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Sacramento Municipal Utility District

2500 R Street Integrated Energy Management Use Case Report

ADM Associates, Inc.

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Sacramento Municipal Utility District

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Prepared by:

ADM Associates, Inc.
3239 Ramos Circle
Sacramento, CA 95827

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1. Executive Summary

2500 R Midtown is a single family development in midtown Sacramento located at 2500 R Street. It is the first Net Zero Energy community in Sacramento's midtown district. This is made feasible by combining LEED certified efficiency measures with a built-in solar energy system through the SMUD SolarSmart Homes program. Funding provided by a federal Smart Grid grant made this project possible. Each of the development's 34 homes contains its own Sunverge Solar Integration System (SIS)—an innovation that makes solar energy more grid friendly than ever before. It not only generates solar energy through photovoltaic (PV) cells, but also stores this energy in lithium-ion batteries so that it may be held in reserve and consumed when energy demand is the most critical. The SIS is one component of the Integrated Energy Management Solution (IEMS), a comprehensive package that also consists of a programmable communicating thermostat (PCT) and remotely switchable outlets called modlets supported by ThinkEco. The system also gives residential homeowners secure online access to their personal energy profile through an SIS web portal, which allows them to track and manage their electricity use and to change settings.

The objective of the study was to verify that the SIS and IEMS could be controlled to provide energy flow to the customer and the grid in pre-defined modes of operation that are beneficial to the utility and the customer. The various modes are classified as use cases and include: Load Shifting, Fleet Operation in Aggregate, Uninterruptable Power Source (UPS), Power Quality, PV Firming, and Regulation.

Of the 34 homes in the new development, 10 customers signed up to be on a special rate that allows them to take advantage of lower rates outside of on-peak hours. These 10 customers participated in SMUD-announced conservation days by taking advantage of the advanced controls available through the SIS and IEMS. In the residential sector, load shifting on conservation days is an approach to demand reduction. Load shifting also occurred on non-conservation weekdays in the summer, but to a lesser extent. A variety of metering was conducted to verify the operation of the IEMS and to quantify the demand savings and other use case benefits of the system.

Load shifting on conservation days at the participating homes was achieved through the following series of activities:

- Using the SIS to store PV power during mid-day and sending this power to the grid during the on-peak period;
- Lowering the cooling set point prior to the on-peak period to pre-cool the house;
- Raising the cooling set point during the on-peak period to reduce air conditioning use; and
- Using the modlets to turn off power to selected loads.

Load shifting on non-conservation weekdays provided 1.35 kW of savings on average from the IEMS. The average incremental IEMS demand savings peaked at 2.80 kW during the first hour and averaged 1.31 kW for the entire on-peak period on conservation days compared to non-conservation weekdays for the participating houses. The average total IEMS load shifting on conservation days compared to no IEMS peaked at 4.38 kW and averaged 2.66 kW for the entire on-peak period. The peak and average demand savings during the on-peak period for different day types per control strategy are presented in Table 1.

Table 1 Average Demand Savings On-Peak Period by Control per House

	Non-Conservation Weekday Demand Savings, kW	Incremental Conservation Day Demand Savings, kW	Total Conservation Day Demand Savings, kW[1]
IEMS, Maximum	1.68	2.80	4.38
IEMS, Average	1.35	1.31	2.66
SIS & PV, Maximum	1.49	2.27	3.87
SIS & PV, Average	1.26	1.07	2.47
PCT, Maximum	na	1.16	1.16
PCT, Average	0.09	0.35	0.19
Modlet, Maximum	0.00	0.003	0.004
Modlet, Average	0.00	0.003	0.004

Although operation of the PCTs did shift air conditioning load, review of control system data showed that the cooling set points were not always set as scheduled, and significant blocks of data were missing. Modlets provided very small savings due to the low load appliances plugged in and variability of use of these loads.

Fleet operation was confirmed, as all 10 participating customers were operated as a fleet. Analysis showed that they all contributed to the average load shifting savings on conservation and non-conservation days.

A critical load panel in the house is wired so the SIS can maintain power to some of the homeowner's loads in the event of a grid power failure. As no confirmed grid power outages occurred prior to the scheduled testing, the uninterruptable power source mode was tested by simulating a grid power failure. When the breaker connecting the SIS to the grid was disconnected, the critical load panel appliances continued to operate. After the scheduled simulation, one other successful use of the UPS occurred when service was disconnected from one home after a customer did not pay their electric bill.

The SIS maintained power quality to the grid in accordance with SMUD interconnection guidelines. The only minor deviation from the power quality guidelines occurred during the UPS test when the SIS was disconnected from the grid and the voltage total harmonic distortion

[1] The sum of maximum demand savings from non-conservation and incremental conservation days may not equal the total conservation day value because they occur on at different times during the on-peak period. The averages on the total conservation day may not equal the sum of the other two day types since incremental conservation day demands are referenced to the highest 3 of 10 non-conservation weekdays whereas the non-conservation weekday demands are averaged across all days of that type.

parameter was slightly exceeded, although this deviation is not conclusive since it was within the uncertainty of the measurement error bounds.

The SIS is functioning according to Sunverge's algorithm to provide PV firming. The current control settings provide firming on the time frame of one minute. It is suggested that for future testing the smoothing period should be increased to level out the power flow to the grid during times of partly cloudy / partly sunny conditions.

Only one simulated regulation test occurred prior to the deadline of this report and it showed very promising results. The simulated regulation test signal had some timing problems due to the simulation tool. Despite this issue, it appeared that the response time of the SIS units were less than four seconds. The responses were within 100 W of the requests. It is recommended that additional regulation testing should be conducted to verify responses.

Many of the SIS use cases have competing resources or goals. For the purposes of this evaluation, testing for each use case was conducted independently. The SIS does have the capability to operate multiple use cases simultaneously through layering of programs based on priority and the ability to reserve portions of the battery for different use cases. Some modes of operation have competing interest in the use of battery storage allocation. When establishing the operation of the SIS, a strategy must be developed to identify which modes are the most important or financially rewarding to the invested party.

The following recommendations are provided for consideration.

- Further investigate the PCTs to determine whether they are able to schedule the control of the cooling set point in a reliable manner.
- If possible, consider providing a complete and time-consistent dataset of the PCT cooling set points for analysis.
- Work with Sunverge to develop longer PV firming control settings.
- Identify if there are any standards for PV firming.
- Conduct additional regulation testing to verify responses and consider approaches for providing larger requested changes.
- Determine the priority level of these use case strategies.
- Investigate the spinning and non-spinning reserve capability the SIS has and conduct tests to verify.

2. Project Description

2500 R Midtown is a single family development in midtown Sacramento located at 2500 R Street. It is the first Net Zero Energy community in Sacramento's midtown district. This is made possible by combining LEED certified efficiency measures with a built-in solar energy system (SMUD SolarSmart Homes program). Each of the 34 homes contains its own Sunverge Solar Integration System (SIS)—an innovation that makes solar energy more grid friendly than ever before. It not only generates solar energy through photovoltaic (PV) cells, but also stores this energy in lithium-ion batteries so that it may be held in reserve and consumed when energy demand is the most critical. The system also gives residential homeowners secure online access to their personal energy profile through an SIS web portal so they have an easy way to track and manage their electricity use and change settings.

This project employs Sunverge's Solar Integration System (SIS), an energy storage and managed control system using PV generation, with demand responsive load controls and a customer home energy management system (collectively the Integrated Energy Management Solution, IEMS), in order to test utility scale benefits such as renewable resource firming, regulation support, voltage support, and renewable energy time shifting of the PV generation. These systems as a whole are designed to provide individual customer benefit by optimizing whole house energy consumption, while also providing the ability to shift PV generation during the off-peak to on-peak consumption in order to avoid time of use (TOU) or critical peak pricing (CPP) events (where applicable). In addition, Sunverge's integrated energy management system has the ability to act as an aggregated fleet of devices in order to provide the aforementioned utility scale benefits.

SMUD partnered with 2500 R Group, LLC (a joint venture between Sunverge Energy, Inc. and Pacific Housing Inc.) to complete the project. 2500 R Group installed Sunverge SIS systems and ThinkEco products while SMUD contracted with ADM Associates, an independent evaluator, to assist SMUD and 2500 R Group in developing the research design, sample and control designs, data requirements and analysis methods.

This project provides a benchmark in determining whether combined energy storage, distributed generation, and demand response can be controlled and aggregated in order to provide multiple grid management resources. In addition, this project tests whether these resources can be simultaneously used on the customer side to manage electricity use and minimize costs. The value propositions associated with distributed assets such as these have not been proven within the utility industry and many logistical and operational questions were addressed. This project allowed SMUD to implement, evaluate, and advance these technologies as part of its broader SmartSacramento initiative.

