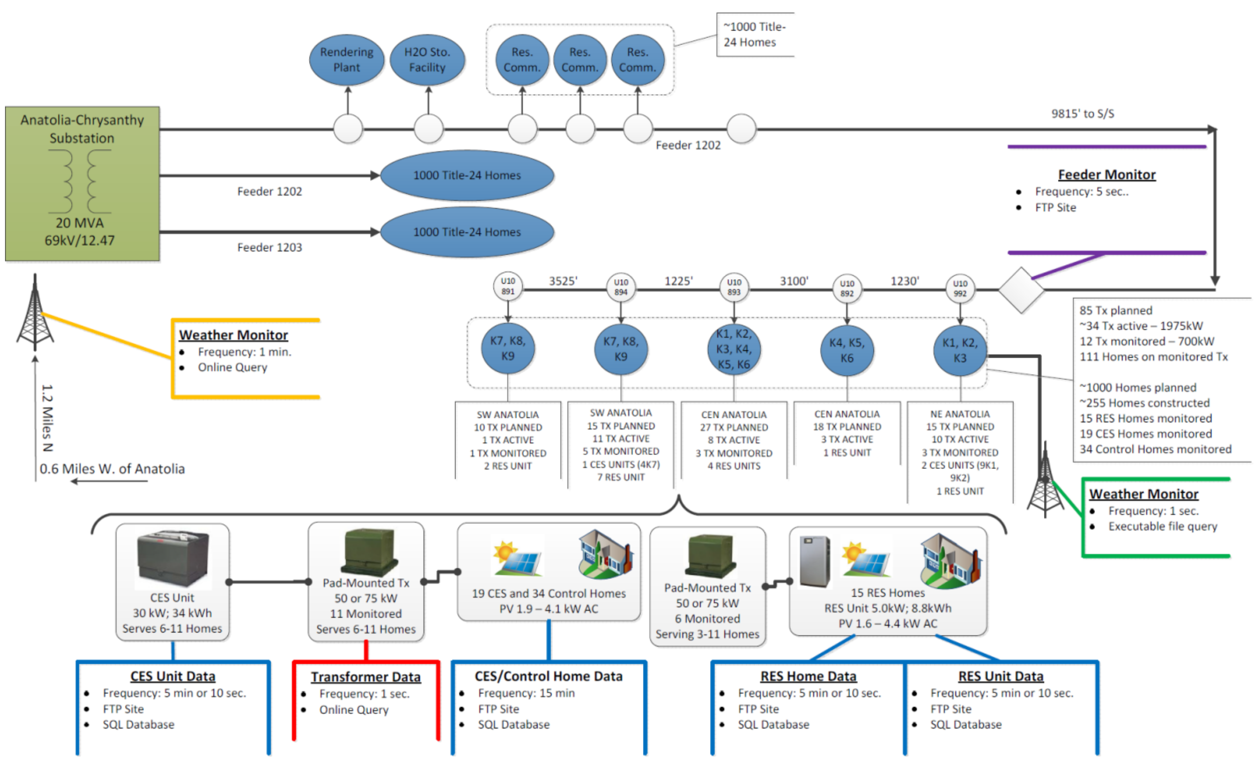


Figure 25. Diagram of Monitoring Plan

Distribution Monitoring

Most of the monitoring equipment we used was off the shelf, but twelve distribution transformers were instrumented with data collection hardware provided by NREL. Transformer metering was deployed in order cover all three of the CES transformers, six transformers with RES attached (covering 10 RES units) and three baseline transformers. These units collect one second voltage, current, power, power factor and temperature measurements and transmit the data out in real-time to servers located at NREL where it is archived and made available to project team members for data analysis.

The basic system architecture is given in Figure 26. Each meter collects data from its location and transmits the data over the Internet back to the data concentrator. The data concentrator collates the multiple incoming data streams, producing one large data stream containing all of the information from the various measurement points. The concentrator data stream is then passed to the data historian. The data historian is responsible for maintaining and updating the database that stores all of the received measurements. The historian also acts as the data hub for other applications, including various visualization applications, data processing, modeling inputs, and data retrieval tools. The data visualization applications present live and historic data in a variety of informative displays. Depending on the number of fielded meters and their data rates, hardware requirements, and reliability concerns, the concentrator, historian, and visualization applications may be hosted on one or multiple servers.

Data Collection and Storage

All of the collected data was eventually concentrated at an FTP site hosted by NREL. This site was available to all project partners for data processing and analysis tasks. Due to the varied nature of collected data sets all data was stored on this site in its native form with little preprocessing to standardize structures. All of these raw data sets are available in comma separated variable or excel spreadsheet format. Participating customer, RES, and CES data sets are uploaded daily by scripts running at Gridpoint and NREL. Anonymous home data collected by Sunpower is uploaded on a monthly basis. Weather, irradiance and distribution transformer measurement data is periodically uploaded by NREL using a series of scripts which process the raw binary data stored internally. The SMUD SCADA measurements were periodically uploaded by SMUD personnel. Several additional scripts and programs were developed specifically to process and analyze the large volume of data stored on the FTP site.

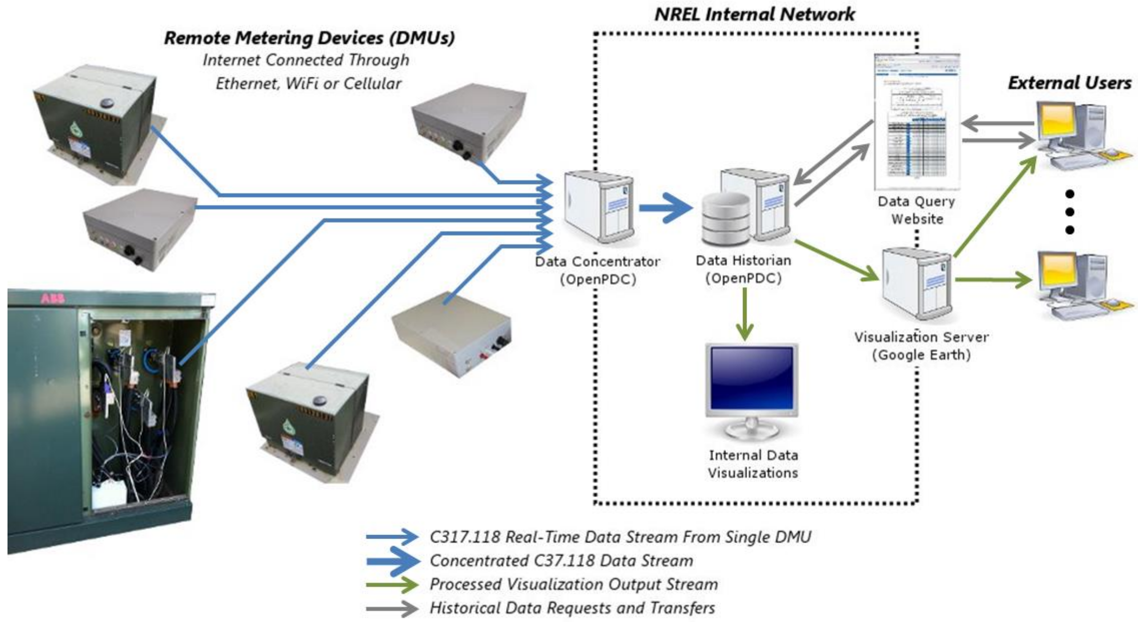


Figure 26: Distribution transformer data collection network architecture

The individual meters are outfitted with cellular modems and communicate with the data collection servers over the Internet using the IEEE C37.118 protocol[18]. When a connection is established, configuration information is exchanged and then data transmission begins. Each measurement set is packaged into a data frame, time-stamped, and transmitted to the data concentrator on a point-by-point basis.

The data concentrator maintains active connections to all of the fielded measurement devices. It also collates the incoming data frames by putting the measurements from the same time point into one augmented frame containing all of the measured values from that timestamp. In the system architecture of Figure 26, this combined data stream is then forwarded to the historian using the same C37.118 protocol for archival. The server side software for both the concentrator and historian is provided by the OpenPDC[19] package which handles the communications, data archival and provides an open source platform for integration of the data retrieval and visualization applications.

A.1 Operating Scenarios Run

During the project, we ran many different operating scenarios that looked at variables of energy storage system operating mode, time of day, time of year, rate structure and solar insolation levels. The total number of tests run is shown in Table 23 and Table 24. Refer to the Monitoring and Testing Plan for details of the testing plan.

[18] "*C37.118.2-2011 - IEEE Standard for Synchrophasor Data Transfer for Power Systems*", Dec 28 2011

[19] "*OpenPDC – Open Source Phasor Data Concentrator*", http://openpdc.codeplex.com/

Table 23. RES Unit Testing Log

	Number of Tests Run			
Unit	Firming	Predictive Load Shifting	Custom Load Shifting	Load Shirfting by Price
RES1	150	90	140	24
RES2	165	91	143	25
RES3	98	83	66	24
RES4	108	43	112	7
RES5	140	74	116	17
RES6	70	33	28	25
RES7	71	35	70	20
RES8	159	90	138	24
RES9	145	90	138	24
RES10	120	84	70	24
RES11	36	34	39	17
RES12	151	91	130	30
RES13	98	79	55	17
RES14	83	56	98	7
RES15	143	88	134	24
Total	**1737**	**1061**	**1477**	**309**

Table 24. CES Unit Testing Log

	# of Tests Run	
CES Unit #	Firming	Load Shifting
1	121	258
2	110	216
3	83	245
Total	314	719

A.2 Amount of Load Shifted

During the project, SMUD ran several types of load shifting – optimal dispatch for SMUD, to optimal dispatch for the customer and dispatch via a predictive algorithm. The project team tracked the total amount of load shifted over the testing period and Figure 27 shows the results, by unit. Some units had a low about of load shifted, but that was due to their low down time, as shown by the availability data.

Figure 27. Total Amount of Load Shifted During Test Period, by Unit

Unit	kWh of Load Shifted	Availability
RES 1	1,025	82%
RES 2	930	93%
RES 3	509	66%
RES 4	543	69%
RES 5	660	84%
RES 6	183	42%
RES 7	493	61%
RES 8	751	95%
RES 9	667	93%
RES 10	471	75%
RES 11	154	35%
RES 12	833	94%
RES 13	334	64%
RES 14	758	57%
RES 15	1,010	87%
CES 1	3,848	80%
CES 2	3,468	73%
CES 3	2,695	76%

A.3 Battery Cycling

Table 25 summarizes the number of cycles run for smoothing. The units with a low number of cycles correspond to those units with low availability. Refer to the Q4 2012 data report for a more in depth analysis of the smoothing testing done and its effectiveness.

Table 25. Summary of Cycling for Smoothing Testing

RES Unit	Number of Cycles	Total Hours of Smoothing Testing	Average Cycles per Hour
RES 1	7,846	718	10.9
RES 2	4,274	493	8.7
RES 3	7,790	552	14.1
RES 4	617	102	6.0
RES 5	4,030	263	15.3
RES 6	5,833	227	25.7
RES 7	556	130	4.3
RES 8	6,272	566	11.1
RES 9	6,504	597	10.9
RES 10	9,500	615	15.4
RES 11	625	66	9.5
RES 12	7,586	457	16.6
RES 13	12,064	566	21.3
RES 14	6,587	535	12.3
RES 15	7,237	580	12.5
CES 1	12,860	1,006	12.8
CES 2	14,427	871	16.6
CES 3	14,265	874	16.3

A.4 Battery Efficiency

The project team tracked unit roundtrip efficiency in two ways throughout the project. The first was spot calculations throughout the project. Units were chosen s that had good availability and days which the units had a full charge and discharge. However, as shown in Table 26 and Table 27, a consistent trend in how efficiency changed with time was not seen.

Table 26. Sampling of RES Round Trip Efficiency

Unit	5/25/3013	1/25/2013	11/1/2012	7/4/2012	6/15/2012
RES 2	91%	90%	84%	83%	82%
RES 3	N/A	86%	81%	83%	85%
RES 5	87%	87%	80%	79%	83%

Table 27. Sampling of CES Round Trip Efficiency

Unit	5/25/2013	3/3/2013	11/2/2012
CES 1	82%	88%	85%
CES 2	86%	85%	86%

Second, the project team did a more in depth statistical analysis over a longer time period. The result is shown in Figure 28 and Figure 29 below. A total of 27 days were chosen for the RES data and 24 days for the CES data based on data quality, data availability, and battery operating scenario. These days were intentionally grouped throughout six weeks in order to use continuous logged data. The gap in data is due to a several month period in which the units mostly ran in firming mode. The figure shows that there is great variability in the performance of each battery.

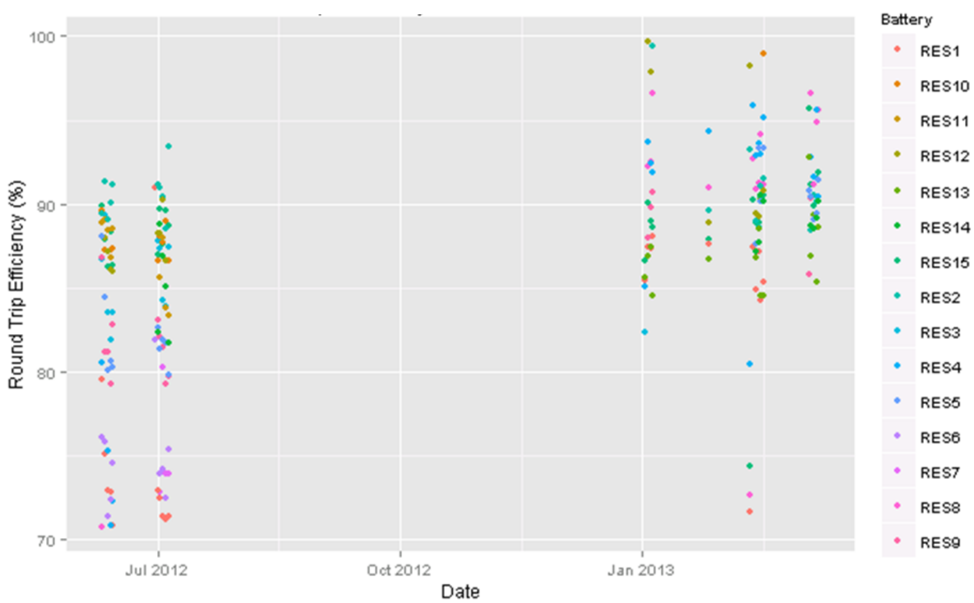


Figure 28. RES System Efficiency Over Time

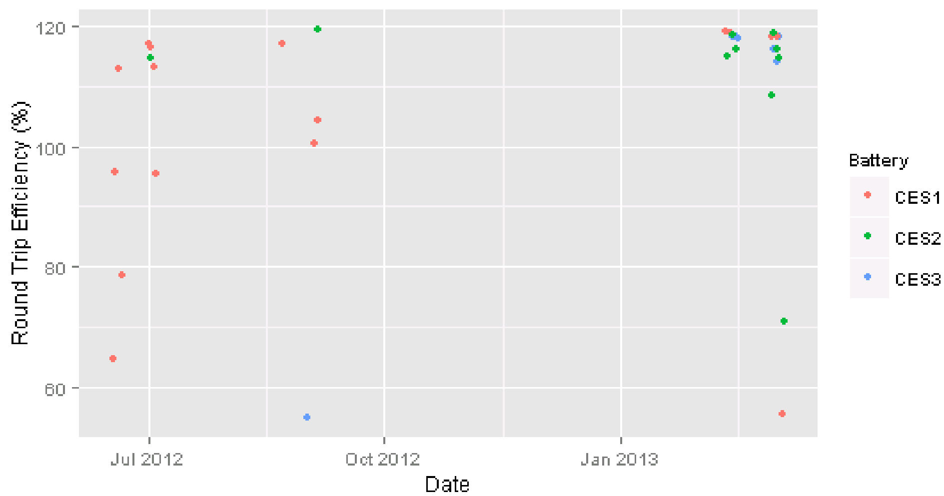


Figure 29. CES System Efficiency Over Time

From these two sets of analysis, the project team cannot draw any conclusions but this is not unexpected. The testing period was short compared to the typical lifetime of an energy storage unit (potentially 10+ years), so significant changes in efficiency might not be seen.

A.5 Solar Resource

During the course of the test period, the project team collected one minute solar insolation and weather data at a weather station in the neighborhood. Throughout the project, weather data was analyzed to characterize weather patterns and understand the variability in solar insolation.

To quantify the number of variable and sunny days, the project team leveraged a parameter that provides a pragmatic measure of short term variability. The parameter is calculated by first normalizing the measured global horizontal irradiation (GHI) by the output of a GHI clear sky model. In general, clear sky models estimate the terrestrial solar radiation under a cloudless sky as a function of the solar elevation angle, site altitude, aerosol concentration, water vapor, and various atmospheric conditions (Reno, Hansen, & Stein, 2012).[20] After normalizing the GHI values in this way, the result is known as the clear sky index. This index is useful because it captures the variability in solar resource that stems from cloud cover or other interference with direct sunlight but ignores that natural seasonal and daily variability of solar irradiation. Finally, the mean index change from one time interval to the next is calculated for each day. This parameter captures the mean expected change in resource likely to occur from one sampling interval to the next and is therefore a suitable measure of the type of short-term variability that we seek to quantify in this study (Perez, Kivalov, Schlemmer, Hemker Jr., & Hoff,

[20] In this analysis a modified Berger–Duffie (BD) model (1979) was used; the coefficient was adjusted so that the model better represented the local GHI in Sacramento on a clear day. The extraterrestrial radiation parameter was calculated using the following equation: $I_0 = 1367.7 \times \left(1 + 0.033 \times \cos\left(\frac{2\pi}{365} \times DOY\right)\right)$ (Reno, Hansen, & Stein, 2012)

2011). Three levels of variability – high, medium and low – were chosen based upon correlations between visual observations of insolation patterns and the corresponding parameter value. A parameter value of less than 0.0078 typically represented a sunny day, as shown in Figure 30. A day scoring higher than 0.028 typically has frequent, large changes in GHI, as shown in Figure 31. Days between 0.028 and 0.0078 were categorized as medium.

Figure 32 summarizes daily insolation variability over the course of the testing period, from April, 2013 to September, 2013. 47% of days were low variability, 38% were medium variability and 16% had a high level of variability. These results aligned with the expectations of weather patterns in Sacramento.

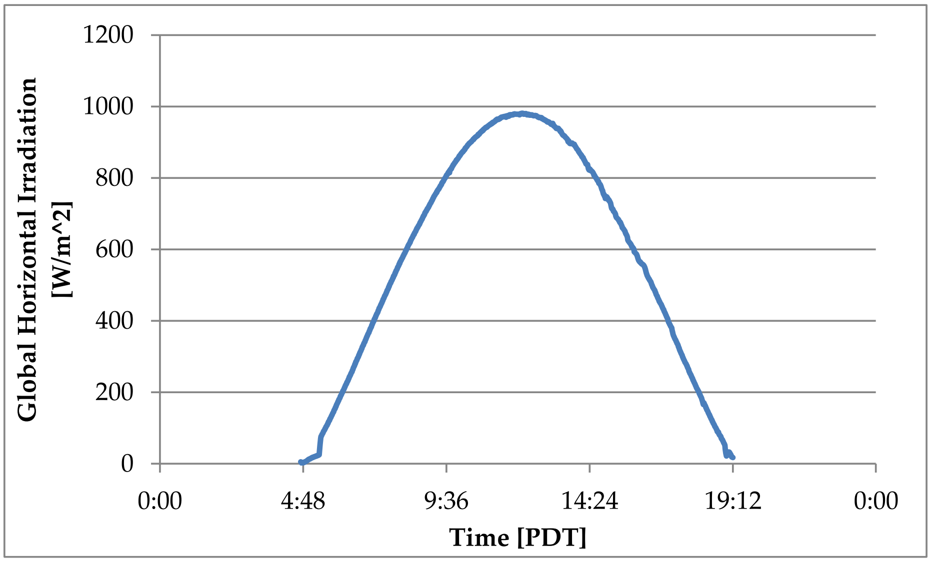


Figure 30. Typical Sunny Day (June, 13 2012)

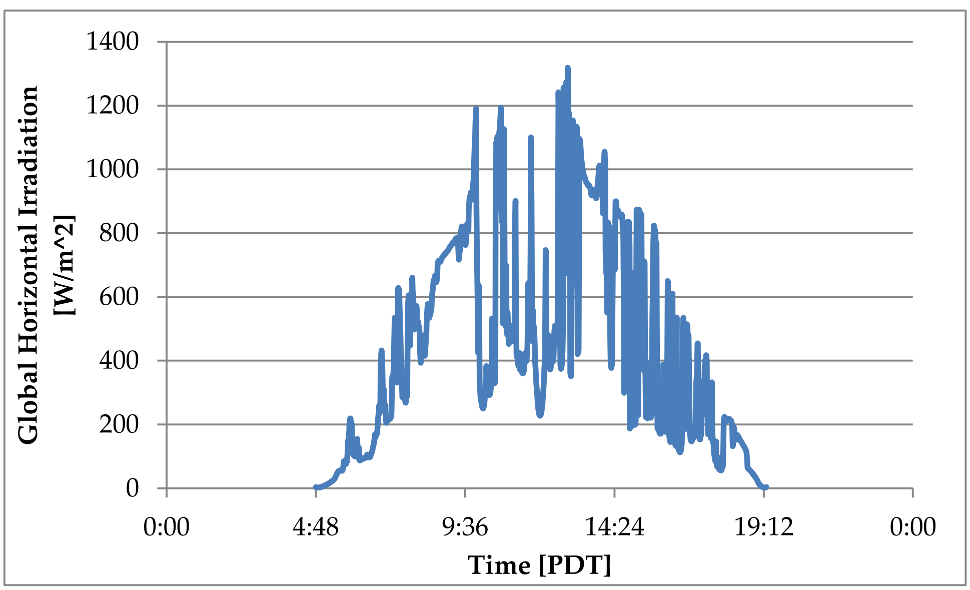


Figure 31. Typical High Variability Day (May 25, 2012)

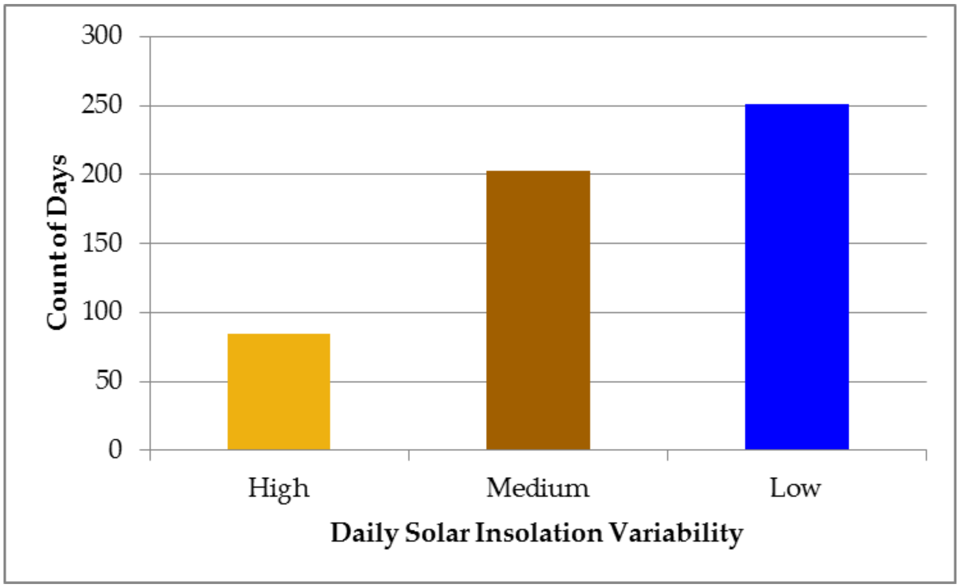


Figure 32. Daily Solar Insolation Variability from April 2012 through September 2013

Appendix B. Customer Focus Group Results

B.1 Introduction

At the end of the project, the project team solicited feedback on the program and equipment from the RES host customers. SMUD wanted their opinion to understand their experiences to:

- inform potential future SMUD programs,
- improve future demonstration projects, and
- inform future equipment design.

SMUD contacted participants via an online survey and by hosting a focus group. The online survey consisted of the questions below. 12 participants completed the survey and the major findings are discussed below.

Survey Questions

- Is your household participating in the Residential Energy Storage Group where a storage battery is installed in your garage or are you participating in the Community Energy Storage Group where storage battery is shared with other homes?
- Overall, how satisfied are you with the program?
- What could be done to improve the program?
- Thinking specifically about the equipment, how satisfied are you with the equipment?
- What could be done to improve the equipment?
- How likely are you to buy an energy storage device in next 3 to 5 years?
- How likely are you to purchase an energy storage system with a 10-year payback?
- How likely are you to recommend energy storage to others?
- How did having an energy storage unit change the way you used energy?
- Is this technology something you would like to manually control or set to an automatic mode?
- Did you use the Home Management Portal? How satisfied were you with the Home Management Portal? Which features did you use?
- Did you use the Sun Power monitor? How satisfied were you with the Sun Power monitor? Which features did you use?
- Please describe any issues you may have experienced with your energy storage system?
- As you may recall, your home was placed on a time of use rate. On a scale of one to five where one means no change at all and five means significant changes, how significantly did the time of use rate change the way you use energy?
- Your home was offered rate protection for your bill. On a scale of one to five where one means no change at all and five means significant changes, how significantly did the rate protection change the way you use energy?

SMUD also held an in person focus group for the RES site host customers. Eight customers attended, along with representatives from SMUD, SunPower, GridPoint and Navigant. The agenda included the items below, along with a facilitated discussion soliciting customer feedback. The key findings from the focus group will be discussed below.

- Project Overview
- Project Goals
- Accomplishments
- Lessons Learned
- Conclusion
- Next steps
- Closing Comments

B.2 Key Findings

From the survey and focus group, SMUD received feedback around 5 major themes:
Customers participated because they: are interested in managing their energy, wanted to demonstrate new technology in a national study, wanted to help the environment, and wanted to control their energy costs. When recruiting for RES site hosts, SMUD received much more interest than we could accommodate. The customers were interested in participating in a US DOE funded project with national implications. They also were interested in trying out new technology that could help them control their energy costs and help the environment.
Customers were happy with SMUD and the team, but in some cases they would have liked the equipment to be outside or smaller and quieter. The whole team received compliments on the professionalism and quick response times to their inquiries or issues. Most customers were happy with the equipment, but those hosts with problematic (e.g. low availability due to problems and troubleshooting) were frustrated with the number of site visits required for maintenance. The most common feedback on the RES units themselves was that they were too loud and could have been smaller.
Customers would have liked to control the energy storage equipment themselves and directly charge the energy storage with PV. As discussed earlier in this report, the customers did not have control over the units. Most customers would have liked control in order to either discharge the units during times of high usage or to store excess PV output for use when the sun goes down.
Adopting energy storage and time of use rates drove some customers to change their behavior, but most did not. Because customers did not have control over the RES units, they did not change their energy usage patterns. A few customers said time of use rates drove behavior changes, but most said that the rates were not high enough to drive any big changes.

Appendix C. Business Model Analysis

Table 28. Potential Distributed Energy Storage and PV Business Models

Model #	Location	Owner	Interconnection	Financing	Utility Control	Compensation
1	Non-Customer	SMUD	Direct to Grid	N/A	SMUD 100% Controls Asset	N/A
2	Non-Customer	SMUD	Direct to PV	N/A	SMUD 100% Controls Asset	N/A
3	Non-Customer	Third Party	Direct to Grid	N/A	Owner 100% Controls Asset	Regular Fixed Payments
4	Non-Customer	Third Party	Direct to Grid	N/A	Owner 100% Controls Asset	Payment by Service
5	Non-Customer	Third Party	Direct to PV	N/A	Owner 100% Controls Asset	Regular Fixed Payments
6	Non-Customer	Third Party	Direct to PV	N/A	Owner 100% Controls Asset	Payment by Service
7	Non-Customer	Third Party	Direct to Grid	N/A	Owner Mostly Controls Asset, with Occasional Utility Control	Regular Fixed Payments
8	Non-Customer	Third Party	Direct to Grid	N/A	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
9	Non-Customer	Third Party	Direct to PV	N/A	Owner Mostly Controls Asset, with Occasional Utility Control	Regular Fixed Payments
10	Non-Customer	Third Party	Direct to PV	N/A	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
11	Customer	Customer	Direct to Grid	Customer Owns	Owner 100% Controls Asset	Upfront incentives
12	Customer	Customer	Direct to Grid	Customer Owns	Owner 100% Controls Asset	Payment by Service

13	Customer	Customer	Direct to Grid	Customer Owns	Owner 100% Controls Asset	Upfront + Payment by Service
14	Customer	Customer	Direct to PV	Customer Owns	Owner 100% Controls Asset	Upfront incentives
15	Customer	Customer	Direct to PV	Customer Owns	Owner 100% Controls Asset	Payment by Service
16	Customer	Customer	Direct to PV	Customer Owns	Owner 100% Controls Asset	Upfront + Payment by Service
17	Customer	Customer	Direct to Grid	Customer Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Upfront incentives
18	Customer	Customer	Direct to Grid	Customer Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
19	Customer	Customer	Direct to Grid	Customer Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Upfront + Payment by Service
20	Customer	Customer	Direct to PV	Customer Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Upfront incentives
21	Customer	Customer	Direct to PV	Customer Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
22	Customer	Customer	Direct to PV	Customer Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Upfront + Payment by Service
23	Customer	Customer	Direct to Grid	SMUD Leases to customer	Owner 100% Controls Asset	Payment by Service
24	Customer	Customer	Direct to PV	SMUD Leases to customer	Owner 100% Controls Asset	Payment by Service
25	Customer	Customer	Direct to Grid	SMUD Leases to customer	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
26	Customer	Customer	Direct to PV	SMUD Leases to customer	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
27	Customer	Customer	Direct to Grid	SMUD Provides loan	Owner 100% Controls Asset	Payment by Service
28	Customer	Customer	Direct to PV	SMUD Provides loan	Owner 100% Controls Asset	Payment by Service

29	Customer	Customer	Direct to Grid	SMUD Provides loan	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
30	Customer	Customer	Direct to PV	SMUD Provides loan	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
31	Customer	SMUD	Direct to Grid	SMUD Owns	SMUD 100% Controls Asset	Regular Fixed Payments
32	Customer	SMUD	Direct to PV	SMUD Owns	SMUD 100% Controls Asset	Regular Fixed Payments
33	Customer	SMUD	Direct to Grid	SMUD Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Regular Fixed Payments
34	Customer	SMUD	Direct to PV	SMUD Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Regular Fixed Payments
35	Customer	SMUD	Direct to Grid	SMUD Owns	Owner Mostly Controls Asset, with Occasional Utility Control	N/A
36	Customer	SMUD	Direct to PV	SMUD Owns	Owner Mostly Controls Asset, with Occasional Utility Control	N/A
37	Customer	Third Party	Direct to Grid	Third Party Owns	Owner 100% Controls Asset	Upfront incentives
38	Customer	Third Party	Direct to PV	Third Party Owns	Owner 100% Controls Asset	Upfront incentives
39	Customer	Third Party	Direct to Grid	Third Party Owns	Owner 100% Controls Asset	Upfront + Payment by Service
40	Customer	Third Party	Direct to PV	Third Party Owns	Owner 100% Controls Asset	Upfront + Payment by Service
41	Customer	Third Party	Direct to Grid	Third Party Owns	Owner 100% Controls Asset	Payment by Service
42	Customer	Third Party	Direct to PV	Third Party Owns	Owner 100% Controls Asset	Payment by Service
43	Customer	Third Party	Direct to Grid	Third Party Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Upfront incentives
44	Customer	Third Party	Direct to PV	Third Party Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Upfront incentives

45	Customer	Third Party	Direct to Grid	Third Party Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
46	Customer	Third Party	Direct to PV	Third Party Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
47	Customer	Third Party	Direct to Grid	Third Party Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
48	Customer	Third Party	Direct to PV	Third Party Owns	Owner Mostly Controls Asset, with Occasional Utility Control	Payment by Service
49	Customer	Third Party	Direct to Grid	Third Party Owns	SMUD 100% Controls Asset	Upfront incentives
50	Customer	Third Party	Direct to PV	Third Party Owns	SMUD 100% Controls Asset	Upfront incentives
51	Customer	Third Party	Direct to Grid	Third Party Owns	SMUD 100% Controls Asset	Upfront + Payment by Service
52	Customer	Third Party	Direct to PV	Third Party Owns	SMUD 100% Controls Asset	Upfront + Payment by Service
53	Customer	Third Party	Direct to Grid	Third Party Owns	SMUD 100% Controls Asset	Payment by Service
54	Customer	Third Party	Direct to PV	Third Party Owns	SMUD 100% Controls Asset	Payment by Service

Table 29. Pros and Cons of Each Business Model

	SMUD		Customer		Third Party	
Model #	Pros	Cons	Pros	Cons	Pros	Cons

1	SMUD retains 100% control; easy for SMUD to monetize benefits; asset could be moved if need be, can be installed anywhere and not just in high penetration PV community; Likely easier to integrate with existing SMUD communications and control systems	If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	None	No involvement in business model beyond equipment manufacture and installation
2	SMUD retains 100% control; easy for SMUD to monetize benefits; asset could be moved if need be	If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate; SMUD would need a solar system to tie the ES to and this might require a longer timeline for negotiations	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	None	No involvement in business model beyond equipment manufacture and installation

3	Billing/payment is simpler and does not require equipment to monitor usage; Likely easier to integrate with existing SMUD communications and control systems	SMUD cannot control energy storage if it is needed; energy storage might not be used as efficiently as possible because not being paid for performance;	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; flat billing is simple to implement	Owner would not have opportunity to improve revenue beyond fixed payment
4	ES will be used efficiently because being paid for performance; Likely easier to integrate with existing SMUD communications and control systems	More complex billing and monitoring equipment required; SMUD cannot control energy storage	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; Owner can optimize operation to maximize revenue	Complex software and hardware might be required to track usage, performance, and revenue
5	Billing/payment is simpler and does not require equipment to monitor usage	SMUD cannot control energy storage if it is needed; energy storage might not be used as efficiently as possible because not being paid for performance;	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; flat billing is simple to implement; owner could offer as a product to enhance value of PV systems	Owner would not have opportunity to improve revenue beyond fixed payment;

6	ES will be used efficiently because being paid for performance	More complex billing and monitoring equipment required; SMUD cannot control energy storage	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; Owner can optimize operation to maximize revenue; owner could offer as a product to enhance value of PV systems	Complex software and hardware might be required to track usage, performance and reveneu
7	Billing/payment is simpler and does not require equipment to monitor usage; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	Energy storage might not be used as efficiently as possible because not being paid for performance; communications and control equipment needed	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; flat billing is simple to implement	Owner would not have opportunity to improve revenue beyond fixed payment

8	ES will be used efficiently because being paid for performance; SMUD can control as needed; Likely easier to integrate with existing SMUD communications and control systems	More complex billing and monitoring equipment required; SMUD cannot control energy storage; communications and control equipment needed	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; Owner can optimize operation to maximize revenue	Complex software and hardware might be required to track usage, performance and revenue
9	Billing/payment is simpler and does not require equipment to monitor usage	Energy storage might not be used as efficiently as possible because not being paid for performance; communications and control equipment needed	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; flat billing is simple to implement; owner could offer as a product to enhance value of PV systems	Owner would not have opportunity to improve revenue beyond fixed payment;

10	ES will be used efficiently because being paid for performance; SMUD can control as needed	More complex billing and monitoring equipment required; communications and control equipment needed	None	No involvement or direct benefit; could be installed near or on their yard if they have a transformer nearby	Industry has involvement and benefits beyond equipment manufacture and installation; Owner can optimize operation to maximize revenue; owner could offer as a product to enhance value of PV systems	Complex software and hardware might be required to track usage, performance and revenue
11	Incentive scheme is easy to implement; no monitoring or communications needed; direct connection to grid can allow energy storage to be used for grid support functions; Likely easier to integrate with existing SMUD communications and control systems	Energy storage might not be used in a way that benefits SMUD; SMUD cannot control equipment if needed	Customer controls and captures all the benefits; one time incentive is easier than on going incentives	Would likely required significant up front investment, even with incentives; owner would be responsible for maintenance; customer cannot use PV to directly charge ES	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

12	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions ;Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required; SMUD cannot control	Customer controls and captures all the benefits;	Would likely required significant up front investments; owner would be responsible for maintenance; customer cannot use PV to directly charge ES; incentive accrued overtime and results in large upfront costs	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation
13	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required; SMUD cannot control	Customer controls and captures all the benefits; upfront incentives reduce up front cost	Would likely required significant up front investments; owner would be responsible for maintenance; customer cannot use PV to directly charge ES;	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

14	Incentive scheme is easy to implement; no monitoring or communications needed	Energy storage might not be used in a way that benefits SMUD; SMUD cannot control equipment if needed; direct connection to PV might not allow for grid support functions	Customer controls and captures all the benefits; one time incentive is easier than on going incentives; customers can charge ES with PV	Would likely required significant up front investment, even with incentives; owner would be responsible for maintenance	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation
15	SMUD could design incentive scheme to promote usage it wants	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions; SMUD cannot control	Customer controls and captures all the benefits; customers can charge ES with PV	Would likely required significant up front investments; owner would be responsible for maintenance; incentive accrued overtime and results in large upfront costs	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation
16	SMUD could design incentive scheme to promote usage it wants	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions; SMUD cannot control	Customer controls and captures all the benefits; upfront incentives reduce up front cost; customers can charge ES with PV	Would likely required significant up front investments; owner would be responsible for maintenance;	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

17	Incentive scheme is easy to implement; no monitoring or communications needed; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	energy storage might not be used in a way that benefits SMUD;	Customer controls and captures most the benefits; one time incentive is easier than on going incentives	Would likely required significant up front investment, even with incentives; owner would be responsible for maintenance; customer cannot use PV to directly charge ES	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

18	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required	Customer controls and captures most of the benefits;	Would likely required significant up front investments; owner would be responsible for maintenance; customer cannot use PV to directly charge ES; incentive accrued overtime and results in large upfront costs	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation
19	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required	Customer controls and captures most of the benefits; upfront incentives reduce up front cost	Would likely required significant up front investments; owner would be responsible for maintenance; customer cannot use PV to directly charge ES;	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

20	Incentive scheme is easy to implement; no monitoring or communications needed; SMUD can control if needed	Energy storage might not be used in a way that benefits SMUD; direct connection to PV might not allow for grid support functions	Customer controls and captures most of the benefits; one time incentive is easier than on going incentives; customers can charge ES with PV	Would likely required significant up front investment, even with incentives; owner would be responsible for maintenance	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation
21	SMUD could design incentive scheme to promote usage it wants; SMUD can control if needed	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions	Customer controls and captures most of the benefits; customers can charge ES with PV	Would likely required significant up front investments; owner would be responsible for maintenance; incentive accrued overtime and results in large upfront costs	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation
22	SMUD could design incentive scheme to promote usage it wants; SMUD can control if needed	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions	Customer controls and captures most of the benefits; upfront incentives reduce up front cost; customers can charge ES with PV	Would likely required significant up front investments; owner would be responsible for maintenance;	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

23	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD could specify required equipment features or controls in order to get the lease; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required; SMUD cannot control; developing a lease program could require significant overhead and is a new business area for SMUD	Customer controls and captures all the benefits; no upfront costs	Owner would be responsible for maintenance; customer cannot use PV to directly charge ES;	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

24	SMUD could design incentive scheme to promote usage it wants; SMUD could specify required equipment features or controls in order to get the lease	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions; SMUD cannot control; developing a lease program could require significant overhead and is a new business area for SMUD	Customer controls and captures all the benefits; customers can charge ES with PV' no upfront costs	Owner would be responsible for maintenance	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

25	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; SMUD could specify required equipment features or controls in order to get the lease; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required; developing a lease program could require significant overhead and is a new business area for SMUD	Customer controls and captures most of the benefits; no upfront costs	Owner would be responsible for maintenance; customer cannot use PV to directly charge ES	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

26	SMUD could design incentive scheme to promote usage it wants; SMUD can control if needed; SMUD could specify required equipment features or controls in order to get the lease	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions; developing a lease program could require significant overhead and is a new business area for SMUD	Customer controls and captures most of the benefits; customers can charge ES with PV; no upfront costs	Owner would be responsible for maintenance	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

27	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD could specify required equipment features or controls in order to get the loan; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required; SMUD cannot control; developing a loan program could require significant overhead and is a new business area for SMUD	Customer controls and captures all the benefits; no upfront costs	Owner would be responsible for maintenance; customer cannot use PV to directly charge ES;	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

28	SMUD could design incentive scheme to promote usage it wants; SMUD could specify required equipment features or controls in order to get the lease	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions; SMUD cannot control; developing a loan program could require significant overhead and is a new business area for SMUD	Customer controls and captures all the benefits; customers can charge ES with PV' no upfront costs	Owner would be responsible for maintenance	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

29	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; SMUD could specify required equipment features or controls in order to get the lease; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required; developing a loan program could require significant overhead and is a new business area for SMUD	Customer controls and captures most of the benefits; no upfront costs	Owner would be responsible for maintenance; customer cannot use PV to directly charge ES	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

30	SMUD could design incentive scheme to promote usage it wants; SMUD can control if needed; SMUD could specify required equipment features or controls in order to get the lease	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might not allow for grid support functions; developing a loan program could require significant overhead and is a new business area for SMUD	Customer controls and captures most of the benefits; customers can charge ES with PV; no upfront costs	Owner would be responsible for maintenance	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation
31	SMUD controls ES; ES can be used for grid support and renewable integration; Likely easier to integrate with existing SMUD communications and control systems	Maintenance and troubleshooting can be difficult if need to coordinate with homeowner; If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	Gets payment in return for giving up floorspace	Customer does not have control over unit; unit could take up floorspace	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

32	SMUD controls ES;	Maintenance and troubleshooting can be difficult if need to coordinate with homeowner; ES might not be able to do grid support; If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	Gets payment in return for giving up floorspace	Customer does not have control over unit; unit could take up floorspace	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation
33	SMUD can control ES if needed; ES can be used for grid support and renewable integration; Likely easier to integrate with existing SMUD communications and control systems	Maintenance and troubleshooting can be difficult if need to coordinate with homeowner; If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	Gets payment in return for giving up floorspace; customer can control and get some benefits beyond fixed payment	Unit could take up floorspace	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

34	SMUD controls ES;	Maintenance and troubleshooting can be difficult if need to coordinate with homeowner; ES might not be able to do grid support; If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	gets payment in return for giving up floorspace; customer can control and get some benefits beyond fixed payment	Unit could take up floorspace	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation
35	SMUD can control ES if needed; ES can be used for grid support and renewable integration; Likely easier to integrate with existing SMUD communications and control systems	Maintenance and troubleshooting can be difficult if need to coordinate with homeowner; If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	Customer can control and get some benefits beyond fixed payment	Unit could take up floorspace	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation

36	SMUD controls ES;	Maintenance and troubleshooting can be difficult if need to coordinate with homeowner; ES might not be able to do grid support; If incentive programs are developed nationally or statewide and they are taxed based, SMUD might not be able to participate	Customer can control and get some benefits beyond fixed payment	Unit could take up floorspace	Does not require vendor to develop ownership and financing models	No involvement in business model beyond equipment manufacture and installation
37	Incentive scheme is easy to implement; no monitoring or communications needed; direct grid connection could allow for grid support functions; Likely easier to integrate with existing SMUD communications and control systems	SMUD cannot control energy storage if it is needed; energy storage might not be used as efficiently as possible because not being paid for performance;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry

38	Incentive scheme is easy to implement; no monitoring or communications needed	SMUD cannot control energy storage if it is needed; energy storage might not be used as efficiently as possible because not being paid for performance;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry
39	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry; complex software and hardware might be required to track usage, performance, and revenue

40	SMUD could design incentive scheme to promote usage it wants;	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might now allow for grid support functions; SMUD cannot control	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry; complex software and hardware might be required to track usage, performance, and revenue
41	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required; SMUD cannot control	Customer gets most benefits but does not have to do maintenance; no up front costs	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed;	In the near term, financing might be difficult to obtain for relatively new industry; high upfront costs; complex software and hardware might be required to track usage, performance, and revenue

42	SMUD could design incentive scheme to promote usage it wants;	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might now allow for grid support functions; SMUD cannot control	Customer gets most benefits but does not have to do maintenance; no up front costs	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed;	In the near term, financing might be difficult to obtain for relatively new industry; high up front costs; complex software and hardware might be required to track usage, performance, and revenue
43	Incentive scheme is easy to implement; no monitoring or communications needed; direct grid connection could allow for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	energy storage might not be used as efficiently as possible because not being paid for performance;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry

44	Incentive scheme is easy to implement; no monitoring or communications needed; SMUD can control if needed	SMUD cannot control energy storage if it is needed; energy storage might not be used as efficiently as possible because not being paid for performance;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry
45	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry; complex software and hardware might be required to track usage, performance, and revenue

46	SMUD could design incentive scheme to promote usage it wants; SMUD can control if needed	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might now allow for grid support functions;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry;
47	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required;	Customer gets most benefits but does not have to do maintenance; no up front costs	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed;	In the near term, financing might be difficult to obtain for relatively new industry; high upfront costs; complex software and hardware might be required to track usage, performance, and revenue

48	SMUD could design incentive scheme to promote usage it wants; SMUD can control if needed	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might now allow for grid support functions;	Customer gets most benefits but does not have to do maintenance; no up front costs	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed;	In the near term, financing might be difficult to obtain for relatively new industry; high up front costs; complex software and hardware might be required to track usage, performance, and revenue
49	Incentive scheme is easy to implement; no monitoring or communications needed; direct grid connection could allow for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	Energy storage might not be used as efficiently as possible because not being paid for performance;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry

50	Incentive scheme is easy to implement; no monitoring or communications needed; SMUD can control if needed	SMUD can not control energy storage if it is needed; energy storage might not be used as efficiently as possible because not being paid for performance;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry
51	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD can control if needed; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry; complex software and hardware might be required to track usage, performance, and revenue

52	SMUD could design incentive scheme to promote usage it wants; SMUD can control if needed	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might now allow for grid support functions;	Customer gets most benefits but does not have to do maintenance	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation; third party can control as needed; upfront incentive helps reduce first costs	In the near term, financing might be difficult to obtain for relatively new industry; complex software and hardware might be required to track usage, performance, and revenue
53	SMUD could design incentive scheme to promote usage it wants; direct connection to grid can allow energy storage to be used for grid support functions; SMUD controls; Likely easier to integrate with existing SMUD communications and control systems	More overhead and equipment required for running incentive program; monitoring equipment required;	Customer gets most benefits but does not have to do maintenance; no up front costs	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation;	In the near term, financing might be difficult to obtain for relatively new industry; high upfront costs; third party does not control; complex software and hardware might be required to track usage, performance, and revenue

54	SMUD could design incentive scheme to promote usage it wants; SMUD controls	More overhead and equipment required for running incentive program; monitoring equipment required; direct connection to PV might now allow for grid support functions;	Customer gets most benefits but does not have to do maintenance; no up front costs	Customer cannot control how they want	Allows for industry participation beyond just manufacture and installation	In the near term, financing might be difficult to obtain for relatively new industry; high up front costs; third party does not control; complex software and hardware might be required to track usage, performance, and revenue

Appendix D. Interim Report

Department of Energy

DE-EE0002066

Sacramento Municipal Utility District
PV and Smart Grid Pilot at Anatolia

Mark Rawson
Principal Investigator
(916) 732-6364
mrawson@smud.org

Submitted By: Ed Sanchez
Project Manager
(916) 732-5572
esanche@smud.org

Jun 30, 2012

DUNS: 009235342
Sacramento Municipal Utility District
6201 S Street
Sacramento, CA

Grant Period: 12/31/2009 – 09/30/2013
Reporting End Date: 30 Jun 2012
Technical Progress Report

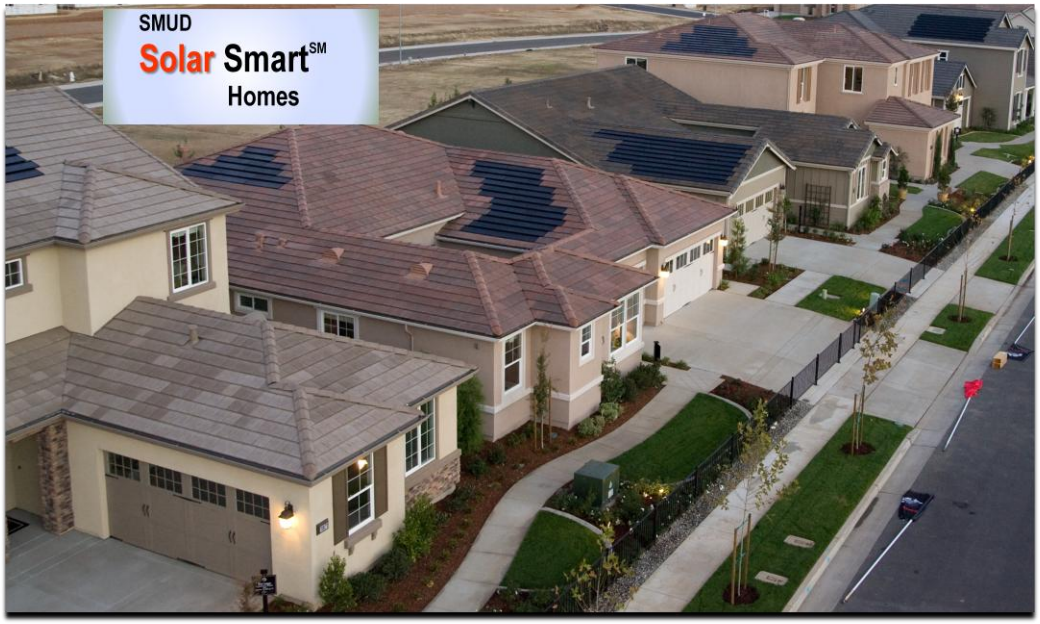
Signed: Mark R. Rawson

DE-EE0002066

Sacramento Municipal Utility District

PV and Smart Grid Pilot at Anatolia

Technical Project Progress Report



Acknowledgment: This material is based upon work supported by the Department of Energy and the California Energy Commission under Award Number DE-EE0002066.

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

Table of Contents

List of Figures and Tables

Figures:

Tables:

1. Executive Summary

This report has been requested by the Department of Energy as a status update on the project. The following sections discuss:

- A summary of the work done to date,
- Lessons learned to date,
- Testing conducted to date and our testing plan going forward,
- Preliminary observations

The U. S. Department of Energy under DE-FOA-0000085 High Penetration Solar Deployment funded agreements with the Sacramento Municipal Utility District (SMUD) along with other project partners to include Navigant Consulting, SunPower, GridPoint, the National Renewable Energy Laboratory, and California Energy Commission - to fund and implement the Anatolia PV and Storage Demonstration Pilot for a total Project cost of $5,962,409.00

- SMUD is demonstrating advanced lithium ion storage at customer and distribution transformer locations in the Anatolia III Solar Smart Homes Community to locate in the southeast portion of SMUD's service territory in the city of Rancho Cordova, CA.
- The overarching goals of this demonstration are to:
  - Firm intermittency of PV generation,
  - Mitigate reliability impacts of large penetrations of PV,
  - Reduce utility system peak load.

The Grant is being used to conduct research on the value of energy storage sited on a customer residence and as a distribution asset. These funds are being used for the design, integration, testing and application energy storage appliances in a community with a high concentration of PV homes, homes that are of similar vintage, and at the end of a distribution circuit.

The combination of these characteristics makes this a unique environment to validate the benefits of this technology for both the home owner and utilities. SMUD is operating the technology to investigate the use of energy storage for renewable energy firming and load shifting along with assessing the impact of dynamic prices and critical peak prices over the course of the study. These funds support high resolution telemetry at the homeowner's residence, at the transformer and substation along with metrological data to assess the impact of this technology on grid operations. Finally, the homeowner will have access to a new energy management portal allowing the customer to visualize and generate reports related to energy consumption, generating and the operating mode of the energy storage appliance in their home.

SMUD has used the grant funds to procure fifteen Residential Energy Storage appliances and three Community Energy Storage appliances. The grant funds support the design, integration, testing, recruitment, support, and de-commissioning of these energy storage devices. The funds were also used to support the system integration and development of a home energy portal and data analysis conducted by the national Renewable Energy Laboratory. These energy storage systems are evaluated in two configurations: both behind the meter – Residential Energy Storage (RES) and on the primary distribution system through a Community Energy Storage (CES) system.
The grant supports federal and state goals by integrating large amounts of distributed renewable energy that is critical to California achieving its current RPS target of 33% renewable energy. Moreover, it is increasingly clear that distributed solar PV, both in rooftop and ground-mounted applications,

Printed on Recycled Paper

represents the greatest opportunity for implementing distributed renewable energy in California over the next 10 years. However, a number of important technical issues exist that will influence the amount of PV that can be integrated at the distribution level. Distributed energy storage systems may be able to provide a method through which large amounts of renewable energy can be integrated into traditional distribution systems without causing disturbances during intermittency events. For this reason, projects such as this are being done in order to study the degree to which competitively priced, multi-megawatt, long duration advanced energy systems can be used for utility grid applications. The project will investigate the level to which load management, peak load shaving, time shifting, and renewable integration can be accomplished through these advanced storage technologies.
Energy storage technologies can be integrated with distributed renewable energy resources such as PV to create value for customers and the utility. This will include determining the impact of energy storage on a high PV penetration distribution feeder, shaving the super peak load of the feeder, and the operational improvements supported by energy storage. The energy storage system integrated community and residential energy storage will test and demonstrate the operation of these technologies while ensuring reliability to the loads, and reduction of peak, and super peak load. These project benefits directly support SMUD's strategic directives for Reliability, Environmental Protection, and Research and Development. Project technical objectives include:

1. Demonstrate the ability of an integrated PV system into the Smart Grid through two-way communication and control capability between the utility and PV inverters.

    - Demonstrate communications between the utility and energy storage located both behind the meter and on distribution feeders,
    - Demonstrate communications and control capability using both broadband and Advanced Metering Infrastructure (AMI) network,
    - Examine the capabilities and limitations of managing PV inverters through smart meters.

2. Assess the production characteristics of distributed PV in a high penetration scenario to support adequate models and forecasting techniques with which to consider distributed PV as a grid resource.
    - Leverage over two years of distribution feeder monitoring in a high penetration SolarSmart HomesSM community,
    - Expand the existing Anatolia monitoring platform to include high resolution monitoring at fifteen (15) homes and three (3) distribution transformers.

3. Demonstrate energy storage as a potential solution for "firming" the variable output of PV; show how energy storage might be for overcoming these problems.

    - Both Residential Energy Storage (RES) and Community Energy Storage (CES) will be integrated with rooftop PV and operated in a real world utility distribution system.
    - The systems will be sized to test capacity firming of PV and how it could provide value for customers (end-users) and utilities.

2. Residential Energy Storage

2.1 UL Testing

The RES appliance was subject to the following testing for UL 1741 & IEEE 1547 compliance. These tests were necessary for residential installation.

The product was evaluated to determine compliance with the applicable requirements of the UL Safety Standard: Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources, UL 1741First Edition, Dated May 7, 1999 - Revisions through and including November 7, 2005, and the Interconnection Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547 first edition dated 2003.

During the testing process, there were no significant anomalies noted. Appliance passed both the UL 1741 & IEEE 1547 certification.

2.2 *Customer Recruitment*

Our goal was to identify, screen, and commit candidates to the Energy Storage project using multiple channels of communication including e-mails, letters, and an open house conducted at the Lennar model homes. The most successful recruiting effort was face-to-face interaction with the customer and use of a mock up residential energy storage device so customers would have an accurate picture of the space the device would consume in their garage for the duration of the project.

The Open House presentation included the following steps and in addition required several 1:1 discussions with the customer to reach agreement:

Introductions

1. Introductions
2. Overview of project (provided hand-out, marketing materials)
3. Discussed project participation criteria and next steps which included the following topic:
    a. Customer Site screening,
    b. Technical screening,
    c. Customer agreement,
    d. Schedule installation,
    e. Install and commission,
    f. Incentive paid,
    g. Monitoring,
    h. Schedule decommission or extension.

    Sample selection criteria:

    - A residential SMUD customer in Lennar's Anatolia community,
    - Pay your own SMUD bill,
    - Live in a single family dwelling that you own,
    - Have broadband Internet access,
    - Do not plan on moving during the next 18 months,
    - Are not on SMUD's Medical Equipment Discount Program,
    - Are not on SMUD's Low-Income Energy Assistance Program Rate (EAPR),
    - Do not operate a child care or convalescent care business in the home,
    - Are not a SMUD employee.

4. Q&A
5. Garage and Utility Panel Review (Photos and Checklist)
6. Update Master Spreadsheet
7. Sign Customer Agreement (second meeting)

The residential energy storage recruitment effort was extremely successful and the project was fully subscribed with a week of the open house. The Community Energy Storage recruitment did not attract participants during the open house and after repeated e-mails, letters, and phone calls a decision was made to visit high potential customers face to face at their homes. The project was successful in recruiting two customers and the third CES device was cited on SMUD property at a future distribution substation.

2.3 *Implementation*

2.3.1 Permitting

Permitting was required by the City of Rancho Cordova. The process began approximately 2 months before the actual date of our first install. Communication with the permitting officer and lead electrical inspector proved to be extremely beneficial. Given the new technology and unfamiliarity of equipment, the city was provided installation manuals and equipment specs to aid in understanding our objective. After review, the jurisdiction was also supplied with stamped drawings and location layouts where each installation would take place. Through much interaction with the permitting office, applications were submitted to install Electrical Management Equipment. Two days later, the permits for all 15 residential installs were issued. These permits were necessary because of the installation of new circuits within the homes' panel box. This process was surprisingly smooth, which is credited to the abundance of communication with the permitting office and essential personnel.

2.3.2 Installation

Once the Electrical permits were in place, site surveys of each location were performed by both the sub-contractor selected to perform the physical installations and GridPoint who managed the oversight of all installs. This installation consisted of the RES appliance, all essential branch circuits, and a protective bollard required by the local jurisdiction. The pictures below show (clockwise from upper left): inspection to site a unit, an RES unit before installation, inspection during commissioning and the final product.


Figure 1. Collage of RES Installation Process

2.3.3 Commissioning

Pre-start up—Visually inspects all connection points to assure all conductors are properly landed and ground connections are secure. Take incoming voltage readings to confirm proper line voltage Start-up—Confirm appliance is operating as designed. Run through both charge and discharge cycles. Commissioning—Upon commissioning, communications and data transfer is verified. Readings obtained via a performance log are matched against actual onsite readings. The site identifiers are also confirmed. After Commissioning, Homeowner's are presented with the site URL along with their username and password to access the portal.

2.4 Performance Objectives

The designated SAFT modules cannot be graded as "performing as designed." It is my understanding that these modules were designed more as a constant charge/constant volt lithium module used more commonly in telecom backup power systems. A large amount of work needed to be performed in order to implement a more aggressive charging algorithm. The internal resistance of the battery has resulted in a 5% loss as a consequence of the metering electronics placed within the modules. This loss has been observed when the modules are powered up and sitting idle. A pre-charge board needed to be designed to reduce the charging current during the charger ramp-up cycle. The RES modules have proven to be problematic while at low SOC levels (below 20%). SAFT has not had similar issues with the CES modules indicating the RES type of modules have isolated issues. All operating modes are functional.

2.5 Lessons Learned

Lessons learned fall into the following categories:

Testing

The project experienced a threefold increase in time required to complete underwriter laboratory testing, which lasted three months. This task was scheduled for three months and took nine months. This delay

Printed on Recycled Paper

was caused by the new technology and the lack of batteries required for testing. An example was UL required batteries which had significant duty cycles. This unforeseen requirement caused a six week delay in acquiring the batteries. We also experienced delays in clearing customs for Lithium Ion batteries shipped from France along with expensive duties and shipping costs, which required significant intervention and negation to complete the shipment.

The project experienced significant mitigation in the field for the RES units to address manufacturing defects, systems errors, firmware updates, and equipment failures. Many customers experienced multiple site visits and were pleasantly open, welcoming, and accommodating of the multiple visits required. The positive relationship was maintained by vendors, partners, and System Integrator GridPoint and included gifts to these homeowners in recognition of the inconvenience. Customers remain both engaged and enthusiastic.

Materials

Both PowerHub and Silent Power experience delays in delivery as a result of the long lead times for battery delivery. A lesson learned would be to allow more time for manufacturing, delivery, and testing of critical components. In addition, some components were damaged during testing, which further increased the cycle time for equipment delivery to the field.

Customer Engagement

Close and frequent customer contact is essential to the project's success. The project was fortunate to have recruited customers who clearly understood the value of PV driving their decision to purchase a Solar Smart Home in the Anatolia neighborhood. Further, they understood the connection and value proposition of energy storage integrated with PV and the potential to avoid peak prices as dynamic rates become pervasive. The customers were thoroughly educated on the project, its objectives, duration, and the risks associated with the effort. Again, the positive relationship was maintained by vendors, partners, and System Integrator GridPoint and included gifts to these homeowners in recognition of the inconvenience. Customers remain both engaged and enthusiastic. Last, the incentives needed to be robust so we offered each customer a $500 incentive to participate, including no additional costs to be incurred as a result of the project, SMUD rate protection as a result of any battery inefficiency and utility firming modes, and SMUD's assurance that the customer's property will be restored to pre-project condition.

Unplanned Issues

An example of an unplanned issue occurred when a customer noted degraded internet service and contacted his ISP for support. The ISP noted EM noise emitting from the RES unit and placed an EM filter to prevent the RES unit from affecting neighboring homes. This EM filter placed on the COAX cable did not help the RES customer with his degraded internet service so we decided to shut this and all RES units down until a fix to the noise issue was developed. Silent Power developed and tested an EM filter which blocked 90% of the EM noise generated by the RES unit. We applied the EM filter and asked the ISP provider to re-test the unit and the noise level appeared to be at or below acceptable noise limits and the customer is now satisfied with his internet service. All units were brought back online.

Safety

SMUD staff took it upon themselves to brief the local fire department on the deployment of the energy storage devices, attended fire Department Operations meetings, and conducted homeowner tours of the devices. Safety is our number one priority and SMUD sought to ensure both internal and external safety staffs were informed and kept abreast of all project activities. These steps along with the rigorous testing conducted by the UL for RES units aided and expedited the permitting process.

Safety Incident

SMUD encountered a safety issue with one of the RES units. The homeowner detected smoke and smelled something burning. The homeowner contacted RES vendor SunPower whom we were fortunate to already have in the development applying the EM fix and other software updates. The RES vendor drove to the home immediately and shut the unit down. SMUD was later informed of the issue and requested all units be shut down until a safety investigation and root cause analysis could be conducted. The smoke and burning smell detected by the homeowner were the result of a loose connection. The loose connection in turn resulted in overheating the shielding materials. The RES vendor developed a robust set of checklists for quality control; all RES units were inspected by the RES vendor, SMUD Staff, and the System integrator before the units were re-commissioned and energized.

See "Residential Energy Storage" Exhibits include the following technical specifications:

1. SMUD Home Energy Management Portal
2. Permit Process
3. Silent Power On-Demand Energy Appliance
4. SMUD High Pen Monitoring Specification

3. Community Energy Storage

3.1 IEEE 1547 Testing

SMUD Distribution Planning staff planned on leveraging the CES manufacturing facility and direct observation for the testing of the CES Units. However, the manufacturer lacked the equipment required to complete the testing without significant additional costs; SMUD typically relies on independent testing and does not possess internal testing capability. As a result, Distribution Planning staff requested independent testing of the CES units to meet IEEE 1547 standards, which was a new requirement and determined to be out of scope, requiring a new and separate agreement with a lab to complete requested testing.

SMUD entered into an agreement with NREL for testing the Community Energy Storage (CES) equipment for compliance to IEEE 1547 interconnection standards. The intent of this initiative was to have a third party verification of the proper operation and performance of the CES units. Three CES units, produced by PowerHub of Blacksburg, Virginia were delivered to NREL's Distributed Energy Resource Test Facility (DERTF). NREL tested each unit for IEEE 1547 compliance to the extent of using laboratory equipment and resources at the DERTF. Testing occurred at NREL beginning in November of 2011 and finishing in March of 2012. The following is a description of the tests completed and summarized results of the testing.

Minor excursions from a few of the 1547 test categories were identified during testing at NREL. These excursions were characterized and NREL provided recommendations on the severity or impact of these findings. After the characteristics of each unit were documented and understood, NREL shipped all three units to SMUD for final integration.

During testing, NREL supported troubleshooting and tuning of CES units that exhibited operational and performance issues. This process added significant time and effort to the testing initiative. Below is a list of some CES issues encountered and addressed by NREL and PowerHub during the testing time.

- CES #1: Transceiver chip for PITS communications failure. Troubleshoot and replace chip.

- CES #1: Unit did not initially pass Unintentional Islanding test. NREL supported downloading updated firmware and testing of new algorithm.
- CES #1, #2: Unit does not restart with grid voltage less than about 252 Vac, troubleshoot and work-around.
- CES #1, #2, #3: Over- and under-voltage and frequency trip settings had to be adjusted.
- CES #2: Supported replacement of battery cooling fan to increase air circulation for cooling.
- CES #2: Supported check out and verification of cellular control interface with GridPoint.
- CES #1, #2, #3: Persistent "PCS fan failure" warning not correct.
- CES #3: Battery compartment door fastening screws did not line up with tapped holes. This caused the battery door sensor to indicate the door was open. NREL investigated the issue, and modified the unit to allow testing to continue by inserting a stand-off to reposition the sensor.

NREL used the same battery pack to test all three units, the battery was swapped into each unit successively as testing was completed.

The following table summarizes the IEEE 1547.1 tests completed and results of each test for the three CES units tested at NREL.

Printed on Recycled Paper

IEEE 1547.1 TEST	CES UNIT TESTED	RESULT	EXPERIMENTER NOTES
Temperature Stability	CES #1	20 minutes at 105F	Upgraded cooling fan expected to improve temperature capability
Abnormal Voltage	CES #1	Compliant	
Abnormal Frequency	CES #1	Compliant	
Synchronization	CES #1	Compliant	Installer must evaluate in-rush current to determine compatibility
DC Injection	CES #1	Compliant	
Unintentional Islanding	CES #1	Compliant	Updated firmware makes unit compliant
Open Phase	CES #1	Compliant	
Harmonics	CES #1	99% Compliant	Minor 17-23 order even harmonic was recorded beyond limits
Abnormal Voltage	CES #2	Compliant	
Abnormal Frequency	CES #2	Compliant	
Synchronization	CES #2	Compliant	Installer must evaluate in-rush current to determine compatibility
Unintentional Islanding	CES #2	Compliant	
Harmonics	CES #2	Compliant	Unit is compliant when supplied by simulated EPS
Abnormal Voltage	CES #3	Compliant	
Abnormal Frequency	CES #3	Compliant	
Synchronization	CES #3	Compliant	
DC Injection	CES #3	Not Compliant	Beyond limits, though measurement approaching probe measurement floor
Unintentional Islanding	CES #3	Compliant	
Open Phase	CES #3	Compliant	
Harmonics	CES #3	98% Compliant	Minor 17-23 order even harmonics were recorded beyond limits

Refer to individual test reports for each unit for complete details on the testing results.

3.2 *Implementation*

3.2.1 Site Identification

While the Anatolia neighborhood has many transformers, we required a location that had space available to accommodate a CES unit. Thus, space considerations were our driving factor. The second was finding customers willing to host the units. While transformers are technically located on utility right of way property, we wanted to maintain positive customer relationships throughout this process. We were able to find two customers willing to host CES systems. For the third location, SMUD had a transformer in a vacant plot that will be used for a substation in the future.

Printed on Recycled Paper

3.2.2 Installation

The CES installations were performed by SMUD and commissioned by both GridPoint and PowerHub. The CES Units arrived at SMUD's warehouse. GridPoint and PowerHub installed the batteries while units were on the warehouse dock. SMUD had DS personnel pick up a unit and deliver it to the installation site, where it was installed by the same DS crew. The pictures in Figure 2 show (left to right): a CES unit being lifted off a truck, a CES unit being placed on a pad, and the final product.

Figure 2. Collage of CES Installation

3.2.3 Commissioning

The following tests were performed during the commissioning process:
Pre-start up—Visually inspect all connection points to assure all conductors are properly landed and ground connections are secure. Take incoming voltage readings to confirm proper line voltage
Start-up—Confirm appliance is operating as designed. Run through both charge and discharge cycles.
Commissioning—Upon commissioning, communications and data transfer is verified. Readings obtained via a performance log are matched against actual onsite readings. The site identifiers are also confirmed.

3.3 Performance Objectives

CES Modules are operating as designed with no relevant issues at this time and all operating modes are functional. The RES units continue to have issues but the volume and severity have diminished. We currently have 13 of the 15 units operating as designed. One unit that is currently offline has a battery unit that has reached a low state of charge (SOC) and will not "rejoin" the BMS. GridPoint and Silent Power will be onsite to address the unit with the low SOC. The other unit has been problematic throughout the project and has only momentarily been functional. The reasons have been numerous but the current issue is a shipment of replacement batteries, which have had the wrong firmware version applied and that require an upgrade in the field.

3.4 Lessons Learned

The CES units proved to be far easier to install than could have been imagined. The Distribution Services' crews were provided with training materials, a troubleshooting guide, and afforded hands-on training prior to installation. The first unit was installed by a crew of five in less than two hours and the third unit was energized in just over an hour. Consequently, the ease of the remaining installations came from working with enthusiastic DS Services' crews, which resulted in no issues with installation and only minor data connectivity issues associated with the commissioning of the CES appliances.

International shipping – and the resulting paperwork - of the batteries proved to be more time consuming that anticipated and the international tariffs were an unplanned expense.

Testing: While the initial contract for the CES units stated that UL1741 and IEEE 1547 testing were out of scope, it was not until this issue was raised by SMUD's distribution system engineers that the impact of this testing exclusion was made clear. This issue was raised early in the project, but at the time the DS staff was not directly involved. Early involvement of the distribution crews and staff could have significantly improved the testing and unit delivery performance.

See "Community Energy Storage" Exhibit for the following technical specifications:

1. Utility Portal
2. CES Functional Specifications
3. CES Installation, Delivery, and Operating Instructions
4. Troubleshooting Field Guide
5. Battery Management Module – User Guide

4. Monitoring, Data Collection and Testing

4.1 Data Acquisition

4.1.1 Locations

To understand the impacts of high penetration solar and storage on the electrical system, monitoring equipment has been installed throughout the neighborhood, as shown in Figure 3. A combination of voltage, current, power, energy, temperature, and weather data is collected at each numbered location along the electric delivery system. The frequency of data collection varies by location, also shown in Figure 3.

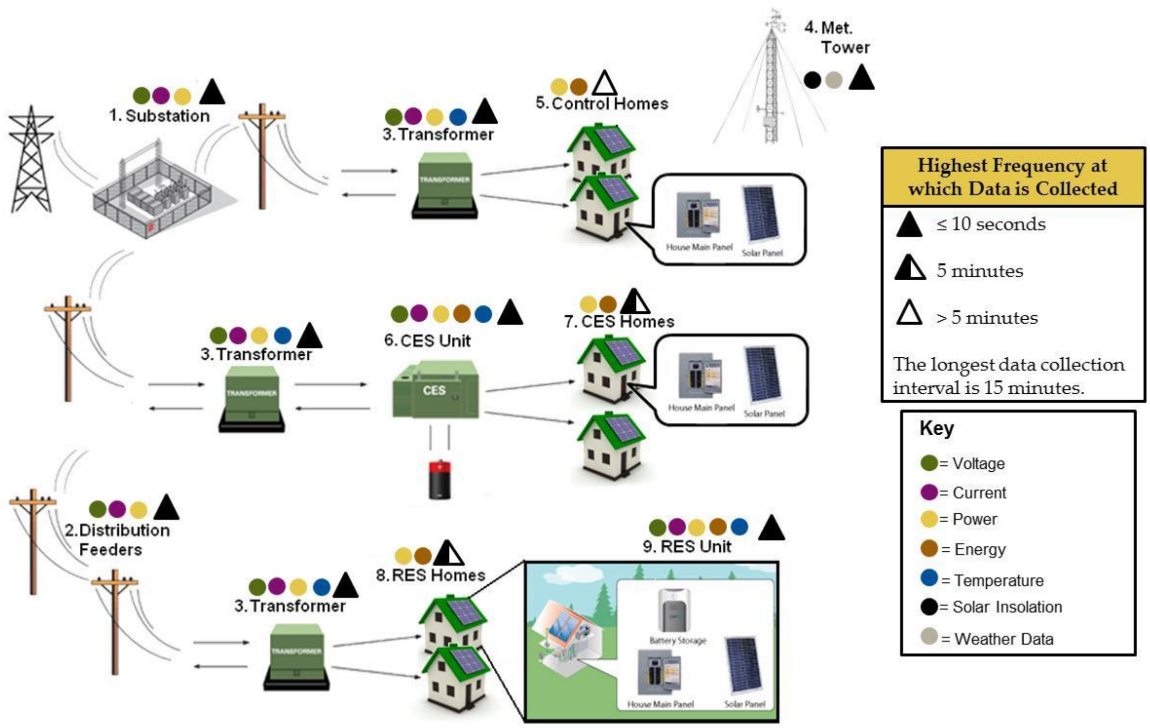


Figure 3. Diagram of the High Frequency Monitoring Installed through the Anatolia Community

The precise locations of community energy storage (CES), residential energy storage (RES), and transformer monitoring devices installed in the neighborhood are depicted in Figure 4, Figure 5, Figure 6, and Figure 7.

Printed on Recycled Paper

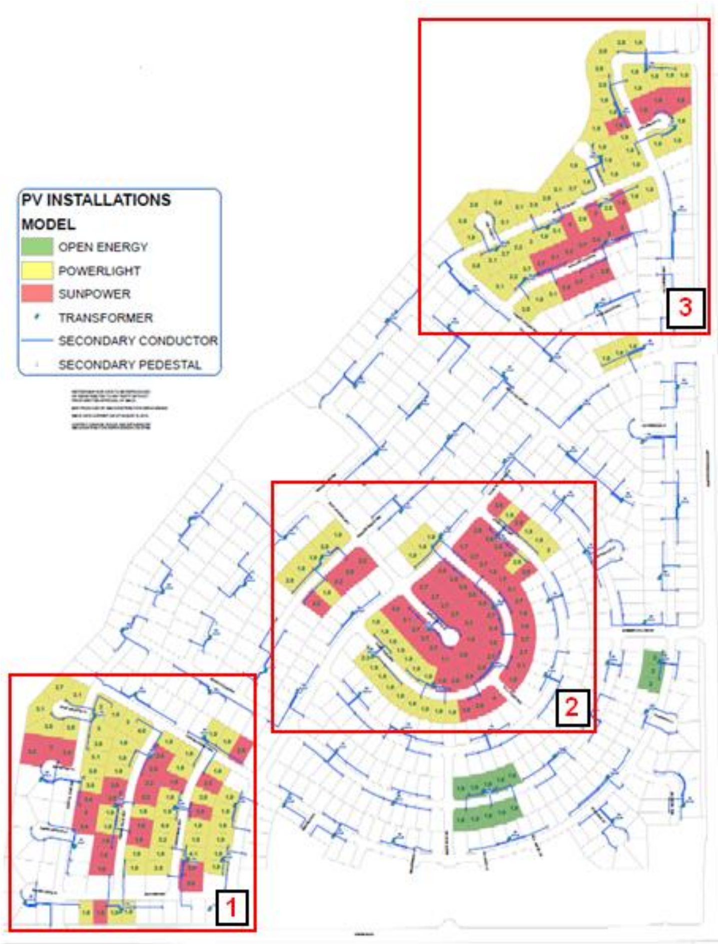


Figure 4. Map of Anatolia neighborhood: 1) Southwest area, 2) Central area, 3) Northeast area

Figure 5. Map of Southwest area of Anatolia neighborhood, along with location of equipment

Printed on Recycled Paper

Figure 6. Map of Central area of Anatolia neighborhood, along with location of equipment

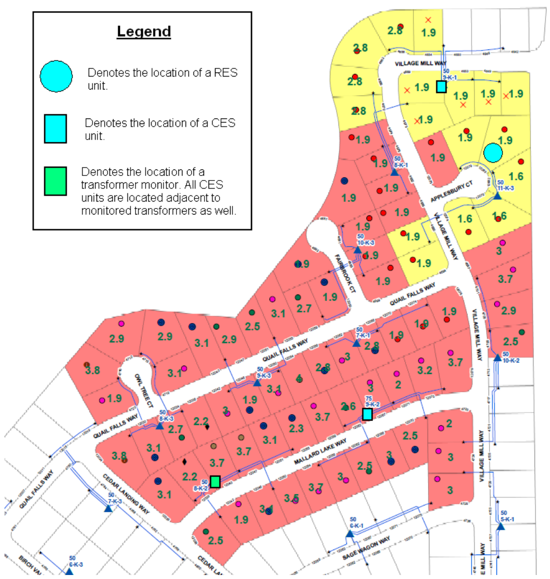


Figure 7. Map of Northeast area of Anatolia neighborhood, along with location of equipment

4.1.2 Equipment and Installation

SMUD is collecting 5 second data at the distribution feeder to the Anatolia neighborhood, which in turn monitors voltage and current for all load data in the study area. Fortunately with this project we had adjacent fiber optic cable running to a generation facility located at a nearby land fill and there were separate fiber strands available to support the data monitoring. This data is collected over SMUD's EMS SCADA and stored in SMUD's OSIsoft PI Historian where project staff queries the PI database for load data which is then FTP'ed to NREL for data aggregation and analysis.

Figure 8. Pictures from Feeder Monitoring Installation

The transformer level monitoring for this project is provided by Distribution Monitoring Units (DMU) developed at NREL. The DMUs installed here are designed specifically for installation on the secondary side of residential distribution transformers. Each meter calculates the phasor and power quality statistics for each of the two hot conductors and the neutral. These measurements are transmitted in real-time at an output rate of 1 Hz. Measurements are transmitted over active TCP connections to servers located at NREL were they are collected and stored. A more detailed description of this data collection network is provided in Section 4.2.

Each DMU outputs measurement data sets at 1 Hz which are transmitted back to the data collection servers in real-time. The output measurement values are given in Table 1.

Table 1: DMU Output Values

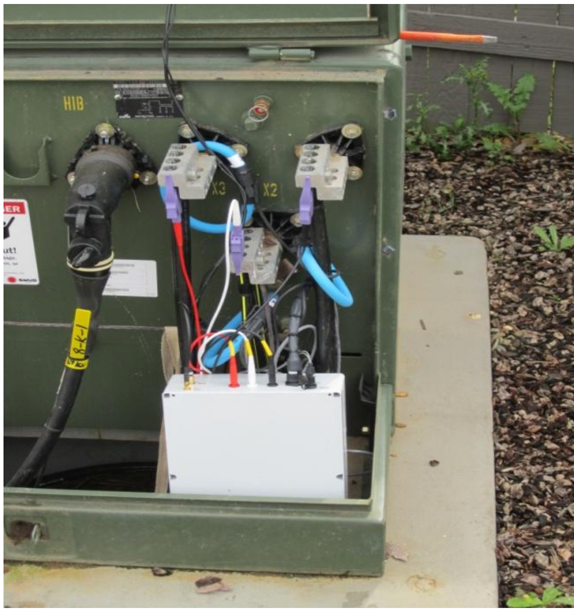
Measurement	Description	Units
$\lvert V_1 \rvert$	Leg 1 - Neu. Voltage Phasor Magnitude	V_{RMS}
θ_{V1}	Leg 1 - Neu. Voltage Phasor Angle	Degrees
$\lvert V_2 \rvert$	Leg 2 - Neu. Voltage Phasor Magnitude	V_{RMS}
θ_{V2}	Leg 2 - Neu. Phasor Angle	Degrees
$\lvert V_{12} \rvert$	Leg 1 - Leg 2 Voltage Phasor Magnitude	V_{RMS}
θ_{V12}	Leg 1 - Leg 2 Voltage Phasor Angle	Degrees
$\lvert I_1 \rvert$	Leg 1 Current Phasor Magnitude	A_{RMS}
θ_{I1}	Leg 1 Current Phasor Angle	Degrees
$\lvert I_2 \rvert$	Leg 2 Current Phasor Magnitude	A_{RMS}
θ_{I2}	Leg 2 Current Phasor Angle	Degrees
$\lvert I_N \rvert$	Neutral Current Phasor Magnitude	A_{RMS}
θ_{IN}	Neutral Current Phasor Angle	Degrees
Frequency	Frequency of Secondary Voltage	Hz
$V_{1\ RMS}$	Leg 1 - Neu. RMS Voltage	V_{RMS}
$V_{2\ RMS}$	Leg 2 - Neu. RMS Voltage	V_{RMS}
$V_{12\ RMS}$	Leg 1 - Leg 2 RMS Voltage	V_{RMS}
$I_{1\ RMS}$	Leg 1 RMS Current	A_{RMS}
$I_{2\ RMS}$	Leg 2 RMS Current	A_{RMS}
$I_{N\ RMS}$	Neutral RMS Current	A_{RMS}
$\lvert S \rvert$	Total Apparent Power Flow	VA
P	Total Real Power Flow	W
Q	Total Reactive Power Flow	VAR
pf	Total Power Factor, $P/\lvert S \rvert$	
pf_{DISP}	Displacement Power Factor, $\cos(\theta_{V12}-\theta_{I1})$	
Meter Internal Temp.	Temp. Measured on Meter PCB	Deg C
Transformer Temp.	External Temperature Probe	Deg C

DMUs have been installed on twelve transformers throughout the Anatolia feeder; their locations are given in Table 2.

Table 2: DMUs Installed in Anatolia Subdivision

Serial Number	Version	Transformer	Install date	Latitude	Longitude
00100	SPDTv1.3	2K9	16-Mar-11	38.526413	-121.23262
00101	SPDTv2.3	9K2	01-Mar-12	38.534273	-121.22576
00102	SPDTv1.3	3K7	17-Mar-11	38.527578	-121.23498
00103	SPDTv1.3	8K2	17-Mar-11	38.533783	-121.22711
00104	SPDTv1.3	9K1	16-Mar-11	38.536513	-121.22508
00105	SPDTv2.3	1K8	05-Jul-11	38.52721	-121.23369
00106	SPDTv2.3	2K1	04-Nov-11	38.530596	-121.23016
00107	SPDTv2.3	8K5	04-Nov-11	38.528866	-121.22772
00108	SPDTv2.3	10K5	04-Nov-11	38.529173	-121.22966
00109	SPDTv2.3	4K7	04-Nov-11	38.528333	-121.23425
00110	SPDTv2.3	5K7	04-Nov-11	38.52804	-121.23244
00111	SPDTv2.3	2K7	04-Nov-11	38.526605	-121.23424

Pictures of the DMU installation on transformer 9K1 are given in **Error! Reference source not found.** and Figure 10.



Error! Reference source not found. shows the DMU installed on the transformer secondary with the voltage clips attached to the Z-bars and the Rogowski coils wrapped around the outgoing conductors.

Figure 10: DMU Installed on 9K1

InFigure 10 the transformer lid has been closed and the combo GPS/Cellular antenna is visible on top of the transformer case.

To date 11 of the 12 transformer monitors have been installed with the twelfth unit (transformer 8K5) at SMUD awaiting re-installation following necessary repairs. The eleven fielded units have been collecting data and functioning correctly for several months.

4.2 Data Collection and Storage

The data collected for this project can be organized into the following eight different categories:

1. GridPoint and SunPower RES and CES Data
2. Hourly Weather Data
3. Predicted Home Data
4. SunPower Supplemental Home Data
5. One Second Irradiance Data
6. SMUD SCADA Data
7. Transformer Monitor Data
8. One Minute Weather Data

The following sections explain:

- the type of data that is included in each of these data categories,
- where this data is being stored,
- how the data is updated,
- how this data is being queried so that analysis can be performed on it.

Section 4.2.1 and 4.2.2 cover data categories 1 through 6 and Sections 4.2.3 and 4.2.4 cover categories 7 and 8 respectively.

4.2.1 NREL FTP Site

In order to facilitate data sharing on this project NREL has setup an FTP repository to hold all of the various raw data sets associated with this project so that team members can have access to the raw data files necessary to perform analysis. Through a variety of transfer mechanisms with the different team members and data sources this FTP site is continually updated with the most recent data.
The data housed on this FTP is listed below along a brief description of the data set and the update mechanisms.

- *GridPoint and SunPower RES, CES, Hourly Weather, and Predicted Home Data* – Daily zip files containing RES, CES, PV, and RES home load monitoring data from GridPoint and SunPower measurements at RES and CES locations. This data is collected at 5 minute intervals. On days in which the batteries are used to perform firming, an additional data set is produced, which has RES home load, RES monitoring, and CES monitoring data collected at a frequency of 10 seconds. Predicted hourly home load and PV production data for each RES home is also included in this dataset. Finally, hourly weather data collected from two different weather stations is included in this dataset. New files are automatically transferred from GridPoint to NREL and uploaded onto the FTP site on a daily basis
- *SunPower Supplemental Home Data* – This dataset contains supplemental net household and PV production data collected by SunPower to augment the CES and RES impact analysis. A portion of this data is collected from households that are served by transformer locations that have CES. This data will enrich the CES impact analysis. This dataset also includes net household and PV production data collected by SunPower from households that are connected to neither RES nor CES devices. This data will serve as baseline data and will enrich both the CES and RES impact analysis. All of the data in this dataset is collected at 15 minute intervals. This data is stored as excel files containing a month's worth of data each. Files are transferred to NREL by email on a monthly basis and then added to the FTP site.

- *One Second Irradiance Data* – One second global horizontal irradiance measurements are taken by the NREL sensor located near the neighborhood entrance. Files are in comma separated value text format and contain a day's worth of one second data each. New files are periodically uploaded with a transfer from internal NREL servers.

- *SMUD SCADA Data* – Excel files containing a month of SCADA data each, measured at the entrance to the Anatolia Neighborhood. This data is collected at 5 second intervals. New data sets are periodically uploaded by SMUD.

4.2.2 Querying Data Stored on the FTP Site

In order to effectively query the data stored on the FTP site so that analysis can be carried out efficiently, various databases, query scripts and techniques have been developed by Navigant, GridPoint, and NREL.

GridPoint designed an SQL database which can accommodate all the GridPoint and SunPower RES, CES, Hourly Weather, and Predicted Data. GridPoint also created a data parser which loads all of this data into the database after it has been downloaded from the FTP site. Both the database and parser were delivered to Navigant. Navigant used the parser to populate the database with the data from the FTP site and periodically uses the data parser to update the SQL database with new files from the FTP site. Since receiving the database, Navigant has written the SQL query scripts necessary to pull data of interest from the database. The queries enable Navigant to pull specific metrics, from specific RES units, CES units, or homes on specific dates and times. Together the database, parser, and query scripts enable Navigant to efficiently pull the required data for carrying out their analysis.

Navigant also designed a data parser to create a single data table which collects all of the SunPower Supplemental Homes Data downloaded from the FTP site. Navigant then incorporates this table into the SQL database designed by GridPoint so that all data can be accessed from a single database. Finally, Navigant wrote the SQL query scripts necessary to pull data of interest from this table.

NREL developed a script to pull One Second Irradiance Data directly from the FTP site. This script has been delivered to Navigant and is used to facilitate data retrieval for analysis applications.
The organization of the SMUD SCADA Data within each Excel file obviates the need for a database, data parser, or query scripts. This is because each day of data is already organized in its own tab within each file and therefore no further query is required to find the necessary piece of data. The way in which the SMUD data is going to be used in the analysis only requires that a particular day of SCADA data be identified and the organization of the SMUD SCADA Data file makes this task easy and efficient.

4.2.3 Distribution Monitoring Data Collection and Servers

In this each DMU streams data back to a central server at NREL in real time. As data is received by the collection server, it is made available to a variety of visualization and analysis applications. The received data will also be stored locally at the receiving end. The basic system architecture is given in Figure 11. This data stream flows out of the meter through the cellular connection and internet then to the server hosting the data concentrator. The data concentrator collates the multiple incoming data streams, producing one large data stream containing all of the information from the various DMUs. The concentrator data stream is then passed to all of the applications requiring the measurement data. These include, but are not limited to, the data historian and various visualization applications. The data historian is responsible for maintaining and updating the database that stores all of the received measurements. The data visualization applications present both live and historic data in a variety of informative displays.

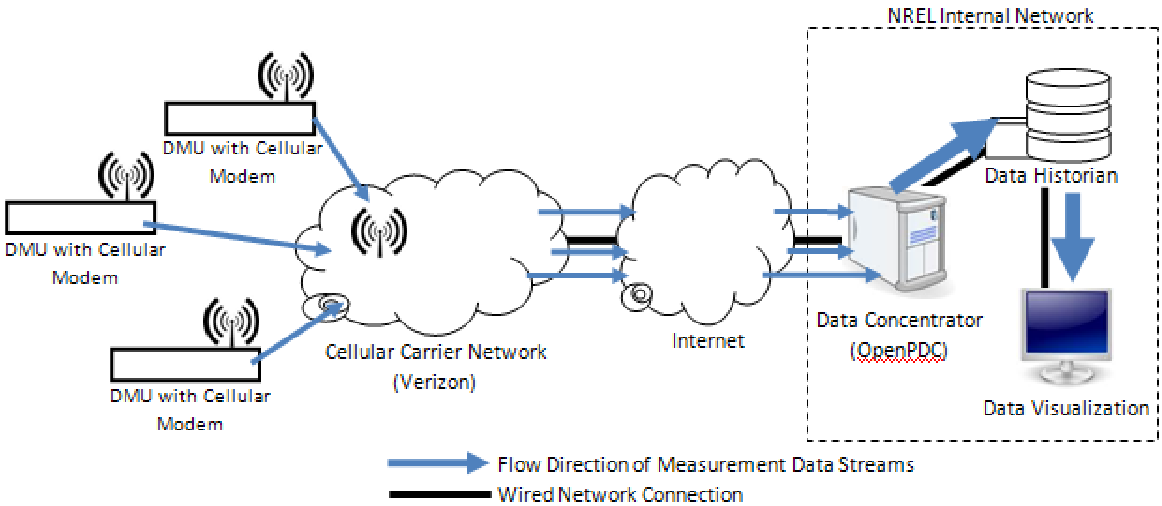


Figure 11 Simplified data collection network architecture

In order to facilitate retrieval of data from the historian a website has been developed. The website is the NREL Distribution Monitoring Database (DMD) query tool. It incorporates data with other outside sources of distribution measurement data into one easy to use HTML form-based tool for retrieving data sets. Internal and external (non-NREL) researchers can log onto this website, create and execute a database query, then download the results. Security to the DMD site is controlled with username and password authentication.

After creating an account and logging in the user can specify a query with the HTML form given in Figure 12. The first field here specifies the active project, which the user can select any project of which they are a member, and the remainder of the form will be setup based on the data sets that are associated with the active project. The next block of input sets up the timing parameters for the data set that the user is requesting. User inputs here include the data set start time, end time, and resolution and output time formatting. The last block of input is presented as a table of checkboxes through which the user can specify which measurement vectors to include in the output data set. In this case each column corresponds to a DMU and row to a measurement available for that DMU. The user adds a measurement to the output file by checking the corresponding box.

Upon submitting the form of Figure 12 the DMD website will connect to the historian and pull the data which the user has requested. This data will then be formatted into *.txt files containing semi-colon separated values. The *.txt files are combined into one ZIP archive which the user can then download through the *Download Results* subpage of the DMD site. Depending on the size of the requested data set it can take several seconds to hours for the query to be processed and the results made available for download.

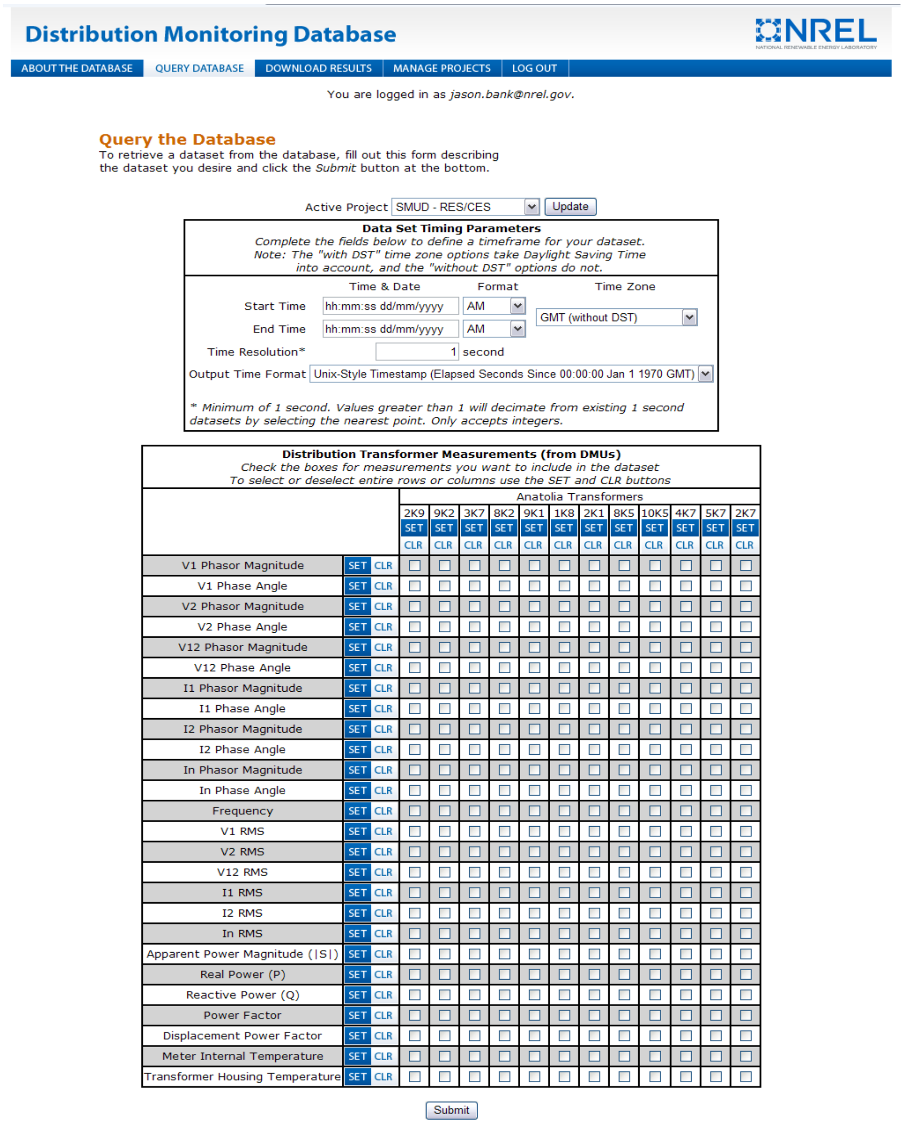


Figure 12: DMD Query Request Form

4.2.4 Measurement and Instrumentation Data Center

Data collected by the one minute Rotating Shadowband Radiometer (RSR) and weather station located at the Anatolia Substation is housed on NREL's Measurement and Instrumentation Data Center (MIDC) servers. The internal data logger captures one minute data from a variety of sensors, stores it internally and the MIDC servers download data sets from it hourly. The parameters measured at this location are summarized in Table 3.

Table 3: RSR Met Station Output Values

Description	Units
Global Horizontal	W/m^2
Direct Normal	W/m^2
Diffuse Horizontal	W/m^2
Global Horizontal PSP	W/m^2
Air Temperature	Deg C
Relative Humidity	%
Station Pressure	mBar
Zenith Angle	Degrees

These one minute data sets are available dating back to the installation of the met tower in February 2009 and are freely available for download from the internet at *http://www.nrel.gov/midc/smud_anatolia/*.

4.3 Testing

4.3.1 Test Plan

We have created an initial test plan around the operating scenarios to answer this project's Key Research Question (both the operating scenarios and Key Research Questions are in the Appendix). A testing schedule was created around the following constraints:

- We are currently scheduling through September. We'll revisit the plan in September.
- The storage appliances must run in Firming mode for the first two weeks for calibration.
- To take advantage of the Super Peak Season (SMUD's system peak is typically from 4 to 7 PM during the summer months) and associated TOU pricing, we are only running one RES firming scenario.
- Operating Scenarios 9 through 11 are not needed until Super Peak Season.
- Operating Scenarios 5 and 6 are demonstrations, rather than tests. So they only will be run a few times.
- We scheduled tests in one week blocks, starting on Saturdays to minimize the time required for scheduling and to avoid schedule changes on the weekend.
- We are doing firming throughout the year to assess the value of firming as a function of seasonal weather patterns.
- For June, July and August, we are only trying custom firming scenario 11 because the sun doesn't set until ~8 PM. Based upon what we learn this summer, we will try other start times next summer.
- Statistical significance at the 90% confidence interval.

Refer to our Monitoring and Testing Plan for the full schedule. This test plan will be reviewed and likely revised over time as we: analyze initial results, learn more about the storage unit's behavior; and add operating scenarios.

4.3.2 Tests Performed to Date

Table 4 shows what tests have been run on the RES units through May (June testing is still ongoing at the time of the writing of this report). Load shifting by price was not run through May because SMUD's Time of Use Rates did not go into effect until June 1st. We had prioritized firming during the spring to take advantage of the variable solar insolation that is typical in the Sacramento area at that time of year. As discussed above, we will focus our summer testing on load shifting because that is when SMUD's super peak occurs.

Table 4. Summary of RES Testing Through May

	Number of Tests Run		
RES Unit #	Firming	Predictive Load Shifting	Custom Load Shifting
1	41	15	6
2	46	16	16
3	46	16	24
5	43	16	14
6	43	16	10
7	17	6	7
8	42	16	18
9	37	16	17
9	23	1	11
10	42	16	15
11	22	1	21
12	42	16	15
13	41	16	17
14	2	0	0
15	43	19	9

Table 5 shows a summary of CES testing through May. These units were installed much later than the RES units, so they have less testing days. In the summer, we will be equally prioritizing firming – to see if storage has any value in moderating air conditioning loads or solar ramps because of clouds – and load shifting.

Table 5. Summary of CES Testing Through May

	Number of Tests Run	
CES Unit #	Firming	Load Shifting
1	29	26
2	27	34
3	28	3

4.3.3 Preliminary Observations

This section presents our preliminary observations of the data from each of the battery operating modes. The data presented here should be considered draft as we continue to run tests and study data.

4.3.3.1 RES Firming

May 31, 2012 was a RES Firming Test Day. This was also a clear day and therefore, as Figure 15 shows, PV output was very predictable and contributed no intermittency to the load that the grid had to serve in this home. However, as Figure 13 shows, there are appliances in the home that contributed significantly to load variability. In the case of the home connected to RES Unit 6, there was an appliance cycling on and off from 12PM to 12AM that caused load to oscillate over a ~4,000 watt band. This was likely the air conditioning system maintaining home temperature throughout the day and night. Figure 13 also shows how the firming action of the battery (in this case alternating charging and discharging cycles), dampened the load that the grid had to provide to this home. Firming was scheduled to take place from 8AM to 4PM on this day, but the firming action of the battery did not start until the home load began to exhibit load oscillations at around 12PM. The impact of the firming action can be clearly observed by looking at the home load when firming stops at 4PM. After 4PM, without the benefit of the RES firming action, the graph shows how the home load oscillates over a much larger band.

The high resolution 10 second frequency data graphed in Figure 15 shows a more detailed view of the period highlighted by the red box in Figure 13. In addition to showing the home load with firming, this graph also shows a calculated value which represents what the home load would have been without firming. Once again, the damping effect of the RES firming action is plainly depicted in the graph. Other than an initial power spike at the beginning of a disturbance (i.e. when the home load either rises or falls rapidly), the home load with firming oscillates over a narrower power band than the home load without firming. The cause of the spike at the beginning and end of each oscillation is due to the fact that the firming algorithm adjusts the target output of the battery every 10 seconds; therefore, there is a 10 second lag between when the ideal target output is calculated and when the battery can try to achieve that target ideal output.

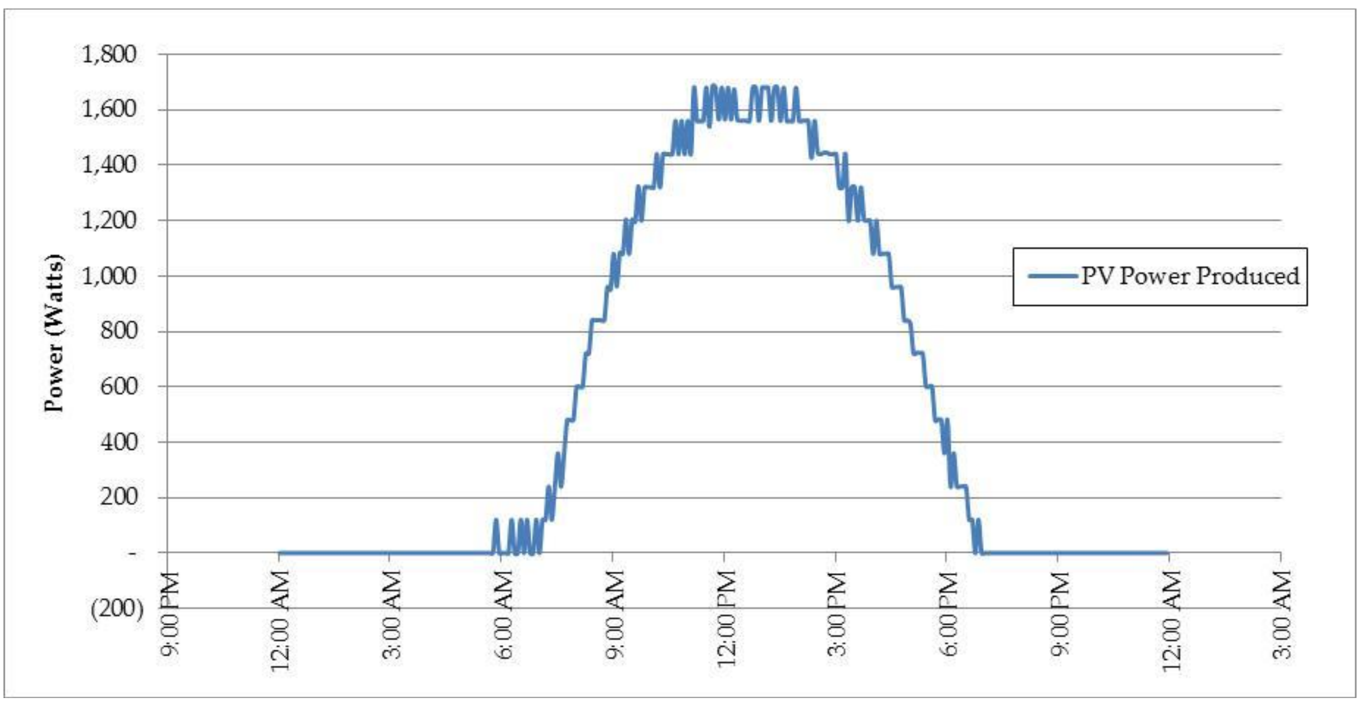


Figure 12. RES Unit 6, May 31st 2012, PV Power Produced During Firming

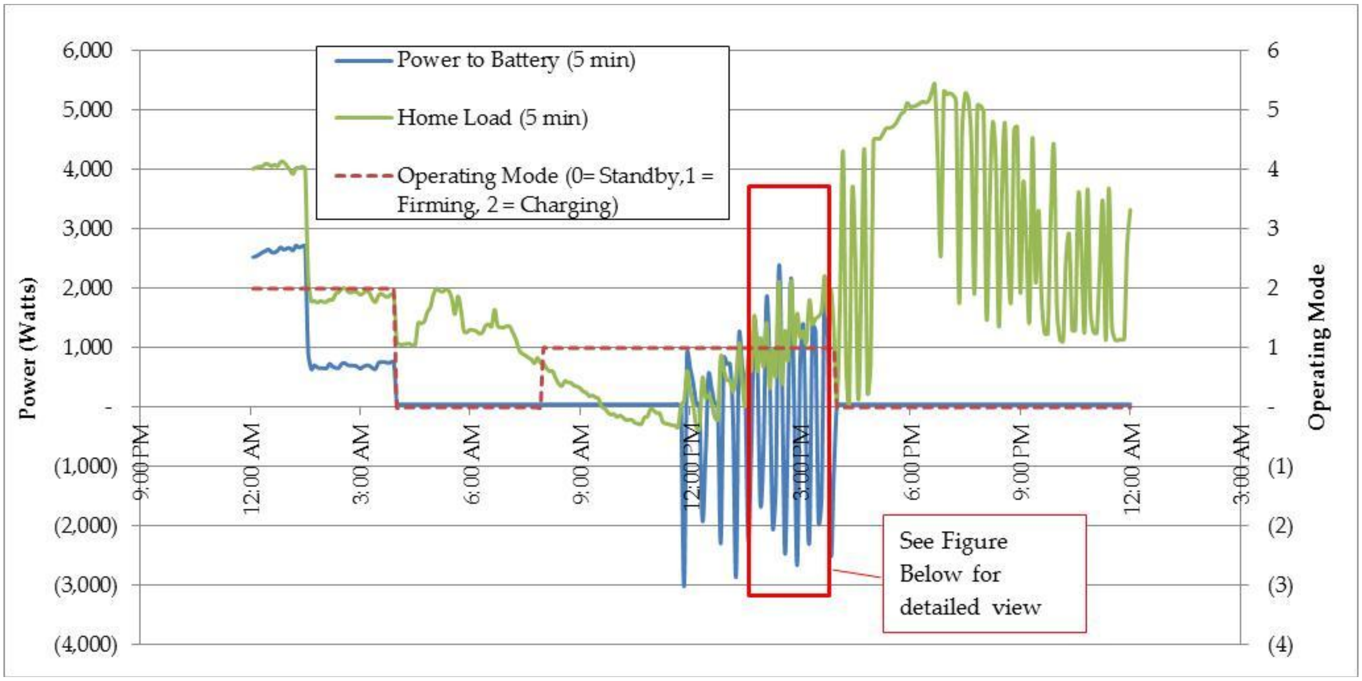


Figure 13. RES Unit 6, May 31st 2012, Battery Power and Home Load During Firming

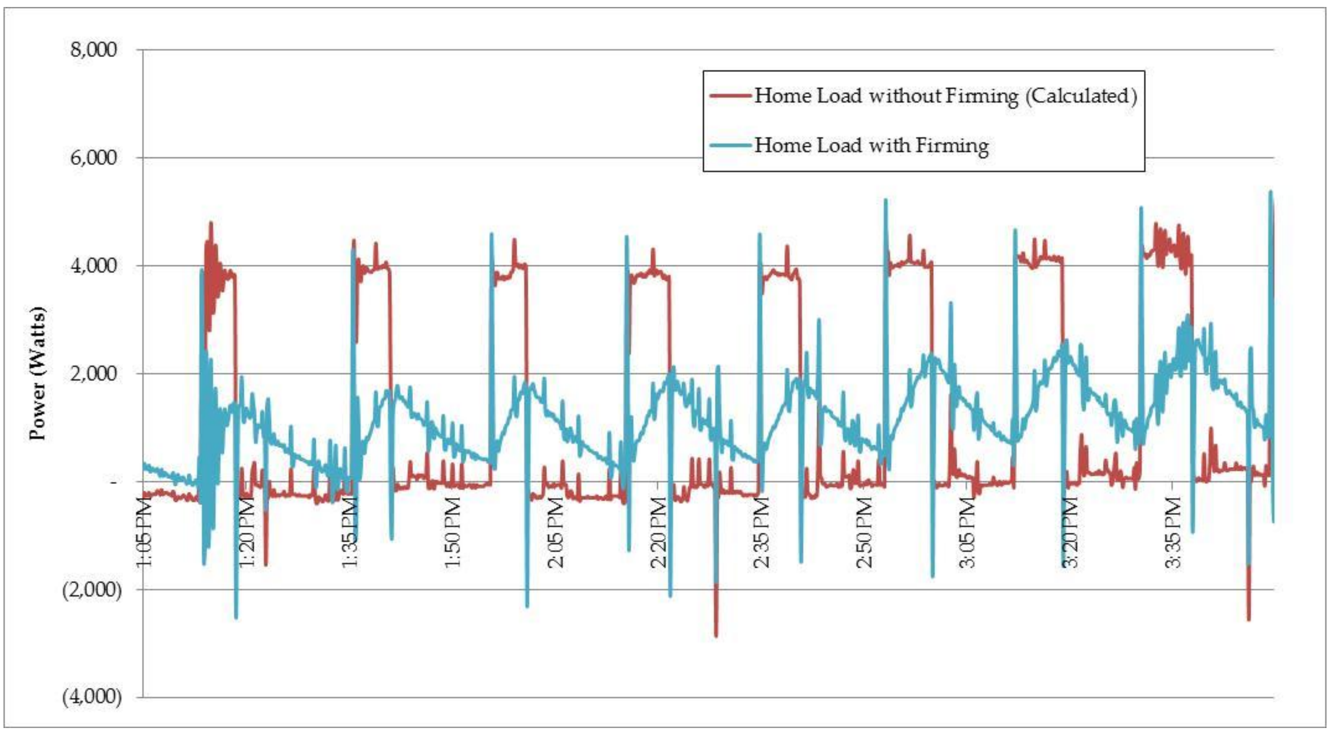


Figure 15. RES Unit 6, May 31st 2012, Home Load with Firming vs. Home Load without Firming

4.3.3.2 RES Custom Load Shifting

The graphs in Figure 15 through Figure 18 show the results of custom load shift testing on a clear day and on an intermittent day. Figure 15 and Figure 17 show the PV outputs of two homes connected to RES units on April 13th and 15th respectively. These graphs show that the 13th was an intermittent day, in terms of solar output, and the 15th was a clear day. Figure 16 and Figure 18 show the home load, the RES power discharge (a positive value represents discharging and a negative value represents charging), and the operating mode of the battery. On both of these days the battery was scheduled to charge from 12AM to 4AM, this time was chosen for charging because it is off-peak and presumably when electricity demand, and therefore price, is lowest. The impacts of this charging can be observed in the home load of each graph; there is a step change increase in home load during the period of time when the batteries were charging. The batteries were then scheduled to discharge from 3PM to 4PM. During this time the batteries discharged at a rate of ~5.5kW, which depletes the batteries from full charge to about 20% state of charge, which for technical reasons is effectively fully depleted. The impact of this discharge on the home load is visible in Figure 16 and Figure 18. The PV power was already causing electricity to be exported to the grid and the added battery discharge from 3PM to 4PM is so large that the homes export a significant amount of electricity to the grid during this time.

These results demonstrate that regardless of PV output, the RES units have the potential to alter net home load for several hours. Although the battery discharges on these days were scheduled for a single hour, the discharges could have been scheduled for 3 to 4 hours and the batteries would have been able to provide about 1.8kW to 1.4kW of power over this period. This might be a more ideal RES discharge period and power output in terms of addressing peak demand during SMUD's summer "super-peak" period from 4PM to 7PM. In future custom load shifting test days the discharging will be scheduled to take place later in the day, and over this longer period so the batteries are not fully depleted in a single hour, and can better address SMUD's "super-peak" period.

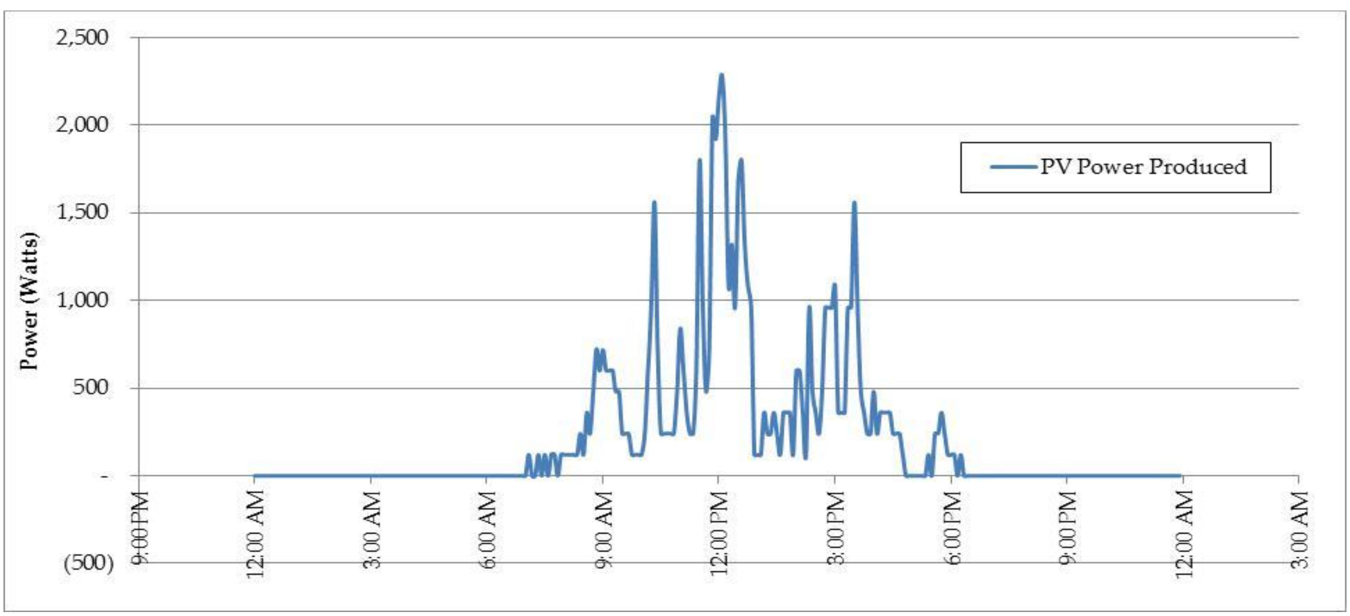


Figure 15. RES Unit 13, April 13th 2012, PV Power Produced During Custom Load Shifting

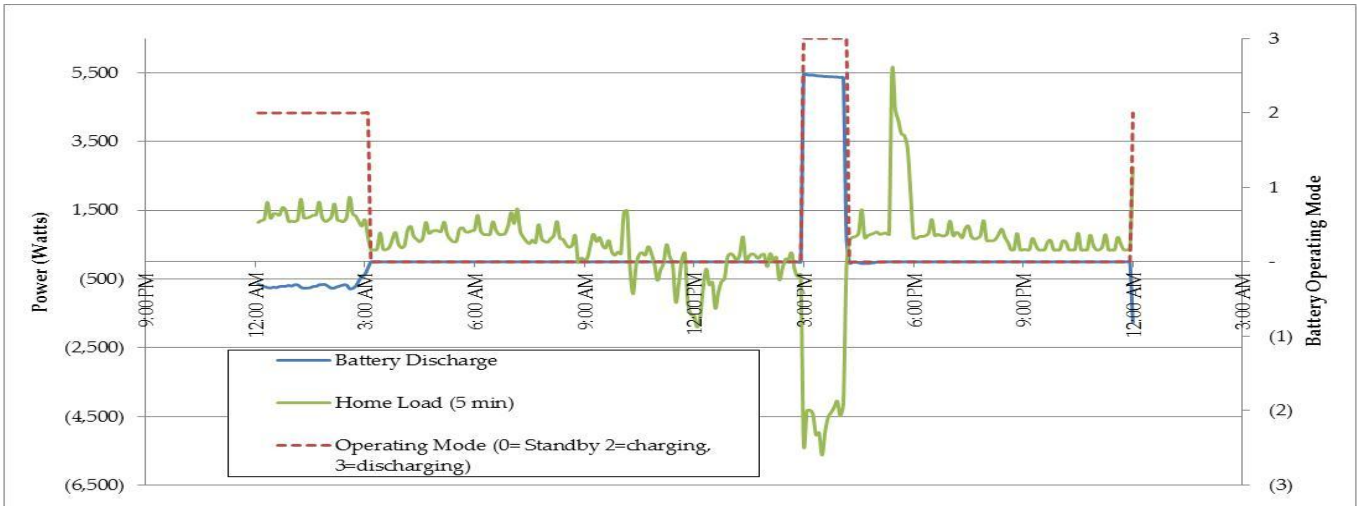


Figure 16. RES Unit 13, April 13th 2012, Battery Power and Home Load During Custom Load Shifting

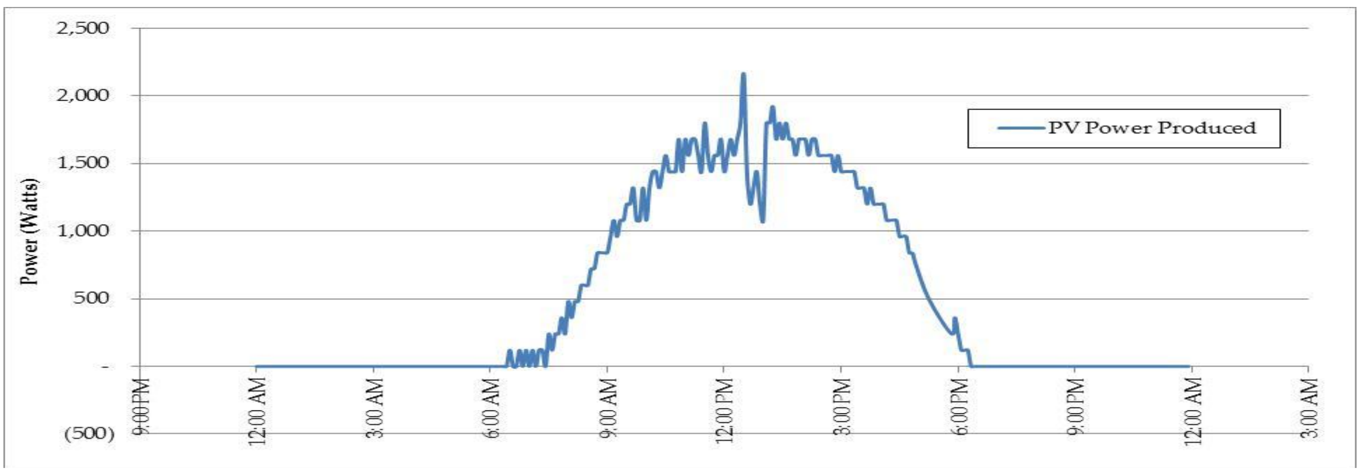


Figure 17. RES Unit 12, April 15th 2012, PV Power Produced During Custom Load Shifting

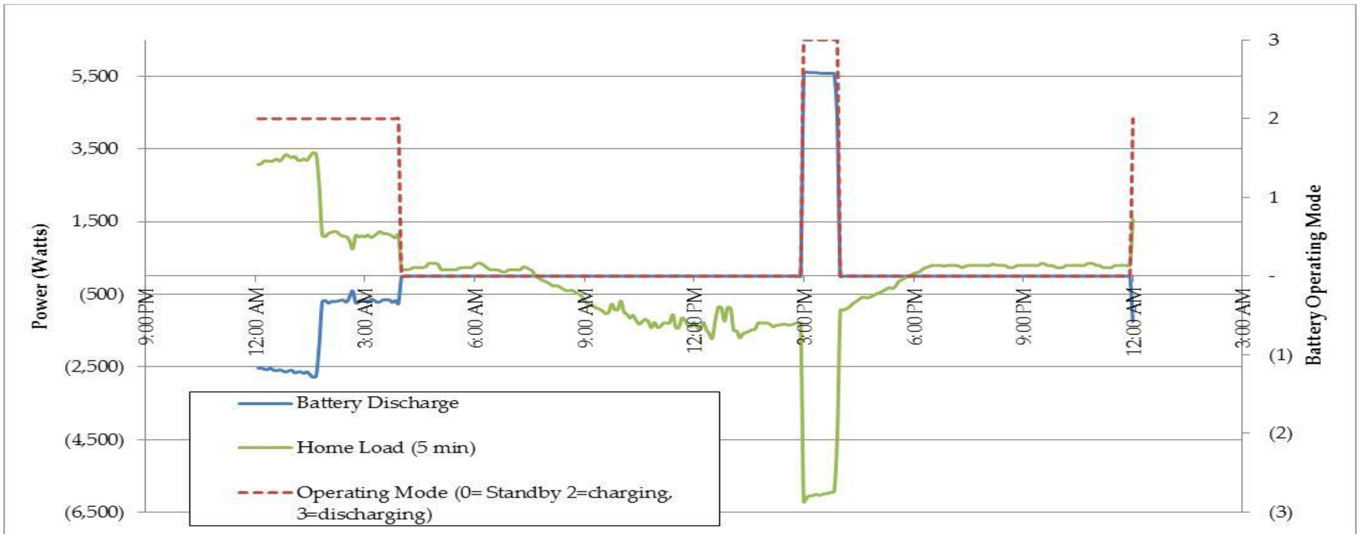


Figure 18. RES Unit 12, April 15th 2012, Battery Power and Home Load During Custom Load Shifting

4.3.3.3 RES Predictive Load Shifting

Figure 19 through Figure 21 show the results of Predictive Load Shift Testing from various RES homes on May 15th and
Figure 22 shows the same for an RES home on May 12th. Both of these days were perfectly clear days with optimum PV production (PV power output graphs are not shown). The algorithm that controls the battery output for Predictive Load Shift Testing uses information such as historical load, weather (current and forecasts), and PV output, etc. to forecast day-ahead load shifting requirements with the goal to achieve levelized energy by utilizing the RES units. Although more analysis will need to be conducted in order to fully understand how well the algorithm is working, a general pattern of how the algorithm is causing RES to operate on May 15th can be determined by comparing Figure 19 through Figure 21. In each of these cases the algorithm causes the battery to charge from 8AM to 12:30PM. The algorithm then causes the battery to discharge very gradually over a period of about 8 to 12 hours. This discharging is initiated either late in the day (as in Figure 19 and Figure 20) or late at night (as in Figure 21). Our team will continue to analyze this battery operating mode and assess its value as preliminary results show variations in behavior that we cannot explain yet.