SMUD customers on the standard non-electric heating rate pay a flat rate of $0.1033/kWh for the base amount up to 765 kWh/month during the summer months. Over that they pay $0.1836/kWh. Customers that live in this development and sign up for a special time of use rate pay only $0.064/kWh for the base amount and $0.161/kWh above the base amount during the summer months. However, on non-holiday weekdays during the 4:00 p.m.-7:00 p.m. on peak hours the rate is $.28/kWh and jumps to $.75/kWh on conservations days called by SMUD.

The Project:

The development was built in three phases of construction with a total of 34 houses. The houses range in size from 1,251 sqft. to 1,828 sqft. The development consists of 28 two-story houses and six three-story houses. The houses were occupied as completed from December 2013 to September 2014. The last house, which was the developer's demo house, is currently on the market for sale. Full installation of the Sunverge SIS systems and ThinkEco products (the IEMS) was completed by June 30, 2014 in accordance with a federal Smart Grid grant.

The exterior of the model houses are shown in Figure 1 and Figure 2. These homes are standalone with narrow yards between them which contain utilities and the SIS units.

Figure 1 Two-Story and Three-Story Model Homes.

Figure 2 Row of Houses (PV on Roof) and Narrow Side Yard Between Houses.

The Sunverge integrated energy management solution employed for this project consisted of three components which were installed in all 34 houses. They are:

1. Sunverge's SIS (see Figure 3) consisting of solar PV panels[2], lithium-ion battery storage, inverter, and integrated controls. The PV panels are rated at 2.25 kW output, inverter output is rated to 4.5 kW, and the battery storage at 11.7 kWh[3].

2. Programmable Communicating Thermostat (PCT): Carrier ComfortChoice® Touch[4] with Zigbee communication protocol to a ThinkEco Ethernet gateway. Remote access is enabled through the ThinkEco web portal.

3. Modlet[5]: a remotely controllable 120V wall outlet dual receptacle (see Figure 4) with Zigbee communication protocol to a ThinkEco Ethernet gateway. Remote access is enabled through the ThinkEco web portal.

Figure 3 Sunverge SIS unit (Door Open) on the Right and Air Conditioning Unit on the Left.

[2] The SIS can be integrated with various forms of generation, though PV is the most common use at this time.
[3] SIS specs at: https://sunverge.zendesk.com/home, Datasheet: 135149SUN_Datasheet_150V_PR02.pdf
[4] Additional information at: http://www.comfortchoice.com/products.aspx
[5] Additional information at: http://www.thinkecoinc.com/products/the-modlet/

Figure 4 Modlet Plugged into Wall Outlet with Appliance Cord.

Customers were provided the opportunity to sign up for special SMUD rates. These TOU-CPP (time of use, critical peak pricing) rates provide the customer the ability to utilize load shifting capabilities of the IEMS. Ten households signed up for the TOU-CPP rate. Those customers were then eligible to participate in conservation days called by SMUD.

Conservation days can occur on any summer (June 1 through September 30) non-holiday weekday, but typically on very hot days when the grid system demand is high. The on-peak period for conservation days runs from 4:00 p.m. to 7:00 p.m.

Use Cases:

This report investigates some of the operating characteristics of the integrated energy management solution, particularly the SIS. The SIS can be controlled to operate in various modes. Each mode has a specific algorithm to provide certain desirable responses that benefit the utility, the customer, or both. This report only investigates whether these modes of operation are functional and does not attempt to identify whether they are set to provide optimum results.

The list of use cases investigated is as follows:

- Load Shifting
- Fleet Operation in Aggregate
- Uninterruptable Power Source (UPS)
- Power Quality
- PV Firming
- Regulation

Metering Methodology:

ADM used a variety of metering in order to accomplish the quantitative investigation. ADM installed independent metering on several houses in order to verify data being collected by the SIS, PCT, and modlets. These meters were installed at a sample of three customers (#S63, S71, & S43, collectively referred to as "Group A"), and a sample of five customers (#S52, S45, S69, S66, & S51, collectively referred to as "Group B"). The list of metering points for these houses is provided in Table 2, and the arrangement of the meters that compare the data collected by the SIS units is diagramed in Figure 5. Pictures of the metering equipment can be found in Figure 6 through Figure 8.

Table 2 List of ADM Metering Points.

# of Houses	Group	Measurement	Metering Equipment	Units	Data Interval
3	A	AC Power Measurement from SIS To and From Main House Panel (Grid), Line 1 & 2	AEMC PEL 103, Power Energy Logger	V, A, kW, Hz, THD%	1 second
3	A	AC Power Measurement To Critical Load Panel, Line 1 & 2	AEMC PEL 103, Power Energy Logger	V, A, kW, Hz, THD%	1 second
3	A	Voltage (dc) from PV Panels to SIS	Hobo 4-Channel Logger, w/ voltage divider	Vdc	1 minute
3	A	Current (dc) from PV Panels to SIS	Hobo 4-Channel Logger, w/ 4-20mA output CT	Idc	1 minute
3	A	Energy Use of HVAC Fan Unit	WattNode, & TandD wireless pulse logger	kWh	1 minute
3	A	Temperature in house at Thermostat	TandD wireless Temperature logger	ºF	1 minute
8	A & B	Energy Use of Air Conditioner	WattNode, & TandD wireless pulse logger	kWh	1 minute
1	Volunteer from Group A	Energy Use of Appliances	WattNode, & pulse logger, Quantity=2	kWh	1 minute

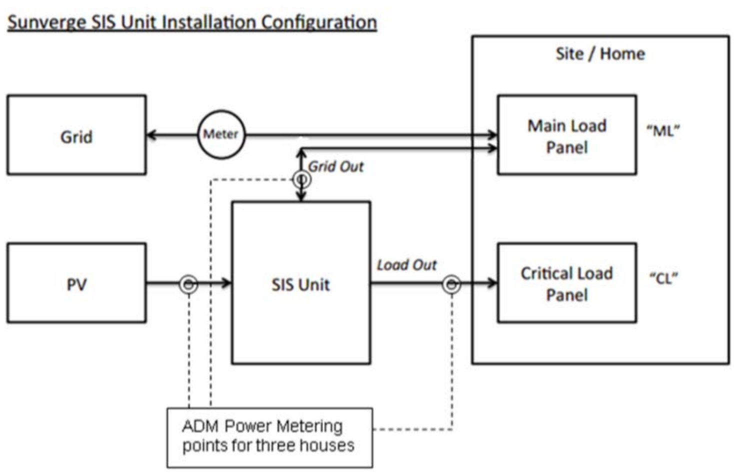

Figure 5 Arrangement of Power Meters around SIS Installed by ADM at Three Houses.

Data from the SIS system are collected by Sunverge in approximately 4-12 second intervals. Only a small portion of the fine time resolution data was used for analysis, as only small sets of data were needed for special use case analysis. Data from the SIS (most in 15-minute intervals) included power measurements from both power lines to and from the main panel (connection to grid), to the critical load panel, from the PV panels, the main meter connection to the house (delivered and received), battery state of charge, and line frequency. Additionally, PCT for a selection of sites included 1-minute data for indoor temperature at the thermostat, heating and cooling set points, unit runtime, system operating mode, and fan mode. Sunverge also provided power use data for the modlets of the customers on the TOU-CPP rate.

Figure 6 Box Mounted in Garage Containing Power Meters, Loggers and Laptop for Remote Data Collection.

Figure 7 Air Conditioning Power Meter (inside) and Wireless Pulse Logger (outside).

Figure 8 Wireless Temperature Logger Mounted Next to Carrier Thermostat (PCT).

SMUD also provided whole house 1-hour interval data delivered to and received from the main meter.

A description of the monitoring equipment and accuracies is provided in Appendix A.

3. Load Shifting

One of the primary goals of this study is to determine the load shifting capacity provided by the Integrated Energy Management Solution (IEMS) to the houses participating in this project. Load shifting is traditionally considered to be reducing or turning off loads during a prime on-peak period and increasing them or turning them back on during a less critical time or off-peak period. This project expands the term Load Shifting to include on-site power generation. All 34 homes received the SIS-plus package. The homeowners of ten of these houses also signed up for SMUD's residential Smart Pricing Option C, Optimum Off-Peak Plan (aka TOU-CPP) rate. For this sub group of customers load shifting occurred on non-holiday summer weekdays from June 1st through September 30th. The on-peak period for those days is between 4:00 p.m. and 7:00 p.m. SMUD can designate up to 12 conservation days during the summer, but typically only calls such events on very hot days when the grid system demand is high. Non-conservation days are any summer days not classified as conservation days.

IEMS Goals:

Demonstrate the ability of the IEMS to implement peak load management and bill savings on non-conservation and conservation days for customers signed up on TOU-CPP rates.

- On non-conservation days, offset demand and reduce some demand by using IEMS. Zero net imports. Reserve the majority of battery capacity in SIS for UPS (uninterrupted power supply).
- On conservation days, offset *and* reduce demand and load at the homes by using IEMS. Zero net imports. Maximize net exports by reserving only some battery capacity in the SIS for UPS.

The Sunverge team set parameters and controls to target these objectives. In meeting these objectives, Sunverge would demonstrate the ability of the SIS to shift renewables' time of use by capturing the solar energy generated by PV during off-peak periods and charging the battery for later use or exporting the energy to the grid during peak periods. For the homes on the TOU-CPP rate, the PCTs were set to increase the load shifting over that which is supplied by the SIS alone. On non-conservation days, equipment was set to slightly reduce load during on-peak period without impacting customer comfort, and on conservation days the equipment was set to reduce load with some impact on customer comfort and behavior during on-peak period. Additionally the modlets were turned off on conservation days during the on-peak period.

IEMS Test Plan:

Details of the test plan are as follows:

For TOU-CPP customers, on Conservation Days and Non-Conservation Days, the goals are to reduce loads in the home and offset demand during the peak period. On Conservation Days, a more aggressive strategy for achieving these goals is implemented compared to Non-Conservation Days.

On both Conservation Days and Non-Conservation Days, the IEMS prepares for the peak period by using PV power to charge the battery in the early part of the day. When the battery becomes full, excess PV power is sent out of the SIS to power loads in the home or sent out to the grid.

On Non-Conservation Days, during the peak period from 4:00 p.m. to 7:00 p.m., the IEMS takes the following actions:

- Increase the temperature set point in the home by 1 degree F to reduce HVAC usage.
- Export some power but primarily offset demand in the home by using PV and battery energy to power loads.
- Reserve battery capacity for UPS and backup power functions.

On Conservation Days, the IEMS takes certain actions just before and during the peak period:

- From 2:00 p.m. to 4:00 p.m., pre-cool the home by decreasing the temperature set point by 3 degrees F.
- From 4:00 p.m. to 7:00 p.m., offset and reduce load in the home by:
    - Increasing temperature set point in the home by 3 degrees F above the scheduled set point (for a total of 6 degree F increase at 4:00 p.m. from the pre-cooling set point) to significantly reduce HVAC usage.
    - Turning off modlets to reduce plug loads.
    - Offsetting demand in the home using PV and battery energy to power loads, and export additional power to SMUD.
    - Reserving some battery capacity for UPS, but prioritize exporting power to SMUD during the peak period.

During the summer of 2014 there were 10 customers that were signed up for the TOU-CPP rate and there were eight conservation days. Although most customers participated in all conservation days, a few customers signed up later than others and missed the first event. Table 3 lists the participation by conservation event day.

Table 3 List of Conservation Days by Customer Participation

Customer #	July 1	July 25	July 29	July 30	Aug 1	Sept 11	Sept 12	Sept 16
S43	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
S58	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
S60	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
S65	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
S46	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
S70	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
S56	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
S59	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
S51	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
S48	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

M&V Evaluation:

The evaluation looks at load shifting for the following control equipment and conditions:

1. IEMS load shifting on non-conservation weekdays
2. IEMS load shifting on conservation days relative to non-conservation weekdays (i.e. incremental conservation day demand savings)
3. IEMS load shifting on conservation days relative to no IEMS (i.e. total conservation day demand savings)
4. SIS & PV load shifting on non-conservation weekdays
5. SIS & PV load shifting on conservation days relative to non-conservation weekdays (i.e. incremental conservation day demand savings)
6. SIS & PV load shifting on conservation days relative to no SIS or PV (i.e. total conservation day demand savings)
7. PV generation load profiles on conservation and non-conservation weekdays
8. SIS (battery only) load shifting on non-conservation weekdays
9. SIS (battery only) load shifting on conservation days relative to non-conservation weekdays (i.e. incremental conservation day demand savings)
10. SIS (battery only) load shifting on conservation days relative to no SIS (i.e. total conservation day demand savings)
11. PCT air conditioning load shifting on conservation days relative to non-conservation weekdays
12. Modlet load shifting on conservation days relative to non-conservation weekdays

Three sources of data were available for the measurement and verification evaluation: utility house meters, IEMS meters and system status, and evaluation contractor's installed meters. As will be discussed later the metered data from the IEMS were validated using the evaluation contractor's independent meters. The SMUD residential data were available from grid Smart Meters from the date the customers moved in and included both delivered and received energy in 1-hour intervals. Data from the IEMS meters were requested in 15-minute intervals. Power measurements from the independent meters were used in 15-minute intervals.

The load shifting evaluation focused on the 10 houses on the TOU-CPP rate. The load profiles of appliances and equipment in the TOU-CPP rate houses were averaged for the eight conservation days and the 77 non-conservation weekdays and are charted in Figure 9. This is provided just to show typical house load profiles for these customers. The conservation day loads are higher because they are hotter than average days. The average conservation day profile also shows a significant drop in load during the SMUD on-peak period, which is the result of the effective operation of the IEMS. The two components of the IEMS that contribute to the drop during the on-peak period are the PCT and the modlets.

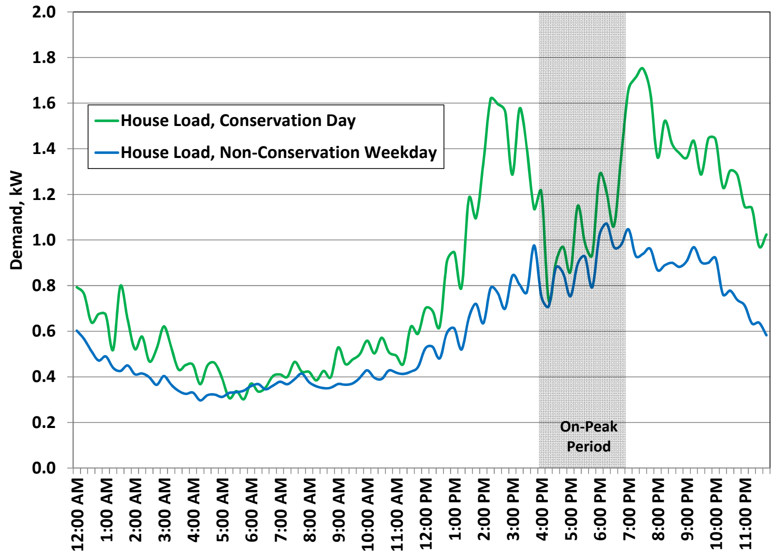

Figure 9 House Loads on Conservation and Non-Conservation Weekdays for TOU-CPP Homes.

Equations for calculating some of the key parameters are given here.

Net Utility Load = SMUD meter delivered – SMUD meter received (Eq. 1)

Net Utility Load = SIS meter site power in – SIS meter site power out (Eq. 2)

Total House Load = Main Panel Load + Critical Panel Load. (Eq. 3)

Note that the first equation for *Net Utility Load* uses SMUD meter data, and the second uses data collected by the SIS. It is the same calculation but evaluated with different data sources.

There are two breaker panels that supply power to the loads in the house. The critical load panel is directly metered by the SIS. The load of the main panel is not directly metered, but there is meter data to determine the main panel load.

Main Panel Load = Net Utility Load + SIS grid out (Eq. 4)

Keeping in mind that SIS grid out is a net of SIS grid out and SIS grid in and should be positive when supplying power to the grid. This then gives us:

Total House Load = Net Utility Load + SIS grid out + Critical Panel Load. (Eq. 5)

The savings for the SIS and PV generation is shown in the following equation and does not include savings associated with the PCT (air conditioning) or modlets.

SIS & PV Savings = Total House Load – Net Utility Load (Eq. 6)

Substituting you get:

SIS & PV Savings = SIS grid out + Critical Panel Load *(Eq. 7)*

To separate out just the SIS load shifting from the battery, you subtract the PV generation or savings. The PV generation is the power output by the panels and adjusted for the inverter efficiency. A small correction of 0.985 included as discussed in chapter 9.

*PV Savings = PV power * Inverter Efficiency * 0.985* *(Eq. 8)*

Subtracting the PV savings leaves the SIS battery only load shifting:

SIS Savings = SIS grid out + Critical Panel Load – PV Savings *(Eq. 9)*

3.1 IEMS Load Shifting on Non-Conservation Weekdays:

This section starts off with presenting the evaluation results of the load shifting for the IEMS on non-conservation weekdays. Demand savings (or load shifting) was first determined as a total aggregated impact of the IEMS on the utility meter. Non-conservation weekdays shift load off the on-peak period but not as aggressively as on conservation days. The comparison group is the 24 houses in the development that are not on the TOU-CPP rate. Since the houses in the comparison group also have PV generation that component must also be added. The savings is as follows.

IEMS Savings = Net Utility Load (non-TOU-CPP house) – Net Utility Load (TOU-CPP house) + PV Savings *(Eq. 10)*

The average house IEMS savings profile is shown in Figure 10 and is highest during the on-peak period. The gray shaded area in the figure is the on-peak period. Note that uncertainty in the measurements and methodology can lead to some small negative demand savings The savings peaks at 1.68 kW and averages 1.35 kW across the three hour on-peak period.