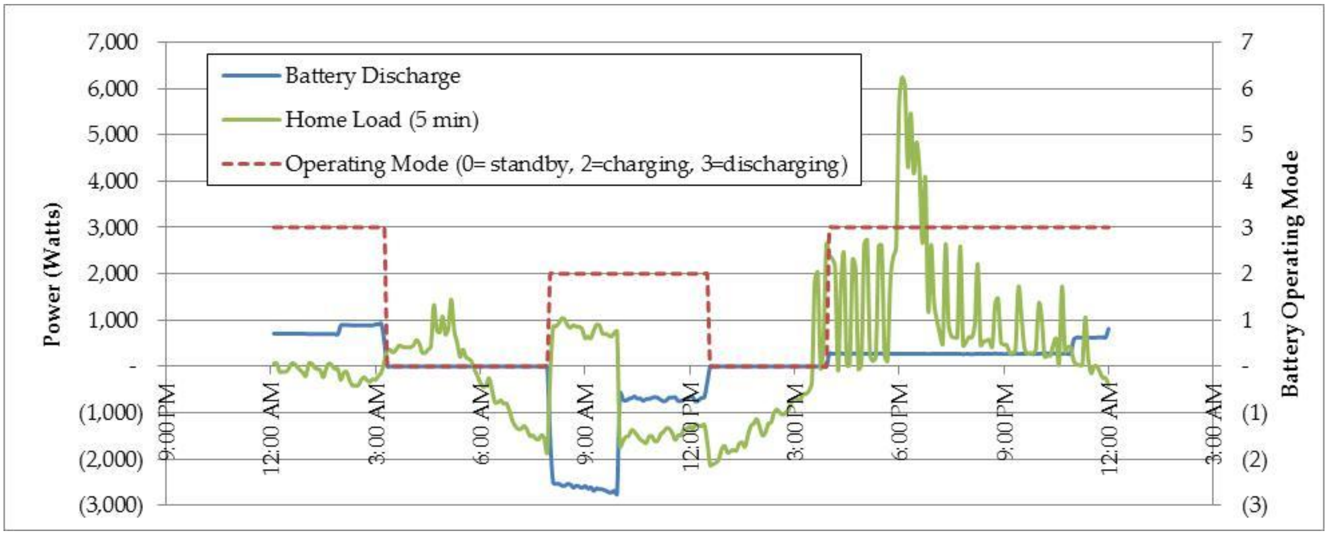


Figure 19. RES 15, May 15th 2012, Battery Power and Home Load During Predictive Load Shifting

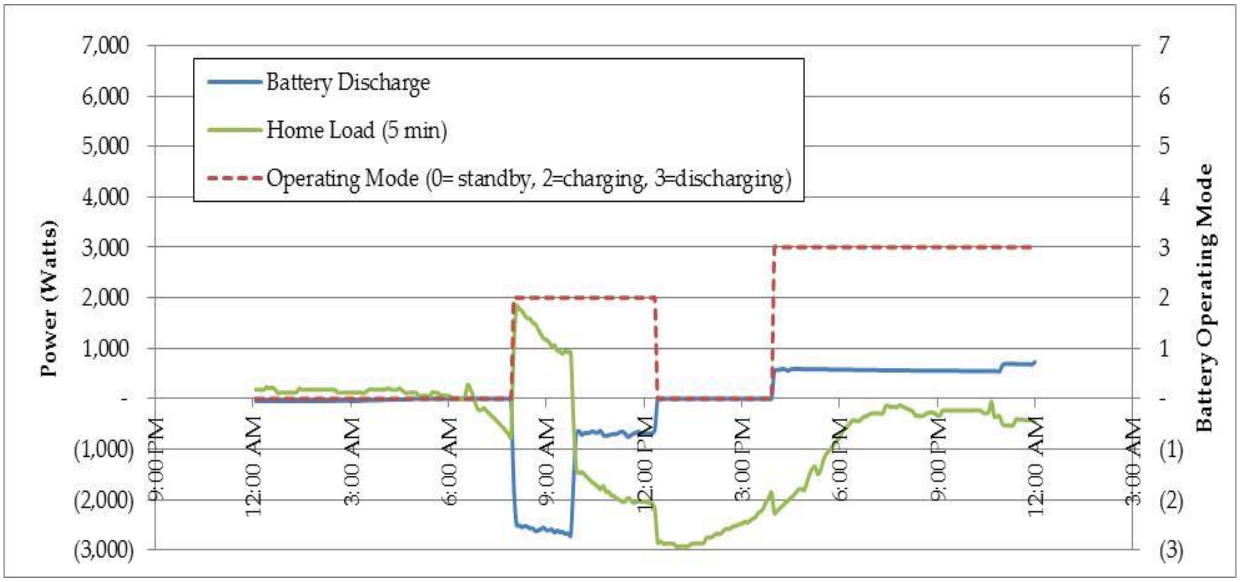


Figure 20. RES 1, May 15th 2012, Battery Power and Home Load During Predictive Load Shifting

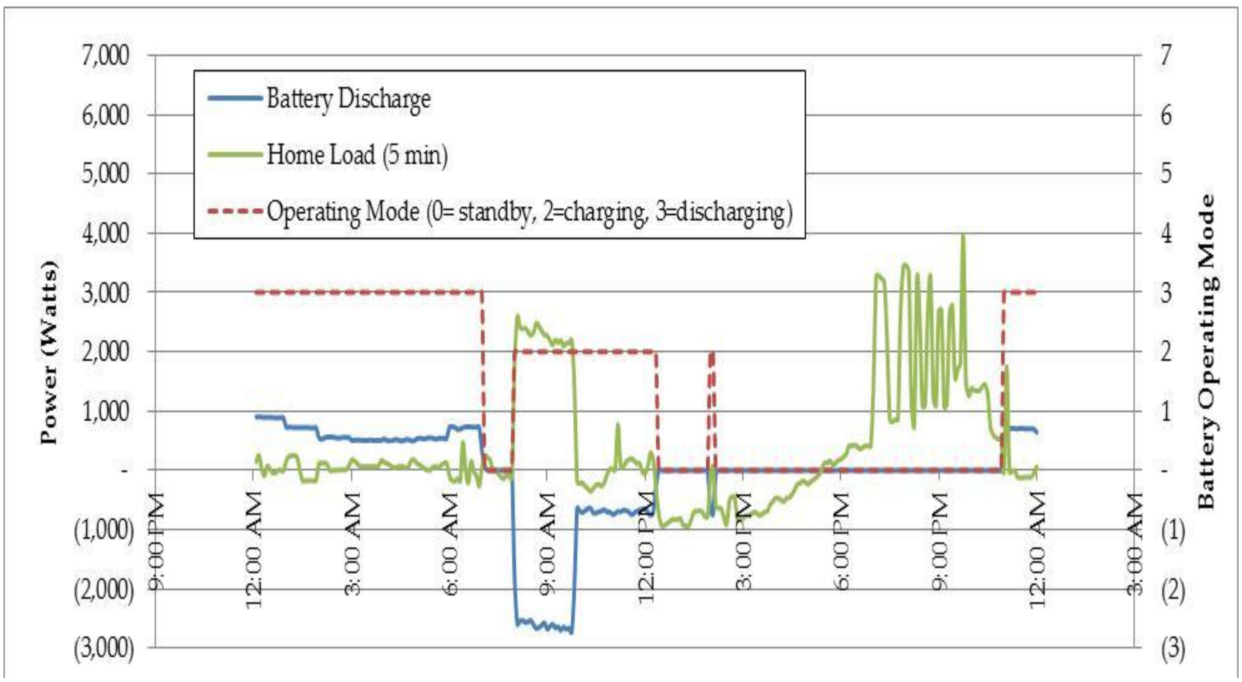


Figure 21. RES 9, May 15th 2012, Battery Power and Home Load During Predictive Load Shifting

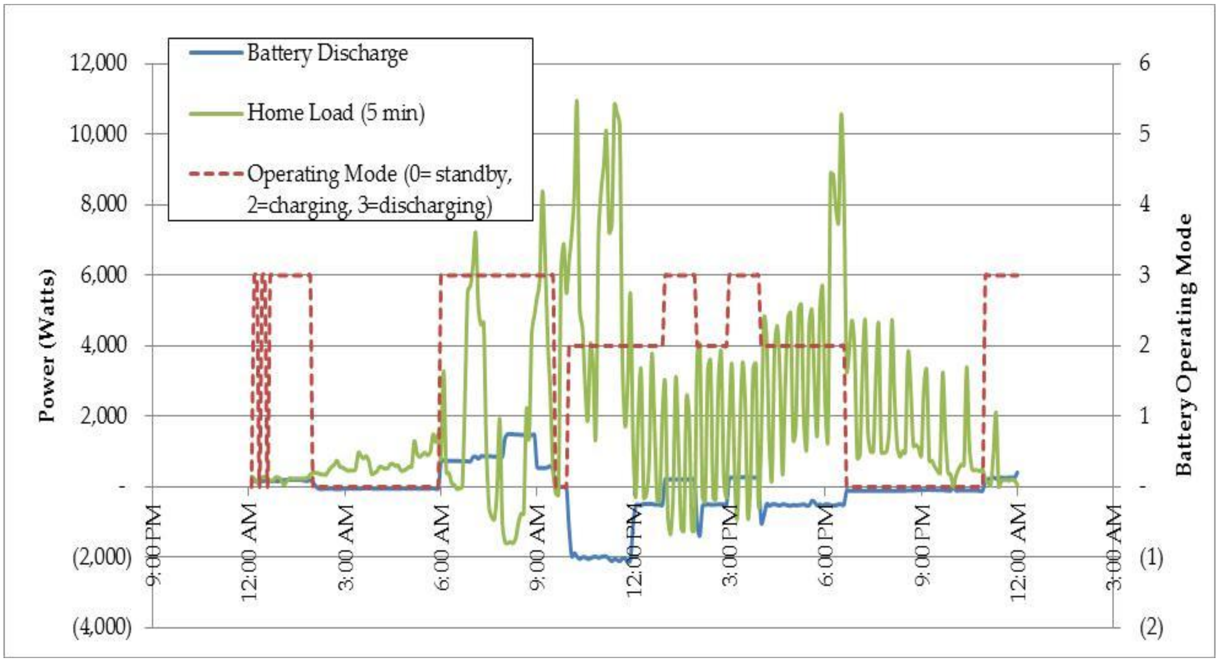


Figure 22. RES 8, May 12th 2012, Battery Power and Home Load During Predictive Load

4.3.3.4 CES Custom Load Shifting

Figure 23 shows the results from a CES Custom Load Shift Test Day. The shape of the global horizontal irradiance (GHI) curve suggests that this was a clear day with high and consistent PV output. The corresponding shape of the transformer load curve from about 7:30AM to about 4:30PM confirms this hypothesis; the transformer load curve exhibits that shape one would expect when about ten 2kW PV arrays are all supplying power to the grid. On this Custom Load Shift Testing Day the CES unit was scheduled to charge from 4AM to 6AM. During this time the battery reached a full state of charge. The impact of this charge is clearly depicted in the transformer load curve during that time. The CES unit was then scheduled to discharge from 2PM to 3PM. The battery was effectively depleted over this discharge period.

The insights and lessons learned from these results are very similar to those that were drawn from the RES Custom Load Shifting tests; therefore, rather than providing a protracted discussion, the insights and lessons learned are simply summarized in bullet form below.

- CES units have the potential to drastically alter transformer load for several hours.
- Discharge could have been scheduled for 3 to 4 hours and the batteries would have been able to provide about 5kW to 6.7kW of power over this period.
- A longer discharge period that takes place later in the day will be scheduled in future tests to better address SMUD's "super-peak" period.
- The ideal charging period depends on when SMUD's cost of electricity supply is lowest.
- Reliable cloud forecasts could allow SMUD to determine if there will be enough energy from the aggregate PV systems to make charging the CES units during the peak PV production period worthwhile.

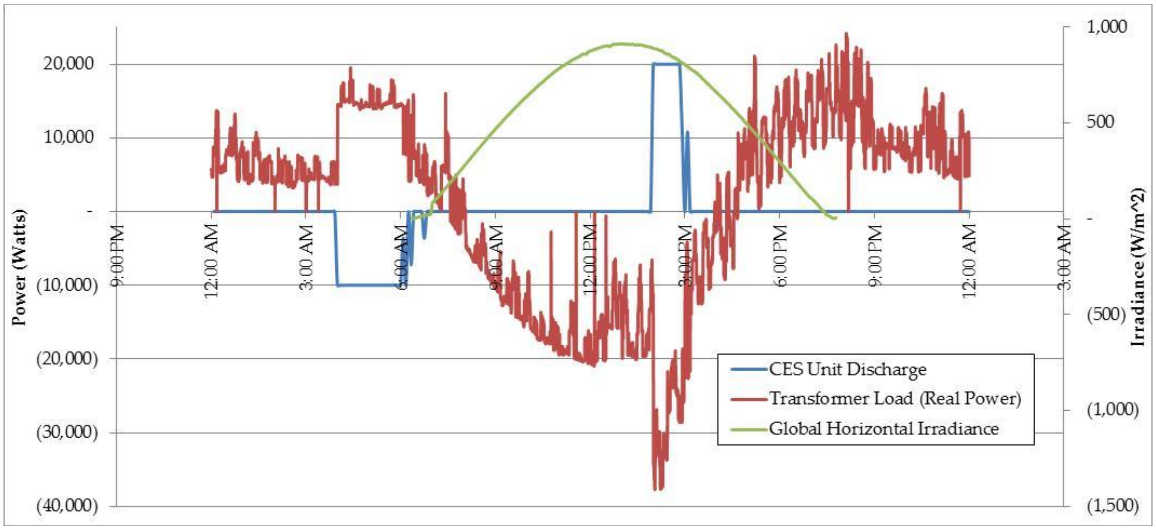


Figure 23. April 22nd 2012, Weather, CES Discharge & Transformer Load on CES Custom Load Shifting

CES Firming

We have run many days of CES firming, but we are still analyzing the data and interpreting the results. We anticipate having this data ready to present for our next update report. Feeder Monitoring Figure 24 shows feeder load data on a sunny day in October. The Figure shows that when the sun is shining, the high penetration of PV systems in the neighborhood results in a net export. This has implications for the value of storage and potentially on the feeder level impacts of intermittent solar going forward in our study.

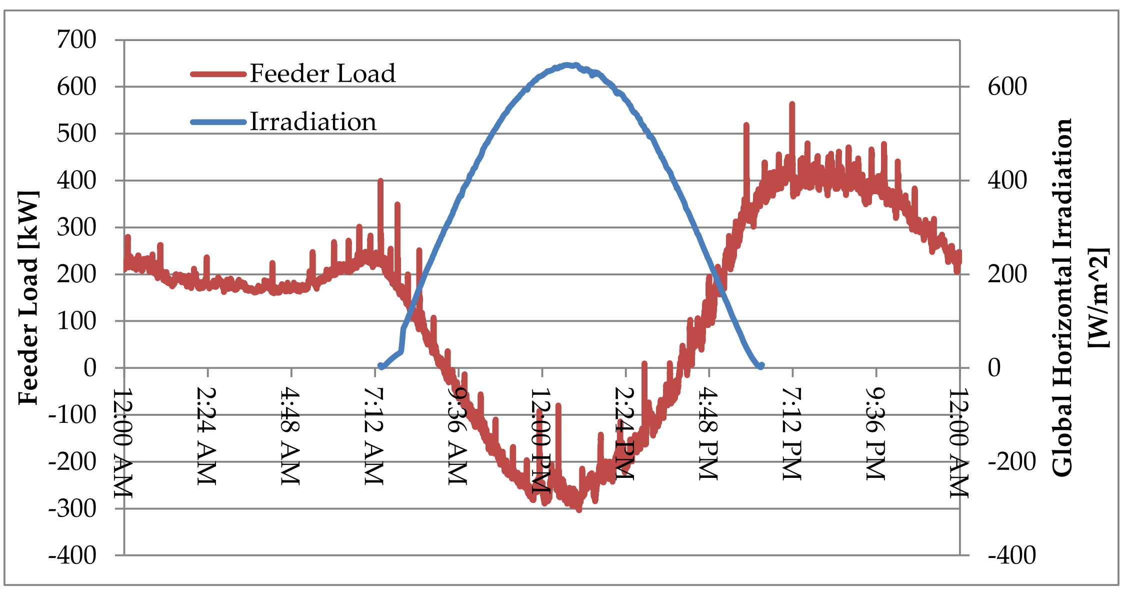


Figure 24. Demonstration of Feeder Level Export on Sunny Day

4.4 Lessons Learned

- So far the equipment is operating as expected with only minor issues with the Transformer monitoring equipment failing. The Transformer equipment when it does fail can often be reset by an SMUD troubleshooter but if the unit fails to respond it must be sent back to NREL for service. This has happen four times over the course of the project and all units are online and operating as designed.

- The cellular modems occasionally drop data but this is largely due to the remote location of this neighborhood and the sparse cellular coverage
- The homes in this neighborhood appear to mostly be net exporters while solar is producing. This will have implications on the effectiveness of firming and the effectiveness of load shifting while solar is producing.
- At the transformer level, when the CES units are placed in load shifting, they discharge in ~1 hour, so we will have to adjust their discharge rate going forward.

Table 6 . Key Research Questions

Strategic Objective 1	**Understand how the integration of energy storage could enhance the value of distributed PV resources within the community**
Key Research Questions	• Does the location of energy storage significantly change the utility's ability to "firm" customer load and distributed PV capacity? • How much storage is necessary to accomplish the desired PV and load firming effects? • Can an integrated PV/energy storage system provide reliability benefits for customers?
Strategic Objective 2	**Determine if the addition of energy storage could add value for the utility**
Key Research Questions	• Can energy storage in a high penetration solar deployment help support SMUD's "super-peak" from 4 PM to 7 PM, particularly when PV output drops off after 5PM? • Does the location of energy storage significantly affect the ability of the utility to manage the resource? • How variable is PV output within a community or distribution feeder, and what is the potential operating impact for the utility?
Strategic Objective 3	**Determine how to leverage SMUD's AMI investment to manage a distributed PV/energy storage resource**
Key Research Questions	• Can a smart meter be used to monitor and control a PV system, and to what extent? • What are the practical challenges associated with using AMI for managing PV? • What are the technical requirements for integrating inverters and smart meters, and what codes, standards and reference designs must be developed?
Strategic Objective 4	**Determine if capacity firming and advanced pricing signals will influence the energy usage behaviors of customers**
Key Research Questions	• Do the customers who have capacity firming capability (energy storage) behave differently than those who do not? • Do the customers with the RES behave differently than those with CES? • How does energy storage impact the customer's ability/desire to respond to pricing signals?

4.5 Current Operating Scenarios

1. **Battery is placed in Load Firming mode.** The storage systems used in this project have a firming algorithm where the storage uses real-time and historical load data, weather data, solar output, etc. to firm a home's net load around a certain value. Putting the battery in this mode will help answer Key Research Question #1 and #2

2 – 4. **Battery provides firming, but the battery capacity is varied.** Key Research Question #2 asks how much storage is necessary to firm PV and customer load in SMUD's service territory. For this project, the actual batteries being used are fixed capacity, but the effective maximum storage capacity is variable. By limiting the output of the battery, this test will simulate the performance of smaller battery and will give SMUD an idea of how much battery capacity is required given the community's particular weather patterns, housing construction, load profiles, etc. The battery SOC will be monitored to see if it reaches its set point. This will also help answer Key Research Question #1.

5. **Battery dispatch to provide frequency regulation.** This test will prove out a function of PV-Storage and will likely be repeated less frequently than other tests. The intent is for SMUD to command the battery to charge or discharge in order to help regulate frequency (or follow load) on the distribution network. The results will then be included in the overall strategic recommendations resulting from this project. This will help answer Key Research Question #3.

6. **Battery dispatch to provide phase balancing.** This operating scenario's intent is to use storage to help SMUD deal with phase imbalances. This operating can only be tested if site selection allows installation of a critical mass of CES on a single phase (A, B or C) in the community. While the existing community likely doesn't have a phase balance issue, this test would hopefully demonstrate that the storage units are capable of change loading on on particular phase. This will help answer Key Research Question #3.

7. **Battery is placed in Predictive Load Shifting Mode to optimize on energy.** The storage system being used in this project has a load shifting algorithm that uses information on historical load, weather, PV output, etc. to forecast day-ahead load shifting requirements. This algorithm has a number of optimization goals. This test will optimize to achieve levelized energy by utilizing the CES units. This operating scenario will help answer Key Research Question #2. This might be run with the RES units as well, depending on when the advanced rate is implemented.

8. **Battery is placed in Load Shifting by Price mode to optimize on daily cost of electricity.** In addition to being able to optimize load shifting around energy usage, the storage system can also optimize on electricity cost (relying on day-ahead electricity prices and forecasted net load). The RES customers will likely be on an advanced electricity rate at some point during the demonstration. Therefore, the load shifting algorithm can be used to minimize the customer's daily electricity cost by charging during times of low cost and discharging during times of high cost. This operating scenario will help answer Key Research Question 2.

9 – 11. **Battery is programmed to discharge during super peak.** Putting the battery in discharge mode during super peak and monitoring total transformer load against the control group's transformers will answer Key Research Question #4. However, SMUD needs to know when to start the discharge given variables such as typical customer loads, solar output profiles, etc.

Printed on Recycled Paper

Operating scenarios 9 through 11 will vary the initiation of discharge to determine when discharge should start in order maximize the usefulness of both PV and storage and if that time varies seasonally.

See "Test and Monitoring Plan" Exhibit for the following technical specifications:

1. PV Storage and Benefits Framework
2. Monitoring and Test Plan
3. SMUD Operating Modes
4. Integration Test Plans
5. RES UL Testing Results
6. High Pen Architecture
7. NREL IEEE 1547Test Plan and results for CES 1,2,3
8. NREL DMU for Distribution Transformers
9. SAFT Tech Specs

4.6 Next Steps

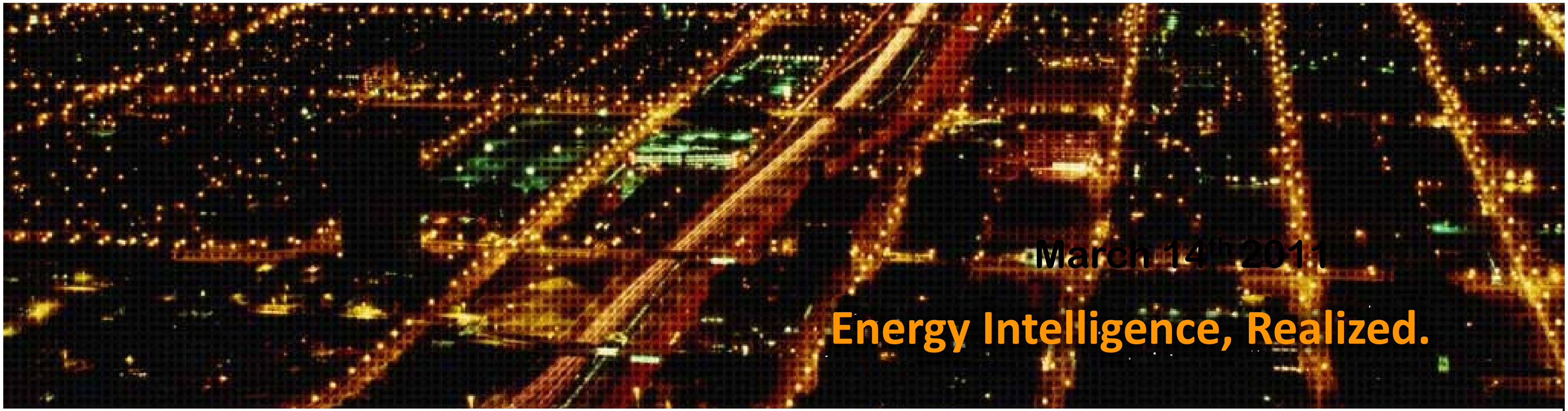
Going forward, we will continue on our current test plan through September. In parallel, we are working on developing methodologies to quantitatively answer the key research questions and begin to analyze the benefits of this project. At the end of September, we will revisit our plan and make adjustments accordingly.

Printed on Recycled Paper

Residential Energy Storage

Technical Specifications

GRIDPOINT

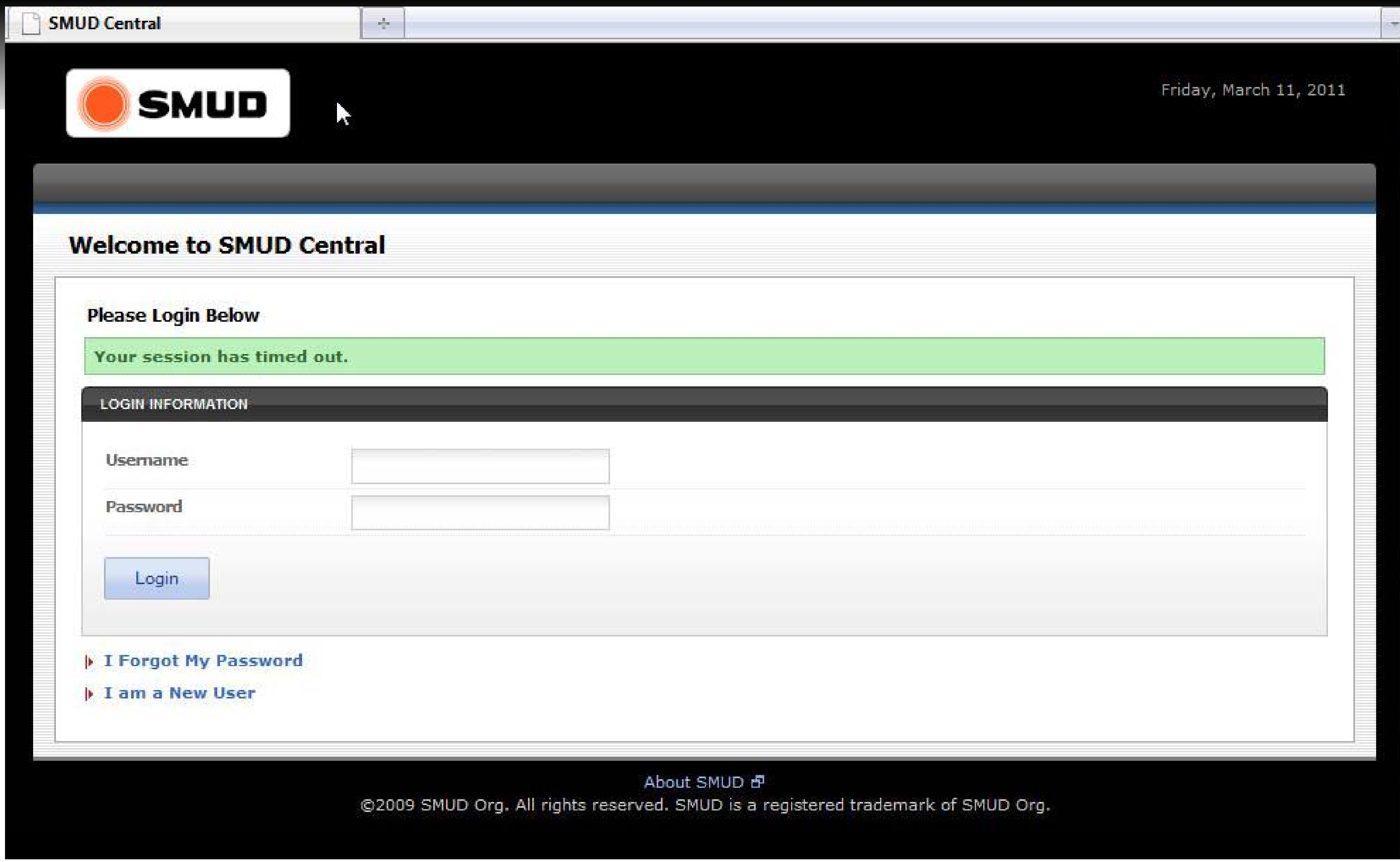


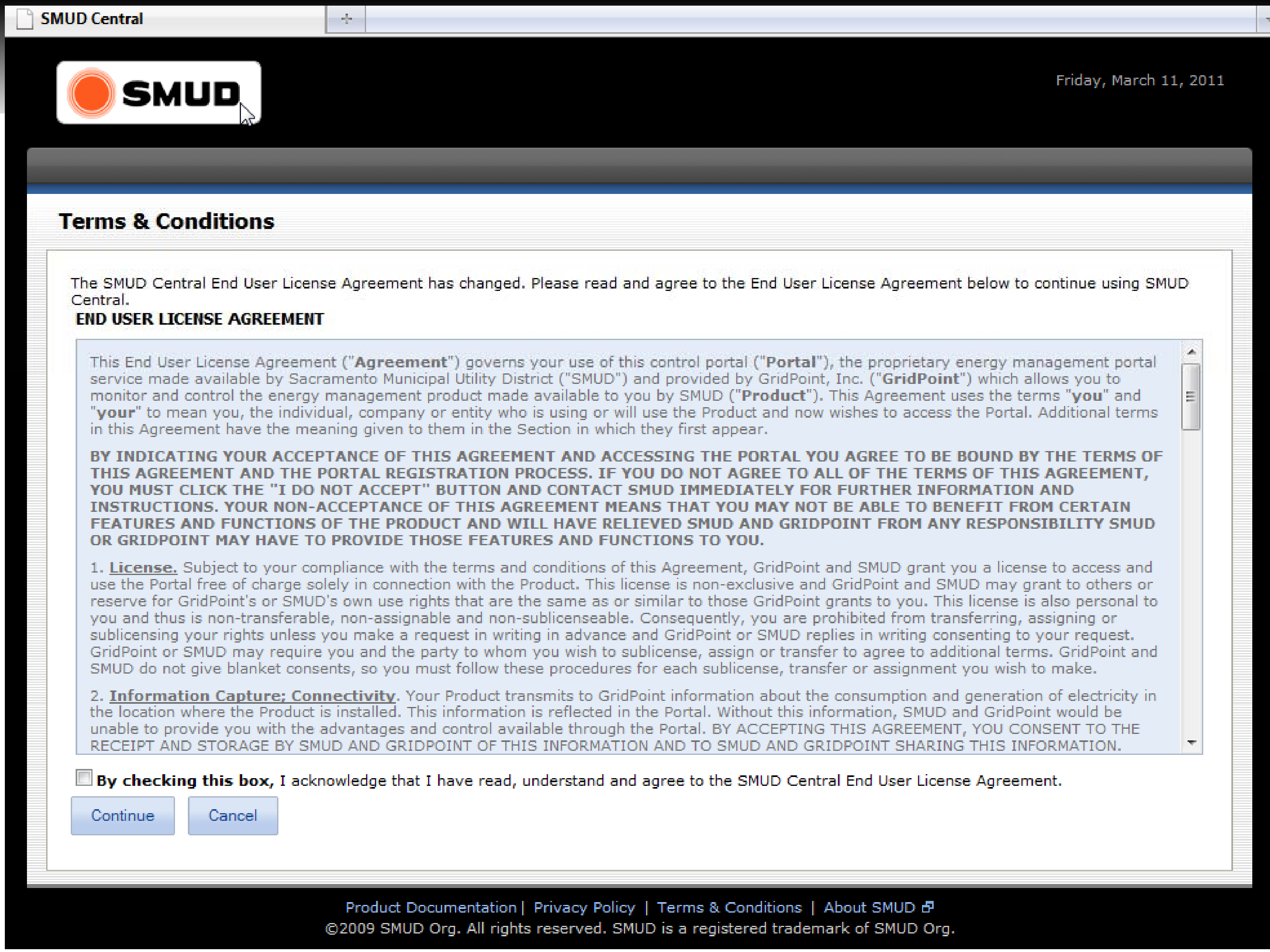
SMUD – HEM Presentation

March 14th 2011

Summary

- Welcome to SMUD Central / Login Screen
- SMUD Policy
- Main Dashboard
- Product Profile, including alerts
- Reports
- My Account
- Customer Service
- Help


SMUD Central
SMUD
Friday, March 11, 2011
Welcome to SMUD Central
Please Login Below
Your session has timed out.
LOGIN INFORMATION
Username
Password
Login
I Forgot My Password
I am a New User
About SMUD
©2009 SMUD Org. All rights reserved. SMUD is a registered trademark of SMUD Org.



SMUD Central

SMUD

Friday, March 11, 2011

Terms & Conditions

The SMUD Central End User License Agreement has changed. Please read and agree to the End User License Agreement below to continue using SMUD Central.

END USER LICENSE AGREEMENT

This End User License Agreement ("**Agreement**") governs your use of this control portal ("**Portal**"), the proprietary energy management portal service made available by Sacramento Municipal Utility District ("SMUD") and provided by GridPoint, Inc. ("**GridPoint**") which allows you to monitor and control the energy management product made available to you by SMUD ("**Product**"). This Agreement uses the terms "**you**" and "**your**" to mean you, the individual, company or entity who is using or will use the Product and now wishes to access the Portal. Additional terms in this Agreement have the meaning given to them in the Section in which they first appear.

BY INDICATING YOUR ACCEPTANCE OF THIS AGREEMENT AND ACCESSING THE PORTAL YOU AGREE TO BE BOUND BY THE TERMS OF THIS AGREEMENT AND THE PORTAL REGISTRATION PROCESS. IF YOU DO NOT AGREE TO ALL OF THE TERMS OF THIS AGREEMENT, YOU MUST CLICK THE "I DO NOT ACCEPT" BUTTON AND CONTACT SMUD IMMEDIATELY FOR FURTHER INFORMATION AND INSTRUCTIONS. YOUR NON-ACCEPTANCE OF THIS AGREEMENT MEANS THAT YOU MAY NOT BE ABLE TO BENEFIT FROM CERTAIN FEATURES AND FUNCTIONS OF THE PRODUCT AND WILL HAVE RELIEVED SMUD AND GRIDPOINT FROM ANY RESPONSIBILITY SMUD OR GRIDPOINT MAY HAVE TO PROVIDE THOSE FEATURES AND FUNCTIONS TO YOU.

1. **License.** Subject to your compliance with the terms and conditions of this Agreement, GridPoint and SMUD grant you a license to access and use the Portal free of charge solely in connection with the Product. This license is non-exclusive and GridPoint and SMUD may grant to others or reserve for GridPoint's or SMUD's own use rights that are the same as or similar to those GridPoint grants to you. This license is also personal to you and thus is non-transferable, non-assignable and non-sublicenseable. Consequently, you are prohibited from transferring, assigning or sublicensing your rights unless you make a request in writing in advance and GridPoint or SMUD replies in writing consenting to your request. GridPoint or SMUD may require you and the party to whom you wish to sublicense, assign or transfer to agree to additional terms. GridPoint and SMUD do not give blanket consents, so you must follow these procedures for each sublicense, transfer or assignment you wish to make.

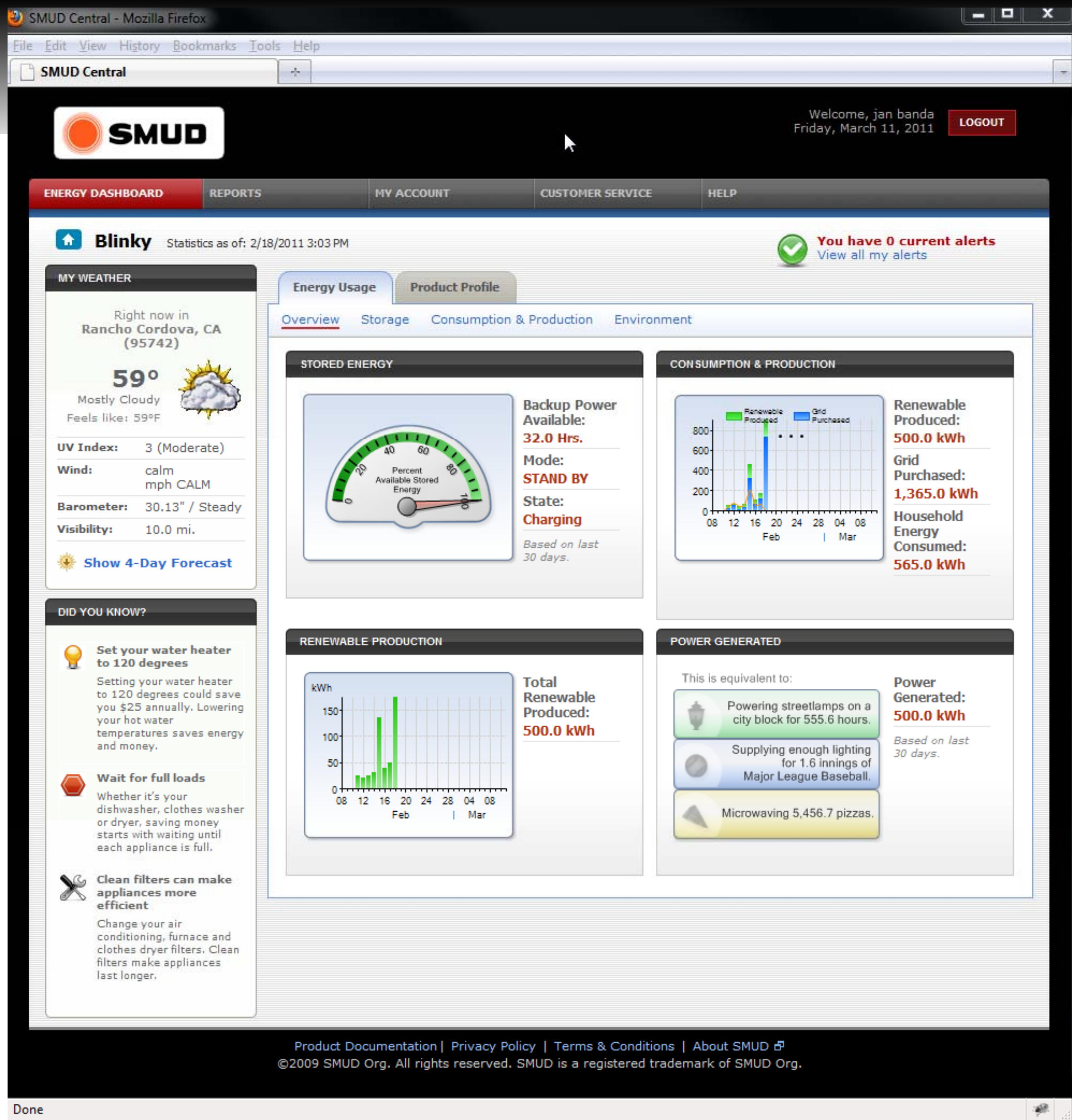
2. **Information Capture; Connectivity**. Your Product transmits to GridPoint information about the consumption and generation of electricity in the location where the Product is installed. This information is reflected in the Portal. Without this information, SMUD and GridPoint would be unable to provide you with the advantages and control available through the Portal. BY ACCEPTING THIS AGREEMENT, YOU CONSENT TO THE RECEIPT AND STORAGE BY SMUD AND GRIDPOINT OF THIS INFORMATION AND TO SMUD AND GRIDPOINT SHARING THIS INFORMATION.

☐ **By checking this box,** I acknowledge that I have read, understand and agree to the SMUD Central End User License Agreement.

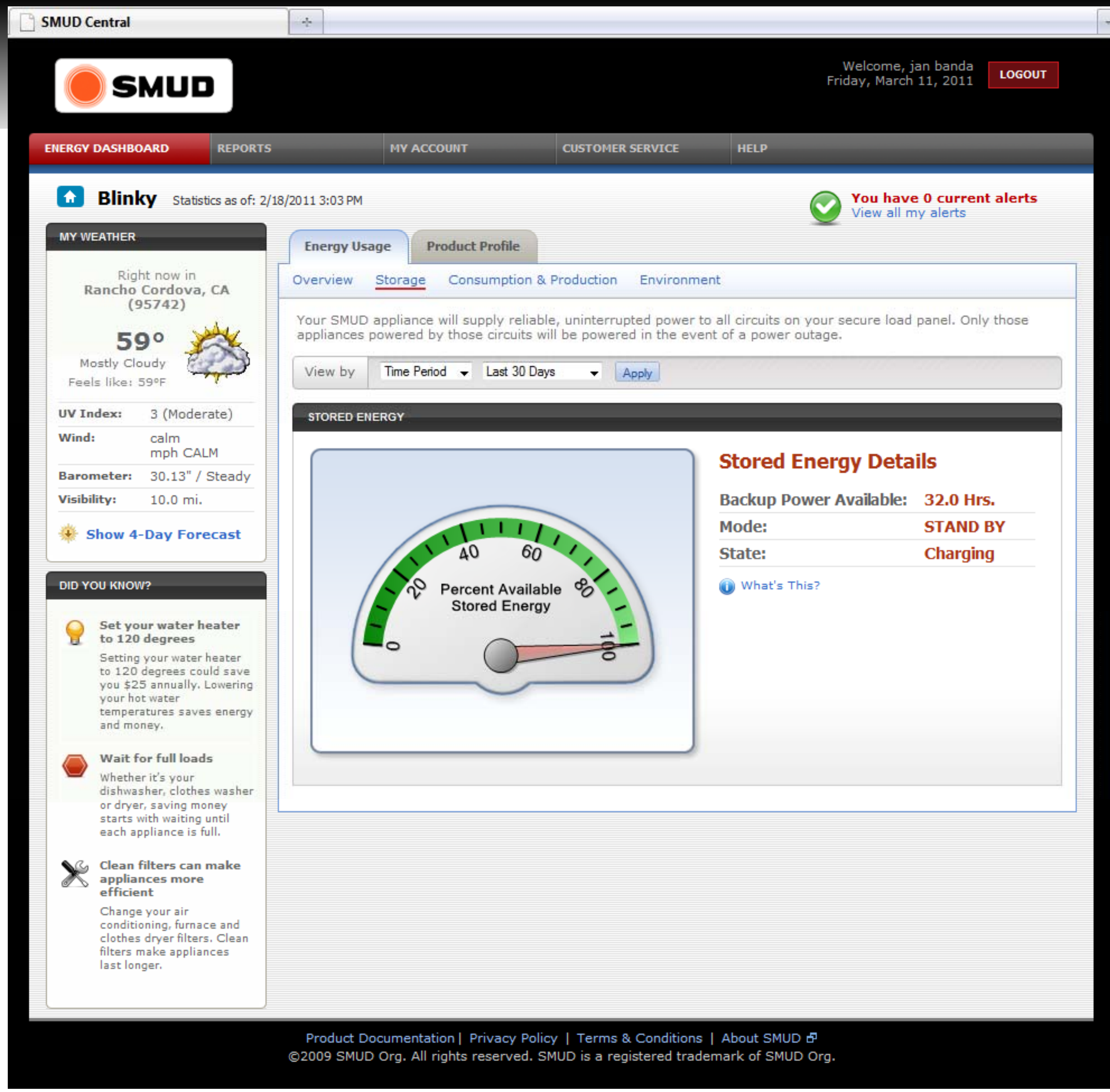
Continue | Cancel

Product Documentation | Privacy Policy | Terms & Conditions | About SMUD

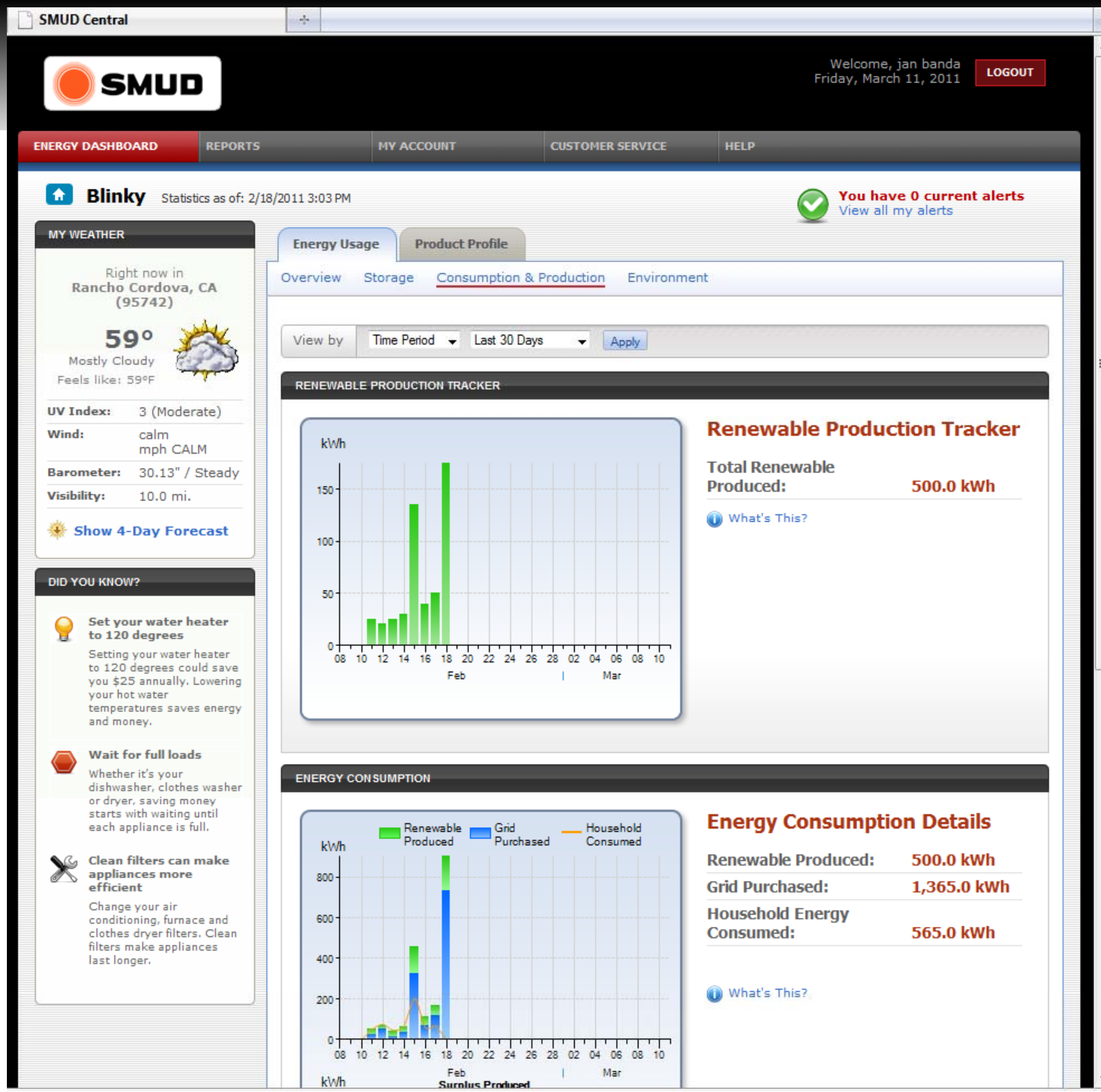
©2009 SMUD Org. All rights reserved. SMUD is a registered trademark of SMUD Org.


SMUD Central - Mozilla Firefox
File Edit View History Bookmarks Tools Help
SMUD Central
SMUD
Welcome, jan banda
Friday, March 11, 2011
LOGOUT
ENERGY DASHBOARD
REPORTS
MY ACCOUNT
CUSTOMER SERVICE
HELP
Blinky
Statistics as of: 2/18/2011 3:03 PM
You have 0 current alerts
View all my alerts
MY WEATHER
Right now in
Rancho Cordova, CA
(95742)
59°
Mostly Cloudy
Feels like: 59°F
UV Index: 3 (Moderate)
Wind: calm mph CALM
Barometer: 30.13" / Steady
Visibility: 10.0 mi.
Show 4-Day Forecast
DID YOU KNOW?
Set your water heater to 120 degrees
Setting your water heater to 120 degrees could save you $25 annually. Lowering your hot water temperatures saves energy and money.
Wait for full loads
Whether it's your dishwasher, clothes washer or dryer, saving money starts with waiting until each appliance is full.
Clean filters can make appliances more efficient
Change your air conditioning, furnace and clothes dryer filters. Clean filters make appliances last longer.
Energy Usage
Product Profile
Overview
Storage
Consumption & Production
Environment
STORED ENERGY
Percent Available Stored Energy
Backup Power Available:
32.0 Hrs.
Mode:
STAND BY
State:
Charging
Based on last 30 days.
CONSUMPTION & PRODUCTION
Renewable Produced
Grid Purchased
Feb
Mar
Renewable Produced:
500.0 kWh
Grid Purchased:
1,365.0 kWh
Household Energy Consumed:
565.0 kWh
RENEWABLE PRODUCTION
kWh
Feb
Mar
Total Renewable Produced:
500.0 kWh
POWER GENERATED
This is equivalent to:
Powering streetlamps on a city block for 555.6 hours.
Supplying enough lighting for 1.6 innings of Major League Baseball.
Microwaving 5,456.7 pizzas.
Power Generated:
500.0 kWh
Based on last 30 days.
Product Documentation | Privacy Policy | Terms & Conditions | About SMUD
©2009 SMUD Org. All rights reserved. SMUD is a registered trademark of SMUD Org.
Done

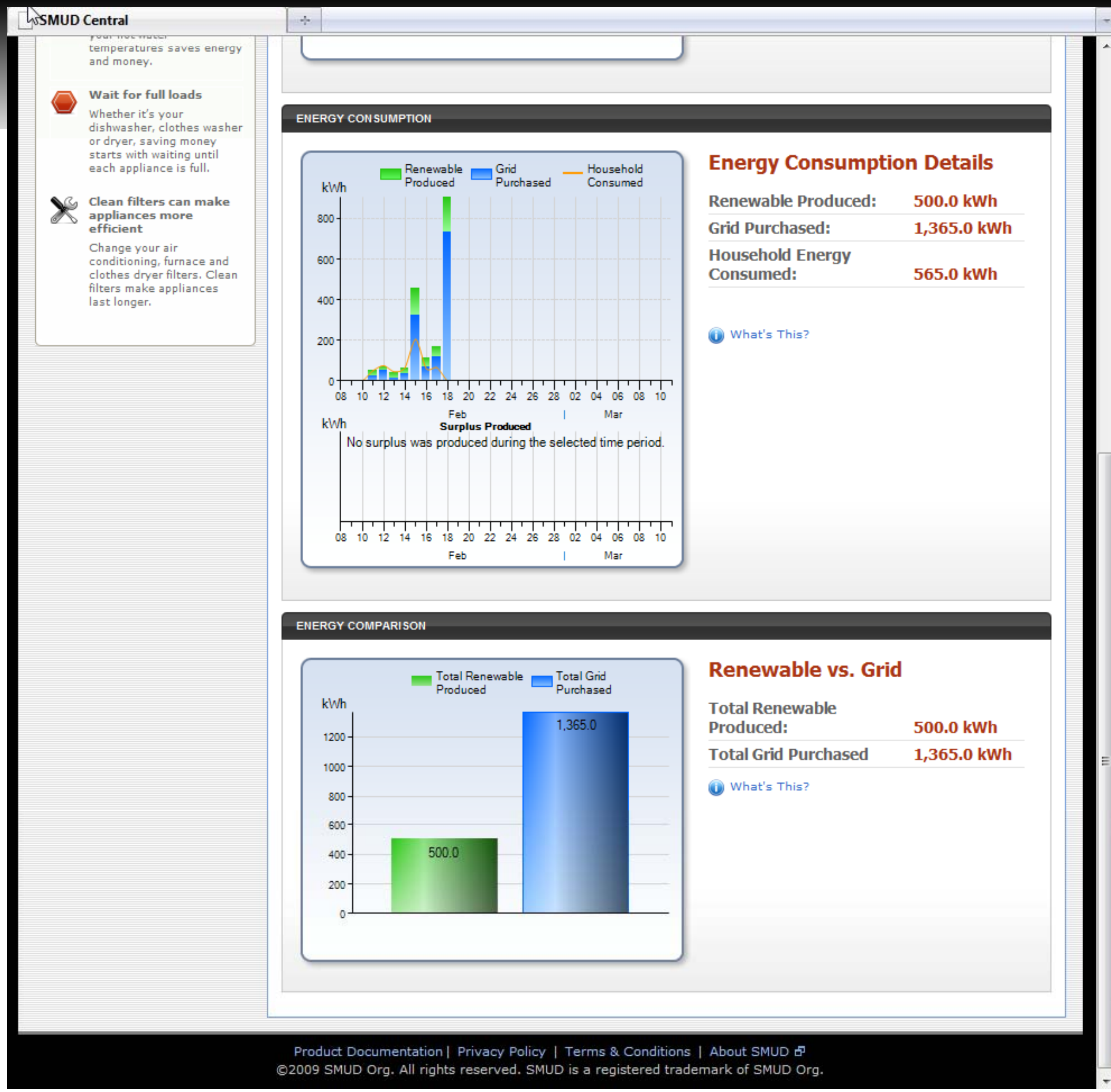
GRIDPOINT

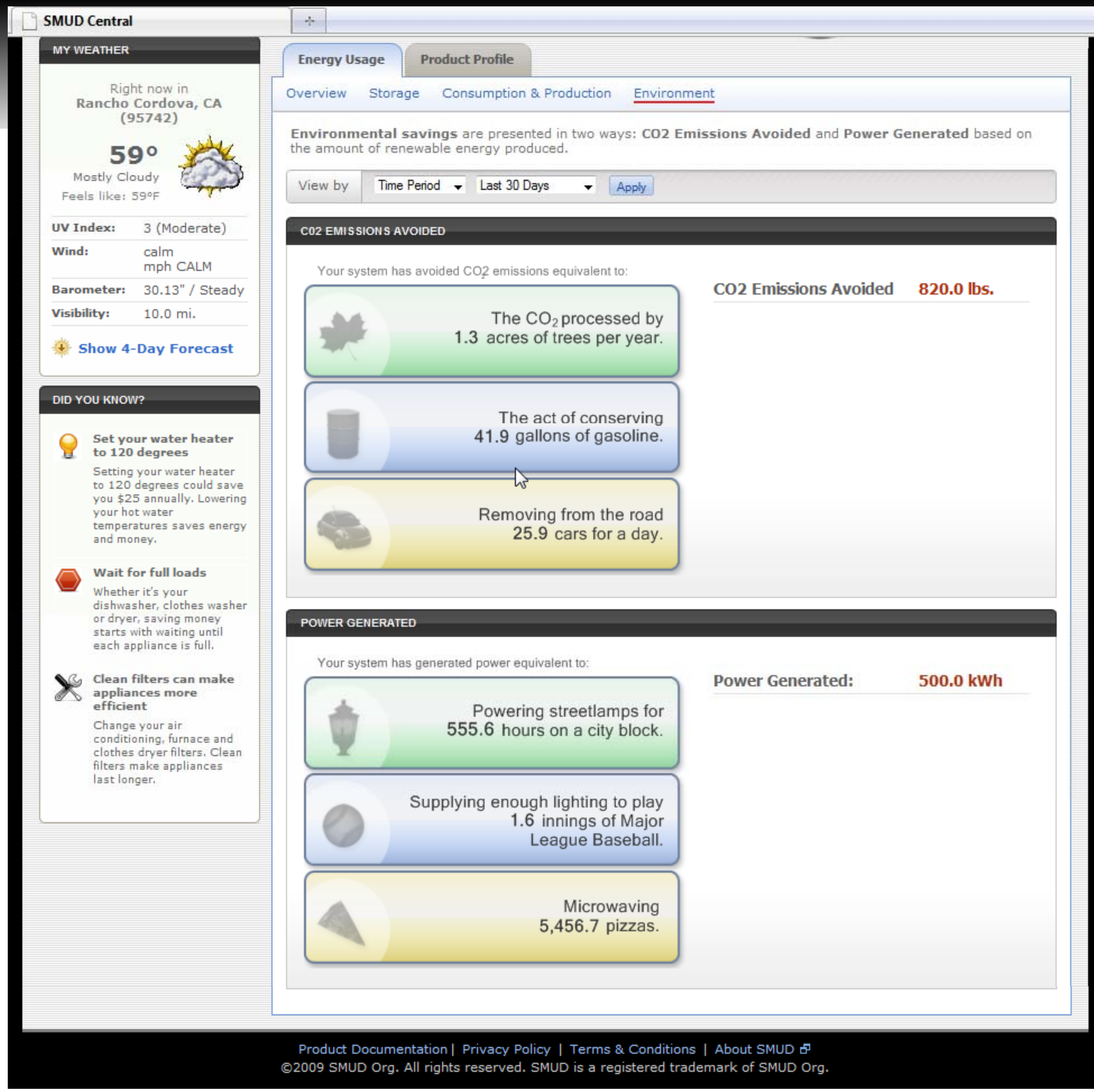

SMUD Central
SMUD
Welcome, jan banda
Friday, March 11, 2011
LOGOUT
ENERGY DASHBOARD
REPORTS
MY ACCOUNT
CUSTOMER SERVICE
HELP
Blinky
Statistics as of: 2/18/2011 3:03 PM
You have 0 current alerts
View all my alerts
MY WEATHER
Right now in
Rancho Cordova, CA
(95742)
59°
Mostly Cloudy
Feels like: 59°F
UV Index: 3 (Moderate)
Wind: calm mph CALM
Barometer: 30.13" / Steady
Visibility: 10.0 mi.
Show 4-Day Forecast
DID YOU KNOW?
Set your water heater to 120 degrees
Setting your water heater to 120 degrees could save you $25 annually. Lowering your hot water temperatures saves energy and money.
Wait for full loads
Whether it's your dishwasher, clothes washer or dryer, saving money starts with waiting until each appliance is full.
Clean filters can make appliances more efficient
Change your air conditioning, furnace and clothes dryer filters. Clean filters make appliances last longer.
Energy Usage
Product Profile
Overview
Storage
Consumption & Production
Environment
Your SMUD appliance will supply reliable, uninterrupted power to all circuits on your secure load panel. Only those appliances powered by those circuits will be powered in the event of a power outage.
View by
Time Period
Last 30 Days
Apply
STORED ENERGY
Percent Available
Stored Energy
0
20
40
60
80
100
Stored Energy Details
Backup Power Available: 32.0 Hrs.
Mode: STAND BY
State: Charging
What's This?
Product Documentation | Privacy Policy | Terms & Conditions | About SMUD
©2009 SMUD Org. All rights reserved. SMUD is a registered trademark of SMUD Org.

GRIDPOINT

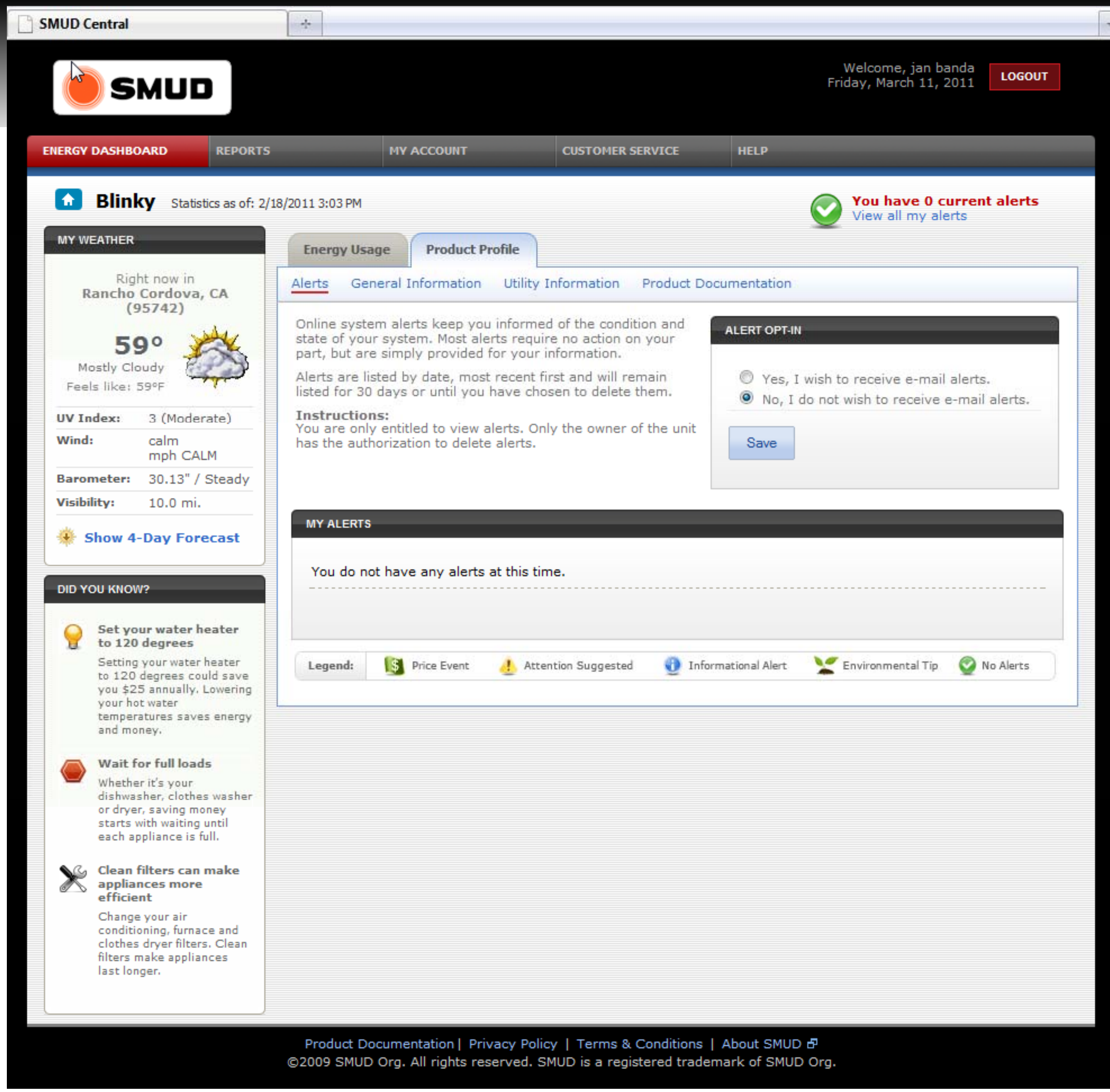

SMUD Central
SMUD
Welcome, jan banda
Friday, March 11, 2011
LOGOUT
ENERGY DASHBOARD
REPORTS
MY ACCOUNT
CUSTOMER SERVICE
HELP
Blinky
Statistics as of: 2/18/2011 3:03 PM
You have 0 current alerts
View all my alerts
MY WEATHER
Right now in
Rancho Cordova, CA
(95742)
59°
Mostly Cloudy
Feels like: 59°F
UV Index: 3 (Moderate)
Wind: calm
mph CALM
Barometer: 30.13" / Steady
Visibility: 10.0 mi.
Show 4-Day Forecast
DID YOU KNOW?
Set your water heater to 120 degrees
Setting your water heater to 120 degrees could save you $25 annually. Lowering your hot water temperatures saves energy and money.
Wait for full loads
Whether it's your dishwasher, clothes washer or dryer, saving money starts with waiting until each appliance is full.
Clean filters can make appliances more efficient
Change your air conditioning, furnace and clothes dryer filters. Clean filters make appliances last longer.
Energy Usage
Product Profile
Overview
Storage
Consumption & Production
Environment
View by
Time Period
Last 30 Days
Apply
RENEWABLE PRODUCTION TRACKER
kWh
150
100
50
0
08 10 12 14 16 18 20 22 24 26 28 02 04 06 08 10
Feb
Mar
Renewable Production Tracker
Total Renewable Produced: 500.0 kWh
What's This?
ENERGY CONSUMPTION
Renewable Produced
Grid Purchased
Household Consumed
kWh
800
600
400
200
0
08 10 12 14 16 18 20 22 24 26 28 02 04 06 08 10
Feb
Mar
kWh
Surplus Produced
Energy Consumption Details
Renewable Produced: 500.0 kWh
Grid Purchased: 1,365.0 kWh
Household Energy Consumed: 565.0 kWh
What's This?

GRIDPOINT

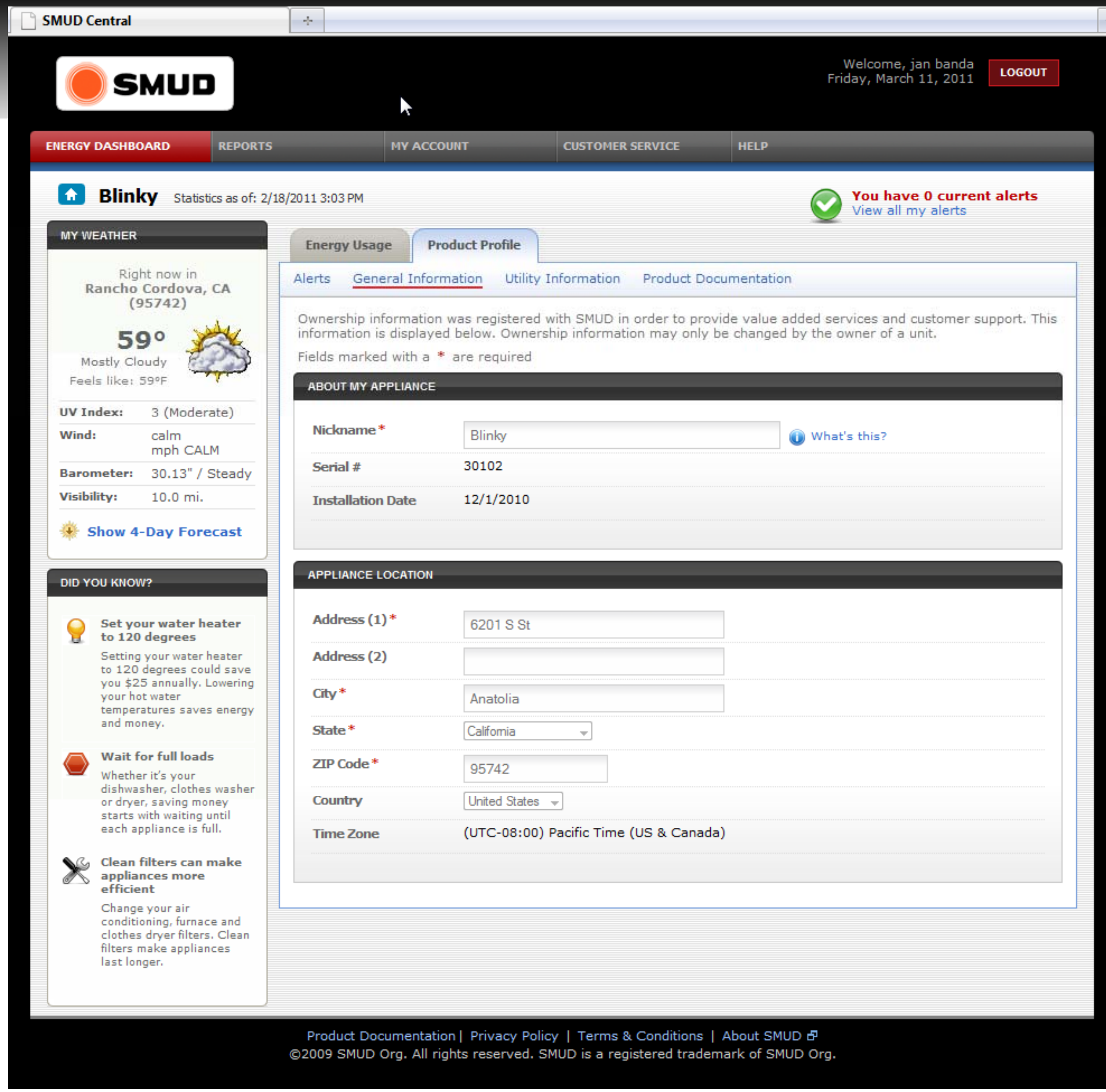

SMUD Central
temperatures saves energy and money.
Wait for full loads
Whether it's your dishwasher, clothes washer or dryer, saving money starts with waiting until each appliance is full.
Clean filters can make appliances more efficient
Change your air conditioning, furnace and clothes dryer filters. Clean filters make appliances last longer.
ENERGY CONSUMPTION
Renewable Produced
Grid Purchased
Household Consumed
kWh
Feb
Mar
Surplus Produced
No surplus was produced during the selected time period.
Energy Consumption Details
Renewable Produced: 500.0 kWh
Grid Purchased: 1,365.0 kWh
Household Energy Consumed: 565.0 kWh
What's This?
ENERGY COMPARISON
Total Renewable Produced
Total Grid Purchased
500.0
1,365.0
Renewable vs. Grid
Total Renewable Produced: 500.0 kWh
Total Grid Purchased 1,365.0 kWh
What's This?
Product Documentation | Privacy Policy | Terms & Conditions | About SMUD
©2009 SMUD Org. All rights reserved. SMUD is a registered trademark of SMUD Org.

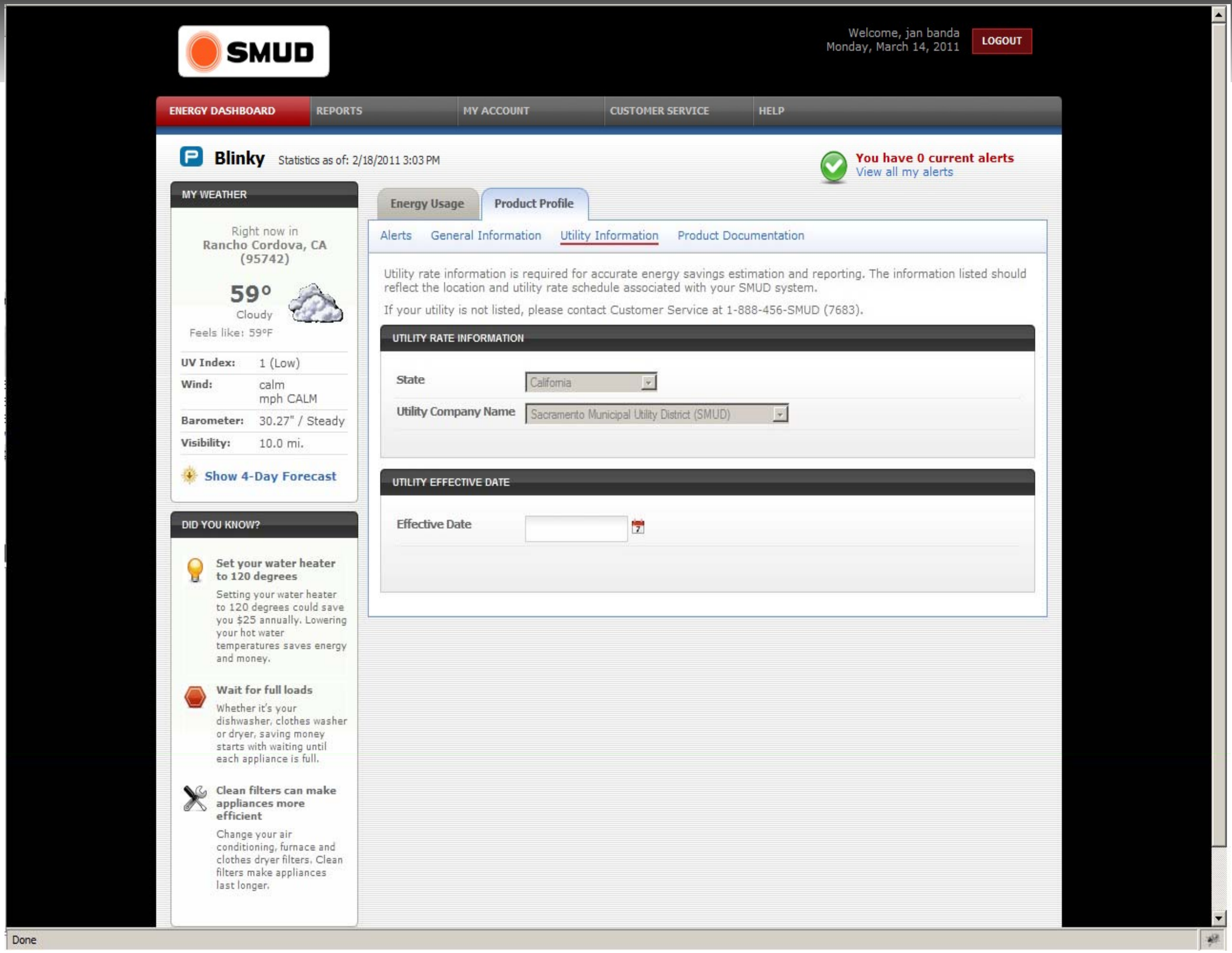

SMUD Central
MY WEATHER
Right now in
Rancho Cordova, CA
(95742)
59°
Mostly Cloudy
Feels like: 59°F
UV Index: 3 (Moderate)
Wind: calm mph CALM
Barometer: 30.13" / Steady
Visibility: 10.0 mi.
Show 4-Day Forecast
DID YOU KNOW?
Set your water heater to 120 degrees
Setting your water heater to 120 degrees could save you $25 annually. Lowering your hot water temperatures saves energy and money.
Wait for full loads
Whether it's your dishwasher, clothes washer or dryer, saving money starts with waiting until each appliance is full.
Clean filters can make appliances more efficient
Change your air conditioning, furnace and clothes dryer filters. Clean filters make appliances last longer.
Energy Usage
Product Profile
Overview
Storage
Consumption & Production
Environment
Environmental savings are presented in two ways: CO2 Emissions Avoided and Power Generated based on the amount of renewable energy produced.
View by
Time Period
Last 30 Days
Apply
C02 EMISSIONS AVOIDED
Your system has avoided CO2 emissions equivalent to:
The CO2 processed by 1.3 acres of trees per year.
The act of conserving 41.9 gallons of gasoline.
Removing from the road 25.9 cars for a day.
CO2 Emissions Avoided 820.0 lbs.
POWER GENERATED
Your system has generated power equivalent to:
Powering streetlamps for 555.6 hours on a city block.
Supplying enough lighting to play 1.6 innings of Major League Baseball.
Microwaving 5,456.7 pizzas.
Power Generated: 500.0 kWh
Product Documentation | Privacy Policy | Terms & Conditions | About SMUD
©2009 SMUD Org. All rights reserved. SMUD is a registered trademark of SMUD Org.

GRIDPOINT

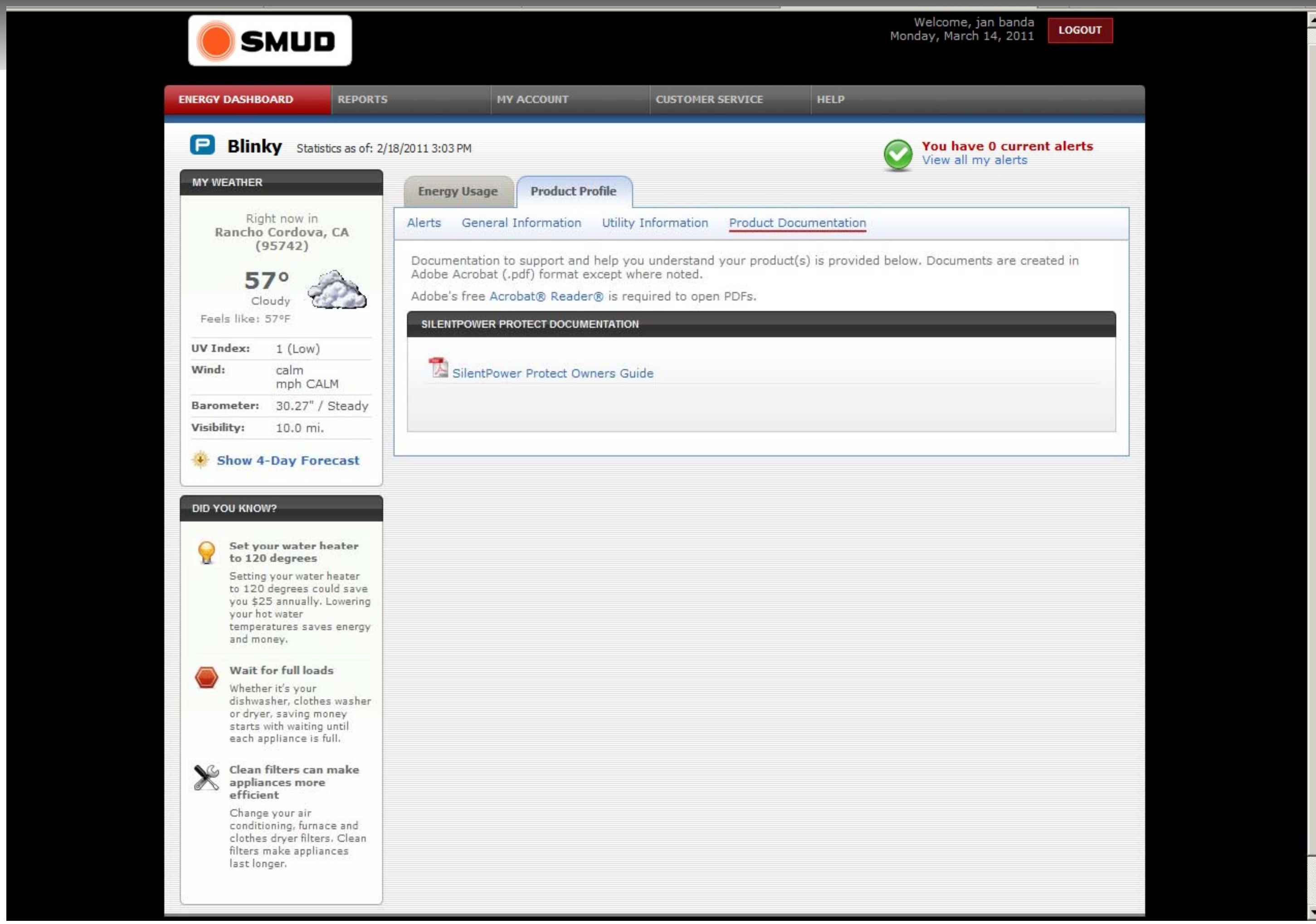

SMUD Central
SMUD
Welcome, jan banda
Friday, March 11, 2011
LOGOUT
ENERGY DASHBOARD
REPORTS
MY ACCOUNT
CUSTOMER SERVICE
HELP
Blinky
Statistics as of: 2/18/2011 3:03 PM
You have 0 current alerts
View all my alerts
MY WEATHER
Right now in
Rancho Cordova, CA
(95742)
59°
Mostly Cloudy
Feels like: 59°F
UV Index: 3 (Moderate)
Wind: calm mph CALM
Barometer: 30.13" / Steady
Visibility: 10.0 mi.
Show 4-Day Forecast
DID YOU KNOW?
Set your water heater to 120 degrees
Setting your water heater to 120 degrees could save you $25 annually. Lowering your hot water temperatures saves energy and money.
Wait for full loads
Whether it's your dishwasher, clothes washer or dryer, saving money starts with waiting until each appliance is full.
Clean filters can make appliances more efficient
Change your air conditioning, furnace and clothes dryer filters. Clean filters make appliances last longer.
Energy Usage
Product Profile
Alerts
General Information
Utility Information
Product Documentation
Online system alerts keep you informed of the condition and state of your system. Most alerts require no action on your part, but are simply provided for your information.
Alerts are listed by date, most recent first and will remain listed for 30 days or until you have chosen to delete them.
Instructions:
You are only entitled to view alerts. Only the owner of the unit has the authorization to delete alerts.
ALERT OPT-IN
Yes, I wish to receive e-mail alerts.
No, I do not wish to receive e-mail alerts.
Save
MY ALERTS
You do not have any alerts at this time.
Legend:
Price Event
Attention Suggested
Informational Alert
Environmental Tip
No Alerts
Product Documentation | Privacy Policy | Terms & Conditions | About SMUD
©2009 SMUD Org. All rights reserved. SMUD is a registered trademark of SMUD Org.

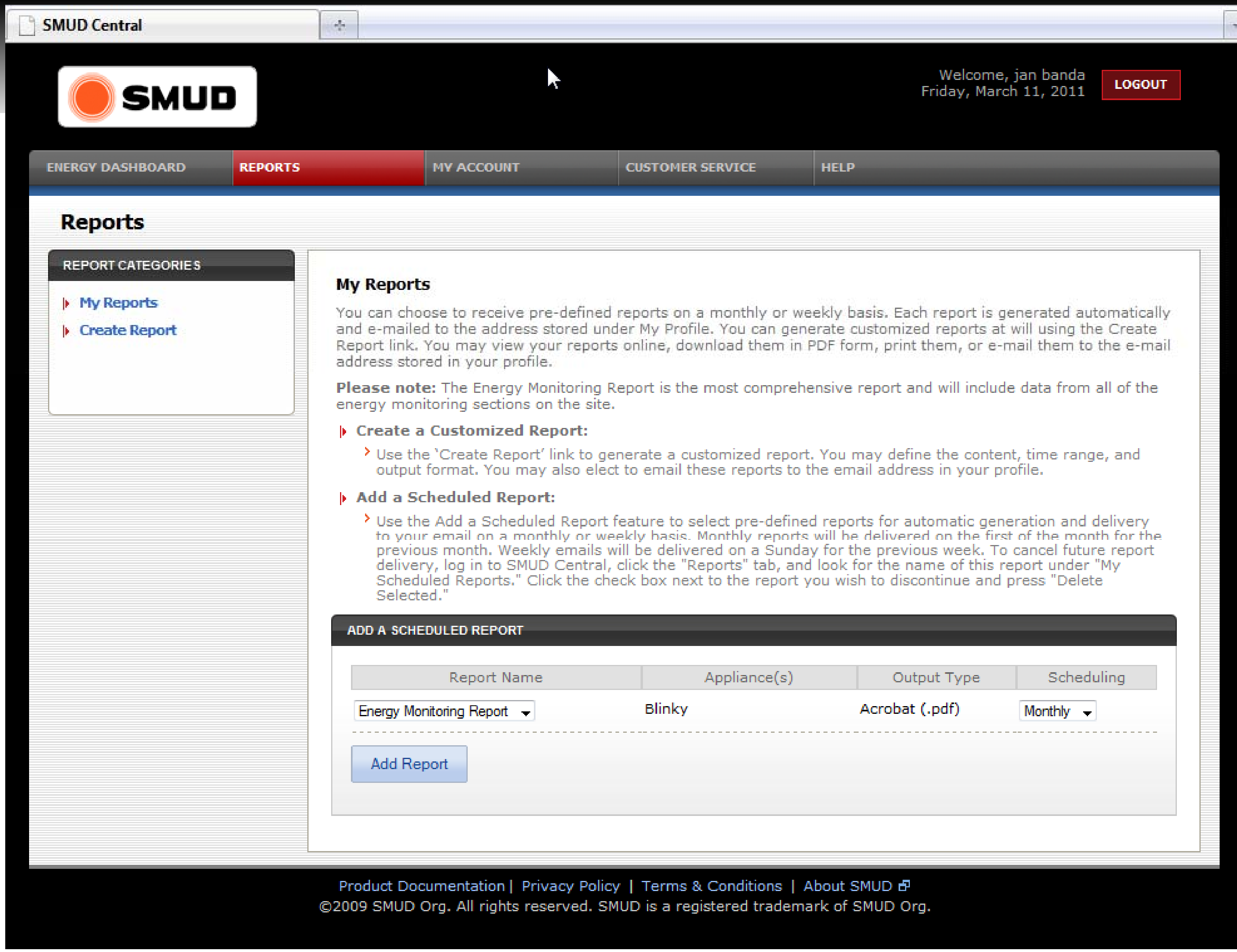
GRIDPOINT


SMUD Central
SMUD
Welcome, jan banda
Friday, March 11, 2011
LOGOUT
ENERGY DASHBOARD
REPORTS
MY ACCOUNT
CUSTOMER SERVICE
HELP
Blinky
Statistics as of: 2/18/2011 3:03 PM
You have 0 current alerts
View all my alerts
MY WEATHER
Right now in
Rancho Cordova, CA
(95742)
59°
Mostly Cloudy
Feels like: 59°F
UV Index: 3 (Moderate)
Wind: calm mph CALM
Barometer: 30.13" / Steady
Visibility: 10.0 mi.
Show 4-Day Forecast
DID YOU KNOW?
Set your water heater to 120 degrees
Setting your water heater to 120 degrees could save you $25 annually. Lowering your hot water temperatures saves energy and money.
Wait for full loads
Whether it's your dishwasher, clothes washer or dryer, saving money starts with waiting until each appliance is full.
Clean filters can make appliances more efficient
Change your air conditioning, furnace and clothes dryer filters. Clean filters make appliances last longer.
Energy Usage
Product Profile
Alerts
General Information
Utility Information
Product Documentation
Ownership information was registered with SMUD in order to provide value added services and customer support. This information is displayed below. Ownership information may only be changed by the owner of a unit.
Fields marked with a * are required
ABOUT MY APPLIANCE
Nickname * Blinky
What's this?
Serial # 30102
Installation Date 12/1/2010
APPLIANCE LOCATION
Address (1) * 6201 S St
Address (2)
City * Anatolia
State * California
ZIP Code * 95742
Country United States
Time Zone (UTC-08:00) Pacific Time (US & Canada)
Product Documentation | Privacy Policy | Terms & Conditions | About SMUD
©2009 SMUD Org. All rights reserved. SMUD is a registered trademark of SMUD Org.

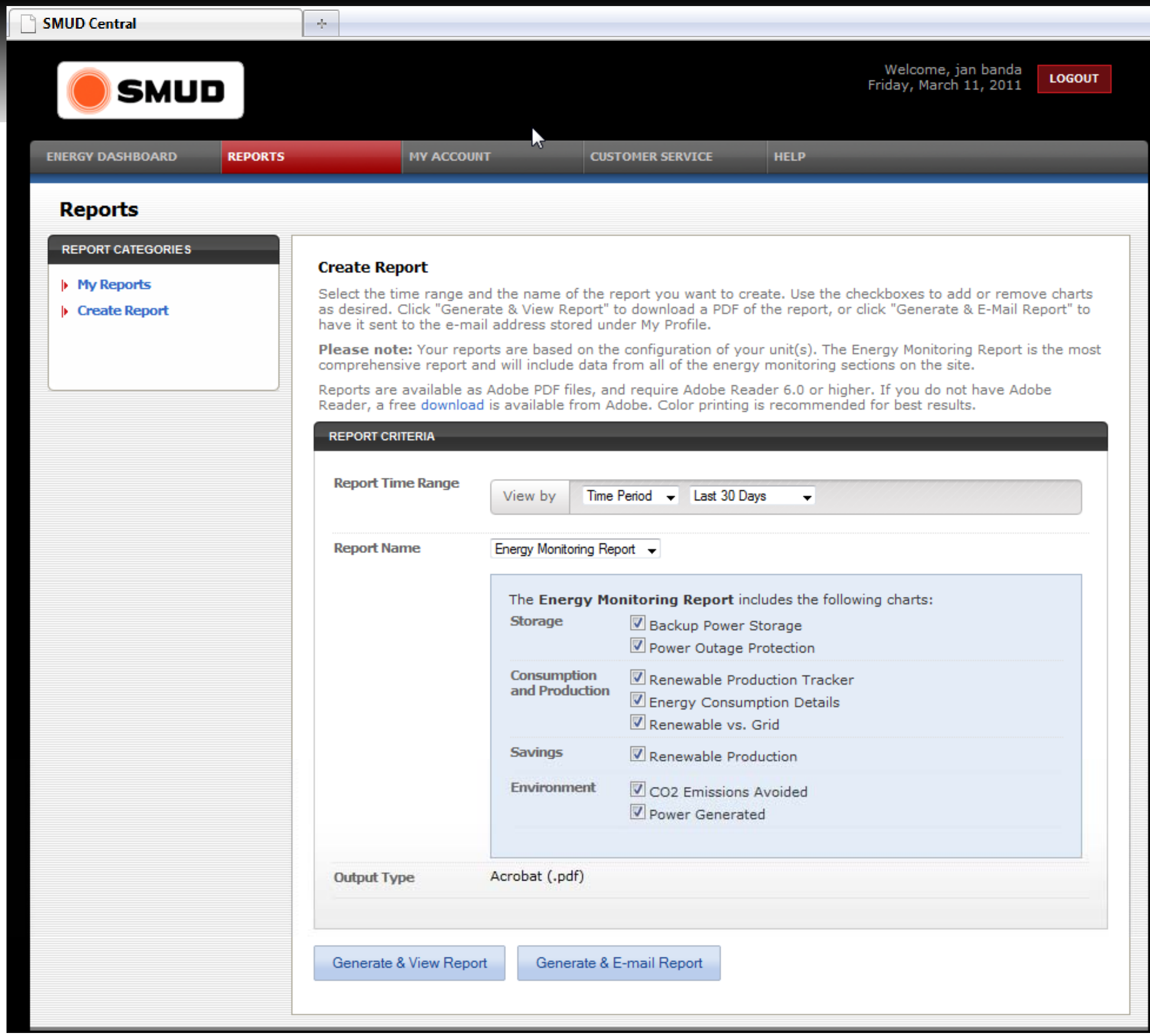

SMUD
Welcome, jan banda
Monday, March 14, 2011
LOGOUT
ENERGY DASHBOARD
REPORTS
MY ACCOUNT
CUSTOMER SERVICE
HELP
Blinky
Statistics as of: 2/18/2011 3:03 PM
You have 0 current alerts
View all my alerts
MY WEATHER
Right now in
Rancho Cordova, CA
(95742)
59°
Cloudy
Feels like: 59°F
UV Index: 1 (Low)
Wind: calm mph CALM
Barometer: 30.27" / Steady
Visibility: 10.0 mi.
Show 4-Day Forecast
DID YOU KNOW?
Set your water heater to 120 degrees
Setting your water heater to 120 degrees could save you $25 annually. Lowering your hot water temperatures saves energy and money.
Wait for full loads
Whether it's your dishwasher, clothes washer or dryer, saving money starts with waiting until each appliance is full.
Clean filters can make appliances more efficient
Change your air conditioning, furnace and clothes dryer filters. Clean filters make appliances last longer.
Energy Usage
Product Profile
Alerts
General Information
Utility Information
Product Documentation
Utility rate information is required for accurate energy savings estimation and reporting. The information listed should reflect the location and utility rate schedule associated with your SMUD system.
If your utility is not listed, please contact Customer Service at 1-888-456-SMUD (7683).
UTILITY RATE INFORMATION
State
California
Utility Company Name
Sacramento Municipal Utility District (SMUD)
UTILITY EFFECTIVE DATE
Effective Date
Done

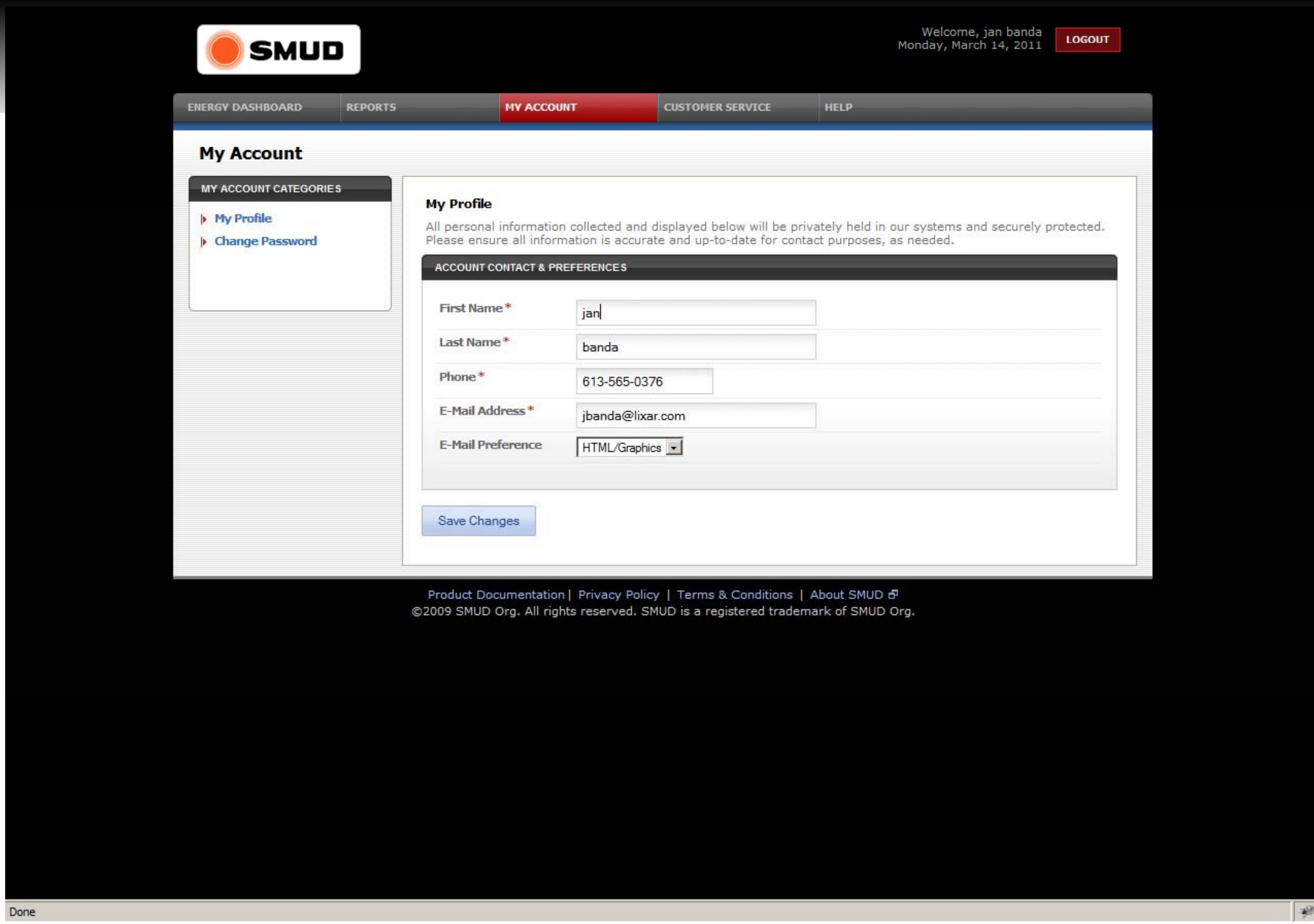
GRIDPOINT

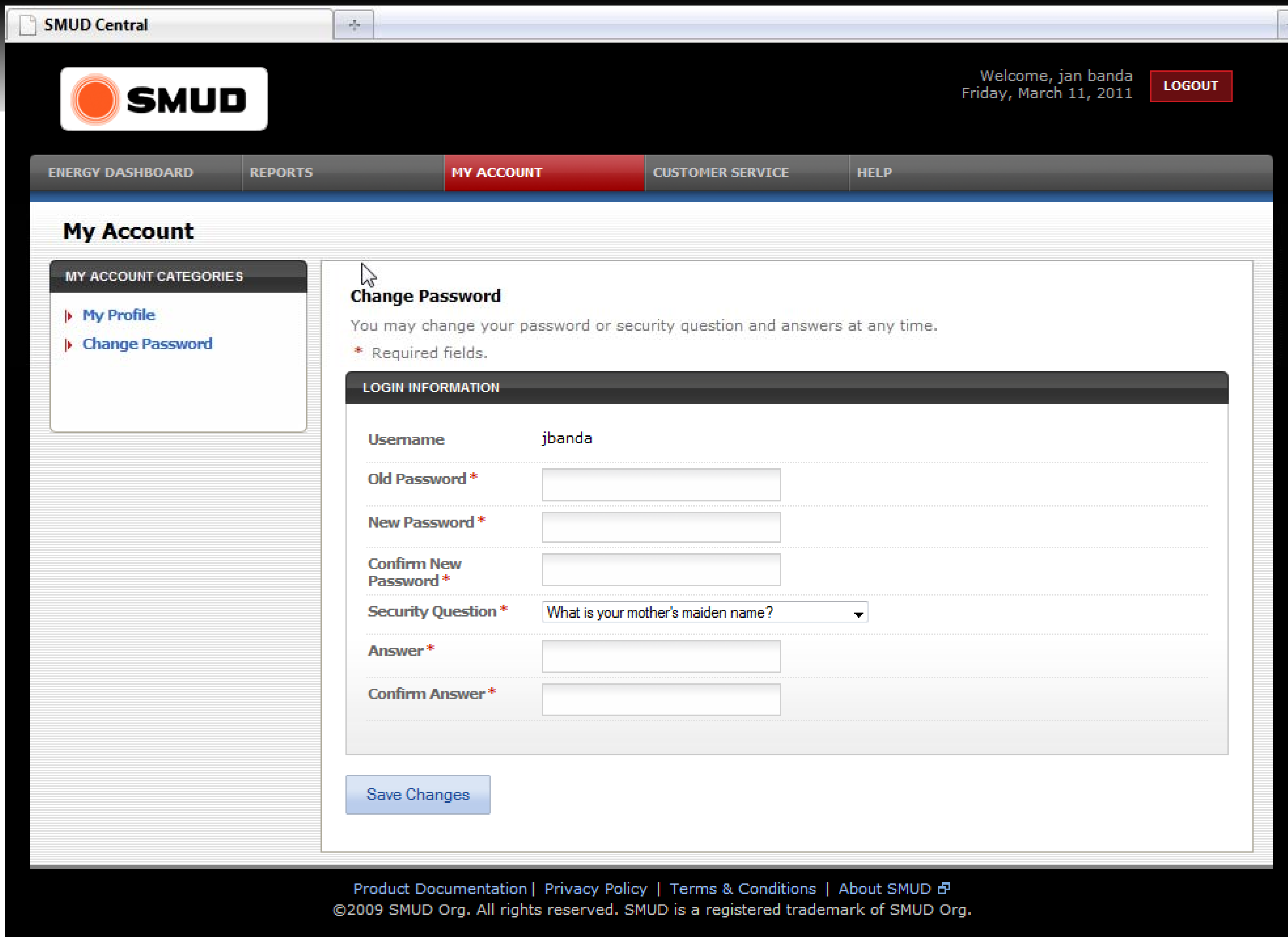

SMUD
Welcome, jan banda
Monday, March 14, 2011
LOGOUT
ENERGY DASHBOARD
REPORTS
MY ACCOUNT
CUSTOMER SERVICE
HELP
Blinky
Statistics as of: 2/18/2011 3:03 PM
You have 0 current alerts
View all my alerts
MY WEATHER
Right now in
Rancho Cordova, CA
(95742)
57°
Cloudy
Feels like: 57°F
UV Index: 1 (Low)
Wind: calm mph CALM
Barometer: 30.27" / Steady
Visibility: 10.0 mi.
Show 4-Day Forecast
DID YOU KNOW?
Set your water heater to 120 degrees
Setting your water heater to 120 degrees could save you $25 annually. Lowering your hot water temperatures saves energy and money.
Wait for full loads
Whether it's your dishwasher, clothes washer or dryer, saving money starts with waiting until each appliance is full.
Clean filters can make appliances more efficient
Change your air conditioning, furnace and clothes dryer filters. Clean filters make appliances last longer.
Energy Usage
Product Profile
Alerts
General Information
Utility Information
Product Documentation
Documentation to support and help you understand your product(s) is provided below. Documents are created in Adobe Acrobat (.pdf) format except where noted.
Adobe's free Acrobat® Reader® is required to open PDFs.
SILENTPOWER PROTECT DOCUMENTATION
SilentPower Protect Owners Guide

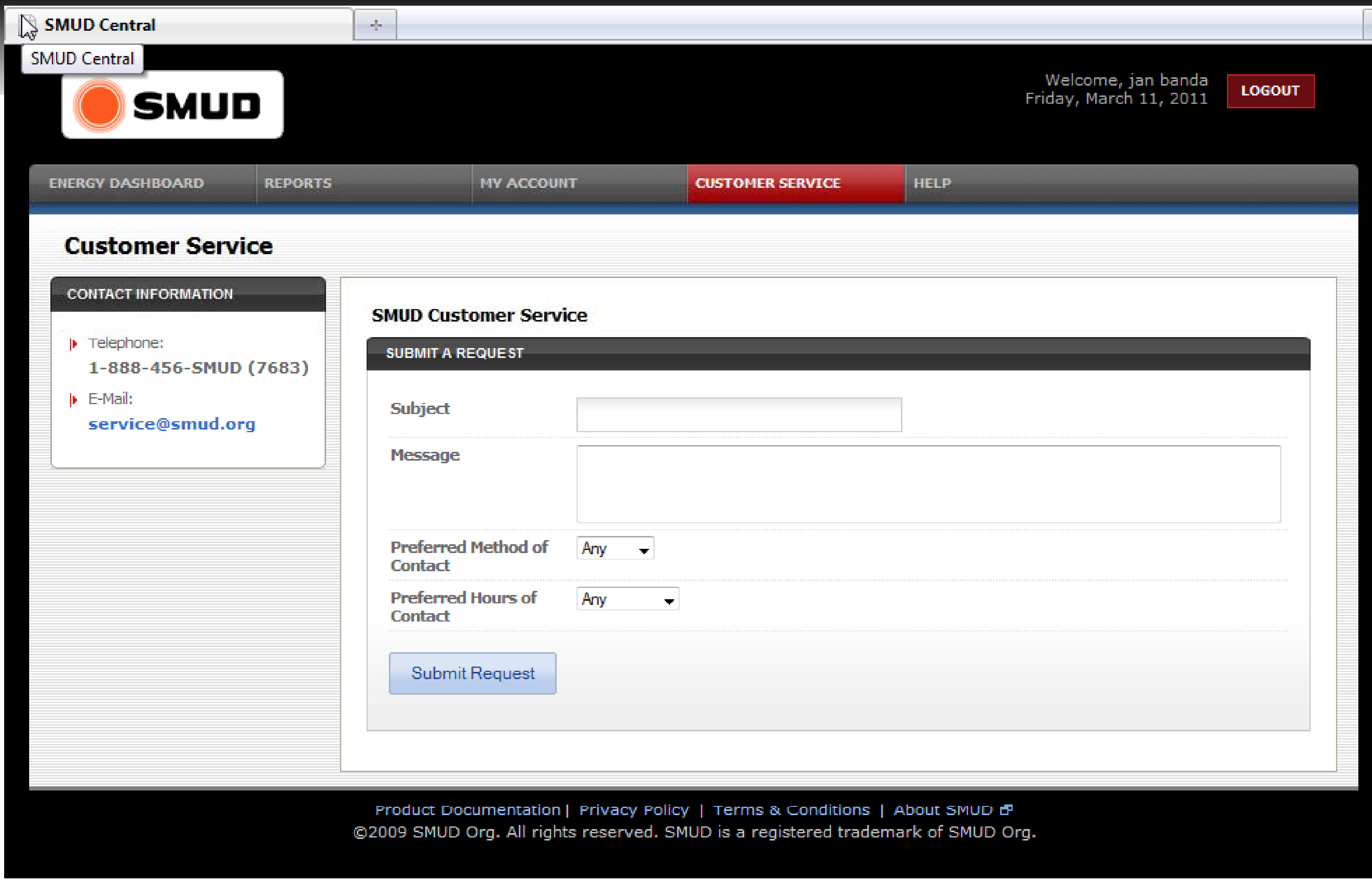

SMUD Central
SMUD
Welcome, jan banda
Friday, March 11, 2011
LOGOUT
ENERGY DASHBOARD
REPORTS
MY ACCOUNT
CUSTOMER SERVICE
HELP
Reports
REPORT CATEGORIES
My Reports
Create Report
My Reports
You can choose to receive pre-defined reports on a monthly or weekly basis. Each report is generated automatically and e-mailed to the address stored under My Profile. You can generate customized reports at will using the Create Report link. You may view your reports online, download them in PDF form, print them, or e-mail them to the e-mail address stored in your profile.
Please note: The Energy Monitoring Report is the most comprehensive report and will include data from all of the energy monitoring sections on the site.
Create a Customized Report:
Use the 'Create Report' link to generate a customized report. You may define the content, time range, and output format. You may also elect to email these reports to the email address in your profile.
Add a Scheduled Report:
Use the Add a Scheduled Report feature to select pre-defined reports for automatic generation and delivery to your email on a monthly or weekly basis. Monthly reports will be delivered on the first of the month for the previous month. Weekly emails will be delivered on a Sunday for the previous week. To cancel future report delivery, log in to SMUD Central, click the "Reports" tab, and look for the name of this report under "My Scheduled Reports." Click the check box next to the report you wish to discontinue and press "Delete Selected."
ADD A SCHEDULED REPORT
Report Name
Appliance(s)
Output Type
Scheduling
Energy Monitoring Report
Blinky
Acrobat (.pdf)
Monthly
Add Report
Product Documentation | Privacy Policy | Terms & Conditions | About SMUD
©2009 SMUD Org. All rights reserved. SMUD is a registered trademark of SMUD Org.

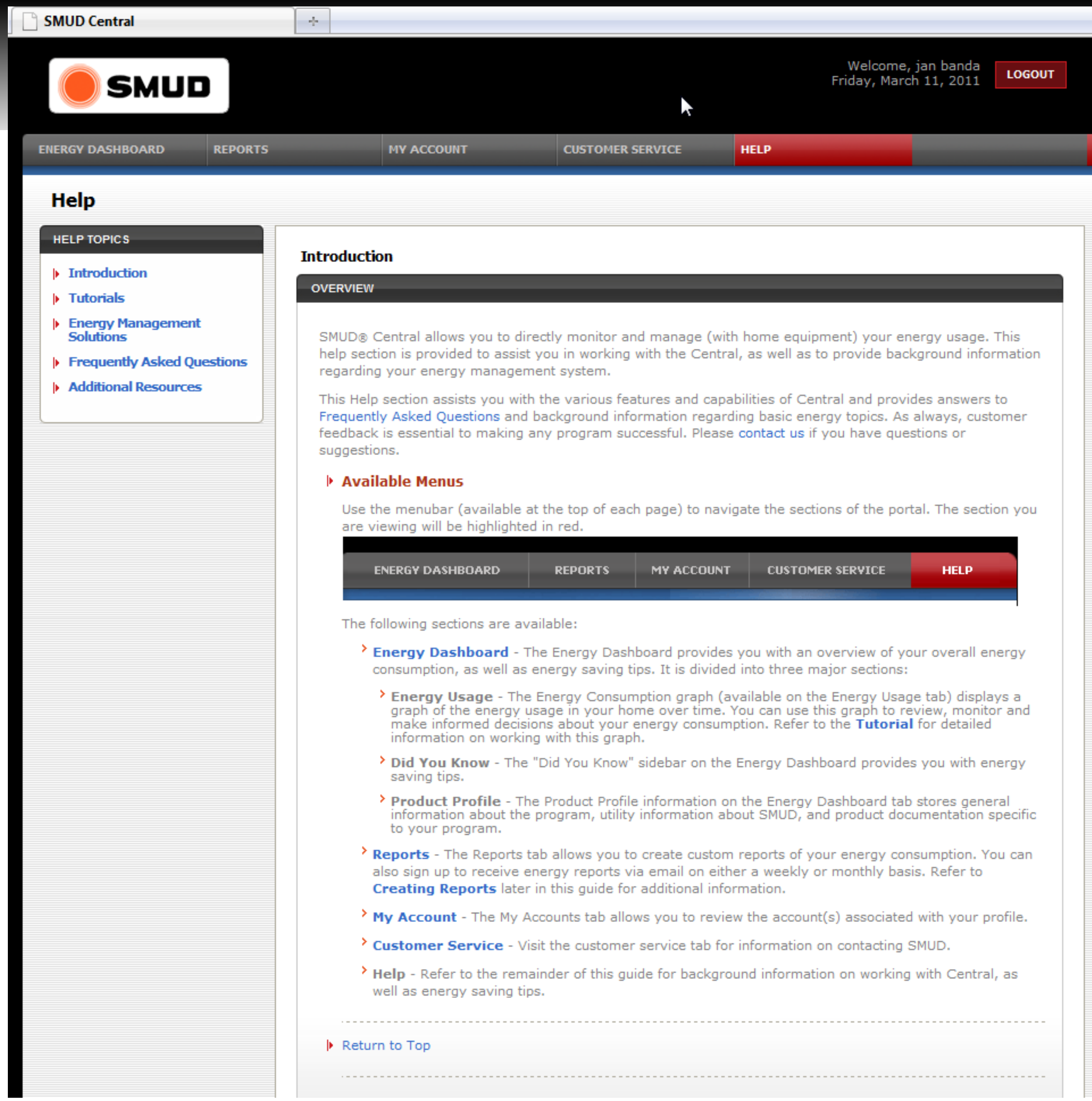
GRIDPOINT


SMUD Central
SMUD
Welcome, jan banda
Friday, March 11, 2011
LOGOUT
ENERGY DASHBOARD
REPORTS
MY ACCOUNT
CUSTOMER SERVICE
HELP
Reports
REPORT CATEGORIES
My Reports
Create Report
Create Report
Select the time range and the name of the report you want to create. Use the checkboxes to add or remove charts as desired. Click "Generate & View Report" to download a PDF of the report, or click "Generate & E-Mail Report" to have it sent to the e-mail address stored under My Profile.
Please note: Your reports are based on the configuration of your unit(s). The Energy Monitoring Report is the most comprehensive report and will include data from all of the energy monitoring sections on the site.
Reports are available as Adobe PDF files, and require Adobe Reader 6.0 or higher. If you do not have Adobe Reader, a free download is available from Adobe. Color printing is recommended for best results.
REPORT CRITERIA
Report Time Range
View by
Time Period
Last 30 Days
Report Name
Energy Monitoring Report
The Energy Monitoring Report includes the following charts:
Storage
Backup Power Storage
Power Outage Protection
Consumption and Production
Renewable Production Tracker
Energy Consumption Details
Renewable vs. Grid
Savings
Renewable Production
Environment
CO2 Emissions Avoided
Power Generated
Output Type
Acrobat (.pdf)
Generate & View Report
Generate & E-mail Report


SMUD
Welcome, jan banda
Monday, March 14, 2011
LOGOUT
ENERGY DASHBOARD
REPORTS
MY ACCOUNT
CUSTOMER SERVICE
HELP
My Account
MY ACCOUNT CATEGORIES
My Profile
Change Password
My Profile
All personal information collected and displayed below will be privately held in our systems and securely protected.
Please ensure all information is accurate and up-to-date for contact purposes, as needed.
ACCOUNT CONTACT & PREFERENCES
First Name *
jan
Last Name *
banda
Phone *
613-565-0376
E-Mail Address *
jbanda@lixar.com
E-Mail Preference
HTML/Graphics
Save Changes
Product Documentation | Privacy Policy | Terms & Conditions | About SMUD
©2009 SMUD Org. All rights reserved. SMUD is a registered trademark of SMUD Org.
Done


SMUD Central
SMUD
Welcome, jan banda
Friday, March 11, 2011
LOGOUT
ENERGY DASHBOARD
REPORTS
MY ACCOUNT
CUSTOMER SERVICE
HELP
My Account
MY ACCOUNT CATEGORIES
My Profile
Change Password
Change Password
You may change your password or security question and answers at any time.
* Required fields.
LOGIN INFORMATION
Username
jbanda
Old Password *
New Password *
Confirm New Password *
Security Question *
What is your mother's maiden name?
Answer *
Confirm Answer *
Save Changes
Product Documentation | Privacy Policy | Terms & Conditions | About SMUD
©2009 SMUD Org. All rights reserved. SMUD is a registered trademark of SMUD Org.


SMUD Central
SMUD Central
SMUD
Welcome, jan banda
Friday, March 11, 2011
LOGOUT
ENERGY DASHBOARD
REPORTS
MY ACCOUNT
CUSTOMER SERVICE
HELP
Customer Service
CONTACT INFORMATION
Telephone:
1-888-456-SMUD (7683)
E-Mail:
service@smud.org
SMUD Customer Service
SUBMIT A REQUEST
Subject
Message
Preferred Method of Contact
Any
Preferred Hours of Contact
Any
Submit Request
Product Documentation | Privacy Policy | Terms & Conditions | About SMUD
©2009 SMUD Org. All rights reserved. SMUD is a registered trademark of SMUD Org.


SMUD Central
SMUD
Welcome, jan banda
Friday, March 11, 2011
LOGOUT
ENERGY DASHBOARD
REPORTS
MY ACCOUNT
CUSTOMER SERVICE
HELP
Help
HELP TOPICS
Introduction
Tutorials
Energy Management Solutions
Frequently Asked Questions
Additional Resources
Introduction
OVERVIEW
SMUD® Central allows you to directly monitor and manage (with home equipment) your energy usage. This help section is provided to assist you in working with the Central, as well as to provide background information regarding your energy management system.
This Help section assists you with the various features and capabilities of Central and provides answers to Frequently Asked Questions and background information regarding basic energy topics. As always, customer feedback is essential to making any program successful. Please contact us if you have questions or suggestions.
Available Menus
Use the menubar (available at the top of each page) to navigate the sections of the portal. The section you are viewing will be highlighted in red.
ENERGY DASHBOARD
REPORTS
MY ACCOUNT
CUSTOMER SERVICE
HELP
The following sections are available:
Energy Dashboard - The Energy Dashboard provides you with an overview of your overall energy consumption, as well as energy saving tips. It is divided into three major sections:
Energy Usage - The Energy Consumption graph (available on the Energy Usage tab) displays a graph of the energy usage in your home over time. You can use this graph to review, monitor and make informed decisions about your energy consumption. Refer to the Tutorial for detailed information on working with this graph.
Did You Know - The "Did You Know" sidebar on the Energy Dashboard provides you with energy saving tips.
Product Profile - The Product Profile information on the Energy Dashboard tab stores general information about the program, utility information about SMUD, and product documentation specific to your program.
Reports - The Reports tab allows you to create custom reports of your energy consumption. You can also sign up to receive energy reports via email on either a weekly or monthly basis. Refer to Creating Reports later in this guide for additional information.
My Account - The My Accounts tab allows you to review the account(s) associated with your profile.
Customer Service - Visit the customer service tab for information on contacting SMUD.
Help - Refer to the remainder of this guide for background information on working with Central, as well as energy saving tips.
Return to Top

SMUD Central

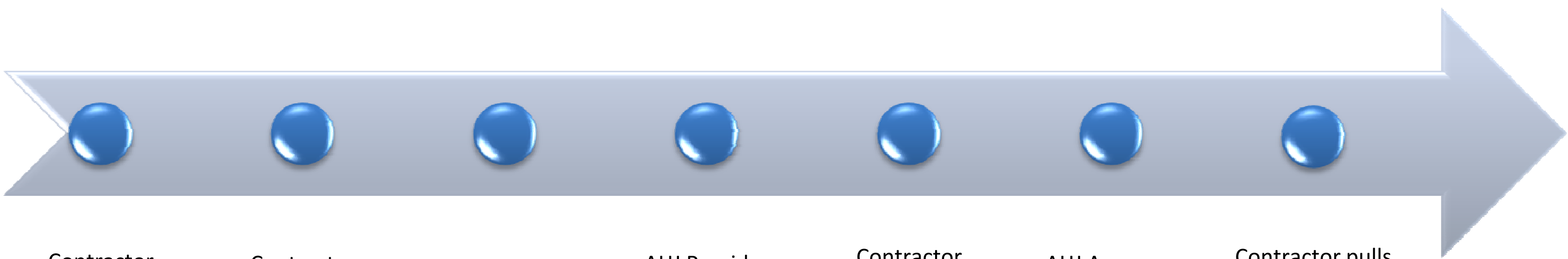
TABLE OF CONTENTS

This help guide includes:

Return to Top

Tutorials

Outline Permit Process



1. Contractor Prepares Permit Pack
2. Contractor Makes Initial Submittal to AHJ. Usually 3 copies 24" x 36"
3. AHJ Reviews Initial Submittal. Fire Department may also review.
4. AHJ Provides Plan Check Comments to Contractor
5. Contractor responds to comments, makes changes as required and resubmits to AHJ
6. AHJ Approves Changes and Issues Permit
7. Contractor pulls and pays for permit and obtains city business license if not already held

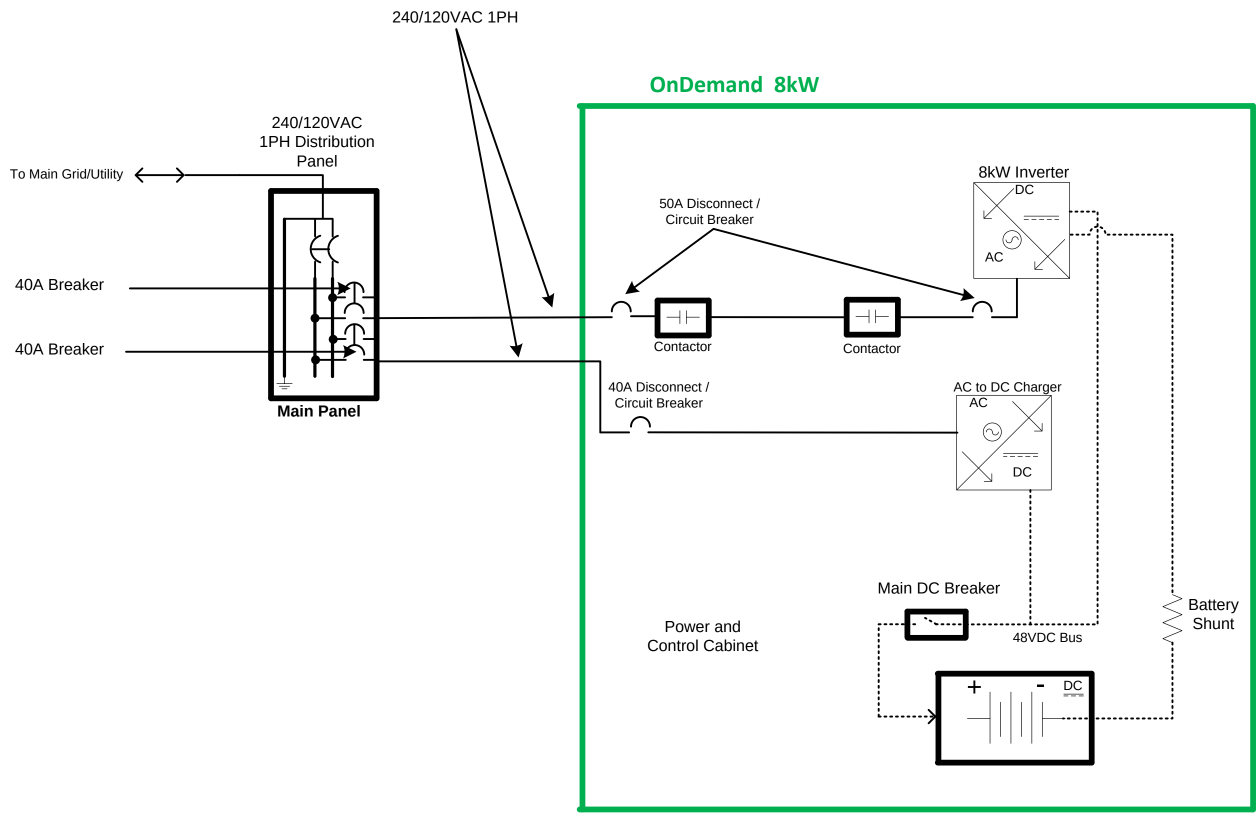
Contractor Prepares Permit Pack; Contractor Makes Initial Submittal to AHJ	Typical Duration 1 -2 weeks.
AHJ Reviews Initial Submittal; AHJ Provides Plan Check Comments to Contractor	Typical Duration anywhere from 1 week to 6 weeks. (Rancho Cordova Usually 2 – 4 weeks)
Contractor responds to comments, makes changes as required and resubmits to AHJ	1 Week or Less depending on severity of revisions
AHJ Approves Changes and Issues Permit; Contractor pulls and pays for permit and obtains city business license if not already held	1 Week or Less. May be concurrent with permit issue

Note:

- Every AHJ (Authority Having Jurisdiction) is different and has different permitting requirements
- Time for plan check review may be mitigated in certain instances by an early meeting with the AHJ to introduce the project and ask for and set expectations.

Silent Power INC.

Typical Installation



OnDemand™

Energy Appliance

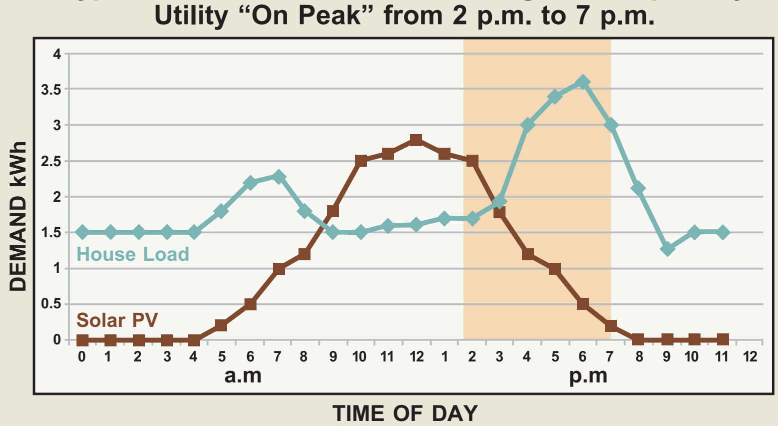
Smart Grid Solution for Integrating Renewables into the Grid

The Silent Power OnDemand™ Energy Appliance is the ideal solution for Electric Utilities and their customers to integrate renewable into the distribution grid. OnDemand™ solves a number of issues that arise as renewable energy production becomes more prevalent.

Aligns Distributed Renewable Production Peaks with the Utility Demand Peaks

Peak solar renewable energy production from photovoltaic panels occurs during peak sunlight hours (typically 9 am to 3 pm). Conversely, the Utilities daily peak residential demand for electricity typically occurs between the hours of 2 pm and 7 pm. As a result many of the grid tie only solar systems in use today are selling energy back in the grid, when the grid doesn't need it. The Silent Power OnDemand™ Energy Appliance stores any excess renewable energy locally, and intelligently uses this stored energy during the Utilities peak demand period, in effect aligning the solar peak with the Utilities peak demand.

Typical Residential Household using 40 kWh per day
Utility "On Peak" from 2 p.m. to 7 p.m.