On average the TOU-CPP rate customers got a credit of $0.15 per day on non-conservation weekdays. The non-TOU-CPP rate customers in the same development spend an average of $0.85 per day on non-conservation weekdays. That is a savings of $1.00 per day for the TOU-CPP rate customers. This adds up to $77.00 per summer savings for the TOU-CPP rate customers on non-conservation weekdays.

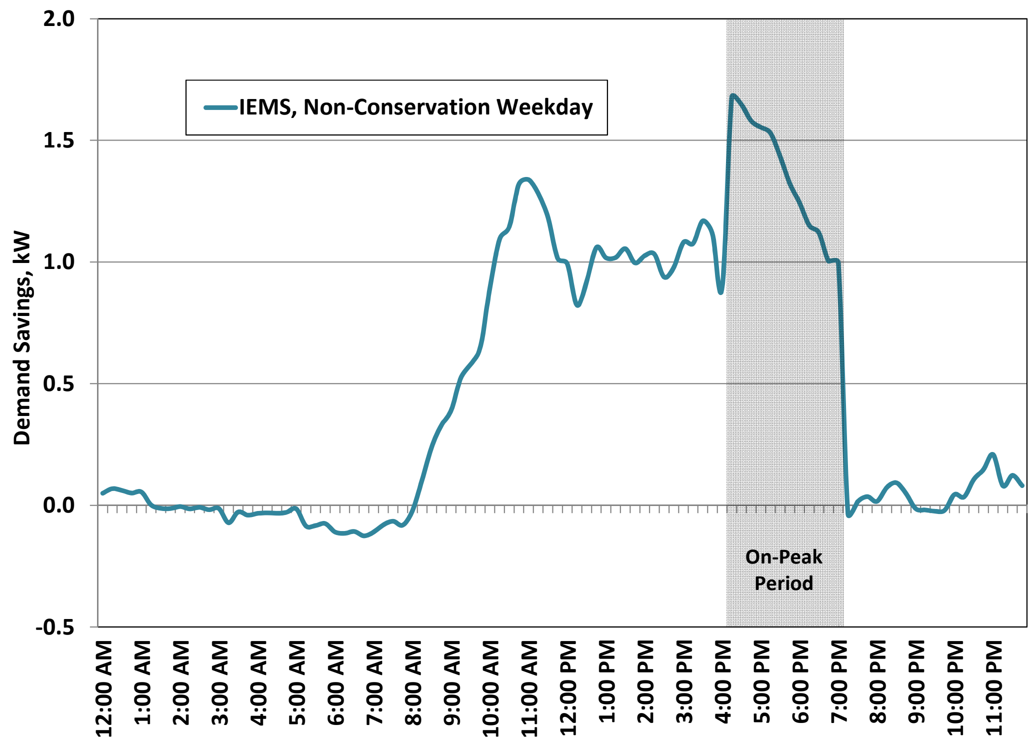

Figure 10 Average House IEMS Load Shifting Savings Profile for Non-Conservation Weekdays.

3.2 IEMS Load Shifting on Conservation Days Relative to Non-Conservation Weekdays:

Demand savings (or load shifting) was first determined as a total aggregated impact of the IEMS on the utility meter. The methodology used to calculate demand savings on conservation days relative to non-conservation weekdays is similar to the approach used for demand response (DR) savings calculations. This is the benefit SMUD sees from calling a conservation day. It is the incremental demand savings provided by the CPP rate relative to the TOU rate.

The demand on event days (conservation days) for the TOU-CPP rate homes are compared to their use on a set of comparative non-conservation baseline days. They act as their own control group. A description of the calculation approach is provided.

For each conservation day the net utility load across all TOU-CPP customers was averaged and a 24-hour profile was developed. Then a 24-hour baseline day was developed from the hottest three of the last ten (3 of 10 approach[6]) eligible days. Eligible days are non-holiday weekdays that were not conservation days during the June 1st to September 30th summer period. A list of the three hottest days used in the baseline development for each conservation day is provided in Appendix B. The net utility load from the non-TOU-CPP houses were used to provide a minor

[6] The X of Y approach (in this case 3 of 10) generally uses the X days with the highest average utility demand during the event window. However since these customers have solar PV power production, a cloudy day would result in the highest utility demand for these customers and would not be representative of the demand on a conservation day which generally will be a hot and clear sky day. Therefore the hottest days were selected for generating the baseline day.

adjustment to the average baseline day relative to the conservation day. A scalar from the non-TOU-CPP houses is used to adjust the baseline day. A scalar is generated for each interval of the day and is a ratio of the conservation day kW[7] divided by the baseline day average kW.

The combined IEMS demand savings results averaged across all eight conservation days and all ten participating customers are shown in Figure 11. The average demand savings during the on-peak period dramatically rises to 2.80 kW early in the on-peak period. It averages 1.31 kW during the on-peak period. From this result it is evident that significant load shifting occurs during the on-peak period of a conservation day relative to a non-conservation day. The load shifting is not level during the three hour event window, but is strongly weighted toward the beginning of the period. This is a characteristic that can be programmed into the IEMS to accommodate the needs of the utility or homeowner. The negative savings before and after the three hour on-peak period are relative to the baseline non-conservation days and reflect precooling by the air conditioning before-hand and re-establishing the thermostat set point after the end of the event. This effect is called the snapback. The characteristic savings of the PV do not show up in this chart because the PV savings is similar for conservation days and non-conservation days.

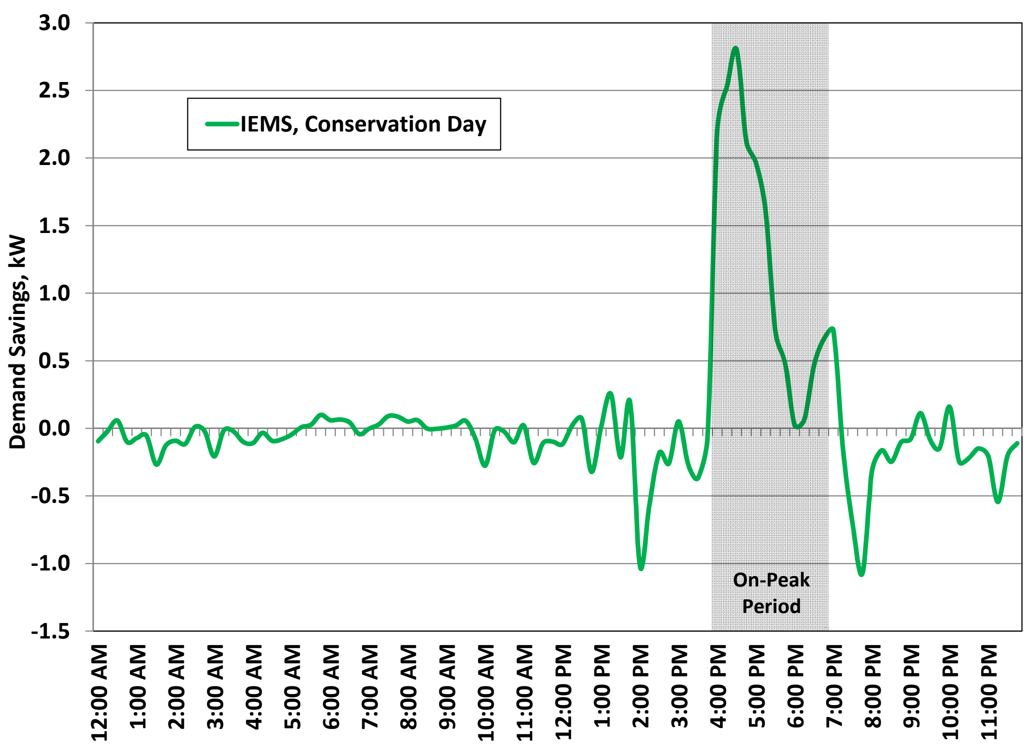

Figure 11 Average House IEMS Load Shifting Savings Profile for Incremental Conservation Days.

[7] Since kWh values can be close to zero or negative they are offset by the minimum value for the day so no ratios provide unreasonable values.

3.3 IEMS Load Shifting on Conservation Days Relative to no IEMS:

The total demand savings attributed to the IEMS is presented in this section. These are the savings for the house compared to the same house if it did not have any IEMS installed. It is the combined effect of savings for the conservation and non-conservation days. The savings profile for the total savings of an average TOU-CPP rate house on a conservation day is shown in Figure 12. The maximum savings is 4.38 kW and averages 2.66 kW over the entire on-peak period.

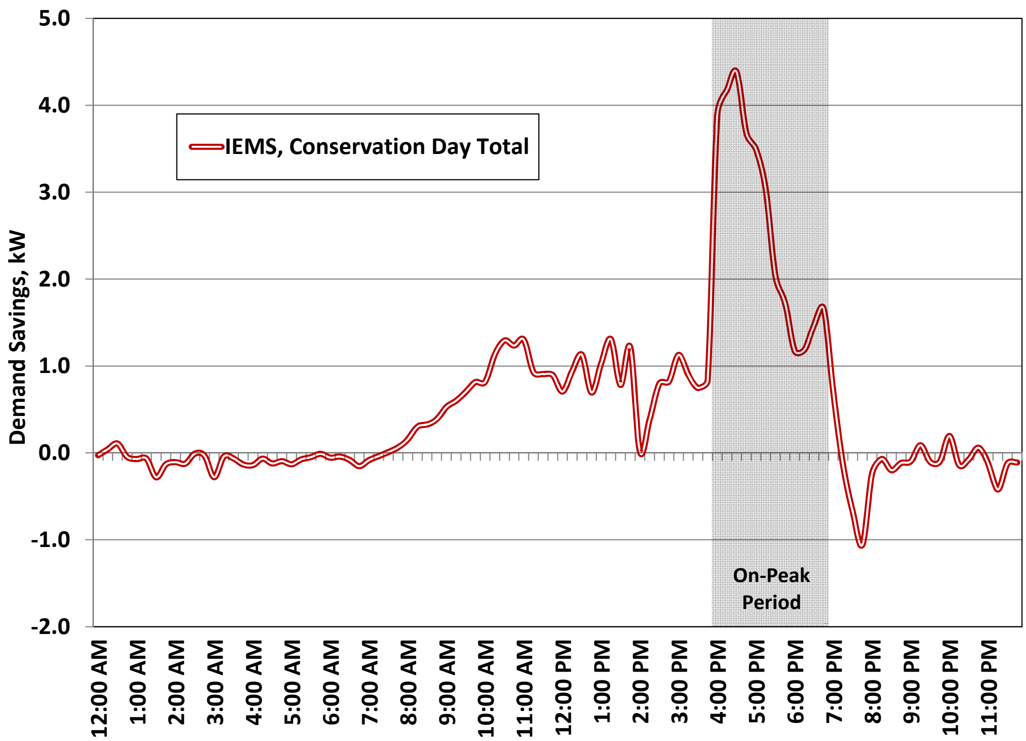

Figure 12 Average House IEMS Total Load Shifting Savings Profile for Conservation Days.

On average the TOU-CPP rate customers got a credit of $2.34 per day on conservation days. The non-TOU-CPP rate customers in the same development spend an average of $1.36 per day on conservation days. That is a savings of $3.71 per day for the TOU-CPP rate customers. This adds up to $29.68 savings for the average TOU-CPP rate customers across all of the eight conservation days, which is in addition to savings on non-conservations days.

3.4 SIS & PV Load Shifting on Non-Conservation Weekdays:

The next investigation looked at the effect of various components of the IEMS - specifically in this and the next two sections the SIS with PV generation as a combined system. Data from the SIS meters were used to calculate the savings presented here according to equation 7 given previously. Houses on the TOU-CPP rate act as their own comparison group for the SIS and PV savings calculations. The average house's non-conservation weekday savings profile is presented in Figure 13. The maximum savings is 1.49 kW and the average savings during the entire on-peak period is 1.26 kW.

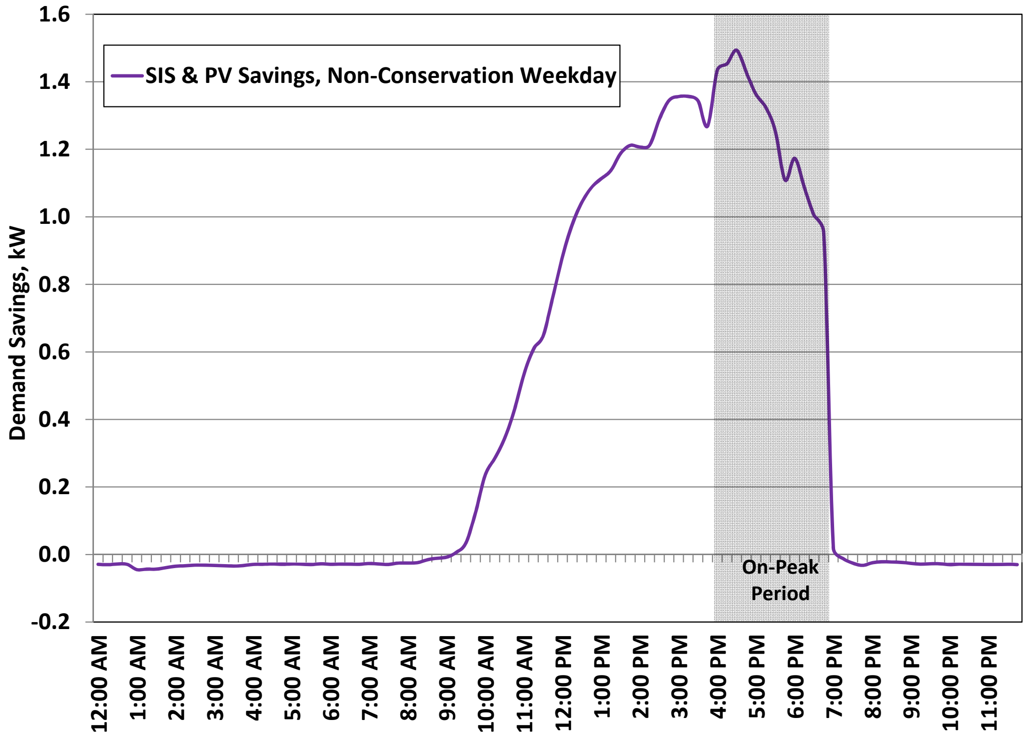

Figure 13 SIS & PV Load Shifting Savings Profile for Non-Conservation Weekdays.

3.5 SIS & PV Load Shifting on Conservation Days Relative to Non-Conservation Weekdays:

The demand on conservation days for the TOU-CPP rate homes are compared to their use on a set of comparative non-conservation baseline days. They act as their own control group. The savings calculation is based on the baseline day comparison developed from the hottest three of the last ten eligible days. The average house conservation day savings profile from the utilities perspective is presented in Figure 14. This is the incremental savings. The maximum savings is 2.27 kW and the average savings during the entire on-peak period is 1.07 kW. Some of the negative values prior to the on-peak period may be from additional storage to the batteries relative to non-conservation weekdays.

The characteristic savings of the PV do not show up in this chart because the PV savings is similar for conservation days and non-conservation days. As a result, Figure 14 shows the value provided by the SIS battery discharging. The energy from the battery is stored PV energy prior to 4:00 p.m., which is then released during the on-peak period.

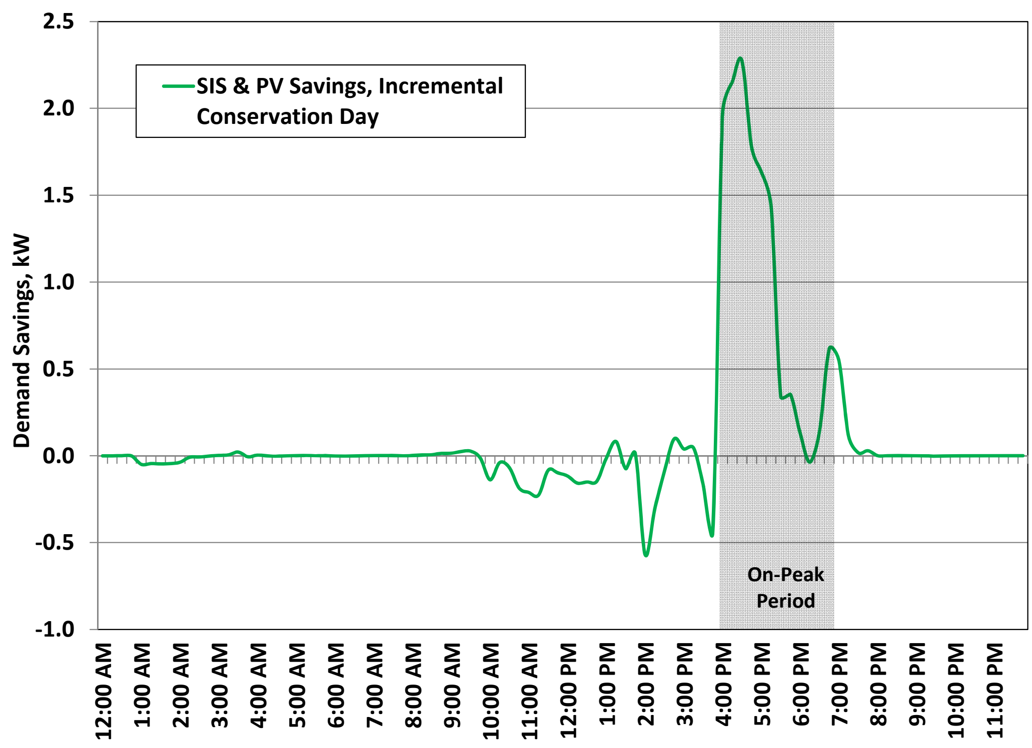

Figure 14 Average House SIS & PV Load Shifting Savings Profile for Incremental Conservation Days.