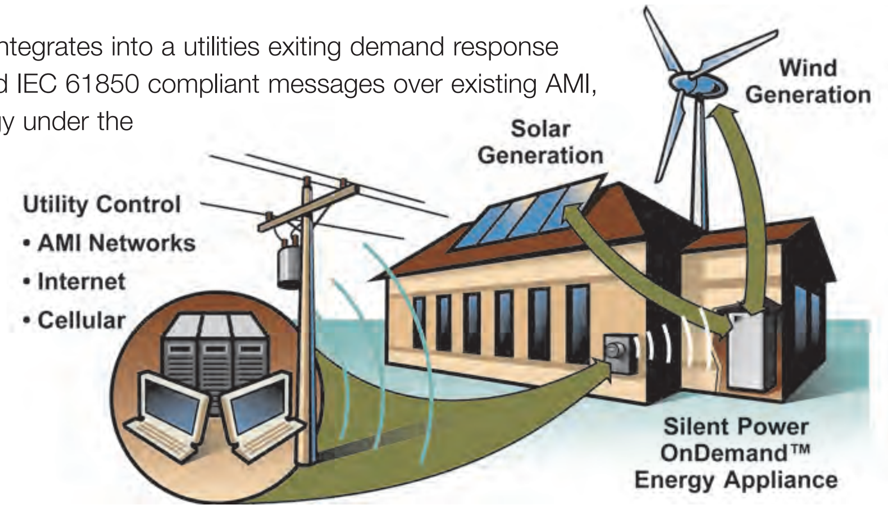


Solar production typically peaks outside the Utilities peak demand

Silent Power OnDemand™ Energy Appliance

Dispatchable Generation Source for Demand Response

Silent Power's OnDemand™ Energy Appliance easily integrates into a utilities exiting demand response system. OnDemand™ communicates standards based IEC 61850 compliant messages over existing AMI, cellular, or Internet networks to put dispatchable energy under the utilities control. During critical demand response periods utilities are able to immediately add system capacity by turning on multiple OnDemand™ Energy Appliances in aggregate for those key hours when extra capacity is needed. Key energy metrics such as renewable energy production, consumption, stored energy are all available to the utility.



Residential or Small Commercial Applications

Silent Power's OnDemand™ Energy Appliance is about the size of a small refrigerator. OnDemand™ is available in 5kW or 10kW electrical output with 10kWhr (20kWhr optional) of energy storage. Energy storage is provided by high capacity, sealed maintenance-free, fully recyclable batteries.

Consumer Benefits

Backup Power — OnDemand™ automatically provides clean, instant, reliable backup power to protect homes and businesses from blackouts and brownouts for critical loads such as computers, refrigerators, security systems, heating systems, and well pumps.

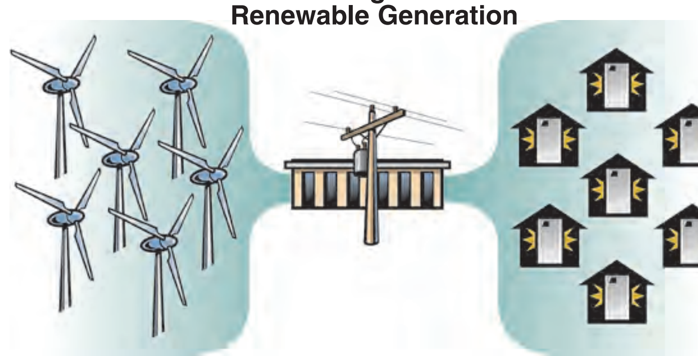
Energy Intelligence – Consumers are provided with detailed energy information including renewable energy production, energy consumption, and net-metered energy.

Renewable Rebates – The OnDemand™ system is eligible for federal tax credits of up to 30% when used with a solar installation. State incentives may apply as well.

Excess Centralized Renewable Production Storage

As centralized renewable production becomes more significant for Utilities (i.e. wind farms, solar farms, etc), there will be times when there is excess centralized production. Utilities will be able to use the OnDemand™ Home Energy Appliance as a distributed energy storage device to store this excess energy for when it is needed the most.

Distributed Storage for Centralized Renewable Generation



Improved Electrical Grid Reliability

As the grid becomes more storage dependent, the OnDemand™ Home Energy Appliance improves network reliability by creating a microgrid architecture through its distributed energy production by providing energy storage at the edge of the grid. This distributed multipoint production/storage design eliminates a single point of failure or vulnerability and is more secure in terms of our nation's energy security.

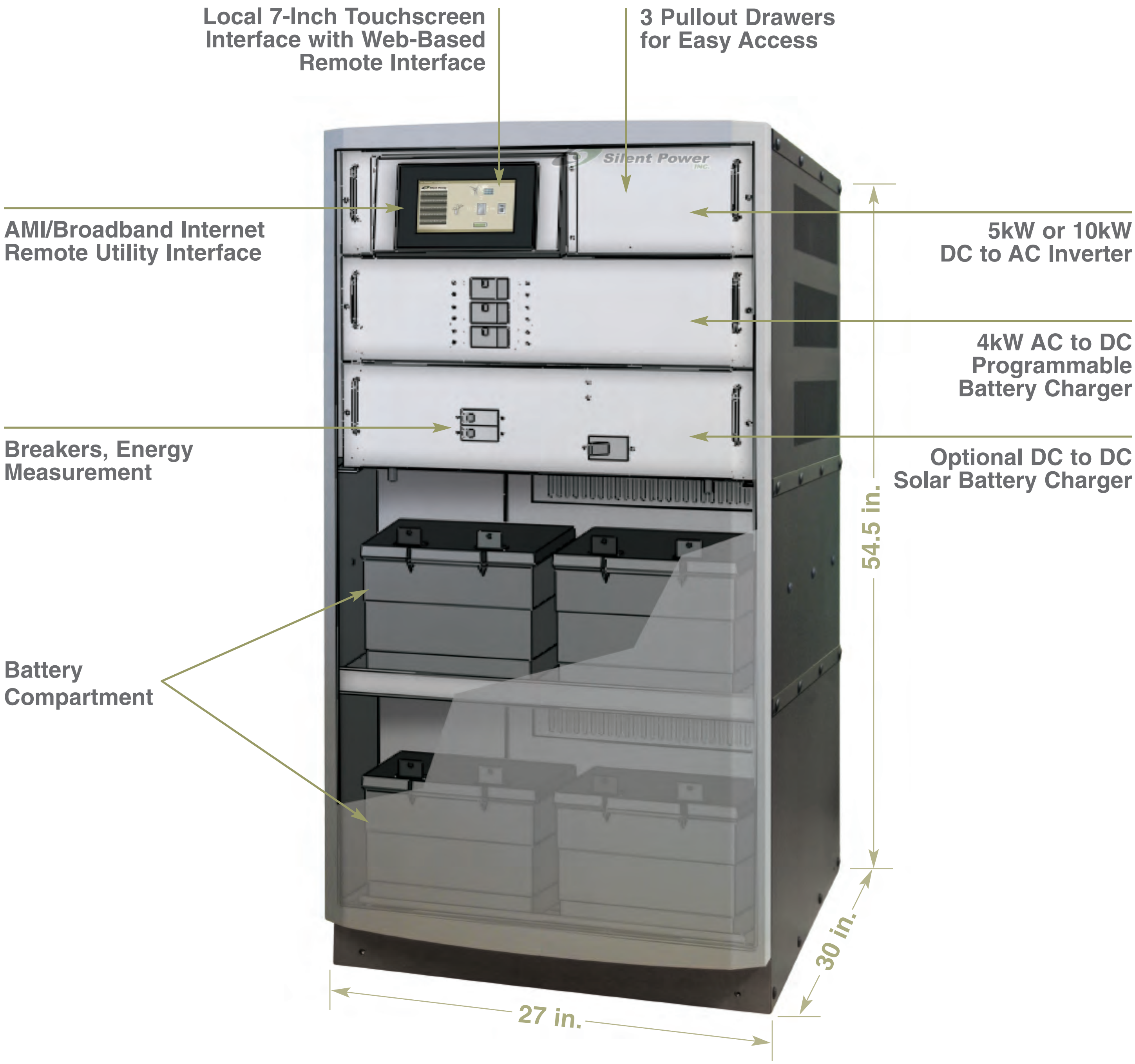
Silent Power INC.

To learn more about Silent Power call: **888.818.1001** or visit our website: **www.silentpwr.com**

© 2010, Silent Power Inc., 8175 Industrial Park Rd., Suite 100, Baxter, MN 56425

Silent Power OnDemand™ Energy Appliance

(Front interior view)



Silent Power INC.

To learn more about Silent Power call: **888.818.1001** or visit our website: **www.silentpwr.com**

© 2010, Silent Power Inc., 8175 Industrial Park Rd., Suite 100, Baxter, MN 56425

About Silent Power Incorporated

Silent Power, Inc. is a manufacturer of advanced energy conversion products for wind, solar, fuel cells, and backup power applications. Silent Power, Inc. products include inverters, battery chargers, and programmable controllers which convert, supply, control, regulate, and distribute electrical power.

TRADEMARKS

OnDemand™ is a trademark of Silent Power, Inc. Other trademarks, registered trademarks, and product names are the property of their respective owners and are used herein for identification purposes only.

NOTICE OF COPYRIGHT

OnDemand™ Energy Appliance Manual © 2010 Silent Power Incorporated. All rights reserved.

DISCLAIMER

UNLESS SPECIFICALLY AGREED TO IN WRITING, SILENT POWER INCORPORATED

(a) MAKES NO WARRANTY AS TO THE ACCURACY, SUFFICIENCY OR SUITABILITY OF ANY TECHNICAL OR OTHER INFORMATION PROVIDED IN ITS MANUALS OR OTHER DOCUMENTATION.

(b) ASSUMES NO RESPONSIBILITY OR LIABILITY FOR LOSS OR DAMAGE, WHETHER DIRECT, INDIRECT, CONSEQUENTIAL OR INCIDENTAL, WHICH MIGHT ARISE OUT OF THE USE OF SUCH INFORMATION. THE USE OF ANY SUCH INFORMATION WILL BE ENTIRELY AT THE USER'S RISK.

(c) REMINDS YOU THAT IF THIS MANUAL IS IN ANY LANGUAGE OTHER THAN ENGLISH, ALTHOUGH STEPS HAVE BEEN TAKEN TO MAINTAIN THE ACCURACY OF THE TRANSLATION, THE ACCURACY CANNOT BE GUARANTEED. APPROVED SILENT POWER CONTENT IS CONTAINED WITH THE ENGLISH LANGUAGE VERSION WHICH IS POSTED AT www.silentpwr.com

NOTE: Due to continuous quality improvement and product updates, the illustrations and or pictures shown in this manual may not exactly match the unit you purchased.

DATE AND REVISION: Nov 2010

PART NUMBER: 60-100080 RevA- OnDemand

Manufacturer's Contact Information:

Telephone:	1 (888) 818-1001 (toll free North America)
	1 (218) 454-3030 (direct)
Fax:	1 (218) 454-3026
Email:	SALES@SILENTPWR.COM
Http:	WWW.SILENTPWR.COM

ONDEMAND MAIN UNIT SERIAL NUMBER ____________________

USER INTERFACE SERIAL NUMBER ________________________

DATE PURCHASED ______________________________________

NOTES:

MODELS: OnDemand™ 0521-xx- / OnDemand™1022-xx
ENERGY APPLIANCE FOR INDOOR USE

INVERTER SYSTEM

Continuous AC Output Power:	5kV – 120VAC / 10kVA – 120/240VAC
Nominal DC Operating Voltage:	48VDC
Range of Operating DC Voltage:	44-66VDC
Max Input DC Voltage:	66VDC
Max Input DC Current:	5kVA – 145A / 10kVA - 290A
Max Input Short Circuit Current:	5kVA – 250A DC, 10kVA – 450A DC
Nominal AC Output Voltage1:	120 or 120/240 VAC ± 3%
Nominal AC Output Frequency:	60Hz ± 0.3%
Max Continuous AC Output Current:	42Amps AC
Max AC Output Fault Current2:	135Amps AC for 10ms
Total Harmonic Distortion:	< 5%
Normal Operation Temp. Range:	-4 to 104° F (-20 to 40° C)

AC TO DC CHARGER SPECIFICATIONS (GRID TO BATTERY)

Continuous Output at 25°C:	83A DC (4000W)
Input Current at Rated Output:	27 A @ 240 VAC
Four Stage Charging Capability:	Bulk, Absorb, Float, Conditioning

RENEWABLE DC TO DC CHARGE CONTROLLER SPECIFICATIONS (OPTIONAL, UP TO 2 PER CABINET)

Continuous Output (per unit):	60 A DC (3200W)
Max. Open Circuit Solar Voltage:	150 VDC
Four Stage Charging Capability:	Bulk, Absorb, Float, Conditioning
MPPT Capability:	Yes

BACKUP POWER FEATURES

AC Pass-through Current to Critical Circuits Panel:	50 A – 120V / 100A - 120/240V
Switching Time upon Grid Outage:	Less than 30 milliseconds
Backup Switching Criteria:	Per IEEE 1547
Continued Solar Production in Island Mode:	Yes

[1] **Nominal AC Input Voltage** The generator input can be wired for either 120VAC or 240VAC/120VAC split phase.
[2] **Max AC Output Fault Current** is the maximum current available for a short period of time before the unit will trip off.

SILENT POWER, INC.
Patent No. 02,818 B2 and US 6,967,852 B2
UL1778, CSA 107.3-05 US 7,0

FCC Information to User: This equipment has been designed but not yet tested to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and the receiver.
- Consult the dealer or an experienced radio/TV technician for help.

Table of Contents

WARRANTY

Warranty

SILENT POWER'S TWO YEAR LIMITED WARRANTY

Silent Power warrants that the products it manufactures will be free from defects in materials and workmanship for a period of two (2) years subject to the conditions set forth below.

The limited warranty is extended to the original purchaser and is transferable. The limited warranty term begins on the date of invoice to the original purchaser of the product. The limited warranty does not apply to any product or part thereof damaged by a) alteration or disassembly, b) accident or abuse, c) corrosion, d) lightning, e) reverse polarity, f) repair or service provided by an unauthorized repair facility, g) operation or installation contrary to instructions pertaining to the product.

Silent Power's liability for any defective product or any part thereof shall be limited to the repair or replacement of the product, at Silent Power's discretion. Silent Power does not warrant or guarantee the workmanship performed by any person or firm installing its products.

THIS LIMITED WARRANTY GIVES YOU SPECIFIC LEGAL RIGHTS, AND YOU MAY ALSO HAVE OTHER RIGHTS THAT VARY FROM STATE TO STATE (OR JURISDICTION TO JURISDICTION). SILENT POWER'S RESPONSIBILITY FOR MALFUNCTIONS AND DEFECTS IN HARDWARE IS LIMITED TO REPAIR AND REPLACEMENT AS SET FORTH IN THIS LIMITED WARRANTY STATEMENT. ALL EXPRESS AND IMPLIED WARRANTIES FOR THE PRODUCT, INCLUDING BUT NOT LIMITED TO ANY IMPLIED WARRANTIES OF AND CONDITIONS OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, ARE LIMITED IN DURATION TO THE LIMITED WARRANTY PERIOD SET FORTH ABOVE AND NO WARRANTIES, WHETHER EXPRESS OR IMPLIED, WILL APPLY AFTER SUCH PERIOD. SOME STATES (OR JURISDICTIONS) DO NOT ALLOW LIMITATIONS ON HOW LONG AN IMPLIED WARRANTY LASTS, SO THE ABOVE LIMITATION MAY NOT APPLY TO YOU.

SILENT POWER DOES NOT ACCEPT LIABILITY BEYOND THE REMEDIES SET FORTH IN THIS LIMITED WARRANTY STATEMENT OR LIABILITY FOR INCIDENTAL OR CONSEQUENTIAL DAMAGES, INCLUDING WITHOUT LIMITATION ANY LIABILITY FOR PRODUCTS NOT BEING AVAILABLE FOR USE. SOME STATES (OR JURISDICTIONS) DO NOT ALLOW THE EXCLUSION OR LIMITATION OF INCIDENTAL OR CONSEQUENTIAL DAMAGES, SO THE ABOVE EXCLUSION OR LIMITATION MAY NOT APPLY TO YOU.

During the two year period beginning on the invoice date, Silent Power will repair or replace products covered under this limited warranty that are returned to Silent Power's facility or to a Silent Power's authorized repair facility, or that are repaired on site by a Silent Power's authorized repair technician. To request limited warranty service, you must contact Silent Power Incorporated at (888) 818-1001 – toll free in North America or directly by dialing 218-454-3030 within the limited warranty period. If warranty service is required, Silent Power will issue a Return Material Authorization (RMA) Number. The requester must mark the outside of the package with the RMA number and include a copy of the original purchase invoice with the return package. Products must be shipped back to Silent Power in their original or equivalent packaging, prepay shipping charges, and insure the shipment or accept the risk of loss or damage during shipment. Silent Power will ship the repaired or replacement products to sender freight prepaid if within the continental United States, where applicable. Shipments to other locations will be made freight collect.

About This Manual

Purpose

The OnDemand™ Energy Appliance Manual provides explanations and procedures for installation and operation.

Scope

This Manual provides safety guidelines, setup information, and procedures for operating and installing the OnDemand™ Energy Appliance. This manual does not provide details about specific brands or types of photovoltaic cells, wind, or hydro-electric generators. You must consult the manuals supplied by the manufacturer of the specific equipment you wish to install for this detailed information.

Conventions Used

The following conventions are used in this manual

WARNING: Warnings identify conditions or practices that could result in personal injury or loss of life.
CAUTION: Cautions identify conditions or practices that could result in damage to the unit or other equipment.
IMPORTANT: These notes contain information that is important for you to know, but are not as critical as a caution or warning.

RELATED INFORMATION

More information about Silent Power Incorporated and its products can be found at: www.silentpwr.com

WARNING: RISK OF INJURY OR LOSS OF LIFE
The OnDemand™ Energy Appliance shall not be used in connection with life support systems or other medical equipment or devices.

CAUTION: THIS UNIT IS TO BE USED INDOORS ONLY.

IMPORTANT: THIS UNIT MUST BE REQUIRED TO BE MOUNTED TO THE FLOOR.

The OnDemand™ Energy Appliance obtains its greatest stability against deformation when installed on a level surface.

SAFETY INSTRUCTIONS

Important Safety Instructions

READ AND SAVE THESE INSTRUCTIONS

The OnDemand™ Energy Appliance manual contains important safety and operating instructions as required by UL and ETL. Before installation, be sure to read and understand these safety instructions thoroughly.

WARNING: FAILURE TO FOLLOW INSTRUCTIONS AND OR OBSERVE ALL RELEVANT SAFETY PRECAUTIONS COULD RESULT IN DAMAGE TO EQUIPMENT, PERSONAL INJURY OR LOSS OF LIFE.

WARNING: SHOCK HAZARD. ENERGIZED FROM BOTH AC AND DC SOURCES. DISCONNECT ALL SOURCES BEFORE SERVICING.

CAUTION: TO REDUCE RISK OF FIRE, CONNECT ONLY TO A CIRCUIT PROVIDED WITH 50 AMPERES MAXIMUM BRANCH CIRCUIT OVER CURRENT PROTECTION IN ACCORDANCE WITH THE NATIONAL ELECTRICAL CODE, ANSI/NFPA 70.

1. Before using the OnDemand™ Energy Appliance, read all instructions and cautionary markings on the unit, the batteries, and all appropriate sections of this manual.
2. Use of accessories not recommended or sold by Silent Power, Inc. could result in a risk of fire, electric shock, or personal injury.
3. The OnDemand™ Energy Appliance is designed to be permanently connected to your AC and DC electrical systems. Silent Power, Inc. recommends that all wiring be done by a certified technician or licensed electrician to ensure adherence to the local and national electrical codes applicable in your jurisdiction.
4. To avoid a risk of fire and electric shock, ensure the existing wiring is in good condition and that the wire is not undersized. Do not operate with damaged, undersized or substandard wiring.
5. To reduce risk of damage and injury, use only valve regulated lead acid (VRLA) absorbed glass mat (AGM) batteries equivalent to Concorde Sun Xtender PVX-2580L. Other types of batteries may burst, causing personal injury and damage.
6. Do not operate the OnDemand™ Energy Appliance if it is damaged in any way. See the Warranty and Product Information section in the OnDemand™ Energy Appliance manual.
7. This unit does not contain user serviceable parts. Do not disassemble except where noted for connecting wiring and cabling. See the Warranty Section of this manual. Enlist the services of a qualified service person when service or repair is required. Incorrect assembly may result in a risk of electrical shock or fire. Internal capacitors remain charged for a time after all power is disconnected.
8. Do not expose the OnDemand™ Energy Appliance to rain, snow, or liquids of any kind. This

(Continued on the next page)

product is designed for indoor use only. Damp environments will significantly shorten service life and corrosion caused by dampness will not be covered by the product warranty.

9. The OnDemand™ Energy Appliance does not accommodate the installation of external batteries.
10. To reduce the risk of electric shock, disconnect all sources of AC and DC power before attempting any maintenance or cleaning. Turning off the controls alone will not reduce this risk.
11. The OnDemand™ Energy Appliance must be provided with equipment grounding conductors connected to the AC input ground and chassis ground terminals.
12. To reduce the risk of overheating, keep the ventilation openings clear and do not install in an area with limited airflow or inadequate clearances around the unit. Refer to the section entitled "SELECTING A LOCATION" in the installation instructions portion of this manual for required clearance.
13. To reduce the chance of short-circuits, always use insulated tools when installing or working with the OnDemand™ Energy Appliance.
14. Remove personal metallic items such as rings, bracelets, necklaces, and watches when working with batteries.
15. To reduce the risk of battery explosion, follow the instructions published by the battery manufacturer and the manufacturer of any equipment you intend to use in the vicinity of a battery. Review the cautionary markings on these products.
16. This equipment contains components which could produce sparks. To prevent fire or explosion, do not install the inverter/charger in compartments containing flammable materials or in locations that require ignition-protected equipment. This includes any space containing gasoline-powered machinery, fuel tanks, as well as joints, fittings, or other connections between components of the fuel system.
17. Be extra cautious to reduce the risk of dropping metal tools onto the batteries due to the risk of explosion.
18. Never attempt to charge a frozen battery.
18. Before disconnecting any cables from battery terminals make sure all accessories that the batteries supply are turned off, so as not to cause an arc above the batteries.
19. Keep the battery terminals clean.

IMPORTANT: BE SURE TO OBTAIN THE APPROPRIATE PERMITS, IF NECESSARY, PRIOR TO STARTING THIS INSTALLATION. INSTALLATIONS MUST MEET ALL LOCAL CODES AND STANDARDS. INSTALLATIONS OF THIS EQUIPMENT SHOULD ONLY BE PERFORMED BY SKILLED PERSONNEL SUCH AS QUALIFIED ELECTRICIANS AND CERTIFIED RENEWABLE ENERGY (RE) SYSTEM INSTALLERS.

SAFETY INSTRUCTIONS

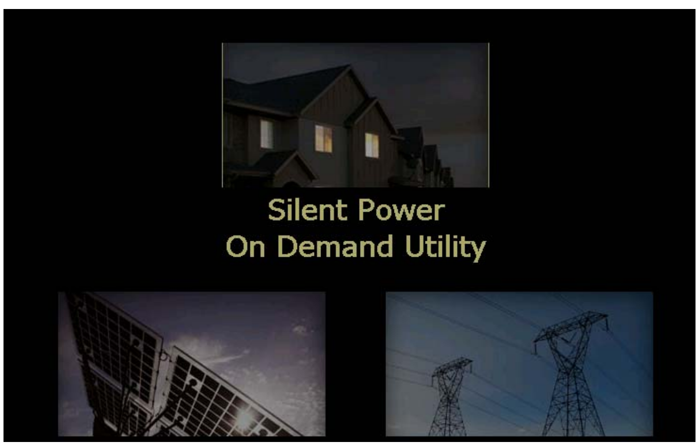
OPERATOR'S MANUAL

SYSTEM OVERVIEW

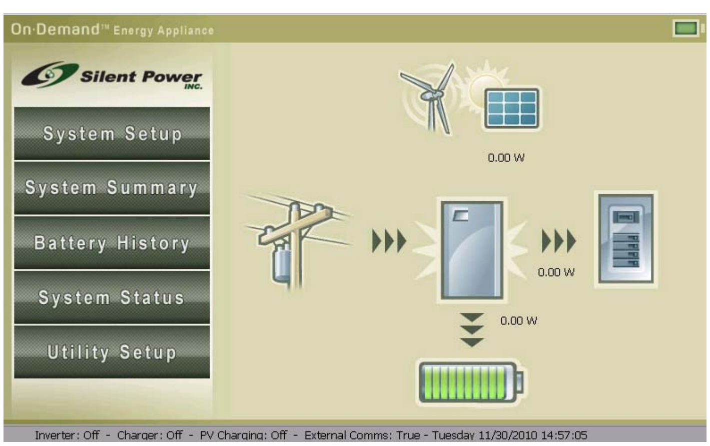
Silent Power's OnDemand™ is an Energy Appliance that integrates renewable energy into the distribution grid. The Silent Power OnDemand™ Energy Appliance stores any excess renewable energy locally and intelligently uses this stored energy during the Utilities peak demand period. During critical demand response periods, utilities are able to immediately add system capacity by turning on multiple OnDemand™ Energy Appliances in aggregate for those key hours when extra capacity is needed. OnDemand™ can provide backup power during blackouts or brownouts as well as providing stored energy to the utility.

USER INTERFACE (U/I)

The User Interface is located on the front of the unit and consists of a touch screen. The U/I is where the operator sets a variety of parameters required by the firmware for the system to function. The U/I is also where the operator monitors the status of the system. The initial screen will automatically default to the following home screen.



THE USER INTERFACE INITIAL SCREEN



THE USER INTERFACE HOME SCREEN

The interface works by touching the icon that you would like to select.

Select System Setup

START UP

CAUTION: DO NOT BEGIN THE START UP PROCESS UNTIL ALL THE STEPS IN THE INSTALLATION INSTRUCTIONS HAVE BEEN COMPLETED.

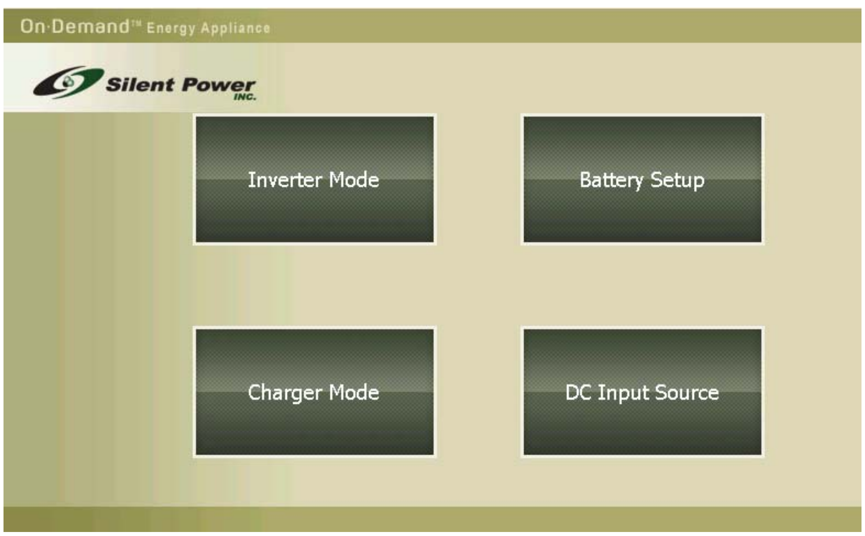
CAUTION: ENSURE THAT THE AC INPUT CIRCUIT BREAKERS ARE OPEN (OFF) WHEN POWERING THE UNIT UP FOR THE FIRST TIME.

1. Turn on the main 250A / 450A DC Circuit Breaker on the front panel of the unit.

Circuit Breaker Panel

250A/450A Circuit Breaker

2. At the System Setup Screen, select Inverter Mode, Charger Mode, Battery Setup or DC Input Source.



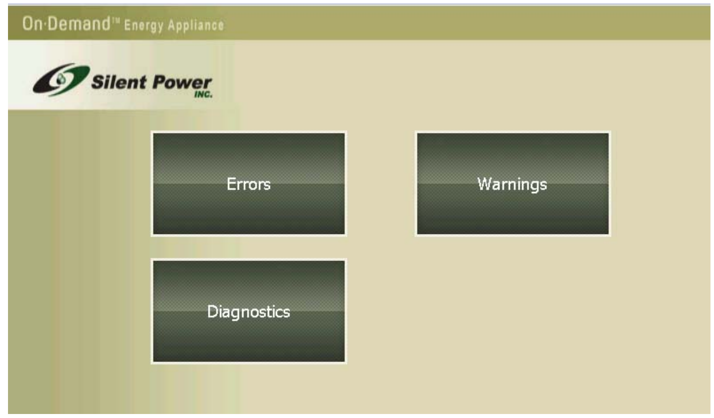
System Setup Screen

INVERTER

TURNING THE INVERTER ON AND OFF

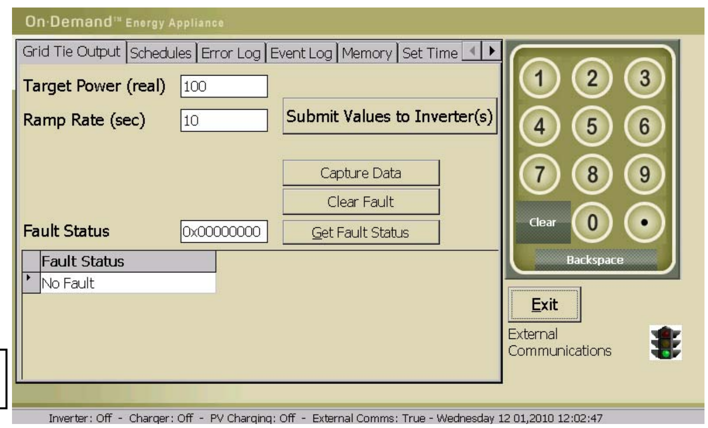
1. Ensure the Inverter and Grid circuit breakers are on.
2. First go to the "System Status" screen located on the home screen to set Target Power.

System Status Screen



3. Choose the Diagnostics icon
   Enter the Target Power (real) value
   Between 1 and 10kW
   Enter the Ramp Rate (sec)
   Typically 10 seconds
4. Touch the "Submit Values to Inverter(s)" icon

Diagnostics Screen

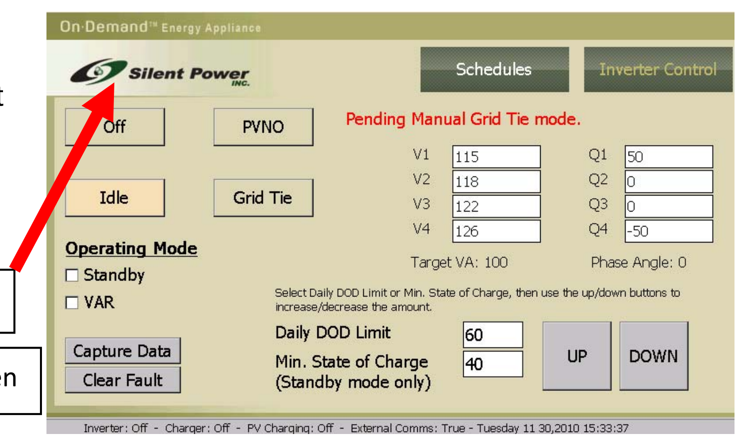


5. Go back to the home screen by touching the Silent Power icon and select System Setup and then Inverter Mode
6. Select the "Grid Tie" icon.

.

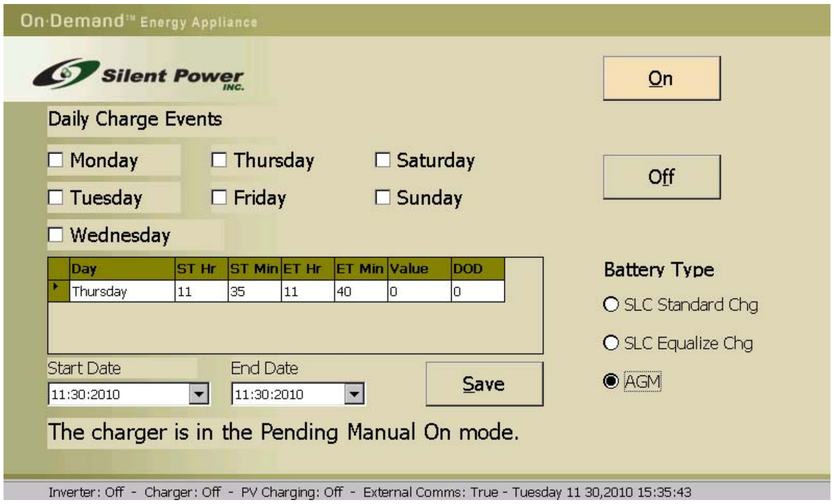
Touch to go back a screen

Inverter Mode Screen



TURNING THE CHARGER ON AND OFF

1. Ensure the Grid circuit breaker is on.
2. Select “On” or “Off” (whichever operation is desired).



CHARGER

CHARGER AUTOMATIC MODE

As mentioned earlier, the OnDemand™ Energy Appliance will automatically start the charging process if the battery bank voltage gets too low regardless of grid status. The low voltage threshold is based on four possible conditions (whichever happens first):

A. The batteries have been below 47.6V for more than 24 hours for a continuous period. B. The batteries have been below 46.0V for more than 2 hours for a continuous period. C. The batteries have been below 45.0V for more than 15 minutes for continuous period. D. The batteries dropped below 44.0V for more than one minute.

The 44.0V for condition D is called the “Low Volt Start Pt”. It can be changed up or down by the operator using the User Interface. When it is changed all the other conditions A through C automatically change by the same amount thus shifting the entire set of conditions.

EQUALIZATION OF THE BATTERIES

In addition to charging the batteries, another requirement of VRLA AGM batteries is the need for “equalization” when needed. Over time the voltage on any one battery in a string can become different from the rest. Equalization charges the battery bank to a higher than normal voltage for a specific amount of time. Both of these values are selectable in the User Interface. To turn equalization on the operator selects the Equalization Menu then scrolls down to the “ON” selection and hits ENTER. The OnDemand™ Energy Appliance will then go through the first two stages of a normal battery charging operation (Bulk and then Absorption) and then increase the battery voltage to the “Equalization Voltage” and stay there for the specific amount of time set in “Equalization Time”.

IMPORTANT: EQUALIZATION CAN BE MANUALLY STOPPED BY SHUTTING OFF THE CHARGER AS ABOVE.

Appendix A

BENEFITS OF SEPARATING THE INVERTER BOARD FROM THE CHARGER BOARD

The OnDemand™ Energy Appliance is a 5kW/10kW 48V Inverter/Charger combination. Instead of being an Inverter when the batteries are full and a Charger when the batteries are charging, the system has a separate inverter board from the charger board. When running off renewable power, all the current for both the house load and for battery charging goes through the charger board. Then as much as is needed by the home goes back out through the inverter board and the rest is used for charging the batteries. The present version the charger board is capable of 4000 watts so it can supply most of the home's continuous needs. However if the house load was steady at 4000 watts there obviously would be no power left to charge the batteries.

The most common inverter systems available today have one board that switches from being an inverter to a charger once the generator is switched on. When the generator kicks in to charge the batteries it is also required to supply all the current needed for the home directly. It does this through a transfer switch which must flip from inverter power to generator power so the inverter can be turned around and used as the charger. There are three main benefits to having a separate charger board over an inverter-switch-to-charger type system. First: the power never comes directly off the generator to run the home. The power for the home always comes through the inverter board which regulates power for both 60Hz and for 120 volts. This makes light bulbs less likely to dim or flicker, electronic clocks remain more accurate, and surges caused by larger appliances are much more quickly and appropriately handled. The second benefit is that there is no switch-over moment as power is switched. This momentary loss of power can, under some conditions, crash computers or confuse plasma TVs. In fact pumps and other large motors can in some cases be damaged by the abrupt change from one power source to another if the two are out of phase at the time of the switch over. The OnDemand™ energy appliance is capable of 2.5X short term current surge. This surge current is supplied by the batteries even while the batteries are being charged. The surge is only momentary so it does not disturb the charging cycle.

Appendix B

CHARGING BASICS

The following section explains why battery and generator parameters must be set before attempting to charge.

TERMINATION VOLTAGE / BULK VOLTAGE:

Typical battery charging algorithms use a three to five stage charging sequence. The one described here is typically used for lead acid batteries. For clarity the definition of a "Bank" of batteries as used here includes all the batteries in the battery box. A "String" of batteries is the minimum subset of the bank needed to produce the full 48V. A bank will often consist of two to four 48V strings.

STAGE ONE: The first stage consists of a current limit stage where only a limited amount of current is provided to the batteries as the battery voltage is brought up slowly to the "Termination Voltage" sometimes called the "bulk voltage". This current limit is imposed to keep the batteries from heating up and boiling down their water level. Often the maximum current limit into each battery is set for
10% or 20% of the battery's Amp Hr rating. For instance a 10% charge rate on a 250AmpHr battery would call for a 25Amp maximum limit. This 25Amps would be per string since the batteries in the string are in series with each other and would each see the same current. A bank consisting of two strings would see 50 Amps and this is what is displayed on the U/I.

The number of strings in parallel making up the battery bank will determine the total amount of current to be supplied by the charger. i.e. four strings of batteries would require 100Amps from the charger in the above example. The User Interface will calculate both the number of strings and the battery bank current limit based on the four user settable parameters: Total Number of Batteries, Volts per Battery of the specific type of battery being installed, Amp Hour Size obtained from the specifications for this battery type and Per Battery Charge Rate recommended for this type of battery. It will then calculate the number of strings and limit the current delivered to the entire bank to "Amp Hour Size" x "Per Battery Charge Rate" x the number of strings. The OnDemand™ Energy Appliance has an internal shunt that measures all the current going into and out of the battery bank so it can control the charger's current to adjust for all sources of battery charging current.

The current limit stage is finished once the batteries reach their "Termination Voltage" or "bulk voltage" for one minute. This is another user settable parameter. For a 48V bank of lead acid batteries this voltage should be set near 58.4V. After this voltage has been reached the charger goes into stage two.

STAGE TWO: The second stage is a constant voltage stage often referred to as the "absorption stage" and is often considered part of the bulk stage. In this stage the voltage is held at or just below the termination voltage and as the batteries fill up the current goes down. This constant voltage level is called the "Absorption Voltage". A typical absorption voltage value would be 56.6V on a 48V battery bank although some battery manufacturers recommend leaving the absorption voltage at the same level as the termination voltage. This voltage is settable by the user. The charger will remain in this stage for the duration of the "Absorption Time" or until the current delivered to the bank reaches 2% of battery AmpHr rating for each string (i.e. if there are two strings the User Interface's display will show 4% of a single battery's AmpHr rating at the time stage two is about to end). The operator can

Appendix B

CHARGING BASICS (CONTINUED)

select the “Absorption Time” or select the 2% option instead. When the “Absorption Time” has been reached or the current has stayed at or below 2% for one minute the charger goes into stage three.

STAGE THREE: The third stage is called the Float stage. It will simply maintain the “Float Voltage” Level on the batteries for the specified amount of time referred to as the “Float Time”. Both of these are user set parameters. Float voltage might be 53V as an example. This is a time when the batteries can settle out and provides the last bit of fill needed to top them off. Once the float time has been reached the charge cycle is complete.

BATTERY COMPARTMENT TEMPERATURE COMPENSATION: The OnDemand™ Energy Appliance has the capability of adjusting the charge rate for both warm and cold batteries. This is done by increasing the various charge stage voltages up by a small voltage for every degree F decrease in battery temperature below 77ºF or decreasing those same voltages a small amount for every degree above 77ºF. The amount of change in voltage depends on the battery type. If the Battery Compartment Temperature Probe is connected (see page 31) the battery bank temperature will be displayed to the right of the Battery Voltage on the default screen. Note: the temperature will only be displayed when the probe is connected. If there is no display, then there is a disconnect somewhere in the probe connections or the probe itself. The OnDemand™ Energy Appliance will attempt to keep the batteries below 95ºF, if it can. It will do this by limiting the current to the batteries in each of the charging stages. If the batteries ever reach 120ºF, the charger will shut off

Appendix C

ONDEMAND AUTHORIZED BATTERIES

WARNING: TO REDUCE RISK OF DAMAGE AND INJURY, USE ONLY VALVE REGULATED LEAD ACID (VRLA) ABSORBED GLASS MAT (AGM) BATTERIES EQUIVALENT TO CONCORDE SUN XTENDER PVX-2580L AND EXIDE MARATHON M12V180FT. OTHER TYPES OF BATTERIES MAY BURST, CAUSING PERSONAL INJURY AND DAMAGE. ADHERE TO THE MANUFACTURER'S RECOMMENDED CHARGING SPECIFICATIONS SHOWN BELOW.

CONCORDE SUN XTENDER PVX-2580L:

The most efficient method of charging Sun Xtender AGM batteries is to use a 3 stage charging profile. In the first stage, a constant current is applied until the voltage reaches a pre-set limit. The first stage is often called the Bulk charging stage. In the second stage, the voltage is held constant at the same pre-set limit until the charging current tapers to a very low value, at which point the battery is fully charged. The second stage is often called the Absorption charging stage. A voltage limit of 2.385 ± 0.015 volts per cell (14.2 to 14.4 volts for a 12 volt battery) should be used when the battery temperature is 25°C (77°F). The battery is fully charged when the current drops below 0.5% of the battery's rated capacity (0.5A for a 100Ah battery). In the third stage, the charging voltage is reduced to a lower value that minimizes the amount of overcharge, while maintaining the battery at 100% state of charge. This third stage is often called the Float charging stage. A float voltage of 2.215 ± 0.015 volts per cell (13.2 to 13.4 volts for a 12 volt battery) should be used when the battery temperature is 25°C (77°F).
Conditioning should only be done when the battery is showing symptoms of capacity loss due to extended time in a partial or low state of charge condition. This could be caused, for example, by low output of a solar powered charger due to a week of cloudy skies.
NOTE: Some chargers use the term Equalizing instead of Conditioning. An equalizing charge is generally applied to flooded lead acid batteries that are susceptible to acid stratification.
The charging voltages at other temperatures can be determined from the following equations:

VPC (Absorption) = 0.00004T2 – 0.006T + 2.510 (where T = C)
VPC (Float) = 0.00004T2 – 0.006T + 2.340 (where T = C), but not less than 2.167 volts per cell
VPC (Conditioning) = 0.00004T2 – 0.006T + 2.705 (where T = C)

INSTALLATION INSTRUCTIONS

IMPORTANT: BE SURE TO OBTAIN THE APPROPRIATE PERMITS, IF NECESSARY, PRIOR TO STARTING THIS INSTALLATION. INSTALLATIONS MUST MEET ALL LOCAL CODES AND STANDARDS. INSTALLATIONS OF THIS EQUIPMENT SHOULD ONLY BE PERFORMED BY SKILLED PERSONNEL SUCH AS QUALIFIED ELECTRICIANS AND CERTIFIED RENEWABLE ENERGY (RE) SYSTEM INSTALLERS.

Audience

This manual is intended for use by qualified installers of renewable energy and power conversion equipment. Installers should be Certified Technicians or Licensed Electricians.

YOUR COMPLETE SYSTEM INCLUDES:

1 . . . .5kW Inverter with OnDemand™0521 models
2 . . . .5kW Inverter with OnDemand™1022 models
1 . . . .4kW Charger
1 . . . .Battery Cable Assembly
4 . . . .Earthquake Brackets
1 . . . .User Interface
1 . . . .User Manual
1 . . . .Registration Sheet
1 . . . .Battery Temp Sensor Cable

TOOLS REQUIRED:

1 . . . .¾" Wrench or Socket
1 . . . .½" Wrench and/or Socket
1 . . . .Medium Duty Flat Blade Screw Driver
1 . . . .Medium Duty Phillips Screw Driver
1 . . . .Set of U.S. Allen Wrenches
1 . . . .Wire Stripper or Electrician’s Knife
1 . . . .Tape Measure
1 . . . .Marking Pen or Pencil

SELECTING A LOCATION

CAUTION: THIS UNIT IS TO BE USED INDOORS ONLY.

Selecting the right location is critical for peak performance and longevity. The site selected should have good ventilation and easy access for monitoring and service. Sites with open drainage or flowing water should be avoided. Garages and utility rooms can be good locations provided the air circulation is adequate and moisture levels are low. The unit should not be installed under pipes carrying water or other fluids.

IMPORTANT: THE LCD DISPLAY MAY NOT BE VISIBLE AT TEMPERATURES BELOW -4°F (-20°C) THEREFORE IN COLD CLIMATES CHOSE A LOCATION WITHIN A BUILDING THAT HAS SOME SOURCE OF HEAT (I.E. ATTACHED GARAGE OR BASEMENT).

Select a location that provides at least 6” of air space around all sides and back of the unit for ventilation. Embed four 1/4” anchor bolts into the cement floor at the intended location of the unit leaving 1” exposed above the cement. The four bolts should be placed in a rectangular pattern 24.5” across the unit and 20” on the sides.

BATTERY BANK CONNECTIONS

CAUTION: ENSURE THAT THE 250A/450A DC BREAKER AND THE GRID AND CIRCUIT BREAKERS ARE OPEN (OFF) BEFORE MAKING ANY CONNECTIONS TO THE ONDEMAND™ ENERGY APPLIANCE. THE BATTERY CABLES MUST BE EQUIPPED WITH LUGS THAT ARE RATED FOR BOTH ALUMINUM AND COPPER (TIN COATED IS SUFFICIENT).

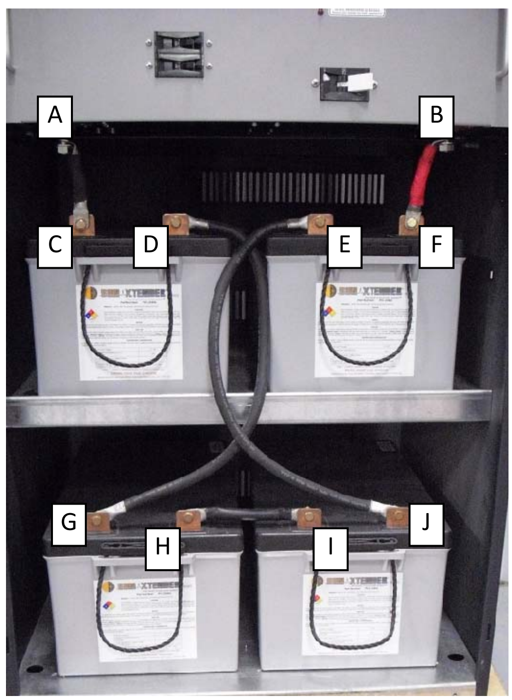
WARNING: THE NEGATIVE TERMINAL OF THE BATTERY BANK IS BONDED TO EARTH GROUND.

WARNING: THIS UNIT IS INTENDED TO BE USED WITH VRLA AGMS EQUIVALENT TO CONCORDE SUN XTENDER PVX-2580L AND EXIDE MARATHON M12V180FT. THE USE OF OTHER BATTERIES MAY BE DANGEROUS AND IS PROHIBITED.

INSTALLING BATTERIES AND CABLES

1. Install four 12V VRLA AGM batteries into the shelves of the unit with their terminals facing outward.
2. Add the short battery cable, H / I , between the positive terminal of the left battery and the negative terminal of the right battery.
3. Attach battery cable G/D and J/E, making sure to use a battery terminal protector on the loose end to prevent a short circuit between positive and negative terminals.
4. Attach positive battery cable, F/B to the red post extending down from the enclosure.
5. Attach negative battery cable C/A.

BATTERY BANK



FIELD WIRING

IMPORTANT: NATIONAL ELECTRIC CODE, ANSI/NFPA 70 WIRING METHODS MUST BE USED.

REMOVE COVER OF FIELD WIRING ENCLOSURE

INSTALLING THE GRID CONNECTIONS

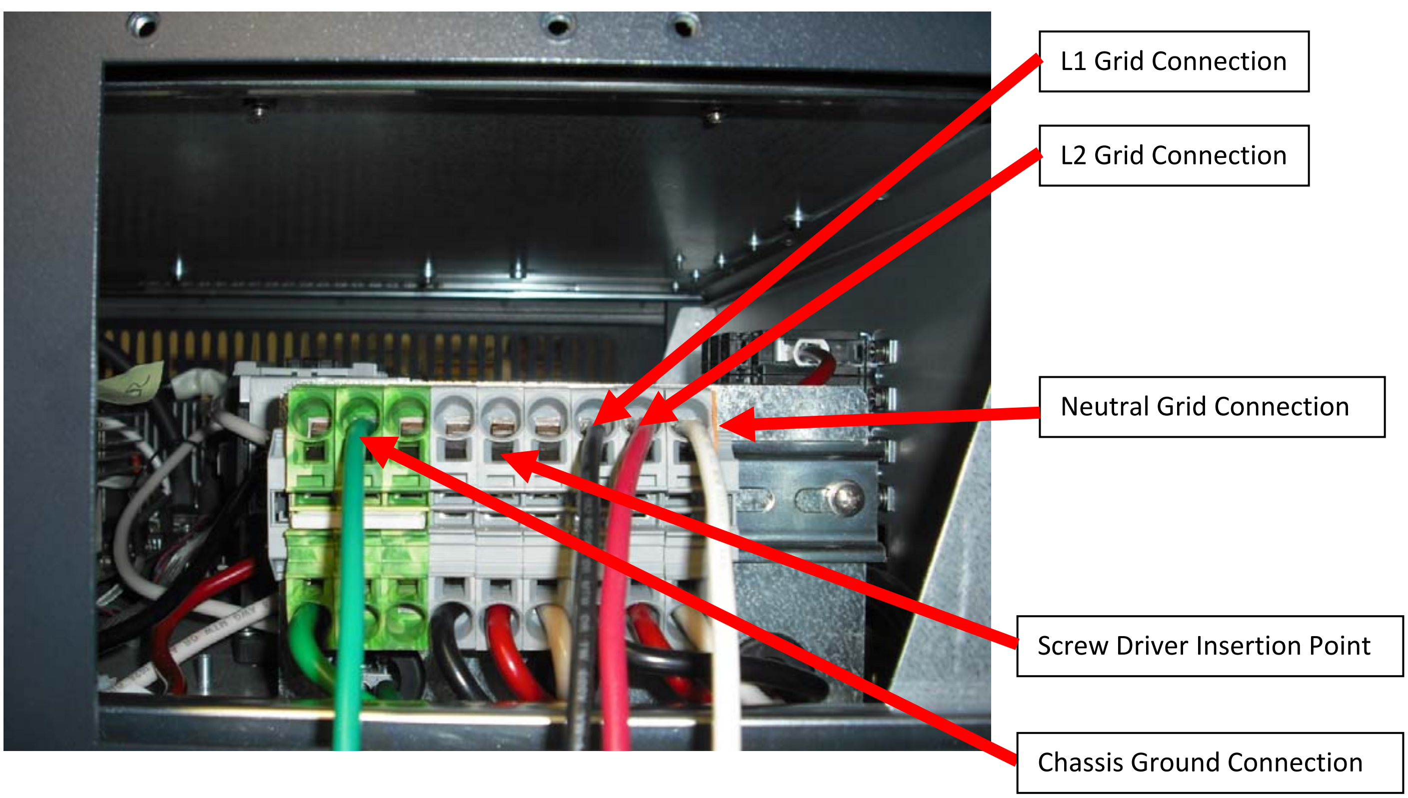
1. The field wiring is done on the left hand side of the unit near the middle drawer section. There are two mating plates with conduit knockouts. Insert conduit into the left hand plate and secure. Feed wire through conduit

For all of the connections, insert a flat bladed small to medium screwdriver into the rectangular slot and push inwards. This opens the spring terminal to push in the wire. After inserting wire, remove tool. Wire is now held firmly in place.

2. Connect the earth ground (Green) wire to the chassis ground bar on the left hand side. This block is tied through the chassis to the battery negative connection. 3. Connect the Neutral (White) wire to the far right terminal.

3. Connect L1 (Black) wire to the third terminal from the right.

4. Connect L2 (Red) wire to the second terminal from the right.



Battery ground to earth ground connections can be made using the chassis ground terminal block detailed above in figure 1, to the battery terminal connection located in the battery breaker door, or they can be made by using the lower gusset plate bolt, provided that a star washer or other powder coat penetrating washer is used between the enclosure finish and the wire terminal lug (see figure 2 below). Ensure that the powder coat finish has been penetrated, and if not remove the powder coat finish under the washer such that contact is made directly to the steel.

Gusset Plate mounting bolt. If connecting the earth ground connection here be certain to make contact directly to the steel using an aggressive star washer between the terminal and the enclosure.

IMPORTANT: SILENT POWER RECOMMENDS 8AWG 90°C WIRE AT A MINIMUM FOR THE CRITICAL CIRCUITS OUTPUT AND GRID INPUT. ALL WIRING MUST HAVE INSULATION THAT MEETS OR EXCEEDS A 300V RATING. TORQUE 8 AWG WIRE TO 25 IN-LBS.

WARNING: CONNECT ONLY TO A CIRCUIT PROVIDED WITH 50 AMPERES MAXIMUM BRANCH CIRCUIT OVERCURRENT PROTECTION IN ACCORDANCE WITH THE NATIONAL ELECTRICAL CODE, ANSI/NFPA 70.

IMPORTANT: THE ONDEMAND™ ENERGY APPLIANCE MUST BE BONDED TO PHYSICAL EARTH AT ONLY ONE PLACE IN THE HOME'S ELECTRICAL SYSTEM. THIS IS OFTEN DONE IN THE MAIN CIRCUIT BREAKER PANEL. IF GRID AND GENERATOR INPUT ARE ABSENT, THE NEUTRAL WILL BE BONDED TO PHYSICAL EARTH WITHIN THE SYSTEM.

ACCOMODATING WIND OR SOLAR GENERATION

The OnDemand™ Energy Appliance will accept solar or wind generation. The PV arrays and Ground Fault Protection Devices shall remain external to the system.

CLOSING THE UNIT

CAUTION: MAKE SURE THE 250A/450A DC CIRCUIT BREAKER IS OPEN (OFF) BEFORE CONNECTING THE NEGATIVE BATTERY CABLES IN THE BATTERY COMPARTMENT.

1. Secure cover of field wiring enclosure.

2. Connect the negative battery cable C/A.

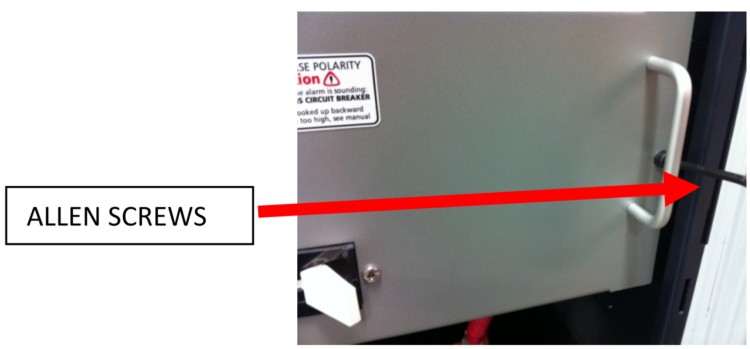
CAUTION: IF THE BATTERY CABLES ARE CONNECTED INCORRECTLY, A REVERSE POLARITY ALARM WILL SOUND. IF ALARM IS ACTIVATED, DO NOT CLOSE THE 250A/450A DC BREAKER.

FIELD SERVICING

WARNING: IF THIS IS NOT THE INITIAL INSTALLATION AND THE BATTERIES HAVE BEEN CONNECTED ENSURE THAT THE 250A/450A DC BREAKER AND BOTH THE GRID AND GENERATOR INPUT CIRCUIT BREAKERS HAVE BEEN OPEN (OFF) FOR AT LEAST 1 MINUTE BEFORE ACCESSING SYSTEM. THIS ALLOWS LARGE SYSTEM CAPACITORS TO DISCHARGE AND MINIMIZES THE RISK OF ACCIDENTAL SHOCK OR DAMAGE TO THE SYSTEM.

1. Unfasten the two screws on the bottom of the front panel. Lift up and pull the panel off and set aside.
2. Remove the bus bars.
3. Remove the Allen screws on either side of each drawer and carefully pull drawer out until it stops.

CAUTION: DO NOT EXTEND DRAWERS BEYOND DESIGNATED STOP.



4. Once service is complete, secure drawers with allen screws.
5. Replace bus bars; torque to 25 ft lbs.
6. Secure front panel with screws.

GRIDPOINT®

Revolutionizing the way you think about energy.™

SMUD – High Penetration Solar Pilot

System Requirements

Monitoring Specification

Wednesday, March 2nd, 2011

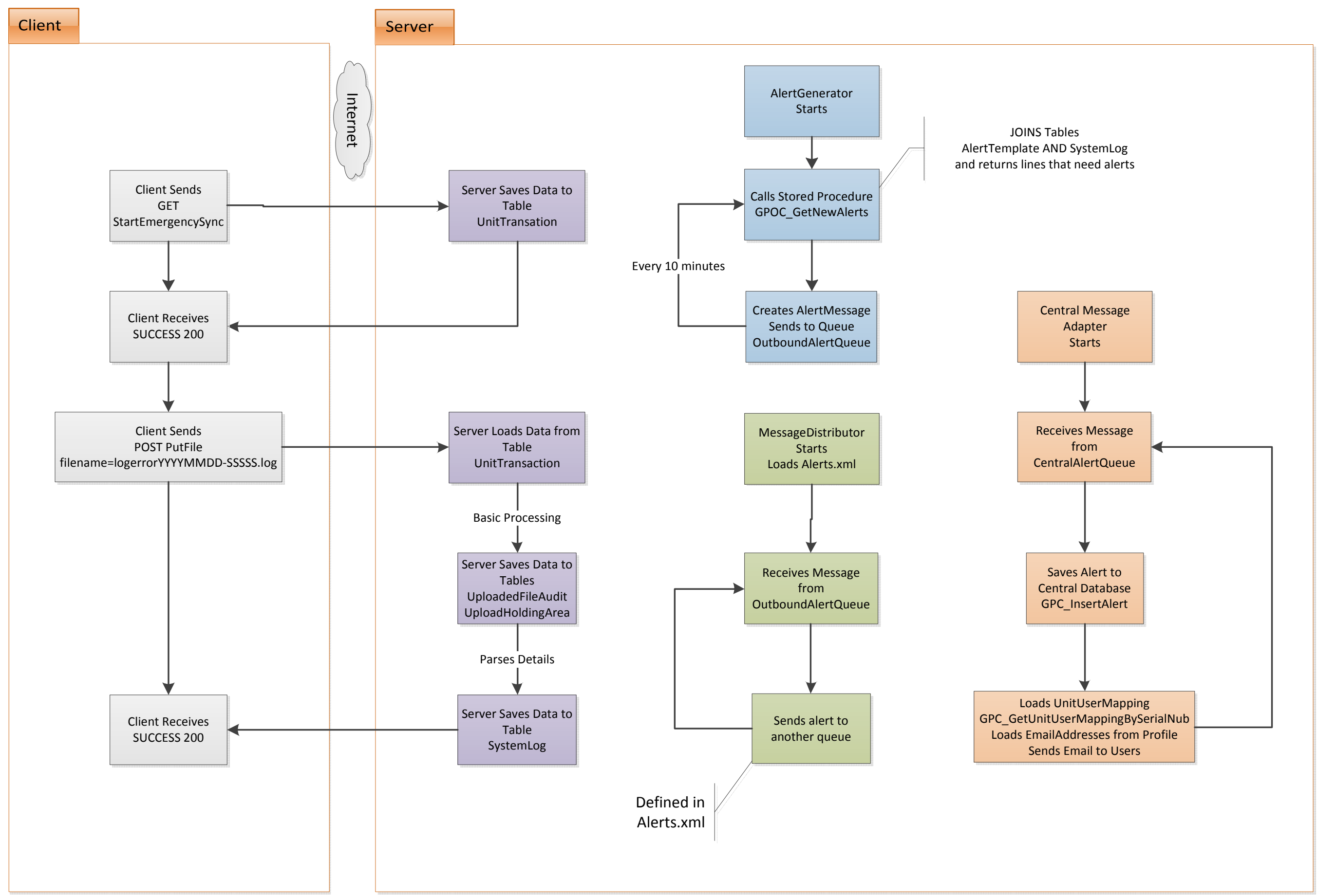
1.0 Table of Contents

2.0 Revision Log

Version	Date	Author	Description
1.0	2011/02/07	Corey Partridge	*First draft*
1.1	2011/02/07	Corey Partridge	*Changed Visio, Added Assumptions*
1.2	2011/02/25	Chris Davison	*Added alerts routing section with some sample entries; stills needs input as to what gets routed where*
1.3	2011/02/28	Chris Davison	*Added communication failure alerts*
1.4	2011/03/01	JS Vachon	*Formatting of the document*

3.0 Components involved

There are 4 separate components needed to successfully transfer in emergency messages.



1.1. RES and CES Clients sends in 2 messages.

EmergencySync message that tells the server the next file is an emergency alarm.

logerrorYYYYMMDD-SSSSS.log file contains the data related to the alarm.

1.2. The server receives the data using the RemoteSyncGateway
   It will create an entry in UnitTransaction table indicating the file is emergency data.
   It will save the file into table UploadedHoldingArea
   The file will be parsed and saved to table SystemLog
1.3. AlarmGenerator looks for potential alarm triggers from the latest data.
   The service will query the SystemLog table in a set interval.
   The default interval is set at 10 minutes and can be configured
   It will look for new entries, and of those entries it will look for key words that are defined in the AlertTemplate table.
   When a match is found it will create and AlertMessage object and place that object on to the OutboundAlertQueue.
1.4. MessageDistributor removes the data from the OutboundAlertQueue and sends it to another queue.
   The application looks up routing information from Alerts.xml
   Finds the queue name (CentralAlertQueue) based of the error id and sends the message into the new queue.
1.5. CentralMessageAdapter removes the data from the CentralAlertQueue
   Pulls alerts off the queue and saves them to a table.
   Loads UnitUserMapping and looks up any users who want to be notified.
   Each user have their email address looked up from the .NET membership profile.
   An email will be sent out to each subscribed user.

4.0 Alerts Routing

The alerts can be routed to 4 different locations depending on the nature of the alert:

Utility Operators		Routing
#1	Email notification to Utility Operators.	All alerts
#2	GCC User Interface for Utility Operators. (*In the case where SMUD does not need access to GCC, those alerts would be directed to the GP Analytics UI)	All alerts
Home Owners (Only for RES systems)		**Routing**
#3	Email notification to Home Owners.	Listed in section 5.0
#4	Display on the HEM.	Listed in section 5.0

Utility Operators

If a utility technician must be alerted of a fault then those messages can be sent to a utility queue. Some changes are required to display battery faults that come from the utility queue on GCC, as it was implemented to show alerts about failed utility events. Also, a custom email client would be created to listen to the utility queue for specific faults that should be emailed to a support email address. The support email address list will be configurable by the production support team. This means there will be no user interface to manage the changes.

Home Owners

For the HEM, fault messages can be set up to be routed to the HEM alert queue as required. The customer can log on and set up email forwarding of the same alert messages that would be shown on the HEM.

5.0 Alerts Listing

The following table shows how each of the alerts will be routed. Alerts are coming from either the RES, the CES or are signals of communication errors with the different appliances.

Communication failure

Alert	Description	Notification to Home Owner?
Unit Missed Regular Sync – RES	Occurs when the RES Unit missed a regular synchronization with the GridPoint Platform.	YES
Unit Missed Regular Sync – CES	Occurs when the CES Unit missed a regular synchronization with the GridPoint Platform.	
Unit Missed Regular Sync – SunPower	Occurs when the SunPower server missed a regular synchronization with the GridPoint Platform.	

RES System

Alert	Description	Notification to Home Owner?
FAULT_OVER_TEMP		YES
FAULT_NO_12V		
FAULT_LIMIT_STOP		
FAULT_BAL_STOP		
FAULT_LINE_OVER_CURRENT		
FAULT_HIGH_BATTERY		
FAULT_LOW_BATTERY		
FAULT_SYNCHRONIZATION		
FAULT_LOW_LINE_FREQUENCY		
FAULT_HIGH_LINE_FREQUENCY		
FAULT_LOW_LINE_VOLTAGE_C		
FAULT_HIGH_LINE_VOLTAGE_C		
FAULT_LOW_LINE_VOLTAGE		
FAULT_HIGH_LINE_VOLTAGE		
FAULT_ISLANDING		
FAULT_WATCH_DOG		
FAULT_SOFTWARE		

CES System

Alert	Description
DC Bus Over Voltage Detected	The DC voltage is above its upper limit. Both the limit and de bounce time are fixed.
DC Bus Under Voltage Detected	The DC voltage is below its lower limit. Both the limit and de bounce time are fixed.
Phase A Under Voltage Detected	The phase A AC voltage is below its lower limit (over voltage limit register) for at least X ms (where X is defined the over voltage time register)
Phase A Over Voltage Detected	The phase A AC voltage is above its upper limit (over voltage limit register) for at least X ms (where X is defined the over voltage time register)
Phase B Under Voltage Detected	The phase B AC voltage is below its lower limit (over voltage limit register) for at least X ms (where X is defined the over voltage time register)
Phase B Over Voltage Detected	The phase B AC voltage is above its upper limit (over voltage limit register) for at least X ms (where X is defined the over voltage time register)
PCS Heat Sink Temp Limit Detected	The PCS heat sink temperature is above its upper limit. Both the limit and de bounce time are fixed.
PCS Internal Fan Failure Detected	The fan on the power conditioning system as failed. This is a discrete signal we read from the PCS.
Unit Power Capacity Limit Detected	
Battery Temp Detected	This was a pass through alarm from the Saft BMM.
Reserve Energy Limit Detected	The battery's state of charge is below the value defined in the reserve energy limit register.
Depleted Energy Limit Detected	The battery's state of charge is below the value defined in the depleted energy limit register.
Unit Shutdown Detected	This is one from the AEP spec that was included in the SMUD version of the spec. Shutdown is as the inverter is turned off, which can be determined by the CES unit status register.
CAN Bus Failure Detected	Occurs when the communication bus between the CCS and the battery controller (Saft BMM) is not working properly

6.0 Modifications Required

The following files will need to be added or modified.

Client Side:

CES File: logerrorYYYYMMDD-SSSSS.log on emergency sync (or in logsysYYYYMMDD-SSSSS.log on a routine sync)

```
Version Info: 2008-03-27 3.0.0.29
20090419-151756 INFO Alert: DC Bus Over Voltage Detected
20090419-151756 INFO Alert: DC Bus Under Voltage Detected
20090419-151756 INFO Alert: Phase A Under Voltage Detected
20090419-151756 INFO Alert: Phase A Over Voltage Detected
20090419-151756 INFO Alert: Phase B Under Voltage Detected
20090419-151756 INFO Alert: Phase B Over Voltage Detected
20090419-151756 INFO Alert: PCS Heat Sink Temp Limit Detected
20090419-151756 INFO Alert: PCS Internal Fan Failure Detected
20090419-151756 INFO Alert: Unit Power Capacity Limit Detected
20090419-151756 INFO Alert: Battery Temp Detected
20090419-151756 INFO Alert: Reserve Energy Limit Detected
20090419-151756 INFO Alert: Depleted Energy Limit Detected
20090419-151756 INFO Alert: Unit Shutdown Detected
20090419-151756 INFO Alert: CAN Bus Failure Detected
```

RES File: logerrorYYYYMMDD-SSSSS.log on emergency sync (or in logsysYYYYMMDD-SSSSS.log on a routine sync)

```
Version Info: 2008-03-27 3.0.0.29
20090419-151756 INFO Alert: FAULT_OVER_TEMP
20090419-151756 INFO Alert: FAULT_NO_12V
20090419-151756 INFO Alert: FAULT_LIMIT_STOP
20090419-151756 INFO Alert: FAULT_BAL_STOP
20090419-151756 INFO Alert: FAULT_LINE_OVER_CURRENT
20090419-151756 INFO Alert: FAULT_HIGH_BATTERY
20090419-151756 INFO Alert: FAULT_LOW_BATTERY
20090419-151600 INFO Alert: FAULT_SYNCHRONIZATION
20090419-151756 INFO Alert: FAULT_LOW_LINE_FREQUENCY
20090419-151756 INFO Alert: FAULT_HIGH_LINE_FREQUENCY
20090419-151756 INFO Alert: FAULT_LOW_LINE_VOLTAGE_C
20090419-151756 INFO Alert: FAULT_HIGH_LINE_VOLTAGE_C
20090419-151756 INFO Alert: FAULT_LOW_LINE_VOLTAGE
20090419-151756 INFO Alert: FAULT_HIGH_LINE_VOLTAGE
20090419-151756 INFO Alert: FAULT_ISLANDING
20090419-151756 INFO Alert: FAULT_WATCH_DOG
20090419-151756 INFO Alert: FAULT_SOFTWARE
```

Alarms Routing:

Server Side:

AlertTemplate.sql

```
--  <copyright file="AlertTemplate.sql" company="GridPoint">
--      Copyright © 2009 GridPoint, Inc.  All rights reserved.
--  </copyright>

-- As the AlertTemplate table has been copied from GPOC instance to GPOC instance,
-- some of the rows are no longer consistent among multiple instances.
-- This script ensures that the AlertTemplate table has all the correct rows and no extraneous rows.

BEGIN TRAN

DELETE FROM AlertTemplate

INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E1','%detected (E1)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E2','%detected (E2)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E205','%detected (E205)%')
```

```
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E205-G1','%Outback - Buy amps > input%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E207','%detected (E207)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E207-G1','%Outback - Temp. sensor fault%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E208','%detected (E208)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E208-G1','%Outback - Comm fault%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E209','%detected (E209)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E209-G1','%Outback - Int. fan failure%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E210','%detected (E210)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E210-G1','%Outback - Low AC voltage out%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E211','%detected (E211)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E211-G1','%Outback - Stacking Error%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E212','%detected (E212)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E212-G1','%Outback - Low Battery voltage%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E214','%detected (E214)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E214-G1','%Outback - High Battery Voltage%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E215','%detected (E215)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E215-G1','%Outback - AC out shorted%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E216','%detected (E216)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E216-G1','%Outback - AC out backfeed%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E217','%detected (E217)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E3','%detected (E3)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E3-G1','IMMEDIATE ERROR: Door Open')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E3C','%cleared (E3)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E4','%detected (E4)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E4-G1','DURATION ERROR: No data from inverter interface')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E401','%detected (E401)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E401-G1','%Outback - Inverter temp > max%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E402','%detected (E402)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E402-G1','IMMEDIATE ERROR: Battery temp > max')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E403','%detected (E403)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E403-G1','IMMEDIATE ERROR: Battery temp < min')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E404','%detected (E404)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E404-G1','IMMEDIATE ERROR: Cabinet temp > max')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E404C','%cleared (E404)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E405','%detected (E405)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E405-G1','IMMEDIATE ERROR: Cabinet temp < min')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('E405C','%cleared (E405)%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('G12','%Changed setpoint%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('G14','%Resetting IO Board on MapsErrCode -15%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('G16','%overridden by user%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('G7','%changed value%')

-- new alert data for SMUD below
--CES
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A1','%CES Unit Status%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A2','%CES Alarm Status%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A3','%Reset Alarms%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A4','%DC Bus Over Voltage Detected%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A5','%DC Bus Over Voltage Cleared%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A6','%DC Bus Under Voltage Detected%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A7','%DC Bus Under Voltage Cleared%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A8','%Phase A Under Voltage Detected%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A9','%Phase A Under Voltage Cleared%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A10','%Phase A Over Voltage Detected%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A11','%Phase A Over Voltage Cleared%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A12','%Phase B Under Voltage Detected%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A13','%Phase B Under Voltage Cleared%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A14','%Phase B Over Voltage Detected%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A15','%Phase B Over Voltage Cleared%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A16','%PCS Heat Sink Temp Limit Detected%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A17','%PCS Heat Sink Temp Limit Cleared%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A18','%PCS Internal Fan Failure Detected%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A19','%PCS Internal Fan Failure Cleared%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A20','%Unit Power Capacity Limit Detected%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A21','%Unit Power Capacity Limit Cleared%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A22','%Battery Temp Detected%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A23','%Battery Temp Cleared%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A24','%Reserve Energy Limit Detected%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A25','%Reserve Energy Limit Cleared%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A26','%Depleted Energy Limit Detected%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A27','%Depleted Energy Limit Cleared%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A28','%Unit Shutdown Detected%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A29','%Unit Shutdown Cleared%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A30','%Grid Connected%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A31','%Grid Disconnected%')
--RES
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A50','%FAULT_OVER_TEMP%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A51','%FAULT_NO_12V%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A52','%FAULT_LIMIT_STOP%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A53','%FAULT_BAL_STOP%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A54','%FAULT_LINE_OVER_CURRENT%')
```

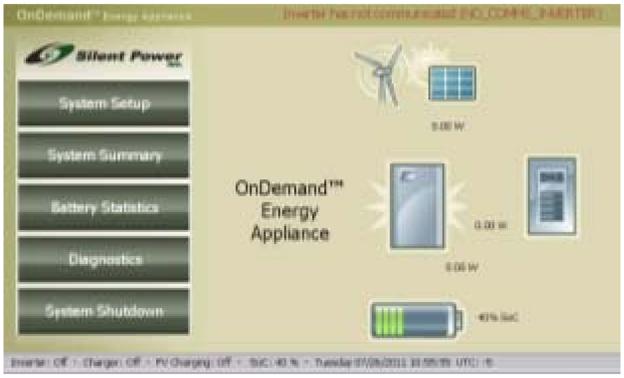
```
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A55','%FAULT_HIGH_BATTERY%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A56','%FAULT_LOW_BATTERY%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A57','%FAULT_SYNCHRONIZATION%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A58','%FAULT_LOW_LINE_FREQUENCY%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A59','%FAULT_HIGH_LINE_FREQUENCY%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A60','%FAULT_LOW_LINE_VOLTAGE_C%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A61','%FAULT_HIGH_LINE_VOLTAGE_C%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A62','%FAULT_LOW_LINE_VOLTAGE%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A63','%FAULT_HIGH_LINE_VOLTAGE%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A64','%FAULT_ISLANDING%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A65','%FAULT_WATCH_DOG%')
INSERT INTO AlertTemplate(AlertType, AlertMatch) VALUES ('A66','%FAULT_SOFTWARE%')

COMMIT
```

Alerts.xml

```
<?xml version="1.0" encoding="utf-8"?>
<!--

Format of alerts in XML file:

<?xml version="1.0" encoding="utf-8"?>
<MessageDistribtutor>

         <Alert type="alertType"  queue="FormatName:DIRECT=OS:server\private$\queuename"/>

</MessageDistributor>

Each alert can be directed to multiple queues.
-->
<MessageDistributor>
         <!-- ******************************************************************************** -->
         <!-- This section may be used to define routes for custom endpoints/internal systems -->
         <!-- ******************************************************************************** -->

         <!-- ********************************************************************************* -->
         <!-- This section contains routes required by the product that should not be modified -->
         <!-- ********************************************************************************* -->

  <!-- Central -->
  <Alert type="G3" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="G4" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="G5" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>

  <Alert type="G10" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="G11" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="G12" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>

  <Alert type="E3" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="E3C" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="E404" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="E405" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="E404C" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="E405C" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>

  <Alert type="E3-G1" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="E404-G1" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="E405-G1" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>

  <!-- Demand Response -->
  <Alert type="DR1" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="DR2" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>

  <!-- Opt-out and Override -->
  <Alert type="DR3" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\utilalertqueue"/>
  <Alert type="DR4" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\utilalertqueue"/>
  <Alert type="G16" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\utilalertqueue"/>

  <!-- Green Message -->
  <Alert type="GM1" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>

  <!-- Alert Messages -->
  <Alert type="A1" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A2" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A3" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A4" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A5" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
```

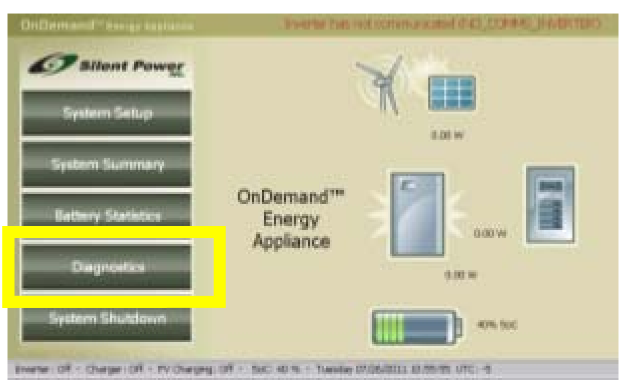
```xml
  <Alert type="A6" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A7" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A8" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A9" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A10" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A11" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A12" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A13" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A14" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A15" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A16" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A17" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A18" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A19" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A20" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A21" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A22" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A23" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A24" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A25" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A26" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A27" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A28" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A29" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A30" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A31" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>

  <Alert type="A50" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A51" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A52" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A53" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A54" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A55" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A56" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A57" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A58" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A59" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A60" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A61" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A62" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A63" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A64" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A65" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>
  <Alert type="A66" queue="FormatName:DIRECT=OS:prd-vs-demo01.gridpoint.com\private$\centralalertqueue"/>

</MessageDistributor>
```

The first step is to confirm that your device is in standby mode.
Start from the Main Menu. It looks like this. If you see another screen in front of you there should be a "back" icon in the upper right corner. Keep pressing it until you reach this main menu.
Press the Silent Power Logo.

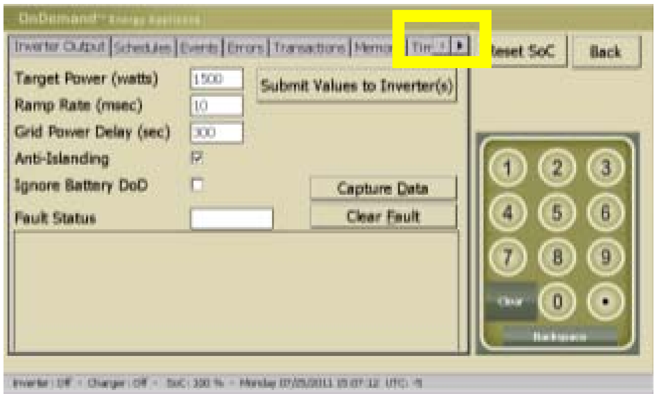


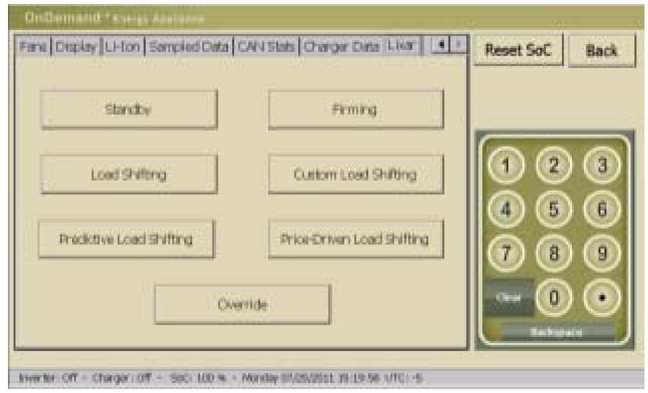
You will have a log in screen. Enter code 123458 and press the sign in icon.
It should then return you to the main menu above.

Touch the Diagnostic icon.



Use the arrow keys to scroll all the way to the right, until you get to the Lixar tab. Then touch the standby Icon. Then touch the back icon until you get back to the main menu.





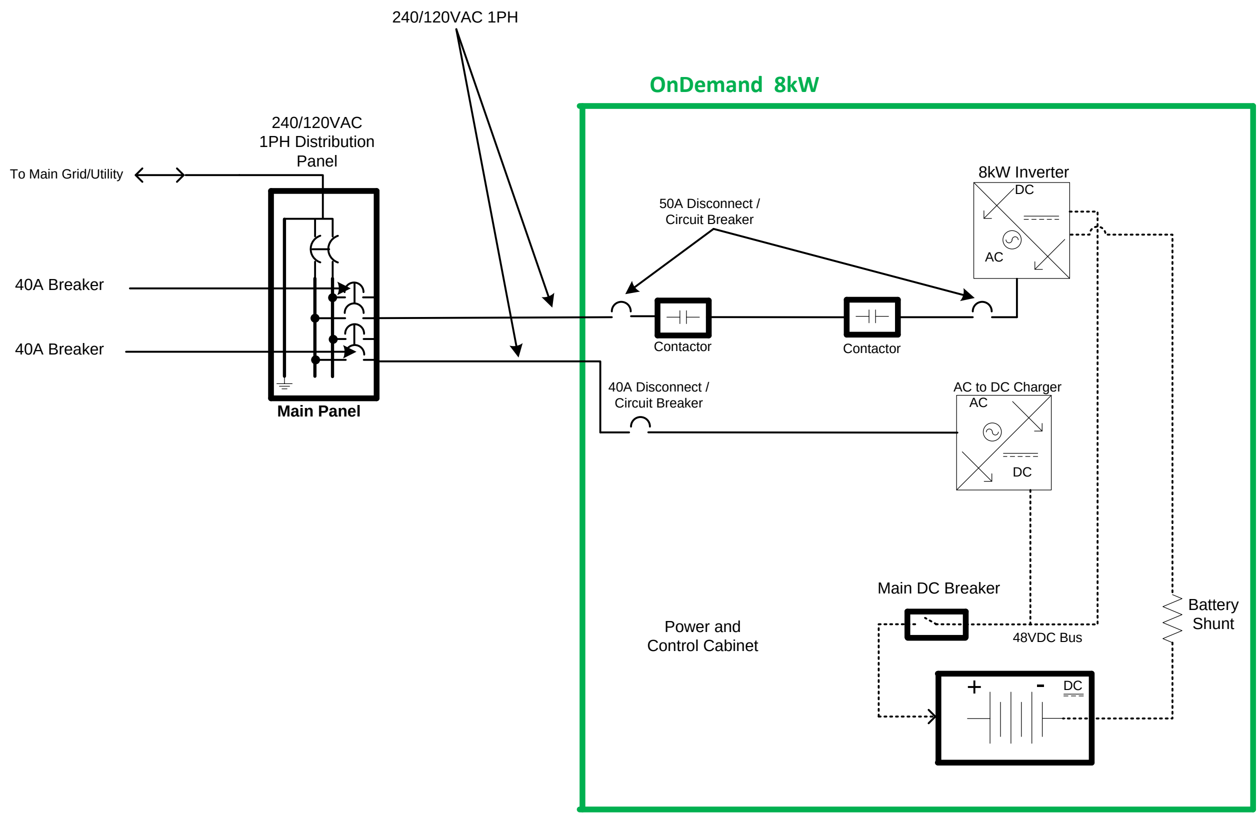
To turn the inverter on and off.

From the main menu, touch the System Setup Icon, then touch inverter control.
Touch the white data box next to the “Target Power”. A keypad will appear. Set the output to 1000 watts, then touch Grid Tie.
You should hear a clunck as the contactors close.
To turn the inverters back off, touch the off icon.

Note: Your login code expires in 10 minutes if no keystrokes have been entered. If this happens, the screen will lock you out and you may have to follow the login steps again.

Silent Power INC.

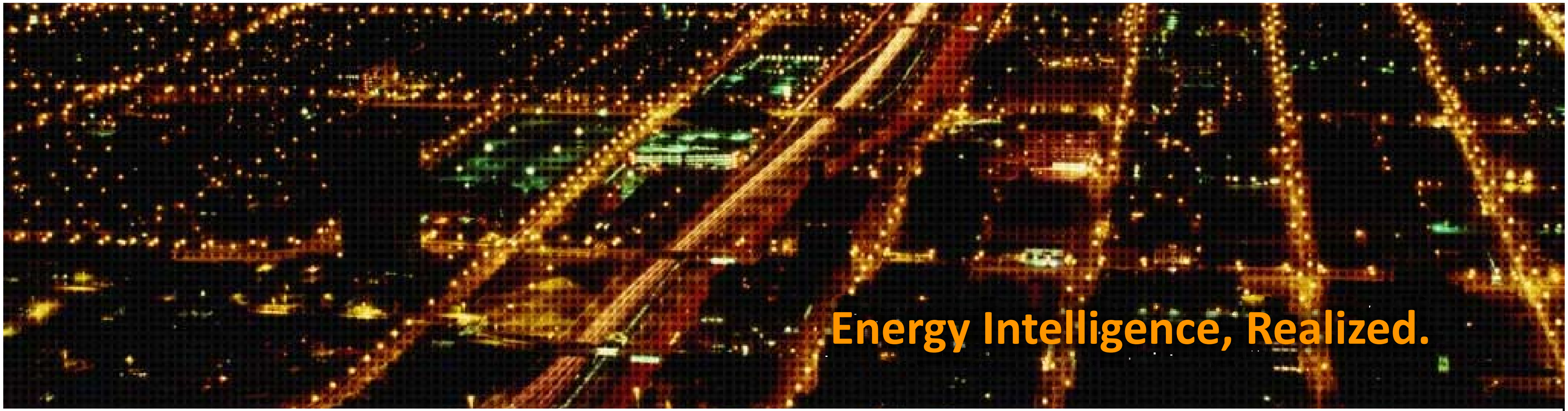
Typical Installation



Community Energy Storage

Technical Specifications

GRIDPOINT



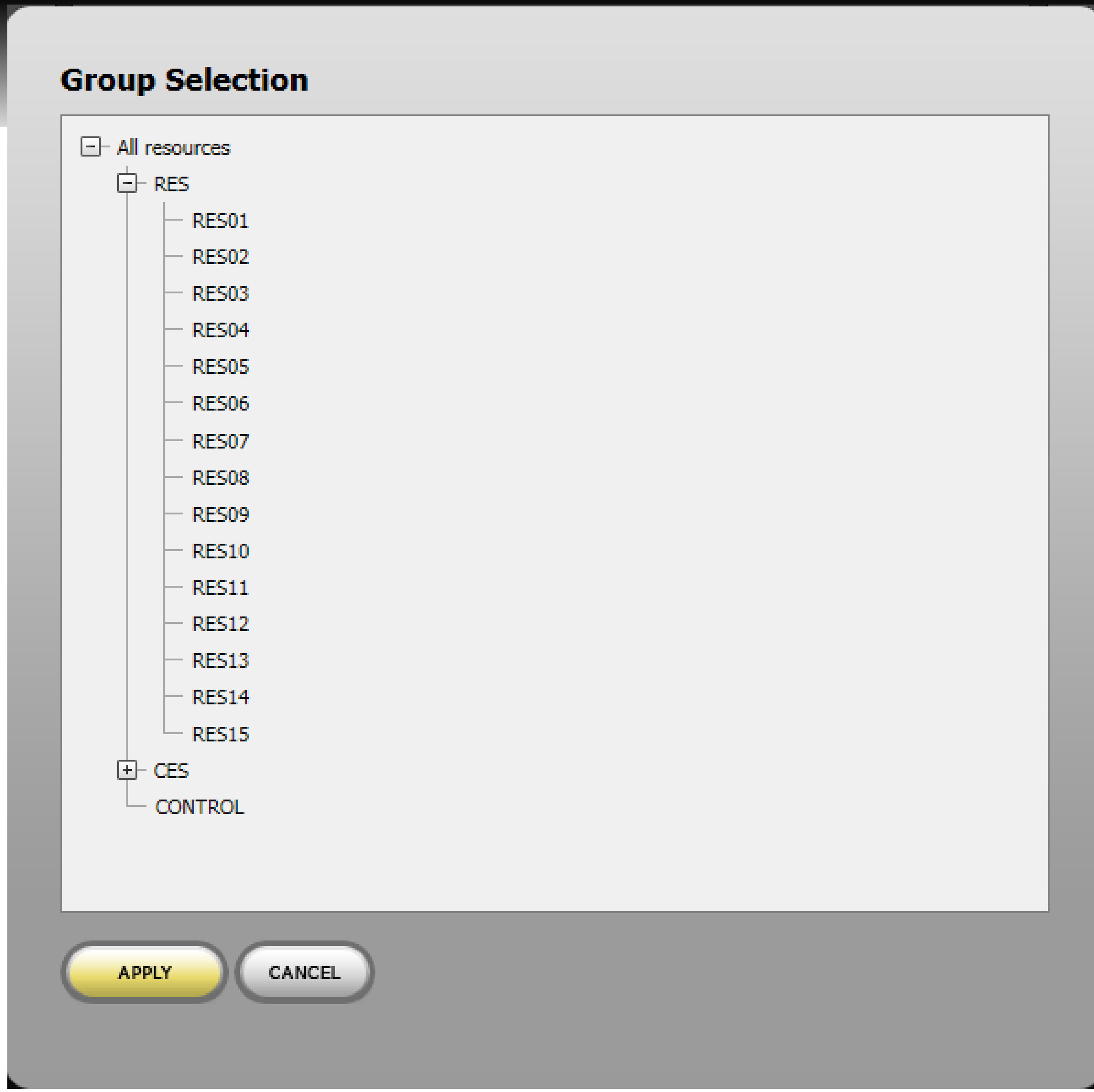
SMUD – Utility Portal Presentation

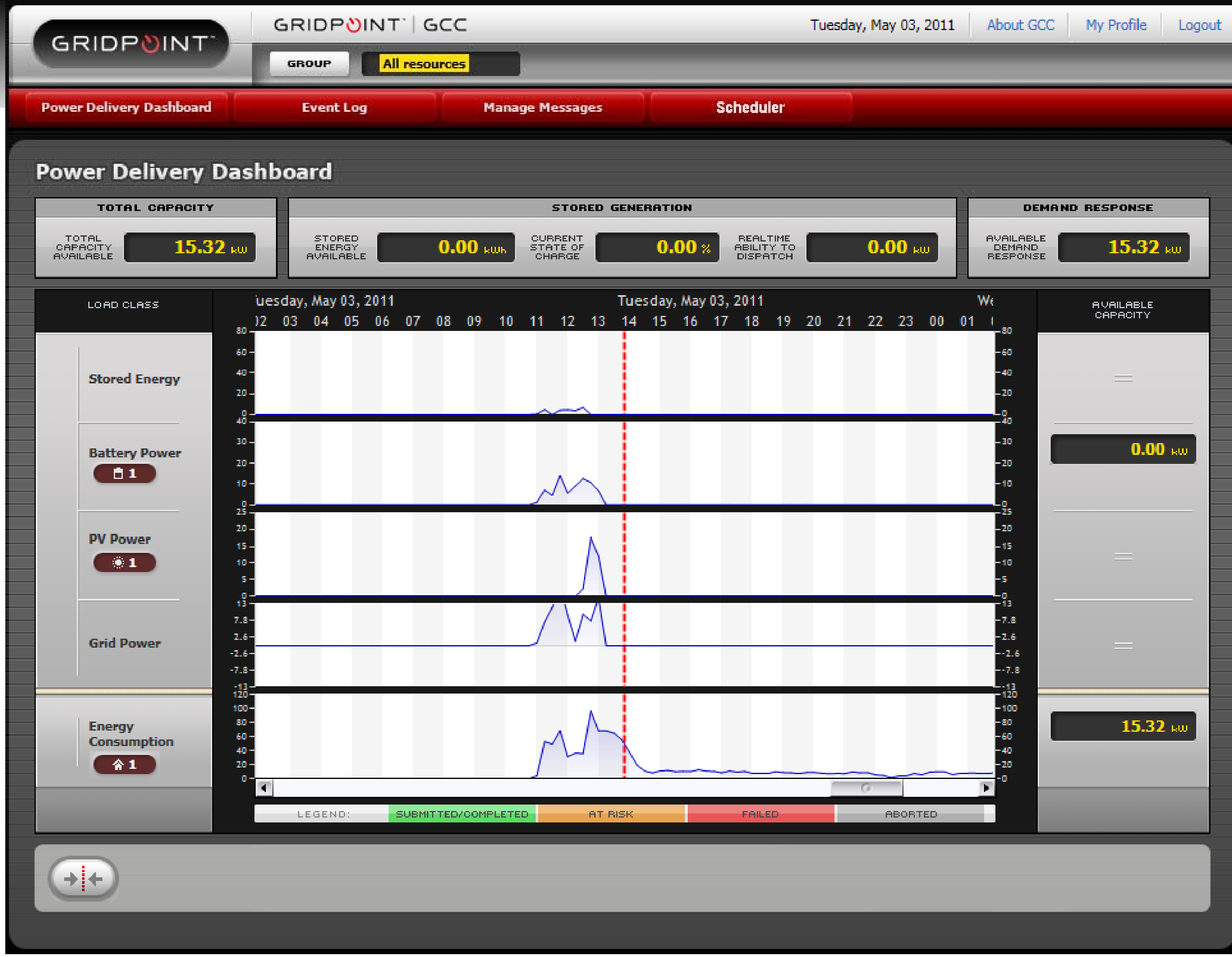
June 12, 2011

Summary

- Login Screen
- Filtering the groups
- Power delivery dashboard
- Event Creation
- Event Log
- Manage Messages
- About GCC
- My Profile
- Scheduler (GP Analytics UI)


GRIDPOINT
GRIDPOINT | GCC
Tuesday, May 03, 2011
GridPoint GCC Login
Username:
Password:
I Forgot My Password
LOGIN


Group Selection
All resources
RES
RES01
RES02
RES03
RES04
RES05
RES06
RES07
RES08
RES09
RES10
RES11
RES12
RES13
RES14
RES15
CES
CONTROL
APPLY
CANCEL


GRIDPOINT
GRIDPOINT | GCC
Tuesday, May 03, 2011
About GCC
My Profile
Logout
GROUP
All resources
Power Delivery Dashboard
Event Log
Manage Messages
Scheduler
Power Delivery Dashboard
TOTAL CAPACITY
TOTAL CAPACITY AVAILABLE
15.32 kW
STORED GENERATION
STORED ENERGY AVAILABLE
0.00 kWh
CURRENT STATE OF CHARGE
0.00 %
REALTIME ABILITY TO DISPATCH
0.00 kW
DEMAND RESPONSE
AVAILABLE DEMAND RESPONSE
15.32 kW
LOAD CLASS
Tuesday, May 03, 2011
AVAILABLE CAPACITY
Stored Energy
Battery Power
PV Power
Grid Power
Energy Consumption
0.00 kW
15.32 kW
LEGEND:
SUBMITTED/COMPLETED
AT RISK
FAILED
ABORTED

GRIDPOINT | GCC

Tuesday, May 03, 2011 | About GCC | My Profile | Logout

Power Delivery Dashboard | Event Log | Manage Messages | Scheduler

Event Log

FILTER EVENTS

User(s): All

Status: All

Start Date & Time:

End Date & Time:

Scheduled Duration: All

Peaker Name: All

Apply Filter

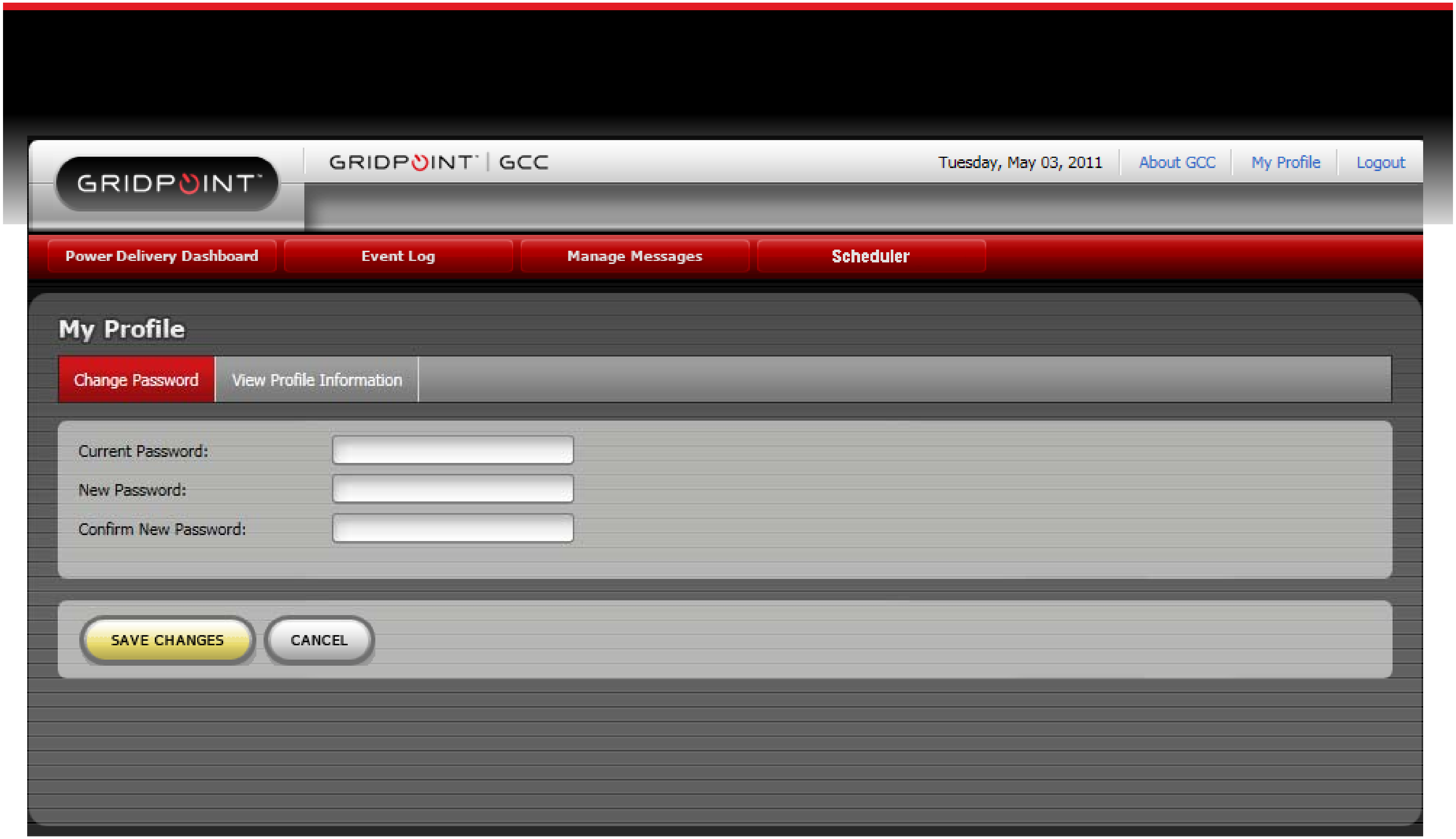
Reset Filter

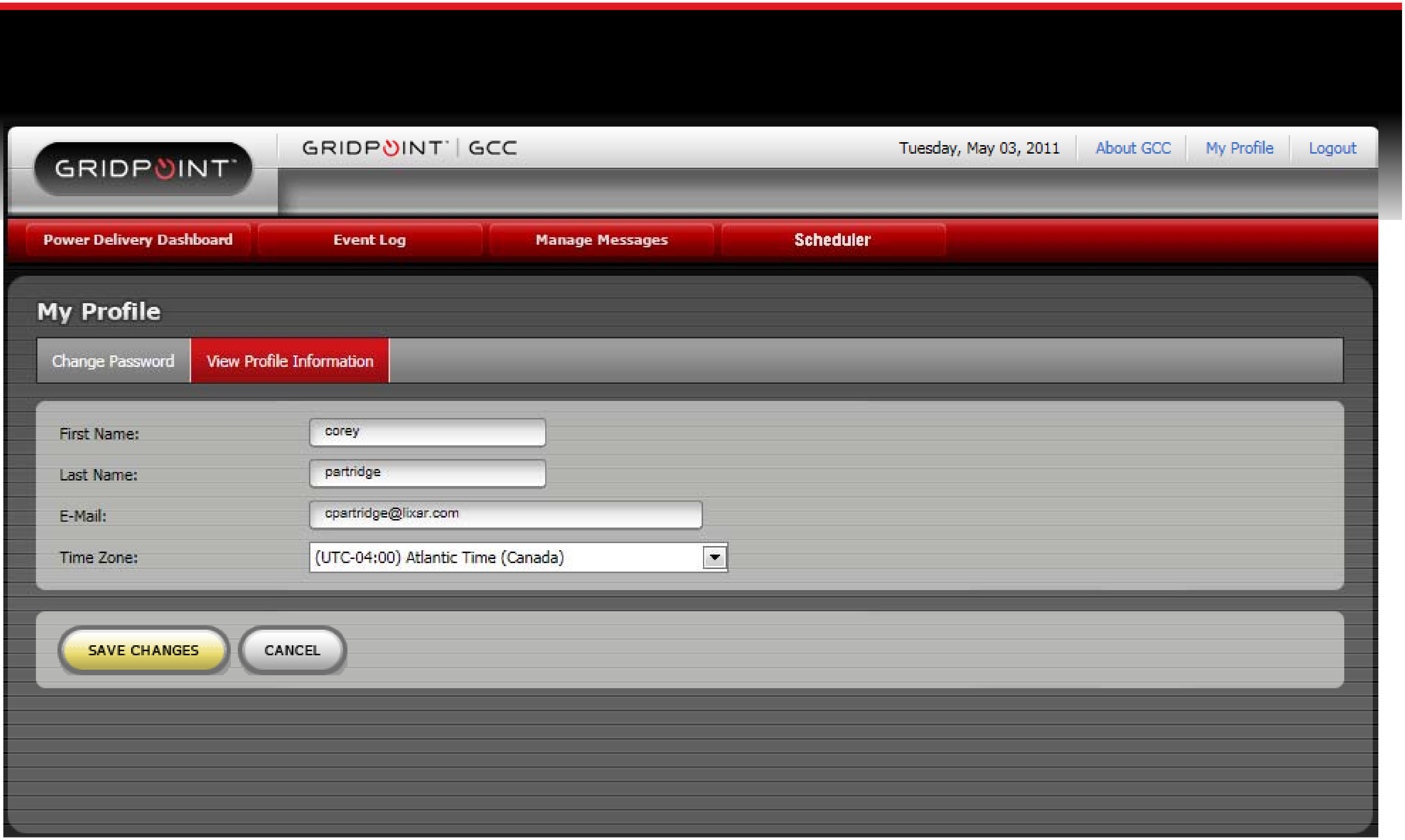
ID	User	Peaker Name	Scheduled Duration	Start Date & Time	End Date & Time	Status
2895	GCI_SMUD	BATTERY	0.25	04/25/2011 16:40	04/25/2011 16:55	Completed
2894	GCI_SMUD	BATTERY	0.25	04/25/2011 16:28	04/25/2011 16:43	Aborted
2893	GCI_SMUD	BATTERY	0.25	04/25/2011 16:24	04/25/2011 16:39	Aborted
2892	GCI_SMUD	BATTERY	0.25	04/25/2011 16:41	04/25/2011 16:56	Aborted
2891	GCI_SMUD	BATTERY	0.25	04/25/2011 16:20	04/25/2011 16:35	Aborted
2890	GCI_SMUD	BATTERY	0.25	04/25/2011 15:59	04/25/2011 16:14	Aborted
2889	GCI_SMUD	BATTERY	0.0166666666666667	04/25/2011 15:56	04/25/2011 15:57	Aborted
2888	GCI_SMUD	BATTERY	24	04/25/2011 15:44	04/26/2011 15:44	Aborted
2887	GCI_SMUD	BATTERY	24	04/25/2011 15:29	04/26/2011 15:29	Aborted
2886	GCI_SMUD	BATTERY	24	04/25/2011 15:20	04/26/2011 15:20	Aborted

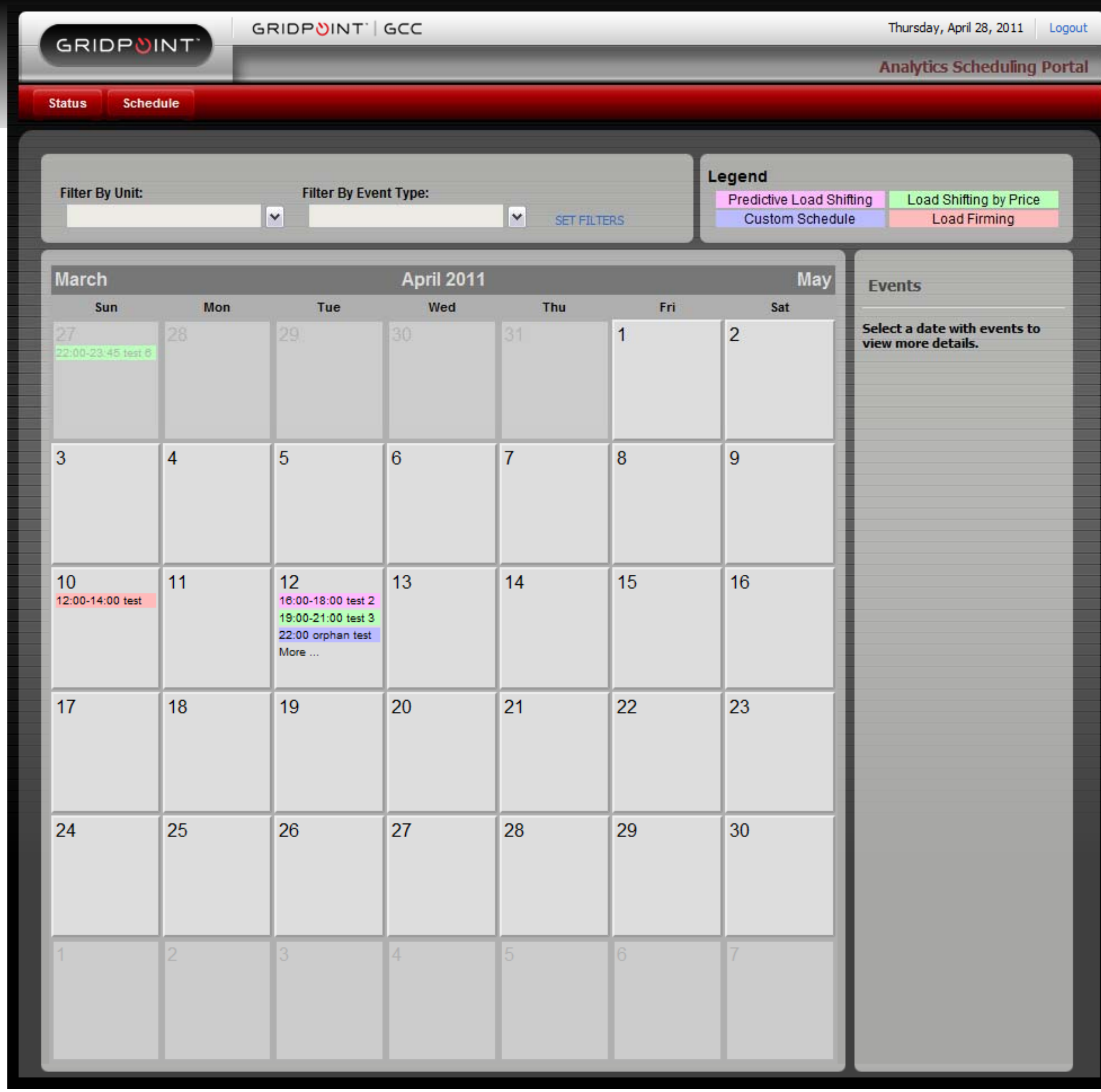
1 | 2 | 3 | 4 | 5 | 6

	Published Date & Time	Published To Group	Message Text	Created By
Select	04/18/2011 14:03	RES	Hello	cpartridge
Select	04/08/2011 14:57	All resources	Hi ho hi ho!	cpartridge
Select	04/08/2011 14:52	All resources	hey!	cpartridge
Select	04/04/2011 12:19	RES	Hello everybody	cpartridge


GridPoint Control Console
Software Version: Local (3.2)
Release Date: August 2009
Licensed To: SMUD
CLOSE

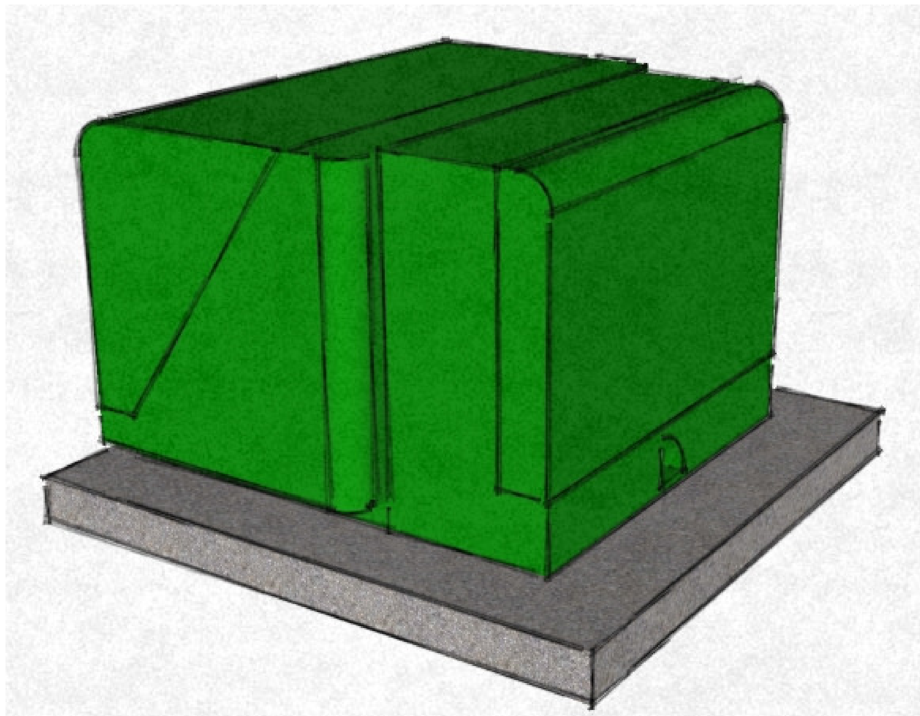

GRIDPOINT
GRIDPOINT | GCC
Tuesday, May 03, 2011
About GCC
My Profile
Logout
Power Delivery Dashboard
Event Log
Manage Messages
Scheduler
My Profile
Change Password
View Profile Information
Current Password:
New Password:
Confirm New Password:
SAVE CHANGES
CANCEL


GRIDPOINT
GRIDPOINT | GCC
Tuesday, May 03, 2011
About GCC
My Profile
Logout
Power Delivery Dashboard
Event Log
Manage Messages
Scheduler
My Profile
Change Password
View Profile Information
First Name:
corey
Last Name:
partridge
E-Mail:
cpartridge@lixar.com
Time Zone:
(UTC-04:00) Atlantic Time (Canada)
SAVE CHANGES
CANCEL


GRIDPOINT
GRIDPOINT | GCC
Thursday, April 28, 2011
Logout
Analytics Scheduling Portal
Status
Schedule
Filter By Unit:
Filter By Event Type:
SET FILTERS
Legend
Predictive Load Shifting
Load Shifting by Price
Custom Schedule
Load Firming
March
April 2011
May
Sun
Mon
Tue
Wed
Thu
Fri
Sat
22:00-23:45 test 6
12:00-14:00 test
16:00-18:00 test 2
19:00-21:00 test 3
22:00 orphan test
More ...
Events
Select a date with events to view more details.

Community Energy Storage CE-3030

The CES device offers utility support functions to the houses served by a distribution transformer. The split phase 240V stationary storage units (30kW-30kWh) are connected in parallel with residential loads and controlled by the utility for increased power reliability, and support for renewable sources.



CE-3030 units measure roughly 35” tall, 38” wide, 40” deep and sit next to the neighborhood distribution transformer.

PowerHub Systems
(Formerly VPT Energy Systems)
1700 Kraft Dr.
Suite 1325
Blacksburg, Virginia, 24060
P: +1-540-443-9214
www.vpt-es.com

Functional Specification For Community Energy Storage (CES) Unit – Sacramento Municipal Utility District Version

Revision 0.8

Revision History			
Version	**Author**	**Date**	**Comments**
0.2	Jack Lesko & Jay Kidd	24 Jun 2010	Revised from 10 Feb 2010
0.3	Edits from Mike	04 Aug 2010	
0.4	Jack Lesko & Jay Kidd	13 Aug 2010	Revision including updated mode definitions CES State Matrix
0.5	Glenn Skutt, Tim Thacker	1-Sep-2010	Revised and updated electrical performance requirements
0.6	Glenn Skutt	16-Sep-2010	Updates based on review with GridPoint
0.7	Jack Lesko	4 Nov-2010	Updated based on review with GridPoint (18 Oct-2010)
0.8	Jack Lesko	18 Nov-2010	Updated based on final review with GridPoint (18 Nov 2010) – All changes accepted, comments addressed/tracked/resolved

TABLE OF CONTENTS

Acknowledgements

This Functional Specification for a Community Energy Storage (CES) unit for the Sacramento Municipal Utility District (SMUD) has been developed as a derivative work from information in the American Electric Power (AEP) CES specification Revision 2.2 DRAFT. That specification is available for at http://www.aeptechcenter.com/ces/cesfunctionspec.htm and use of the material in that specification is limited to the license agreement contained therein.

Specification Content

The SMUD Community Energy Storage (CES) system consists of a storage unit (SU), a power conversion system (PCS), and a communication/control system (CCS). The SU consists of the battery pack and battery management system that coordinates the energy storage status of the battery pack. The PCS converts the DC energy in the battery pack to AC energy appropriate for the distribution utility circuit and acts to both charge and discharge the battery pack. The CCS coordinates the operation of the PCS based on the status of the SU and subject to control signals from the GridPoint's enegy management software.

The overall control scheme of the CES is described in the GridPoint functional specification (SMUD Storage System Interface-SensorSpec v.0 6.doc). The CES electrical performance and communications requirements are described in this functional specification. For system operation, it is necessary to consider this document in coordination with the associated GridPoint system operational document. This functional specification, however, describes the technical requirements of the CES unit adequately for evaluation of a particular hardware implementation relative to the applicable acceptance test procedure document. Finally, this technical specification for the CES unit describes the operation of the CES unit itself. The appropriate use of the CES unit on any particular power distribution system is the responsibility of the system designer and/or operator.

The format and section numbering of the referenced AEP draft specification is the basis for the section numbering of the present document. Since the SMUD application does not involve the operation of the CES as a stand-alone backup power source, the relevant sections of the reference document have been removed. The deleted sections are labeled here as "reserved" so as to maintain the relevant section numbering of the other functional requirements between this document and the AEP reference document.

List of Acronyms

BMM – Battery Module Manager
CCS – Communication/Control System of the PCS
CES – Community Energy Storage
CT – Current Transformer
DDC – Distribution Dispatch Center
DER – Distributed Energy Resources
GEM – GridPoint Energy Manager
GNOC – GridPoint Network Operations Center
MAIFI – Momentary Average Interruption Frequency Index
OMS – Outage Management System
PCS – Power Conversion System (AC/DC converter plus CCS unit)
SAIDI – System Average Interruption Duration Index
SAIFI - System Average Interruption Frequency Index
SCADA – Supervisory Control and Data Acquisition
SMUD – Sacramento Municipal Utility District
URD – Underground Residential Distribution

1. Introduction – CES

The SMUD Community Energy Storage (CES) consists of multiple small battery-based energy storage units connected to the secondary-side of standard 240/120V utility transformers. The CES is controlled remotely through the use of GridPoint energy management software. The individual CES Units are pad-mounted and will be deployed in Underground Residential Distribution (URD) settings adjacent to a single phase pad mount transformer. A large number of these small storage units can be aggregated regionally and controlled as a fleet. In SMUD's immediate application, the CES units will be used for solar firming in neighborhoods that have a high level of residential solar PV.

The individual CES have controls to manage their charge and discharge activity in response to local needs. The local energy needs will be managed by the GridPoint energy management system or by integration into another control platform.

The SMUD CES will provide capacity, efficiency, and reliability benefits through the following key functions:

Grid functions:

1.) Serve as a local peak shaving device
2.) Provide local voltage control
3.) Provide efficient, convenient integration with renewable resources

2. Scope – CES Unit

This document defines the requirements for an enclosed assembly of batteries, controls and power conversion system comprising an individual pad-mount CES Unit. The CES Unit control will be controlled as detailed in the GridPoint energy management functional specification. Compatibility with that specification is required, and is intended through the requirements contained herein.

The fundamental components of the CES Unit are the:

1.) enclosure with provision for cable terminations
2.) isolating contactor
3.) communication/control hardware
4.) power conversion system (PCS)
5.) storage unit (battery pack and battery management unit)

These components are to be provided as a single assembly and are shown in Figure 1.

Notes:

1.) The SMUD CES is not intended to perform local load following and is not intended to operate as a backup power unit. Instead, in the SMUD CES implementation, the CES provides load management and solar-firming services and only operates while grid connected. The SMUD CES unit is not intended to provide reliability enhancement to the SMUD distribution circuit.
2.) CES power flow and operational state is managed and controlled by the GridPoint energy management system.

3.) It is not a requirement to perform voltage regulation apart from remaining within prescribed secondary voltage constraints.
4.) It is not a requirement to perform power quality functions such as flicker mitigation. This is anticipated as a future requirement.

Communications: The communications hardware and antenna are as required to interact with the GridPoint Energy Manager (GEM) and GridPoint Network Operations Center (GNOC) network software and are included within scope of this functional specification.

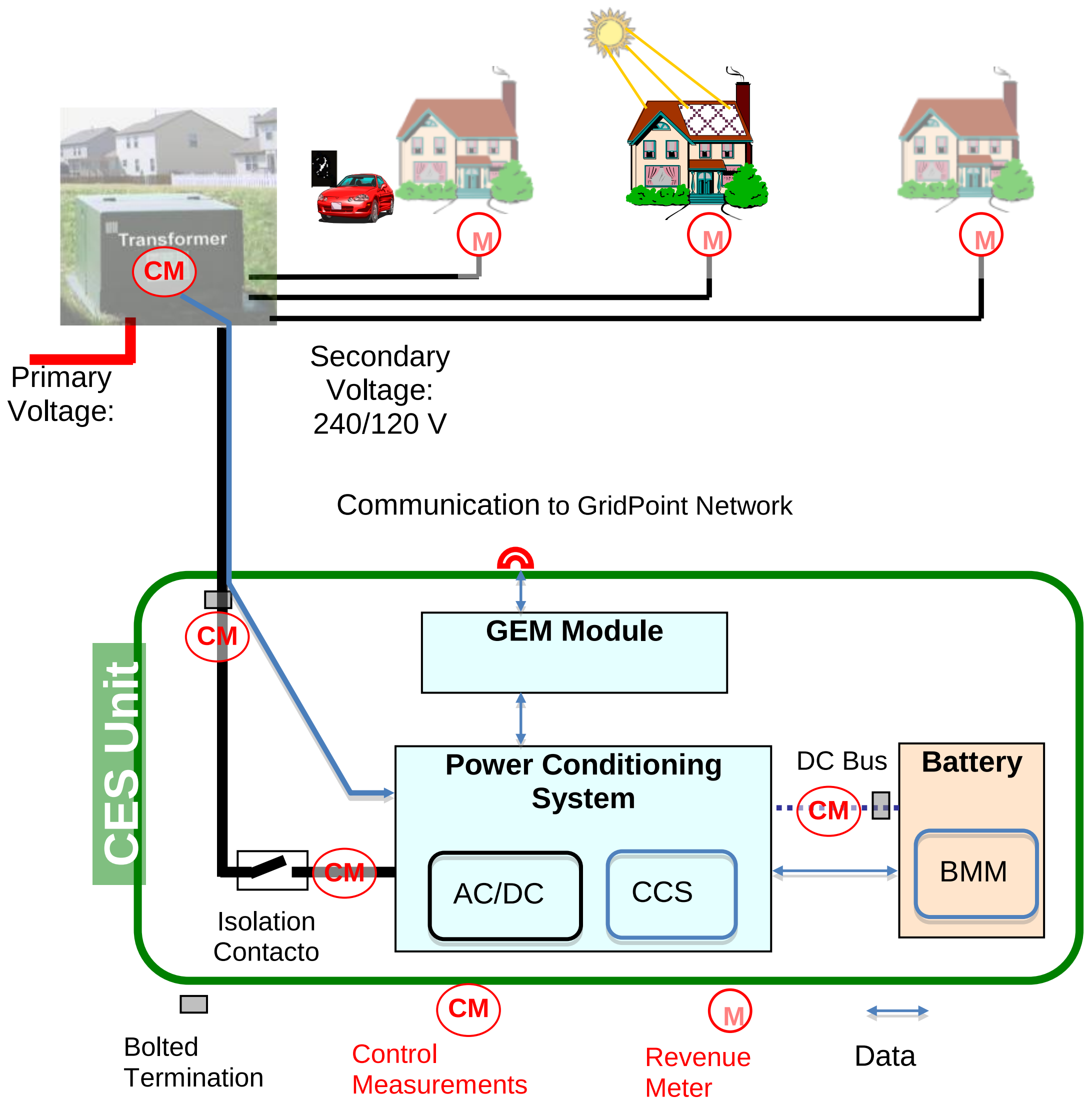


Figure 1.Layout of CES installation and its main components. The Power Conditioning System (PCS) contains both the AC/DC power stage and the Communication and Control System (CCS). The BMM is the Battery Module Manager within the battery unit.

3. Electrical Requirements and Connections

Figure 2 shows the connection of a CES Unit to a transformer secondary low voltage system that is also connected to several residences. Following are the requirements for the electrical connection and layout of CES Units:

3.1. Ratings

Following are fundamental CES Unit ratings. Note that power, energy and ampacity ratings apply through the full temperature range specified in the Environment Section of this specification, even if demonstrated at specific temperature.

3.1.1. **AC Voltage -** The CES AC interface voltage shall be single-phase 240/120V (center tapped 240V).

3.1.2. **BIL -** All 240/120 V AC components shall be 30 kV BIL, consistent with IEEE C57.12.25 Section 6.2.1™

3.1.3. **Power and Energy** – The power and energy ratings shall be:

Rated Power (kW)	Rated Energy (kWh) *
30	30

* Energy at 25° C at initial installation.