3.6 SIS & PV Load Shifting on Conservation Days Relative to no SIS & PV:

The overall demand savings attributed to the SIS and PV is presented in this section. These are the savings for the house compared to the same house if it did not have any PV or SIS installed. It compares the data from the same houses for the same days to determine total conservation day savings. The savings profile for the total savings of an average TOU-CPP rate house on a conservation day is shown in Figure 12. The maximum savings is 3.87 kW and averages 2.47 kW over the entire on-peak period.

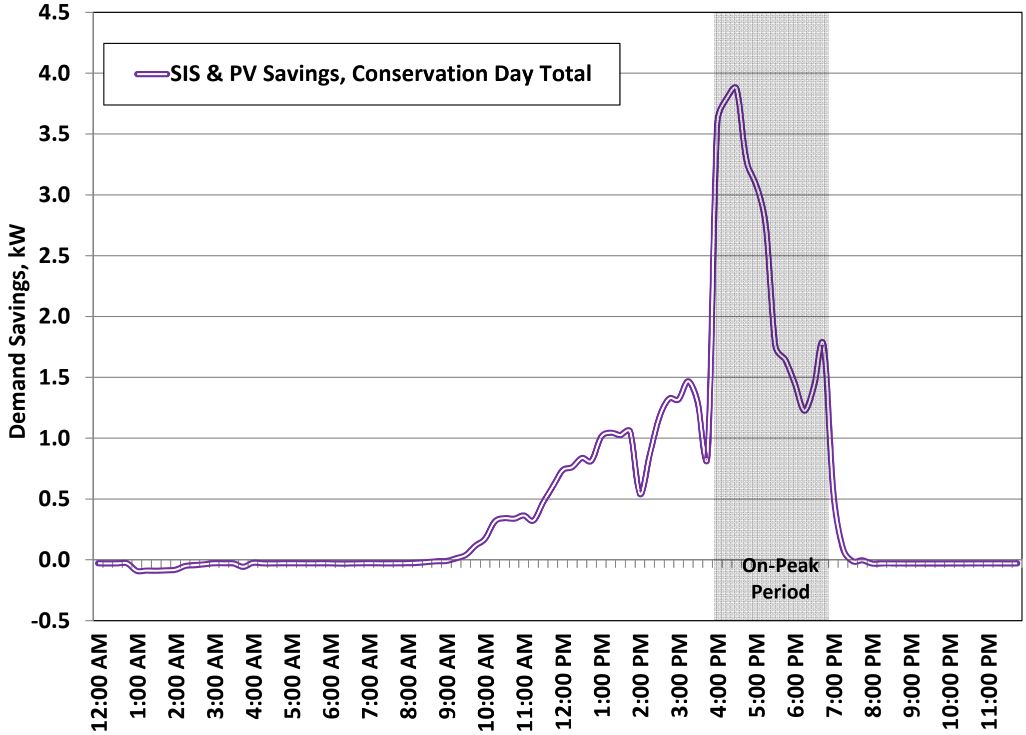

Figure 15 Average House SIS & PV Total Load Shifting Savings Profile for Conservation Days.

3.7 PV Generation:

The PV generation load profiles are developed using data from the SIS and using equation 8 given previously. Profiles for conservation days and non-conservation days are shown in Figure 16. These are characteristic of solar PV generation profiles which peak during mid-day and are declining rapidly during the on-peak period. The average demand savings from PV only over the entire on-peak period is 0.77 kW on a conservation day.

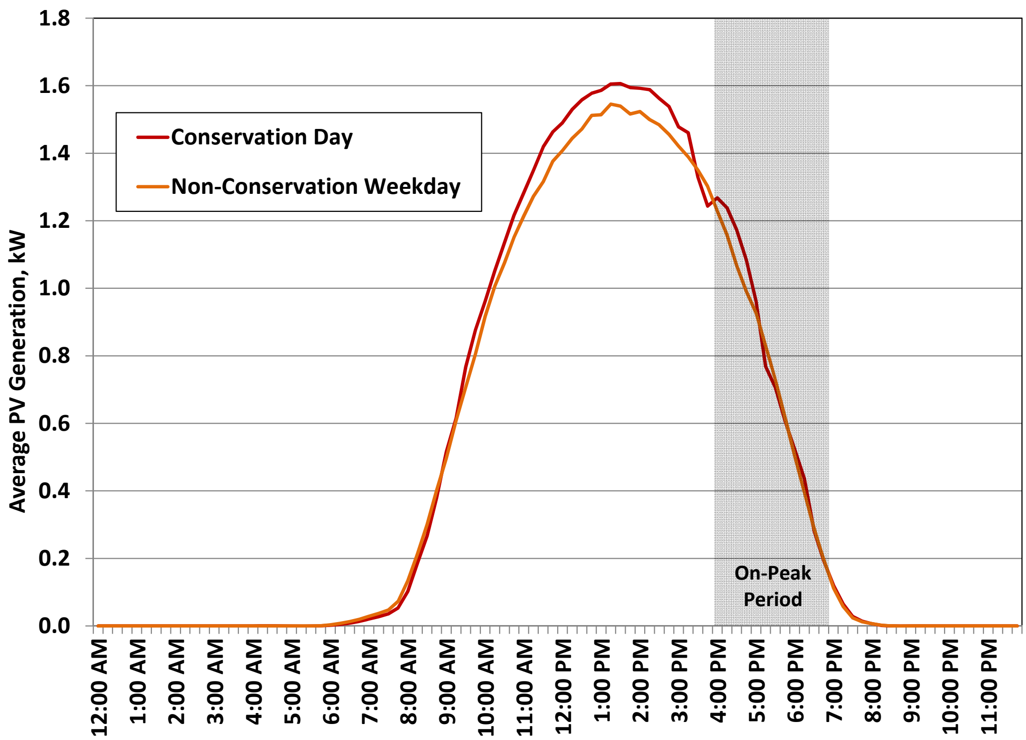

Figure 16 PV Power Generation Profiles for Conservation and Non-Conservation Days.

3.8 SIS Battery-Enabled Load Shifting on Non-Conservation Weekdays:

How the SIS battery stores PV energy and contributes to load shifting is provided in this and the next two sections. It is calculated using equation 9 given previously and uses data from the SIS. The non-conservation weekday demand profile is shown in Figure 17. In this discussion of the SIS battery only, negative values on the demand profile correlate to the battery charging, or storing, energy while the positive values correlate to the battery discharging energy to the house loads or grid. There is a dip in the demand profile during the middle of the day as the SIS is charging the battery from PV and storing the energy for release during the on-peak period. The maximum demand discharge occurs at the end of the on-peak period and reaches 0.76 kW. The average discharge during the entire on-peak period is 0.51 kW.

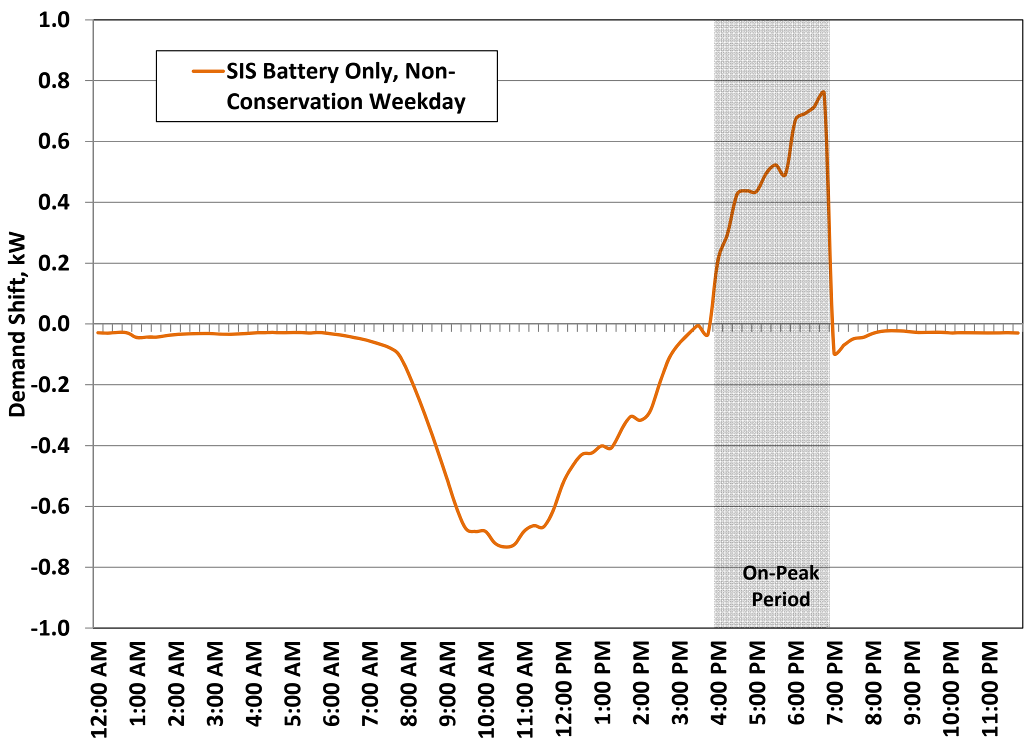

Figure 17 SIS Battery Only Load Shifting Demand Profile for Non-Conservation Weekdays.