The power and energy ratings shall be based on a Reference Duty Cycle measured at the AC interface and defined as:

(Discharge power) = (Rated Power)
(Discharge time) = (Rated Energy) / (Rated Power)
(Charge power) ≤ (Rated Power)
(Charge Time) < (2 x Discharge Time)

The charge portion of the cycle shall be at or below rated power and have a duration that is less than twice the discharge duration.

Physical dimensions are as described in the Enclosure section of this specification.

3.1.4. **Efficiency -** The roundtrip AC energy efficiency, measured at the AC interface, shall be at least 85%, based on a full rated energy cycle at ½ rated power for both discharge and charge with a battery temperature of 25° C. This is described as:

(Discharge power) = (½ Rated Power)

(Discharge time) = (2 x Rated Energy) / (Rated Power)
(Charge power) = (½ Rated Power)
(Charge Time) = (Time to reach full charge)

3.1.5. **Parasitic Losses -** The total CES Unit losses shall be determined for standby operation, including power electronics and any environmental controls such as heaters.

3.1.6. **Inrush Capability –** Not Applicable

3.1.7. **Through-circuit Ampacity** - The isolating contactor continuous current rating and load interrupting capability shall be at least 250 Amps peak, suitable for worst-case real or reactive loads. Fault duty is 50 kA for 2 cycles. All associated terminations and wiring in the source to load side path must also meet this requirement. This ampacity is necessary because the CES Unit may be associated with transformers up to 100 kVA.

3.1.8. **Self Discharge** – As a practical consideration, self discharge is not expected to be a significant factor due to the frequent (daily) cycling of the CES Units. The supplier is required to provide self-discharge characteristics.

3.1.9. **Stability –** Not applicable [AEP specification on islanded voltage tolerance not applicable for the SMUD application].

3.2. Termination of external AC power interface.

3.2.1. The CES Unit shall include provision for standard two-hole pads for cable termination. Each termination position (pair of holes) shall be suitable for a standard pad plus a stacking pad. Sufficient space in the termination cavity shall be permitted in accordance with IEEE C57.12.28.

3.2.2. The source side termination buses shall each have at least four pairs of holes to accommodate at least four external terminations plus a spare position for two temporary terminations plus internal connections (unless connected otherwise).

3.2.3. The load side termination buses are not supplied, as they are not applicable for the SMUD application.

3.2.4. The neutral termination bus shall have at least four pairs of holes to accommodate four external terminations and a driven ground and a temporary ground and a bond to the tank ground.

3.2.5. Reserved

3.2.6. Reserved

3.2.7. The pad, ground rod, and secondary conductor terminations will be provided by others.

3.3. Voltage shall be measured and controlled across both 120V AC legs. Voltage measurement shall be within +/- 0.5% true RMS.

3.4. Current transformers or other current sensors shall be provided as part of the CES Unit to permit measurement of current magnitude and phase angle of the adjacent transformer (on the secondary side). Current magnitude towards the load may be by residual calculation. Current measurement shall be within 0.5% true RMS. The current sensors shall be field replaceable without interruption to connected customers. Current magnitude of the other loads (residences) attached to the transformer may be provided through interface. Current measurement shall be within +/- 0.5% true RMS.

3.5. Surge Protection

3.5.1. The CES Unit shall meet the recommendations as set forth in the following complementary standards IEEE C62.41™, IEEE C62.41.1™, IEEE C62.41.2™ (see note a) and IEEE C62.45™ (see note b). It is necessary to subject the CES Unit to all the standard and additional test waveforms as defined within those standards. The necessity of the three additional surge-testing waveforms is due to the possibility of contactor interference, fuse operation and capacitor switching in the application of the CES unit. Design options shall be provided for low, medium and high exposure to lightning activity and switching transients.

CES Units shall be considered in Category C locations.

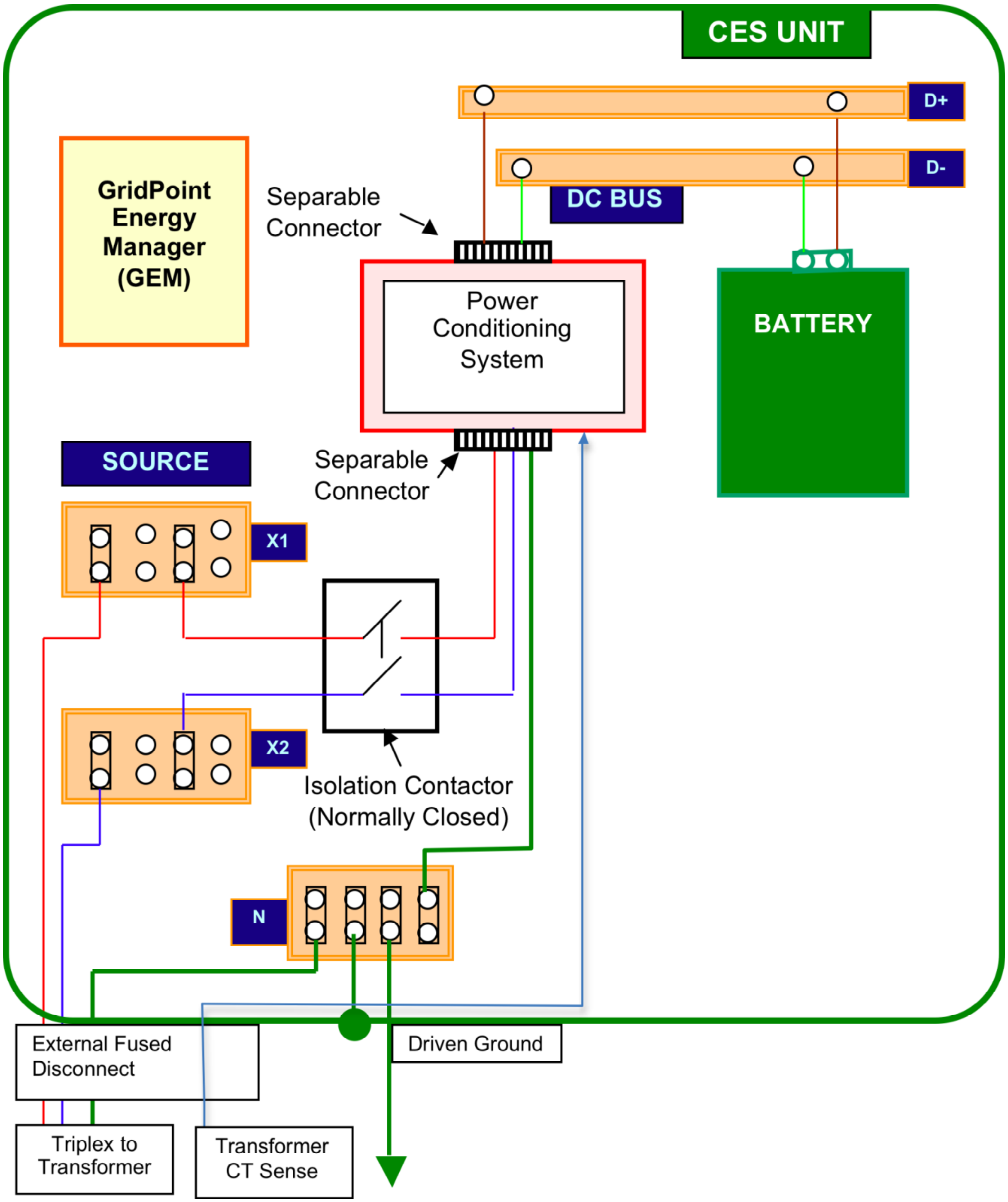


Figure 2. CES Unit AC connection diagram. Note that the transformer CT sense wiring comes to the CES through a separate conduit installed as part of CES site preparation.

3.5.2. The CES Unit control shall meet the applicable test requirements of IEEE C37.90.1 Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus.

3.6. A source side isolation contactor shall be provided for disconnecting the CES unit from the transformer secondary connection (islanding). This contactor will be operated by the CES Unit communication/control hardware.

3.7. The CES Unit shall be equipped with a means to isolate the PCS from the cable terminations. This may be accomplished through a suitable separable connector.

3.8. The CES Unit PCS, control, batteries, and current sensors shall be modularized and connected in a manner that enables field replacement of each module. Adequate instructions shall be provided to promote safe work practices for module replacement.

3.9. Reserved

3.10. The PCS shall be designed to operate in all four power quadrants at rated power magnitude (kVA); real and reactive power in or out. This function is not required or implemented for the SMUD demonstration project.

4. Enclosure

The CES Unit shall be contained within a weatherproof, tamper resistant, metal enclosure suitable for mounting outdoors on a concrete, fiberglass or equivalent pad in accordance with the following requirements.

4.1. The enclosure shall be dust tight.

4.2. The CES Unit may be designed such that scheduled maintenance is required. However, when/where possible, fans and pumps will be avoided. If maintenance is required, such details will be provided with suitable documentation and recommended timing.

4.3. Batteries, PCS, and controls shall be accessible and removable for replacement.

4.4. The 30kVA – 30kWh CES Unit enclosure size will be limited to :

Power (kW)	Energy (kWh)	Width (Inches)	Depth (Inches)	Height (Inches)
30	30	38	40	35

These dimensions describe the maximum outside measurement of the enclosure walls. An additional 6 inches is permitted for any external protrusions such as cooling fins, bump outs or communications antennae.

Physical size targets may be considered a lower priority for design purposes should the battery forms proposed be exceeded during development.

4.5. The CES Unit enclosure shall comply with the construction requirements of IEEE C57.12.25 Section 6, except as explicitly applicable to the HV compartment or oil containment.

4.6. The CES Unit enclosure shall be dimensionally compatible with pads suitable for Type I pad mounted transformers as described in IEEE C57.12.25 Section 6. All AC power cable entry shall be through the bottom of the CES Unit through openings in the pad.

4.7. The CES Unit enclosure shall comply with the security requirements of IEEE C57.12.28 Section 4. Physical security of the CES system is dependant on the CES Unit enclosure which limits access to controls and physical network connections.

4.8. The CES Unit enclosure shall comply with the coating system requirements of IEEE C57.12.28 Section 5. The final coat shall be per discretion of the customer and would preferably be light in color so as not to enhance solar thermal radiation absorption.

4.9. The CES Unit enclosure, hardware and compartments shall be made of the mild steel (for normal environments).

4.10. Enclosure grounding provisions shall consist of a steel pad with a 1/2-13 UNC tapped hole, 7/16-inch deep (similar to tank grounding requirements of IEEE C57.12.25). This ground pad shall be secured on or near the enclosure base in the secondary termination portion of the compartment

4.11. Wiring and weather tight enclosure egress to an external antenna shall be provided.

4.12. Reserved

4.13. A nameplate shall be provided including:
Manufacturer Name
Connection diagram
CES Unit ratings; Power, energy, voltage, BIL
Specimen data; serial number, date of manufacture

The nameplate shall meet the requirements of IEEE C57.12.00

4.14. Signage shall indicate AC bus, Neutral bus, DC bus, Isolation Contactor, Module names. Custom signage will be in accordance with specific GridPoint/SMUD requirements.

4.15. All necessary safety signs and warnings as described in ANSI Z535-2002 (entire series from Z535.1 through Z535.6) shall be included on the CES unit box.

4.16. All necessary signs and warnings for identification of hazardous materials as described in NFPA 704 shall be included on the CES unit box.

5. RESERVED

6. Control Functions

The CES Unit Communication/Control Systems is responsible for performing the following functions in order of priority:

1. Protect itself (isolate for any internal fault)
2. Remain within CES Unit power constraints
3. Remain within voltage constraints
4. Isolate and perform islanding in response to system anomalies
5. Charge / discharge Real Power in response to GridPoint energy management commands
6. Absorb / provide Reactive Power in response to GridPoint energy management commands
7. Communicate status and diagnostic data

To accomplish this, the CES Unit shall operate the Power Conversion System (PCS) and isolation contactor in response to its own control settings and local measurements and also in response to commands from the GEM and GNOC. The CES Unit control will also respond to manual commands that are issued remotely or locally. “Manual” commands may be scripted into other applications within a larger DER hierarchy.

Following are specific requirements of the CES Unit Communication/Control System (CCS) and GEM Unit controller:

6.1. The CCS shall interact with the GEM controller to enable the CES Unit’s participation in the overall GridPoint network control scheme specified in the GridPoint “SMUD Storage System Interface-SensorSpec v.0 6.doc” document.

6.2. The CCS shall perform islanding as specified in the Islanding section of this specification.

6.3. The GEM controller shall perform logging as specified in the Logging section of this specification, including daily archiving.

6.4. The GEM controller shall participate in the time synchronization feature managed by the GridPoint network and specified in the GridPoint “SMUD Storage System Interface v0 3” document.

6.5. CES Unit operations and administration

The CES unit shall possess the ability to operate in the following modes or states. These modes are defined below and also summarized below in a state matrix. A state diagram for these modes is also shown in the Figure 3.

Standby: The CES unit is neither charging nor discharging; the battery system state of charge may fluctuate depending on system conditions. The CES unit draws minimal power from the grid for communications and sensing when the grid is present; the unit draws this minimal standby power from the battery when the grid is absent.

Charge: While grid connected, the CES unit is drawing current from the grid at a specified rate and using it to increase the stored chemical energy in the battery.

Discharge: While grid connected, the CES unit is a current source and supplying power to the grid at a specified level by using the stored chemical energy in the batteries.

Firm: While grid connected, the CES unit is regulating its output automatically at unity power factor based on 1) the measured load on the secondary side of the transformer 2) a specified target output and 3) specified gains and a control loop calculation; from the perspective of the grid, the output may be load (charging) or generation (discharging).

Battery Charge Maintenance : While grid connected, the CES unit is maintaining a specified battery state of charge by applying a trickle (maintenance) charge to the batteries.

Sleep: The CES unit is commanded to sleep or has reached the Depleted Energy setting[1] and the isolation contactor is opened; the unit draws standby power from the storage battery for maintaining control power, communications, and closing energy for the isolation contactor for X days.

Faulted: A fault has been detected and the unit disconnects from the grid, opens the battery contactor and discontinues switching of the inverter gates, if the grid is still present all sensing and communications are still operating and remote diagnosis is possible; a manual reset of the system is required to allow for connection to the grid.

[1] Depleted Energy setting will depend on the Manufacturer's recommendation for depth of discharge and the reserve power desired for maintaining control power, communications, and closing energy for the isolation contactor.

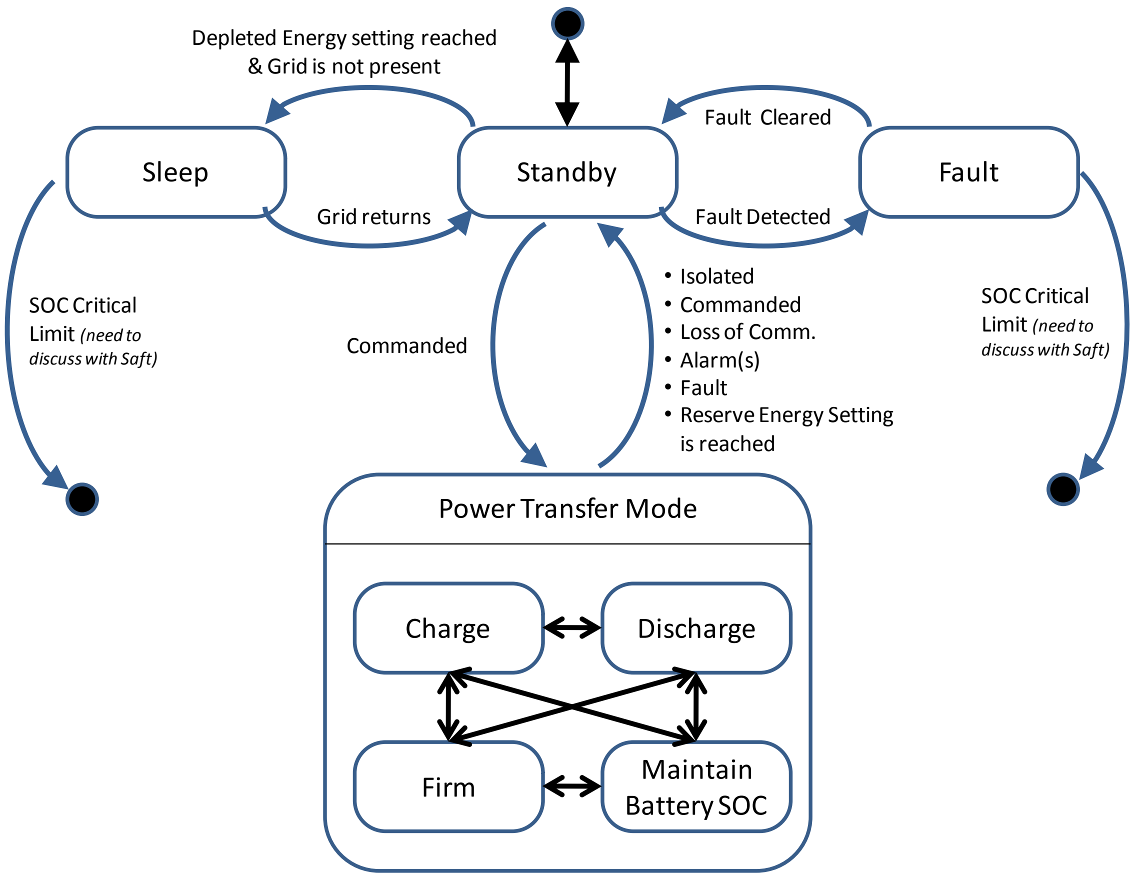


Figure 3. State diagram of CES operation.

CES State Matrix

Mode Description	Transition into Mode Triggered By:	Transition out of Mode Triggered By:	Inverter State	AC contactor	Battery Contactor	Comm Active	Sensors Active	System Power	Logging
Standby	• Isolated • Commanded • Loss of Comm. • Alarm(s) • Fault • Reserve Energy Setting is reached	• Commanded GEM/CCS • Depleted Energy setting reached & Grid is not present	No Gate Switching	Closed or Open	Closed	Y	Y	Grid/Battery	Y
Charge	Commanded	Commanded	Charge	Closed	Closed	Y	Y	Grid	Y
Discharge	Commanded	Commanded	Discharge	Closed	Closed	Y	Y	Battery	Y
Battery Charge Maintenance	Commanded	Commanded	Charge or Discharge	Closed	Closed	Y	Y	Grid/Battery	Y
Firming	Commanded	Commanded	Charge or Discharge	Closed	Closed	Y	Y	Grid/Battery	Y
Sleep	Depleted Energy Setting reached & Grid is not present	Grid Returns	No Gate Switching	Open	Closed	minimal	minimal	Battery	Y w/limited logging
Fault	Fault Detected	Fault Cleared	No Gate Switching	Open	Open	Y	Y	Grid	Y

6.5.1. The CCS shall respond to manual commands issued remotely or locally, including the following:

- Change modes: Charge / Discharge / Firm / Battery Maintenance / Standby
- Change status: Enable / disable
- Reset alarms
- Island control: Initiate / Return
- System Reset / Restart

6.5.2. A compatible **CES Management Application** shall be provided to permit remote or local manual monitoring and control. All settings must be viewable and settable, statuses viewable, operating parameters viewable, and logs configurable and viewable. The CES Management Application is software that may be run on a PC such as a laptop and carried into the field. Basic access levels and functions shall be:

User Type	Permissions	Password	Functions
Viewer	Read	Level 1	View settings, logs
Operator	Read / Write	Level 2	Change settings, issue commands, download logs, view current status
Administrator	Read / Write	Level 3	Complete control including security, firmware updates, system configuration

6.5.3. Control buttons and indicating lights shall be provided for fundamental status and operations without use of remote access, the GEM, or a locally attached PC. These shall be:

Button	Light	Function
Enable	Enabled	Enables automatic operation
Disable	Disabled	Disables automatic operation, terminating any Charge / discharge / Firm
Reset	Alarm	Resets all Manual Reset Alarms
Power	Power	On / Off, system restart
Contactor	Isolate	Open / Close Isolation Contactor

The control buttons and indicating lights shall be on the exterior of the CCS enclosure so that they are accessible by opening the CES Unit enclosure.

The physical arrangement and operation of the Isolation Contactor may make the associated button and light unnecessary.

6.6. Loss of communications or power

6.6.1. The CES Unit shall remain functional in the absence or loss of communication from the GridPoint Network Operations Center (GNOC). The CES Unit shall continue the previous control state for the remainder of the current event being managed by the GEM. On expiration of the event, the CES Unit shall standby.

6.6.2. During an interruption to communications with the GNOC, the GEM shall make repeated attempts to re-establish communications at a set time interval (variable setting, default of 5 minutes). When communications have been reestablished, the CES Unit and GEM shall make any necessary updates to resume appropriate operation.

The CES Unit shall remain functional in the case of a loss of communication from the GEM to the CCS (modbus). The CES Unit shall immediately enter the standby mode if the communication link between the GEM and the CCS is lost, as indicated by a failure of the GEM to poll the CCS within expected polling rate (variable setting, default value of 5 polling periods).

6.6.3. The CES Unit CCS and GEM shall have non-volatile memory. In the event of total loss of power (battery replacement or DC bus disconnect) the CES Unit shall retain all current and logged information and be capable of restarting without reconfiguring.

6.6.4. No single mode of failure shall result in loss of power to the control and data acquisition module.

6.6.5. Any significant loss of DC voltage shall be logged and reported by alarm. A “significant” loss of DC voltage shall be defined by a variable parameter with a default by manufacturer recommendation.

6.7. Voltage and Power Measurement and Constraints

6.7.1. The CES Unit and CCS shall be capable of operating in all four power quadrants in response to GridPoint network commands or islanding requirements; real power in or out, reactive power in or out.

6.7.2. The CES Unit CCS shall measure voltage, current, phase angle, real power and reactive power at the CES Unit AC Interface. The power flow from the transformer towards the attached customer loads may be provided to the CES Unit CCS through the remote sense input.

6.7.3. The GEM Unit shall have a Report Demand Interval (variable setting; default = 5 minutes), which is used for logging and reporting power flows.

6.7.4. The CES Unit CCS shall have a Capacity Demand Interval (variable setting; default = 1 minute), which is used for comparing CES Unit burden and capability.

6.7.5. The SMUD CES Unit shall not attempt to regulate voltage at the PCC.

6.7.6. The CES Unit shall have power constraints as an override. Power constraints will be established for the CES Unit itself and for the associated transformer / secondary system. These two constraints shall be compared to the corresponding power flows based on the Capacity Demand Interval described above.

If the input or output in kVA at the CES Unit AC Interface exceeds the Unit Power Limit (variable setting, default = magnitude of CES Unit Power Rating, separate values for charge and discharge), it shall limit charge or discharge accordingly.

6.7.7. The CES Unit will maintain compliance with power constraints by making adjustments with the following priority:

1.0 Adjust VAR input / output.
2.0 Adjust real power input / output

It is permissible to change charge / discharge / standby states to control voltage or power flow.

6.7.8. The CES Unit CCS shall have a Firming Evaluation Interval (variable setting; default = 1 second), which is used for comparing CES Unit output with firming target setpoint. See SMUD Storage System Interface-SensorSpec v.0 6.doc and SMUD Firming Algorithm Definition v0 7.docx for further details.

6.7.9. In the firming mode, the CES Unit shall respond to changes in the measured transformer load (as measured by the remote sense input) and change its output accordingly to match the target setpoint.

6.8. CES Communication/Control System communications

6.8.1. The CES Unit GEM controller may be in a separate enclosure and provide space and mounting rack for the on board communications. The GEM controller component modules shall be similar to the following:

a) Maximum radio size (including mounting screws. Cables extend out):
Width: 7 1/2” (measured from side-to-side where the sides do not have connectors, LEDs or other user-servicable items).
Length: 8 3/4” (allow an additional inch for connectors)
Thickness: 2 13/16”

b) Power Supply
Nominal 24 VDC
Maximum output 0.5A continuous
Power: Average 12 Watts maximum

6.8.2. The CES Unit GEM controller shall include a USB port, ANSI Type 2 Optical Port, and/or Ethernet connection for administrative functions from an attached portable computer. Physical access will be controlled by access to the CES Unit enclosure.

6.8.3. Communication interface to the GNOC will be per the GridPoint GEM as specified in GridPoint document "SMUD Storage System Interface-SensorSpec v.0 6.doc" The GridPoint network communications and remote management applications, as well as any other communication interfaces such as into home networks or for local management functions, shall be compliant with any applicable security requirements.

6.8.4. The CES Unit CCS shall include a USB port for administrative functions from an attached portable computer. Physical access will be controlled by access to the CES Unit enclosure.

7. Islanding[2]

CES deployment is intended to perform load following at the circuit level. During normal system conditions, therefore, the discharge commands of the CES Unit will be issued by the GridPoint Energy Manager; in charge or discharge mode, the CES Unit output will remain constant until an updated command is received. In firm mode, the CES Unit will manage its output by evaluating the current transformer load and system state every few seconds (no subcycle control required). For the SMUD CES application, the CES Unit will not operate during a grid outage and is not required to provide backup power to the connected secondary loads.

7.1. Transition to Island Mode

In the event of a momentary or permanent power system outage, the CES Unit will go into islanding mode as required by UL 1741 and IEEE 1547. The isolation contactor will open and the CES Unit will operate in standby. Planning for standby operation and islanding shall include the following constraints.

7.1.1. While system conditions are normal, in anticipation of islanding, battery discharge shall be restricted to leave a minimum available energy setting, Reserve Energy (percent of rated CES Unit energy, variable setting, default 1%).

7.1.2. Automated sensing and responding to anomalous system conditions shall be in compliance with IEEE 1547-2003, specifically Section 4.2.3 on Voltage response and Section 4.2.4 on Frequency response. On transition to islanding, the CES Unit transition to STANDBY mode.

[2] The term "Islanding" is retained for the purposes of heading continuity to the AEP Functional Specification Rev. 2.2. However in the case of the SMUD deployment, "islanding" is used to define isolation of the CES unit from the secondary side of the transformer and will not continue to energize the circuit or draw power from the grid, as intentionally islanded operation is not allowed.

7.1.3. Islanding shall be permitted if the CES Unit is enabled regardless of the CES Unit state; standby, firm, battery charge maintenance, discharge, or charge.

7.1.4. Islanding shall NOT occur if the CES Unit is disabled through local or remote command, or if the CES Unit is faulted.

7.1.5. The islanding contactor will not open under conditions specified in the Protection section of this specification.

7.1.6. Islanding may be invoked manually. The CES Unit shall respond to a remote or local command to initiate the islanding process.

7.1.7. When the line disconnect has opened, the CES Unit will continue to communicate through the CCS as usual. The CES Unit will automatically enter SLEEP mode based on the CES Unit remaining energy.

7.1.8. An automated transition to island shall be reported to the GNOC.

7.2. Operation in Island mode

Once the islanding event has occurred, the CES Unit shall remain in STANDBY or SLEEP mode for as long as possible within the constraints described below.

7.2.1. Reserved

7.2.2. Reserved

7.2.3. Reserved

7.2.4. While battery state of charge remains above depleted energy level, reliability data shall be logged throughout the islanding event. From the source side voltage measurement, the duration and type (momentary or permanent) of outage will be recorded. The collected data will be communicated to the GNOC where they will be aggregated at the circuit level to calculate the impact on circuit SAIFI, SAIDI, and MAIFI.

7.2.5. Reserved

7.2.6. Reserved

7.2.7. Reserved

7.2.8. The STANDBY islanded mode will consume stored energy until a set Depleted Energy setting is reached (variable setting; percent of rated CES Unit energy, default = 1%). When the State of Charge is reduced to this level, the CES Unit shall go into SLEEP mode. Due to safety concerns, the isolation contactor shall remain open.

The communication/controls system shall be put into a sleep mode to reduce power consumption. The CES Unit shall be capable of recovery from a Depleted Energy state for a period of not less than two weeks. One scenario of concern is a catastrophic power system outage where large numbers of CES Units may have run to a Depleted Energy state. When the normal supply is restored, the CES Units must recover in an automated fashion.

Selection of the Depleted Energy setting will depend on the Manufacturer's recommendation for depth of discharge and the reserve power desired for maintaining control power, communications, and closing energy for the isolation contactor. Accuracy of the State of Charge estimate must also be taken into consideration to assure sufficient energy to return.

Restoring the CES Unit following a Depleted Energy event will require:

- Return of system voltage, in accordance with the System Stable criteria
- Automated close of the Isolation Contactor. Timing shall be consistent with the requirements of for staged return from islanding.
- CES Unit control logging of event end and communication to the GNOC.

7.2.9. System voltage, source side of the open isolation contactor, shall be monitored continuously during islanding in preparation to initiate the return transition.

7.3. Transition from Island Mode

The Island Return process is intended to provide flexible control over the CES Units and optimize the participation of the affected CES Units in restoration efforts. Considerations are:

- Maintaining the CES Unit state-of-charge for possible repeated outages (minimize islanding duration)
- Assuring that system conditions are stable (longer time prior to returning)
- Reducing cold load pick-up (longer time prior to returning)
- Avoiding simultaneous return of multiple CES Units (staged return times)
- Autonomous CES Unit control (minimize dependence on communications which may be burdened during outage conditions)

To accomplish this, two time intervals are employed, a System Stable Interval and a Return Delay Interval.

7.3.1. Unless inhibited, the CES Unit shall automatically synchronize and perform closed transition return following an outage. A CES Unit that tripped due to overload or fault is not inhibited.

7.3.2. The Island Return process may be inhibited by a remote or local command. If the CES Unit was disconnected from the grid manually, the return shall be inhibited by default, and a manual command shall be required to enable the Island Return process. The inhibit feature may be invoked manually at any time, regardless of CES Unit mode.

7.3.3. The Island Return process shall require expiration of two interval times before closing the Islanding Contactor, the System Stable interval followed by the Return Delay interval.

7.3.4. Prior to return, the CES Unit shall measure stable system voltage (source side of the open isolation contactor) for a set time interval (variable setting, default of 5 minutes). Stable system voltage is defined as being within specially defined voltage magnitude and frequency settings (variable settings, defaults of 115 V, 126 V, 59.3 Hz, 60.5 Hz). The voltage magnitude may be set according to expected site conditions, and the frequency may be set consistent with IEEE 1547-2003 Section 4.2.6. These settings may be selected to assure that multiple units are not returning to a system that is not able to support the returning load and that local service conditions will not be degraded by the return.

7.3.5. If the voltage and frequency criteria are not satisfied continuously during the Stable System interval, then the Stable System interval timer shall be reset to zero and timing reinitiated when the criteria are satisfied.

7.3.6. Synchronization shall begin and the Return Delay Interval shall begin when the Stable System interval timer has expired.

7.3.7. The Return Delay (variable setting, default = 10 seconds) of a CES unit following the restoration of a stable system is to be determined by the GEM Controller in coordination with the GNOC. When the CCS determines that a stable system is restored (as described above in 7.3.4). following the return delay the GEM controller can determine an appropriate time to reconnect a given CES Unit.

7.3.8. Criteria for synchronization shall be in accordance with IEEE 1547 Table 5. The Isolation Contactor shall be closed when the Return Delay interval has expired AND the synchronization criterion is satisfied.

7.3.9. The CES Unit will provide updated status and operating data on the next Command Interval when prompted by the GNOC as usual. In order to avoid burden on the communications system, the update is not invoked from the CES Unit.

7.4. Reserved

8. Logging

Data logging can be managed both locally and through data aggregation at the GNOC level. Listed below are a minimum set of data recording functions for the CES Unit itself. This data definition is subject to revision in accordance with GridPoint/SMUD requirements and options.

8.1. The GEM shall poll Modbus registers for all operating and performance data on a periodic basis and roll data up into 5-minute intervals using min, max, and avg summary statistics. These 5-min summary values shall be reported to the GNOC every 5 minutes when a connection is available. When no connection is available the GEM shall cache data in non-volatile memory until the connection is restored.

8.2. The GEM shall have enough non-volatile memory to store at least one week of cached data locally.

8.3. Time based performance data logs shall be stored in the GNOC for duration of the program.

8.4. The GEM will provide all data to the server in 5 min intervals and persisted in a data base.

8.5. All raw data persisted in the server will be available through periodic reports as described in document.

8.6. Requirements for logging of alarms and fundamental operating and performance data are described in "SMUD Storage System Interface-SensorSpec v.0 6.doc".

9. Environmental

CES shall be designed to perform all its functions in the following outdoor environment:

Operating Ambient Temperature:	-30°C to +50°C
Survival Ambient Temperature:	-40°C to +60°C
Humidity:	10% to 100% condensing
Transportation / Storage Ambient Temp:	-30°C to +50°C for up to 6 months
Altitude:	Sea level to 2000 m without kVA derating
Seismic risk:	Uniform Building Code Zone 4

10. Harmonics, Noise and EMI emissions

10.1. It is not intended to utilize the SMUD CES Units to correct harmonics. The following emissions requirements presume the system is connected to a clean system and describes the limits for the CES Unit to the contribution to distortion. Following are the requirements on current and voltage harmonics of CES at the point of common coupling to the utility system:

- Total Demand Distortion (TDD) at 50%-100% of rated power < 5%
- Individual harmonic currents during peak shaving (as a source) per IEEE Std. 1547-2003

- Individual harmonic currents during charging & standby (as a load) per IEEE Std. 519-1992

10.2. CES EMI shall not exceed levels established in the FCC Code of Federal Regulations in Sections 15.109 and 15.209. In addition, CES shall have the capability to withstand EMI in accordance with IEEE Std. C37.90.2-1995.

11. Computer Models

The CES Unit supplier shall provide information suitable for development of models for the digital simulation of the CES Unit response to all operating modes and to anomalous conditions. Supplier engineers shall work with SMUD in developing simulation models and shall promptly communicate changes to the models as the design evolves. The intent of this requirement is to provide adequate information regarding operational characteristics so that associated studies can be undertaken. For example, if the CES Unit is connected with a known source side driving point impedance and a motor of known starting characteristics is started, it is desired to know how the CES Unit will respond and what impact it will have on voltages and currents.

12. Protection

12.1. The CES Unit shall be self-protecting for AC or DC component failures. Protection shall coordinate with pad-mount transformer internal fusing such that the CES Unit is isolated while the isolating contactor remains closed and the load remains on the grid. If adequate fault interrupting capability is not provided, then the transformer protection or grid protection may be used for handling catastrophic failures.

12.2. Reserved.

12.3. The CES Unit shall use over current sensing to inhibit opening of the islanding contactor for any condition that exceeds the interrupting capability of the contactor.

12.4. The CES Unit shall stand by (isolate itself from the grid by opening the isolating contactor and not discharge) when:

- An uncorrectable voltage violation occurs
- Loss of neutral is detected by neutral shift relative to ground
- Current exceeds the storage maximum momentary capacity

12.5. Reserved

12.6. Response to grid faults. The CES will respond to grid abnormalities as described in Section 12.4 above.

13. Communications

The CES Unit GEM controller shall include multiple communications options such as cellular, mesh node, Wi-Fi, and Wi-Max. Selection between communications options will depend on specific sites. An appropriate communications board and antenna shall be provided when this determination is made.

The control interface to the CES Unit GEM controller is as specified for operation with the GridPoint NOC. The specifics of the control algorithms and requirements placed on the communications interface and controller are as detailed in GridPoint Documents “SMUD Firming Algorithm Definition v0 7.docx” and “SMUD Storage System Interface-SensorSpec v.0 6.doc”.

14. Factory Acceptance Testing

The system supplier shall conduct system operation tests according to applicable standards and procedures included in IEEE Standard 1547.1-2005, and agreed upon between the SMUD and the system supplier. SMUD representatives and the supplier shall be allowed to participate in factory acceptance tests covering the functionality of all system components at partial rated power. The acceptance test plan shall be designed to provide confirmation of the CES Unit ratings based on an agreed reference duty cycle.

15. CES Unit Alarms and Status

The CES Units will provide a minimum set of status and alarm information to the GridPoint NOC; other alarm and status information may be defined based on GridPoint/SMUD agreement, and such additional or alternative alarm and status information may supplement or replace that defined below. The interface will be through the GEM to the GNOC. Aggregate CES data will be provided by the GNOC.

Date/time stamps are required in all logs. Time synchronization will be managed by the GNOC. The CES Unit control shall provide a feature to synchronize in response to the GNOC time management feature.

15.1. Individual CES Unit Alarms are tabulated here. All events shall be time stamped.

Alarm	Action	Reset
Overvoltage	Trip	Manual
Undervoltage	Warning	Manual
Battery Temp	Inhibit	Auto
Reserve Energy Limit	Inhibit	Auto
Depleted Energy Limit	Trip	Manual
PCS-1 Temp Limit	Trip	Manual
PCS-2 Temp Limit		
Unit Power Capacity	Trip	Manual
DC Bus Overvoltage	Warning	Auto
DC Bus Undervoltage	Warning	Auto
Unit Shutdown	Trip	Manual
Comm Failure	Warning	Auto

15.2. CES Unit status to the GridPoint Network Operations Center for interface and ultimate DDC display will be provided in the form of operating parameters tabulated here.

Mode	Standby/Tripped/Available	
Unit Real Power	In / Out	kW
Unit Reactive Power	In / Out	kVAR
AC Voltage	240/120	Volts
Island	Duration	Min
State of Charge		Percent

16. **CES Unit Settings and Operating Parameters**

Please reference SMUD Storage System Interface-SensorSpec v.0 6.doc for CES Unit setting and operating parameters between the CCS and GEM.

17. Standards & Code Compliance

The CES and subsystems shall be designed, manufactured, and tested according to the latest revision of applicable standards including but not limited to IEEE, ANSI, NEC, and NEMA. Equipment furnished shall meet the guidelines defined in the applicable portions of standards listed in the Table below.

APPLICABLE STANDARDS & CODES

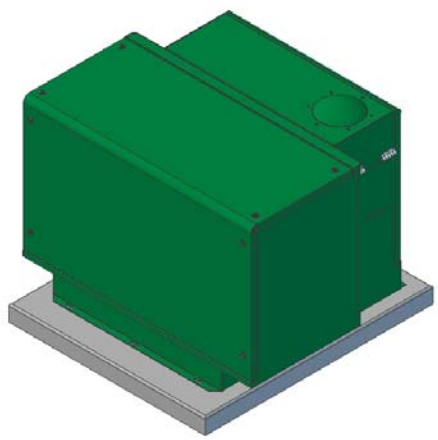
1	ANSI/IEEE Std C2-2007TM	National Electrical Safety Code.
2	ANSI C57.12.25-1990	Pad-Mounted Transformer Requirements
3	ANSI C57.12.28-2005	Pad-Mounted Equipment Enclosure Integrity
4	ANSI Z535 – 2002	Product Safety Signs and Labels.
5	FCC Sections15.109 & 15.209	FCC Code of Federal Regulations Radiated Emission Limits; General Requirements.
6	IEEE Std 519-1992TM	IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.
7	IEEE Standard 1547-2003 (R 2008)TM	IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.
8	IEEE Standard 1547.1-2005 TM	IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
9	IEEE Standard 1547.2-2008 TM	Interconnecting Distributed Resources with Electric Power Systems
10	IEEE Standard 1547.3-2007 TM	Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems
11	IEEE C37.90.2-2004 TM	IEEE Standard Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.
12	IEEE Std. C37.90.1-2002 TM	IEEE Standard for Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems (ANSI).
13	IEEE Std. C62.41-1991(R 1995) TM	IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits.
14	IEEE Std. C62.41.1-2002 TM	IEEE Guide on the Surges Environment in Low-Voltage (1000V and Less) AC Power Circuits.
15	IEEE Std. C62.41.2-2002 TM	IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits.
16	IEEE Standard C62.45-2002 TM	IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits.
17	NFPA 704	Standard System for the Identification of the Hazards of Materials for Emergency Response.
18	Smart Energy Profile (SEP)	Standard system for communication with demand side management equipment
19	Uniform Building Code	Applicable to seismic rating (i.e., up to 5% peak acceleration with 10% probability of being exceeded in 50 years)
20	UL 1778	Underwriters Laboratory's Standard for UNINTERRUPTIBLE POWER SYSTEMS (UPS) for up to 600V A.C.
21	UL 1741	UL Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources

PowerHub Systems

DELIVERY, INSTALLATION, and OPERATION INSTRUCTIONS for MODEL CE3030-240

30kW-30kWH Community Energy Storage Unit

Document #112111 Revision DRAFT
November 21, 2011



IMPORTANT SAFETY INSTRUCTIONS

SAVE THESE INSTRUCTIONS - THIS MANUAL CONTAINS IMPORTANT INSTRUCTIONS FOR POWERHUB SYSTEMS MODEL CE3030-240 GRID-TIED COMMUNITY ENERGY STORAGE UNIT THAT SHALL BE FOLLOWED DURING INSTALLATION AND MAINTENANCE OF THE CE3030-240 UNIT.

PowerHub Systems
1700 Kraft Dr. Suite 1325
Blacksburg, VA 24060
(540) 443-9214
Copyright 2011, PowerHub System

1.0 General Information

1.1 Warnings

The PowerHub Community Energy Storage (CES) unit presents a SHOCK HAZARD. Before installing, read all instructions, cautionary markings and other appropriate sections of this guide. Failure to follow these warnings could result in severe shock or even death. Exercise extreme caution at all times to prevent possible accidents.

These instructions are not meant to cover every safety eventuality nor to replace any local or site specific safety procedures. The information in this section is intended as a supplement to local or site specific procedures. PowerHub does not assume responsibility for the compliance or noncompliance to any code, national, local, or otherwise for the proper installation of the PowerHub CES unit or associated equipment supplied.

A potential for personal injury and/or equipment damage exists if electrical codes and these instructions are not followed. The PowerHub CES unit contains LETHAL VOLTAGES. Authorized service personnel only should perform all repairs and service as the CES unit is intended for deployment by utility service personnel only.

1.2 Description

This guide is designed to detail and provide instruction for the delivery, installation and operation of the PowerHub CES unit.

1.3 Delivery of Unit

The CES unit is shipped to the utility service location as an assembled power conditioning system (PCS) plus battery box assembly. The battery storage modules are already installed within the CES battery enclosure. There are a total of 18 battery-related units in each CES battery enclosure: 17 battery modules and one separate battery module manager (BMM). Other supporting required cabling and equipment is also included. The detailed packing list for the CES unit is given in Table 1 below.

Table 1. Packing list for CE-3030 unit.

Item	Number	Description/Packing list
1	1	CES unit power conditioning system (PCS) and battery box assembly. The battery box assembly includes: (17) Saft 24M Synerion battery modules (B1); two battery frames (A1, A2); (1) Battery Manager Module (BMM) (B2); (16) intermodule battery connection cables (PC1); (15) intermodule communication cables (CC1); (1) positive lead termination cable (PC2); (1) negative lead termination cable (PC3); (1) inter-string communication connection cable (CC2); (1) inter-string power connection cable (PC4); (1) BMM-to-battery stack communication cable (CC3); (1) communication ring terminator (CC4).
2	3	Current sense cables (each 30m in length), (PCS-CS)
3	2	Transport lifting bars, (H2)
4	4 sets	Lifting bar hardware, (H3)
5	2	Suction cup lifting handles for removal of the battery box lid.

1.4 Site Preparation Work

Prior to CES unit delivery, the vault and pad are required to be installed and prepared per the reference specification. Specifically, the CES mounting location shall include provision for standard two-hole pads for cable termination. Each termination position (pair of holes) shall be suitable for a standard pad plus a stacking pad. Sufficient space in the termination cavity shall be permitted in accordance with IEEE C57.12.28.

The service wires from the distribution transformer will be run through conduit to the pad and include 2/0 wires for L1 and L2 and an AWG#1 for N. A driven ground shall be provided within the pad opening for connection to the CES unit.

Current transformer coils will be used as part of the CES unit to permit measurement of current magnitude and phase angle of the load connected to the distribution transformer (excluding the CES unit itself). Conduit from the distribution transformer to the CES unit shall include one 4” conduit for the power wiring and one 4” conduit for the current transformer leads.

1.5 Packing for Transport to Field Installation

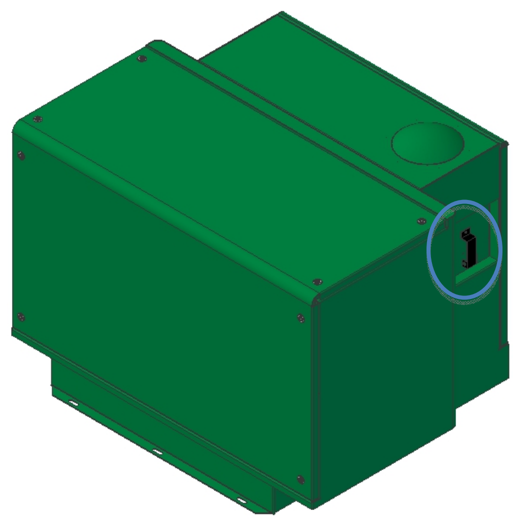
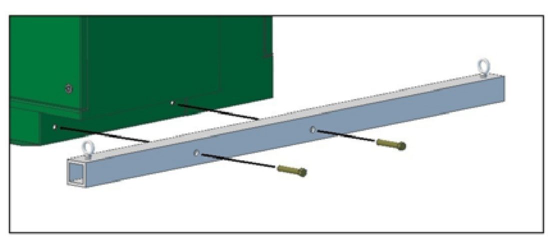
The CE-3030 unit should be shipped to the field installation site with batteries in place. Lifting bars are to be attached to the unit per instructions in Section 2.0 prior to loading on to transport vehicle. Unit should be moved using crane or hoist utilizing the lifting points as illustrated in Section 2.0.

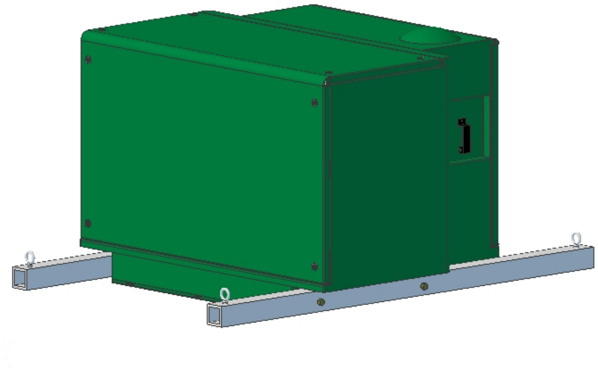
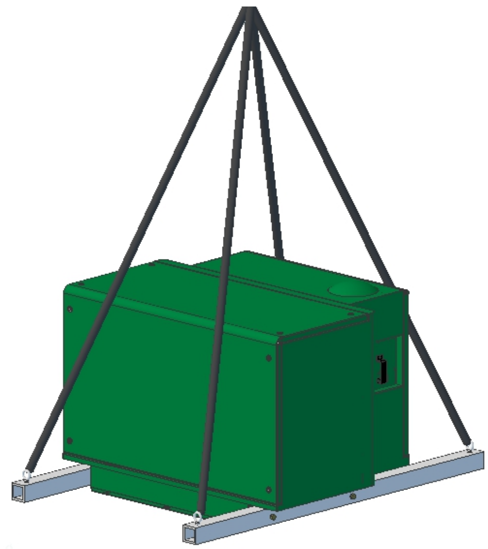
1.6 On Site Installation

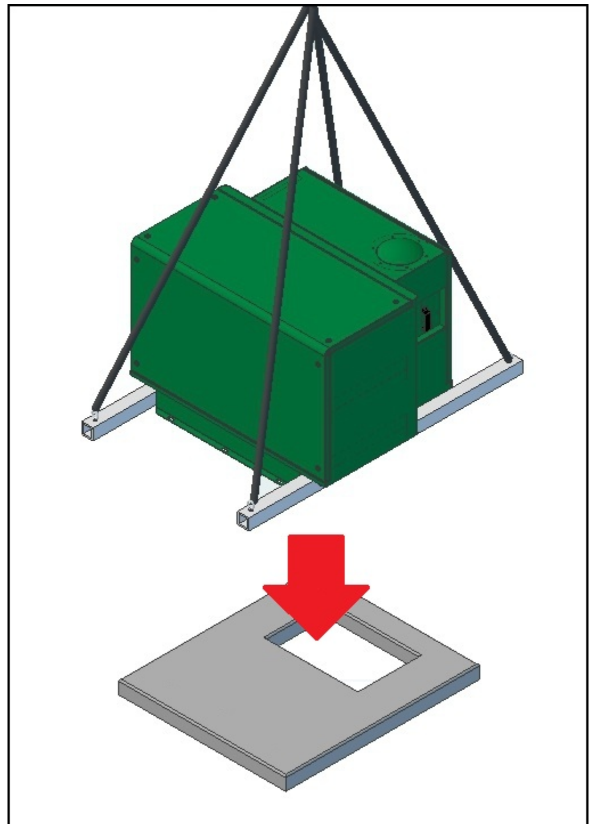
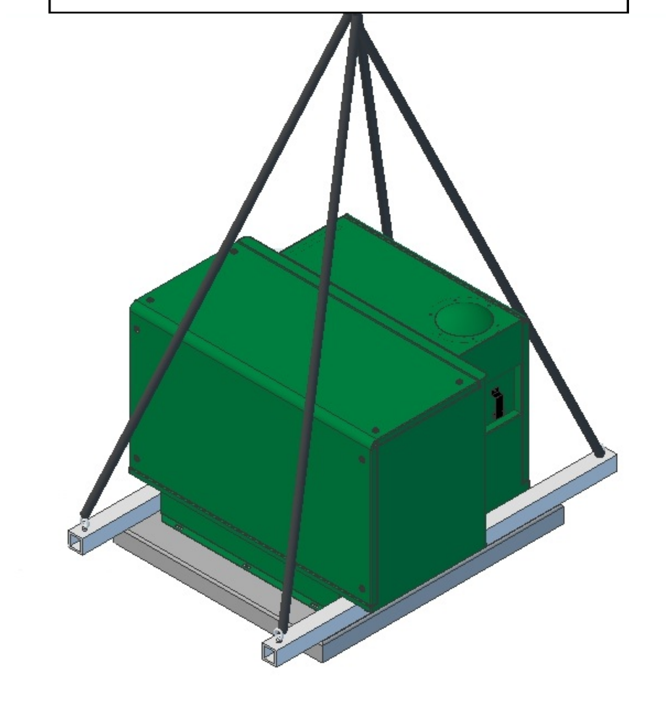
At the field site, the CE-3030 unit will be placed on to the prepared utility pad. The CE-3030 is bolted to the pad utilizing provided hardware or other suitable hardware. Prior to unit placement, the PCS compartment lid is to be removed to allow visibility and wire access as the CE-3030 unit is placed on the utility pad. Prior to permanent unit placement on the pad, the mounting holes are to be marked and drilled. On-site wiring follows the installation instructions given in Section 2.

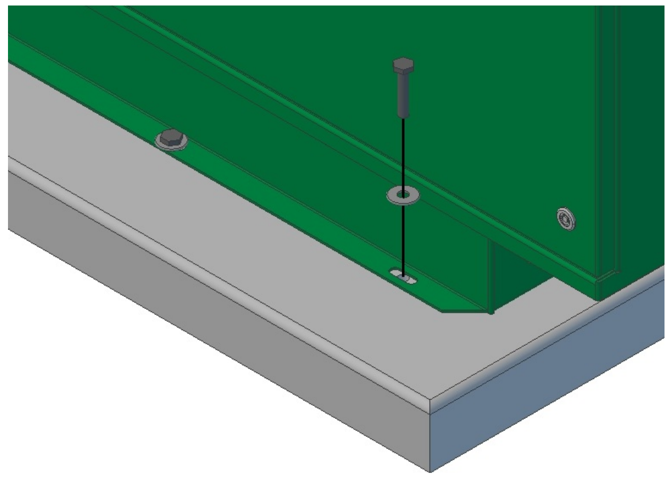
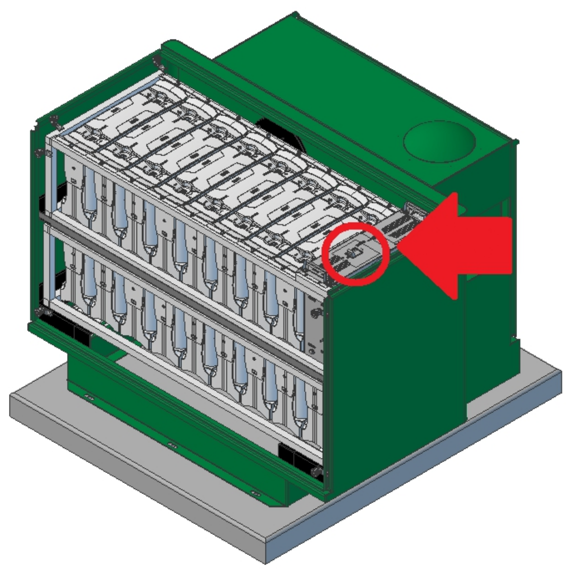
2.0 CE-3030 Installation

The following table presents the basic instructions for unit delivery and installation.

Step Number	***Description of Process***	***Corresponding Image***
2.1	**TRANSPORT AND ON-SITE INSTALLATION:** **Note: The CES unit, when installed and in place has only one operable interface accessible from outside the device and that is the AC-side fused switch disconnect. This is the CES ON/OFF control and is illustrated here with the covering door removed to highlight the handle location.**	
2.2	In order to lift the CES unit, place the square tube lifting rig bars onto either side of the base of the CE-3030 unit, lining up the holes in the lifting rig bars with the holes on the sides of the unit. Secure bars into position using hardware provided.	

		
2.3	Attach hoist webbing to square tube lifting rig bars and hoist assembly into or onto vehicle for transportation to installation site.	

2.4	At installation site, **remove PCS compartment cover.** Hoist assembly onto prepared concrete pad, making sure to align the opening on the bottom of the PCS box with the rectangular opening in the pad.	 
2.5	Position the CE-3030 so that the mounting holes are positioned	

	over the pre-drilled holes in the pad. Guide the unit in place with conduit wiring positioned appropriately in the PCS compartment.	
2.6	Attach CE-3030 to pad using hardware provided. Remove the cover from the battery enclosure.	
2.7	Once unit is installed, Open battery box by removing the screws around the perimeter of the battery box cover using the special Torx tool. Remove lock. Lift lid off the battery box using provided suction cup handles. Replace the battery compartment cover but do not secure with screw. The lock can be put in place to secure the cover in place. NOTE: There are no serviceable parts within the battery compartment and with the exception of installation or relocation, there is no need to open the battery compartment.	

3.0 Wiring and Initial Checkout Test Procedures

3.1 Connection Diagram

Figure 1 below shows the wiring connection diagram for the CE-3030 unit in the field application.

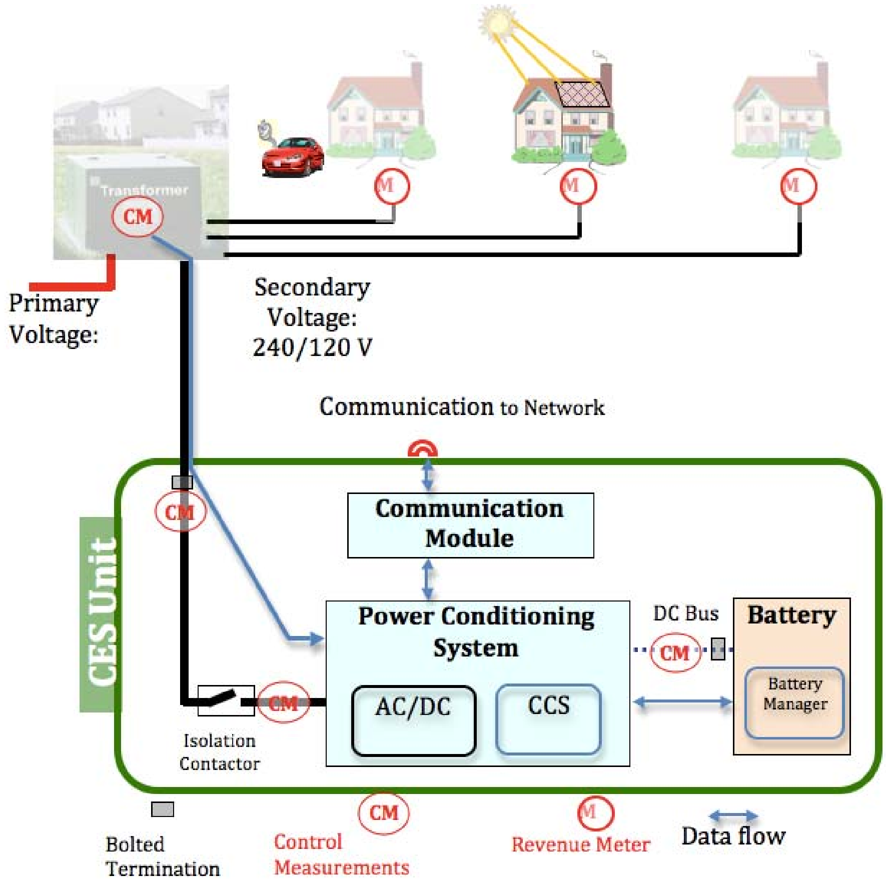


Figure 1 Connection diagram. There are two separate conduits required between the distribution transformer and the CES pad location: one for power and one for current sensors.

Figure 2 shows a photo of the internals of the PCS box with the various parts of the circuit identified.

Figure 2. Photograph of internal construction of the PCS portion of the CES unit. (A) AC-side fused switch disconnect (ON/OFF control), (B) DC-side fused switch disconnect, (C) EMI filter, (D) Current probe amplifier, (E) AC contactor, (F) single grounding point connection.

Figure 3 shows the details for the wiring between the transformer secondary and the CES unit AC input side. There are four power connections to make during installation and three current sense leads to connect.

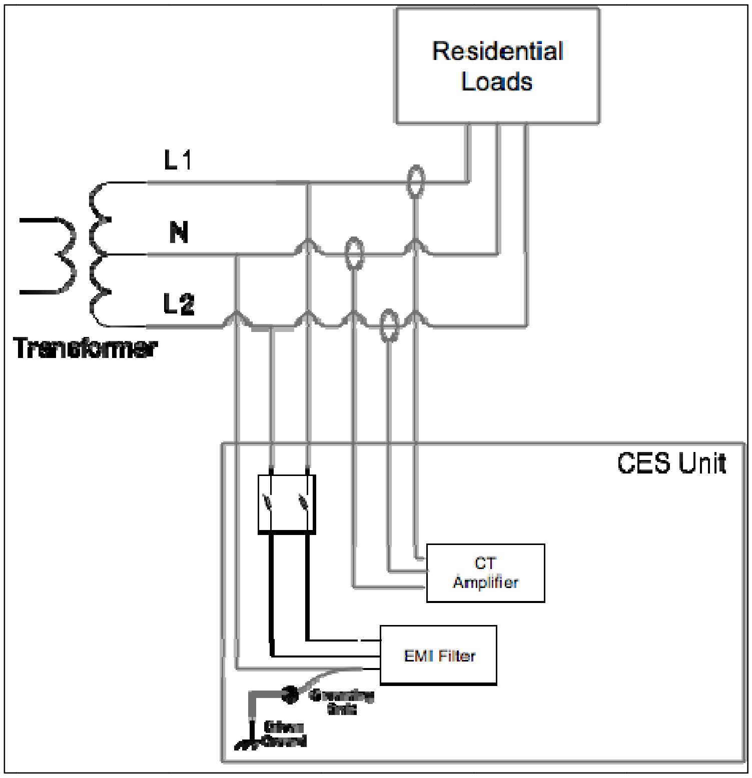


Figure 3. Connection wiring details for the CES unit.

3.2 Power Connections

NOTE: Make sure all disconnect means are open in the CE-3030 before connecting the utility service wires to the CE-3030 as indicated below. The disconnect means are the AC-side fused switch disconnect (the ON/OFF handle that is accessible from outside the unit) and the DC-side fused switch disconnect – Item B in Figure 2 above.

Power lines L1 and L2 are connected to the upper side of the fused AC disconnect as shown in more detail in the picture of Figure 4. The neutral wire involves two connections: the neutral itself is terminated to the single grounding point in the CES. The neutral wire should be terminated with a crimped lug and connected to the point where the braided lead connects to the input side of the EMI filter. This is shown in more detail in the picture of Figure 5. An additional ground connection is to be routed from the driven ground rod to the single grounding point. The easiest point for this termination is to the bulkhead grounding bolt as shown in Figure 2.

Figure 4. Detail of L1 and L2 connection to fused switch disconnect. This disconnect is the ON/OFF control for the CES and the only operable external control for the unit.

Figure 5. Detail of neutral wire connection. The bolt indicated by the circle is the location for connecting the wire to the driven ground in the pad of the unit.

3.3 Current Sense Connection

The three current sense loops are to be connected at the secondary of the transformer so as to sense the current of the connected residential loads only and should not enclose the wires leading to the CES unit. The sense leads are to be run through the conduit to the CES unit and then connected to the color-coded coax connectors in the CES unit. This is shown in Figure 6.

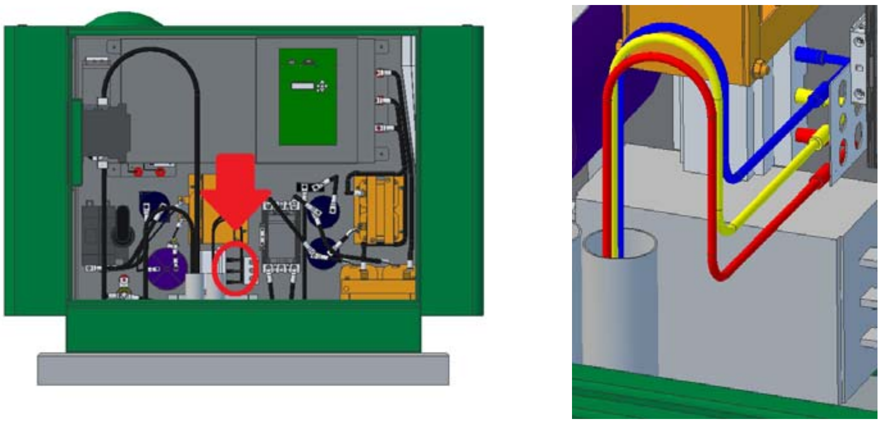


Figure 6. Details of current sense lead connection in the CES unit.

3.4 Connect to Distribution Transformer

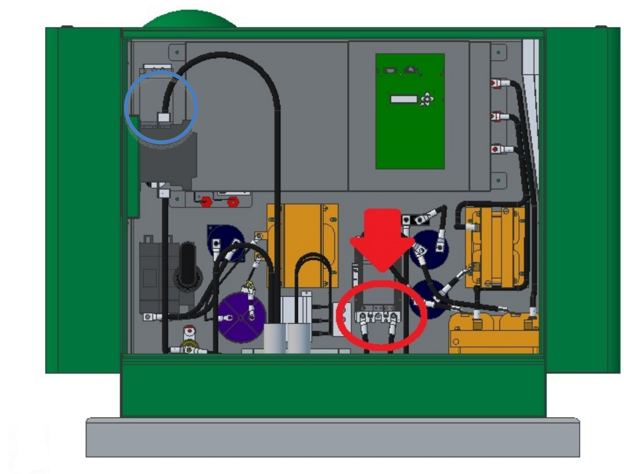
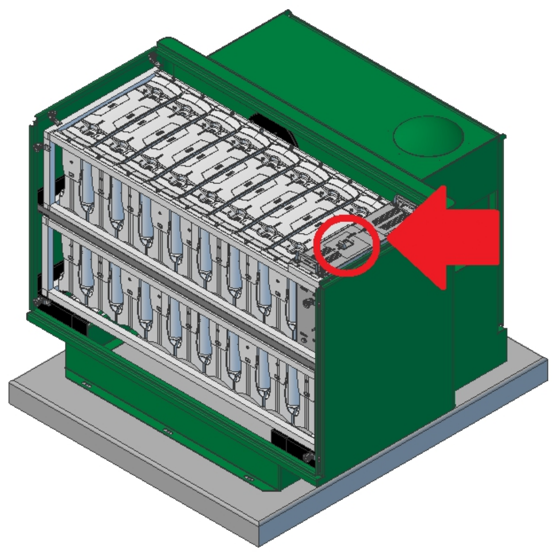
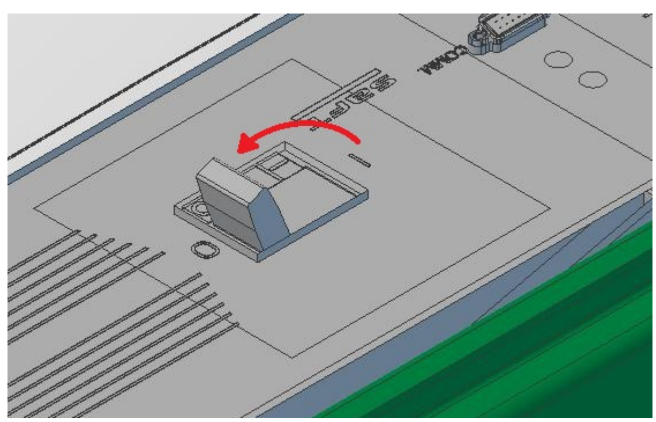
Once the CES unit is wired completely, ensure that the AC-side fused switch disconnect (ON/OFF switch) is in the OFF position. It is now acceptable to connect the L1, L2, N wires to the secondary of the distribution transformer. The CES unit will not be active until the ON/OFF switch disconnect is closed.

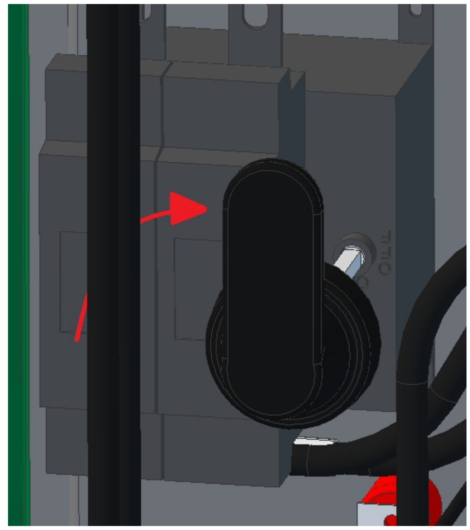
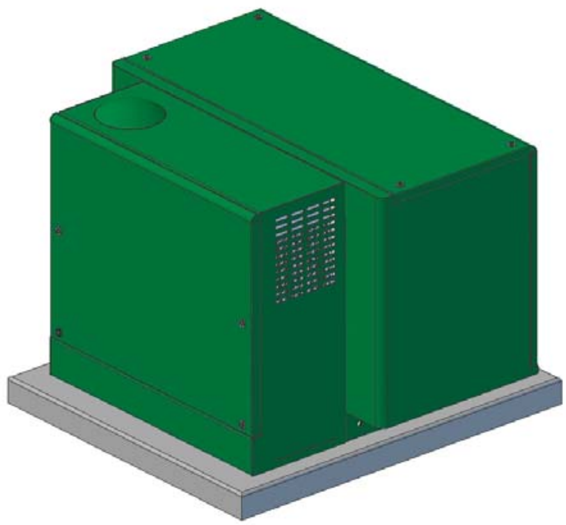
3.5 Check out procedure

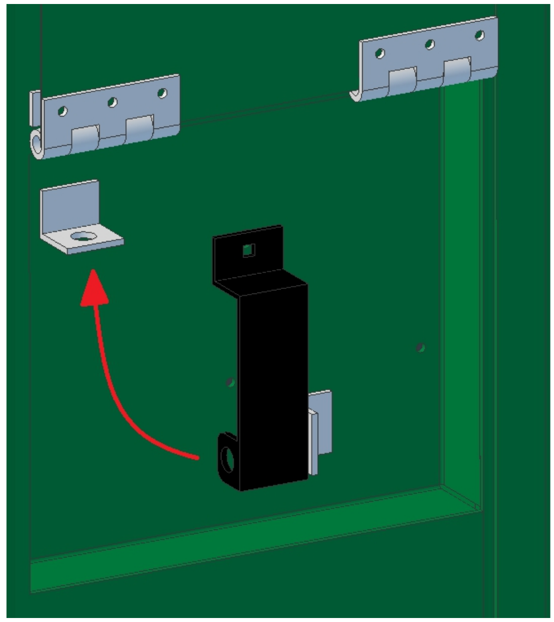
The ON-SITE TESTING check-out procedure is to be carried out once the wiring is completed. All normal precautions for working around live circuits and high voltage DC are to be observed.

The following equipment is required to perform item check-out testing procedures.

Item	Description	Technical Specifications/Requirements
1	Single phase 240/120V split phase transformer	50kVA recommended. Similar type to that used in field deployment if possible.
2	Digital multimeter	VDC to 1000V, Vac to 600V
3	AC power interconnection	240/120Vac, single-phase
4	Network (Internet) access	Standard web browser, account with suitable authorization through Gridpoint Corporation

3.4.1	Use digital multimeter to test for voltage on the utility side of the AC switched disconnect (shown in blue circle in figure on right).	
3.4.2	Remove the battery compartment cover. Turn BMM circuit breaker from OFF to ON. **Replace battery enclosure cover.** Replace the battery compartment cover, secure with screws, and attach lock. NOTE: There are no serviceable parts within the battery compartment and with the exception of installation or relocation; there is no need to open the battery compartment.	 

3.4.3	Close DC-side manual disconnect device.	
3.4.4	Replace PCS enclosure cover.	

3.4.5	Close AC-side switch disconnect.	

3.4.6 Completion and connection to service transformer

Once all wires are connected, turn the DC-side fused switch disconnect to the ON position and then replace the PCS section cover.

3.4.7 Start-up and performance check

Once the CES is wired and connected to the distribution transformer, the ON/OFF switch disconnect can be moved to the ON position. The CES unit should activate and should establish communication with the GridPoint server. At this point, the CES unit can be configured and checked through the GridPoint server interface.

4.0 Service and Emergency Response

4.1 Manual Unit Shutdown

The CE-3030 unit is designed to have only a single externally accessible control: the ON/OFF switch disconnect on the side of the PCS compartment. In the event of a device malfunction or issue, the ON/OFF switch should be turned to the OFF position and can be locked in the OFF position.

4.2 Opening PCS Compartment for Servicing

If there is reason to open the PCS compartment in order to service the inverter or evaluate the configuration of the unit, then the AC-side ON/OFF switch should be locked in the OFF position before removing the PCS cover. The CE-3030 should not be opened for any reason until allowing for the discharge time as indicated on the external warning labels. Once the PCS cover is removed, the DC-side switch disconnect should be turned to the off position and the leads coming to the DC disconnect from the battery box should be checked with a meter to determine if there is any DC voltage still present at that interface.

4.3 Emergency Response Procedure

In the event of a battery failure or other unit event involving the possible discharge or damage within the CE-3030 unit, it is important NOT TO ATTEMPT TO OPEN THE BATTERY COMPARTMENT. There are no serviceable features within the battery compartment that are useful to access in the event of a battery module event. The battery compartment is designed to contain and isolate any battery events. The proper response in the event of a CES malfunction or emergency event is to turn the unit OFF using the AC-side switch disconnect and then to leave the unit and contact the Gridpoint and/or PowerHub for servicing assistance.

Troubleshooting & Field Service

CE-3030

Note Before Servicing

- **NOTE:** There are very few end-user serviceable parts within the CE-3030 and very limited on-site troubleshooting steps to perform in order to determine the cause of unit failures faults. Please use caution when performing all maintenance.

Servicing of CES

- Coordinate with GridPoint to review operating logs of the unit to determine current reported state and error code reporting
- Open door on side of unit and turn AC disconnect from ON to OFF. Lock the AC disconnect handle in the OFF position.
- If unsafe conditions are visible, service should be limited to the external AC Disconnect. Follow lockout tag out procedures and contact support numbers located in the back of this document

Disconnecting for Service

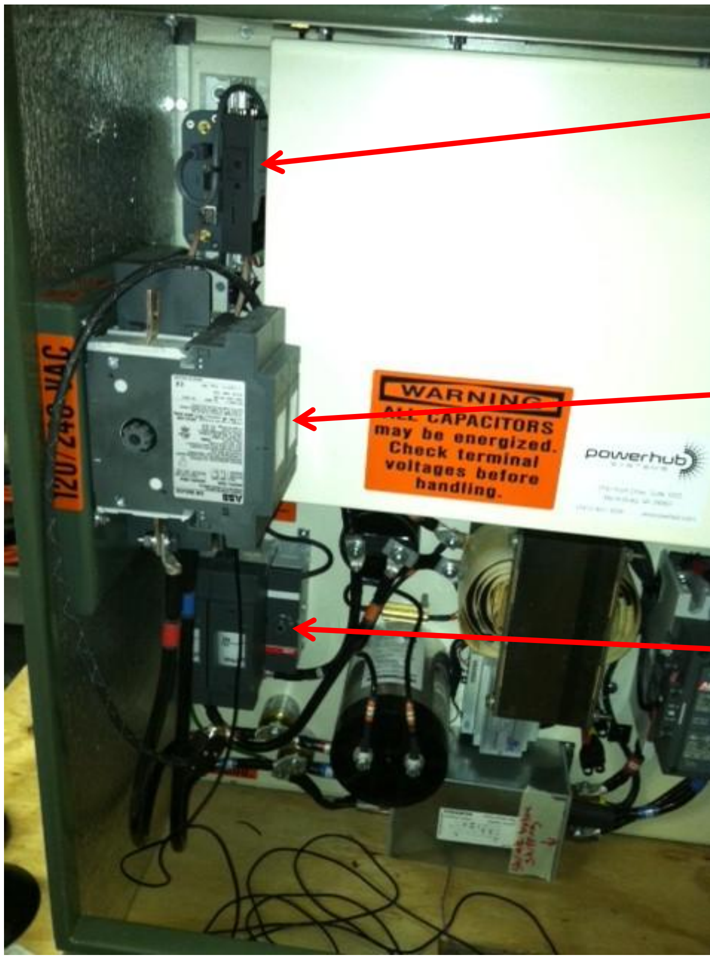
Exterior AC Disconnect

While facing the Power Section of the CES, the exterior disconnect is located on the left hand side. This lock out type handle is designed to follow lock out procedure.

Accessing the Power Section

- Wait 5 minutes before trying to open the front or PCS section of the CE-3030
- Unlock security lock and remove from hasp
- Use large flat screwdriver to turn the quarter-turns in order to open the PCS compartment. Note: it may be necessary to press the PCS door in while turning to be able to turn the quarter-turn closures
- When both quarter turns and the lock are removed it is possible to open the PCS compartment. The PCS door can be removed and set to the side of the unit. Note: take care to retain the washers that are on the PCS door hinge pins, as they are loose and will fall off.

Inside the Power Section



Communication Section

AC Disconnect
and Fuse Holder

DC Disconnect
and Fuse Holder

Warning

- EVEN WITH THE AC DISCONNECT TURNED OFF THERE IS STILL 240VAC PRESENT ON THE INPUT SIDE OF THE AC DISCONNECT DEVICE. ALSO, THERE IS THE POSSIBILITY FOR HIGH VOLTAGE DC PRESENT FROM THE BATTERY COMPARTMENT.

DC Disconnect

- Turn the fused disconnect device for the battery connection OFF. Check for DC voltage present on the top side (battery compartment side) of the DC disconnect using a DC voltmeter. THERE SHOULD NOT BE ANY DC VOLTAGE PRESENT ON THE WIRING COMING FROM THE BATTERY COMPARTMENT.
- IF DC VOLTAGE IS PRESENT ON THE BATTERY COMPARTMENT WIRES, MAKE NOTE OF THIS AND CONTACT THE MANUFACTURER.

Fused DC Disconnect
While checking for voltage, confirm meter equipment is set to DCV.

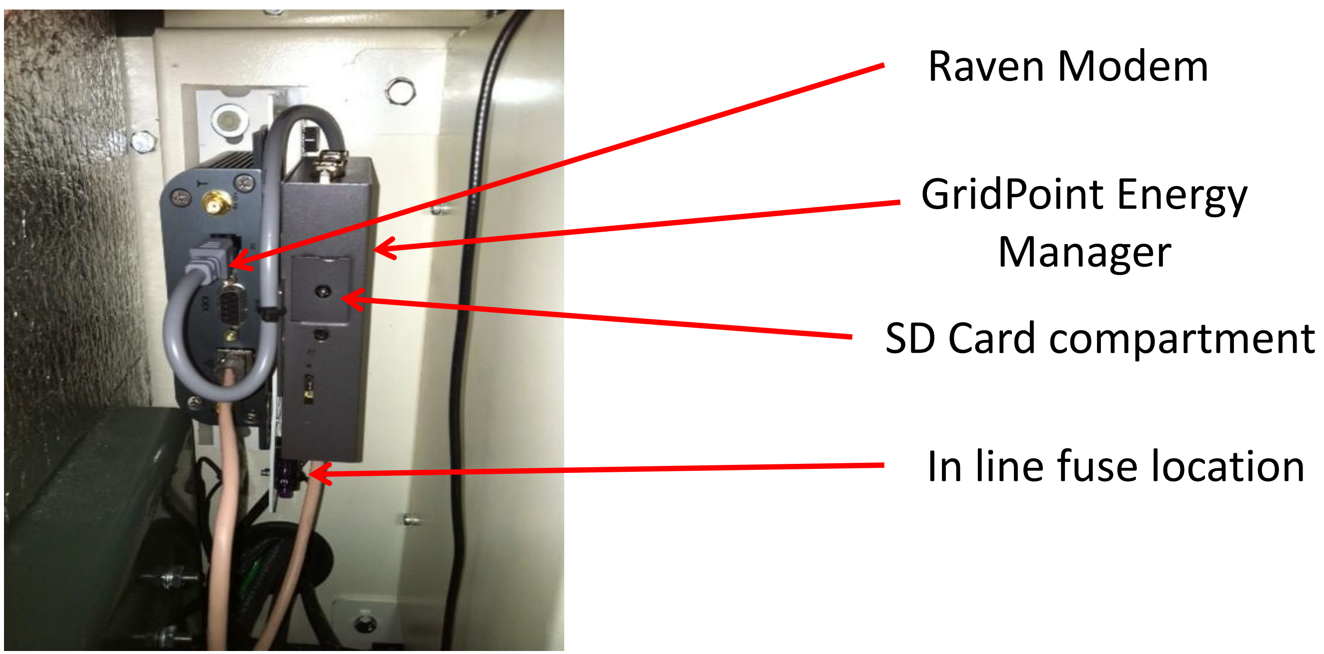
AC Disconnect

- Check fuses: With the AC disconnect and DC disconnect devices in their off position, check all fuses in the CE-3030:
- AC Disconnect: open the fuse doors on the AC disconnect device. Using a multimeter, check each of the fuses in the disconnect for continuity. **MAKE A NOTE OF ANY FUSES THAT MEASURE AS OPEN AND CONTACT POWERHUB/GRIDPOINT TO REPORT SUCH OPEN FUSES**.

AC Disconnect and Fuses
This is a touch safe disconnect. In the off position, fuses are disconnected on both sides.

Communications Section

- Using a fuse extractor or small set of pliers, remove the inline fuse in the modem/gateway assembly. Check for continuity. If this fuse is open, then communication between the network server and the CE-3030 would have been lost. **IF FUSE MEASURES AS OPEN, CONTACT MANUFACTURER TO REPORT AN OPEN COMMUNICATION ASSEMBLY FUSE.**
- It may be necessary to replace the SD card should it become corrupt (see below)



Restart Procedure & Options

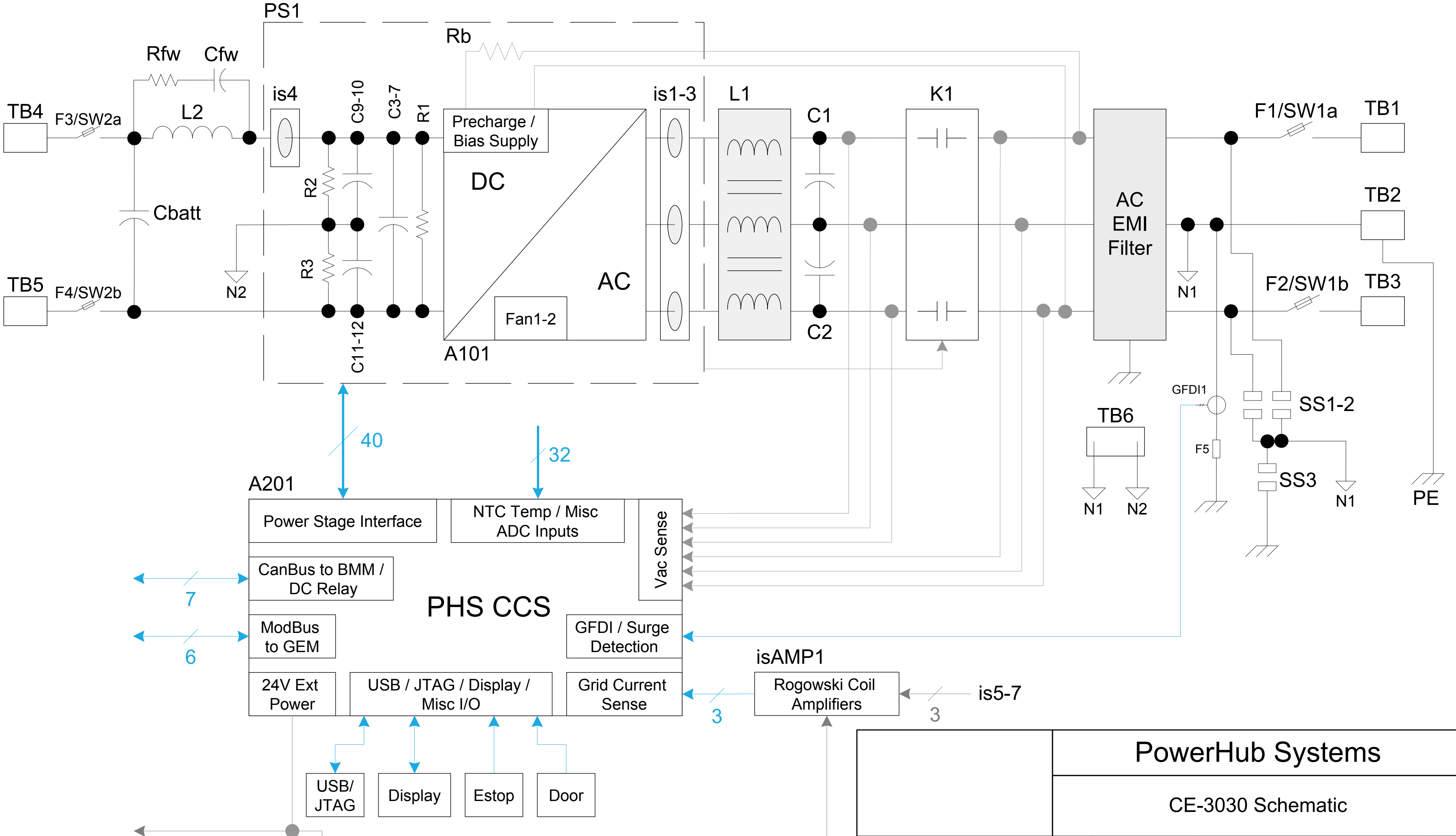
- If any fuses have been determined to be open, then they will need to be replaced with appropriately sized replacement fuses.
- Assuming all fuses were either intact or have been replaced, then reverse the PCS cabinet opening procedure
- Turn the fused disconnect device for the battery connection OFF
- Replace the PCS cabinet door making sure that the metal washers are still in place on the PCS hinge pins
- Use a large flat screwdriver to close the two quarter-turn closure devices. NOTE: PRESSURE MAY NEED TO BE APPLIED TO THE PCS CABINET DOOR NEAR THE QUARTER TURN AREA IN ORDER TO FULLY ENGAGE THE QUARTER TURN DEVICE.
- Place the PCS cabinet lock through the hasp to lock the PCS enclosure.
- Unlock the AC Disconnect handle
- Turn the AC disconnect handle from OFF to ON and close the AC disconnect handle cover.

Restoring Communications

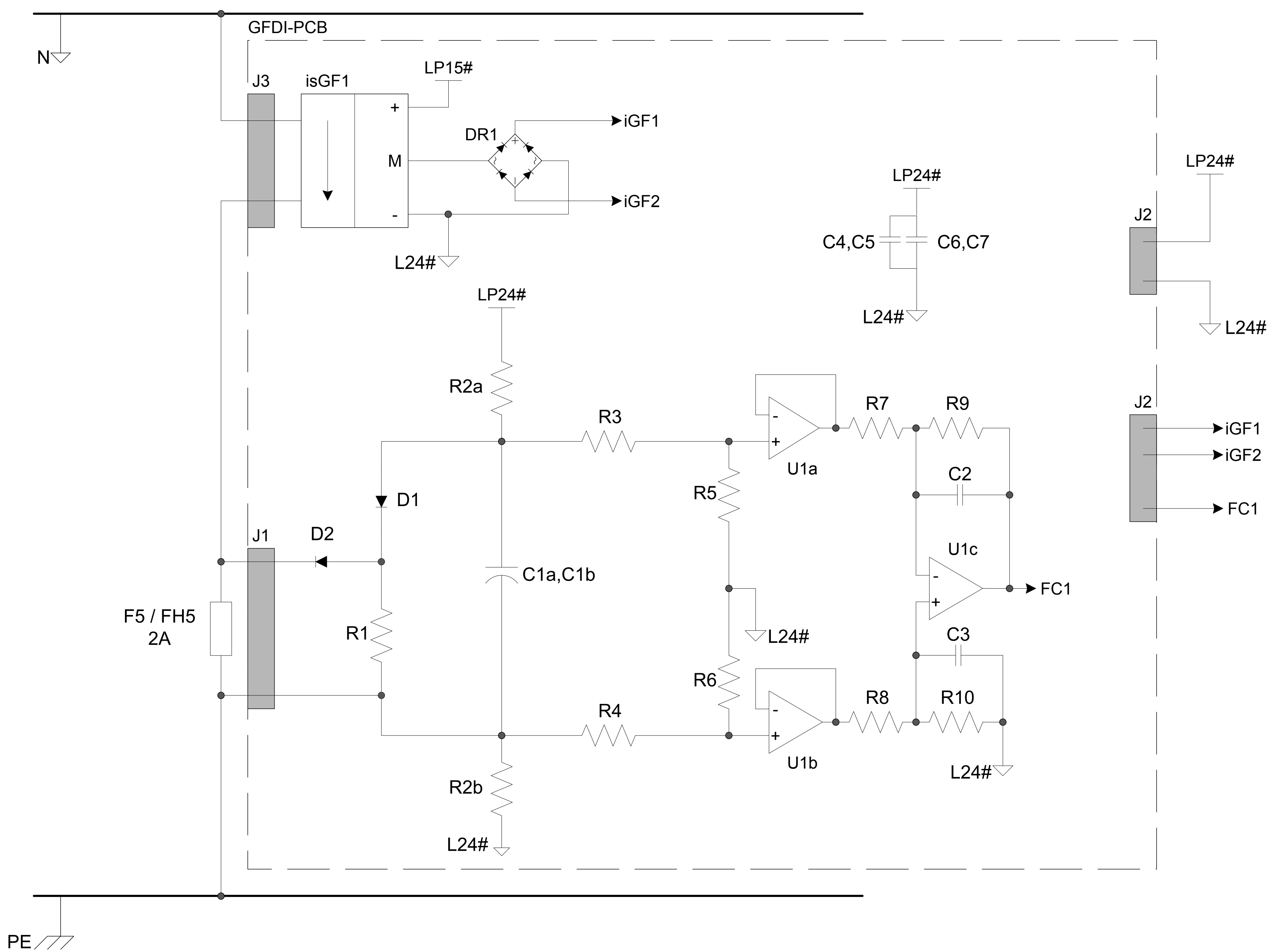
- Connect to the network server as appropriate and coordinate with GridPoint or the manufacturer (PowerHub) to determine whether the CE-3030 unit is operating properly.
- Please refer to the following contact numbers for confirmation and any further assistance that may be required

CE30-30 Support Contact Numbers		
GridPoint	866-800-8906	Emergency-202-420-0015
PowerHub	540-443-9214	

Confidential
Information contained within this document is proprietary to PowerHub Systems. This document is intended for internal use only. Unauthorized duplication is strictly prohibited.



	PowerHub Systems			
	CE-3030 Schematic			
	SIZE	FSCM NO	DWG NO	REV
	SCALE 1 cm : 1 cm		SHEET 1 of 1	



N
GFDI-PCB
J3
isGF1
LP15#
+
M
-
DR1
iGF1
iGF2
L24#
LP24#
C4,C5
C6,C7
L24#
LP24#
J2
L24#
LP24#
R2a
R3
R7
R9
U1a
R5
C2
J2
iGF1
iGF2
FC1
D1
J1
D2
C1a,C1b
U1c
FC1
F5 / FH5
2A
R1
L24#
C3
R6
R8
R10
R4
U1b
L24#
R2b
L24#
PE

Test and Monitoring Plan

PV-STORAGE BENEFITS FRAMEWORK

PV and Smart Grid Pilot at Anatolia

Prepared for:
Sacramento Municipal Utility District
Contract 4500066580
DOE Assistance Agreement DE-EE0002066

November 30, 2010

Navigant Consulting, Inc.
77 South Bedford Street
Suite 400
Burlington, MA 01803

781.270.8303
www.navigantconsulting.com

© 2010 Navigant Consulting, Inc.

Table of Contents

1 Background

The Sacramento Municipal Utility District (SMUD) received a grant from the U.S. Department of Energy (DOE) to conduct a demonstration that adds distributed energy storage to a residential community. The community currently experiences PV penetration of about 20% of peak feeder load. This project will demonstrate battery energy storage in combination with residential PV in a Solar Smart Homes community in Rancho Cordova, California. The energy storage systems are being installed in two configurations: behind the customer meter – Residential Energy Storage (RES) and on the primary distribution system Community Energy Storage (CES) – as shown in Figure 1 below. In addition to the test groups, there will also be a control group.

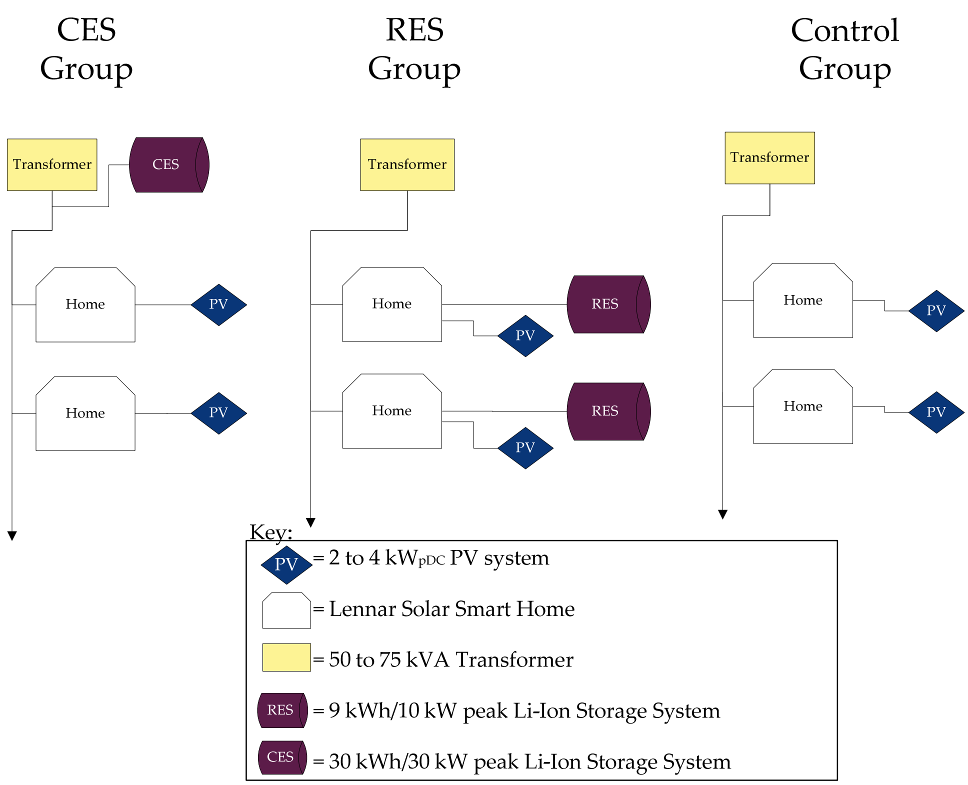


Figure 1. Project testing configurations.

In addition to the testing shown above, the project team will be conducting bench-top test using Advanced Metering Infrastructure to remotely control a PV-Storage system. This test will be conducted at a SMUD facility using qualified equipment.

This project is one of DOE's High Penetration Solar Deployment Projects within the Systems Integration program of the Solar Energy Technologies Program. The High Penetration Solar Deployments have has three main focus areas:

- » Develop modeling tools and database of experience with high penetration scenarios of PV on a distribution system;
- » Develop monitoring, control, and integration systems to enable cost-effective widespread deployment of small modular PV systems;

» Demonstrate integration of photovoltaics and energy storage into Smart Grid applications.

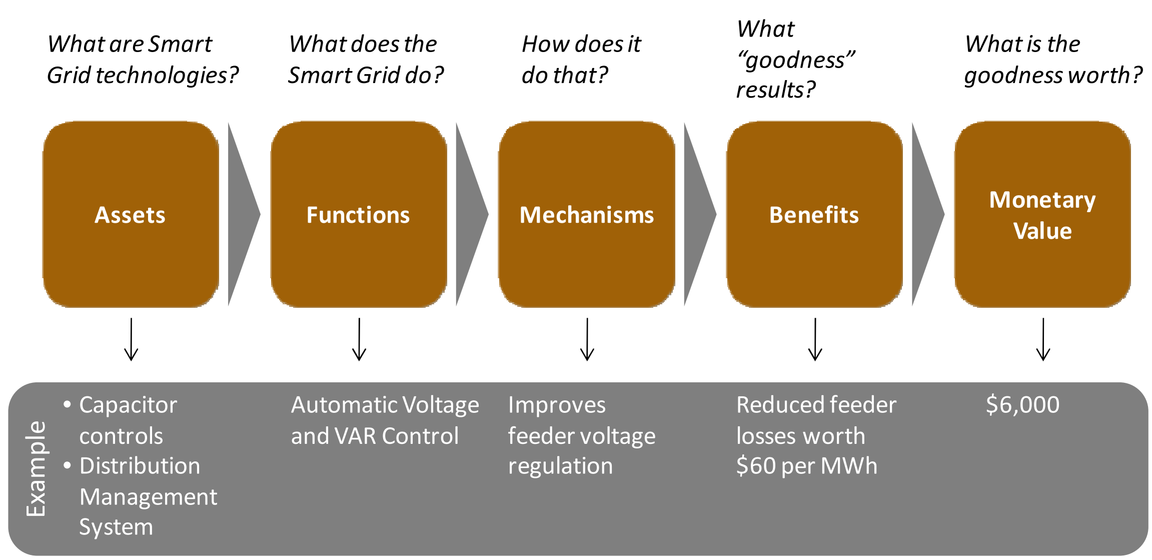
This project and one other – a project led by Commonwealth Edison – relate to the third goal. The results of this project will be shape how utilities use storage to complement and/or manage high levels of PV penetration.

In order to understand the benefits of such a configuration and its strategic implications for SMUD and other utilities, this project includes the creation of a framework for assessing the benefits. This paper describes Navigant's process for creating the framework and its proposed definitions. The framework will be revised as this demonstration project evolves.

2 Methodology

2.1 Smart Grid Benefits

The goal of this demonstration is to better understand how the combination of residential PV and battery energy storage can provide value to a homeowner and a utility, beyond what has been established for PV systems alone. The hypothesis of this demonstration is that there are benefits that can be achieved with an integrated system that cannot be achieved with PV alone. To observe the extent to which these benefits occur requires a valid experiment, the ability to observe the performance of the system within a utility distribution system, and the ability to measure and track performance. The analytical framework applied to this demonstration includes explicit relationships between the technologies involved, what the technologies do, and how that creates a benefit and subsequent value for stakeholders. This concept is described in Figure 2 below with more detailed definitions provided in Table 1.



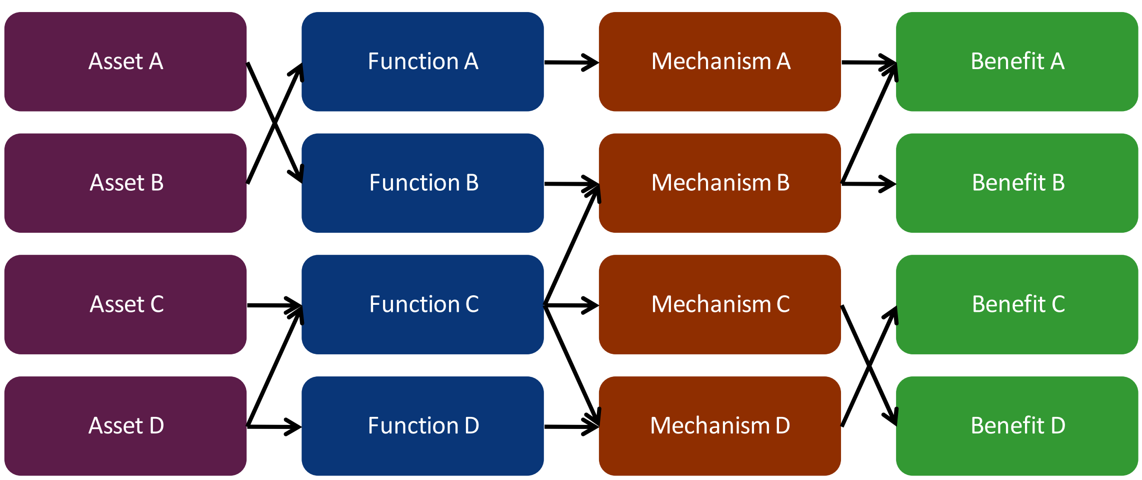
Source: Navigant

Figure 2. Navigant Smart Grid Benefits Framework

Table 1. Definitions of Smart Grid Benefits Framework Elements

Element	Definition
Assets	Hardware and software being deployed or utilized. There are two different Assets defined in the framework.
Functions	Specific actions or operations that can be executed with the Assets. The standard framework includes 13 Smart Grid Functions and three Enabled Energy Resources.
Mechanisms	The means by which Benefits are produced by Functions. There are 28 Mechanisms.
Benefits	The measureable impact or result created by Mechanisms. There are 23 different benefits are specified.
Monetary Value	Benefits quantified in dollars.

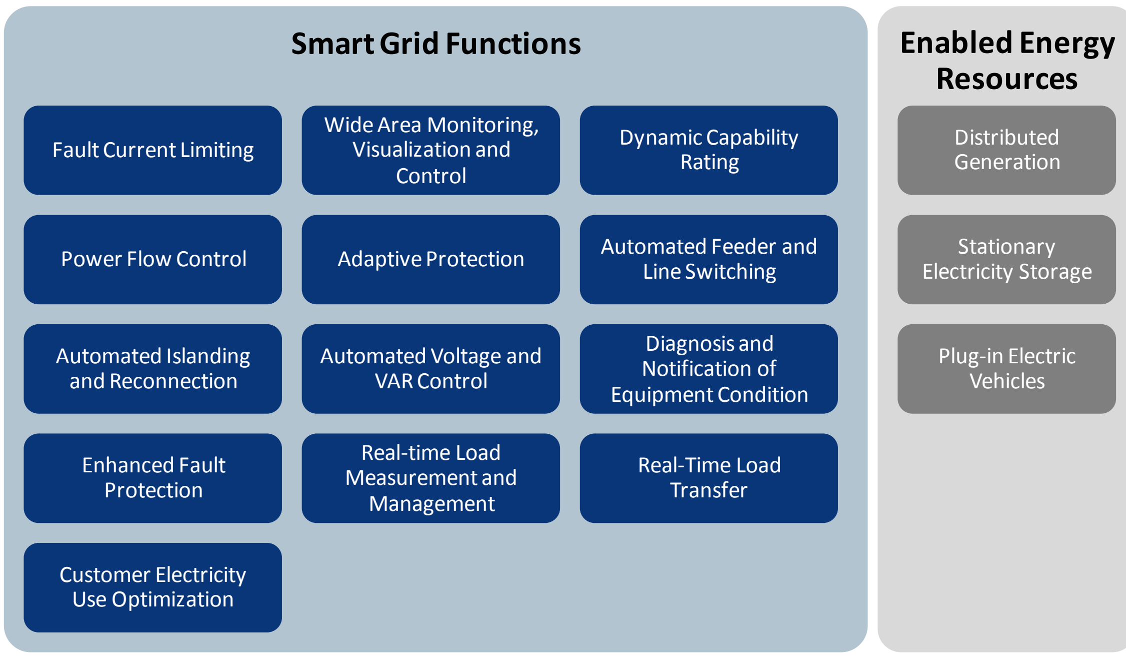
As shown in Figure 3, Assets can be utilized to perform more than one Function, and Functions can deliver one or more benefits depending on the Mechanisms. Benefits can be derived directly from individual Function/Mechanism combinations, or can be accumulated from the combination of multiple Functions and Mechanisms. It is this complexity of interactions that makes assessing the benefits of Smart Grid technologies particularly challenging, and it is what gives the framework its power.



Source: Navigant

Figure 3. Mapping Assets to Benefits

Navigant has developed and refined a Smart Grid Benefits framework over several years, and is currently utilizing it for analyzing Smart Grid metrics and benefits for the Department of Energy's Smart Grid Investment Grants and Smart Grid Demonstration programs. Over time, the framework has evolved to include a discrete set of Assets, Functions and Benefits that can be applied to virtually any typical Smart Grid implementation. Use of the framework tends to focus on Benefits rather than Value (dollars). This is because business and regulatory models must exist or be assumed to express Benefits in monetary terms. While Value may be a key output to be measured in a formal business case analysis, Benefits are more appropriate when evaluating the potential of a new or untested application.



Source: Navigant

Figure 4. Functions of the Standard Smart Grid Benefits Framework

As Smart Grid Functions are implemented to varying degrees, the increased level of system performance will yield benefits in four fundamental categories:

1. Economic – reduced costs, or increased production at the same cost, resulting from improved utility system efficiency and asset utilization;
2. Reliability – reduction in interruptions and service quality events;
3. Environmental – reduced impacts of climate change and effects on human health and ecosystems; and
4. Energy Security – improved energy security (i.e., dependence on foreign sources).

Within each of the four categories are several specific benefits, and each benefit can be derived from multiple sources. Benefits accrue to three primary stakeholder groups: utilities and their consumers; energy consumers (which may be the same as utility consumers); and society.

Source: Navigant

Figure 5 Standard Smart Grid Benefit Categories

2.2 *Summary of a PV-Storage Benefits Framework*

The Anatolia project is a specific demonstration of Enabled Energy Resources (Figure 4). In this case, distributed generation (residential PV) with stationary electricity storage (lithium ion batteries integrated in a storage appliance) is being demonstrated in RES and CES configurations. The existing Smart Grid Benefits framework lacks sufficient detail in these areas to deeply explore the capability and performance of the demonstration systems and express the results in a meaningful way. Therefore, the standard Smart Grid Benefits framework has been expanded to incorporate new detailed relationships for the integrated PV-energy storage system in a residential application. This involves the following enhancements:

» Specifying the Assets of the RES, CES and Control Group;
» Developing the Functions that these Assets enable;
» Determining the Mechanisms through which these Functions will create Benefits;
» Defining the Benefits; and
» Creating the approaches to monetize the Benefits.

2.2.1 Assets

Assets are pieces of equipment or systems of equipment that provide smart grid or energy related functionality. This project is comprised of several pieces of equipment, but their functionality is derived from their combination comprising two systems:

» PV System (distributed generation) – PV modules, mounting hardware, inverter and control software, monitoring equipment and equipment for communications to the system owner and/or the utility;

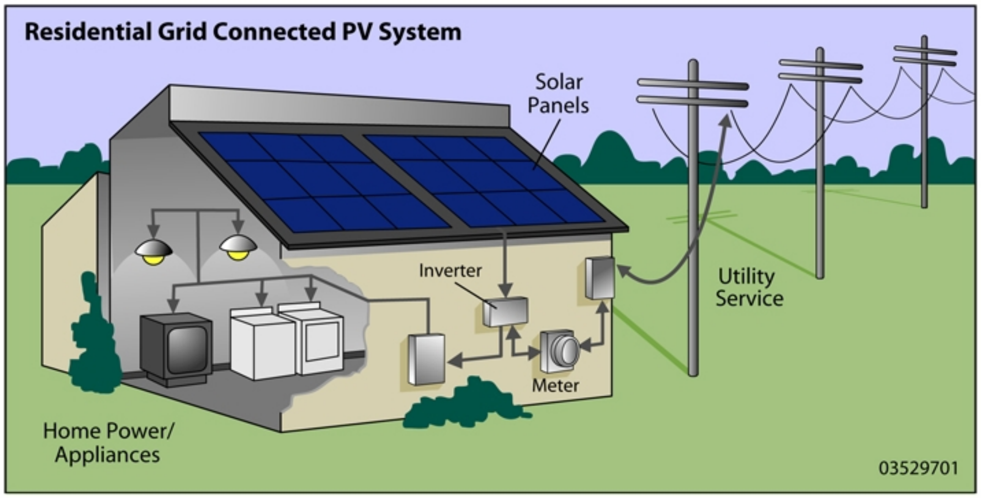


Figure 6. Schematic of Residential Grid Connected PV System (Image Source: DOE)

» Storage Appliance (stationary electricity storage) – batteries, charge controller, inverter[1], monitoring equipment and equipment for communication to the system owner and/or the utility.

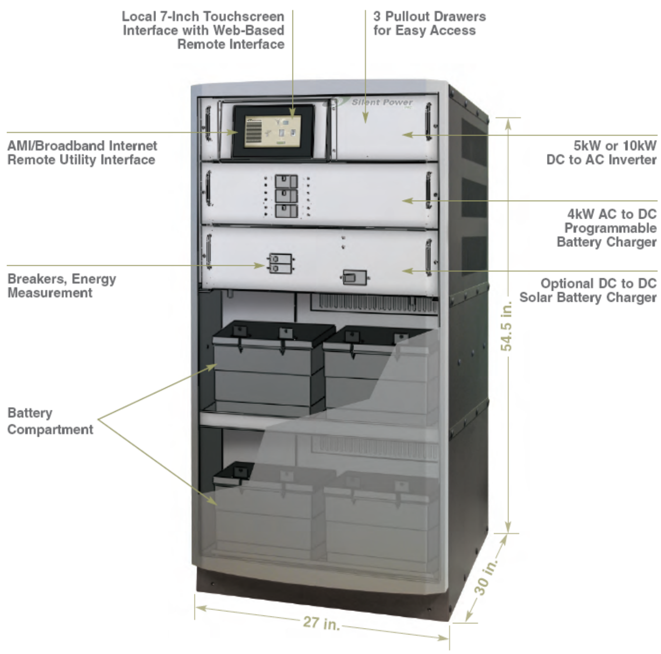


Figure 7 Schematic of a Storage Appliance (Image Source: GridPoint)

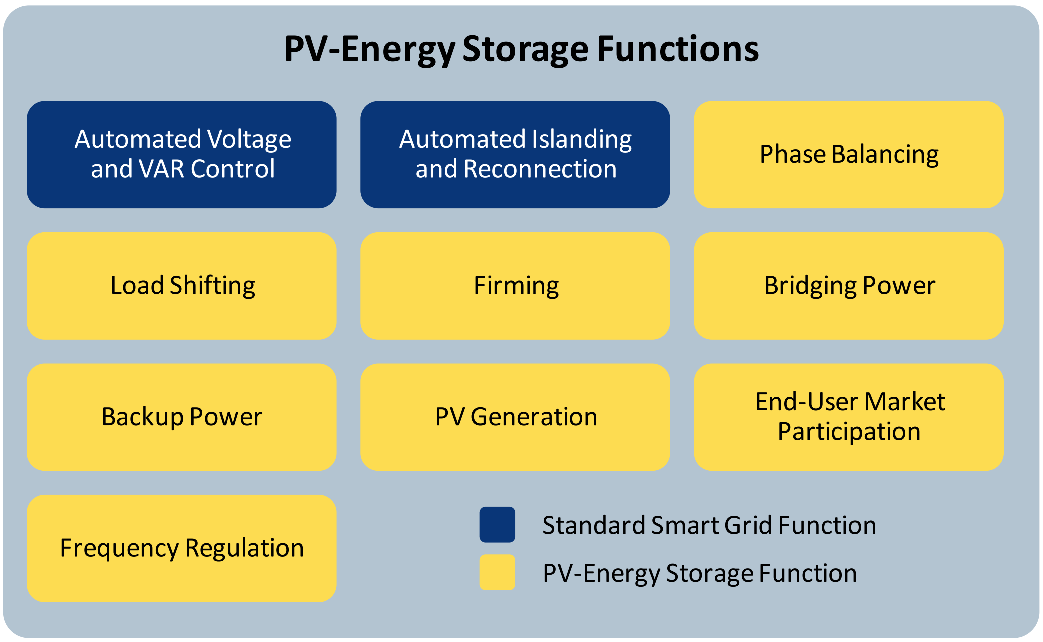
For general applications of this framework (e.g. not just to this project), Navigant assumes these systems will include the equipment above. It is important to note that certain components, like an inverter, could be used as a standalone Smart Grid asset. However, the same is not true for other sub-components such as PV modules. PV modules are only a useful asset when they are connected to an

[1] The inverters for the PV system and the Storage Appliance could be combined in a commercialized system, reducing cost and, potentially, simplifying the control system.

inverter. Due to these component relationships, the assets have been defined at the level of detail where all the sub-components functionality can be realized i.e. a PV System and a Storage Appliance.

2.2.2 Functions

As mentioned above, the Anatolia demonstration implements functionality that has been envisioned, but not explicitly expressed in a standard set of Smart Grid functions. Therefore, several specific new functions have been developed to describe the potential capability of systems like those demonstrated (Figure 8). These functions are described in more detail in Section 3 below.



Source: Navigant

Figure 8. PV-Energy Storage Functions for the Anatolia Demonstration

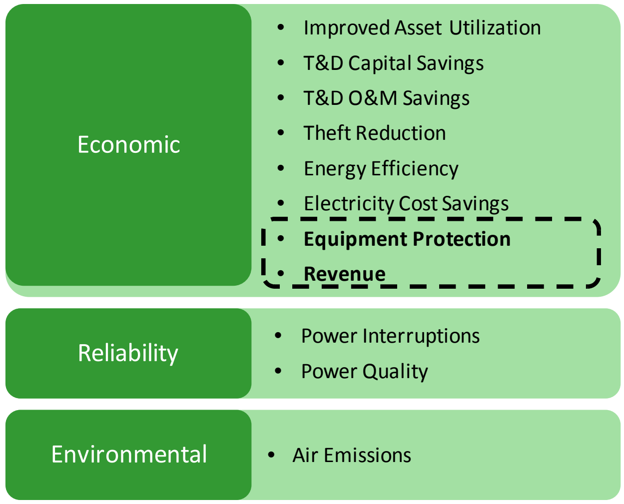
2.2.3 Mechanisms

Mechanisms describe "how" each function provides or enables certain benefits. Since many new functions have been defined beyond the scope of the previous Smart Grid framework, many new mechanisms have also been developed. These mechanisms are described in Section 4 below.

2.2.4 Benefits

The RES and CES being demonstrated have the potential to contribute benefits across several categories (Figure 9). Most of these categories are common to the standard Smart Grid framework, but Equipment Protection and Revenue could be accessible through the PV-Storage functions.[2] Definitions and details of these benefits are provided Section 5.

[2] These benefits could also be accessed from other distributed generation and electricity storage assets.



Source: Navigant

Figure 9. PV-Storage Benefit Categories

These benefits are calculated based upon data recorded during a project's lifetime. For this project, the following metrics will be recorded[3]:

- Home, transformer, and substation load
- PV output
- Storage charge and discharge rates, modes and charge levels
- Status of local voltage control equipment (e.g. load tap changers)
- Weather

In addition, the following information or estimates will be needed from SMUD. The information needed will depend on what Operating Scenarios[4] are run for this project:

- Generation mix and associated emissions data
- Neighborhood reliability data and associated restoration costs
- Line loss estimates throughout the distribution system
- Generation and ancillary service costs
- Distribution level maintenance costs and events (e.g. manual adjustments of phases)

As a baseline, 25 homes in the community are being monitored. In addition, several studies have been conducted in the neighborhood and have collected data to use as a baseline.

[3] These metrics may be modified after the "Testing and Monitoring Plan" has been finalized
[4] These are described in detail in the "Testing and Monitoring Plan" and may also change.

3 Functions

The PV-Storage Benefits framework includes functions that could be supported by an integrated system including PV and electricity storage assets. This assumes that the asset owner/host and the utility choose to interconnect and operate the assets in a manner consistent with the technical capability, and that relevant regulatory rules exist to allow and facilitate that operation. These functions and their definitions are provided in Table 2.

Table 2. Definitions of Functions

Function	Definition
Automated Voltage and VAR Control	The PV System or Storage Appliance's inverters can function as reactive power resources. The inverter could supply or absorb reactive power controled by remote commands via the utility through the asset's communication system or the inverter could be programmed to sense when reactive power is required and automatically act.
Phase Balancing	The Storage Appliance can change load on a phase within a micro-grid or on a feeder based upon utility commands. This could alleviate phase imbalances on a feeder or transformer.
Automated Islanding and Reconnection	Automated islanding and reconnection is achieved by automated separation and subsequent reconnection (autonomous synchronization) of an independently operated portion of the T&D system (i.e., microgrid) from the interconnected electric grid. PV-Storage acts as an energy resource to serve islanded loads in the microgrid.
Load Shifting	Using storage to shift load from peak demand periods to low demand periods. Usually on a time scale measured in hours.
Firming	Storage can be used to stabilize energy (for a customer or group of customers) from the point of view of a transformer/substation. The stabilization could be required because of variations in load or PV output. Time scale is on the order of seconds to minutes.
Bridging Power	Storage can also be used to stabilize energy (customer or group of customers) from the point of view of the customer in the event of short term fluctuations in grid supplied power. Time scale is on the order of seconds to minutes.
Backup Power	Storage provides the ability to provide power utility power outages.
PV Generation	The PV system generates energy for use in the home (e.g. reduces utility load), export to the grid, or storage in the battery.
End-User Market Participation	PV-Storage allows a customer to participate in certain energy markets because the asset can be dispatched as an energy resource.

Frequency Regulation	Storage can support grid frequency by injecting or absorbing power as needed. DG storage, dispatched in unison can serve as a viable frequency regulation resource.

After identifying all the possible functions, the functions were then mapped to the PV-Storage assets, as shown in Table 3. In reviewing the mapping, most of the functionality is enabled by the storage portion of PV-Storage.

Table 3. Mapping of Functions to PV System Components or System

Functions	Contributing Component
Automated Voltage and VAR Control	**PV Inverter**
Phase Balancing	
Automated Islanding and Reconnection	**PV Inverter**
Load Shifting	
Firming	
Bridging Power	
Backup Power	
PV Generation	**PV System**
End-User Market Participation	**PV System**
Frequency Regulation	

Table 4. Mapping of Functions to Energy Storage Components or Appliance

Functions	Contributing Component
Automated Voltage and VAR Control	**Storage Inverter**
Phase Balancing	**Storage Appliance**
Automated Islanding and Reconnection	**Storage Inverter**
Load Shifting	**Storage Appliance**
Firming	**Storage Appliance**
Bridging Power	**Storage Appliance**
Backup Power	**Storage Appliance**
PV Generation	
End-User Market Participation	**Storage Appliance**
Frequency Regulation	**Storage Appliance**

Table 5. Summary: Mapping of Functions to Assets

Functions	Assets

	PV System	Storage Appliance
Automated Voltage and VAR Control	✓	✓
Phase Balancing		✓
Automated Islanding and Reconnection	✓	✓
Load Shifting		✓
Firming		✓
Bridging Power		✓
Backup Power		✓
PV Generation	✓	
End-User Market Participation	✓	✓
Frequency Regulation		✓

These functions are mapped against what is actually possible with the equipment, configurations, and power markets in this demonstration project. As shown in Table 4, Automated Islanding and Reconnection, Bridging Power, and Backup Power are not being tested because the specification governing the interconnection of distributed energy resources, IEEE 1547, does not currently allow islanding. Phase balancing may be tested, but it depends on what houses are selected and what phases they are all on. The demonstration is not configured to test End-User Market Participation, but Navigant will be able to simulate this after data has been taken to see what revenues a customer could have received. Finally, Automated Voltage and VAR Control can be considered in the bench-top testing.

Table 6. Functions tested in this demonstration.

Functions	Tested in This Demonstration?
Automated Voltage and VAR Control	Yes in bench-top testing
Phase Balancing	Maybe, depends on external variables outside the control of this demonstration
Automated Islanding and Reconnection	No
Load Shifting	Yes
Firming	Yes
Bridging Power	No
Backup Power	No
PV Generation	Yes
End-User Market Participation	No, but can be simulated afterwards
Frequency Regulation	Yes

4 Mechanisms

Each function can result in at least one but possibly many benefits through one or more mechanisms (as previously shown in Figure 3). The mechanisms are useful for conceptualizing how each benefit is realized or calculated. Table 7 presents the mapping of mechanisms to functions.

Table 7. Mapping of PV-Storage Mechanisms to Functions

Mechanisms	Functions									
	Automated Voltage and VAR Control	Phase Balancing	Automated Islanding and Reconnection (Micro-Grid Capability)	Load Shifting	Firming	Bridging Power	Backup Power	PV Generation	End-User Market Participation	Frequency Regulation
Improves power factor	✓									
Improves customer load power factor	✓									
Reduces frequency of regulator operations	✓									
Reduces manual capacitor switching	✓									
Offsets central generation	✓	✓		✓	✓			✓		✓
Reduced manual switching		✓								
Avoids 3-phase power imbalance		✓								
Avoids overloading of distribution equipment		✓								
Increased Feeder capacity factor		✓								
Enables islanding or alternative power supply			✓				✓			
Enables optimized restoration			✓							
Shifts demand to off-peak				✓						
Avoids congestion				✓						
Reduces peak load on transmission assets				✓				✓		
Reduces peak load on distribution assets				✓				✓		

Reduces cost of electricity purchases				✓				✓		
Firms energy					✓					
Avoids need to procure Ancillary Services					✓					
Provides alternative short-term power supply						✓				
Reduced equipment cycling						✓				
Decreases loading on system elements								✓		
Reduces T&D electricity throughput								✓		
Customer sells capacity										
Customer sells ancillary services										
Customer sells energy										
Storage rapidly absorbs and discharges power										✓
Avoids overloading of distribution equipment		✓								
Increased Feeder capacity factor		✓								

5 Benefits

5.1 *Definition of Benefits*

The benefits are categorized as Economic, Reliability, or Environmental, as shown in Table 8. These benefits were attributed to each of the functions identified above. Table 9 presents a high level description of each benefit.

Table 8. List of PV-Storage Benefits

Benefit Category	Benefit Sub-category	Benefit
Economic	Improved Asset Utilization	Optimized Generator Operation Deferred Generation Capacity Investments Reduced Regulation Service Cost Reduced Voltage Support Cost Reduced Non-Spinning Reserve Cost Reduced Spinning Reserve Cost Reduced Congestion Cost
	T&D Capital Savings	Deferred Transmission Capacity Investments Deferred Distribution Capacity Investments Reduced Equipment Failures
	T&D O&M Savings	Reduced T&D Operations Cost
	Energy Efficiency	Reduced Electricity Losses
	Electricity Cost Savings	Reduced Electricity Cost
	Equipment Protection	Reduced Customer Equipment Damage
	Revenue	Customer Revenue Utility Revenue
Reliability	Power Interruptions	Reduced Sustained Outages Reduced Major Outages Reduced Restoration Cost
	Power Quality	Reduced Momentary Outages Reduced Sags and Swells
Environmental	Air Emissions	Reduced CO_2 Emissions Reduced SO_X, NO_X, and PM-10 Emissions

Table 9. Description of PV-Storage Benefits

Benefit	Description
Optimized Generator Operation	Better control of load and grid performance would enable grid operators to dispatch a more efficient mix of generation that could be optimized to reduce cost and reduce emissions
Reduced Generation Capacity Investments	Utilities and grid operators ensure that generation capacity can serve the maximum amount of load that planning and operations forecasts indicate. However, this capacity is only required for very short periods each year, when demand peaks. Reducing peak demand and flattening the load curve should reduce the generation capacity required to service load, and lead to cheaper electricity for customers.
Reduced Regulation Service Cost	Due to the near net zero-energy use of storage and its ability to be rapidly respond to both up-regulation and down-regulation, storage is considered a highly capable regulation service asset. Therefore, when storage is dispatched as regulation asset it reduces service cost by more effectively providing the service and by offsetting the use of traditional assets for regulation.
Reduced Voltage Support Cost	Storage used for voltage support offsets the operation of or investment in traditional alternatives such as Load Tap Changers (LTC), reducing the overall cost of voltage support.
Reduced Non-Spinning Reserve Cost	When storage is used in place of traditional spinning reserves for regulation, it shifts the loading order of traditional spinning reserves to become non-spinning reserves. That in turn shifts the highest cost, least utilized reserves out of the loading order. The remaining asset mix results in a reduction in total non-spinning reserve cost. In addition, storage can reduce the peak load and therefore reduce the overall Non-Spinning Reserve obligation for a service territory.
Reduced Spinning Reserve Cost	Storage is an alternative to traditional spinning reserve assets. Storage can offset the use of more expensive assets lowering the average cost of spinning reserve procurement. As with Non-Spinning reserve, storage reduces the overall procurement obligation by reducing peak load.
Reduced Congestion Cost	Transmission congestion is a phenomenon that occurs in electric power markets. It happens when scheduled market transactions (generation and load) result in power flow over a transmission element that exceeds the available capacity for that element. Since grid operators must ensure that physical overloads do not occur, they will dispatch generation so as to prevent them. The functions that provide this benefit either provide lower cost energy, allow the grid operator to manage the flow of electricity around constrained interfaces or reduce overall load to avoid the transmission constraint completely or partially.
Deferred Transmission Capacity Investments	Reducing the load and stress on transmission elements increases asset utilization and reduces the potential need for upgrades. Reduced loading during peak times could enable utilities to defer upgrades on lines and transformers.

Deferred Distribution Capacity Investments	As with transmission lines, reduced loading on distribution feeders during peak times could potentially extending the time before upgrades or capacity additions are required.
Reduced Equipment Failures	Reducing mechanical stresses on equipment increases service life and reduces the probability of premature failure.
Utility Revenue	Rather than using PV-Storage to offset its own costs or usage, a utility could sell the power or ancillary services into an energy market. This benefit captures the resulting revenue.
Customer Revenue	Rather than using PV-Storage to offset utility costs, a customer (or group of customers) could sell the power or ancillary services into an energy market. This benefit captures the resulting revenue.
Reduced Transmission and Distribution Operations Cost	Reduced operation of capacitor banks and feeder switches eliminates the need to send a line worker or crew to the switch location in order to operate it. This reduces the cost associated with the field service worker(s) and service vehicle.
Reduced Electricity Losses	Some of the functions listed help manage peak feeder loads, locate electricity production closer to the load and ensure that customer voltages remain within service tolerances, while minimizing the amount of reactive power provided. These improve the power factor, and reduce line losses for a given load served.
Reduced Electricity Cost	The functions listed could help reduce the cost of electricity during peak times through either production or storage by reducing reliance on high peaking generation resources.
Reduced Sustained Outages	Reduces the likelihood that there will be an outage from the point of view of the customer. The benefit to consumers is based on the value of service.
Reduced Major Outages	The functions listed can isolate portions of the system so that customers will be served by the PV-Storage until the utility can restore service to the area.
Reduced Restoration Cost	The functions that provide these benefits cause fewer outages, which result in fewer restoration costs. These costs can include line crew labor/material/equipment, support services such as logistics, call centers, media relations, and other professional staff time and material associated with service restoration.
Reduced Momentary Outages	With storage, momentary outages could be reduced or eliminated. Moreover, fewer customers on the same or adjacent distribution feeders would experience the momentary interruptions associated with reclosing. Momentary outages last <5 min in duration. The benefit to consumers is based on the value of service.
Reduced Sags and Swells	Adding electricity storage could reduce the frequency and severity of the voltage fluctuations caused by faults. Moreover, fewer customers on the same or adjacent distribution feeders would experience the voltage fluctuation.

Reduced CO_2 Emissions	Functions that provide this benefit can improve performance in many aspects for end-users. These improvements translate into a reduction in CO2 emissions produced by fossil-based electricity generators.
Reduced SOx, NOx, and PM-10 Emissions	Functions that provide these benefits can improve performance in many aspects for end-users. These improvements translate into a reduction in SOx, NOx, and PM-10 emissions produced by fossil-based electricity generators.

5.2 *Mapping of Mechanisms to Benefits*

After defining the mechanisms, each mechanism is mapped to the one or more benefits as shown in Table 10.

Table 10. Mechanism to Benefit Mapping

Benefits	PV-Storage Mechanisms																												
	Improves power factor	Improves customer load power factor	Reduces frequency of regulator operations	Reduces manual capacitor switching	Offsets central generation	Reduced manual switching	Avoids 3-phase power imbalance	Avoids overloading of distribution equipment	Increased Feeder capacity factor	Enables islanding or alternative power supply	Enables optimized restoration	Shifts demand to off-peak	Avoids congestion	Reduces peak load on transmission assets	Reduces peak load on distribution assets	Reduces cost of electricity purchases	Firms energy	Avoids need to procure Ancillary Services	Provides alternative short-term power supply	Reduced equipment cycling	Decreases loading on system elements	Reduces T&D electricity throughput	Customer sells capacity	Customer sells ancillary services	Customer sells energy	Storage rapidly absorbs and discharges power	Avoids overloading of distribution equipment	Increased Feeder capacity factor	Enables islanding or alternative power supply
Optimized Generator Operation																	✓												
Deferred Generation Capacity Investments					✓							✓																	
Reduced Regulation Service Cost																		✓								✓			
Reduced Voltage Support Cost	✓																												
Reduced Non-Spinning Reserve Cost												✓																	
Reduced Spinning Reserve Cost					✓							✓						✓											
Reduced Congestion Cost													✓								✓								

DRAFT – 12-01-2010

Deferred Transmission Capacity Investments														✓															
Deferred Distribution Capacity Investments									✓						✓													✓	
Reduced Equipment Failures								✓																			✓		
Reduced T&D Operations Cost			✓	✓		✓																							
Reduced Electricity Losses	✓						✓					✓										✓							
Reduced Electricity Cost		✓														✓													
Reduced Sustained Outages										✓																			✓
Reduced Major Outages										✓																			✓
Reduced Restoration Cost											✓																		
Reduced Momentary Outages																			✓										
Reduced Sags and Swells (high/low phase voltage)							✓																						
Reduced/Avoided CO2 Emissions					✓																								
Reduced SOx, NOx, and PM-10 Emissions					✓																								
Reduced Customer Equipment Damage																				✓									
Customer Revenue																							✓	✓	✓				
Utility Revenue																										✓			

5.3 *Mapping of Functions to Benefits*

After defining the functions, mechanisms and benefits and their relationships within the framework, a mapping of the functions to the benefits can be completed (as shown in Table 11). This final mapping is more useful for describing how each function, via a given mechanism, provides a benefit. The following sections provide details on the function-benefit relationships and the underlying calculations.

Table 11. Function to Benefit Mapping

Benefits			PV-Storage Functions									
			Automated Voltage and VAR Control	Phase Balancing	Automated Islanding and Reconnection (Micro-Grid Capability)	Load Shifting	Firming	Bridging Power	Backup Power	PV Generation	End-User Market Participation	Frequency Regulation
Economic	Improved Asset Utilization	Optimized Generator Operation					✓					
		Deferred Generation Capacity Investments				✓				✓		
		Reduced Regulation Service Cost					✓					✓
		Reduced Voltage Support Cost	✓									
		Reduced Non-Spinning Reserve Cost				✓						
		Reduced Spinning Reserve Cost				✓	✓			✓		
		Reduced Congestion Cost				✓				✓		
	T&D Capital Savings	Deferred Transmission Capacity Investments				✓				✓		
		Deferred Distribution Capacity Investments		✓		✓				✓		
		Reduced Equipment Failures		✓								
	T&D O&M	Reduced T&D Operations Cost	✓	✓								
	Energy Efficiency	Reduced Electricity Losses	✓	✓		✓				✓		
	Electricty Cost Savings	Reduced Electricity Cost	✓			✓				✓		
	Equipment Protection	Reduced Customer Equipment Damage						✓				
	Revenue	Customer Revenue									✓	
		Utility Revenue										✓
Reliability	Power Interruptions	Reduced Sustained Outages			✓				✓			

		Reduced Major Outages			✓				✓			
		Reduced Restoration Cost			✓							
	Power Quality	Reduced Momentary Outages						✓				
		Reduced Sags and Swells (high/low phase voltage)		✓								
Environmental	Air Emissions	Reduced/Avoided CO2 Emissions	✓	✓		✓	✓			✓		✓
		Reduced SOx, NOx, and PM-10 Emissions	✓	✓		✓	✓			✓		✓

5.3.1 Automated Voltage and VAR Control

With PV-Storage, automated voltage and VAR control can be done with the system's inverters. It is important to note that a storage appliance or PV system is not required to provide this functionality. However, since excess inverter capacity (from either the PV or storage inverter or both) can be used for automated voltage and VAR control, this functionality is being considered in this study. These devices could operate autonomously in response to local events (with the sensors available in inverters) or in response to signals from a central control system (e.g. the utility). By better managing voltage and VAR resources, the transmission and distribution network can be optimized for electrical efficiency (lower losses), and can allow utilities to reduce load through "energy conservation voltage reduction" while maintaining adequate service voltage. These load reductions will reduce the amount of generation required. This function provides six benefits:

» Reduced Voltage Support Cost – The ancillary service of voltage support is necessary to ensure the reliable and efficient operation of the grid. The level of voltage support required at any point in time is determined by the grid operator and/or energy market rules. To the extent that PV-Storage inverters can be used to generate or absorb reactive power to reduce load and reactive power requirements from generation, ancillary service costs for voltage and VAR support could be reduced, decreasing the cost for market participants and utilities.

» Reduced T&D Operations Cost - Automated voltage and VAR control eliminates the need to send a line worker or crew to the location of reactive devices in order to operate them. This reduces the cost associated with the field service worker(s) and service vehicle. The impact of this benefit is determined by estimating the percentage of a field crew's time is dedicated to capacitor switching, and then estimating the time saved by the field service personnel.

» Reduced Electricity Losses - Coordinating the settings of voltage control devices on the transmission and distribution system ensures that customer voltages remain within service tolerances, while minimizing the amount of reactive power provided.

» Reduced Electricity Cost – Because of lower electricity losses, less generation must be purchased to meet load. This results in reduced electricity costs.

» Reduced CO_2 Emissions - Energy reductions achieved through improved efficiency and energy conservation voltage reduction will reduce the amount of generation required to serve load. Assuming that the generation is fossil-based, emissions will be reduced.

» Reduced SO_X, NO_X, and PM-10 Emissions - Energy reductions achieved through improved efficiency and energy conservation voltage reduction will reduce the amount of generation required to serve load. Assuming that the generation is fossil-based, emissions will be reduced.

5.3.2 Phase Balancing

PV-Storage can be used to balance phase loading within a distribution circuit acting as either a load sink or source. These systems could be deployed on an as needed basis or be incorporated to the distribution system planning. Maintaining proper phase balance with in a distribution circuit provides seven benefits:

- Deferred Distribution Capacity Investments - Good balance means that distribution assets can operate closer to optimal capacity and avoids the need to retroactively install new equipment when imbalance occurs.
- Reduced Equipment Failures – Proper balance ensures that equipment experience fewer off-design excursions, reducing wear and tear and the probability of catastrophic failure.
- Reduced T&D Operations Cost – Remotely dispatchable and autonomous assets reduce the need to send personnel into the field when issues arise (such as manually activating switch gear to balance phases).
- Reduced Electricity Losses – Phase balance reduces heating losses and power returning on opposing phases or the neutral conductor resulting in fewer distribution system losses.
- Reduced CO_2 Emissions – Reduction in electricity losses will reduce the amount of generation required to serve load. Assuming that the generation is fossil-based, emissions will be reduced.
- Reduced SO_X, NO_X, and PM-10 Emissions - Reduction in electricity losses reduce the amount of generation required to serve load. Assuming that the generation is fossil-based, emissions will be reduced.

5.3.3 Automated Islanding and Reconnection

A PV-Storage system can be part of a microgrid, which is an integrated energy system consisting of interconnected loads and distributed energy resources which, as an integrated system, can operate in parallel with the grid or as an island. This disconnection and reconnection of the microgrid and the interconnected electric grid would be done automatically as needed based on grid conditions via the PV system and/or storage appliance inverters. This function leads to three benefits:

- Reduced Sustained Outages - Automated islanding and reconnection means portions of the system that include distributed generation can be isolated from areas with excessive damage. Customers within the island, or microgrid, will be served by the PV-Storage until the utility can restore service to the area. Only the customers in the island experience reduced outage time from this improved reliability. While the outage may affect wide areas, and large numbers of customers, the island will most likely be no larger than a single distribution feeder (i.e., < 5,000 customers) or smaller.
- Reduced Major Outages - Automated islanding and reconnection means portions of the system that include PV-Storage can be isolated from areas with excessive damage. Customers within the island, or microgrid, will be served by the distributed generation until the utility can restore service to the area. Only the customers in the island experience reduced outage time from this improved reliability. While the outage may affect wide areas, and large numbers of customers, the island will most likely be no larger than a single distribution feeder (i.e., < 5,000 customers) or smaller.
- Reduce d Restoration Cost – The ability to automatically connect will potentially save the utility staff time and equipment costs associated with reconnection after an outage.

5.3.4 Load Shifting

PV-Storage can be used to shift demand from times of high load to periods of low load. This can be accomplished through charging the battery during off-peak times and discharging during peak. This could be done through utility or customer control, depending on how a PV-Storage system is configured. This function provides ten benefits:

» Deferred Generation Capacity Investments – Load shifting will reduce the amount of central station generation required during peak times. This may improve the overall load profile and allow a more efficient mix of generation resources to be dispatched. This could save utilities money on their generation costs.
» Reduced Spinning Reserve Costs and Reduced Non-Spinning Reserve Costs – The reserve margin is a required capacity above the peak demand that must be available and is typically +15% of peak demand. If peak demand is reduced, reserve margin would be reduced.
» Reduced Congestion Costs – Load shifting provides energy closer to the end use during peak times, so less electricity must be passed through the T&D lines, which reduces congestion.
» Deferred Transmission Capacity Investments – Utilities build transmission with capacity sufficient to serve the maximum amount of load that planning forecasts indicate. The trouble is, this capacity is only required for very short periods each year, when demand peaks. Providing generation capacity closer to the load during peak times reduces the power flow on transmission lines, potentially avoiding or deferring capacity upgrades.
» Deferred Distribution Capacity Investments – Load shifting could be used to relieve load on feeders that are overloaded during peak times, potentially extending the time before upgrades or additions are required.
» Reduced Electricity Losses – By managing peak feeder loads with load shifting, peak feeder losses, which are higher than at non-peak times, would be reduced.
» Reduced Electricity Costs – Load shifting can be used to reduce the cost of electricity when the price of "grid power" is very high. A consumer or the utility realizes savings on their electricity bill.
» Reduced/Avoided CO_2 Emissions – Load shifting reduces electricity peak demand. This translates into a reduction in CO_2 emissions produced by fossil-based electricity generators. However, since electricity storage has an inherent inefficiency associated with it, electricity storage could increase overall CO_2 emissions if fossil fuel generators are used for charging.
» Reduced SO_x, NO_x and PM-10 Emissions – Load shifting reduces electricity peak demand. This translates into a reduction in polluting emissions produced by fossil-based electricity generators. However, since electricity storage has an inherent inefficiency associated with it, electricity storage could increase overall emissions if fossil fuel generators are used for charging.

5.3.5 Firming

PV-Storage can be used to stabilize energy (for a customer or group of customers) from the point of view of a transformer/Substation. The stabilization could be required because of variations in load or PV output. Firming reduces utility’s uncertainty as to how much load will be required to serve a customer or group of customer and results in five benefits:

» Optimized Generator Operation – Firming reduces a load’s volatility from the point of view of the utility. As a result, the utility will likely not have to ramp a generator up and down to meet load. This will allow the generator to run at its optimal level.
» Reduced Regulation Service Cost – Utilities generally need to acquire ancillary regulation services to meet fluctuating demand. Firming would reduce the fluctuation and thus reduce the amount of regulation services required.

- Reduced/Avoided CO_2 Emissions – If generators run at more optimal levels, they will run more efficiently. If they are fossil based, this will result in lower CO_2 emissions.
- Reduced SO_x, NO_x and PM-10 Emissions - If generators run at more optimal levels, they will run more efficiently. If they are fossil based, this will result in lower SO_x, NO_x and PM-10 Emissions.

5.3.6 Bridging Power

During a momentary disruption, storage can provide short term customer load support. This leads to two benefits:

- Reduced Customer Equipment Damage –Sudden short-term loss of power can disrupt and/or damage manufacturing lines, appliances and other specialized equipment. Therefore, avoiding disruption to electrical service prevents damage to customer property.
- Reduced Momentary Outage – Fewer momentary outages leads to enhanced value of service.

5.3.7 Backup Power

During an outage or disruption, Storage can provide energy to supply customer load. Customer's daily operation will then be minimally impacted. This leads to two benefits:

- Reduced Sustained Outages – The storage can provide electricity until the utility can restore service to the area.
- Reduced Major Outages – During longer outages, customers can continue some level of operation, perhaps not full operation because of limitations on battery size, until service is restore.

5.3.8 PV Generation

In PV-Storage, the PV will likely be located on the distribution system, either on primary distribution feeders or behind the meter. Depending on the typical weather patterns in a given region, the generation from PV provides nine benefits:

- Deferred Generation Capacity Investments – Depending on the coincidence between load and PV generation in a given region, PV can offset peak loads at a statistically significant level such that less central station generation capacity is required to meet load at peak times. This may improve the overall load profile and allow a more efficient mix of generation resources to be dispatched. This could save utilities money on their generation costs.
- Reduced Regulation Service Cost – Depending on the coincidence between load and weather patterns in a given region, PV generation could offset fluctuating loads (e.g. air-conditioning loads spiking during sunny hours of the day). As a result, a utility might have to procure less ancillary regulation services and have lower costs.
- Reduced Spinning Reserve Cost - The reserve margin is a required capacity above the peak demand that must be available and is typically +15% of peak demand. If peak demand is reduced in a region with high coincidence between PV generation and peak demand, reserve margin is reduced.
- Reduced Congestion Cost – PV generation provides energy closer to the end use, so less electricity must be passed through the T&D lines, which reduces congestion.

- Deferred Transmission Capacity Investments - Utilities build transmission with capacity sufficient to serve the maximum amount of load that planning forecasts indicate. The trouble is, this capacity is only required for very short periods each year, when demand peaks. Providing generation capacity closer to the load reduces the power flow on transmission lines, potentially avoiding or deferring capacity upgrades. This may be particularly effective during peak load periods.
- Deferred Distribution Capacity Investments – PV generation could be used to relieve load on overloaded feeders, potentially extending the time before upgrades or additions are required.
- Reduced Electricity Losses – Because PV-Storage is distributed, it provides generation closer to the customer and reduces the length which electricity must travel. As a result, electricity losses will be lower.
- Reduced Electricity Costs – PV generation could be used to offset other electricity purchases when the price of "grid power" is high, depending on the coincidence between peak load and PV generation.
- Reduced CO_2 Emissions - PV provides electricity without net CO_2 emissions, reducing the emissions produced by fossil-based electricity generators. In addition, if electricity losses are lower, CO_2 emissions will be lower, depending on the local generation mix.
- Reduced SO_X, NO_X, and PM-10 Emissions - PV provides electricity without net SO_X, NO_X, and PM-10 emissions produced by fossil-based electricity generators providing energy and peak demand. In addition, if electricity losses are lower, SO_X, NO_X, and PM-10 emissions will be lower, depending on the local generation mix.

5.3.9 End-User Market Participation

PV-Storage allows a customer to participate in certain energy markets because of the storage can be dispatched as an energy resource, either as an energy sink or source. The customer would still use utility supplied services for their own needs and could sell firm energy to a utility or other power market participant. This results in one benefit:

- Customer Revenue – Selling services using PV-Storage would result in customer revenue.

5.3.10 Frequency Regulation

Regulation is a purchased ancillary service that is necessary to maintain the grid and service customers. Distributed storage assets, when operated in concert, could provide enough capacity to participate in the regulation markets.

- Reduced Regulation Cost – Depending on the local demand, the storage resource can be dispatched to offset regulation services purchases thereby reducing the overall cost of regulation.
- Utility Revenue – Depending on a Utility service territory and market conditions, the storage asset can be used entirely or partially for sales in the ancillary service market.
- Reduced CO_2 Emissions – Unlike traditional regulation assets, storage is a near net-zero energy resource. When storage displaces traditional assets emissions are reduced.
- Reduced SO_X, NO_X, and PM-10 Emissions – Unlike traditional regulation assets, storage is a near net-zero energy resource. When storage displaces traditional assets emissions are reduced.

6 Value

6.1 Summary

The final step in Navigant's cost benefit analysis is to monetize the value a benefit provides. In general, a value calculation is based upon measurable and quantifiable data points taken before and after a project is implemented.

Table 12. Summary of Benefit Value Calculations

Benefit	Input Parameters	Monetization Calculation
Optimized Generator Operation	• Hourly Generation Cost ($/MWh) • Annual Generator Dispatch (MWh) • Annual Energy Storage Efficiency (%)	**Value ($)** = {[Hourly Generation Cost ($/MWh) * Annual Generator Dispatch (MWh)]$_{Baseline}$ – [Hourly Generation Cost ($/MWh) * Annual Generator Dispatch (MWh)]$_{Project}$}* Energy Storage Efficiency (%)
Deferred Generation Capacity Investments	• Price of Capacity at Annual Peak ($/MW), • Amount of Generation Shifted (MW) • PV's AC Capacity (MW) • PV's ELCC (%)	**Value ($)** = [Price of a Peaking Generator ($/MW) * Amount of Generation Shifted (MW)]Project Or **Value ($)** = [Price of a Peaking Generator ($/MW) * PV's AC Capacity (MW) * Local PV ELCC]$_{Project}$
Reduced Regulation Service Cost	• Annual Regulation purchases (MWh) • Average price of regulation ($/MWh)	**Value ($)** = [[Annual Regulation Purchases]$_{Baseline}$ – [Annual Regulation Purchases]$_{Project}$] * Average Price of Regulation
Reduced Voltage Support Cost	• Capital Carrying Charge of Upgrade ($/yr) • Time deferred (yrs) • Annual Voltage Support purchases (MWh) • Average price of Voltage support ($/MWh)	**Value ($)** = Capital Carrying Charge of Upgrade ($/yr) * Time deferred (yrs) or **Value ($)** = [[Annual Voltage Support Purchases]$_{Baseline}$ – [Annual Voltage Support Purchases]$_{Project}$](MWh) * Average Price of Voltage Support ($/MWh)
Reduced Spinning Reserve Cost	• Annual Spinning reserve purchases (MWh) • Average price of spinning reserves ($/MWh)	**Value ($)** = [[Annual Spinning Reserve Purchases]$_{Baseline}$ – [Annual Spinning Reserve Purchases]$_{Project}$] * Average Price of Spinning Reserve Purchases
Reduced Non-	• Annual Non-Spinning	**Value ($)** = [[Annual Non-Spinning Reserve

Spinning Reserve Cost	reserve purchases (MWh) • Average price of non-spinning reserves ($/MWh)	Purchases]$_{Baseline}$ – [Annual Non-Spinning Reserve Purchases]$_{Project}$] * Average Price of Non-Spinning Reserve Purchases
Reduced Congestion Cost	• Annual Congestion [MWh] • Average Annual Congestion Cost [$/MWh]	**Value ($)** = [[Annual Congestion]$_{Baseline}$ – [Annual Congestion]$_{Project}$] * Average Annual Cost of Congestion
Reduced Congestion Cost	• Congestion (MW) • Price of Congestion ($/MW)	**Value ($)** = [Congestion (MW) * Price of Congestion ($/MW)]$_{Baseline}$ - [Congestion (MW) * Price of Congestion ($/MW)]$_{Project}$
Deferred Transmission Capacity Investments	• Capital Carrying Charge of Upgrade ($/yr) • Time Deferred (yrs)	**Value ($)** = Capital Carrying Charge of Upgrade ($/yr) * Time deferred (yrs) Note: this should only be calculated once since all years of deferral are included
Deferred Distribution Capacity Investments	• Capital Carrying Charge of Upgrade ($/yr) • Time deferred (yrs)	**Value ($) =** Capital Carrying Charge of Upgrade ($/yr) * Time deferred (yrs) Note: this should only be calculated once since all years of deferral are included
Reduced Equipment Failures	• Capital Replacement of Failed Equipment ($) • Portion Caused by Fault Current or Overloaded equipment (%) • Portion Caused by Lack of Condition Diagnosis (%)	For Fault Current Limiting, Dynamic Capability Rating, & Enhanced Fault Protection: **Value ($)** = Capital Replacement of Failed Equipment ($) * Portion Caused by Fault Current or Overloaded Equipment (%) For Diagnosis & Notification of Equipment Condition: **Value ($)** = Capital Replacement of Failed Equipment ($) * Portion Caused by Lack of Condition Diagnosis (%)
Reduced Customer Equipment Damage	• Average Cost of Damage Per Event ($/event) • Number of events (#)	**Value ($)** = [Average Cost of Damage Per Event ($/event) * [Number of Events (#)$_{Baseline}$ - Number of Events (#)$_{Project}$]
Customer Revenue	• Energy Export (kWh) • Energy Price ($/kWh)	**Value ($) = [**Energy Export (kWh)*Energy Price ($/kWh)]$_{Project}$ - **[**Energy Export (kWh)*Energy Price ($/kWh)]$_{Baseline}$
Utility Revenue	• Energy Sales (MWh) • Price Received for Energy	**Value ($) = [**Energy Sales (MW)*Energy Price ($/MWh)+Capacity Sales (MW)*Capacity Price

	Sales ($/MWh) • Capacity Sales (MW) • Price Received for Capacity Sales ($/MW) • Ancillary Service Sales (#) • Price Receive for Ancillary Services ($/#)	($/MW)+Ancillary Service Sales(#)*Ancillary Service Price ($/#)]Project - [Energy Sales (MW)*Energy Price ($/MWh)+Capacity Sales (MW)*Capacity Price ($/MW)+Ancillary Service Sales(#)*Ancillary Service Price ($/#)]Baseline
Reduced T&D Operations Cost	• Number of Manual Phase Adjustments (#) • Cost per Adjustment ($) • Cost for Capacity Switching for the Project ($)	**For Phase Balancing:** **Value ($) =** [Number of manual phase adjustments(#)*Cost per Adjustment($)]Baseline - [Number of manual phase adjustments(#)*Cost per Adjustment($)]Project **For Automated Voltage and VAR Control:** **Value ($) =** [Annual Cost for Capacitor Switching ($)]Baseline - [Annual Cost for Capacitor Switching ($)]Project
Reduced Electricity Losses	• Losses (kWh) • Price of wholesale energy ($/kWh)	**Value ($) =** [Losses (kWh) * Price of wholesale energy ($/kWh)]Baseline - [Losses (kWh) * Price of wholesale energy ($/kWh)]Project
Reduced Electricity Cost	• Energy (kWh) • Energy Rate ($/kWh) • Demand (kW) • Demand Rate ($/kW)	**Value ($) =** {[Energy (kWh) * (Energy Rate ($/kWh)] + [Demand (kW) * Demand Rate ($/kW)]}Baseline - {[Energy (kWh) * (Energy Rate ($/kWh)] + [Demand (kW) * Demand Rate ($/kW)]}Project
Reduced Sustained Outages	• Outage Time (hr) • Load Not Served (kW estimated) • Value of Service ($/kWh)	**Value ($) =** [Outage Time (hr) * Load Not Served (kW estimated) * VOS ($/kWh)]Baseline - [Outage Time (hr) * Load Not Served (kW estimated) * VOS ($/kWh)]Project
Reduced Major Outages	• Outage Time (hr) • Load Not Served (kW) • Value of Service ($/kWh)	**Value ($) =** [Outage Time (hr) * Load Not Served (kW) * VOS ($/kWh)]Baseline - [Outage Time (hr) * Load Not Served (kW) * VOS ($/kWh)]Project
Reduced Restoration Cost	• Number of Outage Events (# events) • Restoration Cost per Event ($/event)	**Value ($) =** [Restoration Cost ($)]Baseline - [Restoration Cost ($)]Project
Reduced Momentary Outages	• Momentary Interruptions (# of interruptions) • Value of Service ($ per interruption)	**Value ($) =** [Momentary Interruptions (# of interruptions) * VOS ($ per interruption)]Baseline - [Momentary Interruptions (# of interruptions) * VOS ($ per interruption)]Project
Reduced Sags and Swells	• Number of High Impedance Faults Cleared (# of events)	**Value ($) =** [Number of High Impedance Faults Cleared (# of events) * VOS ($/event)]Baseline -

	• Value of Service ($/event)	[Number of High Impedance Faults Cleared (# of events) * VOS ($/event)]Project
Reduced CO_2 Emissions	• Line losses (MWH) • CO2 emissions (tons/MWH) • CO2 Emissions (tons) • Value of CO2 ($/ton)	**Value ($) =** [CO2 Emissions (tons) * Value of CO2 ($/ton)]Baseline - [CO2 Emissions (tons) * Value of CO2 ($/ton)] Project **Or** **Value ($)** = [Line losses (MWH) * emissions (tons/MWH) * Value of emission ($/ton)]$_{Baseline}$ - [Line losses (MWH) * emissions (tons/MWH) * Value of emission ($/ton)]$_{Project}$
Reduced SO_X, NO_X, and PM-10 Emissions	• Line losses (MWH) • Emissions (tons/MWH) • Emissions (tons) • Value of Emission ($/ton)	**Value ($) =** [Emissions (tons) * Value of emission ($/ton)]Baseline - [Emissions (tons) * Value of emission ($/ton)] Project **Or** **Value ($)** = [Line losses (MWH) * emissions (tons/MWH) * Value of emission ($/ton)]$_{Baseline}$ - [Line losses (MWH) * emissions (tons/MWH) * Value of emission ($/ton)]$_{Project}$

6.2 Detailed Calculations

6.2.1 Optimized Generator Operation

The Optimized Generator Operation benefit can be realized through one function:

- Firming

This benefit comes from improved performance due to improved heat rate efficiency. In order to determine the value of the benefit, the project would have to track the annual generator dispatch avoided (MWh), along with the hourly cost of the generation ($/MWh). The net electricity cost[5] for charging the Storage Appliance would also be tracked to calculate the benefit using the following formula:

**Value ($)** = {[Hourly Generation Cost ($/MWh) * Annual Generator Dispatch (MWh)]$_{Baseline}$ – [Hourly Generation Cost ($/MWh) * Annual Generator Dispatch (MWh)]$_{Project}$}* Energy Storage Efficiency(%)

Optimized generator operation could be very difficult to track and monetize because of the relatively small size of this demonstration project. The contribution to the optimized generator operation benefit will likely have to be estimated, rather than calculated. In this case, the value could be based on the reduction in marginal generation that could be realized if generators could follow load more closely or if electricity storage could provide ancillary services so that conventional generators could operate at a more optimal level.

6.2.2 Deferred Generation Capacity Investment

The Deferred Generation Capacity Investments benefit can be realized through two functions:

- Load Shifting
- PV Generation

The impact of this benefit is determined by the amount of load shifting (MW), the amount of PV deployed (MW), the coincidence between PV's output and load, and the price paid for capacity ($/MW), which represents the capital expenditures for conventional generation. The cost savings could be accumulated based on the hourly savings. The monetary impact of this benefit is calculated using the following formula for Load Shifting:

Value ($) = [Price of a Peaking Generator ($/MW) * Amount of Generation Shifted (MW)]$_{Project}$

Or the for PV Generation:

Value ($) = [Price of a Peaking Generator ($/MW) * PV's AC Capacity (MW) * Local PV ELCC]$_{Project}$

6.2.3 Reduced Regulation Service Cost

The Reduced Regulation Service cost can be realized through two functions:

[5] The net electricity cost could include the difference between the charging price and the discharge price, as well as any energy losses associated with energy conversion and balance of systems for the energy storage technology.

» Firming
» Frequency Regulation

Both functions could decrease the cost of regulation services by offsetting traditional regulation purchases.

Value ($) = [[Annual Regulation Purchases]$_{Baseline}$ – [Annual Regulation Purchases]$_{Project}$](MWh) * Average Price of Regulation ($/MWh)

6.2.4 Reduced Voltage Support Cost

Reduced Voltage Support Cost is realized through one function:

» Automated Voltage and VAR control

Voltage and VAR support is traditionally provided by either static (capacitor banks or load tap changers) or dynamic resources (generators). Therefore, the cost reduction can be realized either by a differed capital investment in static equipment or by making fewer VAR/Voltage support purchases.

Value ($) = Capital Carrying Charge of Upgrade ($/yr) * Time deferred (yrs)

or

Value ($) = [[Annual Voltage Support Purchases]$_{Baseline}$ – [Annual Voltage Support Purchases]$_{Project}$](MWh) * Average Price of Voltage Support ($/MWh)

6.2.5 Reduced Spinning Reserve Cost

Reduced Spinning Reserve Cost is realized through three functions:

» Load Shifting
» Firming
» PV Generation

Load shifting provides more online capacity during peak demand periods when spinning reserve is most critical and highest cost. During an unexpected loss of generation, storage can be dispatched as spinning reserve to provide energy or storage can reduce demand and avoid spinning reserve purchases.

Firming avoids purchases of spinning reserve at peak price by smoothing peak energy demand.

Distributed PV generation reduces load that must be served by the Utility. Spinning reserve obligations are a percentage of total load served. Therefore, PV generation reduces the required spinning reserve that a utility must procure.

All of these functions reduce purchases of spinning reserve services to reduce annual cost.

Value ($) = [[Annual Spinning Reserve Purchases]$_{Baseline}$ – [Annual Spinning Reserve Purchases]$_{Project}$] * Average Cost of Spinning Reserve

6.2.6 Reduced Non-Spinning Reserve Cost

Reduced Non-Spinning Reserve Cost is realized through two functions:

- » Load Shifting
- » PV Generation

Load shifting and PV generation both offset load. By reducing load the Utility may procure less non-spinning reserve to meet its balancing authority obligations.

Value ($) = [[Annual Non-Spinning Reserve Purchases]$_{\text{Baseline}}$ – [Annual Non-Spinning Reserve Purchases]$_{\text{Project}}$] * Average Cost of Non-Spinning Reserve

6.2.7 Reduced Congestion Cost

Reduced Congestion Cost is achieved through three functions:

- » Load Shifting
- » Firming
- » PV Generation

All three of these functions contribute to reduced congestion cost by reducing peak loads. The transmission constraints that lead to congestion vary significantly by region.

Value ($) = [Congestion (MW) * Price of Congestion ($/MW)]$_{\text{Baseline}}$ - [Congestion (MW) * Price of Congestion ($/MW)]$_{\text{Project}}$

6.2.8 Deferred Transmission Capacity Investments

The Deferred Transmission Capacity Investments benefit can be realized through two functions:

- » Load Shifting
- » PV Generation

Both functions could decrease the loading on transmission system elements and postpone the need for capital upgrades. The project would report the capacity (MW) of load shifted or capacity of PV available (MW) during peak times, which would lead to deferral of equipment or line upgrades per the following equation:

Value ($) = Capital Carrying Charge of Upgrade ($/yr) * Time deferred (yrs)

For each these benefits, the deferred cost could be accumulated over time. For example, a project could be deferred for one year, and then the following year it could be deferred again, depending on loading and the dynamic rating.

6.2.9 Deferred Distribution Capacity Investments

The Deferred Distribution Capacity Investments benefit can be realized through two functions:

- » Load Shifting
- » PV Generation

Both functions could decrease the loading on distribution system elements and postpone the need for capital upgrades. The project would report the capacity (MW) of load shifted or capacity of PV available (MW) during peak times, which would lead to deferral of equipment upgrades.

Value ($) = Capital Carrying Charge of Upgrade ($/yr) * Time deferred (yrs)

6.2.10 Reduced T&D Operations Cost

T&D Operations Cost can be reduced through two different functions:

- Automated Voltage and VAR Control
- Phase Balancing

Each of these functions could reduce costs in different ways. Automated Voltage and VAR Control can reduce the capacitor switching costs ($) because PV-Storage is providing reactive power and capacitor switching required. The formula is:

**Value ($) =** [Annual Cost for Capacitor Switching ($)]$_{Baseline}$ - [Annual Cost for Capacitor Switching ($)]$_{Project}$

If a phase imbalance occurs, using PV-Storage to absorb or dispatch load on a phase could save the costs ($) associated with manual phase adjustments (#) per the following formula:

**Value ($) =** [Number of manual phase adjustments(#)*Cost per Adjustment($)]$_{Baseline}$ - [Number of manual phase adjustments(#)*Cost per Adjustment($)]$_{Project}$

This project will have to track the capacitor switching costs and number of manual phase adjustments over time.

6.2.11 Reduced Electricity Losses

The Reduced Electricity Losses benefit can be realized through three functions:

- Automated Voltage and VAR control
- Load Shifting
- PV Generation

The best approach for determining loss reductions for a project is to make coincident measurements on the portion of the delivery system incurring the losses. For example, if a project were seeking to demonstrate a loss reduction on a distribution feeder, the hourly load and voltage data from smart meters, as well as hourly load and voltage data from the head end of the feeder at the substation could be measured, and the data used to calculate the losses. The monetary impact of this benefit is calculated:

Value ($) = [Losses (kWh) * Price of wholesale energy ($/kWh)]$_{Baseline}$ - [Losses (kWh) * Price of wholesale energy ($/kWh)]$_{Project}$

Several functions can contribute to reducing losses, and projects demonstrating more than one of these functions at one time will see compounded effects.

6.2.12 Reduced Electricity Cost

The Reduced Electricity Cost benefit can be realized through two functions:

- » Load Shifting
- » PV Generation

A project will have to monitor hourly customer electricity use and apply either an estimated hourly rate, or an actual hourly rate, to each hour's usage using the following formula:

**Value ($)** = {[Energy (kWh) * (Energy Rate ($/kWh)] + [Demand (kW) * Demand Rate ($/kW)]}$_{\text{Baseline}}$ - {[Energy (kWh) * (Energy Rate ($/kWh)] + [Demand (kW) * Demand Rate ($/kW)]}$_{\text{Project}}$

Projects may not have tariff structures in place to charge customers in an hourly fashion, and they may not intend to put them in place in the near term. In these cases, the hourly rates could be constant throughout the day.

6.2.13 Reduced Customer Equipment Damage

The Reduced Customer Equipment Damage benefit can be realized through one function:

- » Bridging Power

Bridging power prevent grid power quality issues from damaging sensitive equipment reducing direct damage and possible loss revenue.

Value ($) = [Average Cost of Damage Per Event ($/event) * [Number of Events (#)$_{\text{Baseline}}$ - Number of Events (#)$_{\text{Project}}$]

6.2.14 Customer Revenue

Customer Revenue can be realized through one function:

- » End User Market Participation

The value to the customer will depend on the customer’s ability to export and what price they can obtain for the power. If a customer is in a region where prices vary throughout a day, hourly price data will need to be recorded, along with hourly PV production data and storage charging and discharging data. The value is calculated per the formula:

Value ($) = [**Energy Export (kWh)*Energy Price ($/kWh)]$_{Project}$ - **[Energy Export (kWh)*Energy Price ($/kWh)]$_{Baseline}$

6.2.15 Utility Revenue

Utility Revenue can be realized through one functions:

- » End User Market Participation

The exact nature of revenues is dependent on the local power market. The formula below represents a generic calculation of the benefits and the exact formula would depend on the power market. For a PV-Storage project, a utility would have to track its sales before and after the project is installed.

Value ($) = [**Energy Sales (MW)*Energy Price ($/MWh)+Capacity Sales (MW)*Capacity Price ($/MW)+Ancillary Service Sales(#)*Ancillary Service Price ($/#)]$_{Project}$ - **[Energy Sales (MW)*Energy Price ($/MWh)+Capacity Sales (MW)*Capacity Price ($/MW)+Ancillary Service Sales(#)*Ancillary Service Price ($/#)]$_{Baseline}$

6.2.16 Reduced Sustained Outages

The Reduced Sustained Outages benefit can be realized through two functions:

- » Automated Islanding and Reconnection
- » Backup power

Customer outage time could be logged by smart meters or outage management systems. This data could be compared with typical hourly loads to estimate the "load not served" during the outage. The value of the decreased load not served as a result of these functions must be allocated based on the function's contribution to reducing outage minutes. By applying a value of service (VOS) metric (i.e., by customer class and geographic region), the value of the load not served can be estimated as follows:

Value ($) = [Outage Time (hr) * Load Not Served (kW estimated) * VOS ($/kWh)]$_{Baseline}$ - [Outage Time (hr) * Load Not Served (kW estimated) * VOS ($/kWh)]$_{Project}$

6.2.17 Reduced Major Outages

The Reduced Major Outages benefit can be realized through four functions:

- » Automated Islanding and Reconnection
- » Backup power

As with Reduced Sustained Outages, smart meters will log outage times and this will be multiplied by a VOS metric. An estimate of the load not served may be provided by the project at the time of reporting, or can be pulled from the baseline estimate generated when the project is established.

Value ($) = [Outage Time (hr) * Load Not Served (kW) * VOS ($/kWh)]$_{Baseline}$ - [Outage Time (hr) * Load Not Served (kW) * VOS ($/kWh)]$_{Project}$

6.2.18 Reduced Restoration Cost

The Reduced Restoration Cost benefit can be realized through one function:

» Automated Islanding and Reconnection

The project could report and track the number of outages and the reduction in restoration costs achieved by being able to restore service more quickly. The cause of outages must be reported for the baseline and tracked during the project. For example, a utility could have 10% of all outages caused by equipment failure historically. Therefore, the baseline for outage history (or reliability index) would include the percentages for each type of outage. Over the course of the project, the utility would track outages and causes, and the result would be compared against the baseline.

Value ($) = [Restoration Cost ($)]$_{Baseline}$ - [Restoration Cost ($)]$_{Project}$

6.2.19 Reduced Momentary Outages

The Reduced Momentary Outages benefit can be realized through one function:

» Bridging Power

The value of this benefit is based on the VOS metrics, which are typically determined by customer class (residential, commercial, industrial) and may vary geographically. The VOS is provided as part of the baseline information at the beginning of the project. Otherwise VOS for a similar utility/region is applied. The project should preferably track the momentary outage events, not simply the number of times the lights blink. For example, one event might cause two recloser operations to clear the fault, but only one event should be recorded (not two). The capability of fault location without reclosing must be clearly identified in the project, and a specific monitoring plan should be put in place. Customer momentary interruptions could be logged by smart meters or outage management systems. The metric for momentary interruptions would most likely be the Momentary Average Interruption Frequency Index x (MAIFI) for the project.

Value ($) = [Momentary Interruptions (# of interruptions) * VOS ($ per interruption)]$_{Baseline}$ - [Momentary Interruptions (# of interruptions) * VOS ($ per interruption)]$_{Project}$

6.2.20 Reduced Sags and Swells

The Reduced Sags and Swells benefit can be realized through one function:

» Bridging Power

The project would track the number of high impedance faults that were cleared without causing voltage sags. Feeder monitoring will most likely be required to determine the number and severity of voltage sags since customers do not always detect these events, and most probably go unreported.

Value ($) = [Number of High Impedance Faults Cleared (# of events) * VOS ($/event)]$_{Baseline}$ - [Number of High Impedance Faults Cleared (# of events) * VOS ($/event)]$_{Project}$

VOS would be for power quality events (voltage), and is probably most applicable to customers with sensitive loads. The project should estimate the VOS associated with voltage variations, and could refer to IEEE 1159[6] or a similar guideline to determine the technical impact of these events and calculate the value.

6.2.21 Reduced/Avoided CO2 Emissions

The Reduced CO_2 Emissions benefit can be realized through six functions:

- Automated Voltage and VAR Control
- Phase Balancing
- Load Shifting
- Firming
- PV Generation
- Frequency Regulation

For Automated Voltage and VAR Control, Phase Balancing, Load Shifting, and Frequency Regulation the reduction is due to fewer line losses either because of less reactive losses or more efficient operation. The reduction in emissions is associated with reducing peak demand and the use of central generation. Therefore, the emissions associated with central generation would have to be determined for each project based on the generation mix in the service territory of the project.

Value ($) = [Line losses (MWH) * CO_2 emissions (tons/MWH) * Value of CO_2 ($/ton)]$_{Baseline}$ - [Line losses (MWH) * CO_2 emissions (tons/MWH) * Value of CO_2 ($/ton)]$_{Project}$

For PV Generation, CO_2 reductions are associated with using renewable vs. fossil energy. For Firming, CO_2 reductions are related to more efficient operation of fossil generators. The monetary impact of this benefit is calculated using the following formula:

Value ($) = [$CO_2$ Emissions (tons) * Value of CO_2 ($/ton)]$_{Baseline}$ - [CO_2 Emissions (tons) * Value of CO_2 ($/ton)]$_{Project}$

6.2.22 Reduced SO_x, NO_x and PM-10 Emissions

The Reduced SO_x, NO_x, and PM-10 Emissions benefit can be realized through six functions:

- Automated Voltage and VAR Control
- Phase Balancing
- Load Shifting
- Firming

[6] IEEE Std 1159-1995 IEEE Recommended Practice for Monitoring Electric Power Quality

» PV Generation
» Frequency Regulation

For Automated Voltage and VAR Control, Phase Balancing, Load Shifting, and Frequency Regulation the reduction is due to fewer line losses either because of less reactive losses or more efficient operation. The reduction in emissions is associated with reducing peak demand and the use of central generation. Therefore, the emissions associated with central generation would have to be determined for each project based on the generation mix in the service territory of the project.

Value ($) = [Line losses (MWH) * emissions (tons/MWH) * Value of emission ($/ton)]$_{Baseline}$ - [Line losses (MWH) * emissions (tons/MWH) * Value of emission ($/ton)]$_{Project}$

For PV Generation, emission reductions are associated with using renewable vs. fossil energy. For Firming, emission reductions are related to more efficient operation of fossil generators. The monetary impact of this benefit is calculated using the following formula:

Value ($) = [Emissions (tons) * Value of emission ($/ton)]$_{Baseline}$ - [Emissions (tons) * Value of emission ($/ton)] $_{Project}$

NAVIGANT
ENERGY

Monitoring and Testing Plan

Presented to

SMUD
SACRAMENTO MUNICIPAL UTILITY DISTRICT
The Power To Do More.®

May 10, 2012

FINAL

Presented by:

Navigant Consulting, Inc.
77 S. Bedford Street, Suite 400
Burlington, MA 01803

781.270.8303
www.navigantconsulting.com

NAVIGANT
ENERGY

Table of Contents

NAVIGANT
ENERGY

Table of Contents

Table of Figures

Table of Tables

1. Objective

The Sacramento Municipal Utility District (SMUD) received a grant from the U.S. Department of Energy to conduct a demonstration that adds distributed energy storage to a residential community that currently has a PV penetration of about 20% of peak feeder load. This project will demonstrate battery energy storage in combination with residential PV in a Solar Smart Homes community in Rancho Cordova, California. The energy storage systems are being installed in two configurations: behind the meter – Residential Energy Storage (RES), and on the primary distribution system Community Energy Storage (CES) – as shown in Figure 1 below. In addition to the test groups, there will also be a control group.

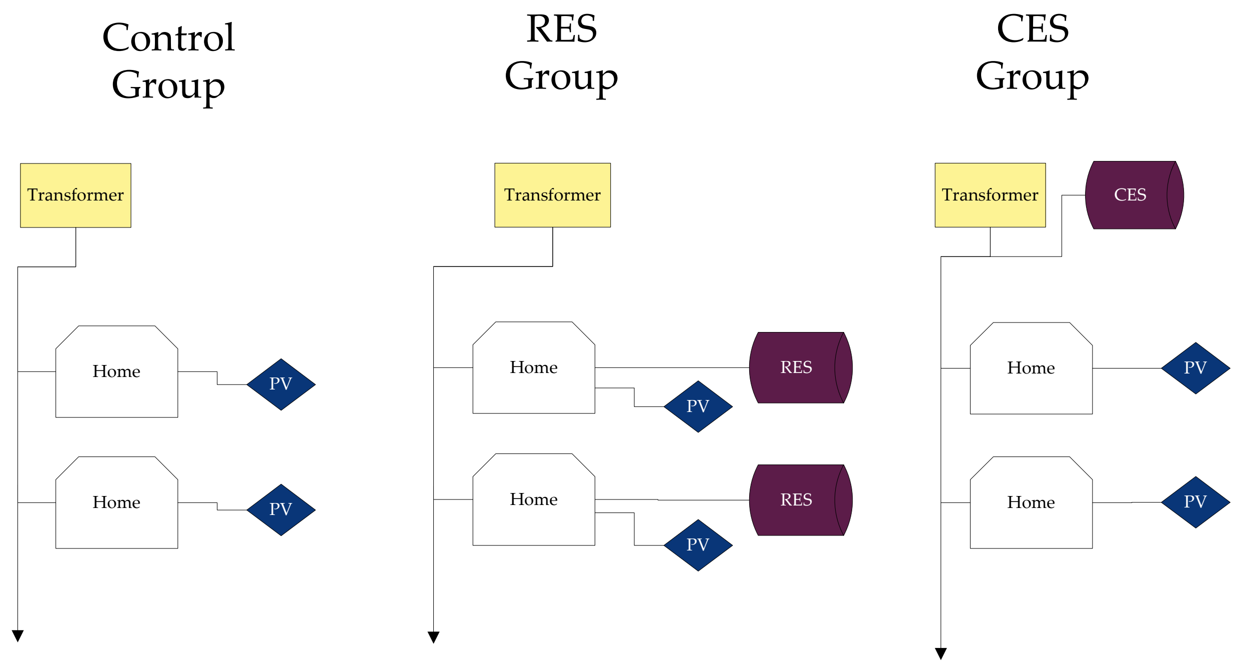


Figure 1. Project testing configurations.

A key part of the demonstration is collection of operating data from the PV systems, energy storage systems, and the utility distribution systems. This information will help SMUD and the utility industry obtain real-world information regarding the performance and capability of advanced energy technologies and applications, and their ability to provide added functionality and value for SMUD and its customers. Key questions include:

- What does adding battery energy storage do to the performance characteristics of residential PV?
- Is there a practical difference between RES and CES? If so, what?
- Does an integrated PV/battery system add additional functionality and value for SMUD and its customers?
- What time of the year and under what weather conditions does energy storage add value?
- How much storage is required to firm load given weather patterns and typical customer loads in SMUD's service territory?

For additional detail regarding SMUD's Key Research Questions see the Appendix.

Purpose of This Plan

This document's purpose is to define the following items in regards to SMUD's PV and Energy Storage Pilot at Anatolia III:

- How key research questions will be answered
- Equipment type and monitoring location
- Equipment monitoring responsibility
- Data types, precision and sample rates
- Data processing and storage procedure
- Test procedure and schedule
- Test procedure roles and responsibilities
- Proposed Operating Scenarios

This document will serve as a guide for the team to discuss the parameters above and for operators to use during testing.

2. Electrical System Configuration

Homes

The homes in this community are Solar Smart residences offered by Lennar Homes. All homes meet or exceed California Title 24, have 14 SEER air conditioners, a 90% efficient furnace, ENERGY STAR qualified windows, compact fluorescent bulbs, and radiant barriers.

PV System

Each home has a SunPower PV system installed with a nameplate capacity between 1.9 and 4.0 kW_{pDC}. Some systems have building integrated photovoltaics and others have traditional roof mounted modules, both manufactured by SunPower. Each PV system is connected to the home's Main Panel via a SunPower inverter.

Energy Storage

The RES system is manufactured by Silent Power and has a 10kW peak, 9 kWh Saft Solion Lithium-Ion battery. The RES system has an integrated control system and inverter. The CES system is manufactured by Powerhub and has a 30 kW peak, 30 kWh Lithium-Ion battery. It also has an integrated control system and inverter.

The batteries can operate in several different modes:

Load Firming – In 10 second intervals, the battery will try to smooth net house load or net load to the transformer around what happened in the past. The battery uses the target set point and actual load from the last two time periods to calculate this using the formula:

Target Set Point (n) = A*a+B*b+C*c+D*d

Where,
A = n-1 Target Set Point
B = n-2 Target Set Point
C = n-1 Actual Measured Load
D = n-2 Actual Measured Load

And,
a, b, c and d are percentages with a+b+c+d=100%

Load Shifting by Price – the battery uses the time periods of a customer's rate schedule to govern charging and discharging. The battery charges during periods of low rates and discharges during periods of high rates, independent of what the rate is. The utility can input rates as they change throughout the year.

Predictive Load Shifting – the battery uses historical load and weather information to predict when to charge and discharge in order to minimize peaks and valleys in load.

Custom Load Shifting – The battery charges or discharges for a period and rate specified by the utility.

Electrical Distribution System

The entire neighborhood is served by single-phase lateral circuits from a three-phase primary feeder which connects to a 20 MVA, 69 kV / 12.47 delta-wye transformer at the nearest substation. In the neighborhood, there are 30 active single-phase, pad-mounted distribution transformers ranging from 50 kVA (21 units) to 75 kVA (9 units).

3. Monitoring System Configuration

Equipment Types and Monitoring Locations

In order to answer all the Key Research Questions, several variables will be monitored throughout the area. Figure 2 shows a schematic of the distribution system with monitoring, storage, and PV mapped out for a sub group of each test group, and Figure 3 is a map of the neighborhood, with the monitoring and storage locations mapped out.

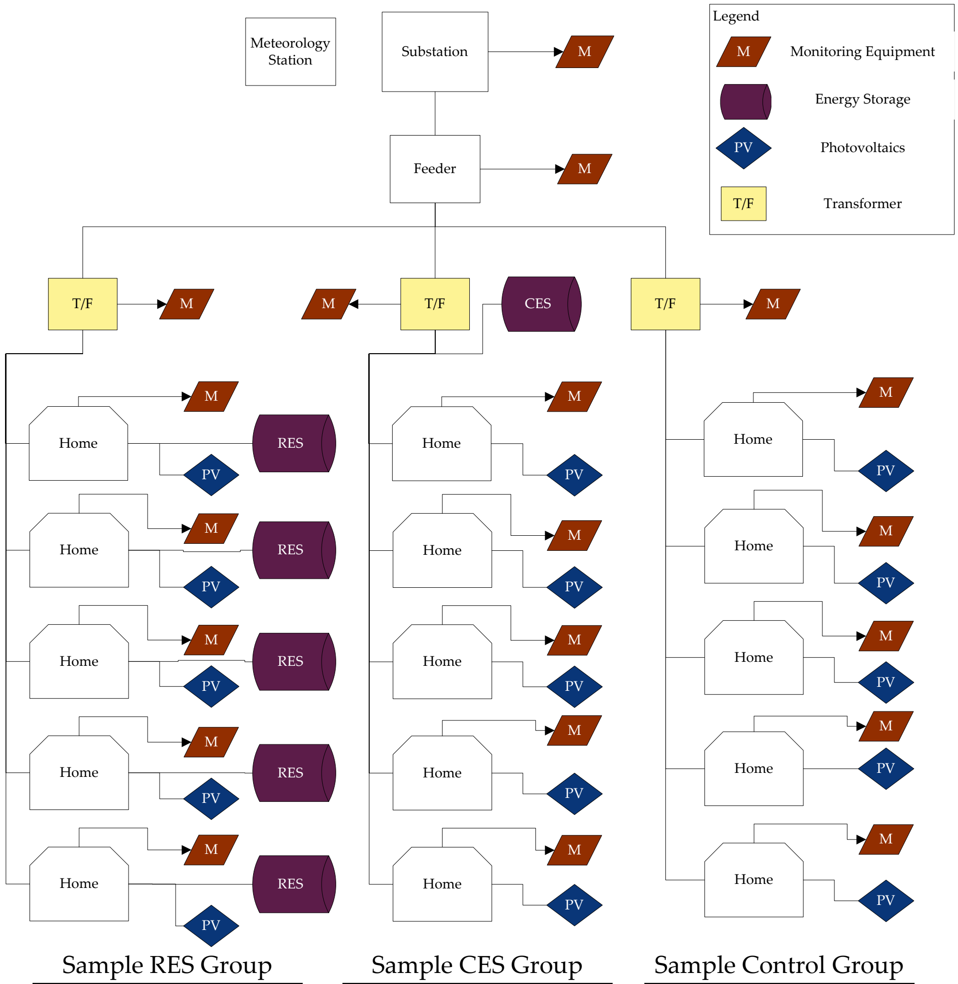


Figure 2. One line diagram of the entire subdivision with monitoring locations included

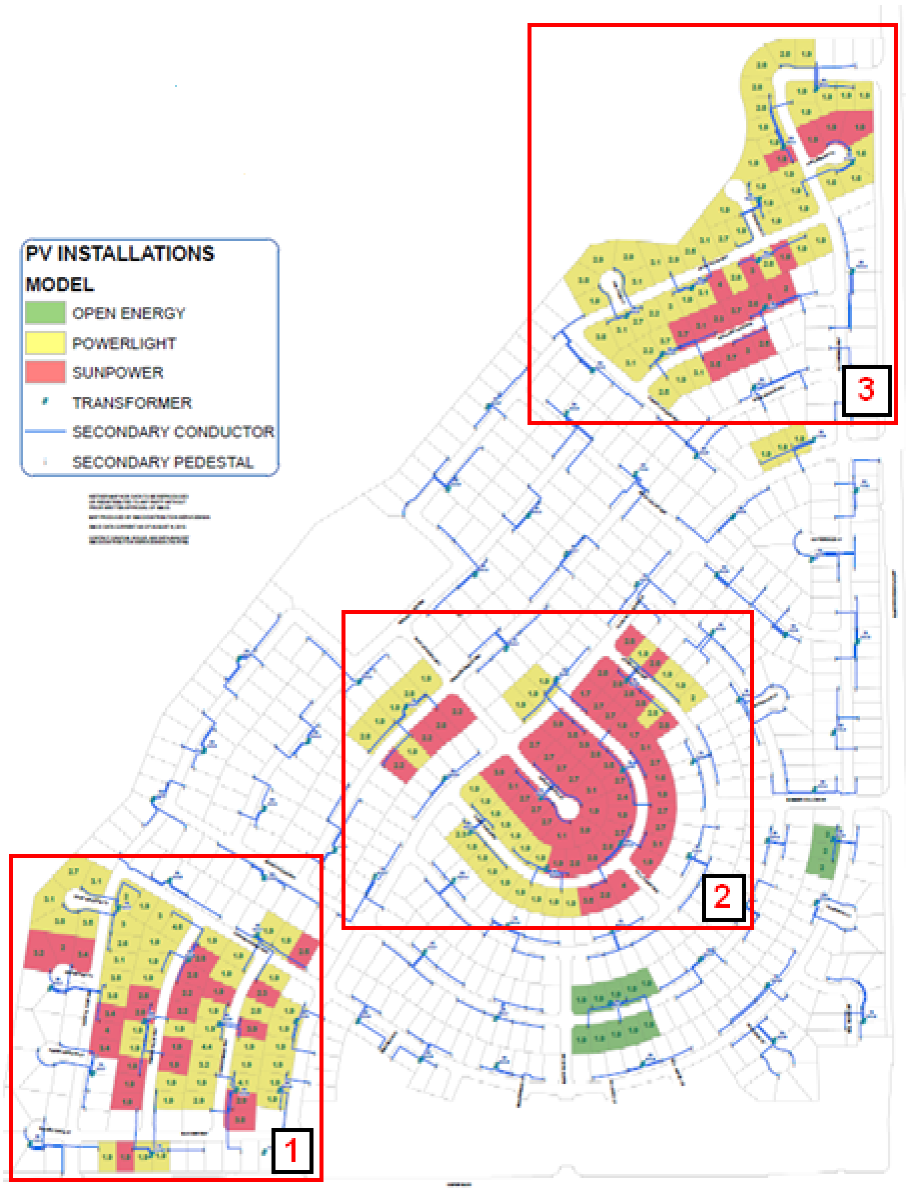


Figure 3. Map of Anatolia neighborhood: 1) Southwest area, 2) Central area, 3) Northeast area

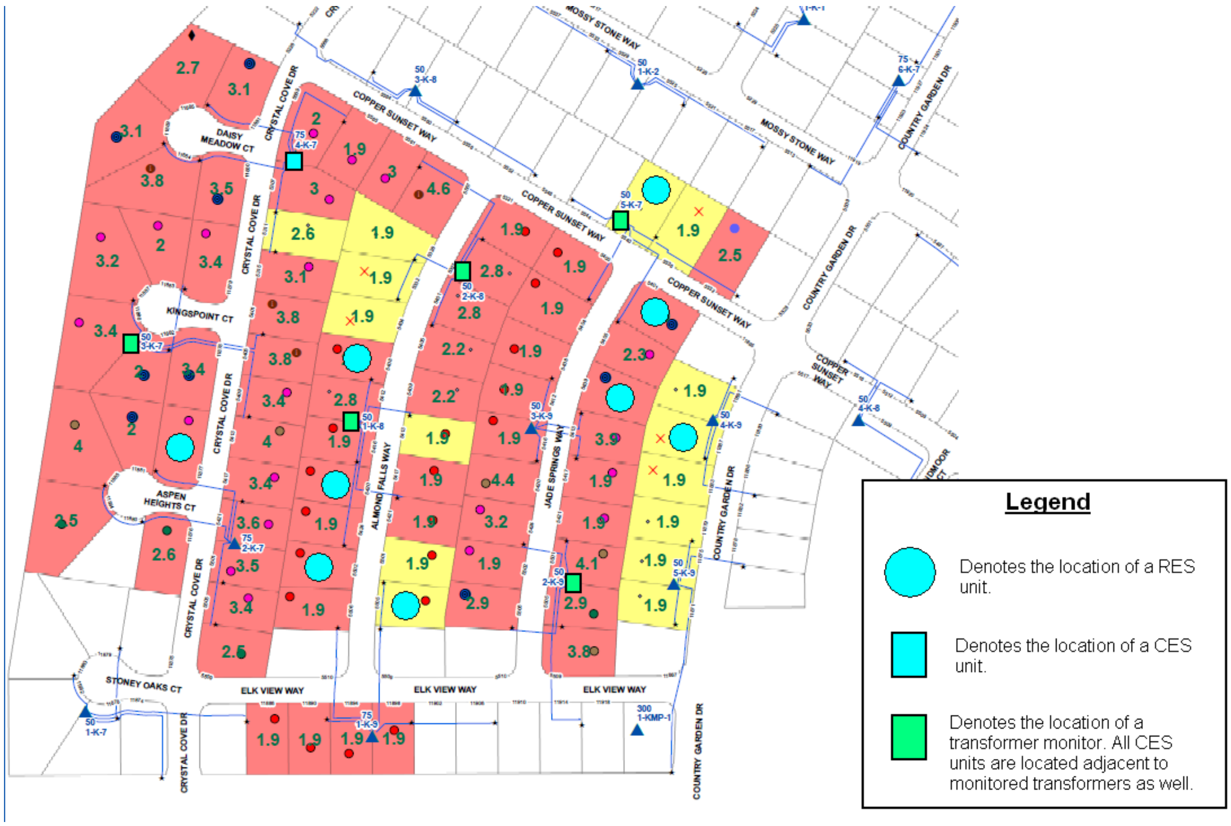


Figure 4. Map of Southwest area of Anatolia neighborhood, along with location of equipment

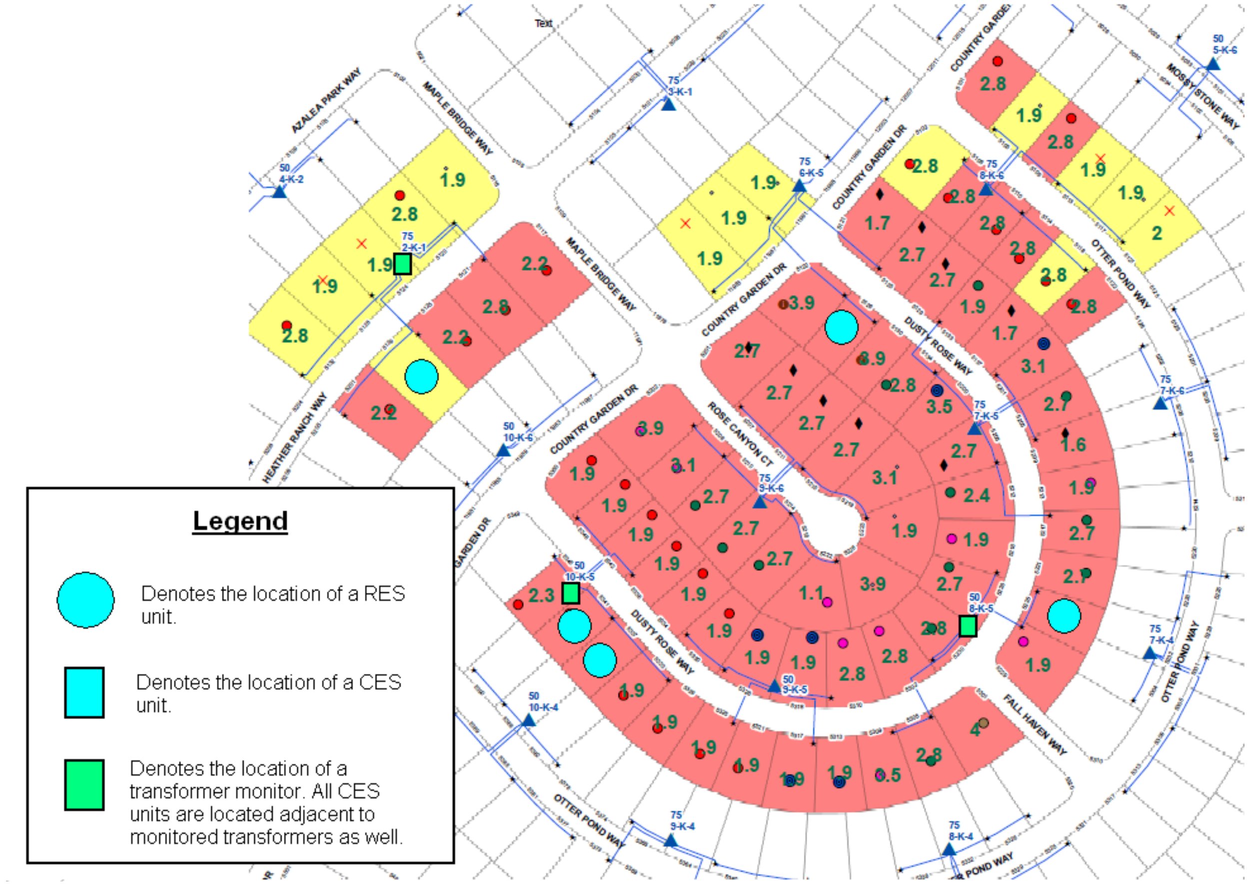


Figure 5. Map of Central area of Anatolia neighborhood, along with location of equipment

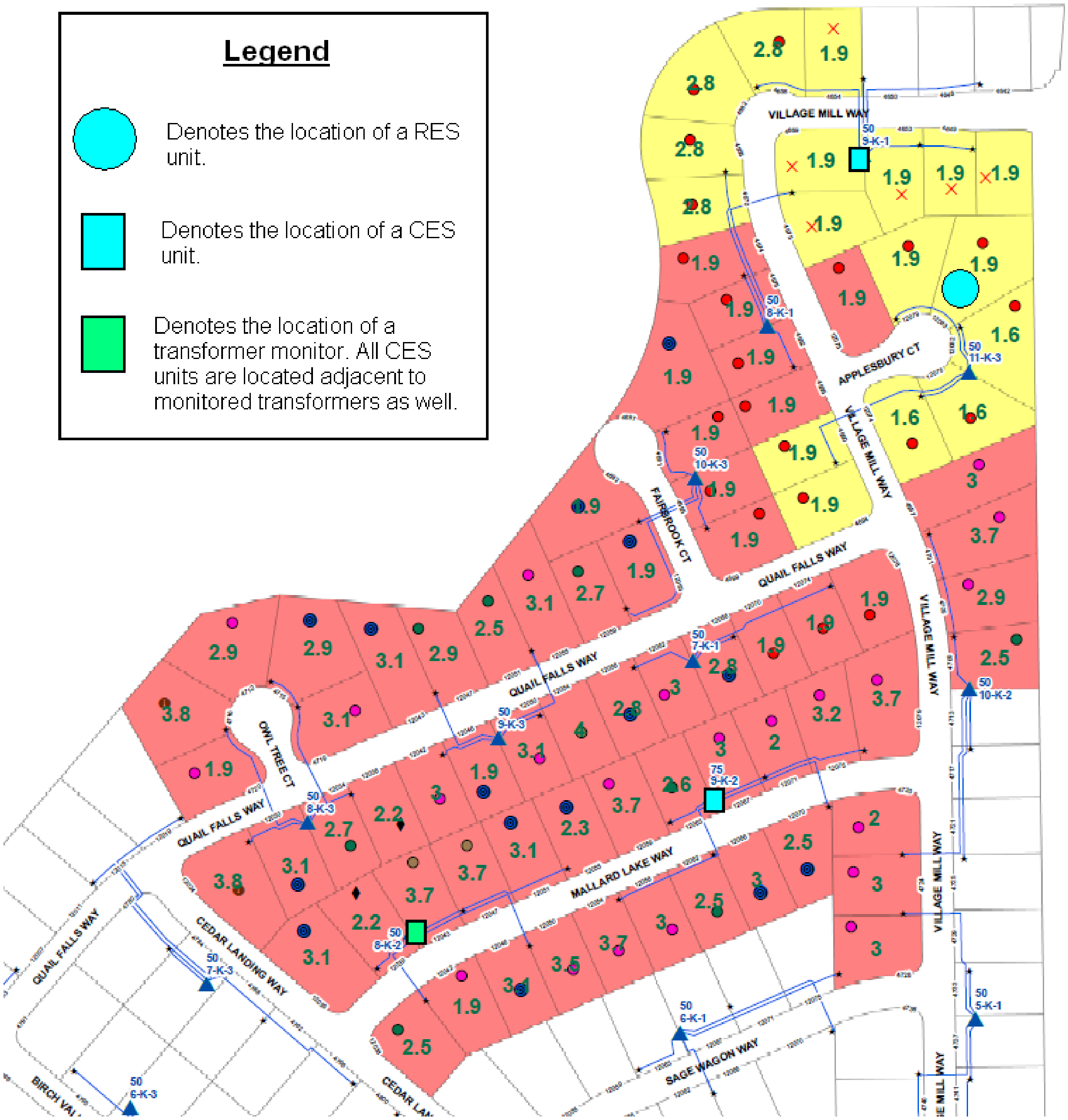


Figure 6. Map of Northeast area of Anatolia neighborhood, along with location of equipment

4. Data

Data processing and storage procedure

SMUD, Gridpoint, NREL, and SunPower will all be collecting data as part of this study. In order to provide an efficient means of accessing and analyzing the data, NREL will be hosting all the data and each team member will have access to the data via a direct connection with NREL. NREL will utilize its Data Concentrator and Data Historian to manage real-time independent server and device data streams and to house historical data transmissions, respectively. SunPower is currently collecting PV inverter output and customer loads. This data will be delivered to GridPoint's server via a NOC-to-NOC connection and then passed to NREL's server(s) for the RES customers and passed directly to NREL for the CES and baseline customers.

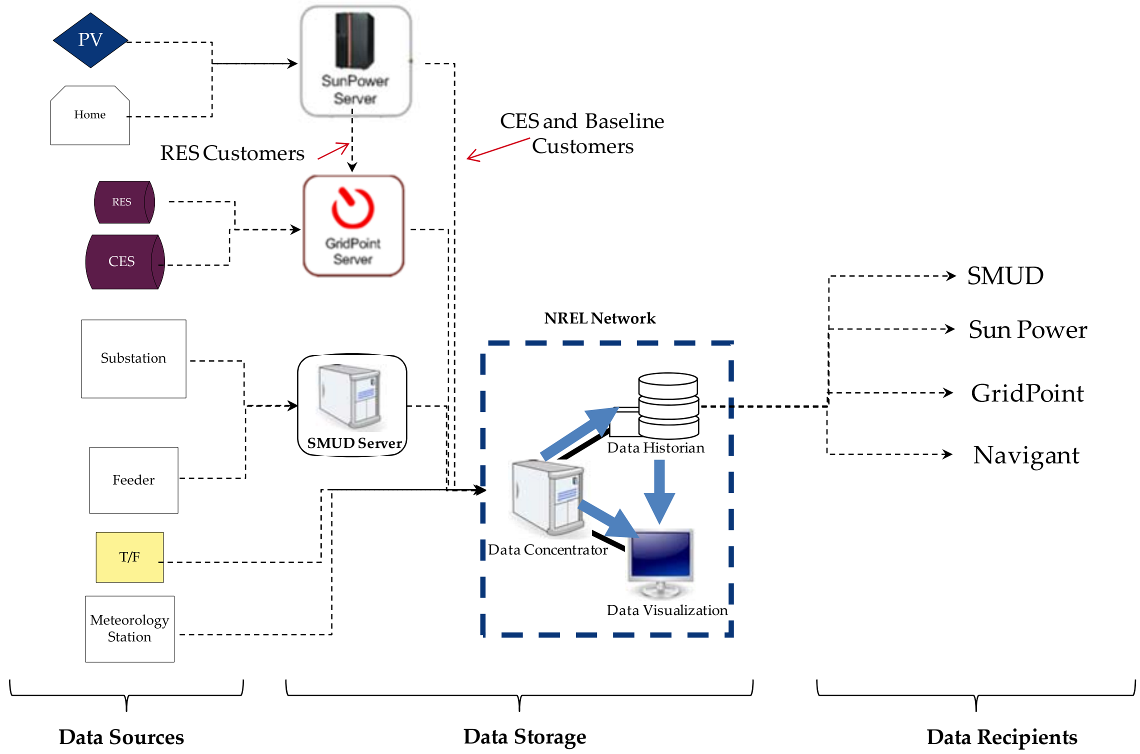


Figure 7. Data management diagram

Data types, precision and sample rates

At each monitored location, various data types will be collected in order to answer the Key Research Questions. Table 7 through Table 10 in the Appendix delineates which team member is responsible for data collection in each location, what data will be collected, what sampling rates will be used and how the data will be time stamped.

5. Operating Scenarios

Monitoring to Assess Technical Challenges with High Penetration Solar

Concerns over the operational impacts of high penetrations of PV on utility distribution circuits are well documented. However, most information is based on isolated PV installations and paper studies that examined the installation of distributed generation on distribution systems. This demonstration will allow SMUD and the DOE to obtain actual operational data. The demonstration will build on the information obtained by NREL in their groundbreaking monitoring program on the Anatolia distribution system that began in 2008. The monitoring approach developed for this demonstration is designed, in part, to explore how integrated PV/energy storage implementation can address:

- Circuit voltage fluctuations

- Changes in circuit power flow, including daily or hourly cycles
- Fluctuations in PV power output caused by clouds

These three technical challenges are the basis of most of the operational concerns that utilities have had about PV on their distribution systems. The following discusses a number of specific research questions that will be explored with the data obtained from monitoring.

Of the 12 Key Research Questions this demonstration is designed around, not all of them will be answered by the monitoring or testing. The following text reviews the questions that will be answered using the monitoring and testing portion of the study

Table 1. Relationship of this Monitoring and Testing Plan to Key Research Questions.

#	Key Research Question	Monitoring Contributes Information?	Testing Contributes Information?
1	Does the location of energy storage significantly change the utility's ability to "firm" customer load and distributed PV capacity?	**YES**	**YES**
2	How much storage is necessary to accomplish the desired PV and load firming effects?	**YES**	**YES**
3	Can an integrated PV/energy storage system provide reliability benefits for customers?	**YES**	**YES**
4	Can energy storage in a high penetration solar deployment help support SMUD's "super-peak" from 4 PM to 7 PM, particularly when PV output drops off after 5PM?	**YES**	**YES**
5	Does the location of energy storage significantly affect the ability of the utility to manage the resource?	**YES**	NO
6	How variable is PV output within a community or distribution feeder, and what is the potential operating impact for the utility?	**YES**	NO
7	Can a smart meter be used to monitor and control a PV system, and to what extent?	NO	NO
8	What are the practical challenges associated with using AMI for managing PV?	NO	NO
9	What are the technical requirements for integrating inverters and smart meters, and what codes, standards and reference designs must be developed?	NO	NO
10	Do the customers who have capacity firming capability (energy storage) behave differently than those who do not?	**YES**	**YES**
11	Do the customers with the RES behave differently than those with CES?	**YES**	NO
12	How does energy storage impact the customer's ability/desire to respond to pricing signals?	**YES**	**YES**

To answer Key Research Questions 1, 2, 4, 10 and 12 the project team designed several operating around three key variables that impact the overall functionality of an integrated PV/Energy Storage system:

1. Battery Mode
2. Battery Maximum Capacity
3. Discharge Initiation Timing during Super Peak

Each of these variables will be tested throughout the year to also understand impacts of seasonable and time of day changes.

Operating Scenarios

1. **Battery is placed in Load Firming mode.** The storage systems used in this project have a firming algorithm where the storage uses real-time and historical load data, weather data, solar output, etc. to firm a home's net load around a certain value. Putting the battery in this mode will help answer Key Research Question #1 and #2

2 – 4. **Battery provides firming, but the battery capacity is varied.** Key Research Question #2 asks how much storage is necessary to firm PV and customer load in SMUD's service territory. For this project, the actual batteries being used are fixed capacity, but the effective maximum storage capacity is variable. By limiting the output of the battery, this test will simulate the performance of smaller battery and will give SMUD an idea of how much battery capacity is required given the community's particular weather patterns, housing construction, load profiles, etc. The battery SOC will be monitored to see if it reaches its set point. This will also help answer Key Research Question #1.

5. **Battery dispatch to provide frequency regulation.** This test will prove out a function of PV-Storage and will likely be repeated less frequently than other tests. The intent is for SMUD to command the battery to charge or discharge in order to help regulate frequency (or follow load) on the distribution network. The results will then be included in the overall strategic recommendations resulting from this project. This will help answer Key Research Question #3.
6. **Battery dispatch to provide phase balancing.** This operating scenario's intent is to use storage to help SMUD deal with phase imbalances. This operating can only be tested if site selection allows installation of a critical mass of CES on a single phase (A, B or C) in the community. While the existing community likely doesn't have a phase balance issue, this test would hopefully demonstrate that the storage units are capable of change loading on on particular phase. This will help answer Key Research Question #3.
7. **Battery is placed in Predictive Load Shifting Mode to optimize on energy.** The storage system being used in this project has a load shifting algorithm that uses information on historical load, weather, PV output, etc. to forecast day ahead load shifting requirements. This algorithm has a number of optimization goals. This test will optimize to achieve levelized energy by utilizing the CES units. This operating scenario will help answer Key Research Question #2. This might be run with the RES units as well, depending on when the advanced rate is implemented.
8. **Battery is placed in Load Shifting by Price mode to optimize on daily cost of electricity.** In addition to being able to optimize load shifting around energy usage, the storage system can also optimize on electricity cost (relying on day-ahead electricity prices and forecasted net load). The RES customers will likely be on an advanced electricity rate at some point during the

demonstration. Therefore, the load shifting algorithm can be used to minimize the customer's daily electricity cost by charging during times of low cost and discharging during times of high cost. This operating scenario will help answer Key Research Question 2.

9 – 11. **Battery is programmed to discharge during super peak.** Putting the battery in discharge mode during super peak and monitoring total transformer load against the control group's transformers will answer Key Research Question #4. However, SMUD needs to know when to start the discharge given variables such as typical customer loads, solar output profiles, etc. Operating scenarios 9 through 11 will vary the initiation of discharge to determine when discharge should start in order maximize the usefulness of both PV and storage and if that time varies seasonally.

Table 2. Operating Scenarios

	Variable and Level					
Operating Scenario	Battery Mode	Battery Maximum Capacity	Discharge Initiation	Key Research Question Addressed	Applies to RES	Applies to CES
1	Load Firming	100%	N/A	1, 2	√	√
2	Load Firming	75%	N/A	1, 2	√	√
3	Load Firming	50%	N/A	1, 2	√	√
4	Load Firming	25%	N/A	1, 2	√	√
5	Custom Load Shifting	100%	N/A	3		√
6	Custom Load Shifting	100%	N/A	3		√
7	Predictive Load Shifting	100%	N/A	4	√	√
8	Load Shifting by Price	100%	N/A	4	√	
9	Custom Load Shifting	100%	4:00 PM	4	√	√
10	Custom Load Shifting	100%	5:00 PM	4	√	√
11	Custom Load Shifting	100%	6:00 PM	4	√	√

Functions Not Being Tested

Due to the regulations governing inverter certification and interconnection standards in the U.S. (e.g. IEEE 1547 and UL 1741), this project will not be able to test voltage regulation and support during outages because, currently, inverters are not allowed to provide voltage regulation and are designed to go off-line during an outage.

Mapping of Operating Scenarios to Benefits Framework

As part of this study, Navigant created a framework for assessing the benefits of PV-Storage system. The framework included 10 functions and 22 associated benefits. Not all of these functions and benefits will be tested as part of this project, but the ones that are related to the operating scenarios are shown in Table 3. The benefits will be calculated at the conclusion of this project using the monitored data.

Table 3. Mapping of Functions and Benefits of this Demonstration

	Function				
Benefit	**Phase Balancing**	**Load Shifting**	**Firming**	**PV Generation**	**Frequency Regulation**
Optimized Generator Operation			✓		
Deferred Generation Capacity Investments		✓		✓	
Reduced Regulation Service Cost			✓		✓
Reduced Non-Spinning Reserve Cost		✓			
Reduced Spinning Reserve Cost		✓	✓	✓	
Reduced Congestion Cost		✓		✓	
Deferred Transmission Capacity Investments		✓		✓	
Deferred Distribution Capacity Investments	✓	✓		✓	
Reduced Equipment Failures	✓				
Reduced T&D Operations Cost	✓				
Reduced Electricity Losses	✓	✓		✓	
Reduced Electricity Cost		✓		✓	
Reduced Sags and Swells (high/low phase voltage)	✓				
Reduced/Avoided CO2 Emissions	✓	✓	✓	✓	✓
Reduced SOx, NOx, and PM-10 Emissions	✓	✓	✓	✓	✓

6. Testing Protocol

Schedule

The appendix contains a schedule based upon the following constraints and assumptions:

- We are currently scheduling from mid-May through September. We'll revisit the plan in September
- The storage appliances must run in Firming mode for the first two weeks for calibration
- To take advantage of the Super Peak Season and associated TOU pricing, we are only running one RES firming scenario.
- Operating Scenarios 9 through 11 are not needed until Super Peak Season.
- Operating Scenarios 5 and 6 are demonstrations, rather than tests. So they only will be run a few times.
- We scheduled tests in one week blocks, starting on Saturdays to minimize the time required for scheduling and to avoid schedule changes on the weekend.
- We are doing firming throughout the year to assess the value of firming as a function of weather.

- For June, July and August, we are only trying custom firming scenario 11 because the doesn't set until ~8 PM. Based upon what we learn this summer, we will try other start times next summer.
- Statistical significance at the 90% confidence interval

The above constraints and assumptions, combined with the time available for testing yields the following count of Operating Scenarios shown in Table 4. The appendix contains a detailed testing calendar. This schedule is meant as a guide and can be altered and updated as need be..

Table 4. High Level Schedule

Operating Scenario	Number of Tests - RES	Number of Tests - CES
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		

TBD

Start Up

1. **Initiation** After SMUD takes control of the units from GridPoint, SMUD should test out all the necessary functionality of the Utility Portal.
2. **Operation** The equipment modes must be set and varied throughout the testing. Table 5 below shows what equipment parameters need to be varied and monitored using the GridPoint Utility Portal. The Appendix contains a data sheet for SMUD staff to record actual settings and observations.

   Each team shown in Table 7 will be responsible for monitoring the state of its equipment to ensure that it is working properly. NCI recommends checking the data from the equipment on a weekly basis. NCI will be reviewing all of the data on a quarterly basis and making any required modifications to the testing schedule (revision will also occur on a quarterly basis).

Table 5. Equipment Operation

Setting	Responsible Party	Frequency
Battery Operating Mode (Firming, Load Shifting, Dispatch, Default Mode*, standby)	SMUD	Daily

Battery Maximum Capacity	SMUD	Daily
Discharge Initiation	SMUD	Daily (during Super Peak)
Load Shifting Mode (Energy, Cost)	SMUD	Weekly or Monthly
Equipment Grouping (RES/CES units in A, B, C groups etc)	SMUD	Weekly or Monthly
Post Test Recovery Mode (resume CES/RES default mode)	SMUD	Daily

*Default mode has yet to be determined but our preference is load shifting mode.

3. **Trouble Shooting** SMUD needs to ensure that its call center staff is aware of this project and an escalation plan is developed.

Appendix

Key Research Questions

The study is centered on 4 strategic objectives and 12 key research questions, shown below in **Error! Reference source not found.**.

Table 6 . Key Research Questions

Strategic Objective 1	**Understand how the integration of energy storage could enhance the value of distributed PV resources within the community**
Key Research Questions	• Does the location of energy storage significantly change the utility's ability to "firm" customer load and distributed PV capacity? • How much storage is necessary to accomplish the desired PV and load firming effects? • Can an integrated PV/energy storage system provide reliability benefits for customers?
Strategic Objective 2	**Determine if the addition of energy storage could add value for the utility**
Key Research Questions	• Can energy storage in a high penetration solar deployment help support SMUD's "super-peak" from 4 PM to 7 PM, particularly when PV output drops off after 5PM? • Does the location of energy storage significantly affect the ability of the utility to manage the resource? • How variable is PV output within a community or distribution feeder, and what is the potential operating impact for the utility?
Strategic Objective 3	**Determine how to leverage SMUD's AMI investment to manage a distributed PV/energy storage resource**
Key Research Questions	• Can a smart meter be used to monitor and control a PV system, and to what extent? • What are the practical challenges associated with using AMI for managing PV? • What are the technical requirements for integrating inverters and smart meters, and what codes, standards and reference designs must be

	developed?
Strategic Objective 4	**Determine if capacity firming and advanced pricing signals will influence the energy usage behaviors of customers**
Key Research Questions	• Do the customers who have capacity firming capability (energy storage) behave differently than those who do not? • Do the customers with the RES behave differently than those with CES? • How does energy storage impact the customer's ability/desire to respond to pricing signals?

Data Matrix

Table 7. Data matrix – NREL

Equipment	Data Source	Category	Parameter	Frequency	Units	Data Type	Data Set (TBD)	Time Stamp	Time Sync
50/75 kV Transformers	NREL	Performance Data	V1, Secondary Voltage Leg 1	1 sec	V	single	RMS Value	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	V2, Secondary Voltage Leg 2	1 sec	V	single	RMS Value	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	V12, Total Secondary Voltage	1 sec	V	single	RMS Value	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	I1, Secondary Current, Leg 1	1 sec	A	single	RMS Value	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	I2, Secondary Current, Leg 2	1 sec	A	single	RMS Value	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	Ip, Primary Current[3]	1 sec	A	single	RMS Value	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	Frequency-Voltage-Waveform (V12)	1 sec	Hz	single		Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	Power-Real	1 sec	W	single	average	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	Power-Reactive	1 sec	VAR	single	average	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	Power-Apparent	1 sec	VA	single		Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	Power-Factor	1 sec	-	single		Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	Power-Factor-Displacement	1 sec	-	single		Unix/UTC[1]	GPS
50/75 kV	NREL	Performance Data	Temperature-of-meter	1 sec	C	single	sampled	Unix/UTC[1]	GPS

Transformers									
50/75 kV Transformers	NREL	Performance Data	Temperature-of-transformer	1 sec	C	single	sampled	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	V1, Secondary Voltage Leg 1	1 sec	V	single	Phasor Mag.	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	V2, Secondary Voltage Leg 2	1 sec	V	single	Phasor Mag.	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	V12, Total Secondary Voltage	1 sec	V	single	Phasor Mag.	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	I1, Secondary Current, Leg 1	1 sec	A	single	Phasor Mag.	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	I2, Secondary Current, Leg 2	1 sec	A	single	Phasor Mag.	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	Ip, Primary Current[3]	1 sec	A	single	Phasor Mag.	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	In, Secondary Neutral Current (calculated)[2]	1 sec	A	single	Phasor Mag.	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	V1, Secondary Voltage Leg 1	1 sec	Degrees	single	Phasor Angle	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	V2, Secondary Voltage Leg 2	1 sec	Degrees	single	Phasor Angle	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	V12, Total Secondary Voltage	1 sec	Degrees	single	Phasor Angle	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	I1, Secondary Current, Leg 1	1 sec	Degrees	single	Phasor Angle	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	I2, Secondary Current, Leg 2	1 sec	Degrees	single	Phasor Angle	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	Ip, Primary Current[3]	1 sec	Degrees	single	Phasor Angle	Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Performance Data	In, Secondary Neutral Current (calculated)[2]	1 sec	Degrees	single	Phasor Angle	Unix/UTC[1]	GPS
50/75 kV	NREL	Meta Data	Serial_Number	1 sec	-	single		Unix/UTC[1]	GPS

Transformers									
50/75 kV Transformers	NREL	Meta Data	Meter Latitude	On Demand[4]	Degrees	single		Unix/UTC[1]	GPS
50/75 kV Transformers	NREL	Meta Data	Meter Longitude	On Demand[4]	Degrees	single		Unix/UTC[1]	GPS
Met Tower [Existing]	NREL	Performance Data	Insolation-DirectNormal	1 min	W/m2	single	average	UTC	GPS
Met Tower [Existing]	NREL	Performance Data	Insolation-DiffuseHorizontal	1 min	W/m2	single	average	UTC	GPS
Met Tower [Existing]	NREL	Performance Data	Insolation-GlobalHorizontalirradience	1 min	W/m2	single	average	UTC	GPS
Met Tower [Existing]	NREL	Performance Data	Temperature	1 min	C	single	average	UTC	GPS
Met Tower [Existing]	NREL	Performance Data	RH	1 min	-	single	average	UTC	GPS
Met Tower [Existing]	NREL	Performance Data	Pressure	1 min	mBar	single	average	UTC	GPS
Met Tower [Existing]	NREL	Performance Data	Zenith Angle	1 min	Deg	single	average	UTC	GPS
Insolation Tower [new]	NREL	Performance Data	Insolation-DirectNormal	1 sec	W/m2	single	average	UTC	GPS
Insolation Tower [new]	NREL	Performance Data	Insolation-DiffuseHorizontal	1 sec	W/m2	single	average	UTC	GPS
Insolation Tower [new]	NREL	Performance Data	Insolation-GlobalHorizontalirradience	1 sec	W/m2	single	average	UTC	GPS

[1]Transformer measurement timestamps are reported as the number of elapsed seconds since 12:00:00 am Jan 1 1970 GMT (the Unix Epoch)

[2]The neutral current phasor, In, will be calculated from the I1 and I2 phasors, not measured directly (most of the time the value of neutral current will be far below the useful range of the current probes)

[3]Due to safety concerns we may not be able to put a current probe on the primary side, in which case Ip will not be collected and the probe will be used to monitor In directly

[4]The meter Latitude and Longitude can be requested from the device, usually immediately after installation, otherwise this information is not transmitted

Table 8. Data Table – SunPower

Equipment	Data Source	Category	Parameter	Frequency	Units	Data Type	Data Set (TBD)	Time Stamp
Customer Panel	SunPower	Performance Data	SunPower - Whole-house purchased	5-min	kWh	Single	Avg	UTC
PV Inverter	SunPower	MetaData	InverterID (serial number)	FreqSync				UTC
PV Inverter	SunPower	Performance Data	PV produced	5-min	kWh	Single	Avg	UTC
All	SunPower	MetaData	House ID	FreqSync		ASCII		
Whole-Unit	SunPower	Performance Data	Real power going out to grid (sell > 0, buy < 0). Mapped as -1 X MeterPowerFromAC.		W	Float		
PV	SunPower	MetaData	PV Orientation	FreqSync	N, NE, E, SE, S, SW, W, NW			
All	SunPower	MetaData	Associated Transformer	FreqSync				
PV	SunPower	MetaData	System Size	FreqSync	kW			

Table 9. Data Table – GridPoint

Equipment	Data Source	Category	Parameter	Frequency	Units	Data Type	Data Set (TBD)	Time Stamp	Time Sync
GridPoint	GridPoint	Metadata	HouseID	FreqSync				UTC	GridPoint Server (NIST)
GridPoint	GridPoint	Performance Data	Whole-house consumption predicted	5-min	Wh	Single	Avg	UTC	GridPoint Server (NIST)
GridPoint	GridPoint	Performance Data	Grid consumption predicted	5-min	Wh	Single		UTC	GridPoint Server (NIST)

Calculated	GridPoint	Performance Data	PV predicted	15-min	Wh	Single		UTC	GridPoint Server (NIST)
RES	GridPoint	MetaData	RES Unit Serial Number	EverySync				UTC	GridPoint Server (NIST)
RES	GridPoint	MetaData	RES Firmware version	EverySync				UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	TimeStamps (Date/Time)	5-min		DateTime		UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	RES - Whole-house consumed/purchased	5-min	Wh	Single	Avg	UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	Mode (standby, charge, discharge, firm)	5-min		Bitmap		UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	Battery produced	5-min	Wh	Single	Min, max, avg	UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	Battery consumed	5-min	Wh	Single	Min, max, avg	UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	Battery state-of-charge	5-min	%	Single		UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	Battery voltage	5-min	V	Single	Min, max, avg	UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	Battery current (+ out, - in)	5-min	A	Single	Min, max, avg	UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	Load shifting schedule planned	5-min	Wh	Single		UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	Load shifting schedule applied	5-min	Wh	Single		UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	Temperature - Batteries	5-min	C	Single		UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	Temperature - Inverter highest	5-min	C	Single		UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	Temperature - Charger highest	5-min	C	Single		UTC	GridPoint Server (NIST)

RES	GridPoint	Performance Data	Temperature - Battery if sensor is attached	5-min	C	Single		UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	Temperature - Battery shunt	5-min	C	Single		UTC	GridPoint Server (NIST)
RES	GridPoint	Performance Data	Firming - TimeStamp (Date/Time)	10-sec		DateTime			
RES	GridPoint	Performance Data	Firming - Whole-house consumed/Purchased	10-sec	Wh	Single			
RES	GridPoint	Performance Data	Firming - BatteryStateOfCharge (Available Energy)	10-sec	Wh	Single			
RES	GridPoint	Performance Data	Firming - TargetSetPoint	10-sec	Wh	Single			
RES	GridPoint	Performance Data	Firming - TargetBatteryOutput	10-sec	Wh	Single			
CES	GridPoint	MetaData	CES Unit Serial Number	EverySync		ASCII [16]		UTC	GridPoint Server (NIST)
CES	GridPoint	MetaData	GEM Firmware Version	EverySync		ASCII [32]		UTC	GridPoint Server (NIST)
CES	GridPoint	MetaData	DSP Firmware Version	EverySync		ASCII [4]		UTC	GridPoint Server (NIST)
CES	GridPoint	MetaData	FPGA Firmware Version	EverySync		ASCII [4]		UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	Time Stamps	5-min		DateTime		UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	CES - Whole CES houses consumed/purchased	5-min	Wh	Single	Min, max, avg	UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	CES - CES unit consumed/purchased	5-min	Wh	Single	Min, max, avg	UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	Mode (standby, charge, discharge, firm)	5-min		Bitmap		UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	Battery produced	5-min	Wh	Single	Min, max, avg	UTC	GridPoint Server (NIST)

CES	GridPoint	Performance Data	Battery consumed	5-min	Wh	Single	Min, max, avg	UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	Battery available Energy	5-min	Wh	Single	Min, max, avg	UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	Battery state-of-charge	5-min	%	Single		UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	Battery voltage (Terminal voltage)	5-min	V	Single	Min, max, avg	UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	Battery current (+ out, - in)	5-min	A	Single	Min, max, avg	UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	Load shifting schedule planned	5-min	Wh	Single	Min, max, avg	UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	Load shifting schedule applied	5-min	Wh	Single	Min, max, avg	UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	Temperature - Batteries	5-min	C	Single		UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	Temperature - Cabinet	5-min	C	Single		UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	Temperature - Inverter	5-min	C	Single		UTC	GridPoint Server (NIST)
CES	GridPoint	Performance Data	Firming - TimeStamp (Date/Time)	10-sec		DateTime			
CES	GridPoint	Performance Data	Firming - Whole-house consumed/Purchased	10-sec	Wh	Single			
CES	GridPoint	Performance Data	Firming - BatteryStateOfCharge (Available Energy)	10-sec	%	Single			
CES	GridPoint	Performance Data	Firming - TargetSetPoint	10-sec	Wh	Single			
CES	GridPoint	Performance Data	Firming - TargetBatteryOutput	10-sec	Wh	Single			
Weather	AWS-Weatherbug	Performance Data	TimeStamp (Date/Time)	1-hr				UTC	GridPoint Server (NIST)

Weather	AWS-Weatherbug	Performance Data	Temperature	1-hr	F			UTC	GridPoint Server (NIST)
Weather	AWS-Weatherbug	Performance Data	Relative Humidity	1-hr	%			UTC	GridPoint Server (NIST)
Weather	AWS-Weatherbug	Performance Data	Wind Speed	1-hr	mph			UTC	GridPoint Server (NIST)
Weather	AWS-Weatherbug	Performance Data	Wind Direction	1-hr	deg			UTC	GridPoint Server (NIST)

Table 10. Data Table – SMUD

Equipment	Data Source	Category	Parameter	Frequency	Units	Data Type	Data Set	Necessary Delta to Trigger Recording	TimeStamp	Time Sync
SubStation Bus	SMUD	Performance Data	Potential across A-B Phase	3 sec	kV	Single	Avg	0.01	Local Time	SCADA (GPS)
SubStation Bus	SMUD	Performance Data	Potential across B-C Phase	3 sec	kV	Single	Avg	0.01	Local Time	SCADA (GPS)
SubStation Bus	SMUD	Performance Data	Potential across C-A Phase	3 sec	kV	Single	Avg	0.01	Local Time	SCADA (GPS)
SubStation Bus	SMUD	Performance Data	Ground Current	3 sec	A	Single	Avg	0.1	Local Time	SCADA (GPS)
SubStation Bus	SMUD	Performance Data	Phase A Current	3 sec	A	Single	Avg	0.1	Local Time	SCADA (GPS)
SubStation Bus	SMUD	Performance Data	Phase B Current	3 sec	A	Single	Avg	0.1	Local Time	SCADA (GPS)
SubStation Bus	SMUD	Performance Data	Phase C Current	3 sec	A	Single	Avg	0.1	Local Time	SCADA (GPS)
SubStation Bus	SMUD	Performance Data	Power Factor	3 sec	-	Single	Avg	1	Local Time	SCADA (GPS)
Feeder 1, 2 and	SMUD	Performance	B1201	3 sec	-	Single	Avg	0	Local Time	SCADA

3		Data								(GPS)
Feeder 1, 2 and 3	SMUD	Performance Data	B1201A	3 sec	-	Single	Avg	0	Local Time	SCADA (GPS)
Feeder 1, 2 and 3	SMUD	Performance Data	B1201B	3 sec	-	Single	Avg	0	Local Time	SCADA (GPS)
Feeder 1, 2 and 3	SMUD	Performance Data	Ground Current	3 sec	A	Single	Avg	0.1	Local Time	SCADA (GPS)
Feeder 1, 2 and 3	SMUD	Performance Data	Reactive Power	3 sec	MVAR	Single	Avg	0.1	Local Time	SCADA (GPS)
Feeder 1, 2 and 3	SMUD	Performance Data	Real Power	3 sec	MW	Single	Avg	0.1	Local Time	SCADA (GPS)
Feeder 1, 2 and 3	SMUD	Performance Data	Phase A Current	3 sec	A	Single	Avg	0.1	Local Time	SCADA (GPS)
Feeder 1, 2 and 3	SMUD	Performance Data	Phase B Current	3 sec	A	Single	Avg	0.1	Local Time	SCADA (GPS)
Feeder 1, 2 and 3	SMUD	Performance Data	Phase C Current	3 sec	A	Single	Avg	0.1	Local Time	SCADA (GPS)
Feeder Bus	SMUD	Performance Data	Potential across A-B Phase	3 sec	kV	Single	Avg	0.01	Local Time	SCADA (GPS)
Feeder Bus	SMUD	Performance Data	Potential across B-C Phase	3 sec	kV	Single	Avg	0.01	Local Time	SCADA (GPS)
Feeder Bus	SMUD	Performance Data	Potential across C-A Phase	3 sec	kV	Single	Avg	0.01	Local Time	SCADA (GPS)
Feeder Bus	SMUD	Performance Data	Phase A Current	3 sec	A	Single	Avg	0.1	Local Time	SCADA (GPS)
Feeder Bus	SMUD	Performance Data	Phase B Current	3 sec	A	Single	Avg	0.1	Local Time	SCADA (GPS)
Feeder Bus	SMUD	Performance Data	Phase C Current	3 sec	A	Single	Avg	0.1	Local Time	SCADA (GPS)
Feeder 1, 2 and 3	SMUD	Performance Data	Power Factor	3 sec	-	Single	Avg	1	Local Time	SCADA (GPS)

Feeder 1, 2 and 3 Capacitor Banks	SMUD	Performance Data	Stage Position	3 sec	-	-	0, 1, or 2	-	Local Time	SCADA (GPS)
Transformer	SMUD	Performance Data	Reactive Power	3 sec	MVAR	Single	Avg	0.05	Local Time	SCADA (GPS)
Transformer	SMUD	Performance Data	Real Power	3 sec	MW	Single	Avg	0.05	Local Time	SCADA (GPS)
Transformer	SMUD	Performance Data	Oil Temp	3 sec	C	Single	Avg	0.1	Local Time	SCADA (GPS)
Transformer	SMUD	Performance Data	Tap Position	3 sec	-	Single	Avg	0	Local Time	SCADA (GPS)

NAVIGANT
ENERGY

RES Testing Schedule

May 2012

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
6	7	8	9	10	11 11	12 11
13 11	14 11	15 11	16 11	17 11	18 7	19 7
20 7	21 7	22 7	23 7	24 7	25 1	26 1
27 1	28 1	29 1	30 1	31 1		

June 2012

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					1 8	2 8
3 8	4 8	5 8	6 8	7 8	8 8	9 11
10 11	11 11	12 11	13 11	14 11	15 11	16 7
17 7	18 7	19 7	20 7	21 7	22 7	23 1
24 1	25 1	26 1	27 1	28 1	29 1	30 8

July 2012

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1 8	2 8	3 8	4 8	5 8	6 8	7 11
8 11	9 11	10 11	11 11	12 11	13 11	14 7
15 7	16 7	17 7	18 7	19 7	20 7	21 7
22 1	23 1	24 1	25 1	26 1	27 1	28 1
29 1	30 5	31 6				

August 2012

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1 5	2 6	3 8	4 8
5 8	6 8	7 8	8 8	9 8	10 8	11 11
12 11	13 11	14 11	15 11	16 11	17 11	18 7
19 7	20 7	21 7	22 7	23 7	24 7	25 1
26 1	27 1	28 1	29 1	30 1	31 1	

September 2012

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1 8
2 8	3 8	4 8	5 8	6 8	7 8	8 10
9 10	10 10	11 10	12 10	13 10	14 10	15 7
16 7	17 7	18 7	19 7	20 7	21 7	22 1
23 1	24 1	25 1	26 1	27 1	28 1	29 8
30 8						

CES Testing Schedule

May 2012

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3	4	5
6	7	8	9	10 11	11 11	12 11
13 11	14 11	15 11	16 11	17 11	18 11	19 1
20 1	21 1	22 1	23 1	24 1	25 1	26 11
27 11	28 11	29 11	30 11	31 11		

June 2012

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					1 11	2 11
3 11	4 11	5 11	6 11	7 11	8 11	9 1
10 1	11 1	12 1	13 1	14 1	15 1	16 11
17 11	18 11	19 11	20 11	21 11	22 11	23 2
24 2	25 2	26 2	27 2	28 2	29 2	30 11

July 2012

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1 11	2 11	3 11	4 11	5 11	6 11	7 1
8 1	9 1	10 1	11 1	12 1	13 1	14 11
15 11	16 11	17 11	18 11	19 11	20 11	21 2
22 2	23 2	24 2	25 2	26 2	27 2	28 2
29 2	30 5	31 6				

August 2012

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1 5	2 6	3 11	4 11
5 11	6 11	7 11	8 11	9 11	10 11	11 1
12 1	13 1	14 1	15 1	16 1	17 1	18 11
19 11	20 11	21 11	22 11	23 11	24 11	25 2
26 2	27 2	28 2	29 2	30 2	31 2	

September 2012

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1 11
2 11	3 11	4 11	5 11	6 11	7 11	8 1
9 1	10 1	11 1	12 1	13 1	14 1	15 11
16 11	17 11	18 11	19 11	20 11	21 11	22 2
23 2	24 2	25 2	26 2	27 2	28 2	29 11
30 11						

Data Reporting Form

Date:

Operator Name:

Expected Temperatures:

Expected Cloud Cover:

Operating Scenario:

Battery Operating Mode:

Battery SOC in the Morning:

Battery Maximum Capacity:

Notes or Observations:

GRIDPOINT

SMUD – Operational Modes
Firming and Load Shifting

May 2nd 2011

Summary

- **Operational Modes**
- **Firming Design**
- **Load Shifting Design**
- **Custom Schedule**

Operational modes

Standby	Firming	Predictive Load Shifting	Load Shifting based on pricing	Custom Schedule

- Controlled in the GP Analytics UI.
- Driven by a schedule that needs to be created in advance.
- All modes are mutually exclusive.
- A new operational mode can be started only at the beginning of every 5 minutes periods.
  - For example exactly at 10:00:00, 10:05:00, 10:10:00, etc.

- OTHER VARIABLE:
  - Battery Maximum Capacity (25%, 50% and 100%)

GRIDPOINT

Operational modes

Standby	Firming	Predictive Load Shifting	Load Shifting based on pricing	Custom Schedule

» **Standby**

- Default operational mode.
- Does not need to be planned.

GRIDPOINT

Operational modes

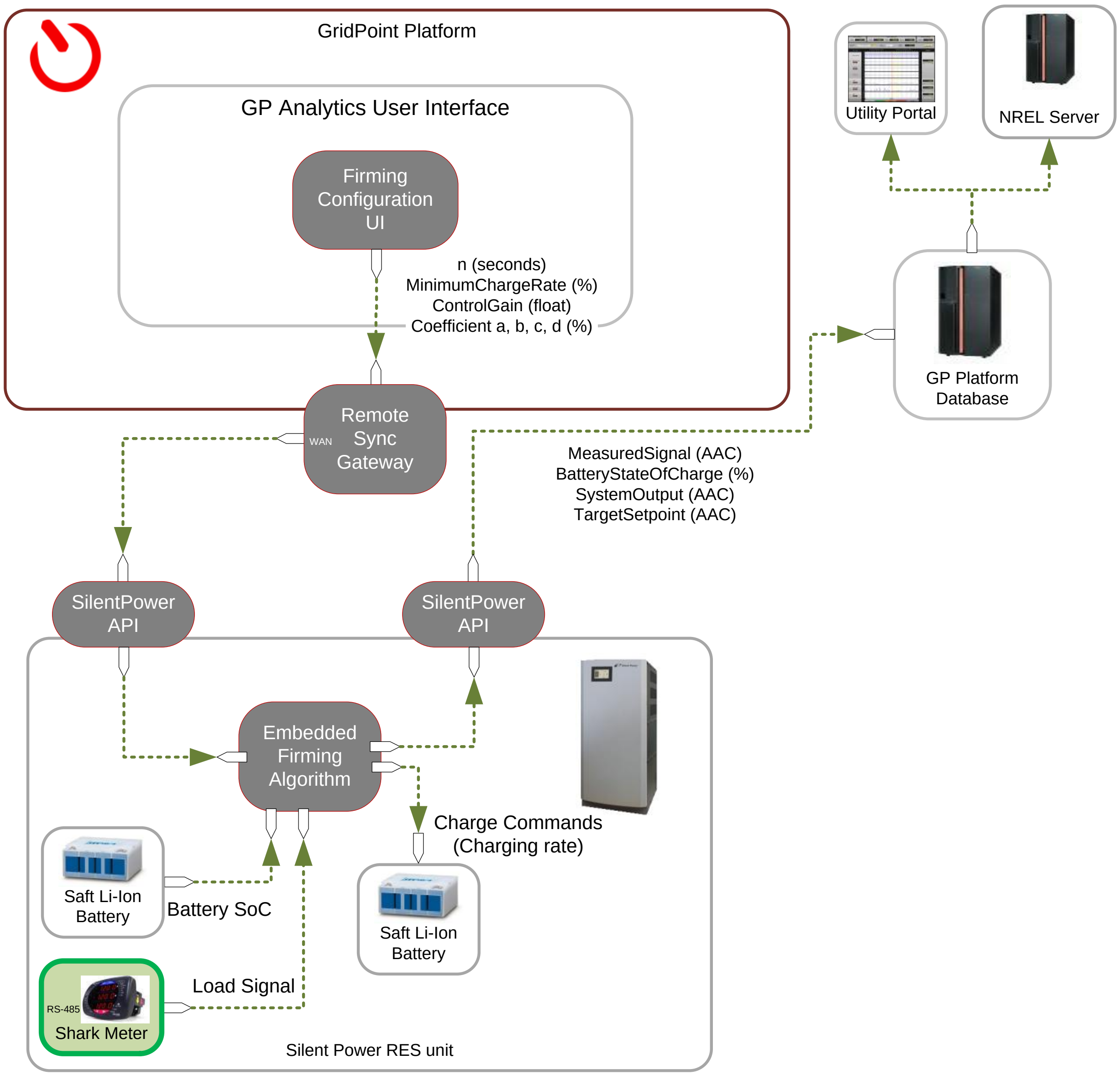
Standby	Firming	Predictive Load Shifting	Load Shifting based on pricing	Custom Schedule

- **Firming**

  GOAL: Reduce the **short-term** variability ("spikiness") of the controlled load from the standpoint of the grid.

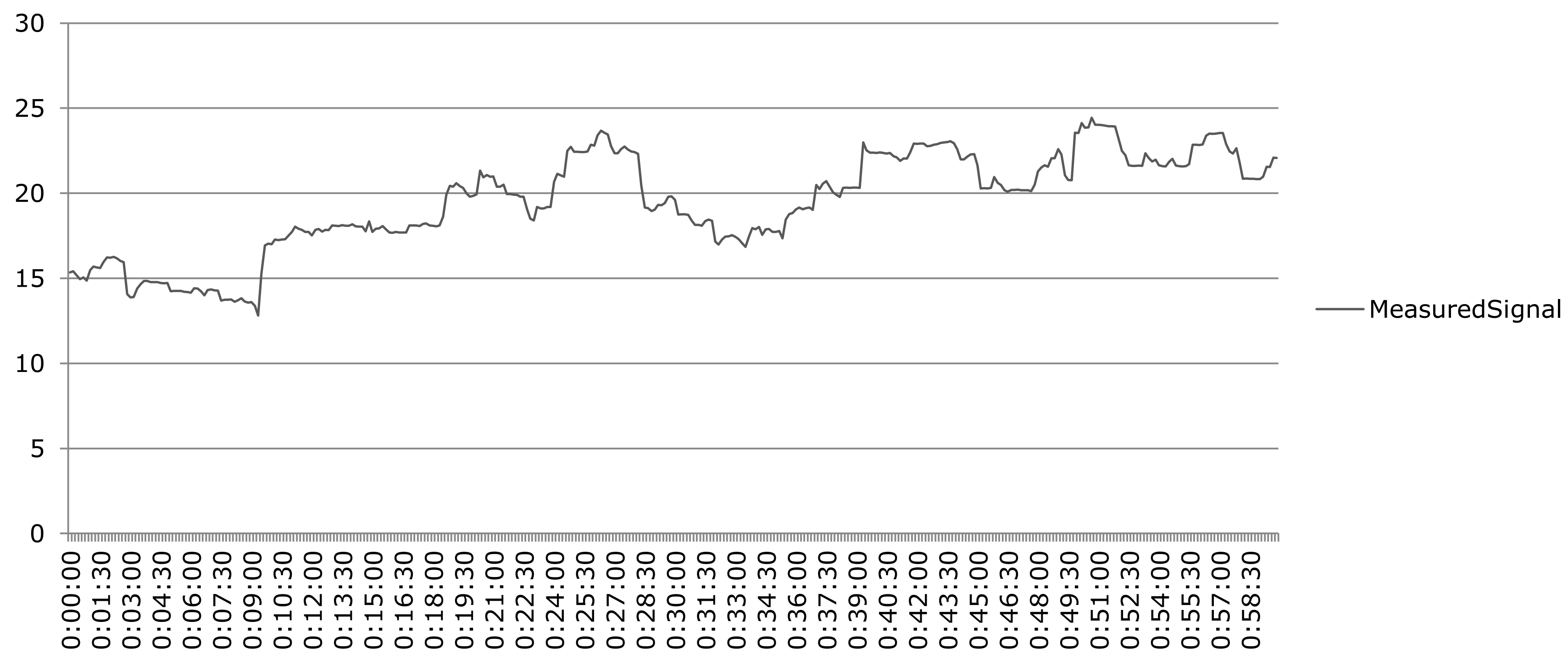
  - ON/OFF command.
  - Adjusts the consumption at a **10 seconds** resolution.
  - Flexible schedule, planned with 15 minutes blocks or more.

SMUD – High Penetration Solar Pilot
Firming Diagram



Firming Design

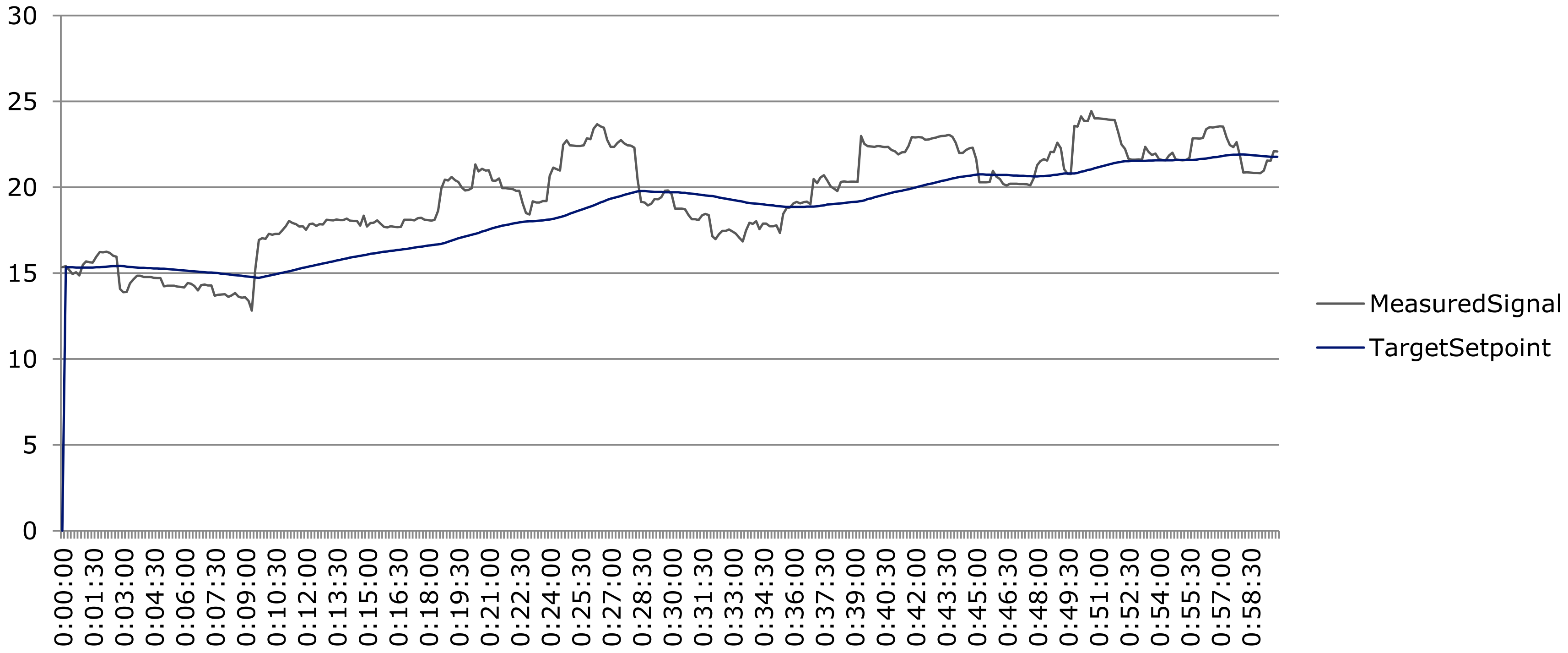
» **Grid Power consumption for the first hour :**



GRIDPOINT

Firming Design

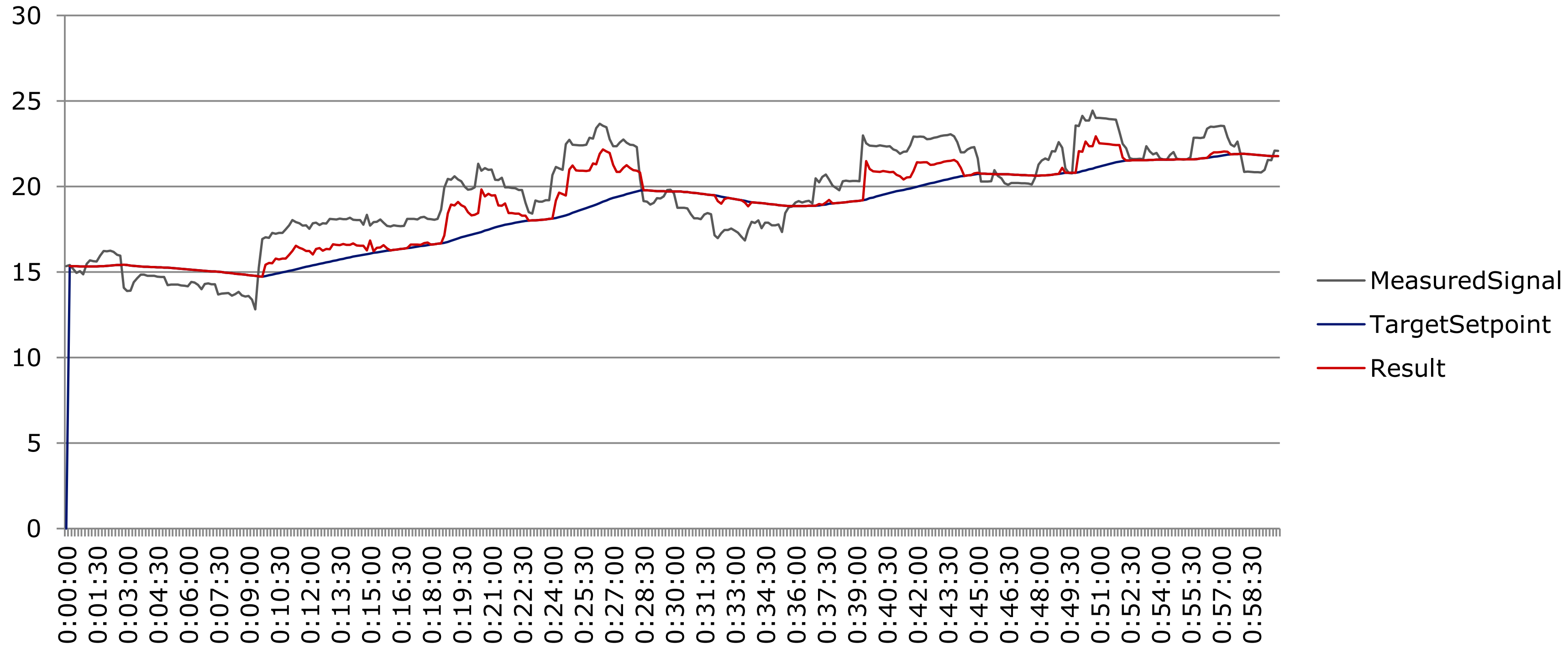
» **Target Setpoint that the algorithm tries to achieve :**



GRIDPOINT

Firming Design

» **In the following graph, we can see the result of firming**



Operational modes

Standby	Firming	Predictive Load Shifting	Load Shifting based on pricing	Custom Schedule

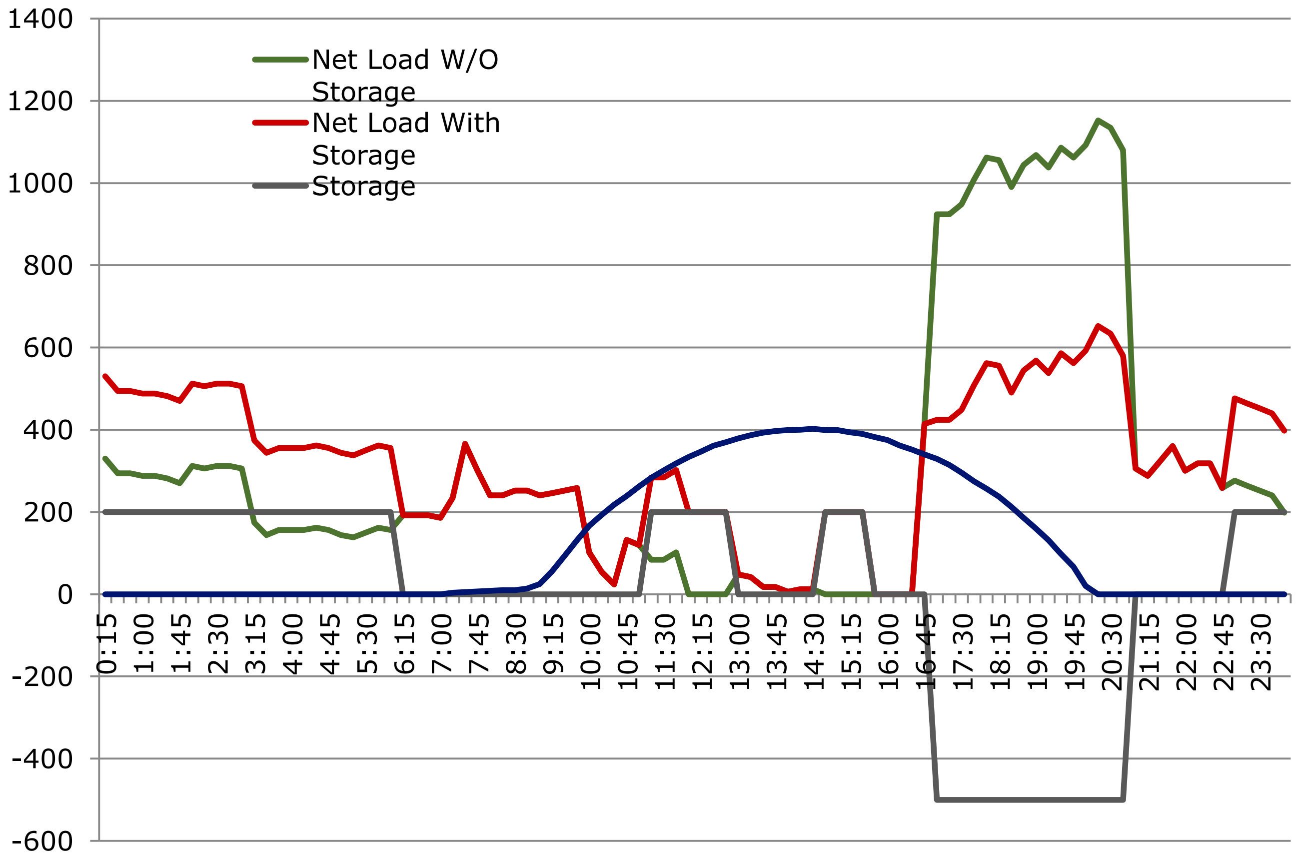
» **Predictive Load Shifting**

GOAL: Load-shift to reduce high and low peaks of the consumption for the day from a stand-point of the grid.