The SIS battery only profile cannot directly be measured and is determined subtractively. Figure 18 provides a comparative perspective of the interaction that the combined SIS & PV load shifting profile from section 3.4 and the PV only load shifting profile from section 3.7 have on the SIS battery only load shifting profile.

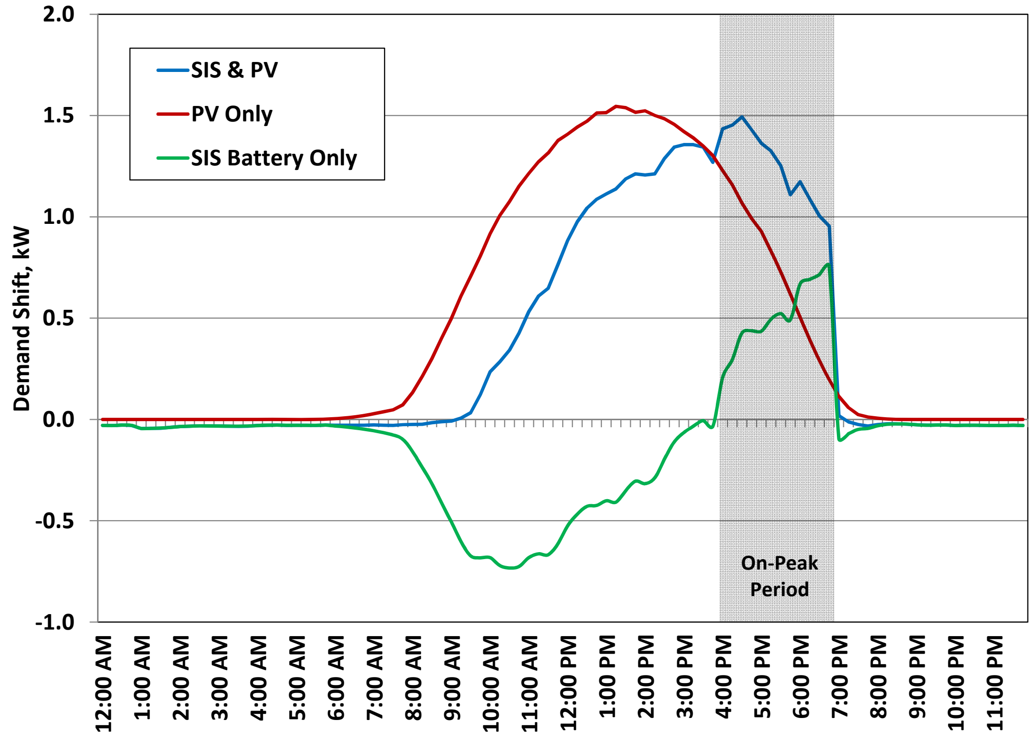

Figure 18 Comparing Load Shifting Profile for Non-Conservation Weekdays.

3.9 SIS Battery-Enabled Load Shifting on Conservation Days Relative to Non-Conservation Weekdays:

The contribution of the SIS battery to load shifting from PV energy stored in the battery on conservation days relative to comparative non-conservation weekdays is provided here. It is calculated using equation 9 given previously and uses data from the SIS meters. The conservation day demand profile is shown in Figure 19. This profile looks almost identical to Figure 14 since as pointed out in the SIS & PV section that there is effectively no difference in the PV contribution to the load savings for conservation days versus non-conservation weekdays. Thus, the incremental savings provided by the SIS on the conservation day relative to the non-conservation day can be attributed to the battery storage. The maximum demand discharge occurs near the beginning of the on-peak period and reaches 2.25 kW. The average demand discharge during the entire on-peak period is 1.07 kW.

Figure 20 provides a comparative perspective of the interaction that the combined SIS & PV load shifting profile from section 3.5 and the PV only load shifting profile from section 3.7 have on the SIS battery only load shifting profile on incremental conservation days. Note that the incremental conservation day PV only profile is very small since the PV contribution is similar for both conservation and non-conservation days. Since the incremental PV only contribution on a conservation day is small then the SIS & PV and SIS battery only load shifting profiles for conservation days relative to non-conservation weekdays are almost the same.

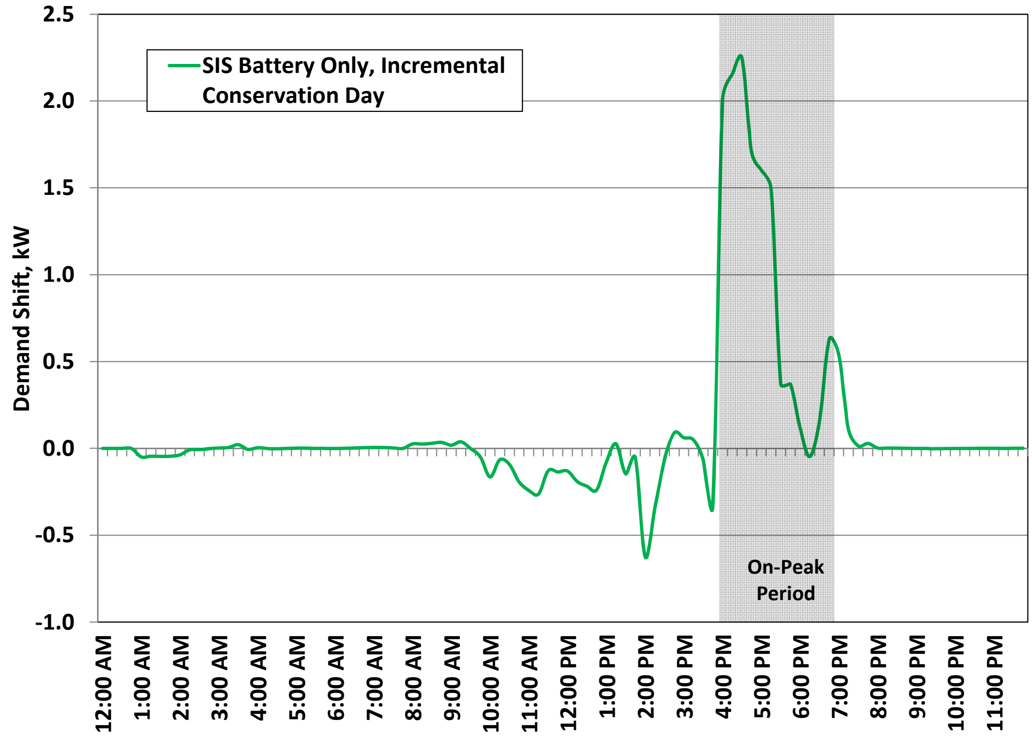

Figure 19 Average House SIS Battery Only Load Shifting Demand Profile for Incremental Conservation Days.

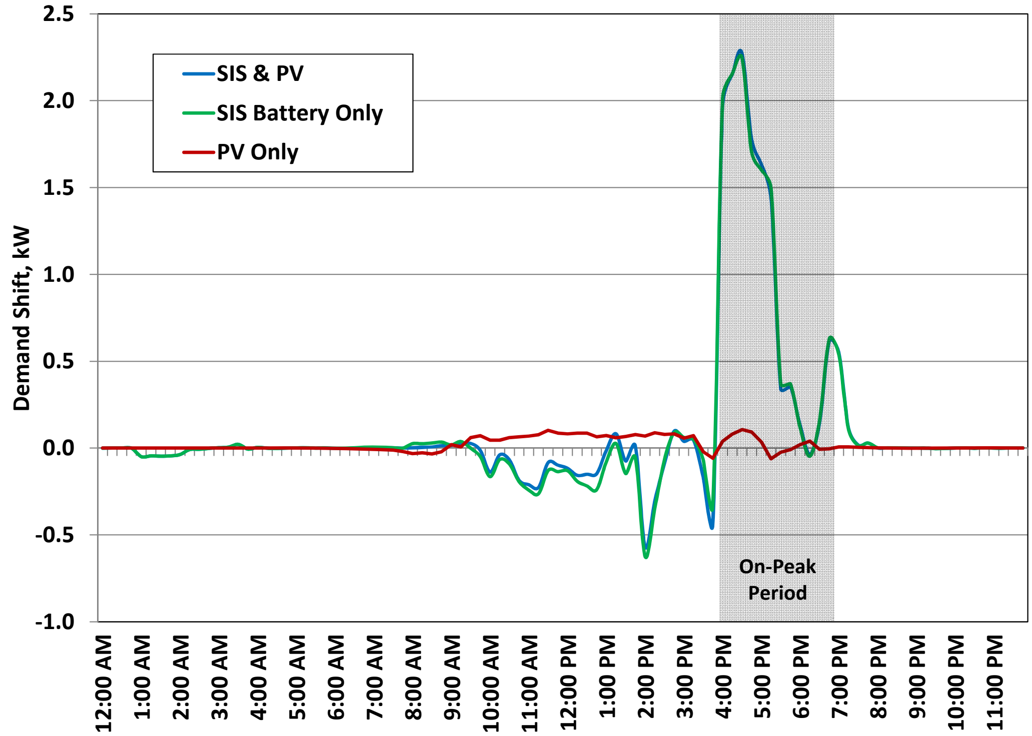

Figure 20 Comparing Incremental Load Shifting Demand Profile for Conservation Days.