- Based on predictions:
  - Weather predictions
  - Previous consumptions
  - PV production predictions
- FULL DAY, HALF DAY

Predictive Load Shifting

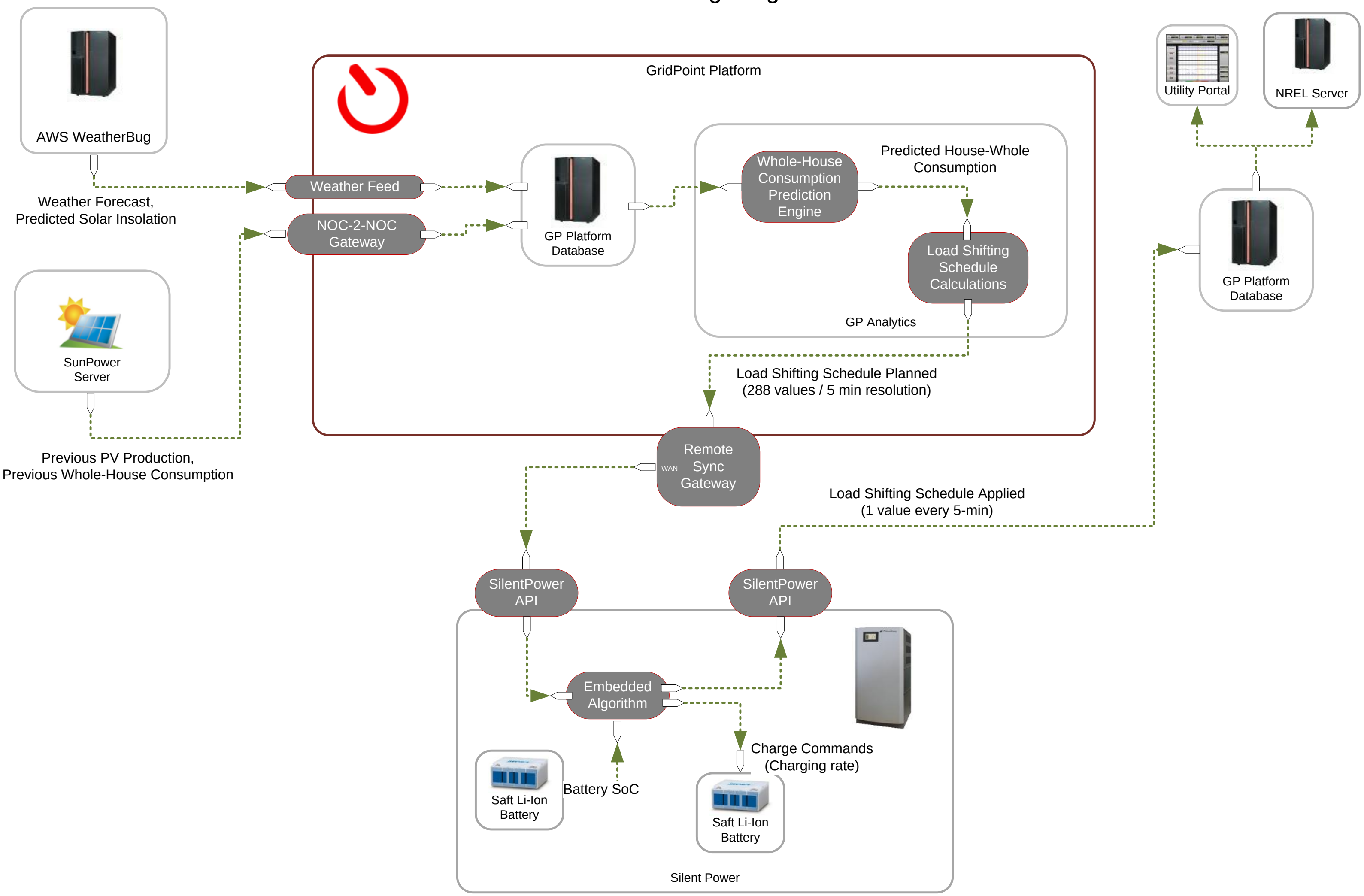
- **The appliances will receive a schedule once or twice a day from the GP Platform.**



GRIDPOINT

Predictive Load Shifting

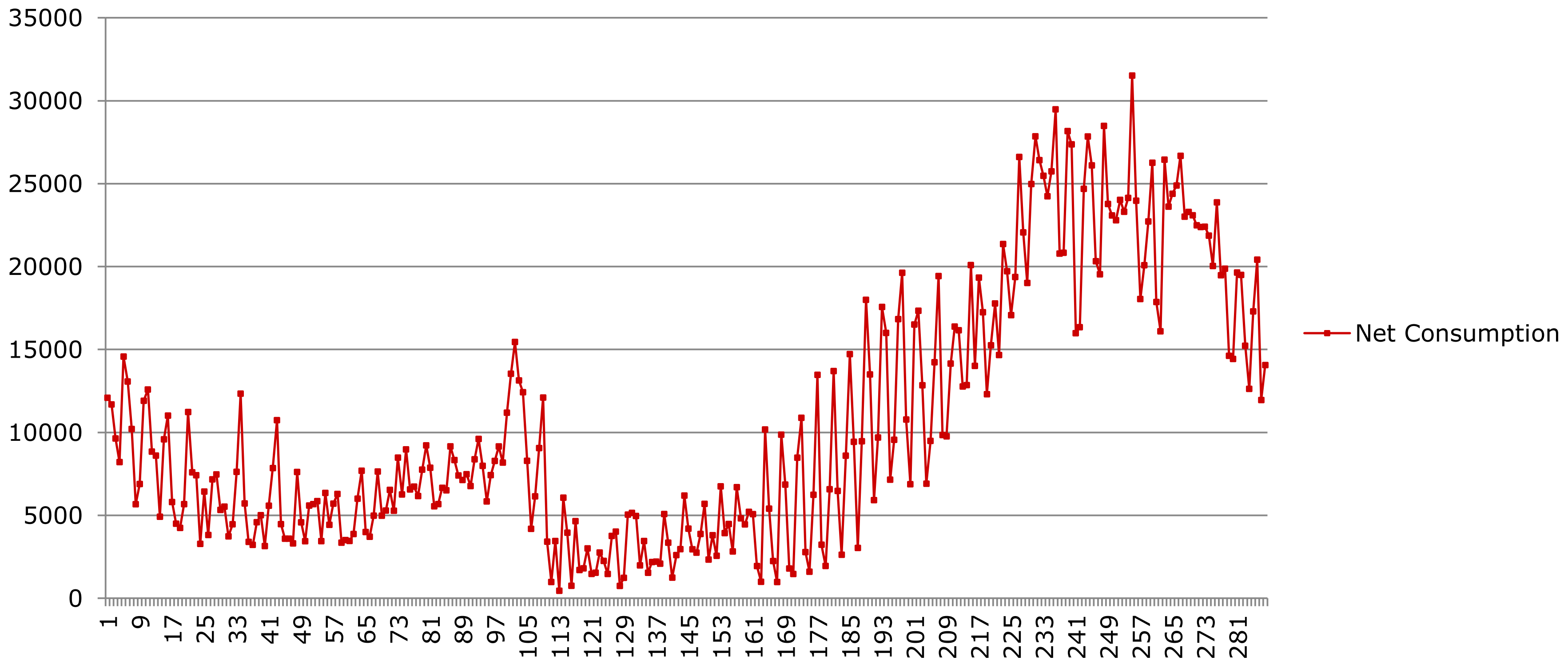
SMUD – High Penetration Solar Pilot
Load Shifting Diagram



GRIDPOINT

Predictive Load Shifting

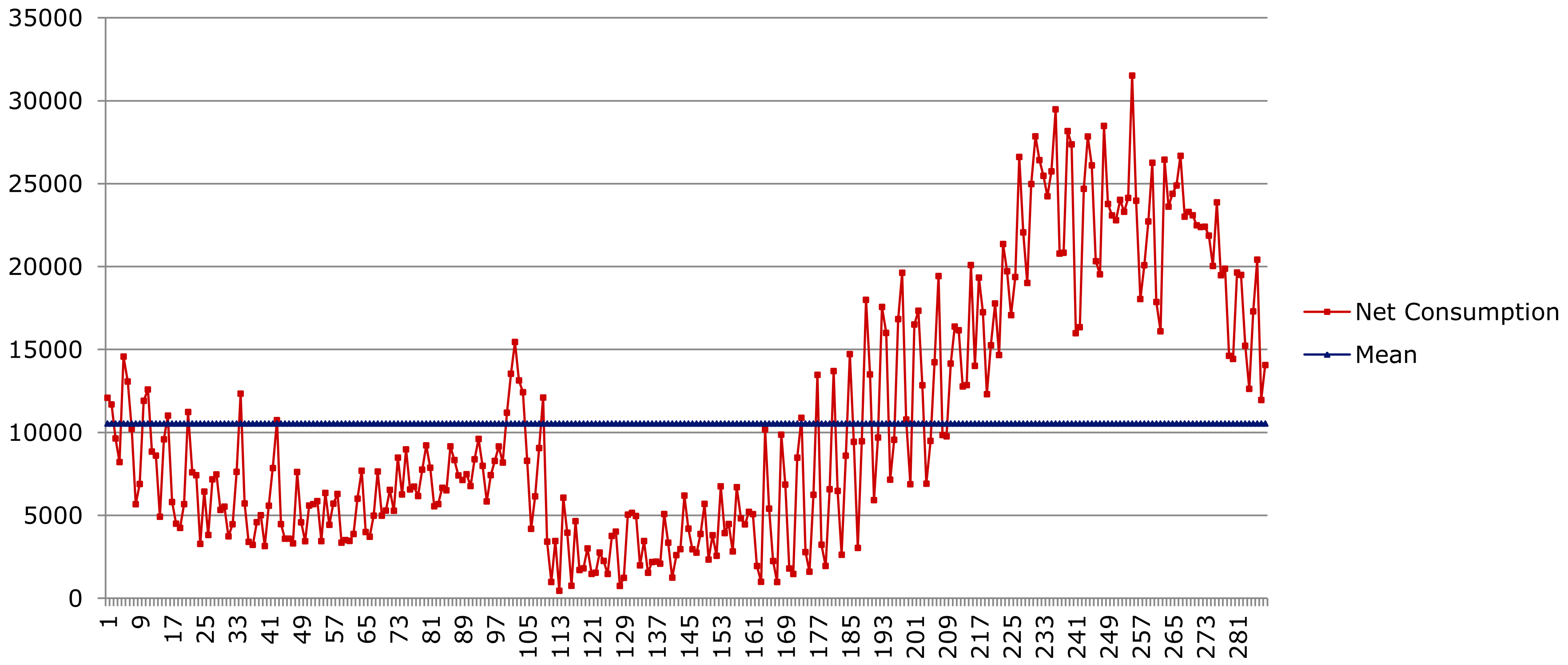
» **Net consumption for a day :**



GRIDPOINT

Predictive Load Shifting

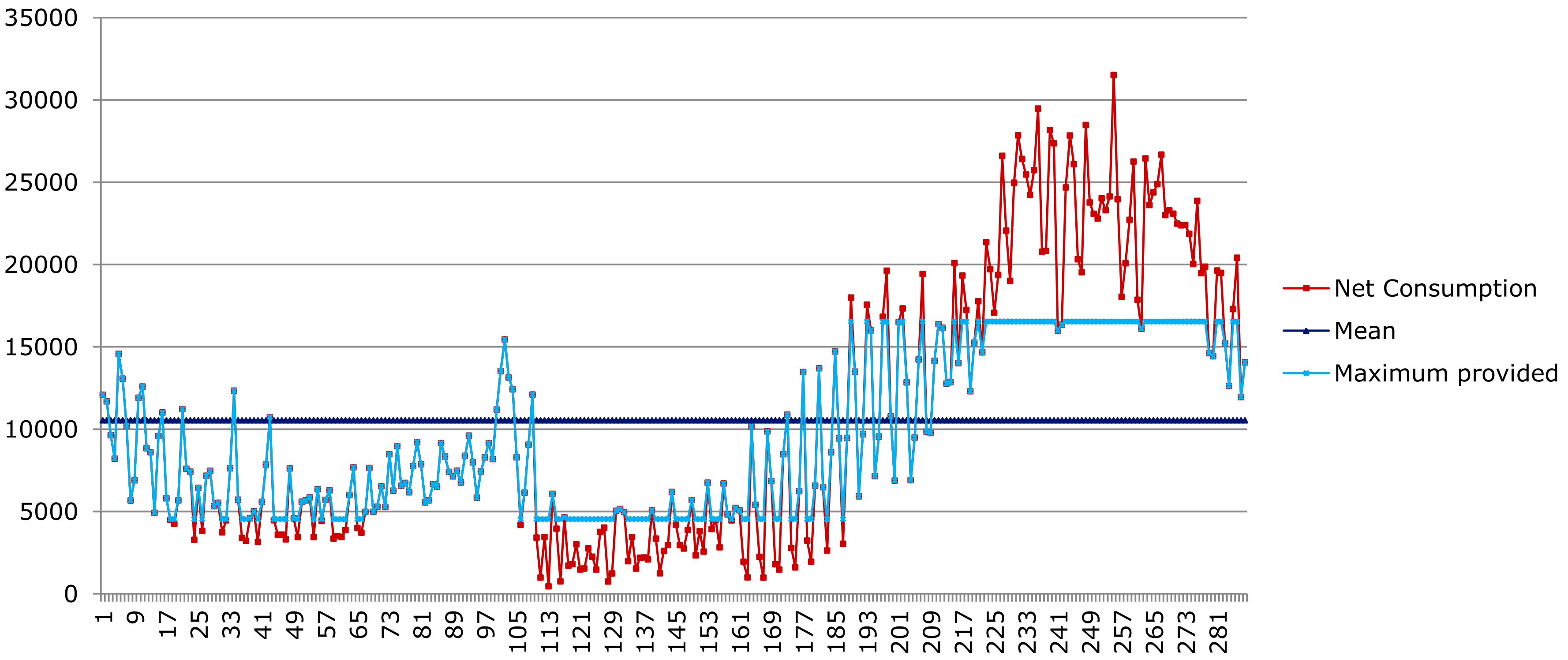
» **Mean consumption for the day :**



GRIDPOINT

Predictive Load Shifting

» **Maximum battery energy provided :**

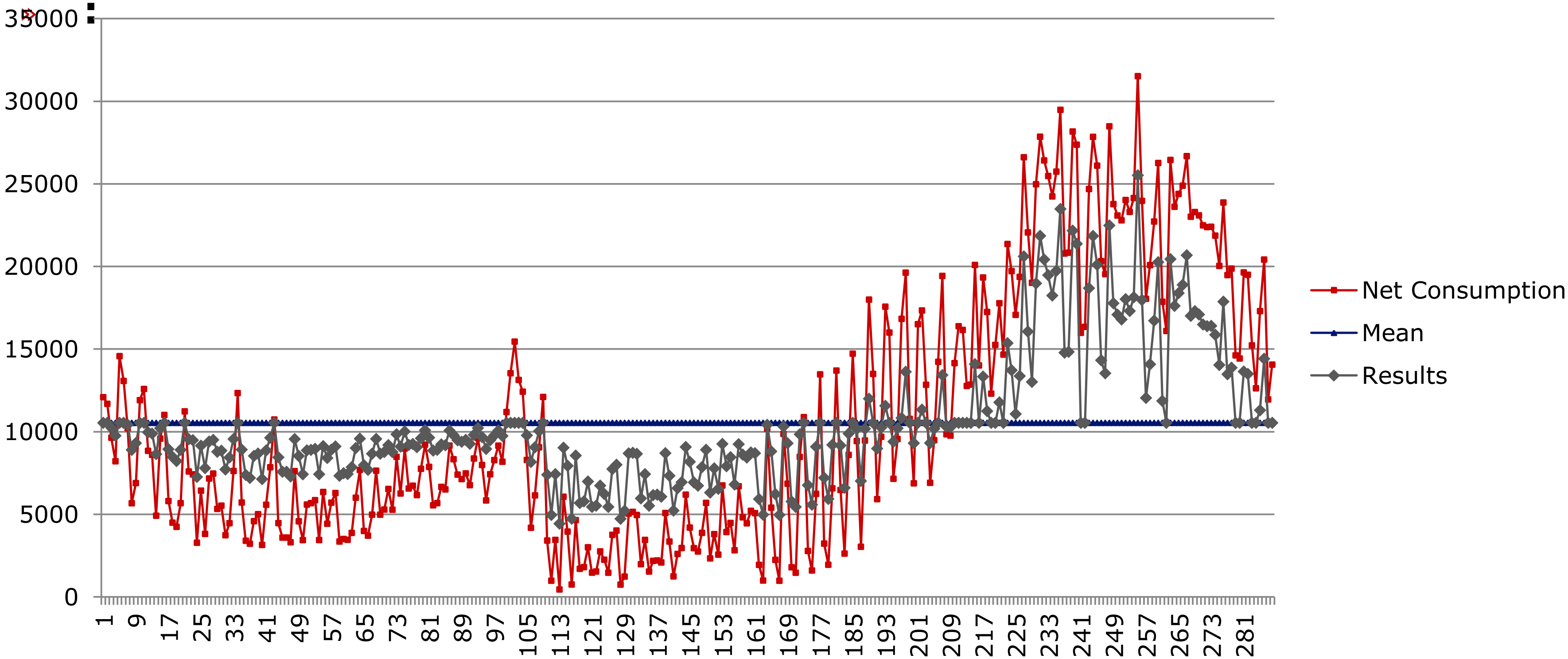


GRIDPOINT

Predictive Load Shifting

» **Results**

» :



GRIDPOINT

Operational modes

Standby	Firming	Predictive Load Shifting	Load Shifting based on pricing	Custom Schedule

» **Load Shifting based on pricing**

GOAL: Load-shift to reduce the cost for the customer based on the pricing table.

- Based on the pricing table
- FULL DAY ONLY

- HARDCODED Load Shifting Schedule: (Pacific Time)

WINTER SEASON - NOVEMBER 1 through APRIL 30

Discharge: Weekdays between 7:00 a.m. and 10:00 a.m., and 5:00 p.m. and 8:00 p.m.

SUMMER SEASON - MAY 1 through OCTOBER 31

Discharge: Weekdays between 2:00 p.m. and 8:00 p.m.

* The appliance would **charge** the rest of the time

Operational modes

Standby	Firming	Predictive Load Shifting	Load Shifting based on pricing	Custom Schedule

- **Custom Schedule**
  - Test case scenarios based on a custom schedule. (charge and discharge events)
  - Schedule built in the GP Analytics UI
  - Ability to specify the charging or discharging rate. (%)
  - Schedule can be planned with blocks of 15 minutes.

Integration Test Plans for Community Energy Storage (CES) Unit – Sacramento Municipal Utility District Version

Revision 0.1

Revision History			
Version	**Author**	**Date**	**Comments**
0.1	Jack Lesko & Jay Kidd	07 Dec 2010	Initial revision for review by GridPoint and SMUD

1 Background

In connection with the award through DOE-ARRA of funding for the Sacramento Municipal Utility District (SMUD) High Penetration Solar Deployment project PowerHub Systems (formerly VPT Energy Systems) will supply to GridPoint Community Energy Storage (CES) units for deployment within this experimental demonstration project.

In the role of supplier, PowerHub will engineer for the SMUD Project and deliver to GridPoint, CES units for subsequent integration with the GridPoint's distributed energy aggregation and control system products. These CES units will employ the demonstrated PowerHub technology for interoperable distributed storage. Specifically, PowerHub will engineer CES units that interact and interface with the GridPoint GEM and a Saft battery pack, suitable to the needs of the SMUD Project deployment.

A key PowerHub deliverable for this effort includes the Integration, Acceptance and Commissioning Test **Strategies**. These are defined as noted below and discussed in further detail in Section 2 Approach.

- **Integration Test:** Those tests required by PowerHub and/or in cooperation with Saft & GridPoint to ensure technical functionality to the specifications while designing and assembling the system,
- **Acceptance Test:** Those tests required by SMUD for acceptance prior to deployment in the field,
- **Commissioning Test:** Those tests required to install and commission the CES units for operation in SMUD deployment.

We emphasize here that this document is a high level discussion of the strategies required to ensure functional integration between systems and that the CES unit and its controls can be safely and effectively deployed in the SMUD distribution circuits. The goal is to communicate the approaches for integration, acceptance and commissioning without excessive documentation and to indicate the critical aspects of the testing as pertinent to SMUD and the system integrators relative to the requirements. The specific testing details are captured elsewhere and results will be recorded as discussed further below with links on how to access them in the working documents. The central tool deployed for these purposes is **Topcased-SYSML**[1] which provides a means to organize, coordinate, and report testing and verification against the requirements.

---

[1] A computer-aided software and systems engineering tool that connects use cases for operating an integrated software/hardware system with the integrated design requirements: http://www.topcased.org/index.php?idd_projet_pere=20

2 Discussion to Integration Testing, Acceptance Testing & Commissioning of SMUD CES units

2.1 Integration Testing

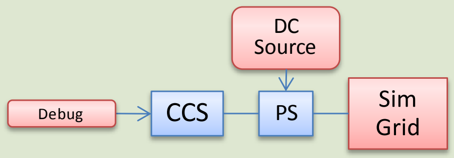
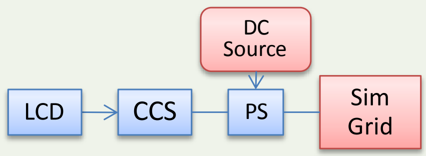
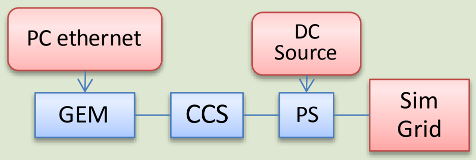
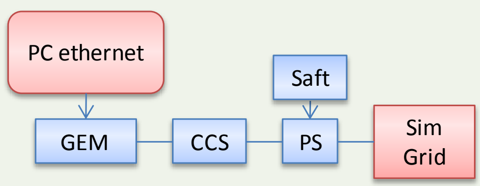
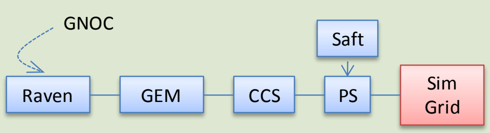
The tests required by PowerHub and/or in cooperation with Saft & GridPoint to ensure technical functionality to the specifications while integrating the hardware and software are separated into a staged sequence. These stages are designated:

- *I1 - Power Stage Integration*
- *I2 - Local Control Integration*
- *I3 - Moxa Integration*
- *I4 - Saft Battery Integration*
- *I5 - GEM/GNOC Integration*

The five integration test stages are directly connected to the requirements and lead logically to the acceptance criteria through use cases also driven by the requirements. Moreover, regression testing is instituted as each stage to assure that any changes or adjustments to hardware and software do not introduce new bugs, errors or conflicts. These five integration stages are summarized in Table xx with details regarding entrance criteria, exit criteria and suggested timing.

The subsections below provide a complete set of details for each of the integration test stages. The level of detail included here in this phase is included so as to clearly communicate between system integrators the functionality required and assessed in the initial stages of the CES integration. The information is organized in the following manner:

- Purpose
- System Configuration & Components
- Firmware Requirements
- Test Requirements
- Entrance & Exit Criteria
- Configuration Management

Integration Systems	Entry Criteria	Date	Exit Criteria	Date
 **I1**	• Hardware (CCS & PS)		• Functioning Power -*Stage Steady State Open Loop Charge and Discharge*	
 **I2**				
 **I3**	• Completion of the GI-6 • Functioning Power Stage		• Critical MODBUS reads are implemented and mode transitions not including Sleep and Standby	
 **I4**	• MODBUS write registers and all the modes • Functioning CAN & Batteries		• Full Saft integration • Full MODBUS implementation • Utility source interconnect functionality met (anti-islanding, within voltage and frequency rages)	
 **I5**	• GridPoint GNOC operational & communicating Completion of the GI-6		• GNOC fully functioning • Meet UL 1741 utility interconnect requirements	

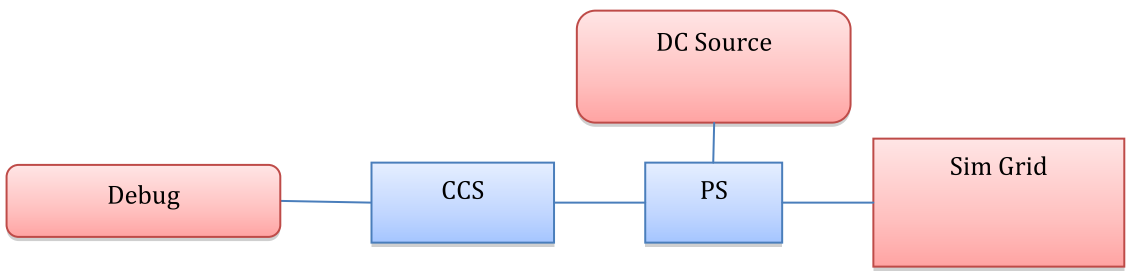
2.1.1 Power Stage Integration (I1)

The Power Stage Integration phase focus is on the integration of the CCS and Power Stage to ensure that basic loop functions work properly at low power levels, ensure that signals (drive, sense) are of reasonable signal/noise and read correctly.

Additionally, the CCS hardware comparators are verified.

2.1.1.1 System Configuration

The system configuration utilized for power stage integration testing is shown below. The role each component plays in the configuration is presented in the following table.



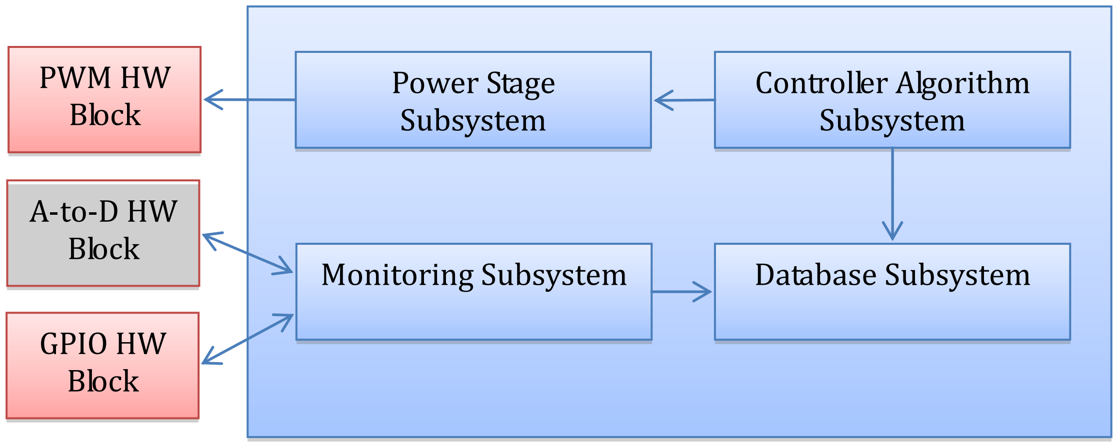
Components	Description
CCS	The control card subsystem developed by PowerHub Systems. The main features of CCS include (1) the TI TMS320F28335 control card, (2) an Altera Cyclone II FPGA, (3) analog-to-digital converters and filters for current, voltage and temperature measurements and (4) hardware protection.
PS	The power stage developed for the SMUD CES application. The CCS interfaces to the PS via a 40-pin ribbon cable. This interface is bi-directional with the CCS providing control signals for the IGBTs, fans and AC contactor located on the PS while the PS provides current, voltage and temperature signals used as inputs to CCS analog-to-digital converters and a fan status signal.
Sim Grid	This provides a simulated power grid for the integration phase. The simulated grid is a split phase 240 VAC source capable of 40 kVA.
DC Source	This provides the DC voltage and current normally supplied by the Saft batteries. The DC source is capable of up to 600 VDC and up to 30kW.
Debug	This represents an engineering workstation running TI's Code Composer Studio 4. From this workstation the CCS control program can be debugged interactively.

2.1.1.2 Firmware Requirements

This section describes the feature requirements of the TI processor and the FPGA for the Power Stage Integration phase.

2.1.1.2.1 DSP

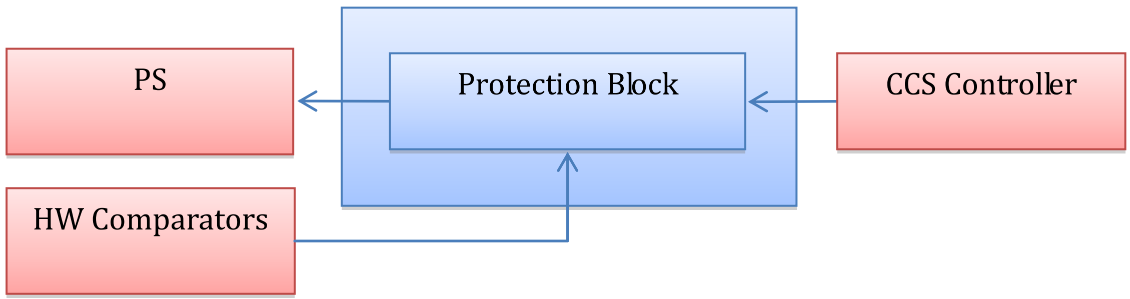
The following diagram depicts the DSP subsystems needed for power stage integration testing. The requirements of each are presented in the table that follows.



Subsystem	Requirements
Power Stage	The Power Stage subsystem provides the interface for driving the power stage switching gates. The on-board PWM hardware block of the TI DSP is utilized to the drive these gates.
Controller Algorithm	For this integration phase the Controller Algorithm subsystem simply switches the power stage at a fixed 10 kHz rate with a 50% duty cycle.
Monitoring	The Monitoring subsystem provides the interface to the on-board analog-to-digital converter hardware block and to the on-board general-purpose input/output block. Both the PS and local CCS sensors provide analog inputs to the TI controller. For this integration phase the only discrete input/output lines implemented are the ones used to monitor and control the internal and heat sink fans and the PCC relay located on the PS.
Database	For this integration phase the Database subsystem is used to store the current operating mode, raw a-to-d values read from the A-to-D HW Block and PS fan status. Note no scaling is applied at this time to the a-to-d values.

2.1.1.2.2 FPGA

The following diagram depicts the FPGA blocks needed for power stage integration testing. The requirements of each are presented in the table that follows.



Block	Requirements
Protection	The Protection block determines if the CCS controller gate switching signals are routed to the PS. Any hardware comparator fault will disable gate switching signals.

2.1.1.3 Test Requirements

The following features are tested and verified during the Power Stage Integration phase.

- Software architecture
- Driving the power stage at a fixed frequency and duty cycle.
- Reading the following analog sensor data from the power stage
- Reading the following analog sensor data from the CCS
- Monitoring and controlling the PS internal and heat sink fans
- Opening and closing the PS PCC relay
- Hardware implemented switching gate protection
- FPGA implemented switching gate protection

2.1.1.4 Entry Criteria

The power stage and CCS have been verified independently. At a minimum the signal integrity of each board should be verified prior to integration. Its contactor manufacturer verifies the PS board while the CCS is verified in-house by PowerHub Systems.

2.1.1.5 Exit Criteria

The following test requirements defined for CCS communications with the PS **MUST** be completely verified before entering the next integration phase.

- The power stage is driven at the predefined frequency and duty cycle
- Analog sensor data is correctly read from the power stage
- The PS internal and heat sink fans can be turned on and off
- The status of the PS internal fan can be read
- The PCC Relay is properly enabled/disabled
- The CCS hardware protection properly enables/disables gate switching in the presence/absence of comparator faults

- FPGA implemented switching gate protection. While not necessary for power stage integration testing it should be done to ensure that the FPGA is properly built and programmed.

Verification of these items ensures the interface requirements between the CCS and the PS have been satisfied.

The remaining test requirements should be satisfied, but are not necessary for passing the Power Stage Integration phase.

- Software architecture. It is difficult, if not impossible, to say the software architecture passes or fails. This purpose of the test requirement is to show that the basic CCS controller firmware executes as expected during this integration phase.
- The ability to read analog sensor data from the CCS board. This is not necessary for passing the Power Stage Integration phase, however any CCS hardware issues uncovered here must be resolved prior to the Local Control Integration (I2) phase.

2.1.1.6 Configuration Management

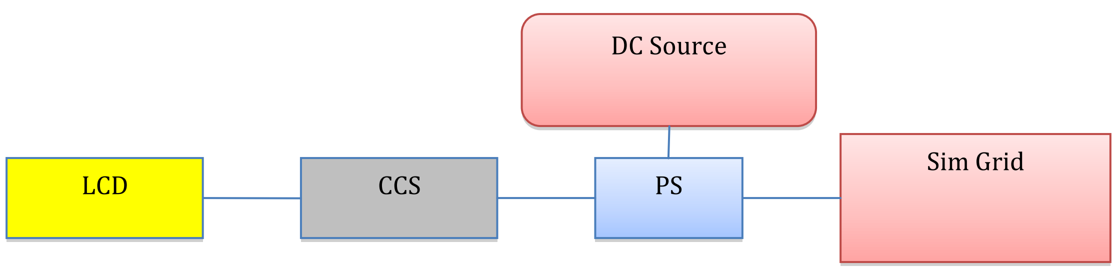
Issues found during testing are entered into bugzilla for tracking purposes. The final code build for both DSP and FPGA will be labeled in subversion as "SMUD-CES-I1".

2.1.2 Local Control Integration (I2)

The Local Control Integration phase focus is on the integration of the LCD module for displaying basic CES unit information and local control of the CES unit enable and the AC contactor.

2.1.2.1 System Configuration

The system configuration utilized for local control integration testing is shown below. Note new components from the previous integration phase are shown in yellow while modified ones are in gray. The role each component plays in the configuration is presented in the following table.



Components	Description
CCS	The CCS firmware developed in I1 with the addition of the FPGA communications and user interface subsystem. The FPGA is updated to include communication blocks for both the DSP and the LCD module.

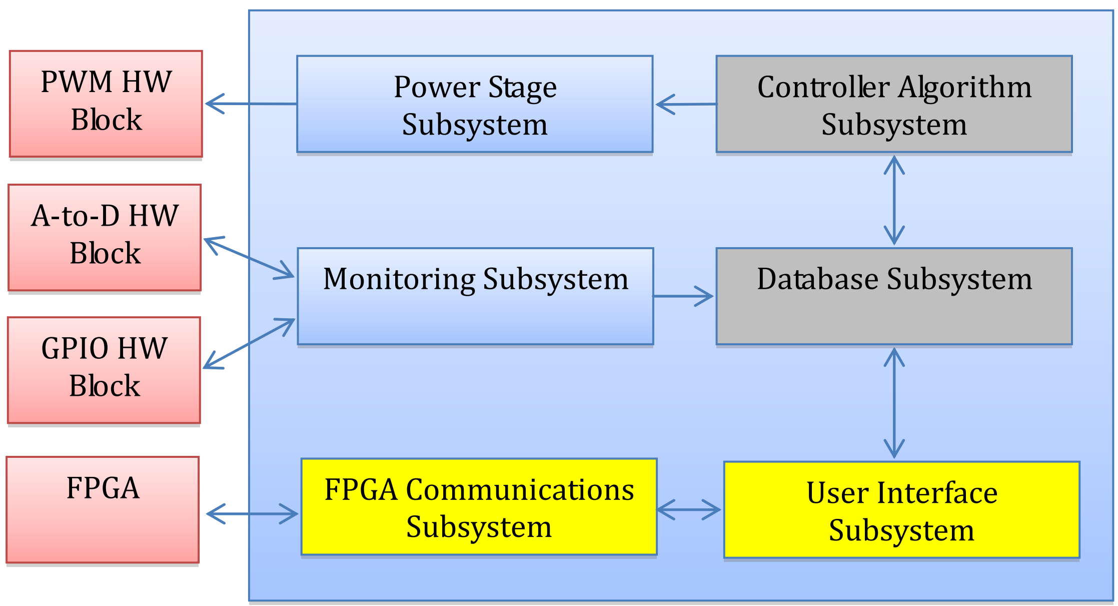
PS	The power stage developed for the SMUD CES application.
Sim Grid	This provides a simulated power grid for the integration phase. The simulated grid is a split phase 240 VAC source capable of 40 kVA.
DC Source	This provides the DC voltage and current normally supplied by the Saft batteries. The DC source is capable of up to 600 VDC and up to 30kW.
LCD	A Crystalfontz 16x2 LCD display used for local status and control of the CES.

2.1.2.2 Firmware Requirements

This section describes the feature requirements of the TI processor and the FPGA for the Local Control Integration phase.

2.1.2.2.1 DSP

The following diagram depicts the DSP subsystems needed for local control integration testing. New subsystems are shown in yellow and modified ones are in gray. The requirements of each are presented in the table that follows.

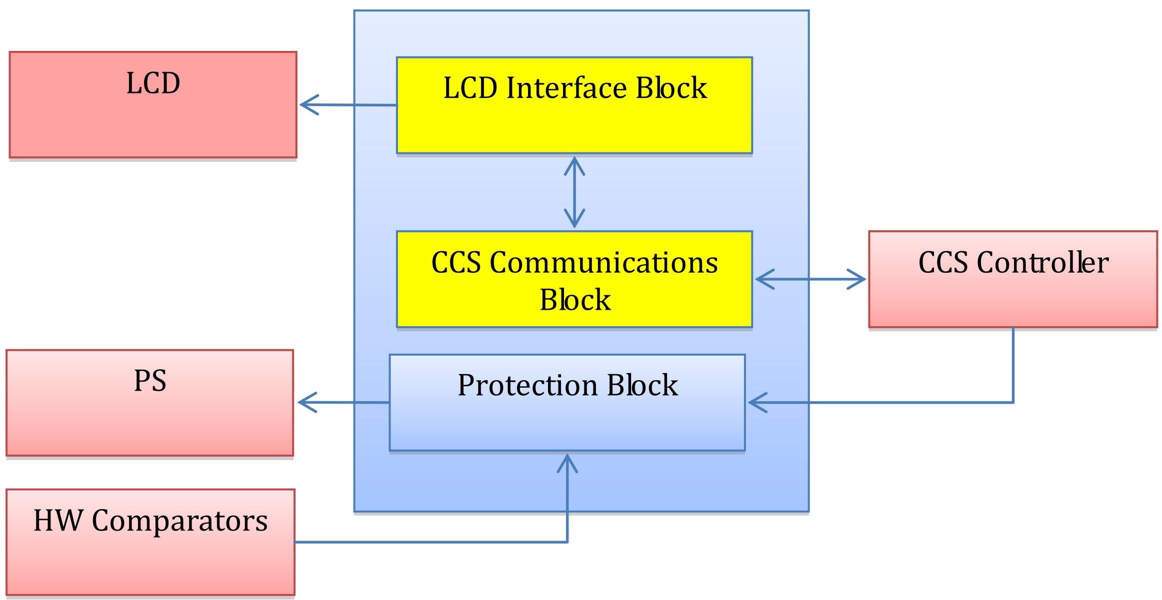


Subsystem	Requirements
Power Stage	The Power Stage subsystem developed and verified in I1.
Controller Algorithm	The Controller Algorithm subsystem developed and verified in I1 extended to provide CES unit enable/disable functionality.
Monitoring	The Monitoring subsystem developed and verified in I1.
Database	The Database storage subsystem developed and verified in I1 extended to store the CES unit enable/disable local control status.
FPGA Communications	The FGA Communications subsystem provides the Master

	side of a master/slave serial interface to the FPGA. A PowerHub Systems proprietary frame format is used to exchange data between the two devices.
User Interface	The User Interface subsystem handles (1) local unit configuration requests, (2) menu navigation events and (3) display updates.

2.1.2.2.2 FPGA

The following diagram depicts the FPGA blocks needed for power stage integration testing. New FPGA blocks are shown in yellow and modified ones are in gray. The requirements of each are presented in the table that follows.



Block	Requirements
Protection	Protection block developed and verified in I1.
LCD Interface	The LCD Interface block implements the RS-232 serial interface to the LCD display module. This interface is implemented in the FPGA due to a lack of serial port interface pins on the TI control card.
CCS Communications	The CCS Communications block provides the Slave side of a master/slave serial interface to the TI controller. A PowerHub Systems proprietary frame format is used to exchange data between the two devices.

2.1.2.3 Test Requirements

The following features are tested and verified during the Local Control Integration phase.

- Local control to open AC contactor
- Local control to close AC contactor
- Local control to enable CES unit

- Local control to disable CES unit
- Local display of current CES unit state

2.1.2.4 Entry Criteria

The successful completion of Power Stage Integration (I1) testing and an available LCD module is required since the focus of this phase is (1) local control of the AC contactor and (2) unit enable/disable processing which affects the generation of the switching signals delivered to the power stage.

Any issues related to the local CCS board analog sensors must be resolved at this time. Specifically, the grid voltage sensors must function properly as they are required for detecting the presence/absence of the simulated grid.

2.1.2.5 Exit Criteria

Local control of the CES via the LCD module **MUST** be completely verified using the testing criteria defined for local control integration testing.

2.1.2.5.1 AC Contactor Control

- The AC contactor is commanded open and the CCS disables gate switching since the CES is no longer connected to the simulated grid.
- The AC contactor is commanded closed and the CCS enables gate switching since the CES is now reconnected to the simulated grid.

2.1.2.5.2 CES Unit Enable

- The CES unit is enabled and the CCS enables gate switching.
- The unit enable LED is turned on when the CES unit is enabled.
- The LCD displays “Standby” when the CES unit is enabled and the contactor is closed.
- The LCD displays “No Grid” when the CES unit is enabled and the contactor is open. Note this display string is only used in the integration phase for debug purposes.

2.1.2.5.3 CES Unit Disable

- The CES unit is disabled and the CCS disables gate switching.
- The unit enable LED is turned off when the CES unit is disabled.
- The LCD displays “No Grid” when the CES unit is disabled and the contactor is closed. Note this display string is only used in the integration phase for debug purposes.

Any open items from the Power Stage Integration (I1) phase should be resolved now and not pushed off into future integration phases.

2.1.2.6 Configuration Management

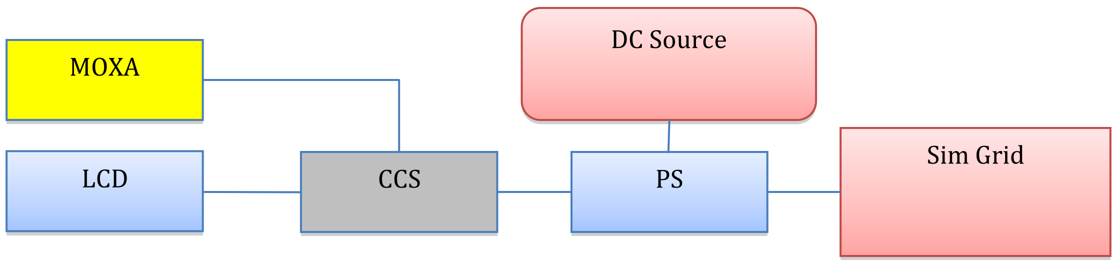
Issues found during testing are entered into bugzilla for tracking purposes. The final code build for both DSP and FPGA will be labeled in subversion as “SMUD-CES-I2”.

2.1.3 MOXA Integration (I3)

The MOXA Integration phase focus is on verifying (1) steady state open loop charge and discharge-operating modes, (2) island detection and (3) integration of the MOXA needed for reading MODBUS input registers and writing the MODBUS operating mode holding register.

2.1.3.1 System Configuration

The system configuration utilized for MOXA integration testing is shown below. Note new components from the previous integration phase are shown in yellow while modified ones are in gray. The role each component plays in the configuration is presented in the following table.



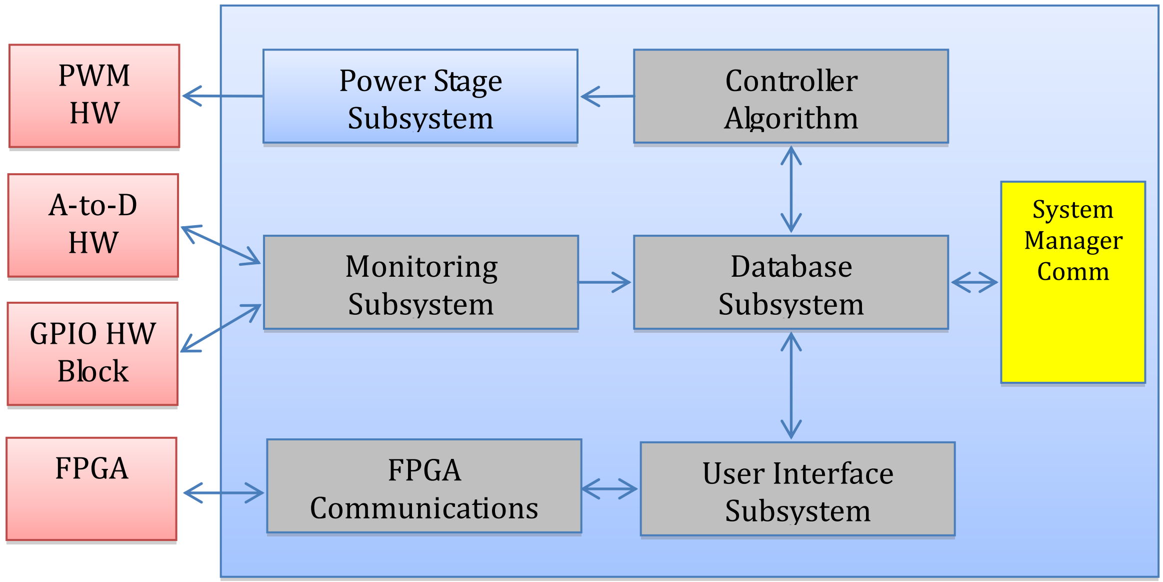
Components	Description
CCS	The CCS firmware developed in I2 with support for the MODBUS interface, monitoring and protection, open loop control for charge and discharge operating modes, and limited remote operating mode support.
PS	The power stage developed for the SMUD CES application.
Sim Grid	This provides a simulated power grid for the integration phase. The simulated grid is a split phase 240 VAC source capable of 40 kVA.
DC Source	This provides the DC voltage and current normally supplied by the Saft batteries. The DC source is capable of up to 600 VDC and up to 30kW.
LCD	A Crystalfontz 16x2 LCD display used for local status and control of the CES.
MOXA	Model UC-7124 embedded computer from MOXA. This device will be programmed with the GridPoint Energy Manager firmware developed for the SMUD CES application.

2.1.3.2 Firmware Requirements

This section describes the feature requirements of the TI processor and the FPGA for the MOXA Integration phase.

2.1.3.2.1 DSP

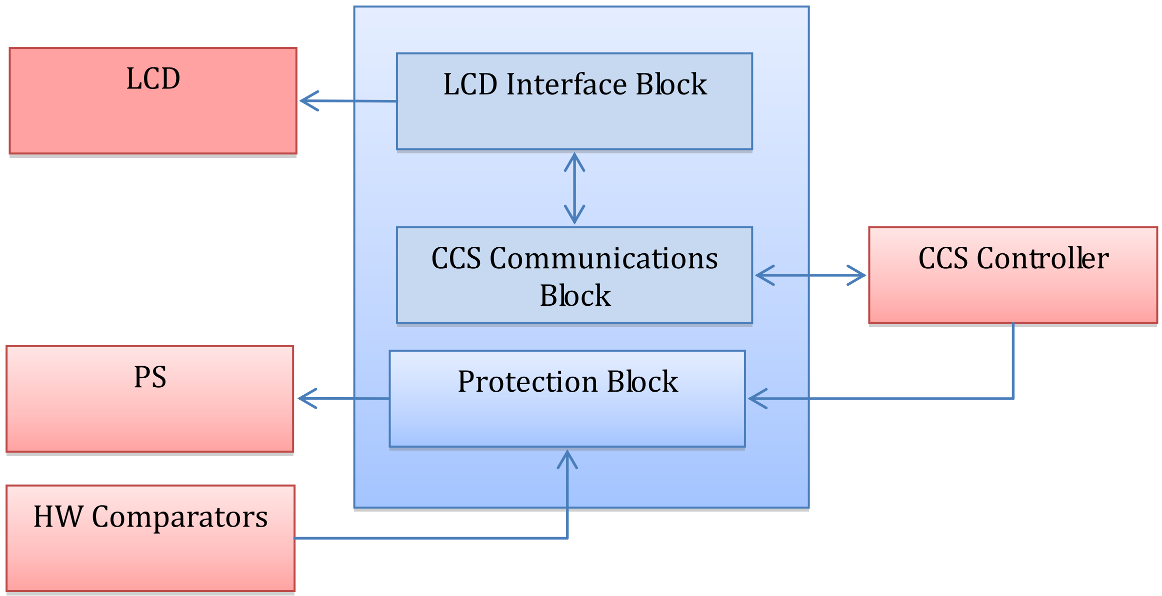
The following diagram depicts the DSP subsystems needed for MOXA integration testing. New subsystems are shown in yellow and modified ones are in gray. The requirements of each are presented in the table that follows.



Subsystem	Requirements
Power Stage	The Power Stage subsystem developed and verified in I1.
Controller Algorithm	The Controller Algorithm subsystem developed and verified in I2 extended to support steady state open loop charge and discharge operating modes and island detection.
Monitoring	The Monitoring subsystem developed and verified in I2 extended to scale the raw analog-to-digital inputs, report sensor threshold violations against default values, and report GPIO states.
Database	The Database storage subsystem developed and verified in I2 extended to store alarm status and scaled analog sensor data.
FPGA Communications	The FGA Communications subsystem developed and verified in I2 extended to transmit alarm status and scaled analog sensor data for display on the LCD.
User Interface	The User Interface subsystem developed and verified in I2 extended to handle requests for alarm status and scaled analog sensor data.
System Manager Comm	The System Manager Comm subsystem implements the MODBUS register map defined for the SMUD CES. For this phase all input registers and the operating mode holding register are implemented

2.1.3.2.2 FPGA

The following diagram depicts the FPGA blocks needed for power stage integration testing. New FPGA blocks are shown in yellow and modified ones are in gray. The requirements of each are presented in the table that follows.



Block	Requirements
Protection	Protection block developed and verified in I1.
LCD Interface	The LCD Interface block developed and verified in I2.
CCS Communications	The CCS Communications block developed and verified in I2.

2.1.3.3 Test Requirements

The following features are tested and verified during the MOXA Integration phase.

- Transitioning between STANDY, CHARGING, DISCHARGING operating modes when commanded. Note Firm, MAINTAIN BATTERY SOC and SLEEP are not supported in this phase.
- Transitioning to the STANDBY operating mode upon detecting loss of communications with the MOXA
- Transitioning to the FAULT operating mode upon detecting any fault
- CES charges when its operating mode is CHARGING
- CES discharges when its operating mode is DISCHARGING
- Reading of the following MODBUS holding registers:

Parameter	Register
Operating Mode	120

- Reading of the following MODBUS input registers:

Parameter	Register
Serial Number	1
DSP Firmware Version	9
FPGA Firmware Version	11
CES Unit Status	2311

Parameter	Register
CES Alarm Status	2312
Communications Status	2313[2]
Grid Voltage Phase A	2315
Grid Voltage Phase B	2316
Grid Current Phase A	2317
Grid Current Phase B	2318
Grid Frequency	2320
Inverter AC Voltage Phase A	2321
Inverter AC Voltage Phase B	2322
Inverter AC Current Neutral	2323
Inverter AC Current Phase A	2324
Inverter AC Current Phase B	2325
Inverter DC Voltage	2326
Inverter DC Current	2327
Inverter Frequency	2329
Reactive Power	2330
PCS Heat Sink Temperature	2331
CCS Temperature	2332
CES Unit Temperature	2333

- Detecting the following alarms[3] using default thresholds:

DC Bus Over Voltage
DC Bus Under Voltage
Phase A Under Voltage
Phase A Over Voltage
Phase B Under Voltage
Phase B Over Voltage
PCS Heat Sink Temp Limit
PCS Internal Fan Failure
Unit Power Capacity Limit

  For this phase alarm detection time stamping is not implemented. It was decided to test this in a subsequent phase when the holding registers are fully implemented by the MOXA. This decision allows both the detection and clearing times to be tested in a single integration phase.
- Reading of the following holding registers returns their respective default value:

[2] Only MODUS communications failure is verified in this phase.
[3] Storage system alarms are tested in the Saft Battery Integration (I4) phase.

Parameter	Register
Firming Sample Period	123
Firming Requested Target Set-point	124
Over Voltage Limit	136
Over Voltage Time	137
Under Voltage Limit	138
Under Voltage Time	139
Reserve Energy Limit	140
Depleted Energy Limit	141
V regulated	142
System Stable Delay	143
Return Delay Base	144
Return Number Range	146
System V min	147
System V max	148
System Frequency Min	149
System Frequency Max	150
Synch Angle	151
Charge Level Timeout	2302
Discharge Level Timeout	2303
GEM Polling Interval	2304
PCS Temperature Limit	2305
Maximum Energy SOC Allowed	2306
Re-closure Time	2307

- Reading of MODBUS registers that are not defined in the SMUD CES MODBUS register map are handled per the MOBDUS RTU serial specification.

2.1.3.4 Entry Criteria

The successful completion of Local Control Integration (I2) testing and an available MOXA programmed with GridPoint firmware developed for the SMUD CES application is required. For this integration phase the MOXA **MUST** support all defined MODBUS input registers and the operating mode holding register. The remaining holding registers (serial number, DSP firmware version and FPGA firmware version) can be tested in a subsequent phase.

2.1.3.5 Exit Criteria

The following test requirements **MUST** be completely verified before entering the next integration phase.

2.1.3.5.1 Operating Mode Input Register

- When the Operating Mode holding register is set to STANDBY and the CCS is not faulted, the CCS terminates any on-going charging or discharging operation
- When in standby the Operating Mode holding register reads STANDBY
- When the Operating Mode holding register is set to CHARGING and the CCS is not faulted, the CCS executes its charging procedure
- When charging the Operating Mode holding register reads CHARGING
- When the Operating Mode holding register is set to DISCHARGING and the CCS is not faulted, the CCS executes its discharging procedure
- When discharging the Operating Mode holding register reads DISCHARGING
- When a MODBUS communications error is detected and the current mode is CHARGE or DISCHARGE the CCS enters the STANDBY operating mode
- Upon detecting any fault, the CCS terminates any on-going charging or discharging operation, stops inverting, opens the AC contactor and enters the FAULT operating mode
- When faulted the Operating Mode holding register reads FAULT
- When in the FAULT operating mode, subsequent operating mode change requests are ignored

2.1.3.5.2 Asset Tag Input Registers

- Reading the Serial Number input register returns “SN01”
- Reading the DSP Firmware Version input register returns the current engineering build number of the DSP at the time of testing
- Reading the FPGA Firmware Version input register returns the current engineering build number of the FPGA at the time of testing

2.1.3.5.3 CES Unit Status Input Register

- When the simulated grid is connected reading the CES Unit Status input register shows bit 0 set
- When the simulated grid is not connected reading the CES Unit Status input register shows bit 0 clear
- When not faulted reading the CES Unit Status input register shows bit 1 set
- When faulted reading the CES Unit Status input register shows bit 1 clear
- When not faulted reading the CES Unit Status input register shows bit 2 set to the state of the AC contactor
- When faulted reading the CES Unit Status input register shows bit 2 set
- Reading the CES Unit Status input register shows bit 3 set. This is the door closed status bit and is not included in this integration phase, but is set to ‘1’ to ensure that the unit is not disabled during lab testing.
- Reading the CES Unit Status input register shows bit 4 clear. This is the cabinet fan status bit and is not included in this integration phase.
- When the PS’s heat sink temperature is equal to or below its predefined threshold the reading the CES Unit Status input register show bit 5 clear

- When the PS's heat sink temperature is above its predefined threshold the reading the CES Unit Status input register show bit 5 set
- When the internal PCS fan is enabled reading the CES Unit Status input register shows bit 6 set
- When the internal PCS fan is not enabled reading the CES Unit Status input register shows bit 6 clear
- When the CES unit is enabled via local control reading the CES Unit Status input register shows bit 7 set
- When the CES unit is disabled via local control reading the CES Unit Status input register shows bit 7 clear

2.1.3.5.4 CES Alarm Status Input Register

- When the DC bus voltage is equal to or below its default lower threshold reading the CES Alarm Status input register shows bit 0 set
- When the DC bus voltage is above its default lower threshold reading the CES Alarm Status input register shows bit 0 clear
- When the DC bus voltage is equal to or below its default upper threshold reading the CES Alarm Status input register shows bit 1 clear
- When the DC bus voltage is above its default upper threshold reading the CES Alarm Status input register shows bit 1 set
- When the inverter's phase A AC voltage is equal to or below its default lower threshold reading the CES Alarm Status input register shows bit 2 set
- When the inverter's phase A AC voltage is above its default lower threshold reading the CES Alarm Status input register shows bit 2 clear
- When the inverter's phase A AC voltage is equal to or below its default upper threshold reading the CES Alarm Status input register shows bit 3 clear
- When the inverter's phase A AC voltage is above its default upper threshold reading the CES Alarm Status input register shows bit 3 set
- When the inverter's phase B AC voltage is equal to or below its default lower threshold reading the CES Alarm Status input register shows bit 4 set
- When the inverter's phase B AC voltage is above its default lower threshold reading the CES Alarm Status input register shows bit 4 clear
- When the inverter's phase B AC voltage is equal to or below its default upper threshold reading the CES Alarm Status input register shows bit 5 clear
- When the inverter's phase B AC voltage is above its default upper threshold reading the CES Alarm Status input register shows bit 5 set
- When the PS's heat sink temperature is equal to or below its predefined threshold reading the CES Alarm Status input register shows bit 6 clear
- When the PS's heat sink temperature is above its predefined threshold reading the CES Alarm Status input register shows bit 6 set
- When the PS's internal fan is operational reading the CES Alarm Status input register shows bit 7 clear
- When the PS's internal fan has failed reading the CES Alarm Status input register shows bit 7 set

- When reading the CES Alarm Status input register the alarms currently not implemented all return 0. These include unit ***power capacity limit***, battery temperature, reserve energy limit, depleted energy limit and unit shutdown.

2.1.3.5.5 Communications Status Input Register

- When the MOXA is communicating normally with the CCS reading the Communications Status input register shows bit 1 clear
- Reading the Communications Status input register after disconnecting the MOXA from the CCS for at least twenty-five seconds (5 * default GEM polling interval) after its last communications shows bit 1 set
- Reading the Communications Status input register shows bit 0 set. This is the CAN Bus status and since it is not implemented in this phase it status is always failed.

2.1.3.5.6 Analog Sensor Input Registers

- The following analog sensors are implemented in this integration phase.

Input Register	Accuracy and Source
Grid Voltage Phase A	$\pm$0.5% of the phase A voltage provided by the simulated grid
Grid Voltage Phase B	$\pm$0.5% of the phase B voltage provided by the simulated grid
Grid Current Phase A	$\pm$0.5% of the phase A current provided by the simulated grid
Grid Current Phase B	$\pm$0.5% of the phase B current provided by the simulated grid
Grid Frequency	$\pm$0.5% of the grid frequency provided by the simulated grid
Inverter AC Voltage Phase A	$\pm$0.5% of the inverter's phase A AC voltage measured by a digital oscilloscope
Inverter AC Voltage Phase B	$\pm$0.5% of the inverter's phase B AC voltage measured by a digital oscilloscope
Inverter AC Current Neutral	$\pm$0.5% of the inverter's AC neutral current measured by a digital oscilloscope
Inverter AC Current Phase A	$\pm$0.5% of the inverter's AC phase A current measured by a digital oscilloscope
Inverter AC Current Phase B	$\pm$0.5% of the inverter's AC phase B current measured by a digital oscilloscope
Inverter DC Voltage	$\pm$0.5% of the DC voltage measured by a digital oscilloscope
Inverter DC Current	$\pm$0.5% of the DC current measured by a digital oscilloscope
Inverter Frequency	$\pm$0.5% of the grid frequency provided by the simulated grid

Input Register	Accuracy and Source
Reactive Power	
PCS Heat Sink Temperature	±0.5% of the temperature measured at the PS's heat sink
CCS Temperature	±0.5% of the temperature measured on the CCS PCB
CES Unit Temperature	±0.5% of the temperature measured within the CES cabinet[4]

2.1.3.5.7 Holding Registers with Default Values

- Reading of the following holding registers during this integration phase results in their respective default value being returned.

Holding Register	Default Value
Firming Sample Period	15
Firming Requested Target Set-point	15
Over Voltage Limit	5000
Over Voltage Time	85
Under Voltage Limit	90
Under Voltage Time	15000
Reserve Energy Limit	15
Depleted Energy Limit	15
V regulated	5000
System Stable Delay	85
Return Delay Base	90
Return Number Range	15000
System V min	15
System V max	15
System Frequency Min	5000
System Frequency Max	85
Synch Angle	90
Charge Level Timeout	15000
Discharge Level Timeout	15
GEM Polling Interval	15
PCS Temperature Limit	5000
Maximum Energy SOC Allowed	85
Re-closure Time	90

2.1.3.5.8 Unsupported MODBUS Registers

- Reading of MODBUS registers that have **not** been implemented in this integration phase returns an exception response with an exception code of

[4] Note this measurement is not the actual CES unit temperature since the unit under test is not installed in its enclosure.

02 (ILLEGAL DATA ADDRESS). Examples of these are all storage system related registers.

2.1.3.5.9 Summary

The MOXA Integration phase is critical for the overall development of the CCS being deployed for the SMUD application since it introduces a real control loop with full monitoring and protection. For this reason all stated test requirements of this phase **MUST** be satisfied before entering the next integration phase.

2.1.3.6 Configuration Management

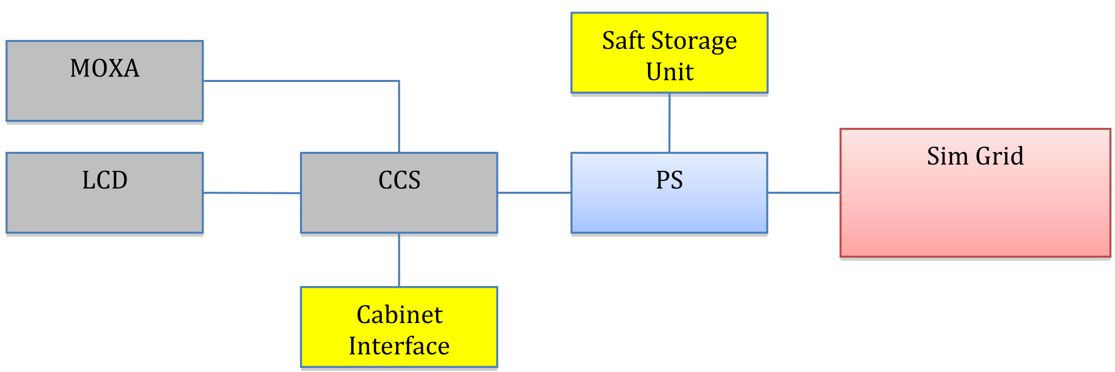
Issues found during testing are entered into bugzilla for tracking purposes. The final code build for both DSP and FPGA will be labeled in subversion as "SMUD-CES-I3".

2.1.4 Saft Battery Integration (I4)

The Saft Battery Integration phase focus is on verifying (1) CAN Bus communications between the Saft BMU and the CCS, (2) battery sensor validation, (3) full implementation of CCS operating modes, (4) alarm detection utilizing programmable thresholds, (5) full implementation of island detection, (6) formal evaluation of utility source interconnect functionality (anti-islanding, within voltage and frequency rages), (7) full integration with cabinet level features and (8) acceptable execution of the GridPoint defined firming algorithm.

2.1.4.1 System Configuration

The system configuration utilized for Saft battery integration testing is shown below. Note new components from the previous integration phase are shown in yellow while modified ones are in gray. The role each component plays in the configuration is presented in the following table.



Components	Description
CCS	The CCS firmware developed in I3 with support for the complete set of MODBUS input and holding registers defined for the SMUD CES application, full operating modes and integration of Saft CAN Open objects.
PS	The power stage developed for the SMUD CES application.
Sim Grid	This provides a simulated power grid for the integration phase. The simulated grid is a split phase 240 VAC source

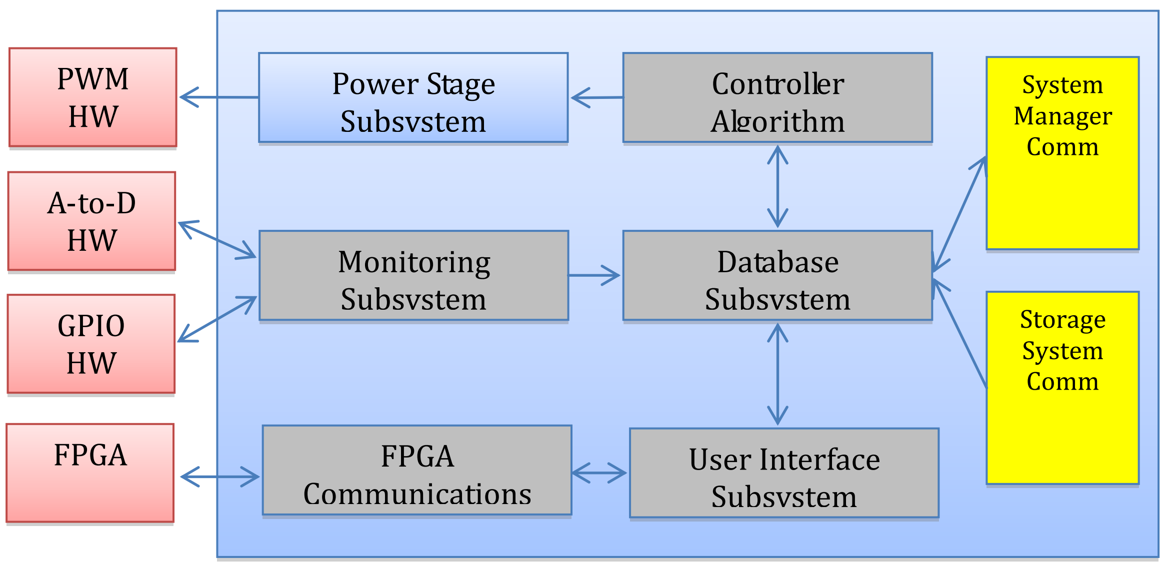
	capable of 40 kVA.
Saft Storage Unit	The battery storage system supplied by Saft for the SMUD CES application. This component communicates with CCS via CAN Bus.
LCD	A Crystalfontz 16x2 LCD display used for local status and control of the CES.
MOXA	The GridPoint gateway with support for all MODBUS holding registers defined for the SMUD CES application.
Cabinet Interface	Digital inputs and outputs and analog inputs provided by the CES unit enclosure.

2.1.4.2 Firmware Requirements

This section describes the feature requirements of the TI processor and the FPGA for the Saft Battery Integration phase.

2.1.4.2.1 DSP

The following diagram depicts the DSP subsystems needed for Saft battery integration testing. New subsystems are shown in yellow and modified ones are in gray. The requirements of each are presented in the table that follows.

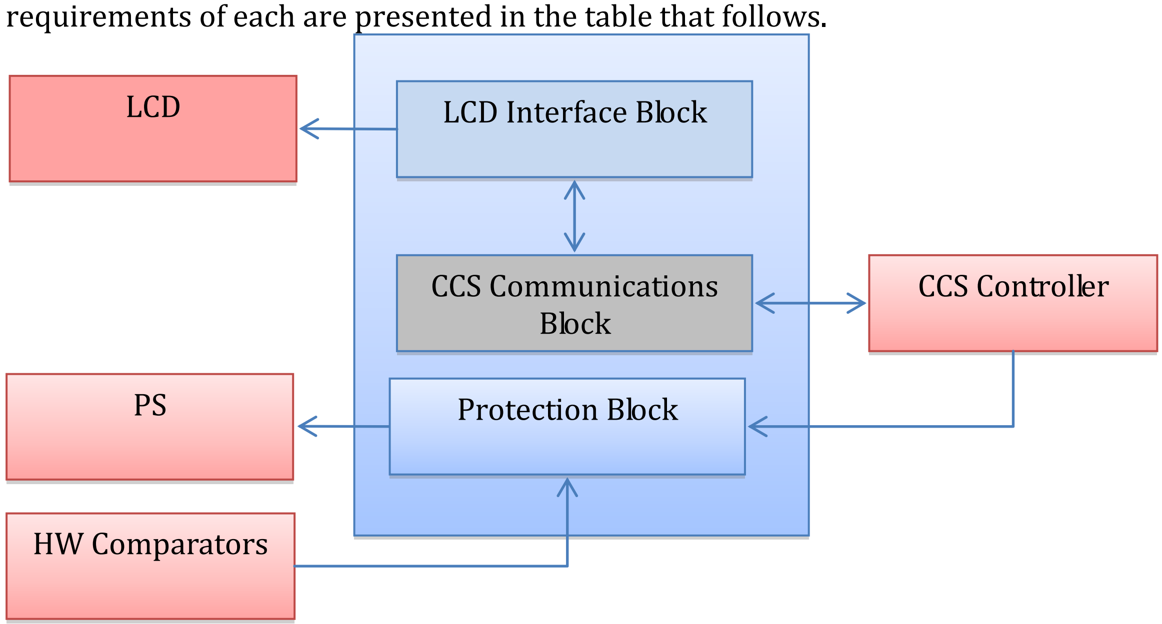


Subsystem	Requirements
Power Stage	The Power Stage subsystem developed and verified in I1.
Controller Algorithm	The Controller Algorithm subsystem developed and verified in I3 extended to support the full implementation of operating modes and island detection.
Monitoring	The Monitoring subsystem developed and verified in I3 extended to support programmable thresholds and cabinet level protection.
Database	The Database storage subsystem developed and verified in I3 extended to support the full implementation of

	MODBUS holding registers and Saft's CAN Open objects.
FPGA Communications	The FGA Communications subsystem developed and verified in I3 extended to transmit storage system status and sensor data for display on the LCD.
User Interface	The User Interface subsystem developed and verified in I3 extended to handle requests for storage system alarm status and sensor data.
System Manager Comm	The System Manager Comm subsystem developed and verified in I3 extended to handle writes requests for each holding register.
Storage System Comm	The Storage System Comm subsystem implements BUS Bus communications with the Saft BMU.

2.1.4.2.2 FPGA

The following diagram depicts the FPGA blocks needed for power stage integration testing. New FPGA blocks are shown in yellow and modified ones are in gray. The requirements of each are presented in the table that follows.



Block	Requirements
Protection	Protection block developed and verified in I1.
LCD Interface	The LCD Interface block developed and verified in I2.
CCS Communications	The CCS Communications block developed and verified in I2 extended to support read and write of the attached EEPROM used for storing CCS configuration data.

2.1.4.3 Test Requirements

The following features are tested and verified during the MOXA Integration phase.

- Transitioning between STANDY, CHARGING, DISCHARGING, FIRM, and MAINTAIN BATTERY SOC operating modes when commanded
- CES executes firming algorithm when its operating mode is FIRM

- CES executes firming algorithm when its operating mode is MAINTAIN BATTERY SOC
- Transitioning to STANDBY when the storage system has reached its reserve energy setting
- Transitioning to the SLEEP operating mode when the storage system has reached its depleted energy setting
- Transitioning to the STANDBY operating mode upon detecting loss of communications with the storage system
- Reading of the following storage system related MODBUS input registers:

Parameter	Register
Nominal Charge Rate	13
Nominal Discharge Rate	14
Maximum Charge Rate	15
Maximum Discharge Rate	16
Maximum Charge Duration	17
Maximum Discharge Duration	18
Nominal/Rated Energy Capacity	19
Maximum/Rated Energy Capacity	20
DC Battery Voltage	2334
Battery Energy Discharged	2335
Battery Energy Charged	2337
Available Energy	2339
Battery State of Charge	2341
Battery Temperature	2342

- Detecting the following storage system alarms:

Battery Temp
Reserve Energy Limit
Depleted Energy Limit

- Full implementation of the MODBUS holding registers defined by the SMUD CES MODBUS register map
- Monitoring of the cabinet door sensor
- Monitoring of the emergency stop button sensor
- Reading of the cabinet temperature when the CCS is in its enclosure
- Control of the CES cabinet fan
- The CES unit shuts down when opening the enclosure.

Additionally, the following features verified in I3 are regression tested in this phase.

- Transitioning to the STANDBY operating mode upon detecting loss of communications with the MOXA

- Transitioning to the FAULT operating mode upon detecting any fault
- CES charges when its operating mode is CHARGING
- CES discharges when its operating mode is DISCHARGING
- Reading the following MODBUS input registers:

Parameter	Register
Serial Number	1
DSP Firmware Version	9
FPGA Firmware Version	11
CES Unit Status	2311
CES Alarm Status	2312
Communications Status	2313[5]
Grid Voltage Phase A	2315
Grid Voltage Phase B	2316
Grid Current Phase A	2317
Grid Current Phase B	2318
Grid Frequency	2320
Inverter AC Voltage Phase A	2321
Inverter AC Voltage Phase B	2322
Inverter AC Current Neutral	2323
Inverter AC Current Phase A	2324
Inverter AC Current Phase B	2325
Inverter DC Voltage	2326
Inverter DC Current	2327
Inverter Frequency	2329
Reactive Power	2330
PCS Heat Sink Temperature	2331
CCS Temperature	2332
CES Unit Temperature	2333

- Detecting the following alarms using both default and **programmable** thresholds:

DC Bus Over Voltage
DC Bus Under Voltage
Phase A Under Voltage
Phase A Over Voltage
Phase B Under Voltage
Phase B Over Voltage
PCS Heat Sink Temp Limit
PCS Internal Fan Failure

[5] Only MODUS communications failure is verified in this phase.

- The CCS executes the GridPoint firming algorithm in accordance with the algorithm's parameters as defined by the following MOBDUS holding registers:

Parameter	Register
Firming Sample Period	123
Firming Requested Target Set-point	124
Control Gain	125
Firming Coefficient a	127
Firming Coefficient b	129
Firming Coefficient c	131
Firming Coefficient d	133
Firming Attenuation Function 'g()'	254

- Reading the following holding registers will returns their respective default value unless previously set via a MODBUS write command.

Parameter	Register
Firming Sample Period	123
Firming Requested Target Set-point	124
Over Voltage Limit	136
Over Voltage Time	137
Under Voltage Limit	138
Under Voltage Time	139
Reserve Energy Limit	140
Depleted Energy Limit	141
V regulated	142
System Stable Delay	143
Return Delay Base	144
Return Number Range	146
System V min	147
System V max	148
System Frequency Min	149
System Frequency Max	150
Synch Angle	151
Charge Level Timeout	2302
Discharge Level Timeout	2303
GEM Polling Interval	2304
PCS Temperature Limit	2305
Maximum Energy SOC Allowed	2306
Re-closure Time	2307

- Reading of MODBUS registers that are not defined in the SMUD CES MODBUS register map are handled per the MOBDUS RTU serial specification.

2.1.4.4 Entry Criteria
The successful completion of MOXA Integration (I3) testing, a complete implementation of the MOXA firmware for the SMUD CES application, an available Saft battery storage system and the CCS mounted in its enclosure is required to completely verify this integration phase.

2.1.4.5 Exit Criteria
The following test requirements **MUST** be completely verified before entering the next integration phase.

- Full implementation of the MODBUS holding registers defined by the SMUD CES MODBUS register map
- Monitoring of the cabinet door sensor
- Monitoring of the emergency stop button sensor
- Reading of the cabinet temperature when the CCS is in its enclosure
- Control of the CES cabinet fan

The following features **MUST** be completely verified using the testing criteria defined for Saft battery integration testing.

2.1.4.5.1 Operating Mode Holding Register Testing
- When the Operating Mode holding register is set to STANDBY and the CCS is not faulted, the CCS terminates any on-going charging, discharging or firming operation
- When in standby the Operating Mode holding register reads STANDBY
- When the Operating Mode holding register is set to CHARGING and the CCS is not faulted, the CCS executes its charging procedure
- When charging the Operating Mode holding register reads CHARGING
- When the Operating Mode holding register is set to DISCHARGING and the CCS is not faulted, the CCS executes its discharging procedure
- When discharging the Operating Mode holding register reads DISCHARGING
- When the Operating Mode holding register is set to FIRM and the CCS is not faulted, the CCS executes its firming procedure
- When firming the Operating Mode holding register reads FIRM
- When the Operating Mode holding register is set to MAINTAIN BATTERY SOC and the CCS is not faulted, the CCS executes its battery maintenance procedure
- When maintaining the battery the Operating Mode holding register reads MAINTAIN BATTERY SOC
- When the battery's state of charge is equal to or above its reserve energy threshold the CCS continues to operate in its current operating mode
- When the battery's state of charge is below its reserve energy threshold and the current operating mode is CHARGE, DISCHARGE, FIRM, or MAINTAIN BATTERY SOC the CCS enters the STANDBY operating mode

- When the battery's state of charge is below its depleted energy threshold the CCS enters the SLEEP operating mode
- When sleeping the Operating Mode holding register reads SLEEP
- Upon detecting MODBUS or CAN Bus loss of communications the CCS enters the STANDBY mode
- Upon detecting any fault, the CCS terminates any on-going charging or discharging operation, stops inverting, opens the AC contactor and enters the FAULT operating mode
- When faulted the Operating Mode holding register reads FAULT
- When in the FAULT operating mode, subsequent operating mode change requests are ignored

2.1.4.5.2 Asset Tag Input Registers Testing

- Reading the Serial Number input register returns "SN02"
- Reading the DSP Firmware Version input register returns the current engineering build number of the DSP at the time of testing
- Reading the FPGA Firmware Version input register returns the current engineering build number of the FPGA at the time of testing

2.1.4.5.3 CES Unit Status Input Register Testing

- The CES Unit Status Input Register (section 2.1.3.5.3) test in I3 **SHOULD** be part of the regression test suite for this integration phase.
- When the cabinet door is closed reading the CES Unit Status input register shows bit 4 set.
- When the cabinet door is open reading the CES Unit Status input register shows bit 4 clear.

2.1.4.5.4 CES Alarm Status Input Register Testing with Thresholds

The alarm detection tests executed in I3's CES Alarm Status Input Register (section 2.1.3.5.4) tests are repeated here, but in this instance the holding registers defined for upper and lower thresholds are utilized. The following table lists the alarm and its associated holding registers (thresholds). Not shown here are the storage system related alarms. These are discussed in the following section. *Note testing of the PCS Heat Sink Temp Limit and PCS Internal Fan Failure **SHOULD** be part of the regression test suite for this integration phase.*

Alarm	Holding Register Name	Register #
DC Bus Over Voltage	Over DC Voltage Limit	2309
DC Bus Under Voltage	Under DC Voltage Limit	2311
Phase A Under Voltage	Under Voltage Limit	138
Phase A Over Voltage	Over Voltage Limit	136
Phase B Under Voltage	Under Voltage Limit	138
Phase B Over Voltage	Over Voltage Limit	136
PCS Heat Sink Temp Limit	N/A	N/A
PCS Internal Fan Failure	N/A	N/A

Alarm	Holding Register Name	Register #
Unit Power Capacity Limit	Maximum/Rated Energy Capacity	20
Unit Shutdown	N/A	N/A

2.1.4.5.5 CES Alarm Status Input Register Testing of Storage System Alarms with Defaults

- When the Saft BMU reports no temperature error via its Error Register CAN Open object reading the CES Alarms Status input register show bit 9 clear.
- When the Saft BMU reports a temperature error via its Error Register CAN Open object reading the CES Alarms Status input register show bit 9 set.
- When the battery's state of charge is equal to or above the default reserve energy limit reading the CES Alarm Status input register shows bit 10 clear.
- When the battery's state of charge is below the default reserve energy limit reading the CES Alarm Status input register shows bit 10 set.
- When the battery's state of charge is equal to or above the default depleted energy limit reading the CES Alarm Status input register shows bit 11 clear.
- When the battery's state of charge is below the default depleted energy limit reading the CES Alarm Status input register shows bit 11 set.

2.1.4.5.6 CES Alarm Status Input Register Testing of Storage System Alarms with Thresholds

The alarm detection tests executed in Section 2.1.4.5.5 CES Alarm Status Input Register Testing of Storage System Alarms with Defaults are repeated here, but in this instance the holding registers defined for energy limit thresholds are utilized. The following table lists the alarm and its associated holding registers (thresholds).

Alarm	Holding Register Name	Register #
Battery Temp	N/A	N/A
Reserve Energy Limit	Reserve Energy Limit	140
Depleted Energy Limit	Depleted Energy Limit	141

2.1.4.5.7 Communications Status Input Register

- When the Saft BMU is communicating normally with the CCS reading the Communications input register shows bit 0 clear
- Reading the Communications Status input register after disconnecting CAN Bus between the Saft BMU and the CCS for at least one second shows bit 0 set

The MOXA Communications Status Input Register test (section 2.1.3.5.5) in I3 **SHOULD** be part of the regression test suite for this integration phase.

2.1.4.5.8 Analog Sensor Input Registers

The Analog Sensor Input Registers (section 2.1.3.5.6) test in I3 **SHOULD** be part of the regression test suite for this integration phase. Note the CES Unit Temperature (2333) input register is now reflective of its expected value since the CCS is enclosed within the cabinet during this integration phase.

2.1.4.5.9 CES Unit Characteristics Input Registers

- Reading the following input registers returns their respective preset value:

Parameter	Value
Nominal Charge Rate	
Nominal Discharge Rate	
Maximum Charge Rate	
Maximum Discharge Rate	
Maximum Charge Duration	
Maximum Discharge Duration	
Nominal/Rated Energy Capacity	
Maximum/Rated Energy Capacity	

2.1.4.5.10 Storage System Parameters Input Registers

- Reading of the following input registers returns the exact data provided to the CCS by the BMU over the CAN Bus.

Input Register	Accuracy
DC Battery Voltage	Equal to value captured with CAN protocol analyzer
Battery Energy Discharged	Equal to value captured with CAN protocol analyzer
Battery Energy Charged	Equal to value captured with CAN protocol analyzer
Available Energy	Equal to value captured with CAN protocol analyzer
Battery State of Charge	Equal to value captured with CAN protocol analyzer
Battery Temperature	Equal to value captured with CAN protocol analyzer

- Reading the following holding registers returns their respective default value:

Holding Register	Default Value
Firming Sample Period	15
Firming Requested Target Set-point	15
Over Voltage Limit	5000
Over Voltage Time	85
Under Voltage Limit	90
Under Voltage Time	15000
Reserve Energy Limit	15
Depleted Energy Limit	15
V regulated	5000

System Stable Delay	85
Return Delay Base	90
Return Number Range	15000
System V min	15
System V max	15
System Frequency Min	5000
System Frequency Max	85
Synch Angle	90
Charge Level Timeout	15000
Discharge Level Timeout	15
GEM Polling Interval	15
PCS Temperature Limit	5000
Maximum Energy SOC Allowed	85
Re-closure Time	90

- Reading of MODBUS registers that are not defined in the SMUD CES MODBUS register map returns an exception response with an exception code of 02 (ILLEGAL DATA ADDRESS).

2.1.4.6 Configuration Management

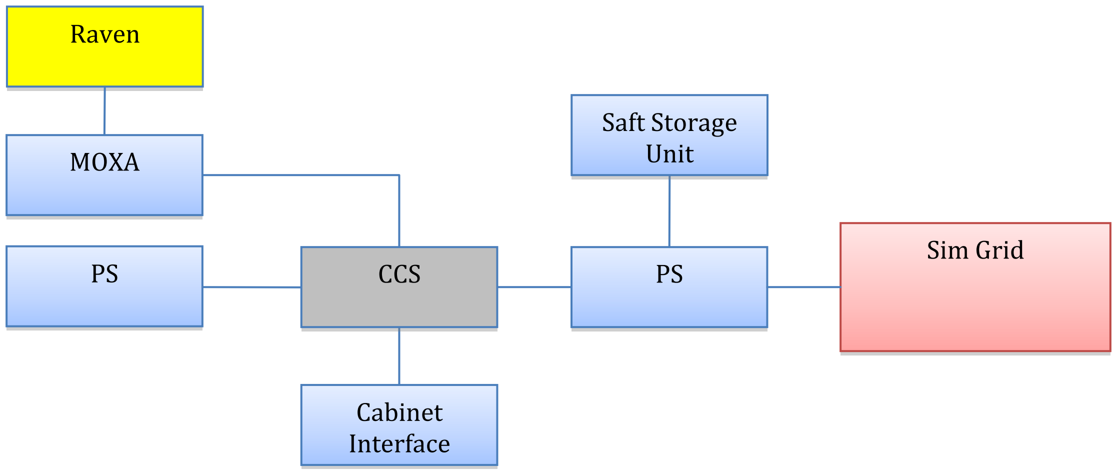
Issues found during testing are entered into bugzilla for tracking purposes. The final code build for both DSP and FPGA will be labeled in subversion as "SMUD-CES-I4".

2.1.5 GEM/GNOC Integration (I5)

The GEM/GNOC Integration phase focus is on verifying (1) the complete end-to-end solution developed by Powerhub Systems and GridPoint for the SMUD CES application and (2) that the CES unit complies with IEEE 1547 and UL 1741 standards to a level deemed acceptable by SMUD.

2.1.5.1 System Configuration

The system configuration utilized for GEM/GNOC integration testing is shown below. Note new components from the previous integration phase are shown in yellow while modified ones are in gray. The role each component plays in the configuration is presented in the following table.



Components	Description
CCS	The CCS firmware developed and verified in I4 extended to support IEEE 1547 for grid re-connect requirements.
PS	The power stage developed for the SMUD CES application.
Sim Grid	This provides a simulated power grid for the integration phase. The simulated grid is a split phase 240 VAC source capable of 40 kVA.
Saft Storage Unit	The battery storage system supplied by Saft for the SMUD CES application. This component communicates with CCS via CAN Bus.
LCD	A Crystalfontz 16x2 LCD display used for local status and control of the CES.
MOXA	The GridPoint gateway verified in I4.
Cabinet Interface	The CES unit enclosure interface verified in I4.
Raven	The Raven is a wireless data communications platform for HSUPA networks being used by GridPoint for back haul connectivity to their NOC.

2.1.5.2 Firmware Requirements

This section describes the feature requirements of the TI processor and the FPGA for the GEM/GNOC Integration phase.

2.1.5.2.1 DSP

No DSP firmware enhancements are required in this integration phase.

2.1.5.2.2 FPGA

No FPGA enhancements are required in this integration phase.

2.1.5.3 Test Requirements

The following features are tested and verified during the GEM/GNOC Integration phase.

- The Raven under control of the MOXA successfully transports SMUD CES MODBUS input register values the GridPoint NOC

- The SMUD CES MODBUS holding registers are settable from the GridPoint NOC
- IEEE 1547 sections …

2.1.5.4 Entry Criteria

The successful completion of Saft Battery Integration (I4) testing and an available provisioned Raven are required to start this final integration phase.

2.1.5.5 Exit Criteria

To ensure successful demonstration of the overall SMUD CES solution the following requirements **MUST** be met.

- The GridPoint NOC receives, displays and achieves all CCS sensor data
- The GridPoint NOC receives, displays and achieves all CCS alarms and associated time stamps
- The GridPoint NOC clears all possible remote resettable faults and the CCS returns to STANDY
- The GridPoint NOC receives, displays and achieves all Saft battery status and operating data
- The GridPoint NOC sends the Firming Attenuation Function 'g()' to the MOXA which in turns writes it to the CCS via the MODBUS

The GridPoint NOC sends alarm thresholds to the MOXA, which in turns writes it to the CCS via the MODBUS

2.2 Acceptance Testing

The acceptance testing is focused on those criteria that ensure operation and connectivity to the grid system for safety and functionality. Use Case driven testing is employed to ensure that all requirements are met to operate the CES storage system in accordance with the SMUD CES Unit specification and the GridPoint Sensor and Interface specification. Use Cases are connected to each of the requirements and tracked in **Topcased-SYSML**[6]; computer software for use in computer-aided software and systems engineering. The use case methodology is used to capture a system's behavioral requirements by detailing scenario-driven threads through the functional requirements.

The use cases for operating the storage unit, and the associated actors, for the SMUD CES deployment are illustrated in **Figure 1**.

[6] http://www.topcased.org/index.php?idd_projet_pere=20

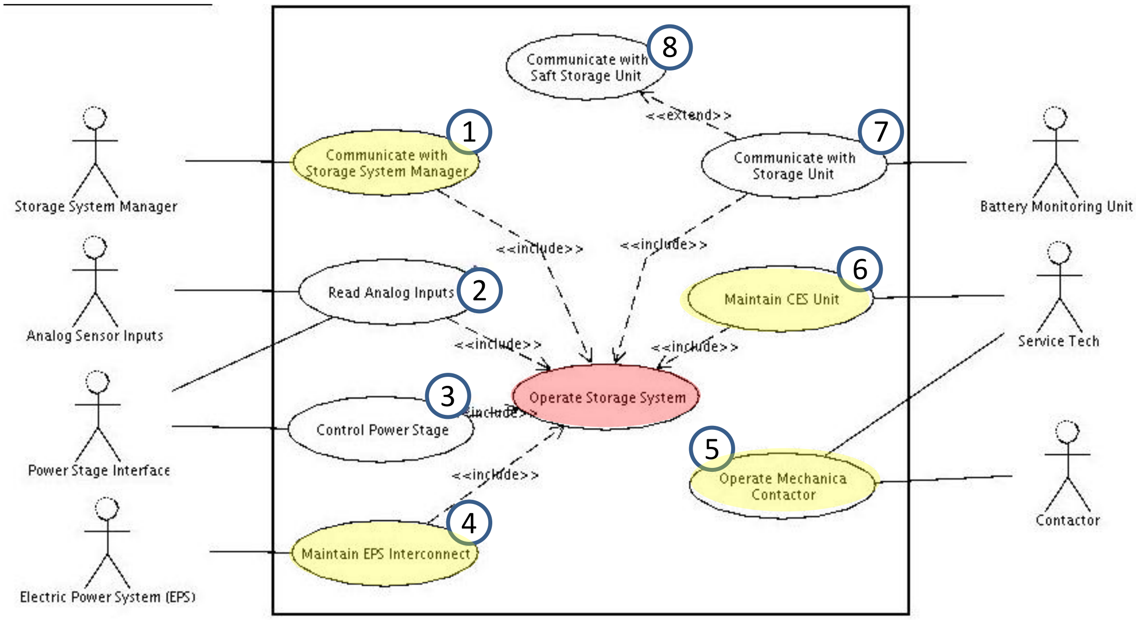


Figure 1. *SMUD CES use cases as organized in the PowerHub Systems Topcased-SYSML tool.*

These 8 use cases are summarized below in the context of the SMUD CES unit deployment:

1. Communicate with Storage System Manager: The Communicate with Storage System Manager use case captures the communications requirements between the CES and the Storage System Manager. For the SMUD CES application this interface is provided by GridPoint's Moxa Controller (the GEM). This use case address all MODBUS transmit and receive functions related to GEM communications.
2. Read Analog Inputs: The Read Analog Inputs use case captures the analog sensor input requirements required by the application. These requirements include the necessary scaling required to report sensor data in the appropriate units.

3. Control Power Stage: The Power Stage Interface use case encapsulates the requirements for interfacing to an associated power stage. For the SMUD CES application the power stage is provided by a Vacon and its interface requirements include controlling both the switching signal and its heat sink and internal fans.

4. Maintain EPS Interconnect: The Maintain EPS Interconnect use case captures the requirements of interfacing to the electric power grid. These requirements are detailed in IEEE 1547. Conformance testing to this standard is part of UL 1741 certification.

5. Operate Mechanical Contactor: The Operate Mechanical Contactor use case captures the requirements of the manual disconnect switch. The switch provides no digital feedback; therefore the CCS uses its sensors behind the EMC Filter to determine the contactor position.

6. Maintain CES Unit: The Maintenance CES Unit use case captures the installation, operation and maintenance requirements of a CES unit. These functions are initiated through the CES unit's user interface.

7. Communicate with Storage Unit: The Communicate with Storage Unit use case captures the communication requirements between the CES communication/control system and the storage unit as defined by the SMUD CES Unit Specification. For the SMUD CES application this interface is provided by Saft's battery monitoring system (BMS). This use case addresses all CAN Bus transmit and receive functions related to Saft communications.

8. Communicate with Saft Storage Unit: The Communicate with Saft Storage Unit use case captures the communication requirements between the CES communication/control system and the Saft storage unit that are outside the requirements of the SMUD CES Unit Specification.

The acceptance testing builds on the integration testing and will be documented internally to PowerHub using TopCased and an intranet Wiki employing the documentation format, as a model, from 1547.1 IEEE "Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems" Section 6.4 and will include the following:

- manufacturer's model number,
- serial number,
- functional software and firmware versions (where applicable),
- testing date and carried out by whom,
- test settings and set up,

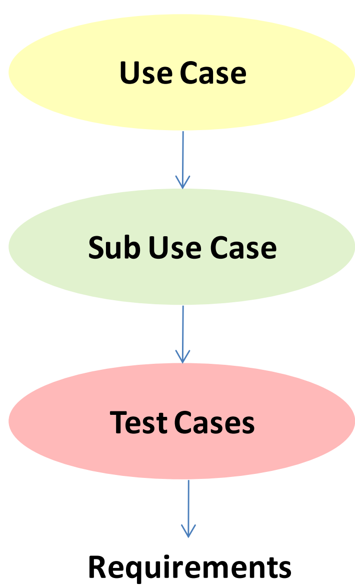


Figure 2. *Uses cases and their connection to the requirements through test cases employed in the SMUD*

CES acceptance criteria.

- manufacturer's stated accuracies,
- production test results.

These procedures and documentation are used for traceability, stored in a data base and connected to the associated requirements to operate the CES storage system in accordance with the SMUD CES Unit specification and the GridPoint Sensor and Interface specification.   Specifically, the use cases are tied to the requirements via intermediate or sub-use cases and test cases as illustrated in ***Figure 2***. The specifics of the test cases are discussed further below.

Use Cases 1, 4, 5, & 6, highlighted in yellow in **Figure 1**, shall be used to define acceptance to Operate Storage System in the SMUD PV and Smart Grid Pilot at Anatolia.   Use cases 1 & 4, Communicate with Storage System Manager & Maintain EPS Interconnect will be treated as an integrated use case exercising the following functionality:

- Communications
- Islanding –detection, operation and return (IEEE 1547 and CES Unit Specification and Storage System Interface)
- Mode Transitions
- Alarm Reporting

Likewise, use cases 5 & 6, Operate Mechanical Contactor & Maintain CES Unit, are considered together given their functional commonalities. These two groupings of use cases (i.e. Group 1: 1 & 4 and Group 2: 5 & 6) are discussed further below.

2.2.1 Group 1 Acceptance Criteria: Use Case 1- Communicate with Storage System Manager& Use Case 2 - Maintain EPS Interconnect

As an example, consider a sub use case "Check Frequency Range" as prescribed by IEE 1547 (UL 1741 interconnect requirements) with the Maintain EPS Interconnect use case (and connected directly to the IEEE 1547/UL 1741 utility interconnections requirements for grid tied inverters), as shown in **Figure 3.**

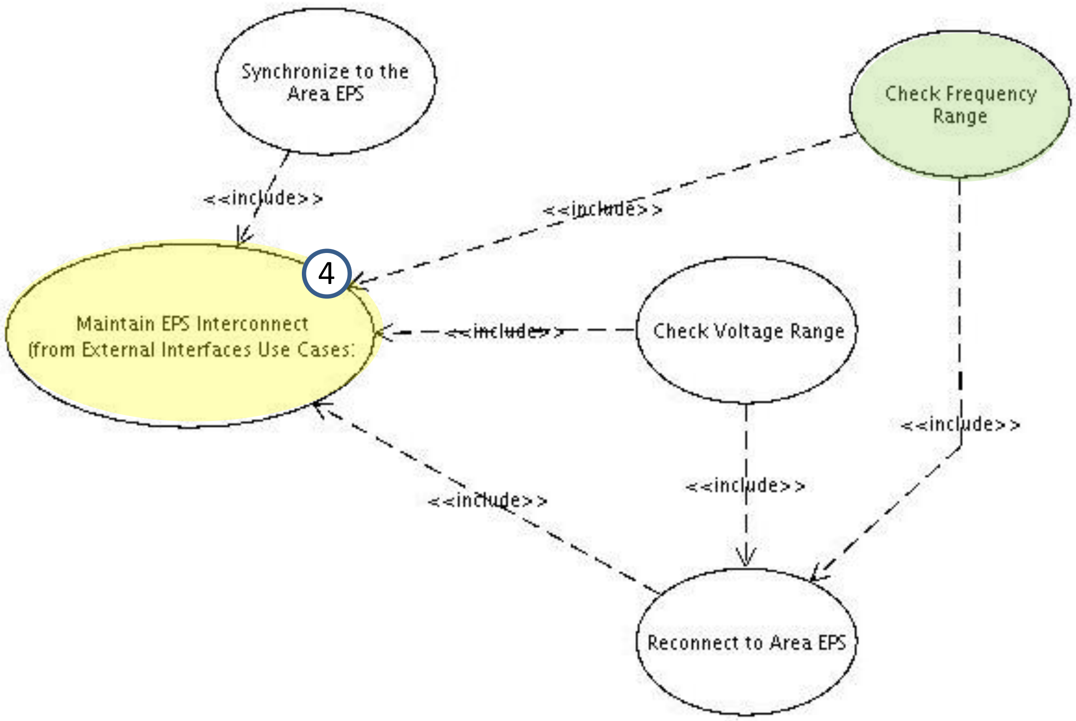


Figure 3. *Example diagram from TopCased mapping the primary use case (Maintain EPS Interconnect) to the sub use case (Check Frequency Range).*

The Sub Use Case "Check Frequency Range" is further expanded as developed in TopCased to map to the requirements as shown in **Figure 4.** Tractability to the requirements is accomplished through the Test Case "Response to Abnormal Frequency", as shown in **Figure 5** and mapped to the requirements called out in IEEE 1547-4.2.4.

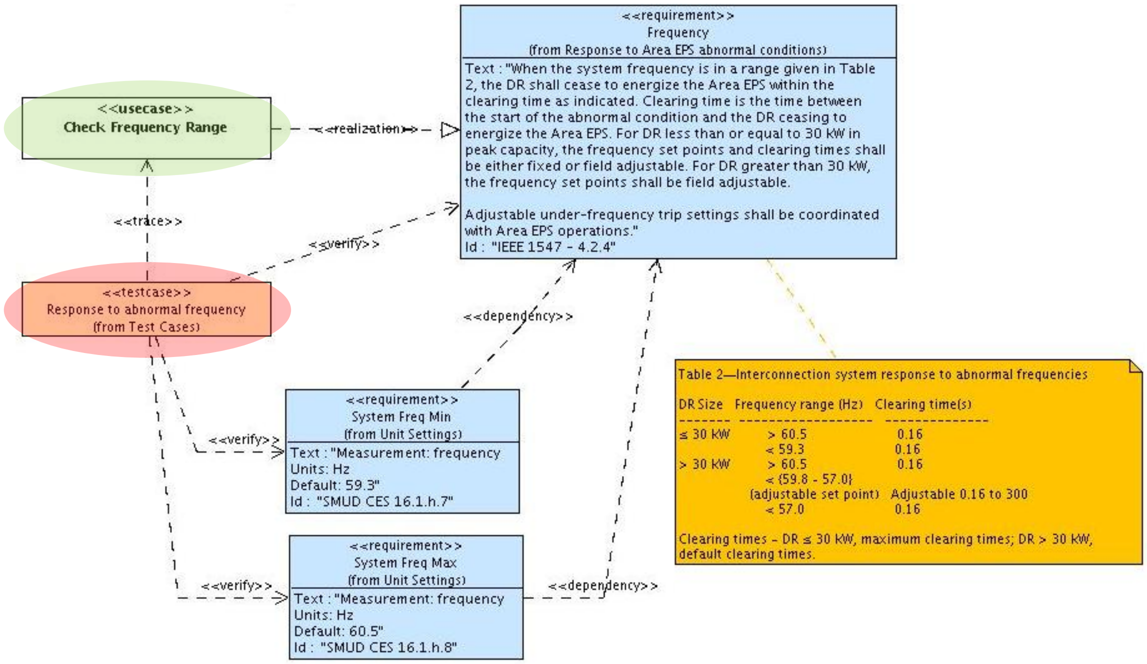


Figure 4. *Example diagram from TopCased mapping the sub use case (Check Frequency Range) to the test case (Response to abnormal frequency) and the requirements as per IEEE 1547-4.2.4.*

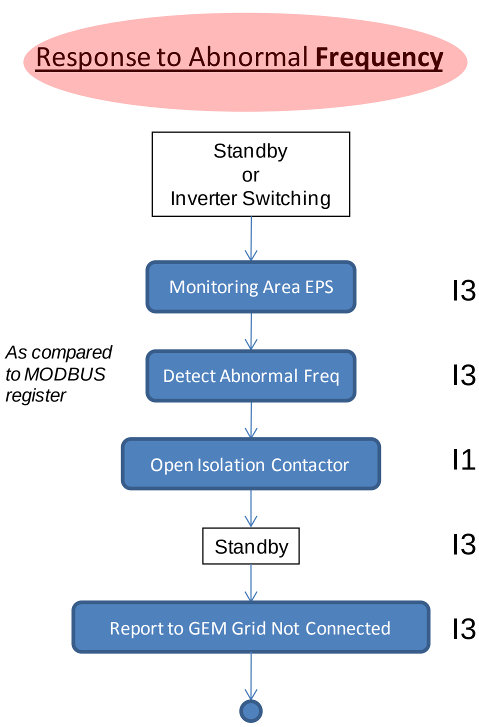


Figure 5. *Example diagram of the test case for Response to Abnormal Frequency*

The test case for the sub use case "Response to abnormal frequency" is also mapped to the integration test stages (i.e. I1 & I3) in the context of the modes of operation Standby and Inverter Switching, (and further discussed below). All interactions physical, command, alarms and communication are exercised and validated within each test case. Again this test case integrates the use case 1 & 4, exercising all aspects of the system, as connected to the requirements, in the context of the SMUD deployment.

Further test cases are developed and will be executed for each of the applicable UL 1741/IEEE 1547 interconnection requirements. The minimum set of acceptance test cases, as called out in IEEE 1547.1Section 5 – Type Tests interconnection requirements, for the

SMUD CES deployment shall be:

5.2 Test for response to abnormal voltage conditions

5.3 Response to abnormal frequency conditions

5.6 Limitation of dc injection for inverters without interconnection transformers

5.7 Unintentional islanding

5.9 Open phase

5.10 Reconnect following abnormal condition disconnect

5.11 Harmonics

Further, in the validation of mode transitions, the CES unit state diagram is employed in accordance with the SMUD CES Unit specification, reproduced here in **Figure 6.**

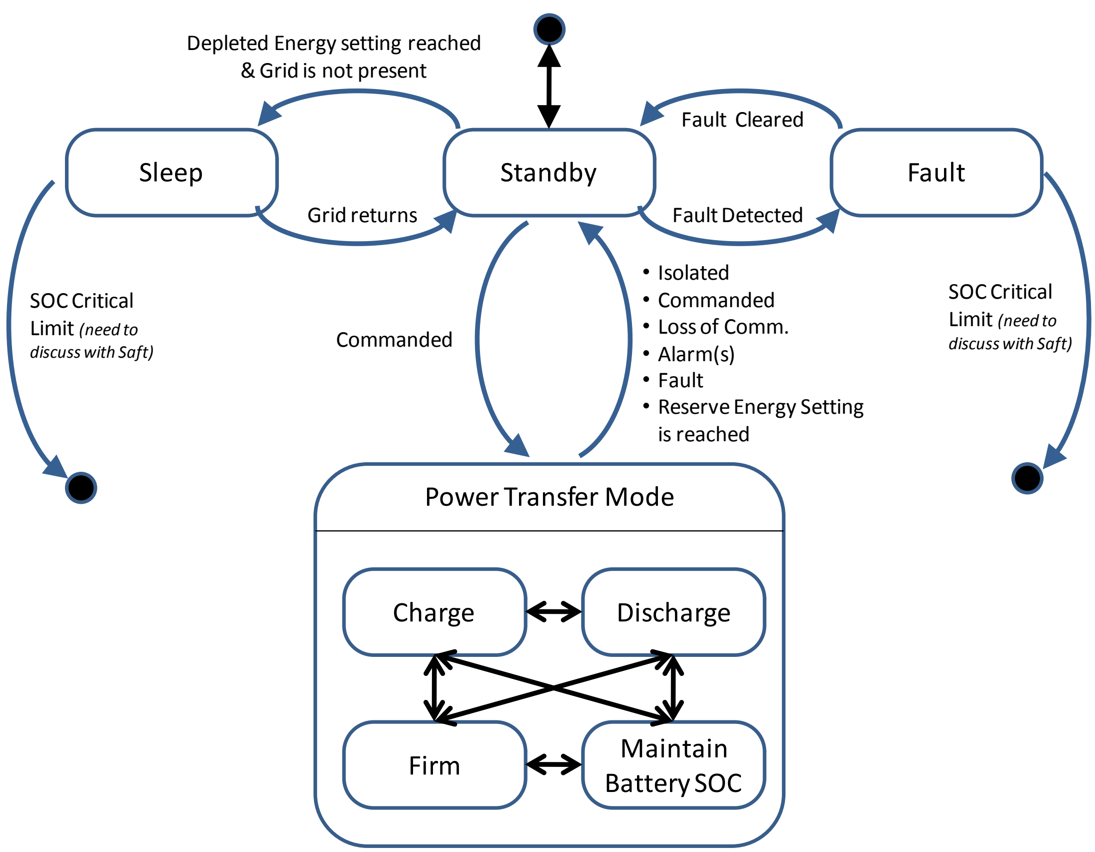


Figure 6. *CES unit State Diagram per the SMUD CES Unit specification*

The following test cases (**Figure 7** & **Figure 8**) are summarized below for the validation of mode transitions in accordance with the state diagram for the SMUD CES unit.

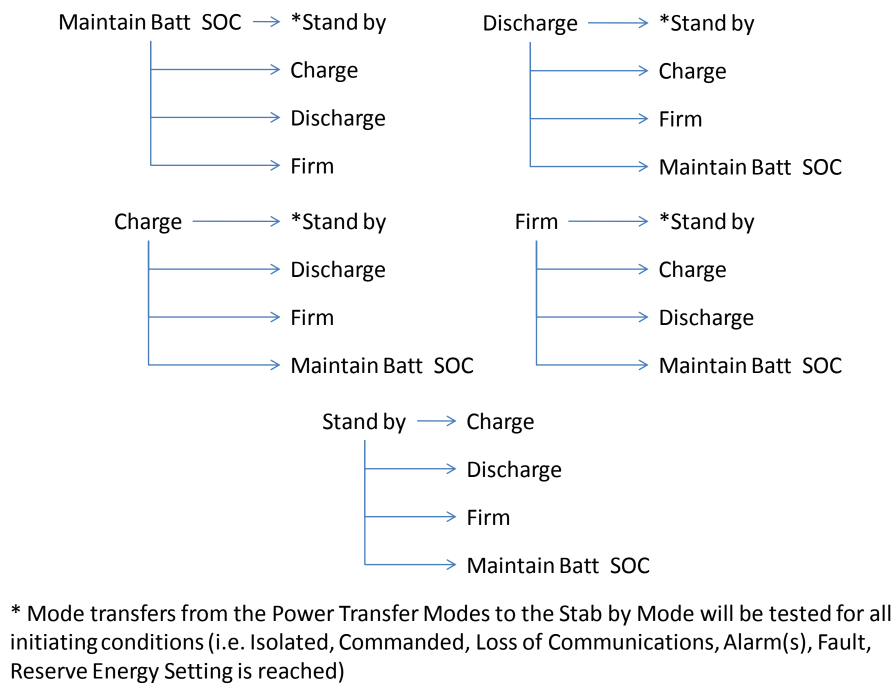


Figure 7. *Test cases for internal and to-from the **Power Transfer Mode** transitions.*

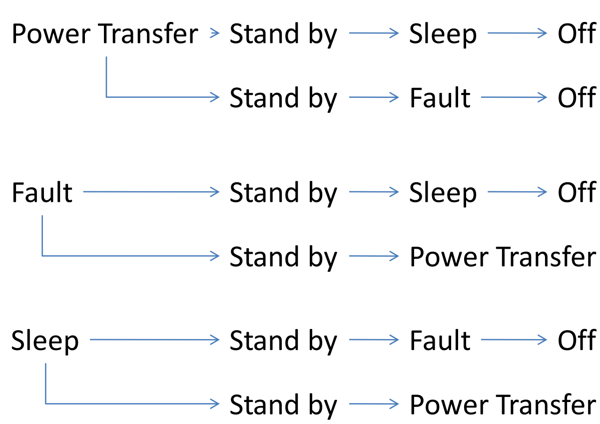


Figure 8. *Test cases for intra mode transfer between **Power Transfer**, **Sleep**, **Standby** and **Fault Modes.***

As an example **Figure 9** illustrates the, the transition from Discharge to Stand by and Stand by to Sleep mode. All interactions physical, command, alarms and communication are exercised and validated within each test case. Again, the integration test stages are also mapped to these test cases for regression.

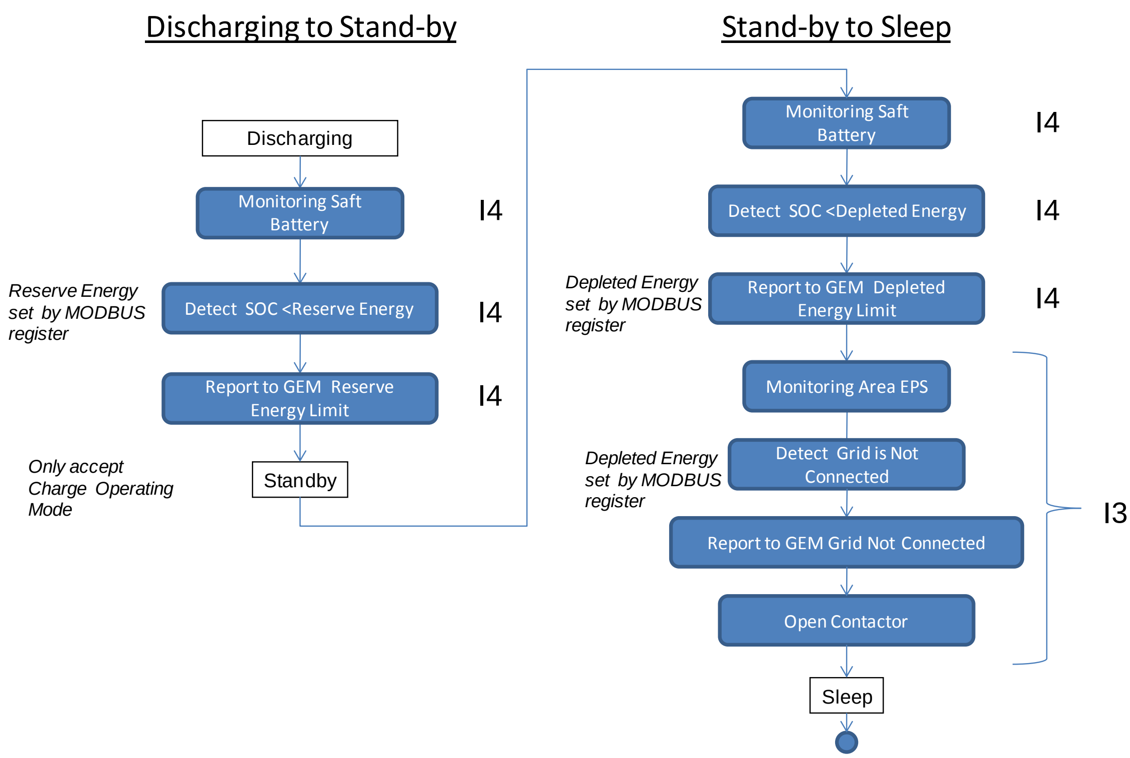


Figure 9. *Example test case showing transition from **Discharge** –to- **Stand by** and **Stand by** –to- **Sleep** mode.*

Again this test case integrates the use case 1 & 4 in terms of mode transitions, exercising all aspects of the system, as connected to the requirements, in the context of the SMUD deployment.

2.2.2 Group 2 Acceptance Criteria: 5 & 6, Operate Mechanical Contactor & Maintain CES Unit

The Group 2 Acceptance Criteria (refer to 2.1.2 Local Control Integration (I2)) are not as involved as Group 1 and will be validated in the laboratory for acceptance per the details provided in the integration testing.

2.3 Commissioning

Commissioning Test will be carried out as per ***1547.1 IEEE "Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems"*** Section 7 and includes the following functional sub-sections.

- 7.2 - Verification and inspections
- 7.3 - Field-conducted type and production tests
- 7.4 - Unintentional islanding functionality test
- 7.5 - Cease-to-energize functionality test
- 7.6 - Revised settings

UL1741

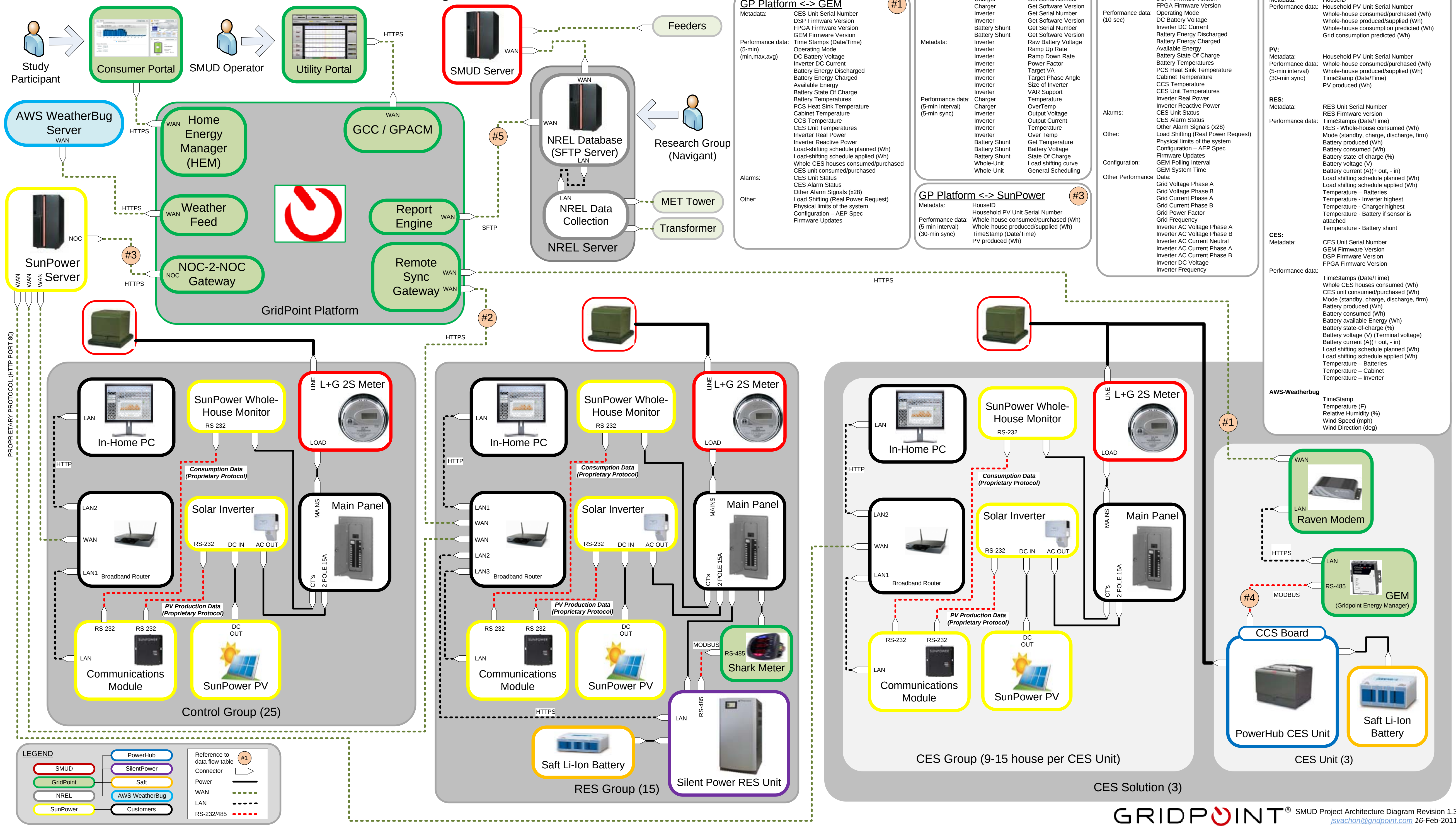
The product was evaluated to determine compliance with the applicable requirements of the UL Safety Standard: Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources, **UL 1741First Edition**, Dated May 7, 1999 - Revisions through and including November 7, 2005 and the Interconnection Standard for Interconnecting Distributed Resources with Electric Power Systems, **IEEE 1547** first edition dated 2003.

Section Number	**Test Description**	**Comment**
UL 1741		
42	Maximum – Voltage Measurements	DONE
43	Temperature – AMBIENT 40ºC	DONE
44	Dielectric Voltage-Withstand Test	DONE
45.2	Output Power Characteristics – Output ratings	DONE
45.3	Input Range	DONE

IEEE 1547	**IEEE 1547.1**	Per UL 1741 Section 39.1 and 46.1.1 "A utility-interactive inverter or interconnection syste (ISE) shall comply with the Standard for Interconnecting Distributed Resources with Electr Systems, IEEE 1547…"	to be done after other tests
	5.1.2.1	Operational Temperature	05/21/11 To 05/24/11 For High Temp; DONE (Low Temp)
	5.1.2.2	Storage Temperature	DONE (Low Temp)
5.1.1	5.2	Response to abnormal voltage	DONE
5.1.1	5.3	Response to abnormal frequency	DONE
5.1.2	5.4	Synchronization	DONE
5.1.3	5.5	-- *Interconnect Integrity tests (heading)* --	
5.1.3.1	5.5.1	Protection from EMI (IEEE C37.90.2)	DONE
5.1.3.2	5.5.2	Surge withstand (C62.45 and C62.41) Location Category A, B, or C	
5.1.3.3	5.5.3	Paralleling Device	05/19/11 (Paralleling Device) will be tested at the end of day 5/23/2011
	5.2	*Response to abnormal voltage (Repeat)*	05/16/11 DONE
	5.3	*Response to abnormal frequency (Repeat)*	05/17/11 DONE
	5.4	*5.1.2 Synchronization (Repeat)*	05/16/11 DONE
5.1.4	5.7	Unintentional Islanding	05/17/11 IN PROCESS
4.2.6	5.10	Reconnection to Area EPS	05/18/11 5/24/11
5.1.5	5.6	Limitation of dc injection	05/16/11 DONE
5.1.6	5.11	Harmonics (Current)	05/16/11 DONE
	5.9	Open Phase	05/18/11 5/24/11
		Sequence for conducting design test per Table 4, IEEE 1547	

Section Number	Test Description	Comments
UL 1741		
47.2	**Abnormal Tests** – Output overload test	DONE
47.3	**Abnormal Tests** – Short-circuit test	05/18/11 Hi Pot Test remaining
47.4	**Abnormal Tests** – DC input Miswiring test	DONE
47.5	**Abnormal Tests** – Ventilation test	DONE
47.6	**Abnormal Tests** – Component Short- and open- circuit	05/19/11 5/26/11
47.7	**Abnormal Tests** – Load transfer test	N/A, no by-pass switch
47.8	Utility Compatibility – Loss of Control Circuit	DONE
48	Grounding Impedance Test	DONE
49	Overcurrent Protection Calibration Test	N/A
50	Strain Relief Test	N/A, no input and output cables, etc.
51	Reduced Spacing on Printed Wiring Boards Tests	Combined with the components short-circuit tests of clause 47.6
52	Bonding Conductor Test	N/A, at least same sized wires used
53	Voltage Surge Test	N/A
54	Calibration Test	N/A
55	Overvoltage Test	N/A
56	Current Withstand Test	N/A
57	Capacitor Voltage Determination Test	DONE
58	Stability	N/A
59	Static Load	N/A
60	Compression Test	N/A
61	Rain Test and Sprinkler Tests	N/A (Indoor Unit)

SMUD – High Penetration Solar Pilot Architecture Diagram



DATA FLOW TABLES

GP Platform <-> GEM (#1)

Metadata:	CES Unit Serial Number
	DSP Firmware Version
	FPGA Firmware Version
	GEM Firmware Version
Performance data:	Time Stamps (Date/Time)
(5-min)	Operating Mode
(min,max,avg)	DC Battery Voltage
	Inverter DC Current
	Battery Energy Discharged
	Battery Energy Charged
	Available Energy
	Battery State Of Charge
	Battery Temperatures
	PCS Heat Sink Temperature
	Cabinet Temperature
	CCS Temperature
	CES Unit Temperatures
	Inverter Real Power
	Inverter Reactive Power
	Load-shifting schedule planned (Wh)
	Load-shifting schedule applied (Wh)
	Whole CES houses consumed/purchased
	CES unit consumed/purchased
Alarms:	CES Unit Status
	CES Alarm Status
	Other Alarm Signals (x28)
Other:	Load Shifting (Real Power Request)
	Physical limits of the system
	Configuration – AEP Spec
	Firmware Updates

GP Platform <-> RES (#2)

Firmware:	Whole-Unit	GetDeviceInfo
	Charger	Get Serial Number
	Charger	Get Software Version
	Inverter	Get Serial Number
	Inverter	Get Software Version
	Battery Shunt	Get Serial Number
	Battery Shunt	Get Software Version
Metadata:	Inverter	Raw Battery Voltage
	Inverter	Ramp Up Rate
	Inverter	Ramp Down Rate
	Inverter	Power Factor
	Inverter	Target VA
	Inverter	Target Phase Angle
	Inverter	Size of Inverter
	Inverter	VAR Support
Performance data:	Charger	Temperature
(5-min interval)	Charger	OverTemp
(5-min sync)	Inverter	Output Voltage
	Inverter	Output Current
	Inverter	Temperature
	Inverter	Over Temp
	Battery Shunt	Get Temperature
	Battery Shunt	Battery Voltage
	Battery Shunt	State Of Charge
	Whole-Unit	Load shifting curve
	Whole-Unit	General Scheduling

GP Platform <-> SunPower (#3)

Metadata:	HouseID
	Household PV Unit Serial Number
Performance data:	Whole-house consumed/purchased (Wh)
(5-min interval)	Whole-house produced/supplied (Wh)
(30-min sync)	TimeStamp (Date/Time)
	PV produced (Wh)

GEM <-> CCS (#4)

Metadata:	CES Unit Serial Number
	DSP Firmware Version
	FPGA Firmware Version
Performance data:	Operating Mode
(10-sec)	DC Battery Voltage
	Inverter DC Current
	Battery Energy Discharged
	Battery Energy Charged
	Available Energy
	Battery State Of Charge
	Battery Temperatures
	PCS Heat Sink Temperature
	Cabinet Temperature
	CCS Temperature
	CES Unit Temperatures
	Inverter Real Power
	Inverter Reactive Power
Alarms:	CES Unit Status
	CES Alarm Status
	Other Alarm Signals (x28)
Other:	Load Shifting (Real Power Request)
	Physical limits of the system
	Configuration – AEP Spec
	Firmware Updates
Configuration:	GEM Polling Interval
	GEM System Time
Other Performance	Data:
	Grid Voltage Phase A
	Grid Voltage Phase B
	Grid Current Phase A
	Grid Current Phase B
	Grid Power Factor
	Grid Frequency
	Inverter AC Voltage Phase A
	Inverter AC Voltage Phase B
	Inverter AC Current Neutral
	Inverter AC Current Phase A
	Inverter AC Current Phase B
	Inverter DC Voltage
	Inverter Frequency

NREL Server <-> GP Platform (#5)

Platform:	
Metadata:	HouseID
Performance data:	Household PV Unit Serial Number
	Whole-house consumed/purchased (Wh)
	Whole-house produced/supplied (Wh)
	Whole-house consumption predicted (Wh)
	Grid consumption predicted (Wh)
PV:	
Metadata:	Household PV Unit Serial Number
Performance data:	Whole-house consumed/purchased (Wh)
(5-min interval)	Whole-house produced/supplied (Wh)
(30-min sync)	TimeStamp (Date/Time)
	PV produced (Wh)
RES:	
Metadata:	RES Unit Serial Number
	RES Firmware version
Performance data:	TimeStamps (Date/Time)
	RES - Whole-house consumed (Wh)
	Mode (standby, charge, discharge, firm)
	Battery produced (Wh)
	Battery consumed (Wh)
	Battery state-of-charge (%)
	Battery voltage (V)
	Battery current (A)(+ out, - in)
	Load shifting schedule planned (Wh)
	Load shifting schedule applied (Wh)
	Temperature – Batteries
	Temperature - Inverter highest
	Temperature - Charger highest
	Temperature - Battery if sensor is attached
	Temperature - Battery shunt
CES:	
Metadata:	CES Unit Serial Number
	GEM Firmware Version
	DSP Firmware Version
	FPGA Firmware Version
Performance data:	
	TimeStamps (Date/Time)
	Whole CES houses consumed (Wh)
	CES unit consumed/purchased (Wh)
	Mode (standby, charge, discharge, firm)
	Battery produced (Wh)
	Battery consumed (Wh)
	Battery available Energy (Wh)
	Battery state-of-charge (%)
	Battery voltage (V) (Terminal voltage)
	Battery current (A)(+ out, - in)
	Load shifting schedule planned (Wh)
	Load shifting schedule applied (Wh)
	Temperature – Batteries
	Temperature – Cabinet
	Temperature – Inverter
AWS-Weatherbug	
	TimeStamp
	Temperature (F)
	Relative Humidity (%)
	Wind Speed (mph)
	Wind Direction (deg)

Revision	Author	Date	Comments
1.00	JS Vachon	18 Déc	Initial document
2.00	JS Vachon	21 Jan 2011	First Revision
3.00	JS Vachon	28 Jan 2011	Release version

Grid Interconnection Test Plan
for PowerHub Systems CE-3030 Unit

Location:	**DERTF Lab at NREL's NWTC**
Planned Testing Dates:	**November 6 – November 28, 2011**
Lead NREL Engineer:	**Greg Martin (303-384-7039)**
Supporting NREL Engineers:	**Jason Bank and Danny Terlip**
NREL Laboratory Supervisor:	**Bill Kramer (303-275-3844)**
NREL EHS Point of Contact:	**Mike Stewart (303-384-6906)**
Manufacturer Representative (PowerHub):	**Glenn Skutt (540-250-2870)**
Customer Representative (SMUD):	**Ed Sanchez (916-732-5572)**
Testing objectives overview:	**IEEE 1547 standard tests and general performance testing**
Description of equipment under test:	**30kW, 30kWh battery energy storage system with inverter interface to utility**

EMERGENCY CONTACT INFORMATION

From the NWTC, dial 911 or 9-911 from any NREL telephone

Notify NREL Security 303-384-6811 (or x1234)

Laboratory Designated Area Representative – Kevin Harrison 303-384-7091

1 INTRODUCTION

Under an agreement between Sacramento Municipal Utility District (SMUD) and the National Renewable Energy laboratory (NREL), an energy storage system will be tested at NREL's Distributed Energy Resources Test Facility (DERTF). The testing is planned to take place during the month of November 2011. The device under test, provided by PowerHub in Blacksburg, Virginia, is an integrated battery energy storage system utilizing a bi-directional inverter interface to connect to the utility grid. The unit will be tested according to IEEE Std. 1547 utility interconnection standards and battery system charging and discharging performance and safety.

This test plan does not necessarily include all the tests required to meet the IEEE 1547 standard due to the uniqueness of the battery-based power electronics that makes some of the IEEE 1547 tests not applicable or impractical. Some additional performance tests are included in the test plan to verify the equipment's continuous output power, efficiency and losses. This test plan uses the standard IEEE 1547 test protocol as a template, where non-applicable tests are indicated as such, and where modifications or additions to the standard test plan are highlighted.

The intent of this test plan is to provide test results that indicate the unit's ability or inability to comply with IEEE 1547 interconnection standards, not to provide official conformance certification. Testing results may be further investigated to assist the unit's manufacturer to identify and correct deviations from the standard. During the test period, three identical units are available for testing. The agreed plan is to perform IEEE 1547 tests and performance tests on one unit, and then to perform only basic functional operation and acceptance tests on the remaining two units.

Design of experiments and test procedures in this test plan reflect experience, lessons learned, and best practices at NREL and draw from the following documents:

> *1547.1 IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems*
>
> *Interim Test Procedures for Evaluating Electrical Performance and Grid Integration of Vehicle-to-Grid Applications; S. Chakraborty, W. Kramer, B. Kroposki, G. Martin, P. McNutt, M. Kuss, T. Markel, and A. Hoke; NREL Technical Report NREL/TP--5500--51001; June 2011*

All testing must be conducted in conformance with NREL and DOE safety requirements by authorized personnel only. Testing is allowed during attended operation only.

All testing will be accomplished under a Safe Work Permit issued by NREL's Environment, Health and Safety Office, and approved by DERTF management. The test setup and operation of equipment is subject to a readiness verification (RV) prior to approval to operate.

Safe operating procedures (SOP) for activities at the DERTF are defined in the DERTF SOP document. All parties involved with the testing must be familiar with the procedures and hazards outlined in this document. In addition, non-NREL people involved in the setup or testing will be required to complete an on-site safety orientation from the NREL EHS coordinator.

2 TEST SETUP

2.1 Equipment Under Test

The CE-3030, manufactured by PowerHub of Blacksburg, Virginia, is a battery energy storage system with a bi-directional inverter for utility grid interconnection. It is a new product built to meet the specifications of a Sacramento Municipal Utility District initiative. The unit can both discharge battery energy into a utility grid as AC power and charge the batteries from the same AC connection. The intent of the equipment is to provide voltage and frequency regulation as well as provide time shifting of energy available from nearby distributed energy (DG) sources. Power dispatch will ultimately be controlled by the utility operator.

The unit connects at 240Vac and is capable of discharging 30kWh of energy at 30kW. It employs lithium ion doped nickel oxide (NCA) batteries and battery management system produced by Saft Batteries and an inverter stage developed and produced by PowerHub. The unit employs both controllable contactors and fuses for electrical protection on both the AC and DC sub-systems within the enclosure. The inverter stage hosts the control interface and supervisory algorithms which interface to the battery management module (BMM) as well as monitor inverter status and external control input. Figures 1 and 2 below show a diagram of the exterior of the unit, and a photograph, respectively.

The unit is encased and sealed on 5 sides with 1/8" steel plating. An air vent and a wire access hole are the only exceptions to contiguous and sealed steel plating. The bottom of the unit is open, it is intended to be mounted over a wiring vault. For this experiment, the unit will be placed on sturdy wood footers to hold the unit off the floor and provide space for wires to enter into the bottom of the unit.

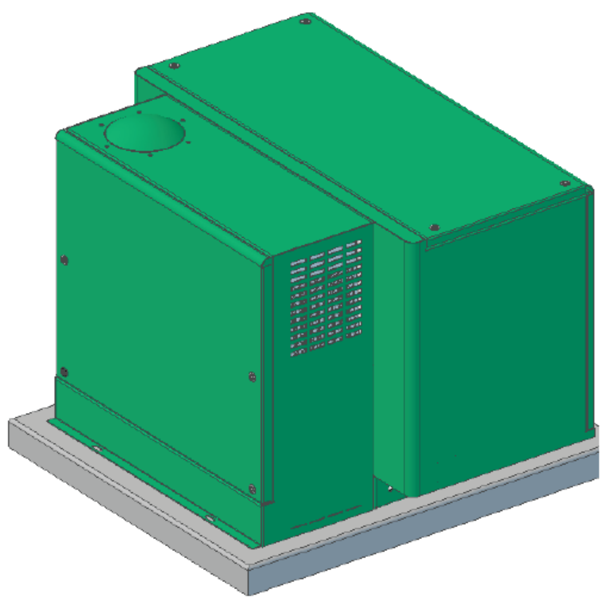


Figure 1. Diagram of CE-3030 Equipment

Figure 2. Photographs of CE-3030 Equipment

2.2 Laboratory Equipment

To accomplish testing of the unit, a grid simulator AC source and a programmable AC load bank are used. Both of these resources are interconnected to the DERTF bus network and ready for use in testing. These components will be connected in parallel on the DERTF AC bus along with the equipment under test (EUT).

The Pacific Power MS-3060 AC source is a programmable grid simulator capable of establishing the abnormal and transient grid conditions necessary for the testing. For this test, two 50kW grid simulator units will be connected together in master-slave control, providing up to 100kW ouput. The output voltage of the source can range from 0 to 480Vac, 50Hz, 60Hz, or 400Hz, and can be set for single-phase, split-phase, or three-phase output. For this test, the grid simulator will be set for nominal 240Vac, 60Hz split-phase. This involves setting one phase to 120Vac $\angle 0^\circ$, another phase to 120Vac $\angle 180^\circ$, and the third phase to 0Vac.

Two load banks are used in testing, connected in parallel on the AC bus. One is a 200kW programmable R-L-C load bank, the other a 100kW R-L programmable load bank. Both will be connected to the experiment to sink power when the bus is energized. For most of the tests, the load banks will be set to sink double the amount of power as can be output by the battery system in order to maintain a stable power system. The balance of load current will be supplied by the grid simulator source. In the special case of the islanding test, where a “tuned” L-C circuit must be set up which matches the impedance of the equipment under test, an iterative process to set and measure actual impedance will be used to adjust the circuit appropriately.

Both grid simulator and load bank are controlled from inside the DERTF. The grid simulator controller offers remote voltage and current monitoring and a computer interface to program voltage and frequency ramps and transients. The load bank is controlled by a lab computer which allows the user to set resistive (real) power, inductive (reactive leading) power and capacitive (reactive lagging) power. The DERTF bus network is controlled by a lab computer and also has a data monitoring and acquisition routine.

2.3 Data Acquisition Equipment

The typical quantities to be measured for this testinga re listed next. Some adjustments may be made based on specific test procedure requirements.

- Line-to-line voltage (V_L1-L2), nominal 240Vac
- Line-to-neutral voltage (V_L1-N), nominal 120Vac
- Line current (I_L1), rated 145A
- Neutral current (I_N), nominal 0A

Instruments to be used for data acquisition are (instrument details are listed below):

- Yokogawa PZ400 power analyzer for mid-bandwidth power, voltage and current monitoring and capture, also harmonic analysis
- Yokogawa DL750 digital oscilloscope for high-bandwidth voltage and current monitoring and capture, also has datalogging capability
- AEMC mid-bandwidth current probe
- Yokogawa high-bandwidth current probe

Yokogawa PZ4000 Power Analyzer

Model No. 253710-D/B5/C7
Serial Number: 12W409170D
Calibration Due: 04/12/12

The Yokogawa PZ4000 power analyzer includes four isolated power measurement modules, Model No. 253752, each with one voltage and one current input. Specifications for the chassis and the IO modules are listed below.

General Specifications:

- Voltage input modules rated to 1000V
- Current inputs rated to 500mV(with conversion probe) or 5A and 20A (direct)
- Maximum sampling rate: 5M S/s
- Maximum sampling rate for 200 ms observation time: 500k S/s (unit without extended memory option) or 5M S/s (unit with the /M3 extended memory option)
- Maximum sampling rate for 10 s observation time: 10k S/s (unit without extended memory option) or 250k S/s (unit with the /M3 extended memory option)
- Time scale accuracy: ± 0.005% of the observation time
- 200 ms observation time: 0.01 ms
- 10 s observation time: 0.5 ms

Yokogawa DL750 ScopeCorder
Model No. 702210-D-J1-HE/M1/C8
Serial Number: 91G546601
Calibration Due: 01/24/12

The DL750 Scopecorder is equipped with seven voltage input modules, Model No. 701260, each with two voltage input channels, and one frequency input module, Model No. 701280, with two voltage input channels.

General Specifications

- Maximum sampling rate: 10M S/s

- Maximum sampling rate for 200 ms observation time: 5M S/s (unit /M1 extended memory option) or 10M S/s (unit with the /M2 extended memory option)
- Maximum sampling rate for 10 s observation time: 100k S/s (unit with /M1 extended memory option) or 500k S/s (unit with the /M3 extended memory option)
- Time scale accuracy: ± 0.005% of the observation time
- 200 ms observation time: 0.01 ms
- 10 s observation time: 0.5 ms

Current Probes

AEMC AC/DC Current Probe Model No. MR561 Specifications

Nominal range	$100A_{AC}$ / $150A_{DC}$	$1000A_{AC}$ / $1500A_{DC}$
Output signal	10 mV/A	1 mV/A
Accuracy	0.5 – 20A: 1.5% of reading ± 0.5A	0.5 – 100A: 1.5% of reading ± 1A
	20 – 100A: 1.5% of reading	100 – 800A: 2.5% of reading
	100 – 150A (DC only): 2.5% of reading	800 – 1000A: 4% of reading
		1000 – 1400A (DC only): 4% of reading
-3dB Bandwidth	DC – 10 kHz	DC – 10 kHz

Yokogawa Current Probe Model No. 701930 Specifications

Nominal Range	150Arms
Output signal	10 mV/A
Accuracy	0 – 150 Arms: 1% of reading ± 0.1A
-3dB Bandwidth	DC – 10 MHz

2.4 Experiment Connection Drawings

The equipment under test connects to the electric power system (EPS) at 240Vac. It interfaces to the DERTF equipment via a fused disconnect switch. Figure 3 shows a full connection diagram of the test system. Figure 4 is a system single-line diagram which gives additional information on wiring.

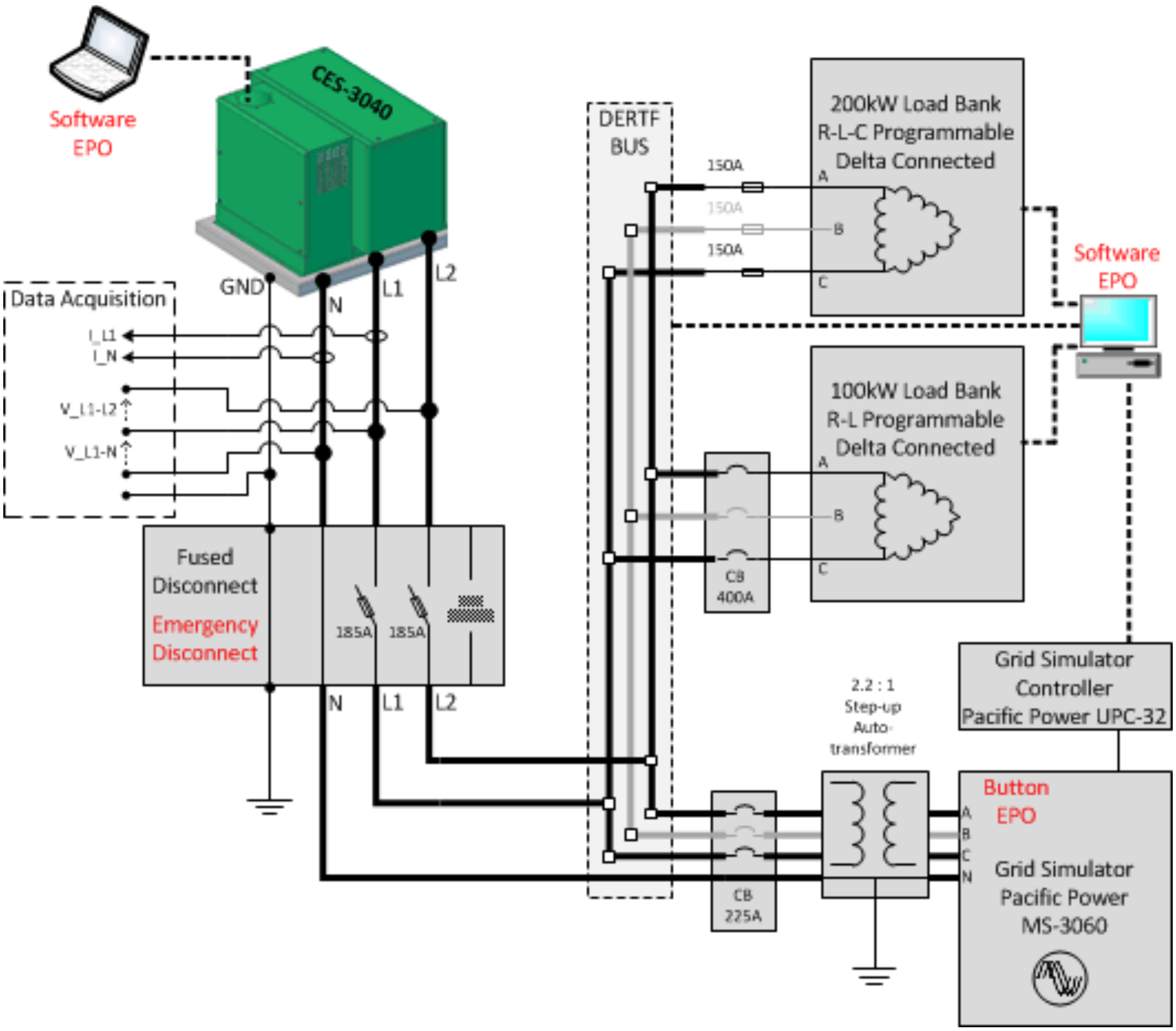


Figure 3. Overall Experiment Setup Lab Connection Diagram

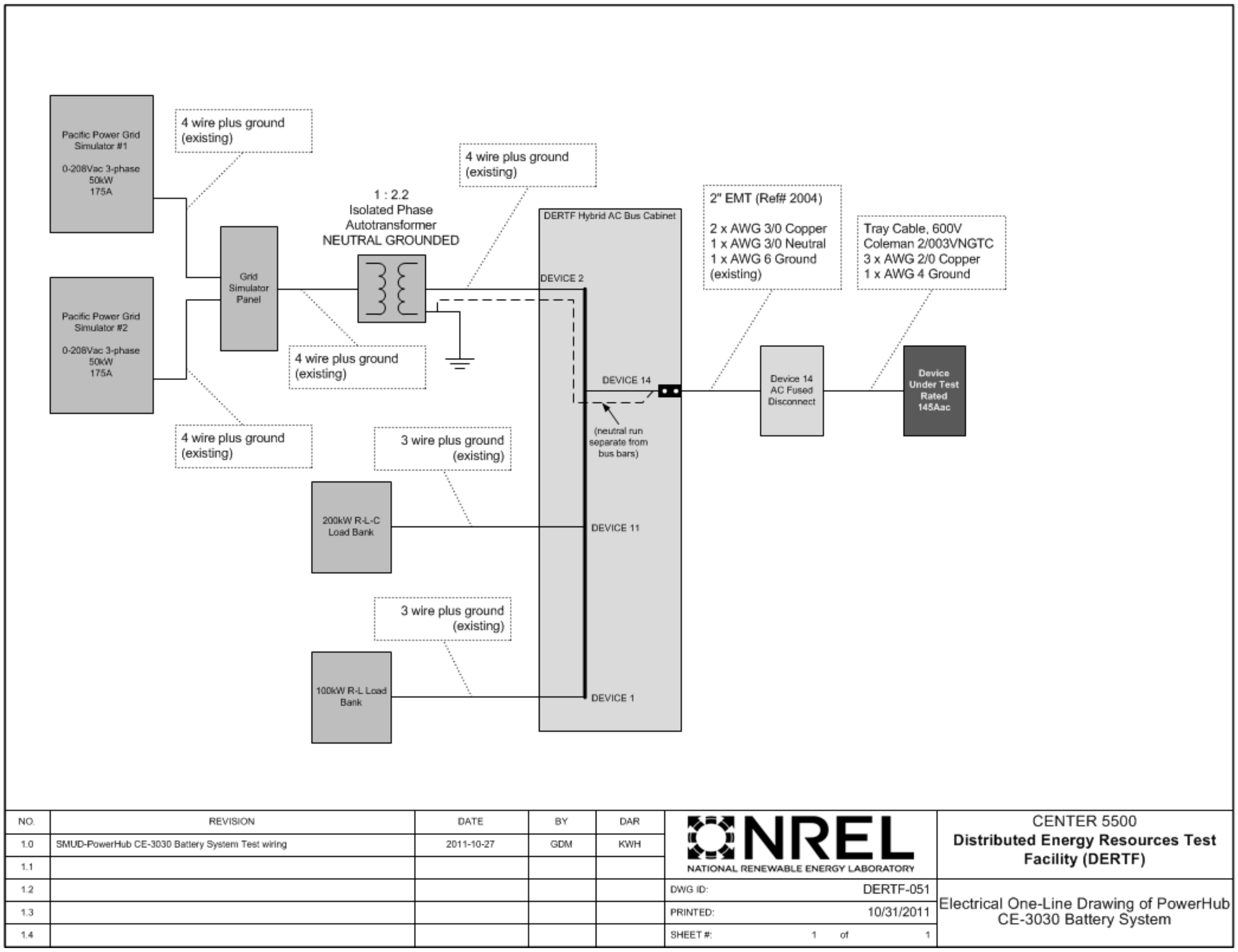


Figure 4. System Single-line Diagram

3 SAFETY

All testing must be conducted in conformance with NREL and DOE safety requirements by authorized personnel only. Testing is allowed during attended operation only.

3.1 Emergency Electrical De-Energization

There are several methods of turning off or disconnecting equipment in this experiment setup. These include:

- Software emergency power off (EPO) provisions
- Mechanical disconnect for the equipment under test
- Push-button EPO on the grid simulator cabinet front panel.

Locations of these EPOs are indicated in Figure 3 above in red text.

Interior to the equipment under test (EUT) there are both fuses and switches protecting both AC and DC circuitry. On the DC link, which is energized by the batteries, there are three protective devices in series:

- A rated DC contactor inside the battery management module can be opened by control signals from the battery management module or from the (human) computer interface.
- A rated DC circuit breaker that will trip if the contactor fails to open.
- A series-rated, fast-blow DC fuse at 200A (in a fused disconnect) will interrupt current should both the contactor and circuit breaker fail to open the circuit.

On the AC side of the inverter, which interfaces to the utility grid, there are two protective devices:

- A mechanical fused disconnect (by ABB) which can be manually operated, but is located inside the unit so access is limited. The fuses in this disconnect are fast-blow 200A.
- An AC rated contactor is located inside the inverter module. This contactor is controlled by the supervisory computer algorithm and is opened automatically if an abnormal condition is sensed. In addition, this contactor can be opened at will by the operator using the computer control interface.

Referring to Figure 3 above, upstream of the EUT is a fused disconnect. It is located near the EUT for easy access by experimenters. This switch is fused at 185A. This disconnect may be used to sever power to (or from) the EUT in case of an emergency condition.

The front panel of the grid simulator power cabinet has an “Emergency Off” button, which will de-energize the grid simulator output. The unit may also be shut down by toggling the “Output Enable” button on the UPC-32 grid simulator controller. Finally, the grid simulator may also be disabled from the computer software interface, which has the same effect as toggling the “Output Enable” button on the UPC-32.

Finally, the computer in the DERTF which controls the bus contactors offers a software-enabled “Emergency Stop” button. This button will signal the system to attempt to open ALL contactors in the buswork regardless of sensed voltage or current.

3.2 Lockout Tagout

Lockout tagout for this experiment can be broken into two overall zones:

Zone 1: The DERTF resident systems, including grid simulator, load bank, buswork, AND the fused disconnect serving the EUT
Zone 2: The wiring connection at the EUT and any internal or instrumentation work inside the EUT.

Unless otherwise stated, all LO/TO actions are intended to lock a device in the safe, de-energized, or "off" state, meaning the electrical device is breaking the electrical circuit and causing an open circuit.

WARNING: Both the AC connections to the EUT and the DC link battery connections inside the EUT may have capacitors which are energized even when the unit is off. Allow sufficient time (at least 10 minutes) per manufacturer specifications to allow the capacitors to bleed down to a low-energy state prior to accessing the unit.

Zone 1 LO/TO Procedure (for AC Device 14 and DERTF bus upstream)
1. Lockout and tagout AC DEVICE 14.
2. Lockout and tagout the AC fused disconnect device inside the EUT per manufacturer direction.
3. Lockout and tagout any other equipment on the bus side of AC Device 14 per the DERTF SOP.

Zone 2 LO/TO Procedure (for EUT)
1. Lockout and tagout AC DEVICE 14.
2. Lockout and tagout the AC fused disconnect device inside the EUT per manufacturer direction.
3. Use the human interface computer to open the DC contactor to disconnect the battery DC voltage.
4. Lockout and tagout the DC fused disconnect device inside the EUT per manufacturer direction.

3.3 Battery Safety

A 34kWh lithium ion doped nickel-carbon-aluminum oxide battery system provides power to the inverter section of the EUT or receives charging current from the inverter. The battery is manufactured by Saft Batteries and its trade name is NCA. The battery is comprised of 17 modules (one module consists of 14 cells), each operates at a nominal 24Vdc (22V – 28V range). The modules are connected in series to generate a nominal system DC voltage of 408V (374V – 476V range). The batteries are managed and supervised by a Saft-supplied battery management module (BMM).

Three separate devices inside the battery compartment provide electrical protection of the battery pack; an electrically operated contactor, a DC rated circuit breaker, and 200A fuses inside a fused disconnect (with mechanical disconnect switch).

The battery management module (BMM) provides automatic monitoring and protection of the battery system. Most importantly, all modules are monitored for temperature and the BMM will open the DC contactor in the event of a temperature above 60°C. A warning is issued to the human interface computer once any temperature reaches 55°C. The BMM will disconnect the battery if an overvoltage, undervoltage, or overcurrent (in both charging and discharging directions) is detected.

All involved personnel must be aware of the following safety considerations. The person in charge of the testing must ensure all affected people are aware of these items, and must ensure all safety systems remain in-place and functional.

- Read and understand the battery system user manual as well as any and all additional safety documentation available. Always follow safety guidelines, cautions, and warnings.
- Set up a restricted access area for battery testing and keep any non-essential personnel away from the testing area.
- Be prepared to ventilate the space where the battery is tested. At the DERTF, test with the large overhead door open and the back door open if possible.
- The unit is encased with steel. All panels and guards must remain in place and secure, and must be undamaged during testing.
- Reinforced insulation protecting battery system leads must be securely bonded to chassis ground and earth ground.
- There is a risk of outgassing from the battery cells if the battery is stressed beyond its safe operating limits. This gas consists of 40% CO, 25% CO_2, 25% H_2, 5% CH_3 and C_2H_4, 5% carbon particulate and residue. The released gas represents a flammable mixture. If any outgassing is sensed or expected, the EUT must be shut down and disconnected, and the building must be evacuated until safe re-entry is allowed by safety authorities.
- There is the risk of extreme heat or fire if the battery is stressed beyond its safe operating limits. If any indication of elevated heat from sensors, smoke, or fire is detected or expected, the EUT must be shut down and disconnected, and the building must be evacuated until safe re-entry is allowed by safety authorities.
- If the battery is stressed beyond its safe operating limits, there is the risk of pressure release of gas containing the above constituents. Appropriate PPE must be work at all times during the testing.
- Be extremely careful to never place tools or other foreign objects anywhere in or on the unit.
- Immediately disconnect the battery if, during operation, the battery emits an unusual smell, feels hot, changes shape, or appears abnormal in any way.
- Follow all manufacturer guidelines and NREL safety practices when installing or dismantling any portion of the battery system.
- Misuse of the batteries could cause them to overheat or ignite and cause serious injuries. Always follow these operational guidelines:
    - Never short-circuit battery terminals.
    - Never apply reverse polarity voltage to the battery terminals.
    - Never over charge or over-discharge the battery.
    - Do not open or disassemble battery modules.
    - Do not subject the battery modules or parts to excessive mechanical stress.
- Always maintain a heavy physical barrier between the battery and personnel whenever the unit is in operation. For this test, a barrier is achieved with the steel plating encasing the unit.
- A CO_2 fire extinguisher must be easily accessible throughout the testing.
- All involved personnel must wear appropriate personal protective equipment during the testing:
    - Safety glasses
    - Full-leg pants and long sleeved shirt (preferably cotton)
    - Closed-toed shoes (steel or safety toe recommended)
- If electrical work is to be performed, workers must adhere to the NFPA 70E requirements for PPE, as well as NREL requirements. These are listed in the DERTF SOP. When verifying zero energy, use of a voltage presence sensor rated for DC is recommended.

3.4 Physical Safety

The EUT is enclosed with 1/8” steel plating on all sides except the bottom. The unit will be placed on footer beams to allow access to the connections underneath the unit. Use caution when working near the unit or when moving the unit. Steel-toed shoes are recommended.

If the unit is operated for long periods of time, surfaces may become warm. Check the surface temperature of the unit regularly during operation (using a thermal sensing device). Do not touch the unit while it is operating.

The unit (with batteries installed) is heavy. Follow all manufacturer-recommended handling procedures for installation and set-up.

4 TEST PROCEDURES

All testing must be conducted in conformance with NREL and DOE safety requirements by authorized personnel only. Testing is allowed during attended operation only.

Two major categories of tests will be performed; IEEE 1547.1 standard tests and additional performance tests. The following list outlines each individual test type and indicates its purpose, modifications for this specific test plan, and deviations from the standard IEEE 1547.1 procedures.

For IEEE 1547.1 tests, refer to the IEEE 1547.1 document for test purpose, procedure, requirements and criteria. These tests shall be performed in accordance with the IEEE 1547.1 document except as otherwise noted. All tests will be performed indoors at room temperature ambient conditions.

4.1 IEEE 1547.1 Standard Tests

4.1.1 Temperature Stability (IEEE 1547.1 Section 5.1)

i. *Purpose:* To verify acceptable EUT measurement accuracy of parameters is maintained throughout allowable operating temperature range.
ii. *Modifications:* No environmental chamber is available for testing. This test will be performed with the goal of verifying the accuracy of the EUT measurements compared to the laboratory instrumentation. To be performed at low temperature at startup (room temperature) as well as at steady state operating temperature. Protective functions must be verified to operate as expected at both minimum attainable and nominal operating temperatures. This test will be repeated for both charging and discharging modes of operation.
iii. *Procedure:* Follow procedure as stated in IEEE 1547.1 section 5.1, modified as indicated in this test procedure.

4.1.2 Response to Abnormal Voltage Conditions (IEEE 1547.1 Section 5.2 and 6.1)

i. *Purpose:* To assess EUT response to abnormal voltage signatures on the EPS it is connected to. The unit should cease to operate when an over-voltage or under-voltage condition of specified magnitude is present, and the trip time of the EUT is tested.
ii. *Modifications:* This test will be repeated only twice unless inconsistent results are observed. This test will be repeated for both charging and discharging modes of operation.
iii. *Procedure:* Follow procedure as stated in IEEE 1547.1 section 5.2, modified as indicated in this test procedure.

4.1.3 Response to Abnormal Frequency Conditions (IEEE 1547.1 Section 5.3 and 6.2)

i. *Purpose:* To assess EUT response to abnormal frequency signatures on the EPS it is connected to. The unit should cease to operate when an over-frequency or under-frequency condition of specified magnitude is present, and the trip time of the EUT is tested.
ii. *Modifications:* This test will be repeated only twice unless inconsistent results are observed. This test will be repeated for both charging and discharging modes of operation.
iii. *Procedure:* Follow procedure as stated in IEEE 1547.1 section 5.3, modified as indicated in this test procedure.

4.1.4 Synchronization (IEEE 1547.1 Section 5.4 and 6.3)

i. *Purpose:* To test the synchronization characteristics of the EUT to the EPS with respect to key sync parameters and with respect to current draw/supply of the EUT. Several variations of this test are possible.
ii. *Modifications:* Referring to IEEE 1547.1 section 5.4, method 1, variation 3 and method 2 for synchronization tests will be performed for both charging and discharging modes of the EUT. This test will be repeated only twice unless inconsistent results are observed.
iii. *Procedure:* Follow procedure as stated in IEEE 1547.1 section 5.4, modified as indicated in this test procedure.

4.1.5 Limitation of DC Injection for Inverters Without Interconnection Transformers (IEEE 1547.1 Section 5.6)

i. *Purpose:* Verify the EUT complies with DC current injection requirements.
ii. *Modifications:* This test should be performed for both charging and discharging modes. This test will be repeated only twice unless inconsistent results are observed.
iii. *Procedure:* Follow procedure as stated in IEEE 1547.1 section 5.6, modified as indicated in this test procedure.

4.1.6 Unintentional Islanding (IEEE 1547.1 Section 5.7)

i. *Purpose:* The purpose of this test is to verify that the DR interconnection component or system ceases to energize the area EPS as specified in IEEE Std 1547 when an unintentional island condition is present. This test determines the trip time of the EUT for the test conditions.
ii. *Modifications:* Tests will be performed for both charging and discharging modes. This test will be repeated only twice unless inconsistent results are observed.
iii. *Procedure:* Follow procedure as stated in IEEE 1547.1 section 5.7, modified as indicated in this test procedure.

4.1.7 Open Phase (IEEE 1547.1 Section 5.9)

i. *Purpose:* To verify that the interconnection system ceases to energize the area EPS upon loss of an individual phase at the point of common coupling or at the point of DR connection.
ii. *Modifications:* This test will require additional hardware setup to implement. A rated AC circuit breaker will be spliced in to one of the lines. The experimenter will be able to manually open one phase using this CB. Repeat in both charging and charging modes. This test will be repeated only twice unless inconsistent results are observed.
iii. *Procedure:* Follow procedure as stated in IEEE 1547.1 section 5.9, modified as indicated in this test procedure.

4.1.8 Reconnect Following Abnormal Condition Disconnect (IEEE 1547.1 Section 5.10)

i. *Purpose:* To verify the functionality of the DR interconnection component or system reconnect timer, which delays the DR reconnection to the area EPS following a trip event.
ii. *Modifications:* Tests will be performed for both charging and discharging modes. This test will be repeated only twice unless inconsistent results are observed.
iii. *Procedure:* Follow procedure as stated in IEEE 1547.1 section 5.10, modified as indicated in this test procedure.

4.1.9 *Harmonics (IEEE 1547.1 Section 5.11)*

i. *Purpose:* To measure the individual current harmonics and total harmonic distortion of the EUT under normal operating conditions.
ii. *Modifications:* This test cannot be run as specified in IEEE 1547.1 at the DERTF. The DERTF can assess harmonics with a smaller EPS source only. The unit could be connected to grid power but additional setup and time would be required. Test should be completed for both charging and discharging modes. This test will be repeated only twice unless inconsistent results are observed.
iii. *Procedure:* Follow procedure as stated in IEEE 1547.1 section 5.11, modified as indicated in this test procedure.

4.2 Optional Performance Tests

4.2.1 *Continuous Output Power (Optional Performance Test)*

i. *Purpose:* Establish the continuous output power level that the EUT can maintain for a specified period of time at the specified ambient operating temperature after reaching thermal equilibrium.
ii. *Modifications:* None.
iii. *Procedure:* See "Interim Test Procedures for Evaluating Electrical Performance and Grid Integration of Vehicle-to-Grid Applications" Section 5.1.2.

4.2.2 *Conversion Efficiency (Optional Performance Test)*

i. *Purpose:* Establish the conversion efficiency of the inverter between the battery and the AC output as a function of output power level.
ii. *Modifications:* Requires additional instrumentation on the DC link internal to the unit.
iii. *Procedure:* See "Interim Test Procedures for Evaluating Electrical Performance and Grid Integration of Vehicle-to-Grid Applications" Section 5.2.2.

4.2.3 *Active Power Reserve (Optional Performance Test)*

i. *Purpose:* Evaluate the EUT's capability to provide active power reserve to the utility using stored energy in the battery. This test is very similar to test 4.13 except the duration for continuous output power at various power levels is measured.
ii. *Modifications:* None.
iii. *Procedure:* See "Interim Test Procedures for Evaluating Electrical Performance and Grid Integration of Vehicle-to-Grid Applications" Section 6.1.2.

4.2.4 *Charging Time (Optional Performance Test)*

i. *Purpose:* Determine the time required to fully charge the battery using manufacturer recommended charging method from a specified starting state of charge at a specified ambient operating temperature.
ii. *Modifications:* Only possible at room temperature conditions.
iii. *Procedure:* See "Interim Test Procedures for Evaluating Electrical Performance and Grid Integration of Vehicle-to-Grid Applications" Section 6.2.2.

4.2.5 Output Overload Self-Protection Test (Optional Performance Test)

i. See UL 1741 Section 47.2.

4.2.6 Short Circuit Self-Protection Test (Optional Performance Test)

ii. See UL 1741 Section 47.3.

4.2.7 Loss of Control Circuit Self-Protection Test (Optional Performance Test)

iii. See UL 1741 Section 47.8.

4.3 Omitted Tests

4.3.1 Interconnection integrity (IEEE 1547.1 Section 5.5)

i. *Purpose:* This category has three sub-tests; EMI interference, surge withstand, and dielectric test of paralleling device.
ii. *Modifications:* These tests require specialized test equipment, test setups, and have the potential to damage the equipment under test. In some cases, factory acceptance testing against these tests is acceptable for compliance. NREL will not perform these tests unless further coordinated with the customer and manufacturer.
iii. *Procedure:* Follow procedure as stated in IEEE 1547.1 section 5.5, modified as indicated in this test procedure.

4.3.2 Reverse Power (for unintentional islanding) (IEEE 1547.1 Section 5.8)

i. *Purpose:* This test is performed to characterize the accuracy of the reverse-power protection magnitude setting(s) of the EUT. The reverse-power protection accuracy of the EUT shall be specified prior to beginning the tests.
ii. *Modifications:* Tests will be performed for both charging and discharging modes.
iii. *Procedure:* Follow procedure as stated in IEEE 1547.1 section 5.8, modified as indicated in this test procedure.

4.3.3 Flicker (IEEE 1547.1 Section 5.12)

i. *Purpose:* Determine if voltage flicker from the EUT could be an issue for the EPS. No specific test for this item is defined in IEEE 1547.1.
ii. *Modifications:* Not applicable.
iii. *Procedure:* Not applicable.

5 TEST REPORT

Data acquisition and storage to be carried out as specified in the test procedures section of this document.

Actual procedure and modifications to standard procedures shall be documented for each test.

Grid Interconnection Test Report
PowerHub Systems CES-3030 Unit #1

Location:	**DERTF Lab at NREL's NWTC**
Testing Dates:	**November 6, 2011 – February 9, 2012**
Lead NREL Engineer, Report Author:	**Greg Martin (303-384-7039)**
NREL Laboratory Supervisor:	**Bill Kramer (303-275-3844)**
NREL EHS Point of Contact:	**Mike Stewart (303-384-6906)**
Manufacturer Representative (PowerHub):	**Glenn Skutt (540-250-2870)**
Customer Representative (SMUD):	**Ed Sanchez (916-732-5572)**
Testing Objective:	**IEEE 1547 standard compliance testing**
Description of equipment under test:	**30kW, 30kWh battery energy storage system with inverter interface to utility**
Revision 1 – Feb 13, 2012	*Greg Martin revised the harmonics results Table 10. An error was made by the experimenter in that the harmonics in the >35 order category were calculated using up to the 100th order harmonic. IEEE 1457.1 states that only up through the 40th harmonic must be used for calculation of the results. This brings the harmonics in this category to within limits.*

TABLE OF CONTENTS

1 SUMMARY

This report presents the results of testing accomplished on a community energy storage (CES) system. The testing was completed by NREL under an agreement with the Sacramento Utility District. The equipment under test (EUT), designed and built by PowerHub, is a 30kW, 30kWh battery-based energy storage system with a power conditioning system (PCS) interface to utility 240Vac power. The unit tested is labeled Unit #1. This report deals with Unit #1 only.

The unit was tested to determine its compliancy with IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems. NREL recommends that the unit is sufficiently compliant with the standard, for the tests completed, to be able to connect to typical electric power systems. There are some minor deviations from the standard that should be reviewed by the project manager. The table below summarizes the IEEE 1547 tests, indicating those that were completed by NREL and the overall result.

Summary of IEEE 1547.1 Tests Performed and Overall Results

Test Category	Disposition	Overall Result
Temperature Stability	Tested	To be determined[3]
Abnormal Voltage	Tested	Compliant[1]
Abnormal Frequency	Tested	Compliant[1]
Synchronization, Method 2	Tested	To be determined[4]
Interconnection Integrity	Not tested	None
DC Injection	Tested	Compliant
Unintentional Islanding	Tested	Compliant
Reverse Power	Not tested / not applicable	None
Open Phase	Tested	Compliant
Reconnection	Not tested / not applicable	None
Harmonics	Tested	To be determined[2]
Flicker	Not tested	None

[1] *Test data indicates deviations from standard but settings can easily be adjusted by user to make unit compliant.*
[2] *Test data indicates some high order even harmonics are beyond limits.*
[3] *The unit tested may not operate at full power capacity at extreme ambient temperatures.*
[4] *The unit exhibits finite startup current transients which must be evaluated by the installer to determine flicker consequences to the local EPS.*

Of particular concern were the unintentional islanding tests. Since a firmware update to the unit was successfully installed, no unintentional islanding of the unit was observed.

Tests were completed using calibrated instruments for data capture and laboratory power supply and load bank equipment. This equipment is intended for use in this type of testing, however NREL recognizes that there are limitations to this equipment. Test methods and conditions may vary based on the facility, engineer running the tests, and data collection capabilities. NREL has made effort to follow the test procedures as described in IEEE 1547.1. This test report indicates cases in which deviations from this procedure are encountered.

2 TEST SETUP

2.1 Equipment Under Test

The EUT, manufactured by PowerHub of Blacksburg, Virginia, is a battery energy storage system with a bi-directional inverter for utility grid interconnection. It is a new product built to meet the specifications of a Sacramento Municipal Utility District project. The unit can both discharge battery energy into a utility grid as AC power, as well as charge the batteries from the same AC connection. The intent of the equipment is to provide voltage and frequency regulation as well as provide time shifting of energy available from nearby distributed energy (DG) sources. Power dispatch will ultimately be controlled by the utility operator.

The unit connects at 240Vac, 60 Hz and is capable of discharging 30kWh of energy at 30kW. It employs lithium ion doped nickel oxide (NCA) batteries and battery management system produced by Saft Batteries and an inverter stage developed and produced by PowerHub. The unit employs both controllable contactors and fuses for electrical protection on both the AC and DC sub-systems within the enclosure. The inverter stage hosts the control interface and supervisory algorithms which interface to the battery management module (BMM) as well as monitor inverter status and external control input.

The unit is encased and sealed on 5 sides with 1/8” steel plating. An air vent and a wire access hole are the only exceptions to contiguous and sealed steel plating. The bottom of the unit is open, it is intended to be mounted over a wiring vault. For this experiment, the unit is tested in-situ on its shipping pallet. This configuration allows a convenient way to connect interface power wires and instrumentation cables through the bottom of the unit.

2.2 Laboratory Equipment

To accomplish testing of the unit, a grid simulator AC source and a programmable AC load bank are used. Both of these resources are interconnected to the DERTF bus network. These components will be connected in parallel on the DERTF AC bus along with the equipment under test (EUT). The Pacific Power MS-3060 AC source is a programmable grid simulator capable of establishing the abnormal and transient grid conditions necessary for the testing. For this test, three 50kW grid simulator units are connected together in master-slave control, providing up to 150kW output. For this test, the grid simulator is set for nominal 240Vac, 60Hz split-phase. This requires setting one phase to 120Vac $\angle 0°$, another phase to 120Vac $\angle 180°$, and the third phase to 0Vac.

Further, a 37.5kVA, 240Vac split-phase, utility-connected transformer is used for testing in some cases. The transformer primary is fed from utility 480Vac. In cases where the transformer is used as the power interface to the equipment under test, the load bank is not used, in effort to emulate actual field connection of the unit. Both transformer and grid simulator may not be connected to the bus simultaneously.

The load bank used for testing is connected in parallel on the AC bus. It is a 200kW programmable R-L-C load bank. The load is connected to the experiment to sink power when the bus is energized. The load bank is required to sink output current from the EUT when it is in discharge mode. When operating in charging mode, the load bank provides a small amount of parallel load to buffer and stabilize the power system. In the special case of the islanding test, where a “tuned” R-L-C circuit must be set up, an iterative process to set and measure actual impedance is used to adjust the circuit appropriately.

Both grid simulator and load bank are controlled from inside the DERTF. The grid simulator controller offers remote voltage and current monitoring and a computer interface to program voltage and frequency ramps and transients. The load bank is controlled by a lab computer which allows the user to set resistive (real) power, inductive (reactive leading) power and capacitive (reactive lagging) power.

2.3 Data Acquisition Equipment

Either power analysis or waveform capturing devices are used, depending on the needs of the test. Either a Yokogawa PZ4000 power analyzer was used, or a Yokoawa DL-750 Scopecorder. Current measurement was provided using AEMC or Fluke current transducers, either 10kHz or 100kHz bandwidth (for harmonics tests). All instruments are calibrated.

2.4 Experiment Connection Drawings

The equipment under test connects to the electric power system (EPS) at 240Vac. At the DERTF, it interfaces to the laboratory equipment via a fused disconnect switch. Figure 1 shows a full connection diagram of the test system. Figure 2 is a system single-line diagram which gives additional information about experiment setup wiring.

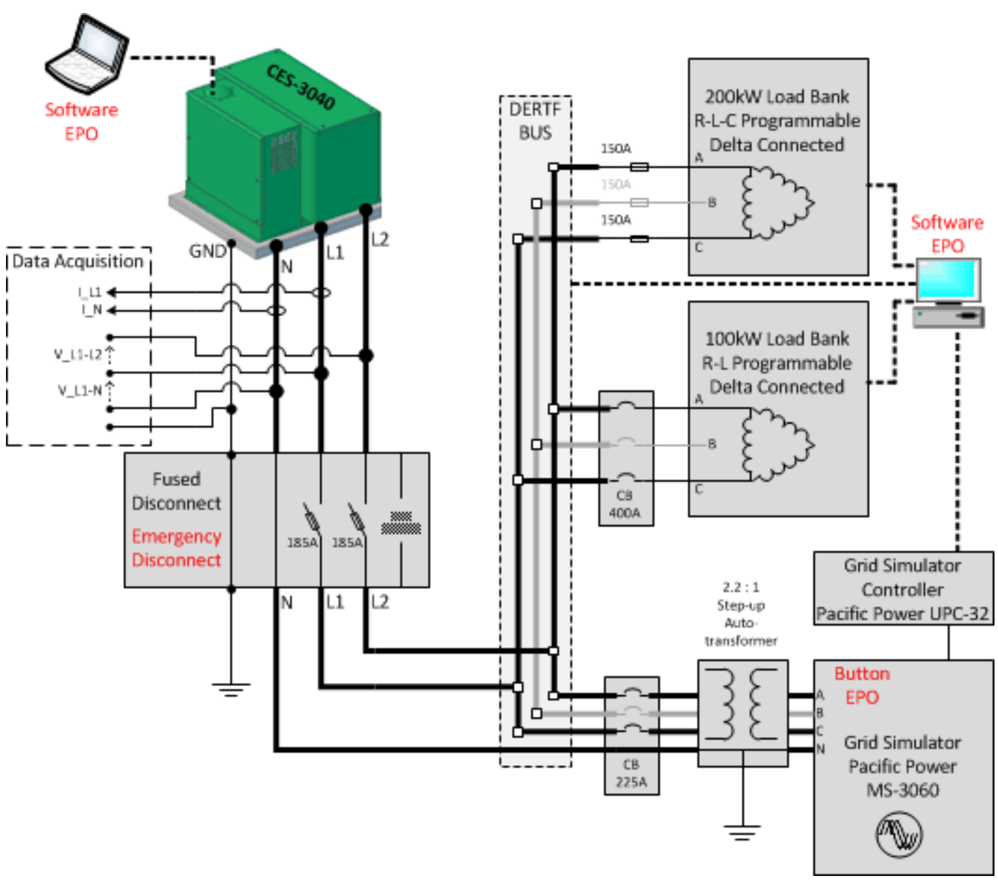


Figure 1. Overall Experiment Setup Lab Connection Diagram

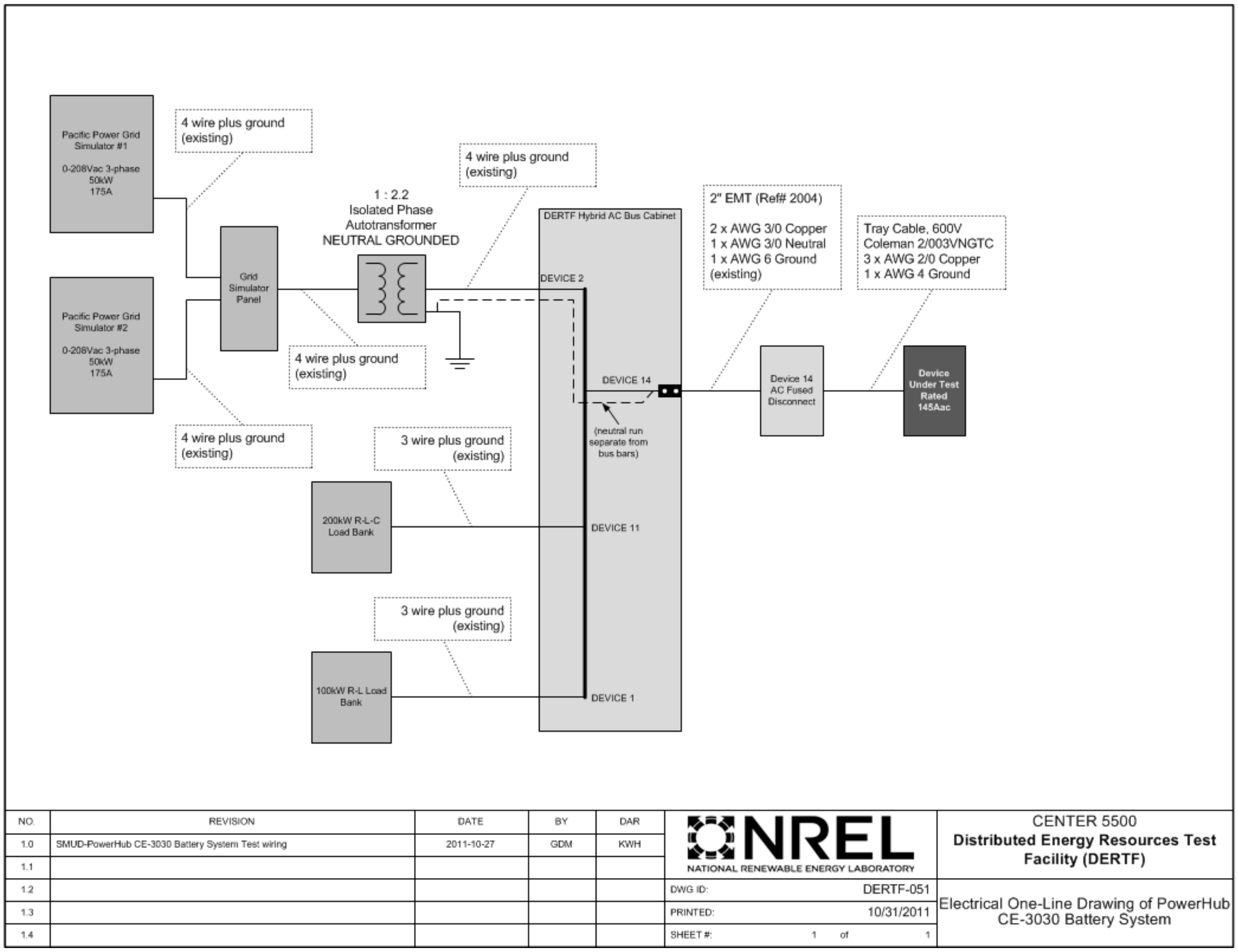


Figure 2. System Single-line Diagram

3 TEST RESULTS

Refer to the accompanying “Grid Interconnection Test Plan for CES Unit” for additional information on safety procedures employed during testing and IEEE 1547.1 test procedure details.

3.1 Temperature Stability (IEEE 1547.1 Section 5.1)

The goal of the operation temperature test in IEEE 1547.1 is to verify both parameter accuracy and equipment functionality across a pre-determined temperature range. The storage temperature test was not performed.

NREL performed temperature performance tests to determine:

1. If there was any operational limitation to the unit operating in an ambient temperature of 105°F.
2. Verify parameter measurement and device operation remains accurate at maximum ambient temperature.

The findings with respect to these two objectives are:

1. A possible temperature limitation to operation was found. When operating at full discharge current (30 kW) in an ambient temperature of at least 105°F, the unit tripped offline due to an internal over-temperature limit. At a discharging or charging power of 15kW, the unit operated successfully in an ambient temperature of at least 105°F. The experimenter believes these tests were at ambient temperatures ranging from 110°F to 130°F. Because of the temperature gradient, moving air, and the use of only one exterior thermocouple, it is impossible to accurately characterize the external temperature conditions. Figure 3 below gives temperature data for several hours of operation at elevated ambient temperatures.
2. Parameter measurement accuracy in the EUT is maintained very well at elevated temperatures. See Figure 4 below for CES reported versus laboratory measured voltage and current parameters. Trip, protection, and actuation devices operate as expected at elevated temperatures tested

Figure 3 below logs temperature data over more than 5 hours of operation at elevated temperature. The EUT trips itself offline due to high PCS heatsink temperature at time 3:50 when the PCS heatsink temp reaches 110°C. The “Lab TC” trace is the thermocouple reading from the thermocouple installed in the chamber. The other three traces are temperature data taken from EUT computer readouts. The experimenter notes that the “Cabinet” temperature data is probably the best measure of actual ambient temperature.

Figure 4 below plots the electrical parameter readings during the same temperature test. The parameter readings are not apparently affected by temperature change.

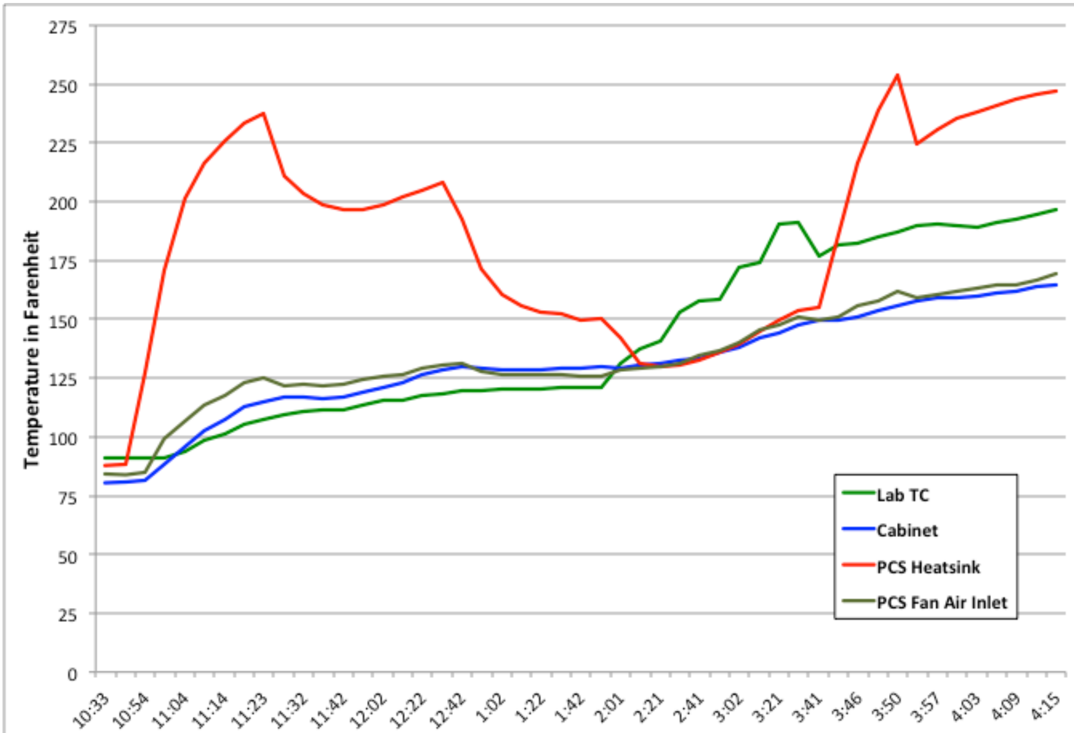


Figure 3: Temperature Data During Elevated Temperature Test

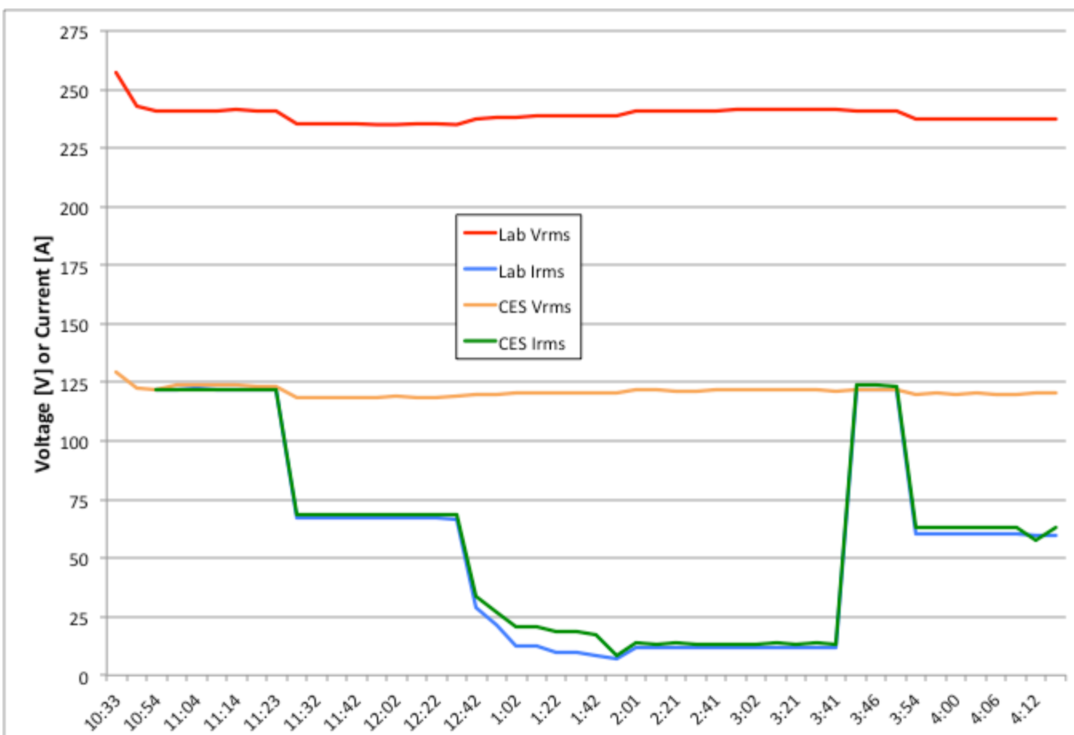


Figure 4: Electrical Parameter Data During Elevated Temperature Test

Since the test lab at NREL does not have a suitable environmental chamber, a makeshift plywood chamber was constructed. The chamber was heated with a resistive heater, and temperature measurements were made using a thermocouple positioned near the vertical midpoint of the chamber, alongside the EUT. Figure 5 shows photographs of the custom chamber used for thermal testing.

Figure 5: Photographs of Thermal Chamber Constructed for CES Testing

3.2 Response to Abnormal Voltage Conditions (IEEE 1547.1 Section 5.2 and 6.1)

The CES unit was successfully tested for its response to abnormal voltages. The unit was found to be in compliance with the required clearing time in response to a voltage step. The unit is also in compliance with the magnitude trip response to a voltage ramp with the caveat that the trip magnitude may have to be adjusted by the user if the trip level magnitude is not compatible with the connected EPS.

It should be noted that the EUT does not implement a two-level response to abnormal voltages. That is, in the event of any EPS voltage excursion V_{EPS} > 132/264V or V_{EPS} < 106/212V, the unit will trip within the required 160 ms. The standard allows 1 s clearing time for 132/212V > V_{EPS} < 144V/288V, and 2 s clearing time for 60/120V > V_{EPS} < 106/212V.

In addition, differences between the laboratory-measured voltage and the EUT measured voltage are observed. This can be seen in the results of the over-voltage and under-voltage ramp tests. In the over-voltage ramp test, the unit trips consistently at a laboratory measured voltage of 130.5/261V, while the EUT is set to trip at 132/264V, indicating a discrepancy of about 3V. The discrepancy at the lower voltage trip level is about 2V.

The experimenter verified that the easily configured user settings for voltage trip magnitude do, in fact, address this offset. The user can set the trip magnitude at the desired level as the voltage differences are offsets, and the unit responds accurately and linearly in changes to trip level. In this report, data from nominal settings are reported, as called out in the IEEE 1547.1 test procedure. This data should NOT be interpreted as being out of compliance with the standard. This data indicates that minor setpoint adjustment is needed to get the desired response, if that response if different from the default.

Table 1 gives test data for both over-voltage and under-voltage ramp trip magnitude responses of the EUT (“OVR” = over voltage ramp, “UVR” = under voltage ramp). Figure 6 gives a graphic of the voltage test signal applied to the EUT with the grid simulator source (“Ramp 1” and “Ramp 2”).

Table 1: Results of Magnitude Response to Abnormal Voltage Tests

Test	Battery SOC	EUT Mode	EUT Settings	Transient Type	Result	Standard Limit
OVR	77	Disch 30	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	261.2 V	264 V
OVR	76	Disch 30	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	261.2 V	264 V
OVR	77	Chrg 15	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	261.0 V	264 V
OVR	78	Chrg 15	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	261.2 V	264 V
OVR	78	Disch 15	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	261.0 V	264 V
OVR	77	Disch 15	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	261.0 V	264 V
OVR	76	Chrg 5	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	261.0 V	264 V
OVR	77	Chrg 5	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	261.2 V	264 V
OVR	77	Standby	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	261.2 V	264 V
OVR	77	Standby	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	261.2 V	264 V
UVR	76	Disch 30	u.v.t. = 10ms, u.v.l. = 106V	Ramp 2	209.8 V	211.2 V
UVR	75	Disch 30	u.v.t. = 10ms, u.v.l. = 106V	Ramp 2	210.2 V	211.2 V
UVR	75	Chrg 15	u.v.t. = 10ms, u.v.l. = 106V	Ramp 2	210.4 V	211.2 V
UVR	75	Chrg 15	u.v.t. = 10ms, u.v.l. = 106V	Ramp 2	210.4 V	211.2 V
UVR	75	Disch 15	u.v.t. = 10ms, u.v.l. = 106V	Ramp 2	210.2 V	211.2 V
UVR	74	Disch 15	u.v.t. = 10ms, u.v.l. = 106V	Ramp 2	210.2 V	211.2 V
UVR	74	Chrg 5	u.v.t. = 10ms, u.v.l. = 106V	Ramp 2	210.4 V	211.2 V
UVR	74	Chrg 5	u.v.t. = 10ms, u.v.l. = 106V	Ramp 2	210.4 V	211.2 V
UVR	74	Standby	u.v.t. = 10ms, u.v.l. = 106V	Ramp 2	210.2 V	211.2 V
UVR	74	Standby	u.v.t. = 10ms, u.v.l. = 106V	Ramp 2	210.2 V	211.2 V

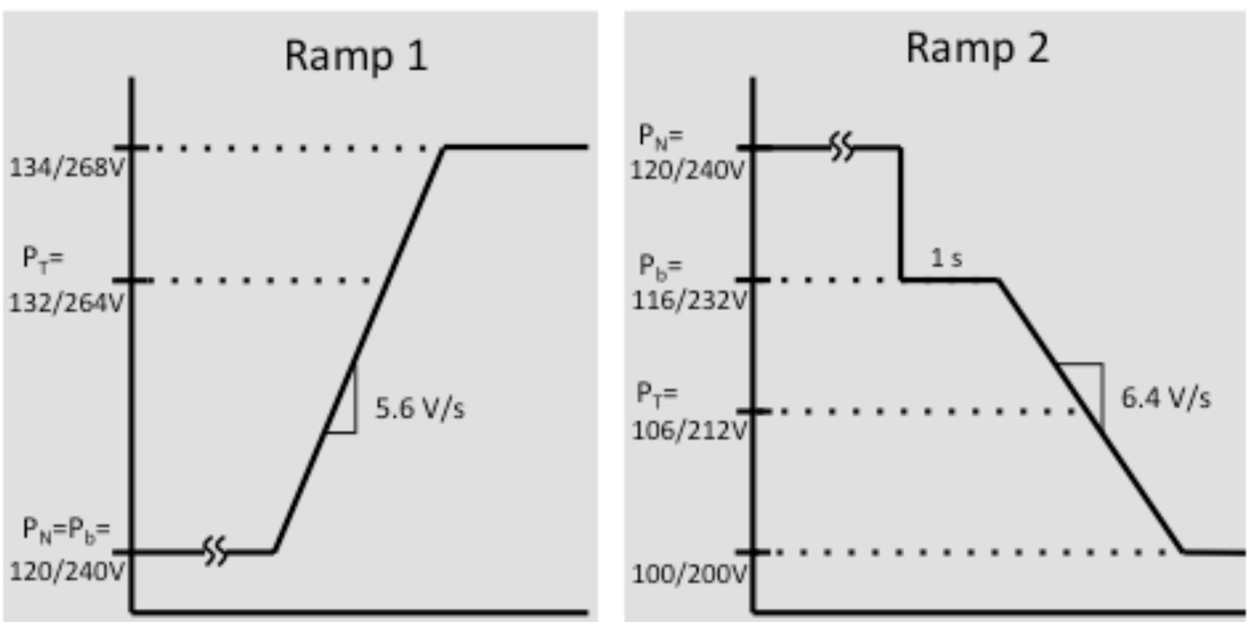


Figure 6: Abnormal Voltage Test Signals ("Ramp 1" and "Ramp 2")

The unit is in compliance with the clearing time requirement in response to an abnormal voltage step. Table 2 gives test data for the trip time tests ("OVs" = over voltage step, "UVS" = under voltage step).

Figure 7 gives a graphic of the voltage test signal applied to the EUT with the grid simulator source ("Step 1" and "Step 2").

Table 2: Results of Trip-Time Response to Abnormal Voltage Tests

Test	Battery SOC	EUT Mode	EUT Settings	Transient Type	Result	Standard Limit
OVS	75	Disch 30	o.v.t. = 10ms, o.v.l. = 132V	Step 1	127.215 ms	160 ms
OVS	71	Disch 30	o.v.t. = 10ms, o.v.l. = 132V	Step 1	131.715 ms	160 ms
OVS	72	Chrg 15	o.v.t. = 10ms, o.v.l. = 132V	Step 1	133.215 ms	160 ms
OVS	74	Chrg 15	o.v.t. = 10ms, o.v.l. = 132V	Step 1	136.215 ms	160 ms
OVS	71	Disch 15	o.v.t. = 10ms, o.v.l. = 132V	Step 1	131.865 ms	160 ms
OVS	70	Disch 15	o.v.t. = 10ms, o.v.l. = 132V	Step 1	122.165 ms	160 ms
OVS	72	Chrg 5	o.v.t. = 10ms, o.v.l. = 132V	Step 1	131.765 ms	160 ms
OVS	72	Chrg 5	o.v.t. = 10ms, o.v.l. = 132V	Step 1	130.465 ms	160 ms
OVS	72	Standby	o.v.t. = 10ms, o.v.l. = 132V	Step 1	136.015 ms	160 ms
OVS	72	Standby	o.v.t. = 10ms, o.v.l. = 132V	Step 1	134.315 ms	160 ms
UVS	71	Disch 30	u.v.t. = 10ms, u.v.l. = 106V	Step 2	110.515 ms	160 ms
UVS	69	Disch 30	u.v.t. = 10ms, u.v.l. = 106V	Step 2	113.465 ms	160 ms
UVS	70	Chrg 15	u.v.t. = 10ms, u.v.l. = 106V	Step 2	108.665 ms	160 ms
UVS	72	Chrg 15	u.v.t. = 10ms, u.v.l. = 106V	Step 2	107.665 ms	160 ms
UVS	70	Disch 15	u.v.t. = 10ms, u.v.l. = 106V	Step 2	105.815 ms	160 ms
UVS	68	Disch 15	u.v.t. = 10ms, u.v.l. = 106V	Step 2	105.365 ms	160 ms
UVS	72	Chrg 5	u.v.t. = 10ms, u.v.l. = 106V	Step 2	105.965 ms	160 ms
UVS	71	Chrg 5	u.v.t. = 10ms, u.v.l. = 106V	Step 2	107.815 ms	160 ms
UVS	71	Standby	u.v.t. = 10ms, u.v.l. = 106V	Step 2	106.265 ms	160 ms
UVS	71	Standby	u.v.t. = 10ms, u.v.l. = 106V	Step 2	111.065 ms	160 ms

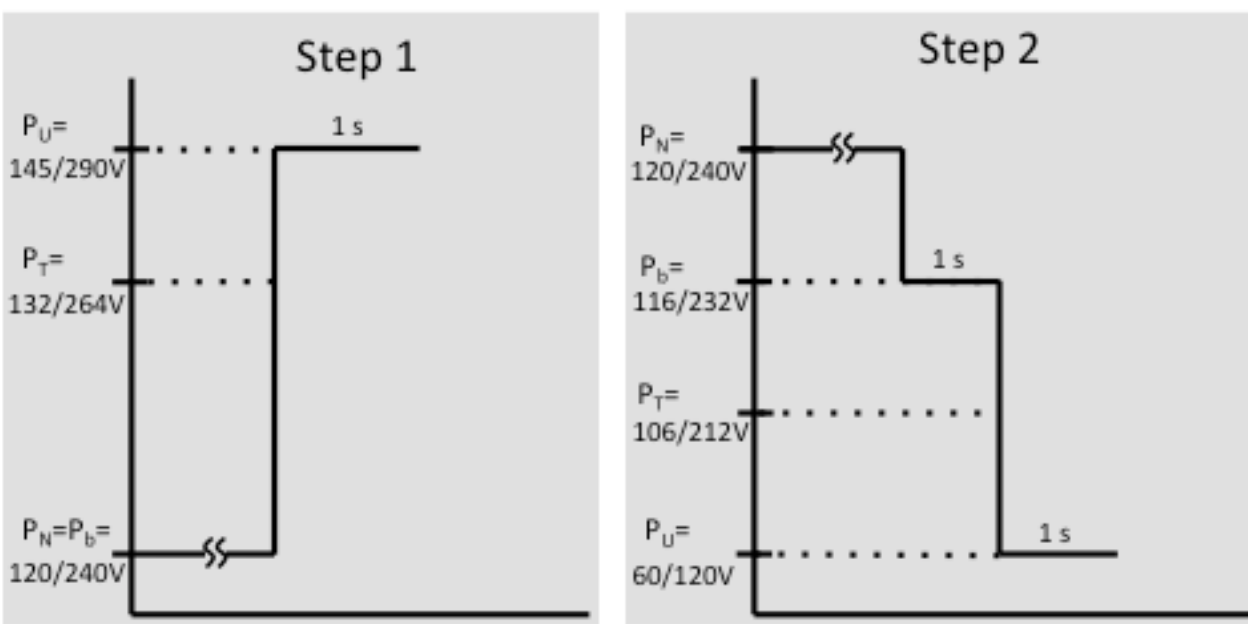


Figure 7: Abnormal Voltage Test Signals ("Step 1" and "Step 2")

3.3 Response to Abnormal Frequency Conditions (IEEE 1547.1 Section 5.3 and 6.2)

The CES unit was successfully tested for its response to abnormal frequencies. The unit was found to be in compliance with the required clearing time in response to a frequency step. The unit is also in compliance with the magnitude trip response to a frequency ramp with the caveat that the trip magnitude may have to be adjusted by the user if the trip level magnitude is not compatible with the connected EPS.

The experimenter verified that the easily configured user settings for frequency trip magnitude do provide accurate adjustment of frequency trip magnitude. The unit responds accurately and linearly in changes to trip level setting. Data in Table 3 show the response in trip magnitude when the setting is changed from 60.5 Hz to 60.4 Hz. This data should NOT be interpreted as being out of compliance with the standard. This data indicates that minor setpoint adjustment is needed to get the desired response, if that response if different from the default.

Table 3 gives test data for both over-frequency and under-frequency ramp trip magnitude responses of the EUT (“OFR” = over frequency ramp, “UFR” = under frequency ramp). Figure 8 gives a graphic of the frequency test signal applied to the EUT with the grid simulator source (“Ramp 1” and “Ramp 2”).

Table 3: Results of Magnitude Response to Abnormal Frequency Tests

Test	Battery SOC	EUT Mode	EUT Settings	Transient Type	Result
OFR	66	Disch 30	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.498 Hz
OFR	65	Disch 30	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.498 Hz
OFR	68	Chrg 15	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.504 Hz
OFR	69	Chrg 15	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.498 Hz
OFR	69	Disch 15	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.512 Hz
OFR	68	Disch 15	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.504 Hz
OFR	69	Chrg 5	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.504 Hz
OFR	69	Chrg 5	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.498 Hz
OFR	69	Standby	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.608 Hz
OFR	69	Standby	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.614 Hz
OFR	64	Disch 30	o.f.t. = 10ms, o.f.l. = 60.4V	Ramp 1	60.418 Hz
OFR	62	Disch 15	o.f.t. = 10ms, o.f.l. = 60.4V	Ramp 1	60.402 Hz
OFR	64	Chrg 15	o.f.t. = 10ms, o.f.l. = 60.4V	Ramp 1	60.404 Hz
OFR	66	Chrg 5	o.f.t. = 10ms, o.f.l. = 60.4V	Ramp 1	60.394 Hz
OFR	66	Standby	o.f.t. = 10ms, o.f.l. = 60.4V	Ramp 1	60.504 Hz
UFR	61	Disch 30	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.300 Hz
UFR	59	Disch 30	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.300 Hz
UFR	62	Chrg 15	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.300 Hz
UFR	66	Chrg 15	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.268 Hz
UFR	65	Disch 15	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.268 Hz
UFR	64	Disch 15	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.276 Hz
UFR	66	Chrg 5	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.300 Hz
UFR	66	Chrg 5	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.284 Hz
UFR	65	Standby	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.162 Hz
UFR	65	Standby	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.162 Hz

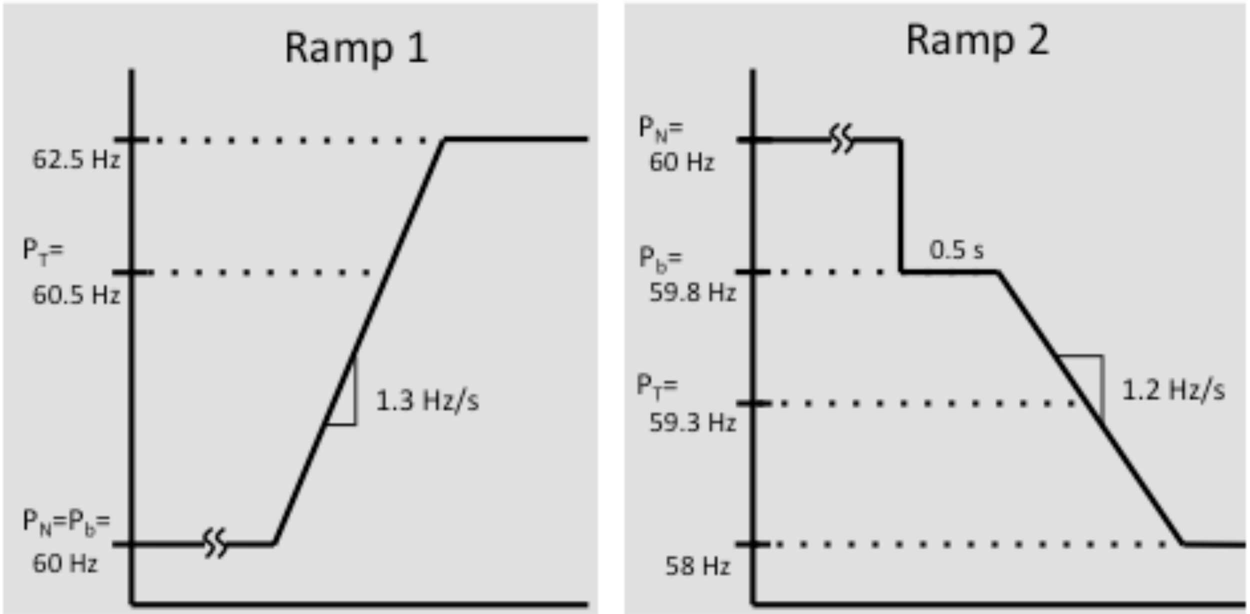


Figure 8: Abnormal Frequency Ramp Test Signals ("Ramp 1" and "Ramp 2")

The unit is in compliance with the clearing time requirement in response to an abnormal frequency step. Table 2 gives test data for the trip time tests ("OVS" = over frequency step, "UVS" = under frequency step). Figure 9 gives a graphic of the frequency test signals applied to the EUT with the grid simulator source ("Step 1" and "Step 2").

Table 4: Results of Trip-Time Response to Abnormal Frequency Tests

Test	Battery SOC	EUT Mode	EUT Settings	Transient Type	Result
OFS	63	Disch 30	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	144.965 ms
OFS	62	Disch 30	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	137.965 ms
OFS	69	Chrg 15	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	140.965 ms
OFS	70	Chrg 15	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	146.665 ms
OFS	66	Disch 15	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	141.265 ms
OFS	66	Disch 15	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	141.065 ms
OFS	67	Chrg 5	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	138.815 ms
OFS	68	Chrg 5	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	140.315 ms
OFS	68	Standby	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	137.215 ms
OFS	68	Standby	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	142.465 ms
UFS	66	Disch 30	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	142.515 ms
UFS	65	Disch 30	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	142.115 ms
UFS	68	Chrg 15	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	150.765 ms
UFS	68	Chrg 15	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	148.615 ms
UFS	65	Disch 15	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	156.165 ms
UFS	65	Disch 15	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	157.065 ms
UFS	66	Chrg 5	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	147.165 ms
UFS	66	Chrg 5	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	142.715 ms
UFS	66	Standby	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	148.715 ms
UFS	66	Standby	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	141.865 ms

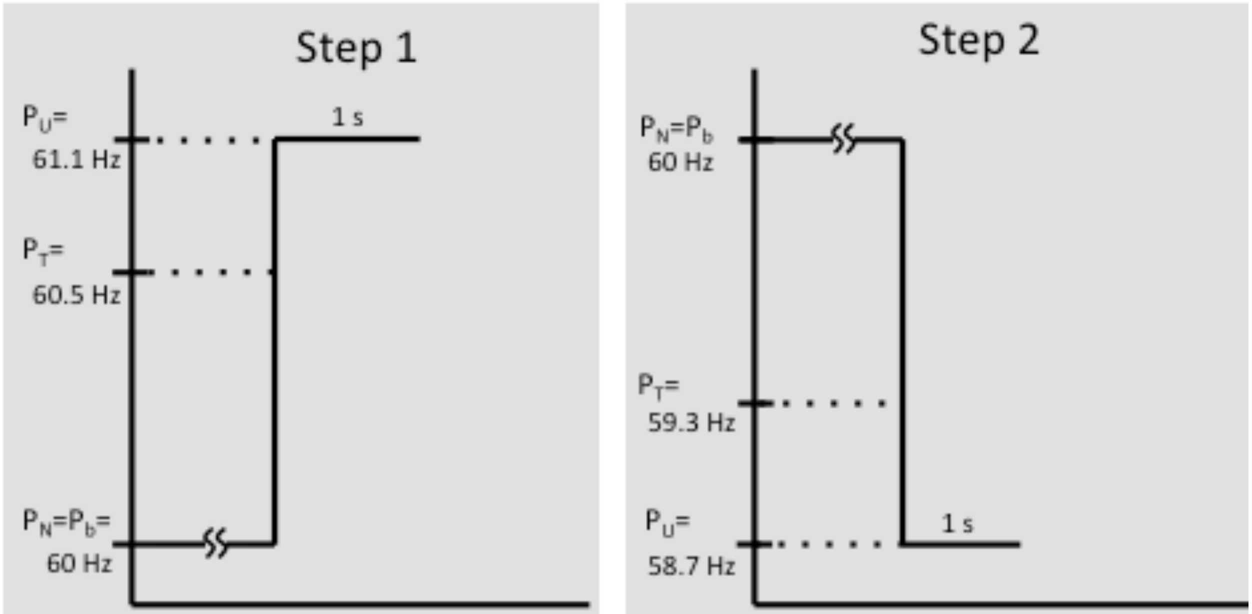


Figure 9: Abnormal Frequency Step Test Signals ("Step 1" and "Step 2")

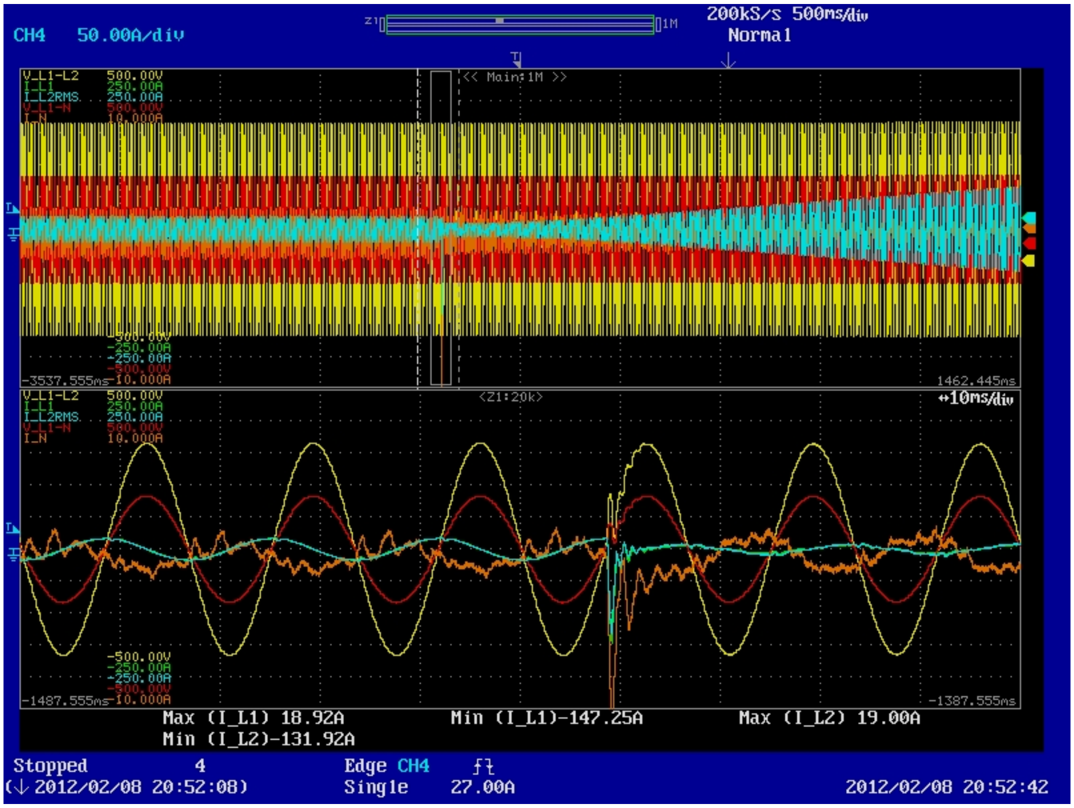
3.4 Synchronization (IEEE 1547.1 Section 5.4 and 6.3)

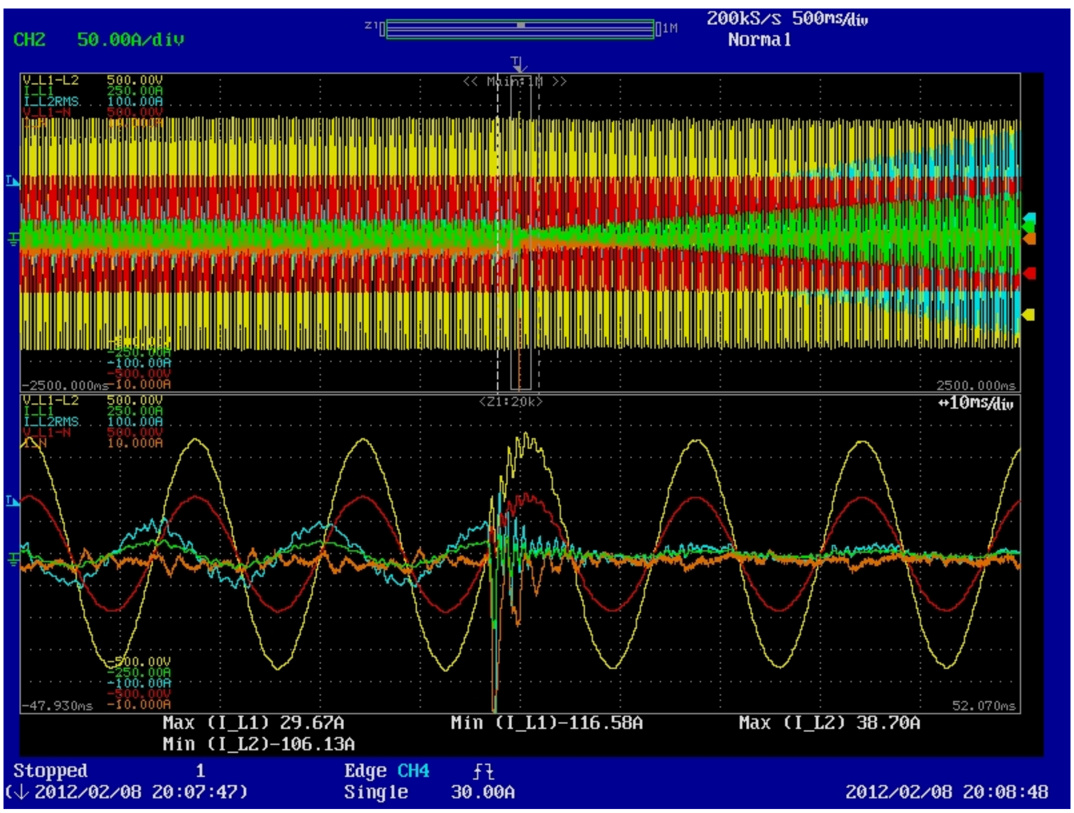
Synchronization of the EUT to the EPS using Method 2 (startup current measurement) from IEEE 1547.1 was tested. Compliance is based on the requirements of the EPS that the unit will connect to, and the assessment of the governing utility or service provider. The results here are intended to provide the utility installer with information to determine whether the EUT would cause flicker concerns on the actual EPS. Synchronization tests were completed using both the grid simulator as well as a utility transformer as the EPS source. The source impedance of the grid simulator used for the tests is TBD. The source impedance of the utility transformer is TBD.

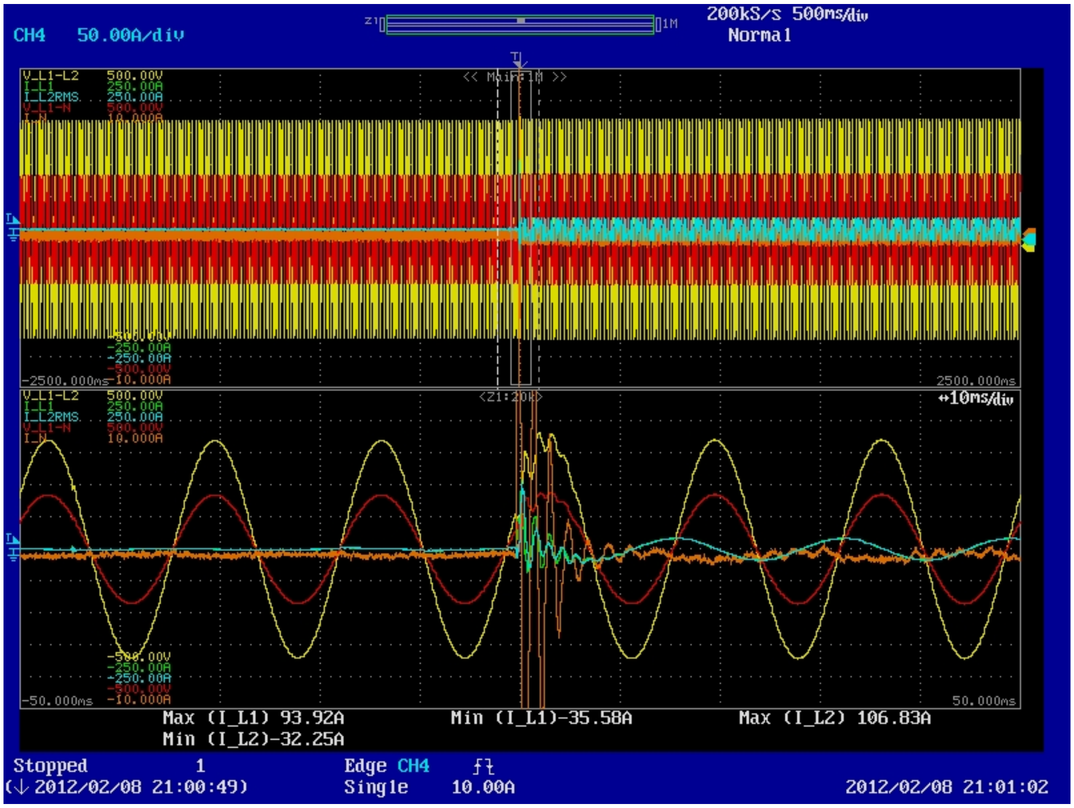
The EUT generally exhibits a startup current transient lasing for less than a ½ cycle (8 ms). In only one case did a current transient magnitude exceed the rated output current of the EUT. Since this transient is non-linear it is difficult to calculate an rms value. Sampling of the current waveform occurred at 200kS/s. For the tests, the peak current value is measured by the scope. Table 5 gives tabulated peak current values obtained for several test trials with various modes of operation. Figure 10 shows the scope image captures of the 4 highlighted tests in Table 5, illustrating some of the largest current transients encountered. All additional scope captures showing each test trial from Table 5 are available upon request.

Table 5: Results of Synchronization Tests

EUT Mode	Battery SOC	Sorce	Peak I [A]	Parallel Load
Disch 30	83	Utility Xfmr	36.3	0
Disch 30	82	Utility Xfmr	65.57	0
Disch 30	82	Utility Xfmr	42.6	0
Disch 30	82	Utility Xfmr	44.47	0
Chrg 15	84	Utility Xfmr	43.13	0
Chrg 15	84	Utility Xfmr	33.8	0
Chrg 15	83	Utility Xfmr	-116.5	0
Chrg 15	84	Utility Xfmr	32.3	0
Standby	83	GridSim	88.17	10.1 ("5")
Disch 30	82	GridSim	-62.67	130 ("65")
Disch 30	82	GridSim	-27.33	130 ("65")
Disch 30	82	GridSim	-69.5	130 ("65")
Disch 30	81	GridSim	-147.25	130 ("65")
Chrg 15	82	GridSim	-126.83	10.1 ("5")
Chrg 15	84	GridSim	25.83	10.1 ("5")
Chrg 15	84	GridSim	-42.25	10.1 ("5")
Chrg 15	84	GridSim	-53.83	10.1 ("5")
Standby	84	GridSim	97.92	10.1 ("5")
Standby	83	GridSim	106.21	10.1 ("5")
Standby	83	GridSim	51.17	10.1 ("5")
Standby	83	Utility Xfmr	-49.67	0
Standby	83	Utility Xfmr	-55.67	0
Standby	83	Utility Xfmr	86.83	0
Standby	83	Utility Xfmr	39.92	0
Chrg 15	83	Utility Xfmr	-60.92	0
Chrg 15	83	Utility Xfmr	55.5	0
Disch 30	84	Utility Xfmr	-124.92	0
Disch 30	82	Utility Xfmr	-99.67	0


CH4 50.00A/div
200kS/s 500ms/div
Normal
Max (I_L1) 18.92A
Min (I_L1)-147.25A
Max (I_L2) 19.00A
Min (I_L2)-131.92A
Stopped 4
(↓ 2012/02/08 20:52:08)
Edge CH4
Single 27.00A
2012/02/08 20:52:42


CH2 50.00A/div
200kS/s 500ms/div
Normal
Max (I_L1) 29.67A
Min (I_L1)-116.58A
Max (I_L2) 38.70A
Min (I_L2)-106.13A
Stopped 1
(↓ 2012/02/08 20:07:47)
Edge CH4
Single 30.00A
2012/02/08 20:08:48



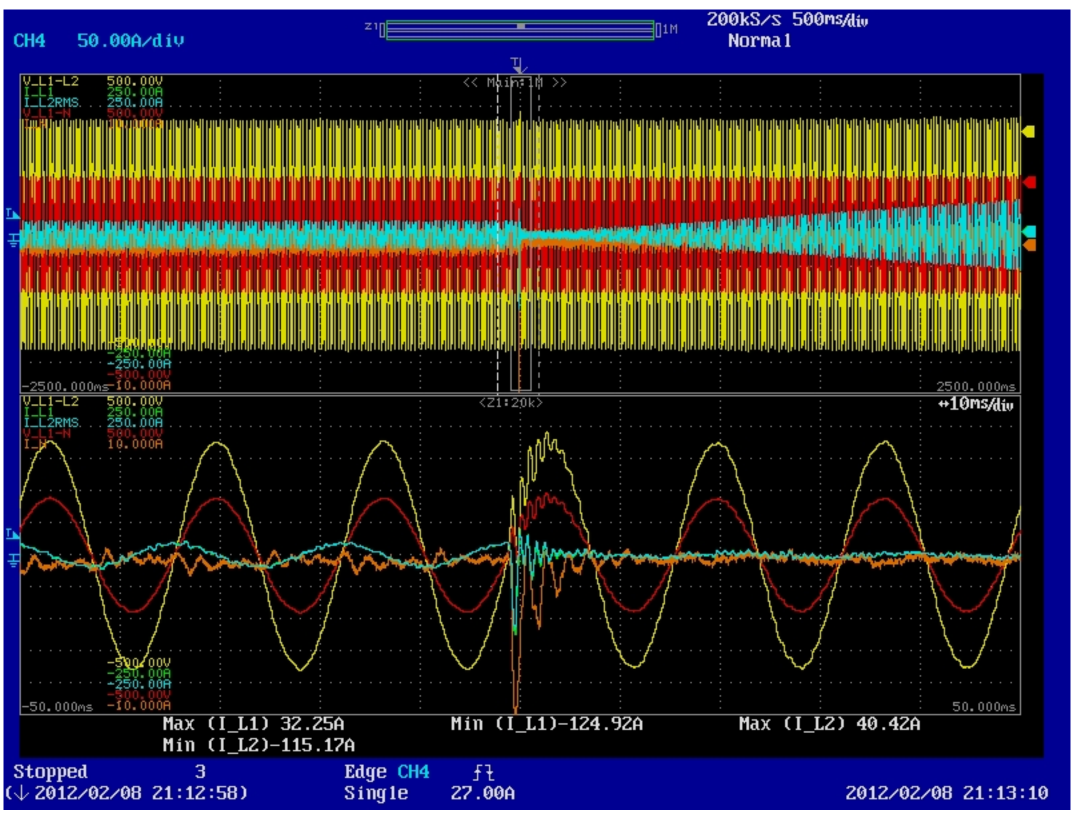


Figure 10: Selected Scope Captures of Synchronization Test Startup Current transients

3.5 Interconnection integrity (IEEE 1547.1 Section 5.5)

This category has three sub-tests; EMI interference, surge withstand, and dielectric test of paralleling device. These tests require specialized test equipment, test setups, and have the potential to damage the equipment under test. In some cases, factory/manufacturer acceptance testing is acceptable for compliance. NREL has not completed these tests.

3.6 Limitation of DC Injection for Inverters (IEEE 1547.1 Section 5.6)

DC injection was calculated for the EUT per IEEE 1547.1 instructions. The EUT is compliant with the DC current injection limit of 0.5%.

The test measurements were accomplished largely using function on the DL750 Scopecorder. The instrument offers, in addition to RMS readings and DC component readings, the ability to average these quantities over a specified time window (5 minutes in this case).

Table 6: Results of DC Injection Tests and Calculation

EUT Mode	SOC End	Avg V_L1 rms	Avg I_L1 rms	Avg V_L2 rms	Avg I_L2 rms	Avg I_L1 dc	Avg I_L2 dc	Calc (I_L1 dc / I_rated) * 100	Calc (I_L2 dc / I_rated) * 100
Chrg 15	87	117.39	67.1516	117.328	67.2707	0.0286	0.2676	0.024	0.223
Disch 30	76	120.75	122.274	120.752	123.272	0.0303	-0.0813	0.025	0.068
Disch 20	70	120.156	80.877	120.172	81.477	0.02434	0.0886	0.020	0.074
Chrg 10	76	121.927	43.898	121.9	43.894	0.02516	0.54853	0.021	0.457
Chrg 4.5	79	121.166	21.264	121.194	21.196	0.02278	0.52659	0.019	0.439
Disch 10	74	122.034	38.162	122.052	38.486	0.02708	0.24518	0.023	0.204
Chrg 15	79	119.587	65.154	119.515	65.246	0.0434	0.5791	0.036	0.483

For the calculated values in Table 6, the rated EUT current (I_rated) is taken to be 120 A.

3.7 Unintentional Islanding (IEEE 1547.1 Section 5.7)

The CES unit was tested for its response to islanding conditions. IEEE 1547 requires equipment to trip offline in the event of islanding conditions within 2 seconds. The unit was found to be in compliance with this requirement. In all test cases, the unit consistently trips offline within a maximum clearing time of 626 ms when an islanding condition is present. Typically, the unit trips offline within about 300 ms. Results of the unintentional islanding tests are given in Table 7.

The unit was tested using the grid simulator as the EPS and the laboratory load bank in parallel to create a tuned resonant circuit to create the island conditions. While the EUT operates at a power factor very near 1, it does produce measurable reactive power flow. This reactive power flow had to be accounted for in setting up the island circuit, as described in IEEE 1547.1 Section 5.7.1.2. The unit was tested at "Q" factors at or exceeding 1. Table 8 gives data of the reactive power flow produced by the unit at various operating modes.

Table 7: Clearing Time Results for Unintentional Islanding Tests

CES Mode	Batt SOC	Vrms	Gridsim Set	Irms	Qmeas	Pmeas	I_CES	Rset	Lset	Cset	Qf	Result
Disch 10kW	59	241.52	120	1.95	0.396	0.261	37.41	18.75	18.4375	21.563	1.063	191.865 ms
Disch 10kW	56	241.56	120	2	0.408	0.27	37.37	18.75	18.75	21.875	1.080	234.865 ms
Disch 10kW	55	241.56	120	2.11	0.413	0.298	37.36	18.5	11.5625	14.375	0.697	206.865 ms
Disch 20kW	50	240.18	119	2.2	0.452	0.277	77.66	38.75	39.375	42	1.049	265.865 ms
Disch 20kW	48	240.18	119	2.23	0.45	0.284	77.63	38.75	39.6875	42.188	1.056	267.865 ms
Disch 20kW	45	240.26	119	1.89	0.45	0.035	77.59	38	39.6875	42.188	1.077	370.365 ms
Disch 30kW	53	240.86	119	3.8	0.654	0.707	117.23	55.25	56.5625	62.188	1.073	225.415 ms
Disch 30kW	44	240.65	119	2.85	0.643	0.242	117.3	57.25	56.5625	62.188	1.036	185.415 ms
Disch 30kW	42	240.64	119	2.77	0.644	0.239	117.28	61.75	39.0625	40	0.640	200.415 ms
Disch 10kW	72	240.54	119.5	1.94	0.352	0.289	37.62	19.25	10.9375	13.75	0.637	182.415 ms
Disch 10kW	69	240.48	119.5	1.97	0.362	0.303	37.6	19.25	12.8125	15	0.720	143.415 ms
Disch 10kW	66	240.61	119.5	1.53	0.381	0.02	37.54	18.5	11.5625	14.375	0.697	221.415 ms
Disch 20kW	62	240.4	119	1.81	0.43	0.081	77.5	38.375	22.8125	26.563	0.641	625.415 ms
Disch 20kW	58	240.4	119	1.75	0.433	0.029	77.5	38.375	24.375	28.438	0.686	570.415 ms
Disch 20kW	51	240.4	119	1.89	0.454	0.013	77.47	39	25	26.875	0.665	335.415 ms

Table 8: Measurement Results of Reactive Power Produced by the EUT

EUT Mode	Parallel Load	Current Meas	Real P Meas	Reactive P Meas	PF Meas
Disch 30	"65" = 132.42A, 0.4kVAR, 31.83kW	117.45	28.28	0.81	0.9996
Disch 20	"45" = 90.1A, 0.28kVAR, 21.61kW	77.66	18.65	0.74	0.9992
Disch 10	"25" = 49.99A, 0.28kVAR, 12.01kW	37.69	9.025	0.705	0.997
Chrg 15	"5" = 10.1A, 0.31kVAR, 2.41kW	62.82	15.09	0.9	0.9982
Chrg 10	"5" = 10.1A, 0.31kVAR, 2.41kW	42.81	10.24	0.89	0.9962
Chrg 5	"5" = 10.1A, 0.31kVAR, 2.41kW	22.73	5.39	0.87	0.9873

3.8 Reverse Power (for unintentional islanding) (IEEE 1547.1 Section 5.8)

This test does not apply to the CES unit under test. The experimenter's understanding is that the CES unit does not utilize reverse power protection or minimum import power flow protection to disconnect in the case of an islanding condition.

3.9 Open Phase (IEEE 1547.1 Section 5.9)

The clearing time of the EUT in response to an open phase condition was tested per IEEE 1547.1. The unit was found to be in compliance with the requirement to disconnect within 2 seconds of the inception of the event.

This test was completed using the grid simulator and programming a transient that takes one phase from rated voltage to 0 V in 0.2 ms. The other phase is left stable at rated voltage.

Table 9 gives the results of the open phase test. The unit trips much faster than is required by the standard. Figure 11 shows an example scope capture of the clearing during the open phase test highlighted in Table 9.

Table 9: Results of Open Phase Tests

EUT Mode	Battery SOC	EUT Current	Clearing Time
Chrg 0.75	59	4.72 A	90.415 ms
Chrg 0.75	58	4.68 A	88.915 ms
Chrg 0.75	58	4.7 A	88.415 ms
Chrg 0.75	58	4.7 A	88.415 ms
Disch 1.5	57	4.75 A	89.865 ms
Disch 1.5	57	4.6 A	89.365 ms
Disch 1.5	57	4.58 A	88.865 ms
Disch 1.5	57	4.57 A	88.865 ms

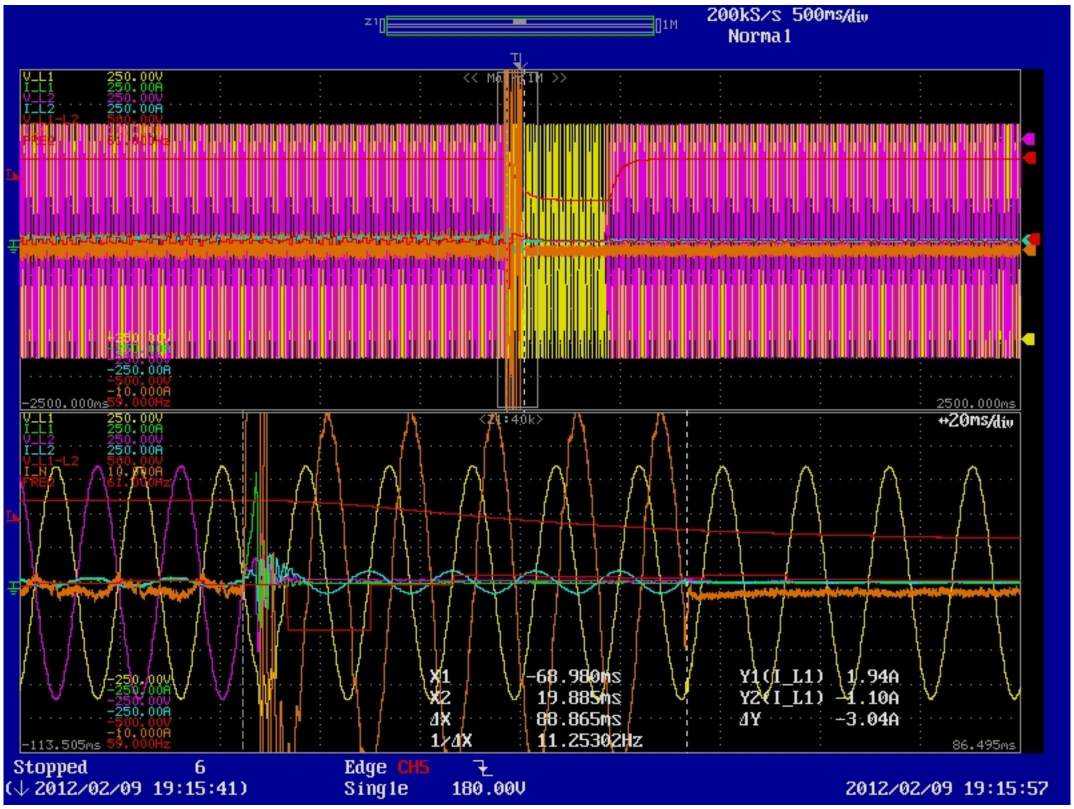


Figure 11: Example Scope Capture of the Response of the EUT to Open Phase

3.10 Reconnect Following Abnormal Condition Disconnect (IEEE 1547.1 Section 5.10)

The CES unit will trip offline when any abnormal conditions exist (as explored here in various other IEEE 1547.1 tests). It will not, however, reconnect automatically when operated using the manufacturer's PITS software. If, in the future, a programmatic change is implemented that will allow the unit to automatically attempt to reconnect after an abnormal condition, this test should be completed.

3.11 Harmonics (IEEE 1547.1 Section 5.11)

Current harmonics injected into the EPS by the EUT were measured. Harmonics were analyzed both with the grid simulator as the EPS source and with the utility transformer as the source. Table 10 gives the results of the harmonic analysis for several test cases. Harmonics were calculated using the harmonics analysis mode on a Yokogawa PZ4000 power analyzer and a 100kHz, 500A current probe.

Deviations beyond specified limits are observed for some test cases for even harmonics, mostly high order. In some cases the deviations are likely due to tolerances in the measurement equipment or existing harmonics on the EPS (especially for the utility transformer cases). The user or utility installer must determine whether the levels of harmonics reported are detrimental to the local EPS to which the EUT is connected.

Table 10: Results of Current Harmonics Tests

		Odd h < 11	Even h < 11	Odd 11 ≤ h < 17	Even 11 ≤ h < 17	Odd 17 ≤ h < 23	Even 17 ≤ h < 23	Odd 23 ≤ h < 35	Even 23 ≤ h < 35	Odd h ≥ 35	Even h ≥ 35	TDD
EPS Source	**EUT Mode**	4.0%	1.0%	2.0%	0.5%	1.5%	0.4%	0.6%	0.2%	0.3%	0.1%	5.0%
Grid Sim	Disch 30	2.42%	0.42%	1.08%	0.00%	0.42%	0.06%	0.58%	0.00%	0.08%	0.05%	1.42%
Grid Sim	Disch 20	2.14%	0.38%	0.62%	0.07%	0.37%	0.08%	0.29%	0.08%	0.03%	0.03%	1.21%
Grid Sim	Disch 10	1.54%	0.34%	0.86%	0.06%	0.37%	0.19%	0.25%	0.03%	0.03%	0.03%	1.02%
Grid Sim	Disch 30	2.42%	0.42%	1.08%	0.00%	0.42%	0.06%	0.58%	0.00%	0.00%	0.03%	1.46%
Grid Sim	Disch 10	1.55%	0.35%	0.85%	0.07%	0.39%	0.19%	0.25%	0.03%	0.03%	0.03%	1.02%
Grid Sim	Chrg 15	1.63%	0.58%	0.61%	0.14%	0.82%	0.20%	0.36%	0.06%	0.03%	0.04%	1.10%
Grid Sim	Chrg 10	1.38%	0.56%	1.13%	0.11%	0.55%	0.17%	0.13%	0.04%	0.03%	0.04%	1.07%
Grid Sim	Chrg 5	1.09%	0.43%	0.63%	0.08%	0.30%	0.44%	0.07%	0.03%	0.03%	0.06%	0.75%
Grid Sim	Disch 30	2.42%	0.33%	1.08%	0.08%	0.50%	0.09%	0.50%	0.00%	0.08%	0.04%	1.46%
Grid Sim	Disch 20	2.19%	0.39%	0.69%	0.06%	0.21%	0.11%	0.30%	0.04%	0.02%	0.02%	1.25%
Grid Sim	Disch 10	1.58%	0.39%	0.78%	0.08%	0.49%	0.20%	0.24%	0.04%	0.03%	0.03%	1.03%
Utility Xfmr	Chrg 15	2.05%	0.83%	0.18%	0.10%	0.48%	0.14%	0.23%	0.03%	0.03%	0.02%	1.32%
Utility Xfmr	Chrg 10	1.74%	0.72%	0.43%	0.13%	0.66%	0.50%	0.22%	0.03%	0.03%	0.02%	1.31%
Utility Xfmr	Chrg 5	2.22%	0.77%	0.40%	0.11%	0.23%	0.43%	0.29%	0.05%	0.03%	0.04%	1.42%
Utility Xfmr	Disch 10	2.19%	0.93%	0.34%	0.10%	0.61%	0.48%	0.24%	0.02%	0.03%	0.03%	1.37%
Utility Xfmr	Disch 20	2.79%	1.07%	0.54%	0.12%	0.46%	0.12%	0.29%	0.03%	0.04%	0.02%	1.67%
Utility Xfmr	Disch 30	2.64%	1.38%	0.62%	0.16%	0.33%	0.10%	0.23%	0.00%	0.03%	0.00%	1.65%

Table 11 is gives more detail on each harmonics test case, including sampling rate, observation window length and electrical parameters.

Table 11: Details for Harmonics Test Trials

Battery SOC	EUT Mode	Power %	Load Bank [A]	Vrms [V]	Irms [A]	I_THD	EPS Source	Sampling Rate	Observation Time
86	Disch 30	100	132 ("65")	241.8	117	1.46	Grid Sim	1 MS/s	100ms window
84	Disch 20	66	89 ("45")	239.34	78.11	1.86	Grid Sim	1 MS/s	100ms window
81	Disch 10	33	48 ("25")	240.88	37.64	3.24	Grid Sim	1 MS/s	100ms window
76	Disch 30	100	132 ("65")	239.8	118	1.48	Grid Sim	250 kS/s	400ms window
72	Disch 10	33	48 ("25")	240.68	37.66	3.26	Grid Sim	250 kS/s	400ms window
73	Chrg 15	100	68 ("35")	239.54	63.07	2.1	Grid Sim	250 kS/s	400ms window
75	Chrg 10	66	48 ("25")	242.44	42.41	3.02	Grid Sim	250 kS/s	400ms window
76	Chrg 5	33	28 ("15")	239.19	22.8	3.96	Grid Sim	250 kS/s	400ms window
52	Disch 30	100	132 ("65")	240.79	117.07	1.49	Grid Sim	250 kS/s	400ms window
52	Disch 20	66	89 ("45")	240.34	77.54	1.94	Grid Sim	250 kS/s	400ms window
52	Disch 10	33	48 ("25")	239.67	37.68	3.28	Grid Sim	250 kS/s	400ms window
52	Chrg 15	100	0	237.61	63.65	2.49	Utility Xfmr	250 kS/s	400ms window
57	Chrg 10	66	0	240.24	42.86	3.66	Utility Xfmr	250 kS/s	400ms window
58	Chrg 5	33	0	242.22	22.65	7.56	Utility Xfmr	250 kS/s	400ms window
58	Disch 10	33	0	248.75	36.06	4.57	Utility Xfmr	250 kS/s	400ms window
56	Disch 20	66	0	252.21	73.56	2.72	Utility Xfmr	250 kS/s	400ms window
55	Disch 30	100	0	256	110	1.8	Utility Xfmr	250 kS/s	400ms window

3.12 Flicker (IEEE 1547.1 Section 5.12)

Results from the Synchronization tests along with impedance information of the EPS to which the EUT will connect are needed to determine flicker. No further testing or calculations have been done for this standard.

Grid Interconnection Test Report
PowerHub Systems CES-3030 Unit #2

Location:	**DERTF Lab at NREL's NWTC**
Testing Dates:	**February 20, 2012 – March 12, 2012**
Lead NREL Engineer, Report Author:	**Greg Martin (303-384-7039)**
NREL Laboratory Supervisor:	**Bill Kramer (303-275-3844)**
NREL EHS Point of Contact:	**Mike Stewart (303-384-6906)**
Manufacturer Representative (PowerHub):	**Glenn Skutt (540-250-2870)**
Customer Representative (SMUD):	**Ed Sanchez (916-732-5572)**
Testing Objective:	**IEEE 1547 standard compliance testing**
Description of equipment under test:	**30kW, 30kWh battery energy storage system with inverter interface to utility**
Revision Status:	**Revision 0 (Initial Release)**

TABLE OF CONTENTS

1 SUMMARY

This report presents the results of testing accomplished on CES #2 for SUMD. The equipment under test (EUT), designed and built by PowerHub, is a 30kW, 30kWh battery-based energy storage system with a power conditioning system (PCS) interface to utility 240Vac power. The unit tested is referred to as CES Unit #2. This report deals with CES Unit #2 only.

The unit was tested to determine its compliancy with IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems. NREL recommends that the unit is sufficiently compliant with the standard, for the tests completed, to be able to connect to typical electric power systems. There are some minor deviations from the standard that should be reviewed by the project manager. The table below summarizes the IEEE 1547 tests, indicating those that were completed by NREL and the overall result.

Summary of IEEE 1547.1 Tests Performed and Overall Results

Test Category	Disposition	Overall Result
Temperature Stability	Not tested	None
Abnormal Voltage	Tested	Compliant[1]
Abnormal Frequency	Tested	Compliant[1]
Synchronization, Method 2	Tested	Compliant/To be determined[2]
Interconnection Integrity	Not tested	None
DC Injection	Not tested	None
Unintentional Islanding	Tested	Compliant
Reverse Power	Not tested / not applicable	None
Open Phase	Not tested	None
Reconnection	Not tested / not applicable	None
Harmonics	Tested	Compliant[3]
Flicker	Not tested	None

[1] *Test data indicates deviations from standard but settings can easily be adjusted by user to make unit compliant.*
[2] *Power system engineer must determine suitability of connecting to target EPS based on inrush current information provided.*
[3] *Unit is compliant when supplied by simulated EPS. Out-of-limit harmonic results when connected to utility transformer are understood to be due to excessive voltage distortion on the utility grid EPS.*

CES Unit #2 was found to operate similarly to CES Unit #1, tested previously.

Tests were completed using calibrated instruments for data capture and laboratory power supply and load bank equipment. This equipment is intended for use in this type of testing, however NREL recognizes that there are limitations to this equipment. Test methods and conditions may vary based on the facility, engineer running the tests, and data collection capabilities. NREL has made effort to follow the test procedures as described in IEEE 1547.1. This test report indicates cases in which deviations from this procedure are encountered.

Please refer to *"Grid Interconnection Test Report PowerHub Systems CES-3030 Unit #1"* for details of the test setup, laboratory equipment, and equipment under test.

2 TEST RESULTS

Refer to the accompanying *"Grid Interconnection Test Plan for CES Unit"* for additional information on safety procedures employed during testing and IEEE 1547.1 test procedure details.

2.1 Temperature Stability (IEEE 1547.1 Section 5.1)

Temperature stability and performance were not tested for CES Unit #2.

2.2 Response to Abnormal Voltage Conditions (IEEE 1547.1 Section 5.2 and 6.1)

CES Unit #2 was successfully tested for its response to abnormal voltages. The unit was found to be in compliance with the required clearing time in response to a voltage step. The unit is also in compliance with the magnitude trip response to a voltage ramp with the caveat that the trip magnitude may have to be adjusted by the user if the trip level magnitude is not compatible with the connected EPS.

It should be noted that the EUT does not implement a two-level response to abnormal voltages. That is, in the event of any EPS voltage excursion V_{EPS} > 132/264V or V_{EPS} < 106/212V, the unit will trip within the required 160 ms. The standard allows 1 s clearing time for 132/212V > V_{EPS} < 144V/288V, and 2 s clearing time for 60/120V > V_{EPS} < 106/212V.

The experimenter verified that configurable user settings for voltage trip magnitude and trip time allow accurate adjustment of these parameters. Table 1 gives test data for both over-voltage and under-voltage ramp trip magnitude responses of the EUT ("OVR" = over voltage ramp, "UVR" = under voltage ramp). Adjustments to the over- and under-voltage magnitude setting in the EUT are made and the response recorded in Table 1. Figure 1 gives a graphic of the voltage test signal applied to the EUT with the grid simulator source ("Ramp 1" and "Ramp 2").

Table 1: Results of Magnitude Response to Abnormal Voltage Tests

Test	Battery SOC	EUT Mode	EUT Settings	Transient Type	Result	Standard Limit
OVR	79	Disch 30	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	129.81 V	132 V (max)
OVR	78	Disch 30	o.v.t. = 10ms, o.v.l. = 128V	Ramp 1	125.94 V	132 V (max)
OVR	81	Chrg 15	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	129.69 V	132 V (max)
OVR	81	Chrg 15	o.v.t. = 10ms, o.v.l. = 128V	Ramp 1	126.13 V	132 V (max)
OVR	78	Disch 15	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	129.63 V	132 V (max)
OVR	79	Disch 15	o.v.t. = 10ms, o.v.l. = 128V	Ramp 1	125.94 V	132 V (max)
OVR	79	Chrg 5	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	129.88 V	132 V (max)
OVR	81	Chrg 5	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	129.94 V	132 V (max)
OVR	79	Standby	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	130.25 V	132 V (max)
UVR	66	Disch 30	o.v.t. = 10ms, o.v.l. = 106V	Ramp 2	105.06 V	105.6 V (min)
UVR	66	Disch 30	o.v.t. = 10ms, o.v.l. = 112V	Ramp 2	110.69 V	105.6 V (min)
UVR	68	Chrg 15	o.v.t. = 10ms, o.v.l. = 106V	Ramp 2	105.6 V	105.6 V (min)
UVR	69	Chrg 15	o.v.t. = 10ms, o.v.l. = 112V	Ramp 2	110.75 V	105.6 V (min)
UVR	66	Disch 15	o.v.t. = 10ms, o.v.l. = 106V	Ramp 2	104.81 V	105.6 V (min)
UVR	68	Disch 15	o.v.t. = 10ms, o.v.l. = 112V	Ramp 2	110.69 V	105.6 V (min)
OVR	68	Chrg 5	o.v.t. = 10ms, o.v.l. = 106V	Ramp 2	104.75 V	105.6 V (min)
OVR	68	Chrg 5	o.v.t. = 10ms, o.v.l. = 112V	Ramp 2	110.75 V	105.6 V (min)
OVR	68	Standby	o.v.t. = 10ms, o.v.l. = 106V	Ramp 2	104.5 V	105.6 V (min)
OVR	68	Standby	o.v.t. = 10ms, o.v.l. = 112V	Ramp 2	110.31 V	105.6 V (min)

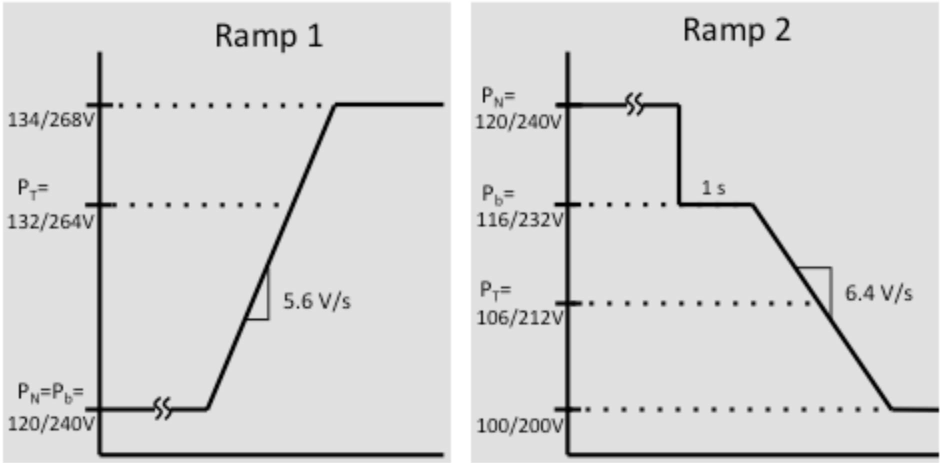


Figure 1: Abnormal Voltage Test Signals ("Ramp 1" and "Ramp 2")

The unit is in compliance with the clearing time requirement in response to an abnormal voltage step. Table 2 gives test data for the trip time tests ("OVS" = over voltage step, "UVS" = under voltage step). Adjustments to the trip time setting (changed from 10 ms to 25 ms) are made and the response recorded in Table 2. Figure 2 gives a graphic of the voltage test signal applied to the EUT with the grid simulator source ("Step 1" and "Step 2").

Table 2: Results of Trip-Time Response to Abnormal Voltage Tests

Test	Battery SOC	EUT Mode	EUT Settings	Transient Type	Result	Standard Limit
OVS	66	Disch 30	o.v.t. = 10ms, o.v.l. = 132V	Step 1	121.78 ms	160 ms (max)
OVS	64	Disch 30	o.v.t. = 25ms, o.v.l. = 132V	Step 1	133.33 ms	160 ms (max)
OVS	66	Chrg 15	o.v.t. = 10ms, o.v.l. = 132V	Step 1	120.88 ms	160 ms (max)
OVS	66	Chrg 15	o.v.t. = 25ms, o.v.l. = 132V	Step 1	136.43 ms	160 ms (max)
OVS	65	Disch 15	o.v.t. = 10ms, o.v.l. = 132V	Step 1	122.93 ms	160 ms (max)
OVS	65	Disch 15	o.v.t. = 25ms, o.v.l. = 132V	Step 1	134.63 ms	160 ms (max)
OVS	66	Chrg 5	o.v.t. = 10ms, o.v.l. = 132V	Step 1	120.48 ms	160 ms (max)
OVS	66	Chrg 5	o.v.t. = 25ms, o.v.l. = 132V	Step 1	139.78 ms	160 ms (max)
OVS	66	Standby	o.v.t. = 10ms, o.v.l. = 132V	Step 1	121.63 ms	160 ms (max)
OVS	66	Standby	o.v.t. = 25ms, o.v.l. = 132V	Step 1	129.63 ms	160 ms (max)
UVS	65	Disch 30	o.v.t. = 10ms, u.v.l. = 106V	Step 2	78.93 ms	160 ms (max)
UVS	64	Disch 30	o.v.t. = 10ms, u.v.l. = 106V	Step 2	99.76 ms	160 ms (max)
UVS	62	Disch 30	o.v.t. = 10ms, u.v.l. = 106V	Step 2	102.98 ms	160 ms (max)
UVS	66	Disch 30	o.v.t. = 10ms, u.v.l. = 106V	Step 2	120.98 ms	160 ms (max)
UVS	66	Disch 30	o.v.t. = 25ms, u.v.l. = 106V	Step 2	120.98 ms	160 ms (max)
UVS	66	Chrg 15	o.v.t. = 10ms, u.v.l. = 106V	Step 2	91.625 ms	160 ms (max)
UVS	66	Chrg 15	o.v.t. = 25ms, u.v.l. = 106V	Step 2	111.29 ms	160 ms (max)
UVS	66	Disch 15	o.v.t. = 10ms, u.v.l. = 106V	Step 2	96.89 ms	160 ms (max)
UVS	66	Disch 15	o.v.t. = 25ms, o.v.l. = 106V	Step 2	111.59 ms	160 ms (max)
UVS	66	Chrg 5	o.v.t. = 10ms, u.v.l. = 106V	Step 2	98.39 ms	160 ms (max)
UVS	66	Chrg 5	o.v.t. = 25ms, o.v.l. = 106V	Step 2	111.34 ms	160 ms (max)
UVS	66	Standby	o.v.t. = 10ms, u.v.l. = 106V	Step 2	95.79 ms	160 ms (max)
UVS	66	Standby	o.v.t. = 25ms, o.v.l. = 106V	Step 2	108.19 ms	160 ms (max)

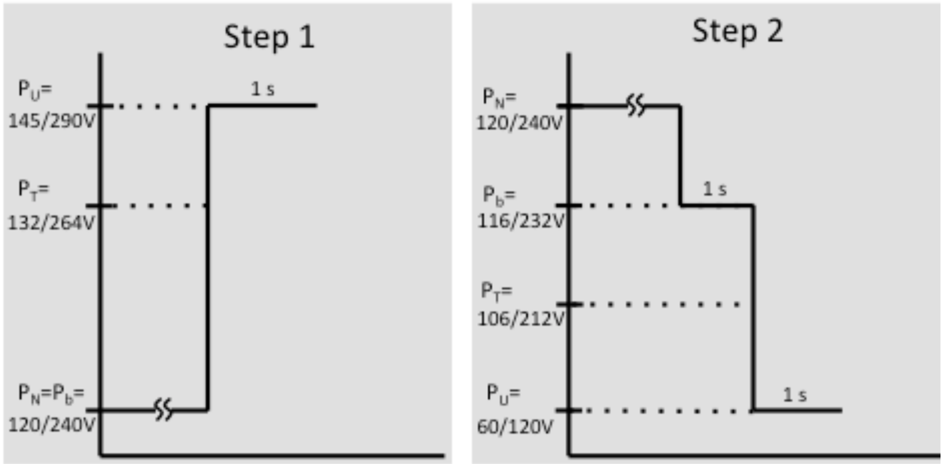


Figure 2: Abnormal Voltage Test Signals ("Step 1" and "Step 2")

2.3 Response to Abnormal Frequency Conditions (IEEE 1547.1 Section 5.3 and 6.2)

CES Unit #2 was successfully tested for its response to abnormal frequencies. The unit was found to be in compliance with the required clearing time in response to a frequency step. The unit is also in compliance with the magnitude trip response to a frequency ramp with the caveat that the trip magnitude may have to be adjusted by the user if the trip level magnitude is not compatible with the connected EPS.

The experimenter verified that the configurable user settings for frequency trip magnitude and time provide accurate adjustment of these parameters. The unit responds appropriately to changes of trip level and trip time settings.

Table 3 gives test data for both over-frequency and under-frequency ramp trip magnitude responses of the EUT ("OFR" = over frequency ramp, "UFR" = under frequency ramp). Adjustments to the over- and under-frequency magnitude limit parameter are made and the response recorded in Table 3. Figure 3 gives a graphic of the frequency test signal applied to the EUT with the grid simulator source ("Ramp 1" and "Ramp 2").

Table 3: Results of Magnitude Response to Abnormal Frequency Tests

Test	Battery SOC	EUT Mode	EUT Settings	Transient Type	Result	Standard Limit
OFR	72	Disch 30	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.584 Hz	60.5 Hz (max)
OFR	71	Disch 30	o.f.t. = 10ms, o.f.l. = 60.4V	Ramp 1	60.424 Hz	60.5 Hz (max)
OFR	72	Chrg 15	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.462 Hz	60.5 Hz (max)
OFR	72	Chrg 15	o.f.t. = 10ms, o.f.l. = 60.4V	Ramp 1	60.342 Hz	60.5 Hz (max)
OFR	70	Disch 15	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.496 Hz	60.5 Hz (max)
OFR	71	Disch 15	o.f.t. = 10ms, o.f.l. = 60.4V	Ramp 1	60.396 Hz	60.5 Hz (max)
OFR	72	Chrg 5	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.568 Hz	60.5 Hz (max)
OFR	72	Chrg 5	o.f.t. = 10ms, o.f.l. = 60.4V	Ramp 1	60.426 Hz	60.5 Hz (max)
OFR	72	Standby	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	60.616 Hz	60.5 Hz (max)
OFR	72	Standby	o.f.t. = 10ms, o.f.l. = 60.4V	Ramp 1	60.476 Hz	60.5 Hz (max)
UFR	71	Disch 30	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.346 Hz	59.3 Hz (min)
UFR	70	Disch 30	u.f.t. = 10ms, u.f.l. = 59.5V	Ramp 2	59.516 Hz	59.3 Hz (min)
UFR	72	Chrg 15	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.28 Hz	59.3 Hz (min)
UFR	72	Chrg 15	u.f.t. = 10ms, u.f.l. = 59.5V	Ramp 2	59.424 Hz	59.3 Hz (min)
UFR	71	Disch 15	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.3 Hz	59.3 Hz (min)
UFR	71	Disch 15	u.f.t. = 10ms, u.f.l. = 59.5V	Ramp 2	59.522 Hz	59.3 Hz (min)
UFR	72	Chrg 5	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.29 Hz	59.3 Hz (min)
UFR	72	Chrg 5	u.f.t. = 10ms, u.f.l. = 59.5V	Ramp 2	59.476 Hz	59.3 Hz (min)
UFR	72	Standby	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	59.146 Hz	59.3 Hz (min)
UFR	72	Standby	u.f.t. = 10ms, u.f.l. = 59.5V	Ramp 2	59.414 Hz	59.3 Hz (min)

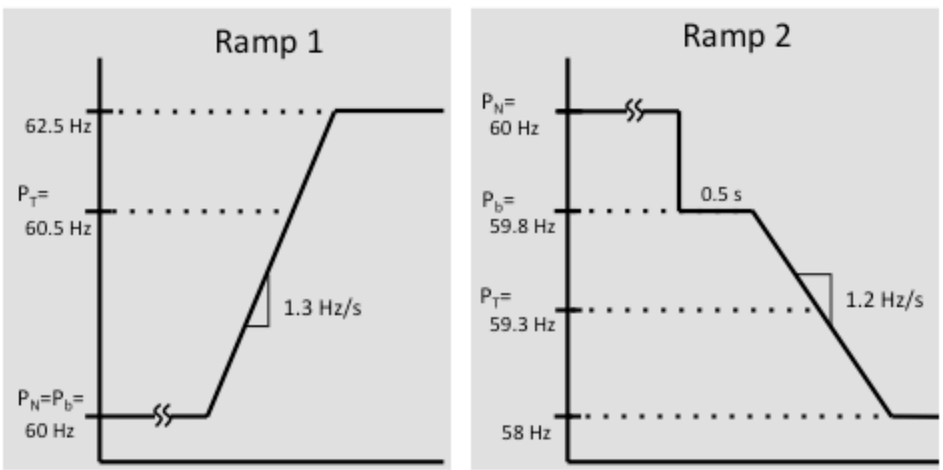


Figure 3: Abnormal Frequency Ramp Test Signals ("Ramp 1" and "Ramp 2")

The unit is in compliance with the clearing time requirement in response to an abnormal frequency step. Table 4 gives test data for the trip time tests ("OVS" = over frequency step, "UVS" = under frequency step). Adjustment from 10 ms to 25 ms over- and under-frequency trip time setting are made and the response indicated in Table 4. Figure 4 gives a graphic of the frequency test signals applied to the EUT with the grid simulator source ("Step 1" and "Step 2").

Table 4: Results of Trip-Time Response to Abnormal Frequency Tests

Test	Battery SOC	EUT Mode	EUT Settings	Transient Type	Result	Standard Limit
OFS	70	Disch 30	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	120.24 ms	160 ms (max)
OFS	68	Disch 30	o.f.t. = 25ms, o.f.l. = 60.5V	Step 1	138.19 ms	160 ms (max)
OFS	71	Chrg 15	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	131.59 ms	160 ms (max)
OFS	70	Chrg 15	o.f.t. = 25ms, o.f.l. = 60.5V	Step 1	135.74 ms	160 ms (max)
OFS	68	Disch 15	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	126.74 ms	160 ms (max)
OFS	69	Disch 15	o.f.t. = 25ms, o.f.l. = 60.5V	Step 1	136.44 ms	160 ms (max)
OFS	70	Chrg 5	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	131.19 ms	160 ms (max)
OFS	70	Chrg 5	o.f.t. = 25ms, o.f.l. = 60.5V	Step 1	153.39 ms	160 ms (max)
OFS	70	Standby	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	117.99 ms	160 ms (max)
OFS	70	Standby	o.f.t. = 25ms, o.f.l. = 60.5V	Step 1	133.99 ms	160 ms (max)
UFS	68	Disch 30	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	139.7 ms	160 ms (max)
UFS	68	Disch 30	u.f.t. = 25ms, u.f.l. = 59.3V	Step 2	144.04 ms	160 ms (max)
UFS	69	Chrg 15	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	128.04 ms	160 ms (max)
UFS	69	Chrg 15	u.f.t. = 25ms, u.f.l. = 59.3V	Step 2	137.14 ms	160 ms (max)
UFS	66	Disch 15	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	124.59 ms	160 ms (max)
UFS	66	Disch 15	u.f.t. = 25ms, u.f.l. = 59.3V	Step 2	138.19 ms	160 ms (max)
UFS	68	Chrg 5	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	132.34 ms	160 ms (max)
UFS	68	Chrg 5	u.f.t. = 25ms, u.f.l. = 59.3V	Step 2	141.79 ms	160 ms (max)
UFS	68	Standby	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	130.24 ms	160 ms (max)
UFS	68	Standby	u.f.t. = 25ms, u.f.l. = 59.3V	Step 2	137.84 ms	160 ms (max)

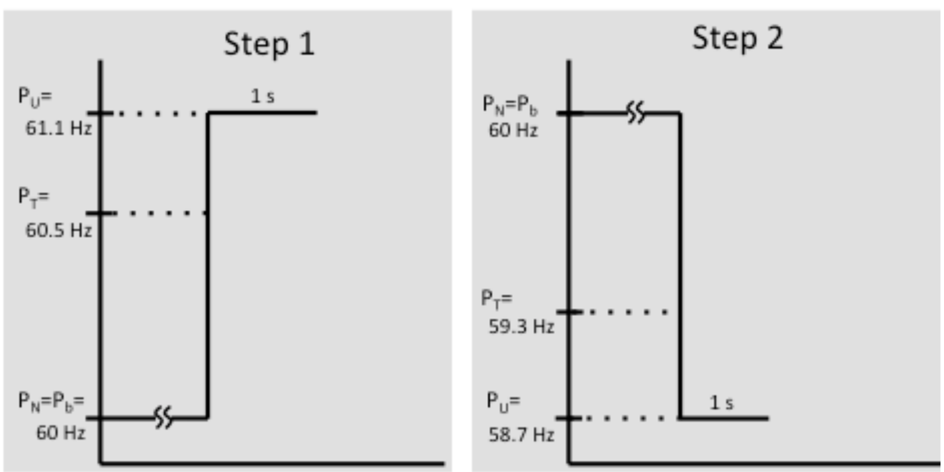


Figure 4: Abnormal Frequency Step Test Signals ("Step 1" and "Step 2")

2.4 Synchronization (IEEE 1547.1 Section 5.4 and 6.3)

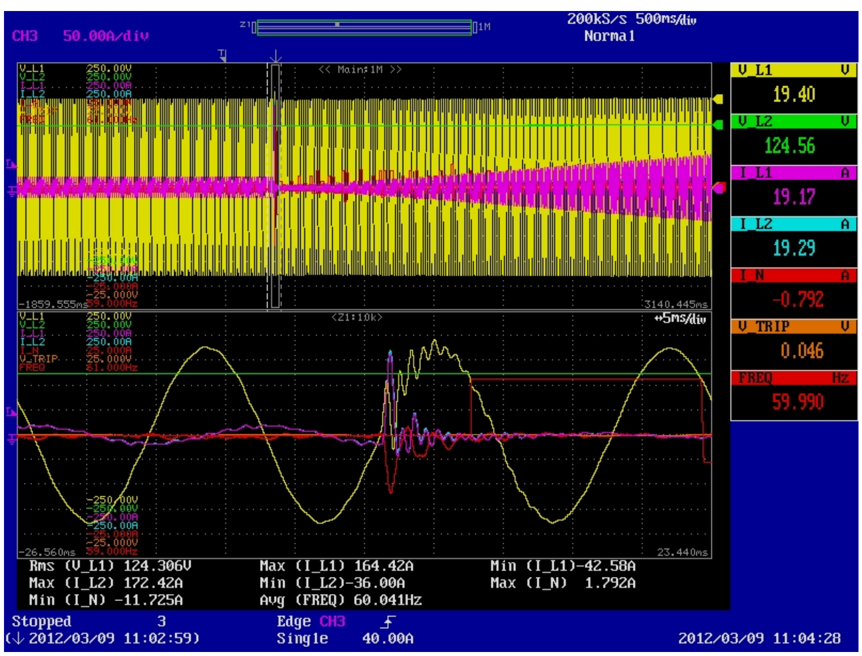
Synchronization of the EUT to the EPS using Method 2 (startup current measurement) from IEEE 1547.1 was tested. Compliance is based on the requirements of the EPS that the unit will connect to, and the assessment of the governing utility or service provider. The results here are intended to provide the utility installer with information to determine whether the EUT would cause flicker concerns on the actual EPS. Synchronization tests were completed using both the grid simulator as well as a utility transformer as the EPS source.

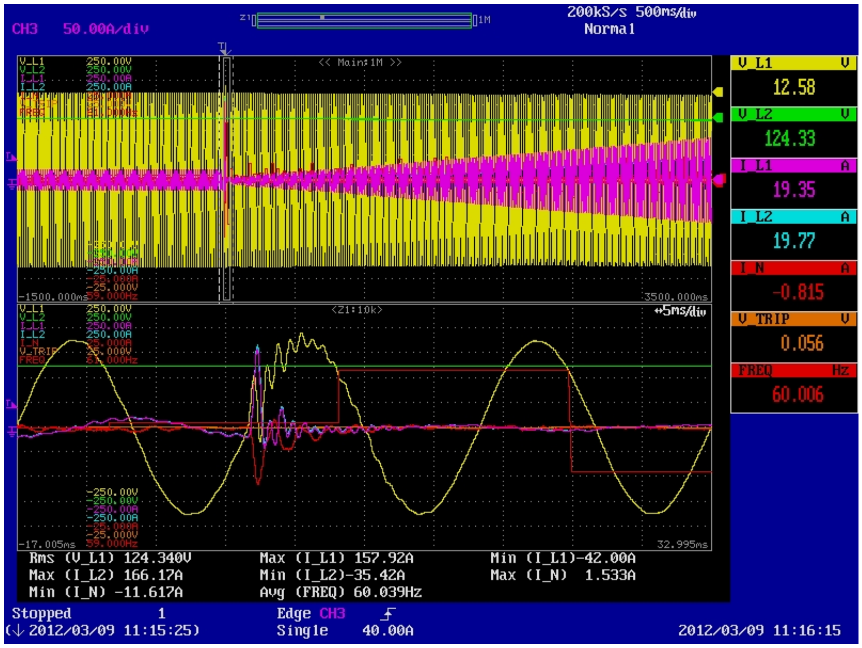
The EUT generally exhibits a startup current transient lasing for less than a ½ cycle (8 ms). In only one case did a current transient magnitude exceed the rated output current of the EUT. Since this transient is non-linear it is difficult to calculate an rms value. Sampling of the current waveform occurred at

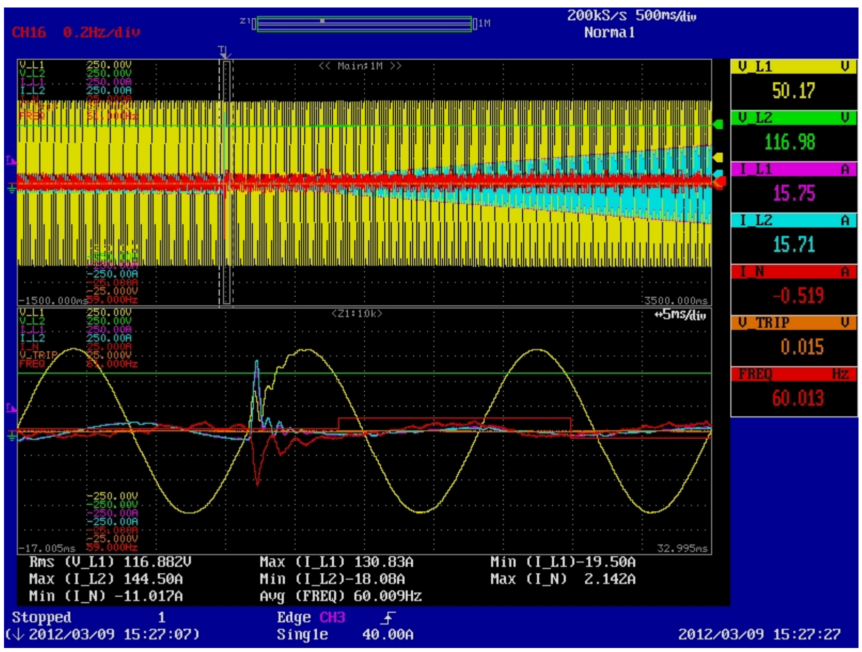
200kS/s. For the tests, the peak current value is measured by the scope. Table 5 gives tabulated peak current values obtained for several test trials with various modes of operation. Figure 5 shows the scope image captures of the 4 highlighted tests in Table 5, illustrating some of the largest current transients encountered. All additional scope captures showing each test trial from Table 5 are available upon request.

Table 5: Results of Synchronization Tests

EUT Mode	Battery SOC	EPS Sorce	Peak Current [A]	Parallel Load
Standby -> Disch 30	85	Utility Xfmr	49.58	0
Standby -> Disch 30	85	Utility Xfmr	172.42	0
Standby -> Disch 30	85	Utility Xfmr	96.83	0
Standby -> Disch 30	85	Utility Xfmr	167.25	0
Standby -> Chrg 15	83	Utility Xfmr	166.17	0
Standby -> Chrg 15	84	Utility Xfmr	66.42	0
Standby -> Chrg 15	84	Utility Xfmr	149.08	0
Standby -> Chrg 15	84	Utility Xfmr	111.25	0
Isolated -> Standby	84	Utility Xfmr	-77.33	0
Isolated -> Standby	84	Utility Xfmr	45.92	0
Isolated -> Standby	84	Utility Xfmr	106.25	0
Isolated -> Standby	84	Utility Xfmr	88.83	0
Standby -> Disch 30	82	GridSim	82.67	130 ("65")
Standby -> Disch 30	82	GridSim	144.5	130 ("65")
Standby -> Disch 30	82	GridSim	132	130 ("65")
Standby -> Disch 30	82	GridSim	154.92	130 ("65")
Standby -> Chrg 15	83	GridSim	122.75	10.1 ("5")
Standby -> Chrg 15	84	GridSim	83.92	10.1 ("5")
Standby -> Chrg 15	84	GridSim	148.5	10.1 ("5")
Standby -> Chrg 15	84	GridSim	142.58	10.1 ("5")
Isolated -> Standby	83	GridSim	140.08	10.1 ("5")
Isolated -> Standby	83	GridSim	-98.92	10.1 ("5")
Isolated -> Standby	83	GridSim	105.92	10.1 ("5")




CH3 50.00A/div
200kS/s 500ms/div
Normal
<< Main:1M >>
<Z1:10k>
V_L1 12.58
V_L2 124.33
I_L1 19.35
I_L2 19.77
I_N -0.815
V_TRIP 0.056
FREQ 60.006
Rms (V_L1) 124.340V
Max (I_L2) 166.17A
Min (I_N) -11.617A
Max (I_L1) 157.92A
Min (I_L2)-35.42A
Avg (FREQ) 60.039Hz
Min (I_L1)-42.00A
Max (I_N) 1.533A
Stopped 1
(↓ 2012/03/09 11:15:25)
Edge CH3
Single 40.00A
2012/03/09 11:16:15


CH16 0.2Hz/div
200kS/s 500ms/div
Normal
<< Main:1M >>
<Z1:10k>
V_L1 50.17
V_L2 116.98
I_L1 15.75
I_L2 15.71
I_N -0.519
V_TRIP 0.015
FREQ 60.013
Rms (V_L1) 116.882V
Max (I_L2) 144.50A
Min (I_N) -11.017A
Max (I_L1) 130.83A
Min (I_L2)-18.08A
Avg (FREQ) 60.009Hz
Min (I_L1)-19.50A
Max (I_N) 2.142A
Stopped 1
(↓ 2012/03/09 15:27:07)
Edge CH3
Single 40.00A
2012/03/09 15:27:27

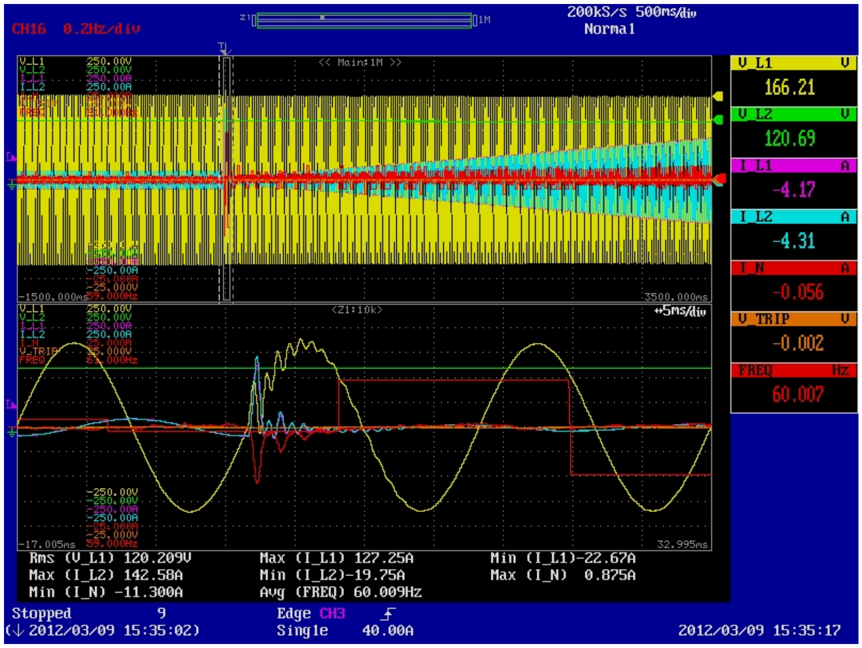


Figure 5: Selected Scope Captures of Synchronization Test Startup Current transients

2.5 Interconnection integrity (IEEE 1547.1 Section 5.5)

This category has three sub-tests; EMI interference, surge withstand, and dielectric test of paralleling device. These tests require specialized test equipment, test setups, and have the potential to damage the equipment under test. In some cases, factory/manufacturer acceptance testing is acceptable for compliance. NREL has not completed these tests.

2.6 Limitation of DC Injection for Inverters (IEEE 1547.1 Section 5.6)

DC injection has not been tested on CES Unit #2.

2.7 Unintentional Islanding (IEEE 1547.1 Section 5.7)

The CES unit was tested for its response to islanding conditions. IEEE 1547 requires equipment to trip offline in the event of islanding conditions within 2 seconds. The unit was found to be in compliance with this requirement. In all test cases, the unit consistently trips offline within a maximum clearing time of 548 ms when an islanding condition is present. Results of the unintentional islanding tests for CES Unit #2 are given in Table 6.

The unit was tested using the grid simulator as the EPS and the laboratory load bank in parallel to create a tuned resonant circuit to create the island conditions. While the EUT operates at a power factor very near 1, it does produce measurable reactive power flow. This reactive power flow had to be accounted for in setting up the island circuit, as described in IEEE 1547.1 Section 5.7.1.2. The unit was tested at “Q” factors at or exceeding 1.

Table 6: Clearing Time Results for Unintentional Islanding Tests

CES Mode	Batt SOC	Vrms	Irms EPS	Qmeas	Pmeas	Irms CES	Rset	Lset	Cset	Qf Calc	Result
Disch 20kW	59	240.12	1.93	0.461	0.092	79.92	38.125	39.375	42.1875	1.069	409.73 ms
Disch 20kW	56	240.16	1.93	0.463	0.04	79.65	38.000	39.375	42.1875	1.073	450.73 ms
Disch 20kW	55	240.2	1.9	0.454	0.39	79.79	38.000	39.375	42.1875	1.073	548.73 ms
Disch 20kW	48	239.93	2.0	0.445	0.178	79.83	38.000	41.25	45.3125	1.138	149.85 ms
Disch 10kW	48	239.46	1.79	0.394	0.166	38.17	18.75	18.4375	21.5625	1.063	173.54 ms
Disch 10kW	48	239.52	1.67	0.369	0.155	38.67	18.75	18.125	21.2500	1.047	186.54 ms
Disch 10kW	45	239.56	1.69	0.387	0.118	38.31	18.625	18.4375	21.8750	1.078	592.54 ms
Disch 10kW	45	239.63	1.66	0.378	0.121	38.07	18.625	18.4375	21.8750	1.078	447.85 ms
Disch 30kW	47	240.69	3.41	0.655	0.494	119.92	55.25	56.5625	62.1875	1.073	234.55 ms
Disch 30kW	41	240.66	2.7	0.648	0.016	121.56	56.25	56.5625	62.1875	1.054	200.95 ms
Disch 30kW	48	240.53	2.66	0.64	0.006	121.1	56.375	56.5625	62.1875	1.052	190.25 ms
Disch 30kW	42	240.7	2.61	0.626	0.049	121.58	56.25	56.5625	62.1875	1.054	241.26 ms

2.8 Reverse Power (for unintentional islanding) (IEEE 1547.1 Section 5.8)

This test does not apply to the CES unit under test. The experimenter's understanding is that the CES unit does not utilize reverse power protection or minimum import power flow protection to disconnect in the case of an islanding condition.

2.9 Open Phase (IEEE 1547.1 Section 5.9)

Open phase was not tested on CES Unit #2.

2.10 Reconnect Following Abnormal Condition Disconnect (IEEE 1547.1 Section 5.10)

The CES unit will trip offline when any abnormal conditions exist (as explored here in various other IEEE 1547.1 tests). It will not, however, reconnect automatically when operated using the manufacturer's PITS software. If, in the future, a programmatic change is implemented that will allow the unit to automatically attempt to reconnect after an abnormal condition, this test should be completed.

2.11 Harmonics (IEEE 1547.1 Section 5.11)

Current harmonics injected into the EPS by the EUT were measured. Harmonics were analyzed both with the grid simulator as the EPS source and with the utility transformer as the source. Table 7 gives the results of the harmonic analysis for several test cases. Harmonics were calculated using the harmonics analysis mode on a Yokogawa PZ4000 power analyzer and a 100kHz, 500A current probe.

Deviations from the harmonic injection limits are highlighted in Table 7. It can be observed from Table 7 that deviations are experienced ONLY when the EUT is operated connected to the utility transformer. It is understood that voltage distortion present on the utility EPS used at the DERTF laboratory caused additional current harmonics measured in these tests. These results are preliminary and can be re-tested, taking into account the EPS voltage distortion, at the request of the customer.

Table 7: Results of Current Harmonics Tests

		Odd h < 11	Even h < 11	Odd 11 ≤ h < 17	Even 11 ≤ h < 17	Odd 17 ≤ h < 23	Even 17 ≤ h < 23	Odd 23 ≤ h < 35	Even 23 ≤ h < 35	Odd h ≥ 35	Even h ≥ 35	TDD
EPS Source	**EUT Mode**	**4.0%**	**1.0%**	**2.0%**	**0.5%**	**1.5%**	**0.4%**	**0.6%**	**0.2%**	**0.3%**	**0.1%**	**5.0%**
Grid Sim	Chrg 15	1.73%	0.58%	0.48%	0.10%	0.85%	0.17%	0.38%	0.05%	0.03%	0.03%	1.13%
Grid Sim	Chrg 10	1.32%	0.53%	1.08%	0.08%	0.55%	0.13%	0.13%	0.03%	0.06%	0.03%	1.03%
Grid Sim	Chrg 5	1.06%	0.42%	0.65%	0.12%	0.17%	0.08%	0.05%	0.03%	0.02%	0.01%	0.72%
Grid Sim	Disch 30	2.46%	0.38%	1.03%	0.08%	0.40%	0.05%	0.48%	0.04%	0.12%	0.01%	1.45%
Grid Sim	Disch 20	2.28%	0.32%	0.65%	0.08%	0.30%	0.06%	0.31%	0.06%	0.03%	0.01%	1.26%
Grid Sim	Disch 10	1.57%	0.31%	0.83%	0.05%	0.47%	0.11%	0.28%	0.03%	0.04%	0.01%	1.03%
Utility Xfmr	Disch 30	3.70%	2.38%	2.53%	0.36%	0.21%	0.23%	0.23%	0.04%	0.03%	0.01%	3.24%
Utility Xfmr	Disch 20	3.72%	2.11%	2.43%	0.33%	0.61%	0.19%	0.28%	0.06%	0.01%	0.01%	3.14%
Utility Xfmr	Disch 10	3.52%	1.87%	2.25%	0.27%	0.53%	0.53%	0.17%	0.05%	0.03%	0.01%	2.93%
Utility Xfmr	Disch 30	3.80%	2.24%	2.58%	0.33%	0.28%	0.08%	0.24%	0.03%	0.03%	0.01%	3.33%
Utility Xfmr	Disch 20	3.55%	2.09%	2.38%	0.35%	0.50%	0.22%	0.27%	0.05%	0.04%	0.02%	3.02%
Utility Xfmr	Disch 10	3.52%	1.87%	2.18%	0.27%	0.52%	0.53%	0.18%	0.05%	0.04%	0.01%	2.90%
Utility Xfmr	Chrg 15	3.35%	1.71%	2.99%	0.26%	0.61%	0.26%	0.28%	0.04%	0.02%	0.01%	3.14%
Utility Xfmr	Chrg 10	3.09%	1.67%	2.89%	0.36%	0.68%	0.38%	0.14%	0.04%	0.02%	0.00%	2.98%
Utility Xfmr	Chrg 5	3.13%	1.78%	3.00%	0.26%	0.24%	0.23%	0.22%	0.04%	0.03%	0.00%	2.95%
Utility Xfmr	Chrg 15	3.24%	1.71%	3.03%	0.23%	0.63%	0.29%	0.25%	0.04%	0.02%	0.01%	3.13%
Utility Xfmr	Chrg 10	3.13%	1.63%	2.82%	0.39%	0.67%	0.46%	0.14%	0.04%	0.03%	0.00%	2.93%
Utility Xfmr	Chrg 5	3.08%	1.78%	2.79%	0.28%	0.31%	0.25%	0.20%	0.05%	0.03%	0.00%	2.78%
Grid Sim	Disch 30	2.33%	0.42%	1.08%	0.17%	0.50%	0.00%	0.50%	0.00%	0.08%	0.00%	1.44%
Grid Sim	Disch 20	2.17%	0.44%	0.63%	0.08%	0.28%	0.10%	0.28%	0.07%	0.03%	0.02%	1.22%
Grid Sim	Disch 10	1.62%	0.34%	0.77%	0.19%	0.45%	0.15%	0.23%	0.06%	0.03%	0.01%	1.04%
Grid Sim	Chrg 15	1.66%	0.74%	0.63%	0.18%	0.80%	0.24%	0.37%	0.09%	0.05%	0.03%	1.15%
Grid Sim	Chrg 10	1.49%	0.66%	1.11%	0.24%	0.54%	0.14%	0.14%	0.06%	0.04%	0.01%	1.13%
Grid Sim	Chrg 5	1.17%	0.60%	0.64%	0.26%	0.18%	0.21%	0.07%	0.05%	0.03%	0.01%	0.81%
Grid Sim	Chrg 15	1.64%	0.65%	0.58%	0.08%	0.88%	0.30%	0.35%	0.06%	0.03%	0.02%	1.12%
Grid Sim	Chrg 10	1.45%	0.55%	1.05%	0.11%	0.55%	0.29%	0.18%	0.07%	0.04%	0.03%	1.06%
Grid Sim	Chrg 5	0.96%	0.62%	0.68%	0.13%	0.23%	0.32%	0.08%	0.05%	0.01%	0.02%	0.79%
Grid Sim	Chrg 15	1.88%	0.69%	0.56%	0.16%	0.91%	0.33%	0.35%	0.10%	0.04%	0.01%	1.22%
Grid Sim	Chrg 10	1.41%	0.59%	1.04%	0.19%	0.53%	0.17%	0.14%	0.07%	0.06%	0.02%	1.06%
Grid Sim	Disch 30	2.38%	0.49%	1.10%	0.07%	0.33%	0.04%	0.45%	0.05%	0.11%	0.01%	1.43%
Grid Sim	Disch 20	2.17%	0.38%	0.59%	0.11%	0.26%	0.12%	0.26%	0.08%	0.03%	0.02%	1.20%
Grid Sim	Disch 10	1.45%	0.38%	0.88%	0.15%	0.41%	0.13%	0.23%	0.06%	0.05%	0.01%	1.03%

NOTE: Harmonics results highlighted above are above limits most likely because of known voltage distortions on the utility grid. Results for tests with the simulated area EPS ("grid simulator") are within limits.

2.12 Flicker (IEEE 1547.1 Section 5.12)

Results from the Synchronization tests along with impedance information of the EPS to which the EUT will connect are needed to determine flicker. No further testing or calculations have been done for this standard.

Grid Interconnection Test Report
PowerHub Systems CES-3030 Unit #3

Location:	**DERTF Lab at NREL's NWTC**	
Testing Dates:	**March 14, 2012 – March 23, 2012**	
Lead NREL Engineer, Report Author:	**Greg Martin**	**(303-384-7039)**
NREL Laboratory Supervisor:	**Bill Kramer**	**(303-275-3844)**
NREL EHS Point of Contact:	**Mike Stewart**	**(303-384-6906)**
Manufacturer Representative (PowerHub):	**Glenn Skutt**	**(540-250-2870)**
Customer Representative (SMUD):	**Ed Sanchez**	**(916-732-5572)**
Testing Objective:	**IEEE 1547 standard compliance testing**	
Description of equipment under test:	**30kW, 30kWh battery energy storage system with inverter interface to utility**	
Revision Status:	**Revision 0 (Initial Release)**	

TABLE OF CONTENTS

1 SUMMARY

This report presents the results of testing accomplished on CES #3 for SMUD. The equipment under test (EUT), designed and built by PowerHub, is a 30kW, 30kWh battery-based energy storage system with a power conditioning system (PCS) interface to utility 240Vac power. The unit tested is referred to as CES Unit #3. This report deals with CES Unit #3 only.

The unit was tested to determine its compliancy with IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems. NREL recommends that the unit is sufficiently compliant with the standard, for the tests completed, to be able to connect to typical electric power systems. There are some minor deviations from the standard that should be reviewed by the project manager. The table below summarizes the IEEE 1547.1 tests, indicating those that were completed by NREL and the overall result.

Summary of IEEE 1547.1 Tests Performed and Overall Results

Test Category	Disposition	Overall Result
Temperature Stability	Not tested	None
Abnormal Voltage	Tested	Compliant[1]
Abnormal Frequency	Tested	Compliant[1]
Synchronization, Method 2	Tested	Compliant/To be determined[2]
Interconnection Integrity	Not tested	None
DC Injection	Tested	Not Compliant[4]
Unintentional Islanding	Tested	Compliant
Reverse Power	Not tested / not applicable	None
Open Phase	Tested	Compliant
Reconnection	Not tested / not applicable	None
Harmonics	Tested	98% Compliant[3]
Flicker	Not tested	None

[1] *Test data indicates deviations from standard but settings can easily be adjusted by user to make unit compliant.*
[2] *Power system engineer must determine suitability of connecting to target EPS based on inrush current information provided.*
[3] *Unit is compliant when supplied by simulated EPS. Results beyond limit are minimal.*
[4] *Unit displays DC injection current in excess of standard. Previous unit did not exhibit this. Manufacturer attempted to programmatically address the issue, and the DC injection was adjusted but not reduced to within limits.*

Tests were completed using calibrated instruments for data capture and laboratory power supply and load bank equipment. This equipment is intended for use in this type of testing, however NREL recognizes that there are limitations to this equipment. Test methods and conditions may vary based on the facility, engineer running the tests, and data collection capabilities. NREL has made effort to follow the test procedures as described in IEEE 1547.1. This test report indicates cases in which deviations from this procedure are encountered.

Please refer to *"Grid Interconnection Test Report PowerHub Systems CES-3030 Unit #1"* for details of the test setup, laboratory equipment, and equipment under test.

2 TEST RESULTS

Refer to the accompanying *"Grid Interconnection Test Plan for CES Unit"* for additional information on safety procedures employed during testing and IEEE 1547.1 test procedure details.

2.1 Temperature Stability (IEEE 1547.1 Section 5.1)

Temperature stability and performance were not tested for CES Unit #2.

2.2 Response to Abnormal Voltage Conditions (IEEE 1547.1 Section 5.2 and 6.1)

CES Unit #3 was successfully tested for its response to abnormal voltages. The unit was found to be in compliance with the required clearing time in response to a voltage step. The unit is also in compliance with the magnitude trip response to a voltage ramp with the caveat that the trip magnitude may have to be adjusted by the user if the trip level magnitude is not compatible with the connected EPS.

It should be noted that the EUT does not implement a two-level response to abnormal voltages. That is, in the event of any EPS voltage excursion V_{EPS} > 132/264V or V_{EPS} < 106/212V, the unit will trip within the required 160 ms. The standard allows 1 s clearing time for 132/212V > V_{EPS} < 144V/288V, and 2 s clearing time for 60/120V > V_{EPS} < 106/212V.

The experimenter verified that configurable user settings for voltage trip magnitude and trip time allow accurate adjustment of these parameters. Table 1 gives test data for both over-voltage and under-voltage ramp trip magnitude responses of the EUT ("OVR" = over voltage ramp, "UVR" = under voltage ramp). Adjustments to the over- and under-voltage magnitude setting in the EUT are made and the response recorded in Table 1. Figure 1 gives a graphic of the voltage test signal applied to the EUT with the grid simulator source ("Ramp 1" and "Ramp 2").

Table 1: Results of Magnitude Response to Abnormal Voltage Tests

Test	Battery SOC	EUT Mode	EUT Settings	Transient Type	Parallel Load Set	Result	Standard Limit
OVR	62	Chrg 15	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	10.1A ("5")	130 V	132 V (max)
OVR	62	Chrg 15	o.v.t. = 10ms, o.v.l. = 128V	Ramp 1	10.1A ("5")	126 V	132 V (max)
OVR	61	Disch 30	o.v.t. = 10ms, o.v.l. = 132V	Ramp 1	128.7A ("65")	130 V	132 V (max)
OVR	59	Disch 30	o.v.t. = 10ms, o.v.l. = 128V	Ramp 1	128.7A ("65")	125.5 V	132 V (max)
UVR	58	Disch 30	o.v.t. = 10ms, o.v.l. = 106V	Ramp 2	128.7A ("65")	105 V	105.6 V (min)
UVR	57	Disch 30	o.v.t. = 10ms, o.v.l. = 112V	Ramp 2	128.7A ("65")	110 V	105.6 V (min)
UVR	59	Chrg 15	o.v.t. = 10ms, o.v.l. = 106V	Ramp 2	10.1A ("5")	105 V	105.6 V (min)
UVR	60	Chrg 15	o.v.t. = 10ms, o.v.l. = 112V	Ramp 2	10.1A ("5")	109.5 V	105.6 V (min)

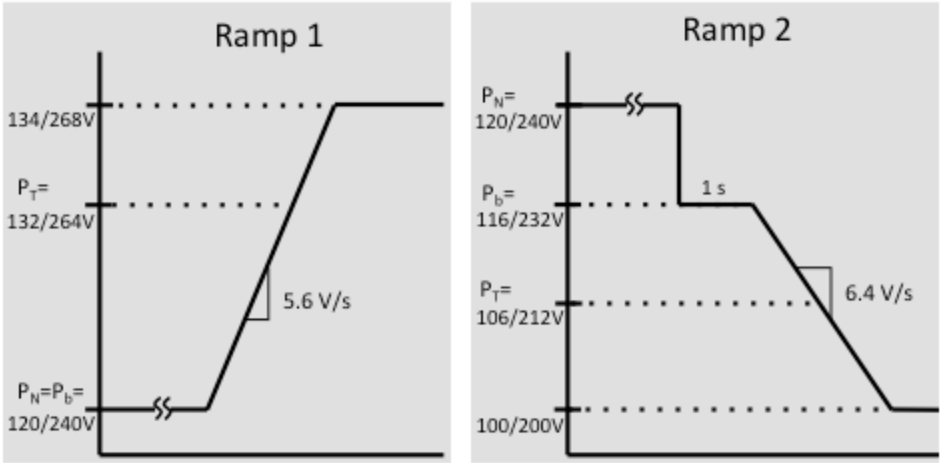


Figure 1: Abnormal Voltage Test Signals ("Ramp 1" and "Ramp 2")

The unit is in compliance with the clearing time requirement in response to an abnormal voltage step. Table 2 gives test data for the trip time tests ("OVS" = over voltage step, "UVS" = under voltage step). Adjustments to the trip time setting (changed from 10 ms to 25 ms) are made and the response recorded in Table 2. Figure 2 gives a graphic of the voltage test signal applied to the EUT with the grid simulator source ("Step 1" and "Step 2").

Table 2: Results of Trip-Time Response to Abnormal Voltage Tests

Test	Battery SOC	EUT Mode	EUT Settings	Transient Type	Parallel Load Set	Result	Standard Limit
OVS	61	Chrg 15	o.v.t. = 10ms, o.v.l. = 132V	Step 1	10.1A ("5")	121.57 ms	160 ms
OVS	63	Chrg 15	o.v.t. = 25ms, o.v.l. = 132V	Step 1	10.1A ("5")	134.52 ms	160 ms
OVS	62	Disch 30	o.v.t. = 10ms, o.v.l. = 132V	Step 1	128.7A ("65")	111.52 ms	160 ms
OVS	61	Disch 30	o.v.t. = 25ms, o.v.l. = 132V	Step 1	128.7A ("65")	116.47 ms	160 ms
UVS	58	Disch 30	o.v.t. = 10ms, u.v.l. = 106V	Step 2	128.7A ("65")	124.27 ms	160 ms
UVS	58	Disch 30	o.v.t. = 25ms, u.v.l. = 106V	Step 2	128.7A ("65")	140.22 ms	160 ms
UVS	59	Disch 15	o.v.t. = 10ms, u.v.l. = 106V	Step 2	10.1A ("5")	117.82 ms	160 ms
UVS	61	Disch 15	o.v.t. = 25ms, o.v.l. = 106V	Step 2	10.1A ("5")	127.77 ms	160 ms

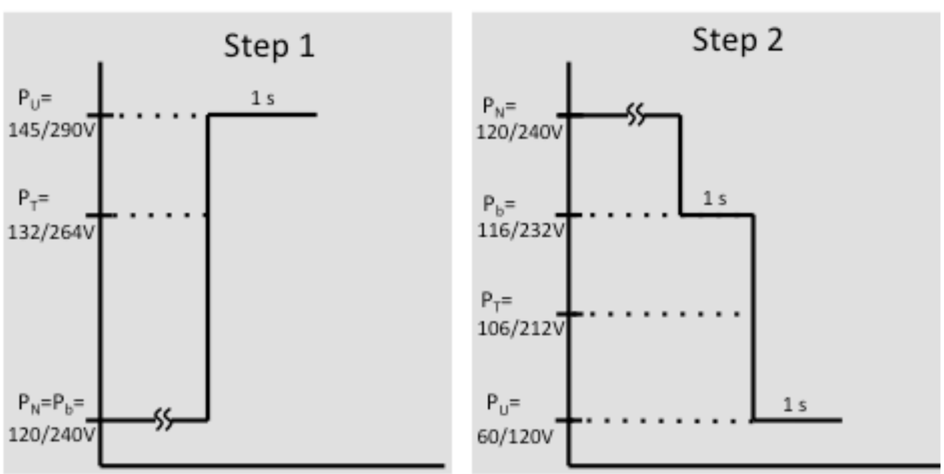


Figure 2: Abnormal Voltage Test Signals ("Step 1" and "Step 2")

2.3 Response to Abnormal Frequency Conditions (IEEE 1547.1 Section 5.3 and 6.2)

CES Unit #3 was successfully tested for its response to abnormal frequencies. The unit was found to be in compliance with the required clearing time in response to a frequency step. The unit is also in compliance with the magnitude trip response to a frequency ramp with the caveat that the trip magnitude may have to be adjusted by the user if the trip level magnitude is not compatible with the connected EPS.

The experimenter verified that the configurable user settings for frequency trip magnitude and time provide accurate adjustment of these parameters. The unit responds appropriately to changes of trip level and trip time settings.

Table 3 gives test data for both over-frequency and under-frequency ramp trip magnitude responses of the EUT ("OFR" = over frequency ramp, "UFR" = under frequency ramp). Figure 3 gives a graphic of the frequency test signal applied to the EUT with the grid simulator source ("Ramp 1" and "Ramp 2").

Table 3: Results of Magnitude Response to Abnormal Frequency Tests

Test	Battery SOC	EUT Mode	EUT Settings	Transient Type	Parallel Load Set	Result	Standard Limit
OFR	64	Chrg 15	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	10.1A ("5")	60.596 Hz	60.5 Hz (max)
OFR	65	Chrg 15	o.f.t. = 10ms, o.f.l. = 60.4V	Ramp 1	10.1A ("5")	60.496 Hz	60.5 Hz (max)
OFR	63	Disch 30	o.f.t. = 10ms, o.f.l. = 60.5V	Ramp 1	128.7A ("65")	60.48 Hz	60.5 Hz (max)
OFR	62	Disch 30	o.f.t. = 10ms, o.f.l. = 60.4V	Ramp 1	128.7A ("65")	60.406 Hz	60.5 Hz (max)
UFR	63	Disch 30	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	128.7A ("65")	59.318 Hz	59.3 Hz (min)
UFR	59	Disch 30	u.f.t. = 10ms, u.f.l. = 59.4V	Ramp 2	128.7A ("65")	59.374 Hz	59.3 Hz (min)
UFR	62	Chrg 15	u.f.t. = 10ms, u.f.l. = 59.3V	Ramp 2	10.1A ("5")	59.312 Hz	59.3 Hz (min)
UFR	63	Chrg 15	u.f.t. = 10ms, u.f.l. = 59.4V	Ramp 2	10.1A ("5")	59.314 Hz	59.3 Hz (min)

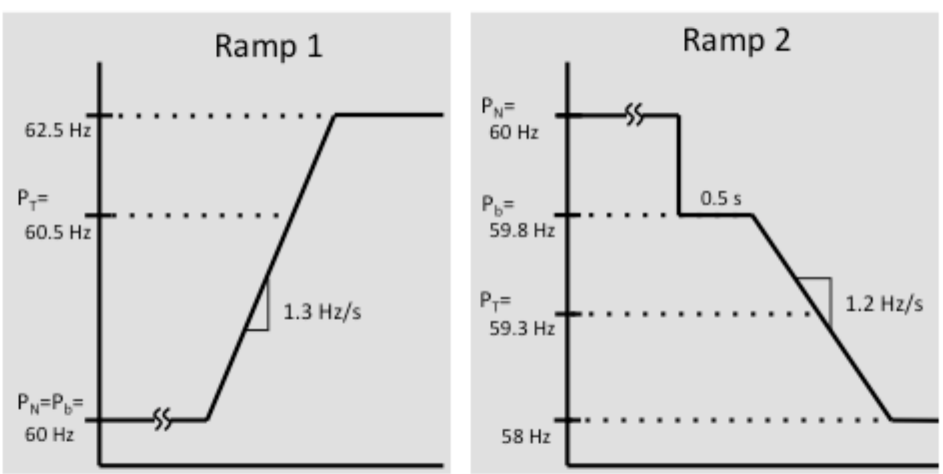


Figure 3: Abnormal Frequency Ramp Test Signals ("Ramp 1" and "Ramp 2")

The unit is in compliance with the clearing time requirement in response to an abnormal frequency step. Table 4 gives test data for the trip time tests ("OVS" = over frequency step, "UVS" = under frequency step). Adjustment from 10 ms to 25 ms over- and under-frequency trip time setting are made and the response indicated in Table 4. Figure 4 gives a graphic of the frequency test signals applied to the EUT with the grid simulator source ("Step 1" and "Step 2").

Table 4: Results of Trip-Time Response to Abnormal Frequency Tests

Test	Battery SOC	EUT Mode	EUT Settings	Transient Type	Parallel Load Set	Result	Standard Limit
OFS	64	Chrg 15	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	10.1A ("5")	114.72 ms	160 ms
OFS	65	Chrg 15	o.f.t. = 25ms, o.f.l. = 60.5V	Step 1	10.1A ("5")	132.22 ms	160 ms
OFS	62	Disch 30	o.f.t. = 10ms, o.f.l. = 60.5V	Step 1	128.7A ("65")	114.22 ms	160 ms
OFS	61	Disch 30	o.f.t. = 25ms, o.f.l. = 60.5V	Step 1	128.7A ("65")	131.62 ms	160 ms
UFS	59	Disch 30	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	128.7A ("65")	126.52 ms	160 ms
UFS	58	Disch 30	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	128.7A ("65")	114.82 ms	160 ms
UFS	61	Chrg 15	u.f.t. = 10ms, u.f.l. = 59.3V	Step 2	10.1A ("5")	117.82 ms	160 ms
UFS	62	Chrg 15	u.f.t. = 25ms, u.f.l. = 59.3V	Step 2	10.1A ("5")	136.82 ms	160 ms

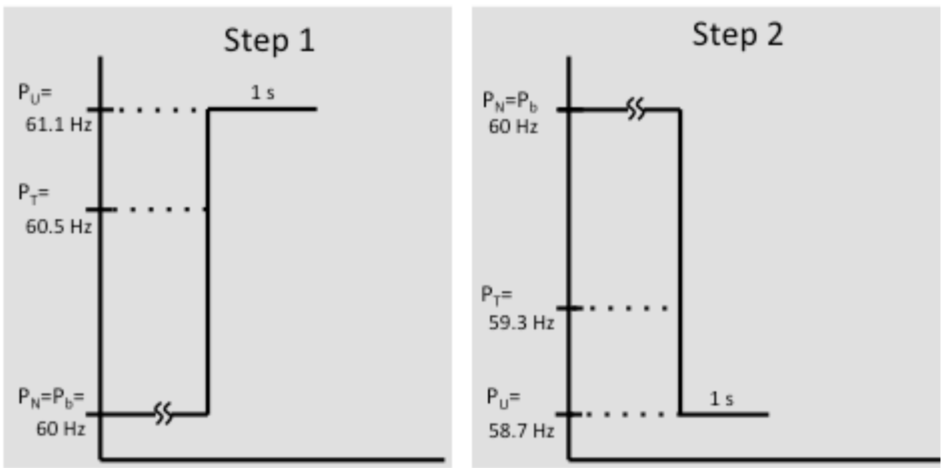


Figure 4: Abnormal Frequency Step Test Signals (“Step 1” and “Step 2”)

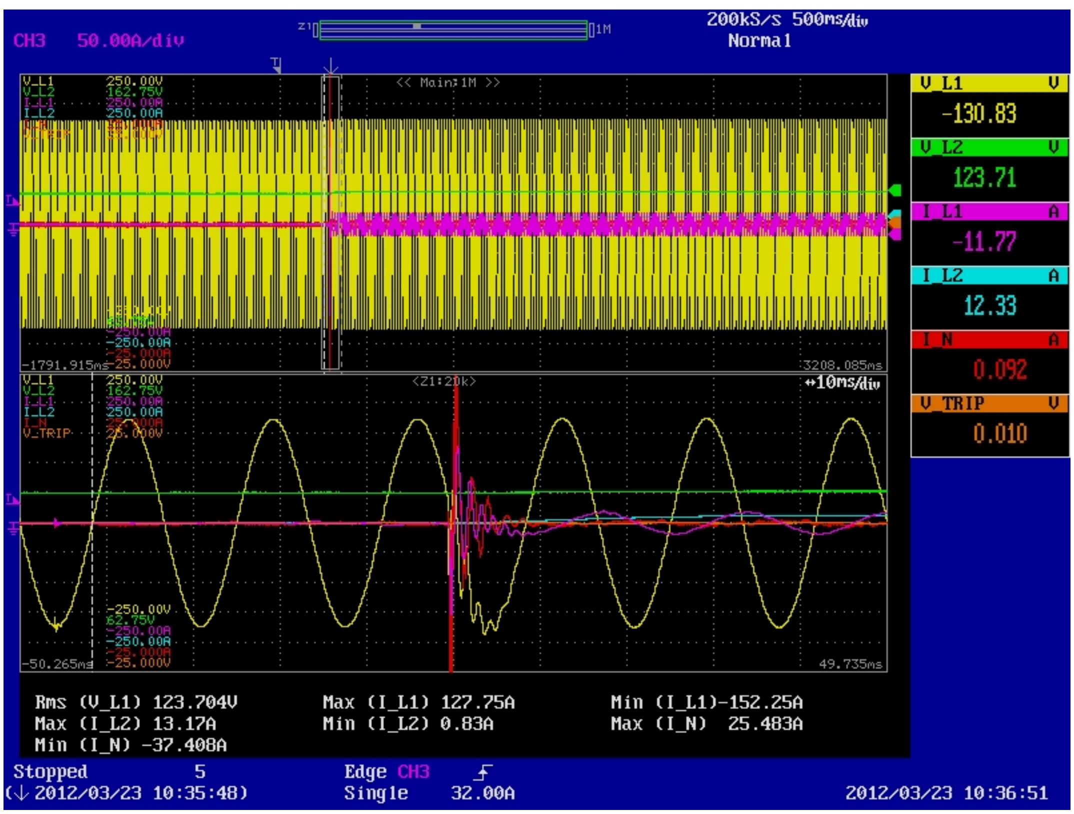
2.4 Synchronization (IEEE 1547.1 Section 5.4 and 6.3)

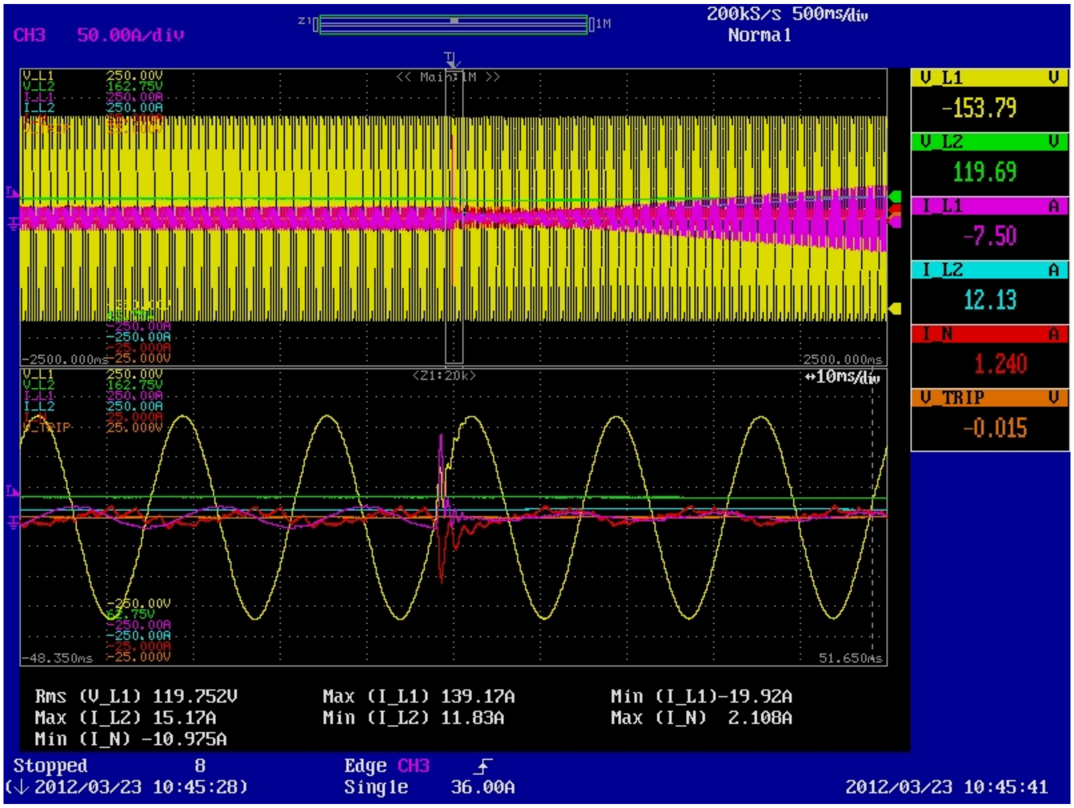
Synchronization of the EUT to the EPS using Method 2 (startup current measurement) from IEEE 1547.1 was tested. Compliance is based on the requirements of the EPS that the unit will connect to, and the assessment of the governing utility or service provider. The results here are intended to provide the utility installer with information to determine whether the EUT would cause flicker concerns on the actual EPS. Synchronization tests were completed using both the grid simulator as well as a utility transformer as the EPS source.

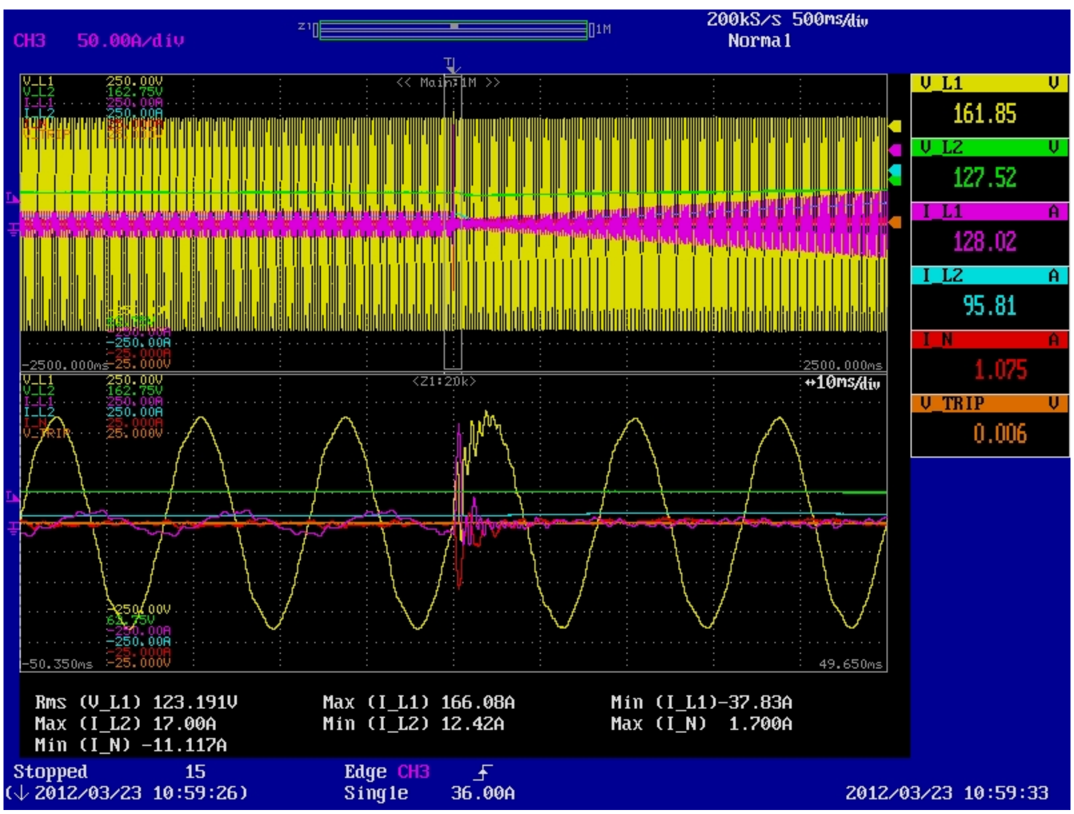
The EUT generally exhibits a startup current transient lasing for less than a ½ cycle (8 ms). In only one case did a current transient magnitude exceed the rated output current of the EUT. Since this transient is non-linear it is difficult to calculate an rms value. Sampling of the current waveform occurred at 200kS/s. For the tests, the peak current value is measured by the scope. Table 5 gives tabulated peak current values obtained for several test trials with various modes of operation. Figure 5 shows the scope image captures of the 4 highlighted tests in Table 5, illustrating some of the largest current transients encountered. All additional scope captures showing each test trial from Table 5 are available upon request.

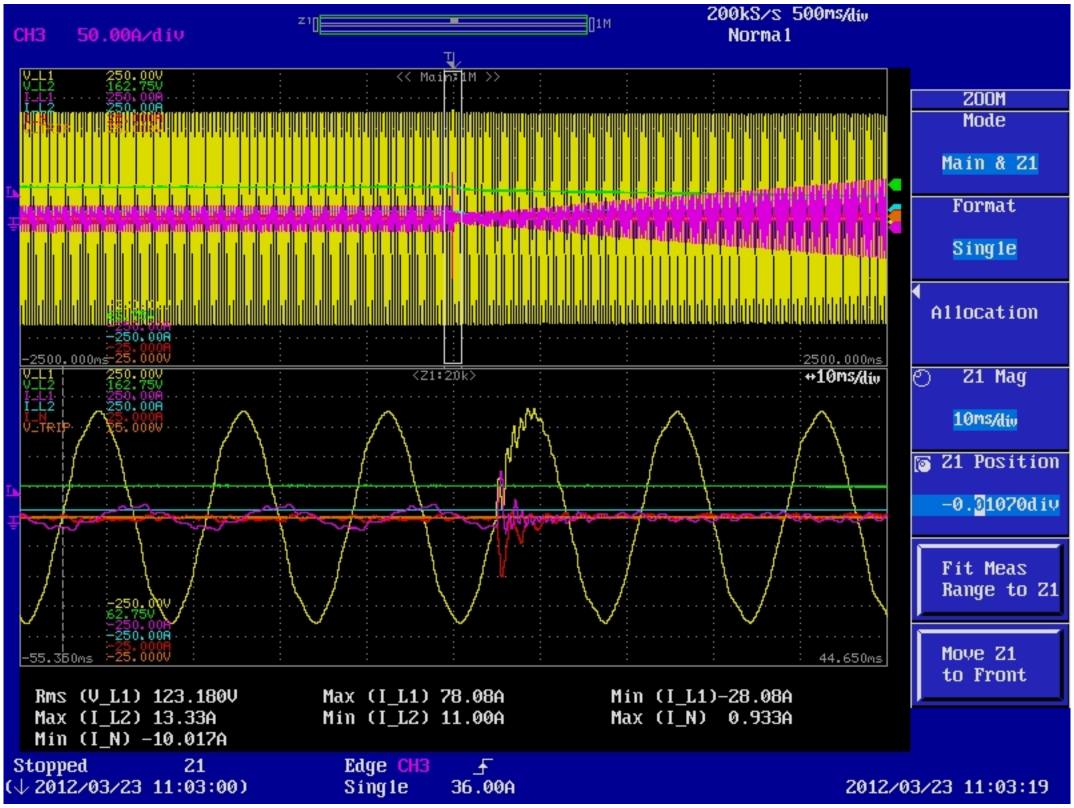
Table 5: Results of Synchronization Tests

EUT Mode	Battery SOC	Sorce	Peak I [A]	Parallel Load
Isolated -> Standby	82	GridSim	-124.42	10.1 ("5")
Isolated -> Standby	82	GridSim	-19.08	10.1 ("5")
Isolated -> Standby	82	GridSim	-152.25	10.1 ("5")
Standby -> Disch 30	80	GridSim	-54.08	130 ("65")
Standby -> Disch 30	79	GridSim	117.42	130 ("65")
Standby -> Disch 30	78	GridSim	139.17	130 ("65")
Standby -> Disch 30	78	GridSim	-50.5	130 ("65")
Standby -> Chrg 15	79	GridSim	-48.58	10.1 ("5")
Standby -> Chrg 15	79	GridSim	-47.33	10.1 ("5")
Standby -> Chrg 15	79	GridSim	-24	10.1 ("5")
Standby -> Chrg 15	79	GridSim	53.83	10.1 ("5")
Standby -> Disch 30	79	Utility Xfmr	54.17	10.1 ("5")
Standby -> Disch 30	79	Utility Xfmr	166.08	10.1 ("5")
Standby -> Disch 30	78	Utility Xfmr	30.08	10.1 ("5")
Standby -> Disch 30	78	Utility Xfmr	-43.67	10.1 ("5")
Standby -> Chrg 15	78	Utility Xfmr	22.67	10.1 ("5")
Standby -> Chrg 15	78	Utility Xfmr	78.08	10.1 ("5")
Standby -> Chrg 15	78	Utility Xfmr	-48.42	10.1 ("5")
Standby -> Chrg 15	78	Utility Xfmr	-48.17	10.1 ("5")
Isolated -> Standby	78	Utility Xfmr	-127.92	10.1 ("5")
Isolated -> Standby	78	Utility Xfmr	63.5	10.1 ("5")
Isolated -> Standby	78	Utility Xfmr	96.33	10.1 ("5")
Isolated -> Standby	78	Utility Xfmr	-113.75	10.1 ("5")




CH3 50.00A/div
200kS/s 500ms/div
Normal
V_L1 -153.79
V_L2 119.69
I_L1 -7.50
I_L2 12.13
I_N 1.240
V_TRIP -0.015
Rms (V_L1) 119.752V
Max (I_L1) 139.17A
Min (I_L1)-19.92A
Max (I_L2) 15.17A
Min (I_L2) 11.83A
Max (I_N) 2.108A
Min (I_N) -10.975A
Stopped 8
(↓ 2012/03/23 10:45:28)
Edge CH3
Single 36.00A
2012/03/23 10:45:41


CH3 50.00A/div
200kS/s 500ms/div
Normal
V_L1 161.85
V_L2 127.52
I_L1 128.02
I_L2 95.81
I_N 1.075
V_TRIP 0.006
Rms (V_L1) 123.191V
Max (I_L1) 166.08A
Min (I_L1)-37.83A
Max (I_L2) 17.00A
Min (I_L2) 12.42A
Max (I_N) 1.700A
Min (I_N) -11.117A
Stopped 15
(↓ 2012/03/23 10:59:26)
Edge CH3
Single 36.00A
2012/03/23 10:59:33



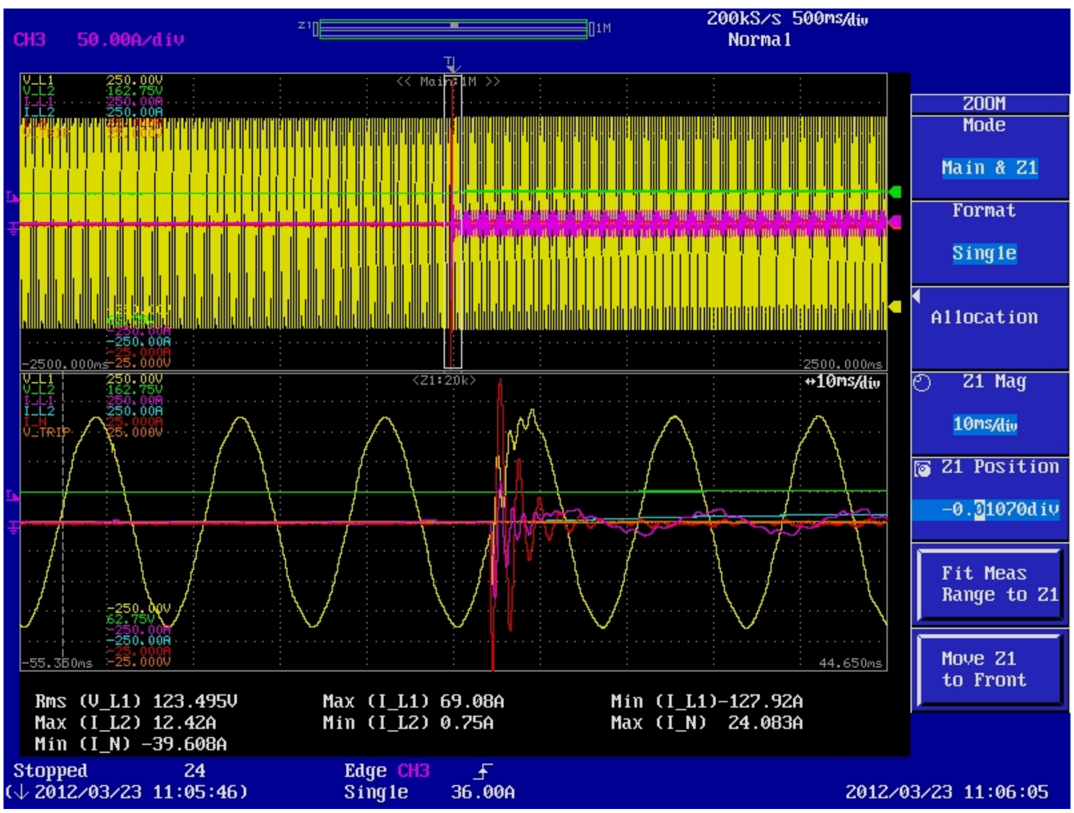


Figure 5: Selected Scope Captures of Synchronization Test Startup Current transients

2.5 Interconnection integrity (IEEE 1547.1 Section 5.5)

This category has three sub-tests; EMI interference, surge withstand, and dielectric test of paralleling device. These tests require specialized test equipment, test setups, and have the potential to damage the equipment under test. In some cases, factory/manufacturer acceptance testing is acceptable for compliance. NREL has not completed these tests.

2.6 Limitation of DC Injection for Inverters (IEEE 1547.1 Section 5.6)

DC injection was tested on CES unit #3. The unit exhibits direct current injection levels in excess of the specified limit in IEEE 1547. Care was taken to investigate the validity and accuracy of the test setup and equipment. It should be noted that the accuracy of the current probes used in this test is 1A. In most cases, this accuracy would allow the argument that the unit may be within the specified limit with this accuracy taken into account. However, the results given here are repeatable and the probe accuracy would have to be subtracted from the measured result every time for this argument to be valid.

Results not meeting the standard limit are highlighted in red text in Table 6. The above-limit DC injection is seen exclusively on L2 (line 2) of the unit. Trials in Table 6 with “N/R” indicate that this test was “quick check” test, using a 10 second average measurement window. IEEE 1547.1 calls for a 5 minute window, which was utilized for some of the tests. The “quick check” tests were done as part of the experimental setup verification, and also to investigate changes to the DC injection after a software update from the manufacturer intended to address the issue.

These tests were made using a calibrated AEMC MR520 AC/DC current probe (specifications included in the Appendix of this document). The experimenter recommends that this test be repeated using a different type of current probe to verify similar results and verify the validity of the measurements made here. Unfortunately, there was no other probe available to make this comparison given the time constraints for completing testing.

Table 6: Results of DC Injection Tests

EUT Mode	Source	Parallel Load [A]	5 min Avg V_L1 rms	5 min Avg I_L1 rms	5 min Avg V_L2 rms	5 min Avg I_L2 rms	5 min Avg I_L1 dc [1]	5 min Avg I_L2 dc [2]	Calc (I_L1 dc / I_rated) * 100	Calc (I_L2 dc / I_rated) * 100	Standard Limit
Disch 30	GridSim	130.1 ("65")	120.74	124.78	120.75	121.174	-0.4925	-1.1390	-0.3940	-0.9112	0.6 ≥ I ≤ -0.6
Chrg 15	GridSim	10.1 ("5")	119.544	67.061	119.517	65.567	-0.2568	-0.6612	-0.2054	-0.5290	0.6 ≥ I ≤ -0.6
Disch 20	GridSim	98.3 ("50")	120.232	82.434	120.18	80.086	-0.4641	-0.9002	-0.3713	-0.7202	0.6 ≥ I ≤ -0.6
Chrg 10	GridSim	10.1 ("5")	120.326	45.16	120.347	44.279	-0.2756	-0.4888	-0.2205	-0.3910	0.6 ≥ I ≤ -0.6
Disch 10	GridSim	55.5 ("28")	120.00	39.83	120.087	38.502	-0.3794	-0.5554	-0.3035	-0.4443	0.6 ≥ I ≤ -0.6
Chrg 5	GridSim	10.1 ("5")	120.056	23.915	120.104	23.431	-0.3286	-0.4401	-0.2629	-0.3521	0.6 ≥ I ≤ -0.6
Disch 30	GridSim	130.1 ("65")	120.778	124.445	120.759	123.596	-0.6992	-1.7920	-0.5594	-1.4336	0.6 ≥ I ≤ -0.6
Disch 30	GridSim	84.5 ("45")	120.541	81.97	120.56	81.49	-0.6630	-1.5900	-0.5304	-1.2720	0.6 ≥ I ≤ -0.6
Chrg 15	GridSim	10.1 ("5")	119.538	67.156	119.488	67.249	-0.5210	-1.2790	-0.4168	-1.0232	0.6 ≥ I ≤ -0.6
Disch 30	GridSim	130.1 ("65")	120.171	126.649	120.219	124.389	0.0547	0.9330	0.0438	0.7464	0.6 ≥ I ≤ -0.6
Chrg 10	GridSim	10.1 ("5")	N/R	N/R	N/R	N/R	-0.5562	-1.2120	-0.4450	-0.9696	0.6 ≥ I ≤ -0.6
Chrg 5	GridSim	10.1 ("5")	N/R	N/R	N/R	N/R	-0.5282	-1.1180	-0.4226	-0.8944	0.6 ≥ I ≤ -0.6
Disch 10	GridSim	49.5 ("25")	N/R	N/R	N/R	N/R	-0.5749	-1.2290	-0.4599	-0.9832	0.6 ≥ I ≤ -0.6
Disch 20	GridSim	84.5 ("45")	N/R	N/R	N/R	N/R	-0.5884	-1.4590	-0.4707	-1.1672	0.6 ≥ I ≤ -0.6
OFF	GridSim	84.5 ("45")	N/R	N/R	N/R	N/R	-0.1022	0.0302	-0.0818	0.0242	0.6 ≥ I ≤ -0.6
Standby	GridSim	84.5 ("45")	N/R	N/R	N/R	N/R	-0.1144	0.0168	-0.0915	0.0134	0.6 ≥ I ≤ -0.6
Standby	GridSim	84.5 ("45")	N/R	N/R	N/R	N/R	-0.0736	0.0340	-0.0589	0.0272	0.6 ≥ I ≤ -0.6
Isolated	GridSim	84.5 ("45")	N/R	N/R	N/R	N/R	-0.0850	0.0142	-0.0680	0.0114	0.6 ≥ I ≤ -0.6
Disch 30	GridSim	130.1 ("65")	N/R	N/R	N/R	N/R	0.0450	1.1200	0.0360	0.8960	0.6 ≥ I ≤ -0.6
Chrg 15	GridSim	10.1 ("5")	N/R	N/R	N/R	N/R	0.1621	-0.6420	0.1297	-0.5136	0.6 ≥ I ≤ -0.6
Standby	GridSim	98.3 ("50")	N/R	N/R	N/R	N/R	0.0810	0.0740	0.0648	0.0592	0.6 ≥ I ≤ -0.6
Chrg 15	GridSim	10.1 ("5")	N/R	N/R	N/R	N/R	0.2640	-0.5068	0.2112	-0.4054	0.6 ≥ I ≤ -0.6
Standby	GridSim	10.1 ("5")	N/R	N/R	N/R	N/R	0.2120	0.0529	0.1696	0.0423	0.6 ≥ I ≤ -0.6
Chrg 5	GridSim	130.1 ("65")	N/R	N/R	N/R	N/R	0.6395	-0.2871	0.5116	-0.2297	0.6 ≥ I ≤ -0.6
Chrg 10	GridSim	84.5 ("45")	N/R	N/R	N/R	N/R	0.5752	-0.4376	0.4602	-0.3501	0.6 ≥ I ≤ -0.6
Chrg 15	GridSim	10.1 ("5")	N/R	N/R	N/R	N/R	0.5836	-0.5429	0.4669	-0.4343	0.6 ≥ I ≤ -0.6
Disch 30	GridSim	130.1 ("65")	N/R	N/R	N/R	N/R	0.3220	-1.1400	0.2576	-0.9120	0.6 ≥ I ≤ -0.6
Standby	GridSim	84.5 ("45")	N/R	N/R	N/R	N/R	0.0578	0.2753	0.0462	0.2202	0.6 ≥ I ≤ -0.6
Disch 30	GridSim	130.1 ("65")	N/R	N/R	N/R	N/R	-0.0570	0.8988	-0.0456	0.7190	0.6 ≥ I ≤ -0.6
ISOLATED	GridSim	10.1 ("5")	N/R	N/R	N/R	N/R	0.1172	0.0545	0.0938	0.0436	0.6 ≥ I ≤ -0.6
ISOLATED	GridSim	10.1 ("5")	N/R	N/R	N/R	N/R	0.1162	0.0610	0.0930	0.0488	0.6 ≥ I ≤ -0.6
Charge 15	GridSim	10.1 ("5")	N/R	N/R	N/R	N/R	-0.7089	0.2109	-0.5671	0.1687	0.6 ≥ I ≤ -0.6
Standby	GridSim	130.1 ("65")	N/R	N/R	N/R	N/R	-0.0698	0.0587	-0.0559	0.0470	0.6 ≥ I ≤ -0.6
Disch 30	GridSim	130.1 ("65")	N/R	N/R	N/R	N/R	-1.3050	0.0690	0.0552	-1.0440	0.6 ≥ I ≤ -0.6
Disch 30	GridSim	130.1 ("65")	N/R	N/R	N/R	N/R	-1.3560	-0.0181	-0.0145	-1.0848	0.6 ≥ I ≤ -0.6
ISOLATED	GridSim	10.1 ("5")	N/R	N/R	N/R	N/R	-0.0730	0.0411	-0.0584	0.0329	0.6 ≥ I ≤ -0.6
Standby	GridSim	10.1 ("5")	N/R	N/R	N/R	N/R	-0.1695	-0.2846	-0.1356	-0.2277	0.6 ≥ I ≤ -0.6
Standby	GridSim	10.1 ("5")	N/R	N/R	N/R	N/R	-0.1815	-0.3007	-0.1452	-0.2406	0.6 ≥ I ≤ -0.6
Charge 15	GridSim	10.1 ("5")	N/R	N/R	N/R	N/R	-0.1010	-1.1260	-0.0808	-0.9008	0.6 ≥ I ≤ -0.6
Charge 10	GridSim	10.1 ("5")	N/R	N/R	N/R	N/R	-0.2042	-1.0622	-0.1634	-0.8498	0.6 ≥ I ≤ -0.6
Disch 30	GridSim	130.1 ("65")	N/R	N/R	N/R	N/R	-0.3499	-1.7130	-0.2799	-1.3704	0.6 ≥ I ≤ -0.6
Disch 20	GridSim	84.5 ("45")	N/R	N/R	N/R	N/R	-0.3154	-1.5380	-0.2523	-1.2304	0.6 ≥ I ≤ -0.6
Standby	GridSim	130.1 ("65")	N/R	N/R	N/R	N/R	0.0265	0.1185	0.0212	0.0948	0.6 ≥ I ≤ -0.6
Isolated	GridSim	130.1 ("65")	N/R	N/R	N/R	N/R	-0.0159	0.0719	-0.0127	0.0575	0.6 ≥ I ≤ -0.6
Disch 30	GridSim	130.1 ("65")	N/R	N/R	N/R	N/R	-0.1263	1.1680	-0.1010	0.9344	0.6 ≥ I ≤ -0.6
Disch 20	GridSim	84.5 ("45")	N/R	N/R	N/R	N/R	-0.1007	1.0330	-0.0806	0.8264	0.6 ≥ I ≤ -0.6

2.7 Unintentional Islanding (IEEE 1547.1 Section 5.7)

The CES unit was tested for its response to islanding conditions. IEEE 1547 requires equipment to trip offline in the event of islanding conditions within 2 seconds. The unit was found to be in compliance with this requirement. In all test cases, the unit consistently trips offline within a maximum clearing time of 368 milliseconds when an islanding condition is present. Results of the unintentional islanding tests for CES Unit #3 are given in Table 7.

The unit was tested using the grid simulator as the EPS and the laboratory load bank in parallel to create a tuned resonant circuit to create the island conditions. While the EUT operates at a power factor very near 1, it does produce measurable reactive power flow. This reactive power flow had to be accounted for in setting up the island circuit, as described in IEEE 1547.1 Section 5.7.1.2. The unit was tested at “Q” factors at or exceeding 1.

Table 7: Clearing Time Results for Unintentional Islanding Tests

CES Mode	Batt SOC	Vrms	Gridsim Set	Irms EPS	Qmeas	Pmeas	Irms CES	Rmeas	Lmeas	Cmeas	Qf Calc	Result
Disch 20kW	59	240.16	119	1.78	0.413	0.092	79.92	19.00	19.69	21.09	1.073	361.5 ms
Disch 20kW	58	240.19	119	1.77	0.426	0.02	77.47	19.00	19.69	21.09	1.073	367.99 ms
Disch 20kW	57	240.14	119	1.76	0.423	0.007	77.44	19.00	19.69	21.09	1.073	351.99 ms
Disch 10kW	57	239.52	119	1.59	0.369	0.094	37.79	9.38	9.06	10.63	1.047	186.84 ms
Disch 10kW	58	239.5	119	1.69	0.39	0.105	37.77	9.38	9.06	10.63	1.047	196.61 ms
Disch 30kW	55	240.55	119	2.82	0.669	0.112	116.94	28.13	28.28	31.09	1.054	196.07 ms
Disch 30kW	55	240.48	119	2.77	0.666	0.04	116.63	28.19	28.28	31.09	1.052	192.82 ms
Disch 30kW	52	240.49	119	2.8	0.673	0.015	116.96	28.19	28.28	31.09	1.052	191.07 ms

2.8 Reverse Power (for unintentional islanding) (IEEE 1547.1 Section 5.8)

This test does not apply to the CES unit under test. The experimenter's understanding is that the CES unit does not utilize reverse power protection or minimum import power flow protection to disconnect in the case of an islanding condition.

2.9 Open Phase (IEEE 1547.1 Section 5.9)

The IEEE 1547.1 test for disconnection time following an open phase event was tested on CES Unit #3. The unit was found to be in compliance with the minimum disconnection time following an open phase. Table 8 gives the trip time results from these tests.

Table 8: Results of Open Phase Tests

EUT Mode	Battery SOC	Clearing Time	ScopeFile
Chrg 0.75	62	74.24 ms	3LPH0000
Chrg 0.75	62	75.09 ms	3LPH0001
Disch 1.5	62	73.39 ms	3LPH0002
Disch 1.5	62	72.44 ms	3LPH0003

2.10 Reconnect Following Abnormal Condition Disconnect (IEEE 1547.1 Section 5.10)

The CES unit will trip offline when abnormal conditions exist (as explored here in various other IEEE 1547.1 tests). It will not, however, reconnect automatically when operated using the manufacturer's PITS software. If, in the future, a programmatic change is implemented that will allow the unit to automatically attempt to reconnect after an abnormal condition, this test should be completed.

2.11 Harmonics (IEEE 1547.1 Section 5.11)

Current harmonics injected into the EPS by the EUT were measured. Harmonics were analyzed both with the grid simulator as the EPS source and with the utility transformer as the source. Table 9 gives the results of the harmonic analysis for several test cases. Harmonics were calculated using the harmonics analysis mode on a Yokogawa PZ4000 power analyzer and a 100kHz, 500A AEMC SR600 AC current probe.

Deviations from the harmonic injection limits are minimal and are highlighted in Table 9. It was found during the testing that the utility EPS (connected to the EUT via 480/240 single phase transformer) contained very high voltage distortion. It is understood that voltage distortion present on the utility EPS used at the DERTF laboratory caused additional current harmonics measured in those tests. Tests with the utility EPS were deemed not valid due to this, and are not included here. Further, IEEE 1547.1 recommends the use of a simulated EPS (such as the one used for these tests at NREL) as a simulated EPS has negligible voltage distortion and thus gives a more accurate measurement of current harmonics created by the EUT.

Table 9: Results of Current Harmonics Tests

		Odd h < 11	Even h < 11	Odd 11 ≤ h < 17	Even 11 ≤ h < 17	Odd 17 ≤ h < 23	Even 17 ≤ h < 23	Odd 23 ≤ h < 35	Even 23 ≤ h < 35	Odd h ≥ 35	Even h ≥ 35	TDD
EPS Source	**EUT Mode**	**4.0%**	**1.0%**	**2.0%**	**0.5%**	**1.5%**	**0.4%**	**0.6%**	**0.2%**	**0.3%**	**0.1%**	**5.0%**
Grid Sim	Chrg 15	1.83%	0.64%	0.46%	0.14%	0.56%	0.53%	0.08%	0.07%	0.03%	0.01%	1.12%
Grid Sim	Chrg 10	1.34%	0.51%	0.34%	0.17%	0.34%	0.46%	0.12%	0.02%	0.03%	0.01%	0.87%
Grid Sim	Chrg 5	1.03%	0.40%	0.53%	0.11%	0.42%	0.28%	0.09%	0.03%	0.02%	0.02%	0.75%
Grid Sim	Chrg 15	1.91%	0.55%	0.44%	0.06%	0.60%	0.63%	0.13%	0.07%	0.03%	0.03%	1.16%
Grid Sim	Chrg 10	1.42%	0.50%	0.29%	0.06%	0.38%	0.33%	0.09%	0.04%	0.03%	0.01%	0.85%
Grid Sim	Chrg 5	1.01%	0.43%	0.58%	0.13%	0.37%	0.26%	0.10%	0.03%	0.03%	0.01%	0.75%
Grid Sim	Disch 30	2.33%	0.42%	1.08%	0.00%	0.33%	0.00%	0.50%	0.00%	0.00%	0.00%	1.39%
Grid Sim	Disch 20	2.23%	0.38%	0.68%	0.06%	0.34%	0.11%	0.29%	0.09%	0.04%	0.01%	1.21%
Grid Sim	Disch 10	1.52%	0.38%	0.85%	0.10%	0.37%	0.08%	0.23%	0.06%	0.03%	0.01%	0.97%
Grid Sim	Disch 30	2.16%	0.40%	1.03%	0.05%	0.38%	0.06%	0.45%	0.04%	0.09%	0.02%	1.26%
Grid Sim	Disch 20	2.04%	0.33%	0.64%	0.02%	0.30%	0.08%	0.27%	0.07%	0.05%	0.02%	1.10%
Grid Sim	Disch 10	1.57%	0.37%	0.76%	0.09%	0.36%	0.11%	0.23%	0.05%	0.03%	0.01%	0.95%

2.12 Flicker (IEEE 1547.1 Section 5.12)

Results from the Synchronization tests along with impedance information of the EPS to which the EUT will connect are needed to determine flicker. No further testing or calculations have been done for this standard.

Distribution Monitoring Unit (DMU),
Model SPDT – for Residential Split-Phase Distribution Transformers

The ARMaDDA Network

NREL has been developing the Advanced Real-time Monitoring and Distribution Data Acquisition (ARMaDDA) network to support research efforts related to the integration of renewable distributed generation into the electric grid. The ARMaDDA network is composed of a variety of remote Distribution Monitoring Units (DMU) and central data collection servers. Each installed DMU records electrical measurement data and transmits it back to the servers through the internet via a provided Ethernet, Wi-Fi, or Cellular connection. These data transmissions form a real-time stream of measurement data similar to those of Phasor Measurement Unit systems as outlined in IEEE Std. C37.118-2005 for synchrophasors. Several models of the DMU exist; supporting a variety of installation locations and communication requirements, the SPDT model is detailed here.

SPDT Model of the DMU

The SPDT model of the DMU is designed specifically for installation on the secondary side of split phase (120/240) distribution transformers. The internal software algorithms have been designed to measure both of the hot legs referenced against the neutral along with all three of these currents. The appropriate total power is also calculated. This hardware and software build of the DMU is also appropriate for metering at the utility panel of a residential customer (120 V and 240 V service).

Representative pictures of this unit are given in Figure 1 and Figure 2. Figure 1 shows one of these units with all of its peripherals attached including voltage probes, Rogowski coils, temperature probe and antenna. Figure 2 gives an example of a typical installation inside the case of a distribution transformer.

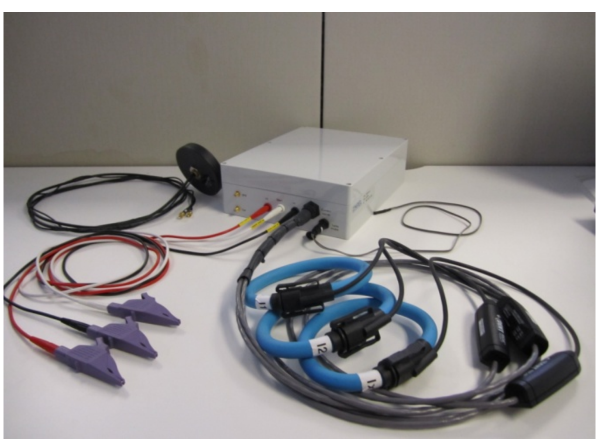


Figure 1: SPDT Model of the DMU with Peripherals

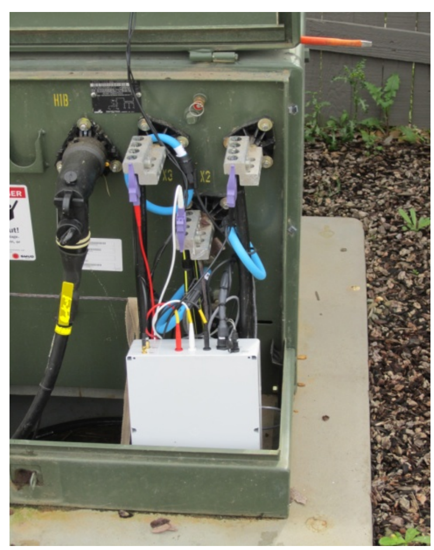


Figure 2: Installed on a Transformer

Output Measurements

This meter is configured to output 6 phasor measurements, a frequency measurement, 6 RMS measurements, 3 power measurements, 2 power factors and 2 temperatures. Detailed descriptions for each of these values are listed below.

Phasor Measurements, compliant to IEEE Std. C37.118-2005 with a GPS clock time reference.

- **V_1** – Magnitude and angle of the leg 1 voltage in volts-rms and degrees respectively. Referenced against the neutral conductor. Nominally 120 V_{RMS} for most installations.
- **V_2** – Magnitude and angle of the leg 2 voltage in volts-rms and degrees respectively. Referenced against the neutral conductor. Since both values are referenced to the neutral **V_2** and **V_1** would normally be 180 degrees out of phase with each other. Nominally 120 V_{RMS} for most installations.
- **V_{12}** – Magnitude and angle of the total transformer secondary voltage in volts-rms and degrees respectively. Measured as the leg 1 voltage referenced against the leg 2 voltage, thus this value will normally be in phase with **V_1**. Nominally 240 V_{RMS} for most installations.
- **I_1** – Magnitude and angle of the leg 1 current in amps-rms and degrees respectively. Polarity is such that for real power flow from utility to customer **I_1** will be in phase with **V_1**.
- **I_2** – Magnitude and angle of the leg 2 current in amps-rms and degrees respectively. Polarity is such that for real power flow from utility to customer **I_2** will be in phase with **V_2**.
- **I_N** – Magnitude and angle of the neutral current in amps-rms and degrees respectively. Polarity is such that for real power flow from utility to customer **I_N** will be 180 degrees out of phase with **V_1**.

Frequency Measurements

- **Frequency** – Frequency of the **V_{12}** waveform. Calculated by measuring the time span between consecutive rising zero crossings and inverting.

RMS Measurements, calculated over an 8 cycle moving window

- **$V_{1\ RMS}$** – Leg 1 voltage in volts-rms. Referenced against the neutral conductor. Nominally 120 V_{RMS} for most installations.
- **$V_{2\ RMS}$** – Leg 2 voltage in volts-rms. Referenced against the neutral conductor. Nominally 120 V_{RMS} for most installations.
- **$V_{12\ RMS}$** – Total transformer secondary voltage in volts-rms. Measured as the leg 1 voltage referenced against the leg 2 voltage. Nominally 240 V_{RMS} for most installations.
- **$I_{1\ RMS}$** – Leg 1 current in amps-rms.
- **$I_{2\ RMS}$** – Leg 2 current in amps-rms.
- **$I_{N\ RMS}$** – Neutral current in amps-rms.

Power Measurements, averaged over an 8 cycle moving window

- **|S|** – Total apparent power flow through the transformer in volt-amps. Implemented as $|\mathbf{S}| = \mathbf{V}_{1\,RMS} * \mathbf{I}_{1\,RMS} + \mathbf{V}_{2\,RMS} * \mathbf{I}_{2\,RMS}$, positive when real power is flowing from the utility to customer and negative if real power is flowing from customer to utility.
- **P** – Total real power flow through the transformer in watts. Implemented using a point-by-point multiplication of the voltage and current waveforms, $P_{INS} = V_1 * I_1 + V_2 * I_2$, and averaging over an 8 cycle moving window. This value is positive when real power is flowing from the utility to customer and negative if real power is flowing from the customer to the utility.
- **Q** – Total reactive power flow through the transformer in volt-amps reactive. Implemented using a point-by-point multiplication of the 90 degree phase shifted voltage and current waveforms, $Q_{INS} = V_1^{+90°} * I_1 + V_2^{+90°} * I_2$, and averaging over an 8 cycle moving window. This value is positive when the customer is consuming reactive power (inductive) and negative when the customer is supplying reactive power (capacitive).

Power Factor Measurements

- **pf** – Total power factor of the transformer, calculated as **P** divided by **|S|**.

- **pf_{DISP}** – Displacement power factor of the transformer, calculated as the cosine of the angle difference between the $\mathbf{V_{12}}$ and $\mathbf{I_1}$ phasors.

Temperature Measurements

- **Meter Internal Temperature** – Temperature measured on the printed circuit board inside the DMU in degrees Celsius.
- **Transformer Housing Temperature** – Temperature measured by DMU external temperature probe, in degrees Celsius. Normally this probe is located inside the transformer housing.

NREL Contact: Jason Bank, Jason.bank@nrel.gov

RōCoil mV™

MilliVolt Output Flex CTs

The DENT RōCoil mV™ Flexible Current Transformers have been designed for accurate measurement of AC current with a safe, millivolt output.

KEY SPECIFICATIONS

4 Lengths	40 cm (16"), 60 cm (24"), 90 cm (36"), 180 cm (72")
4 Window Sizes	13 cm (5"), 19 cm (7"), 26 cm (10"), 52 cm (20")
4 Current Ranges*	16", 1000A, 20A Min 24", 2000A, 40A Min 36", 3000A, 60A Min 72", 6000A, 120A Min
Output Signal	333 mV AC at rated current Max output 1,665 mVAC
Accuracy	< 1% typical at 2% to 500% of rated current

Depending on meter compatibility. See ELITEpro™ and PowerScout™ specifications for details.

ELECTRICAL

All accuracies specified at 20°C (±2°C) with RōCoil mV™ centered on conductor.

Output Signal	(16") 333 mV @ 1000A (24") 333 mV @ 2000A (36") 333 mV @ 3000A (72") 333 mV @ 6000A	1665 mV @ 5000A 999 mV @ 6000A 666 mV @ 6000A
Max Output		1.66VAC
Power Requirement		5-24 VDC, 30 mA Maximum
Wire Color		Red = Power (+) Black = Power (-) White = Signal (+) Green = Signal (-)
Phasing		Arrow Points Towards Load
Phase Shift		< 1° at rated current
Frequency Range		45-600 Hz
Linearity		± 0.2%
Conductor Position Sensitivity		± 2% maximum
Influence of External Field		± 1.5% maximum
Temperature Sensitivity		0.07% per °C

MECHANICAL

Coil Material	Blue thermoplastic rubber, flame retardant UL 94 V-0 rated
Coupling Materials	Polypropylene UL 94 V-0 rated
Case Material	ABS UL 94 V-0 rated
Shielding	85% transducer, 100% output lead
Working Temp	-20 °C to +60 °C (-4° to +140 °F)

SAFETY

Working Voltage	600 Vrms maximum
Dielectric Strength	7400 VAC around coil 600 VAC rated leads
Certifications (CE, ETL Intertek 3168586)	Conforms to UL STD 61010-1 Certified to CAN/CSA STD C22.2 No. 61010

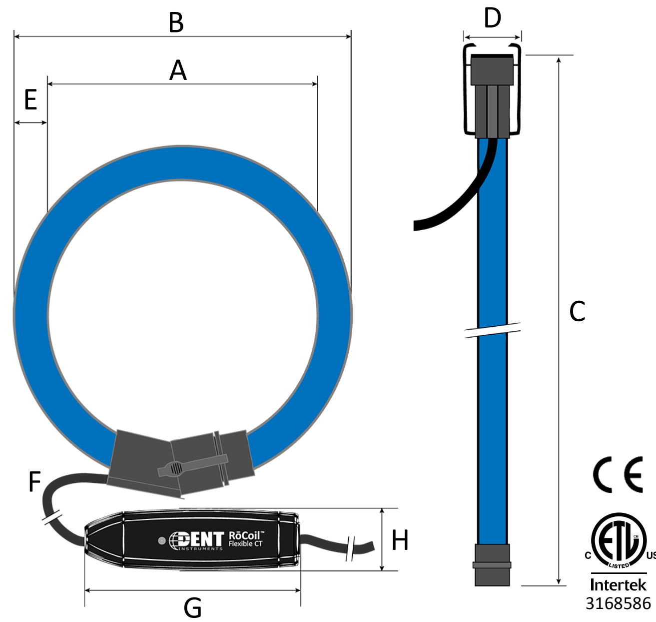
RōCoil mV™ PART NUMBERS*

16" RōCoil mV™	CT-RMV-16-1000	333 mV @ 1000A
24" RōCoil mV™	CT-RMV-24-2000	333 mV @ 2000A
36" RōCoil mV™	CT-RMV-36-3000	333 mV @ 3000A
72" RōCoil mV™	CT-RMV-72-6000	333 mV @ 6000A

Other Sizes, currents, and outputs are available. Please contact the factory for details.

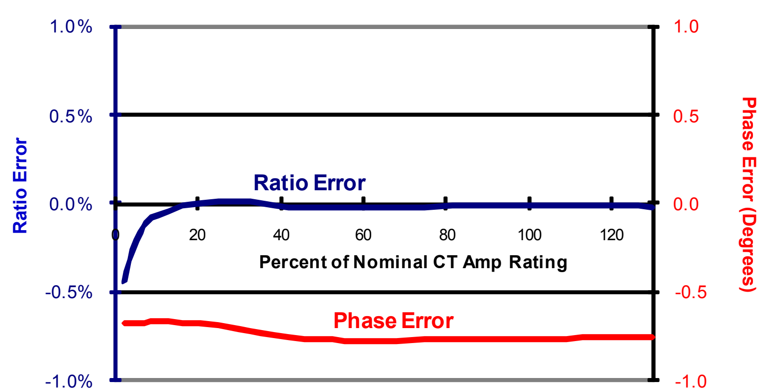
AVAILABLE OPTIONS

*PX-ADPT	Power Cable from Line-Powered **ELITE***pro*™ for powering up to 4 CTs
*PX-US-XFMR	Wall Transformer plus Power Cable capable of powering up to 4 CTs *(US/North America)*
*PX-INT-XFMR	Wall Transformer plus Power Cable capable of powering up to 4 CTs *(International)*



DIMENSIONS

	DIMENSIONS	RMV-16	RMV-24	RMV-36	RMV-72
A	Window Size	13 cm (5")	19 cm (7")	26 cm (10")	52 cm (20")
B	Transformer Coil O.D.	15 cm (6")	21 cm (8")	29 cm (11")	53 cm (21")
C	Transformer Length	40 cm (16")	60 cm (24")	90 cm (36")	180 cm (72")
D	Locking Connector O.D.	3.6 cm (1.4")			
E	Transformer Coil Diameter	1.5 cm (0.6")			
F	Wire Lead Total Length	2 M (80")			
G	Length of mV Module	9.5 cm (3.8")			
H	Width of mV Module	3.2 cm (1.3")			



CONTACT US

DENT Instruments, Inc.
Energy & Power Measurement Solutions

64 NW Franklin Avenue
Bend, Oregon 97701 USA
541.388.4774 | 800.388.0770
www.DENTinstruments.com

© 2010 DENT Instruments, Inc.

rev 031510

INDUSTRIAL BATTERIES Group (Bordeaux)	NS 710 051
MATERIAL SAFETY DATA SHEET (Form: EEC 93/112 Directive) Rechargeable Lithium-ion batteries and cells	
TECHNICAL SPECIFICATION	Revision: d Date: Oct 2009

1. IDENTIFICATION

1.1. PRODUCT: Rechargeable Lithium-ion

Products brand: Lithiated Nickel oxide based VLE, VLM, VLP, VLH and VES Lithium-Ion cells or Lithium-Ion batteries.

Cell IEC designation: Electrochemical system

Electrodes	Lithiated Nickel oxide coated on aluminium foil Carbon coated on copper foil
Electrolyte	Lithiated salt within organic solvent
Nominal voltage	3.6 V

1.2. SUPPLIER

Name :	SAFT S.A (Head office and Management)
Address :	12 rue Sadi Carnot –93170 BAGNOLET France
Phone/Fax :	+33 (0)1 49 93 19 18 /+33 (0)1 49 93 19 50
Factory name :	SAFT Bordeaux
Address :	111/113 Boulevard Alfred Daney-33074 BORDEAUX France
Phone/Fax:	+ 33 (0)5 57 10 64 00 /+33 (0)5 57 10 66 70

1.3. EMERGENCY CALL: www.saftbatteries.com and look for "contact"

In case of emergency (electric shock, leak, exposure or accident),
Call CHEMTREC, day or night. Phone: +1-800-424-9300. (US number)

2. COMPOSITION (base components mass percentage)

2.1. AVERAGE SIZE CELLS WITH ALUMINIUM CASING

c

Materials	%	Plastic	%	Other	%
Nickel	9 – 15%	Polypropylene and polyethylene	6 – 7%	Electrolyte	18 – 20%
Cobalt	1.5 – 3.0%				
Copper	14 – 21%			Carbon	16 – 19%
Aluminium	11 – 13%			Polymer binders	3 – 5%
Lithium	2 – 3%				

Copying is strictly forbidden. Company standard.

2.2. BATTERY COOLING SYSTEM

Depending on type of battery system, it may contain:

- A glycol ethylene based coolant (mass and volume depending on the system) in case of system's including a liquid cooling system,
- A refrigerated coolant (mass, volume and type depending on the system) in case of battery's including an integrated refrigeration unit.

3. HAZARD IDENTIFICATION

3.1. PHYSICAL

The chemical materials components of the cells are contained into a sealed metallic can fitted with a buster disc which opens in case of internal overpressure.

Coolant and refrigerated fluids, if applicable, are contained in hydraulic or refrigerated watertight circuits composed of metallic and/or plastic components.

Cells and batteries are not considered as hazardous as far as they are used in accordance with SAFT recommendations. They could present hazards when a cell has opened or leaked or when the cooling system has leaked.

EYE CONTACT: Contents of an opened cell can cause eye irritation. Dust may cause inflammation of eyelids.

SKIN CONTACT: Electrolyte solution within the cells can cause a skin irritation in case of leak. Contact with lithium and Nickel dioxide may cause allergic dermatitis.

INHALATION: Contents of an opened cell can cause respiratory system and mucosa irritation. Overexposure to Lithium Nickel Dioxide and Lithium Cobalt Dioxide may cause an allergic reaction. If gas is generated during cell disassembly, throat irritation and nauseas may occur. Dimethyl carbonate (within the electrolyte) may be hazardous to loins.

INGESTION: Electrolyte ingestion may cause damages to body tissues and to respiratory and digestive systems. Coolant ingestion may cause abdominal pains, nauseas, vomiting and a loss of conscience.

CARCINOGENICITY: Nickel derivatives are classified in suspected carcinogenic list by the National Toxicology Program of the U.S. Public Health Service.

3.2. CHEMICALS

Electrodes, electrolyte or fluids chemical properties are dangerous only if active materials, electrolyte or fluids are released after a battery crushing or fire on components.

Copying is strictly forbidden. Company standard.

Classification of dangerous matters contained in cells or batteries:

MATTER					CLASSIFICATION			
	Name	Chemical Symbol	Temperature °C (*°F*)	CAS Number	Letter	Hazard identification	Special risk (1)	Caution advice (2)
Electrolyte	Propylene Carbonate	PC	Fusing -50°C (*-58°F*) Ebullition 240°C (*464°F*)	108-32-7	F	Flammable	R11 R34 R36 R37 R38 R41 R43	S16 S24 S25 S26 S28 S36 S37 S38 S39 S41 S45
	Ethylene Carbonate	EC	Fusing 37°C - 39°C (*99°F – 102°F*) Ebullition 246°C (*475°F*)	96-49-1		Irritating		
	Dimethyl Carbonate	DMC	Fusing 2°C - 4°C (*36°F – 39°F*) Ebullition 90°C (*194°F*)	616-38-6	Xi			
	Vinylidene carbonate	VC	Flash point: 18°C (*64°F*) Ebullition 162°C (*324°F*)	872-36-6	C	Corrosive		
	Hexafluorophosphate de Lithium	LiPF6	Non Applicable	21324-40-3				
c Active Matter (+)	Metallic oxide powder (1)	Linilite	>1000°C (*>1832°F*)	198214-24-3			Unclassified	Unclassified
Active Matter (-)	Carbon powder	Cn		1333-86-4			Unclassified	Unclassified

c (1) According to name of the product

Classification of other additional dangerous matters that can be contained in batteries system:

MATTERS					CLASSIFICATION			
	Name	Chemical Symbol	Temperature °C (°F)	CAS Number	Let-ter	Hazard identification	Special risk (1)	Caution advice (2)
Coolant	Glycol ethylene and water mix	EG 1,2-ethanediol C6H602 + H20	Ebullition 197°C *(387°F)* (pure, out of mix)	107-21-1	Xn	Nocif 	R22 R36	S26 S36 S37 S39
Refrigera-ted fluid	Refrigerated fluid	Depending on fluid	Depending on fluid	Depending on fluid	N		R59	S59 S61

Nota : Hazard symbol meaning appears below.

(1) Specific nature risks :

R11	Highly flammable
R20	Harmful by inhalation
R21	Harmful by skin contact
R22	Harmful if swallowed
R34	Causes burns
R36	Irritating to eyes
R37	Irritating to respiratory system
R38	Irritating to skin
R41	Risk of serious damage to eyes
R43	May cause sensitisation by skin contact
R59	Dangerous for the ozone atmosphere layer

(2) Caution advices

S16	Keep away from source of ignition. Do not smoke
S24	Avoid contact with skin
S25	Avoid contact with eyes
S26	In case of contact with eyes, rinse immediately and thoroughly with plenty of water and seek medical advice.
S28	After contact with skin, wash thoroughly.
S36	Wear suitable protective clothing.
S37	Wear suitable gloves.
S38	In case of insufficient ventilation, wear a suitable mask.
S39	Wear eyes suitable protection
S41	In case of fire and/or explosion, do not breathe fumes.
S45	In case of accident, or if you feel unwell, seek medical advice immediately.
S59	Refer to manufacturer for information on recover/recycling.
S61	Avoid release to the environment

Copying is strictly forbidden. Company standard.

4. EMERGENCY FIRST AID

In case of cells or batteries breakage or burst, please evacuate employees from contaminated area and ensure maximal ventilation in order to break-up corrosive gas, smoke and unpleasant odours.

If it occurs, by accident, following measures must be taken :

4.1. INHALATION :

Move to fresh air and ventilate contaminated area. If needed, give oxygen or breathing aid. Consult a doctor immediately.

4.2. SKIN CONTACT :

Remove immediately any contaminated or splashed cloth and wash contaminated areas thoroughly with cold water during more than fifteen minutes. Wash oneself thoroughly with soap and cold water. Do not apply fatty substance. Consult a doctor.

4.3. EYES CONTACT :

Wash immediately and thoroughly with water (eyelids lifted) during 15 to 30 minutes. Don not apply fatty substance. Consult a doctor immediately.

4.4. INGESTION :

If the patient is awaked: let him drink copiously, preferably milk. Do not make the patient vomit. Hospitalize the patient for treatment.

5. MEASURES FOR FIRE FIGHTING

5.1. MEAN OF EXTINCTION

Appropriate : D type fire extinguisher, Argonite, CO_2 dry powder or foam, water.

5.2. SPECIFIC HAZARD

The battery can produce sprayed or decomposed electrolyte smokes with fire if heat exceeds 100°C (212°F) or if it is thrown in fire. Solvents within the electrolyte are flammable liquids and must be kept away from any kind of ignition source.

5.3. SPECIFIC PROTECTION EQUIPMENT

Use an autonomous respiratory device to avoid noxious or toxic smokes or fumes inhalation. Wear protection clothes and equipment to avoid body contact with an electrolyte solution. Cool the battery outside if exposed to fire, to avoid their breaking.

Copying is strictly forbidden. Company standard.

6. MEASURES TO TAKE IN CASE OF ACCIDENTAL DISPERSION

Confine the leak and collect it in a container for its outfall. Recycle according to international, national and local regulations.

7. PRECAUTIONS FOR STORAGE AND HANDLING

IMPORTANT REMARK: Batteries or cells should not be opened, destroyed or incinerated since it may cause fire. Moreover, ingredients contained within could be harmful under some circumstances if exposed.

STORAGE: Store in a cool (in preference under 30°C [86°F]), dry and ventilated area, sheltered from heat, fire, food and drinks. Elevated temperatures can result in shortened battery life. Since short circuit can cause fire, leakage or explosion hazard. Do not leave batteries messy into containers.

HANDLING: Do not short (+) and (-) terminals with metallic goods. Do not mix different types of battery or cells, and do not mix together new ones with old ones. Do not heat directly or braze and do not throw into fire. Such uses can cause leaks or sprayed electrolyte fumes and may cause fire or explosion. In preference, conserve cells and batteries on non conductive plates.

DO NOT APPLY ANY PRESSURE AND DO NOT BEND THE BATTERY: Disassembling a cell or a battery may result in throat irritation caused by gas generation, or in a fire caused by heat generation depending on internal short-circuit kind. Applying a pressure or a any kind of mechanical load may cause deformation of a cell or battery. The sealing section (burst disc) or the watertight part of the cell may be deformed causing electrolyte leakage or a short circuit within the battery with heat generation possibly leading to explosion or a fire.

In every circumstance, follow SAFT recommendations related to maximum current and authorized heat range.

8. EMPLOYEES EXPOSURE CONTROL / INDIVIDUAL PROTECTION

Handle an opened battery only in a well ventilated place.

RESPIRATORY PROTECTION: Not necessary under normal use. In case of incident or after an abusive use, in case of leak or cell opening, use a gas mask that covers the whole face and equipped with ABEK type filters.

EYES PROTECTION: Not necessary under normal use. In case of incident or after an abusive use, in case of leak or cell opening, wear safety glasses with protected side shields or a mask covering the whole face when handling an opened or leaking cell or battery.

HANDS PROTECTION: Not necessary under normal use. Use polypropylene, polyethylene, rubber or Viton gloves when handling an opened battery.

SKIN PROTECTION: Not necessary under normal use. Wear a rubber apron and protective clothes to handle an opened battery.

Copying is strictly forbidden. Company standard.

9. PHYSICOCHEMICAL PROPERTIES

9.1. APPEARENCE

When offered for sale, the Lithium-ion battery or cell described in this material safety data sheet is a sealed unit. It is a manufactured good which does not expose its user to hazardous chemical products contained when used in accordance with manufacturer instructions.

9.2. TEMPERATURE (ambient °C, *°F*)

	Normal use	Occasional use
Storage		-40°C – +65°C *-40°F - +149°F*
Discharging	0°C – +45°C *+32°F - +113°F*	-20°C – +45°C *-4°F - +113°F*
Charging	+5°C – +45°C *+41°F - +113°F*	-20°C – +45°C *-4°F - +113°F*

9.3. SPECIFIC ENERGY : 60 - 150Wh/kg

Nota :

Wh = Nominal voltage x assigned capacity in Ah as defined in applicable IEC standards

kg = Average mass of the battery in kg.

9.4. INSTANTANEOUS SPECIFIC POWER : 400 - 2000W / kg

Nota :

W = 0,5 x nominal voltage x Ip and Ip = current in Ampere, delivered by a fully charged battery and for a voltage that is the half of the nominal voltage after one second

kg = Average mass of the battery in kg.

9.5. MECHANICAL RESISTANCE

As defined in applicable IEC standards.

10. PRODUCT REACTIVITY AND STABILITY

10.1. CONDITIONS TO AVOID ON CELLS OR BATTERIES

- Do not heat above 70°C *(158°F)*,
- Do not incinerate,
- Do not apply an excessive pressure above design resistance,

- Do not bend,,
- Do not swat,
- Do not puncture a hole in,
- Do not make internal or external short-circuit,
- Do not overcharge,
- Do not discharge or leave in self discharge under the minimum specified level,
- Do not expose hydraulic system to a pressure above the maximum specified pressure.

10.2. MATERIALS CONTACT TO BE AVOIDED

Avoid contact with oxidizing agent, acid, base and reducing agent.

10.3. TOXIC, NOXIOUS OR CORROSIVE PRODUCTS

Lithium hexafluorophosphate may react with water in the atmosphere and produce toxic materials including fluorhydric acid. The reaction speed is slow, and decomposition products, fluoric acid included, react very quickly producing fluoric salts. It was confirmed through analysis that never revealed any release of fluoric acid.

Thermal decomposition of the cell may produce release of noxious or toxic fumes of phosphate, phosphate fluoride, phosphoric acid or carbon monoxide (CO).

Thermal decomposition of the cell may produce release of electrolyte liquid and vapor, noxious materials dust and methane.

Abusive use of the battery may lead to coolant leakage.

In case of incident circumstances, combustion of insulating materials of electric circuits, electronic boxes or cards, or cooling circuit components may cause noxious or irritating fumes.

11. TOXICOLOGICAL INFORMATIONS

Skin and eyes irritation. In normal situation, cells and batteries do not contain toxic matters.

12. ECOTOXICOLOGICAL INFORMATIONS

See paragraph 3.

13. INFORMATIONS ON WASTE TREATMENT

Before waste disposal, it is recommended to insulate electrically positive and negative terminals.

13.1. INCINERATION

The battery must not be incinerated or destroyed by end users but only by experienced professionals in approved facilities.

13.2. WASTE DISPOSAL

Do not leave batteries messy into containers.

Do not dispose in non-authorized waste facilities.

INDUSTRIAL BATTERIES Group (Bordeaux)	NS 710 051
MATERIAL SAFETY DATA SHEET (Form: EEC 93/112 Directive) Rechargeable Lithium-ion batteries and cells	
TECHNICAL SPECIFICATION	Revision: d Date: Oct 2009

13.3. RECYCLING

Send to authorized recycling facilities, through regulation authorized carriers.

14. INFORMATIONS REGARDING TRANSPORTATION

14.1. UNITED NATIONS CLASS

Lithium cells and batteries are listed in the hazardous materials list according to UN Recommendations on Dangerous Goods Transportation.

Class UN N° :	3480
Hazard classification :	9
Packaging :	Group II

14.2. INTERNATIONAL AGREEMENTS

By Air International:	IATA
By Sea International:	IMDG
European road transportation:	ADR (road)
European rail transportation:	RID

15. REGULATORY INFORMATIONS

Lithium-ion cells and batteries transportation is regulated by the United Nations Organization, as described in the UN Recommendations for Dangerous Goods Transportation, Model regulation and Manual of Tests and Criteria §38.3.

16. FURTHER INFORMATION

Information contained in this document were gathered from sources considered to be sure and are, following our information, reliable and accurate, at the time of the document issue. However, neither exhaustivity nor perfect reliability cannot be guaranteed. Information does not imply implicit or specific warranty of it.

Contained information only relates to specified products and may be not valid with presence of other associated or manufactured products. It is under the user's responsibility to ensure that the delivered information is suitable for the particular usage he is looking forward to do.

SAFT disclaims all responsibility for loss and damages which could result directly or not, from the herein-contained information use.

Additional information is available by writing or calling appropriate phone numbers as mentioned above.

Copying is strictly forbidden. Company standard.