3.10 SIS Battery Only Load Shifting on Conservation Days Relative to no SIS:

The overall demand shifting attributed to the SIS battery, using PV energy stored in the battery, is presented in this section. These are the profiles for the house compared to the same house if it did not have an SIS installed. It compares the data from the same houses for the same days to determine total conservation day savings. The demand profile of an average TOU-CPP rate house on a conservation day is shown in Figure 21. The maximum discharge is 2.70 kW and averages 1.70 kW over the entire on-peak period.

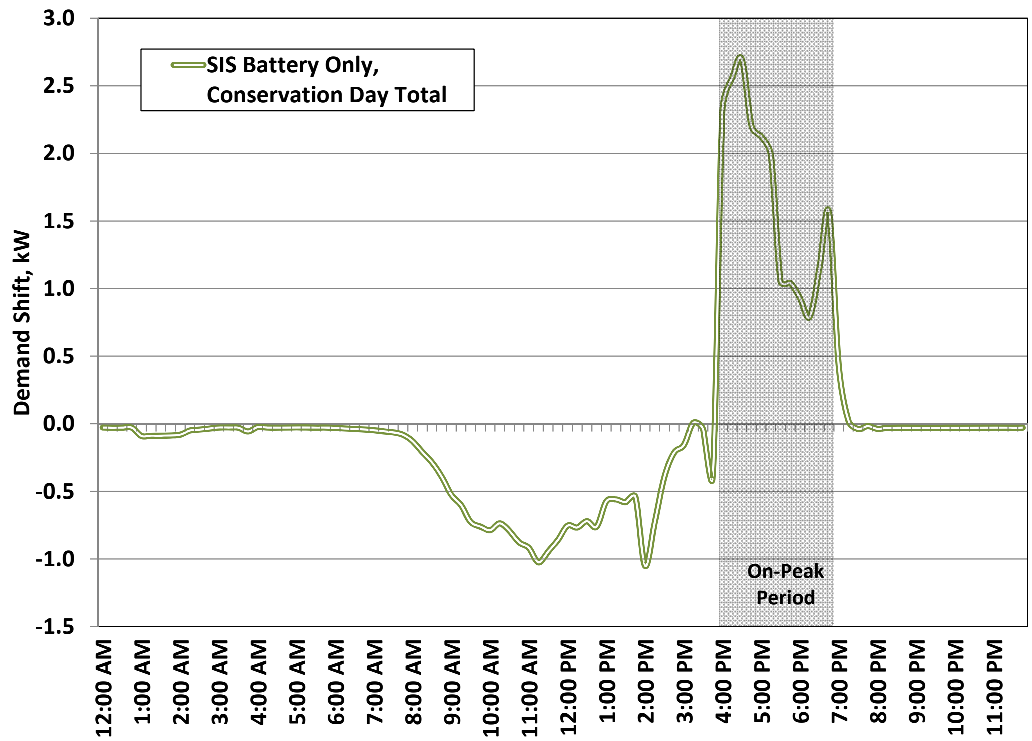

Figure 21 Average House SIS Total Load Shifting Demand Profile for Conservation Days.

Figure 22 provides a comparative perspective of the interaction that the combined SIS & PV load shifting profile from section 3.5 and the PV only load shifting profile from section 3.7 have on the SIS battery only load shifting profile.

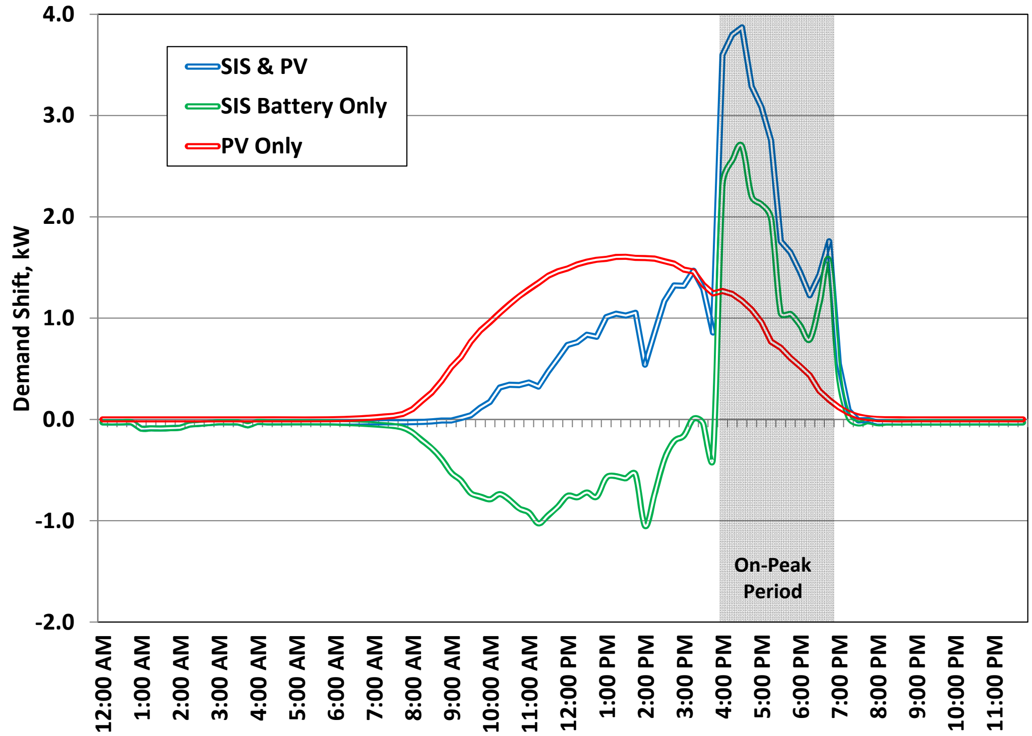

Figure 22 Comparing Total Load Shifting Demand Profiles for Conservation Days.

3.11 PCT Air Conditioning Load Shifting:

On conservation days the PCT thermostats were programmed to pre-cool the house prior to the on-peak period (excluding the first three conservation days). Then for the duration of the on-peak period the cooling set point was increased 3 °F above the original setting. Raising the cooling set point does not turn the air conditioning unit off but reduces the amount it needs to run. The most savings typically occur at the beginning of the on-peak period, with savings diminishing as the temperature in the house approaches the new cooling set point.

The analysis for the PCTs was not as robust as originally planned since there were only ten houses on the TOU-CPP rate. Monitoring equipment specific to the air condition was originally installed at eight houses during the construction phase of the project. Only two of those houses signed up for the TOU-CPP rate. Additionally the PCT data collected by ThinkEco had many missing portions making it too difficult to analyze across multiple units. Although the PCT does not have metered data for the air conditioning unit, it does contain runtime data showing the number of seconds that the compressor was on during each minute. The air conditioning energy use was correlated to the runtime data from the PCT and outdoor temperature. The regressions had an R squared greater than 0.98. This would have been a simple way to greatly expand the number of air conditioning units analyzed without adding additional meters. Unfortunately besides the missing data from the PCT there were unexplained time shifts in the data which could not be accounted for except on the two units with on the independent metering. The time shifts in the data were later corrected, but not in time to be taken into account for this analysis.

The analysis was limited to data from the two air conditioning units independently metered by ADM and from houses with the TOU-CPP rate. The first three conservation days did not have pre-cooling applied to the control algorithm. The base for the analysis used the same house air conditioners on the three hottest of the last ten eligible baseline days. The baseline day profiles were adjusted using the total day air conditioning load of the conservation days divided by the total day air conditioning load on the baseline days. All eight conservation days for the two houses with ADM metering were included in the average per air conditioner profiles in Figure 23. The pre-cooling period prior to the on-peak period shows negative savings as is expected, as does the period immediately following the on-peak period as the air conditioning cools the house back down to the original cooling set point. Due to the limited number of sites and days included in this analysis, the uncertainty in the savings is high as can be seen in the fluctuations of the profile.

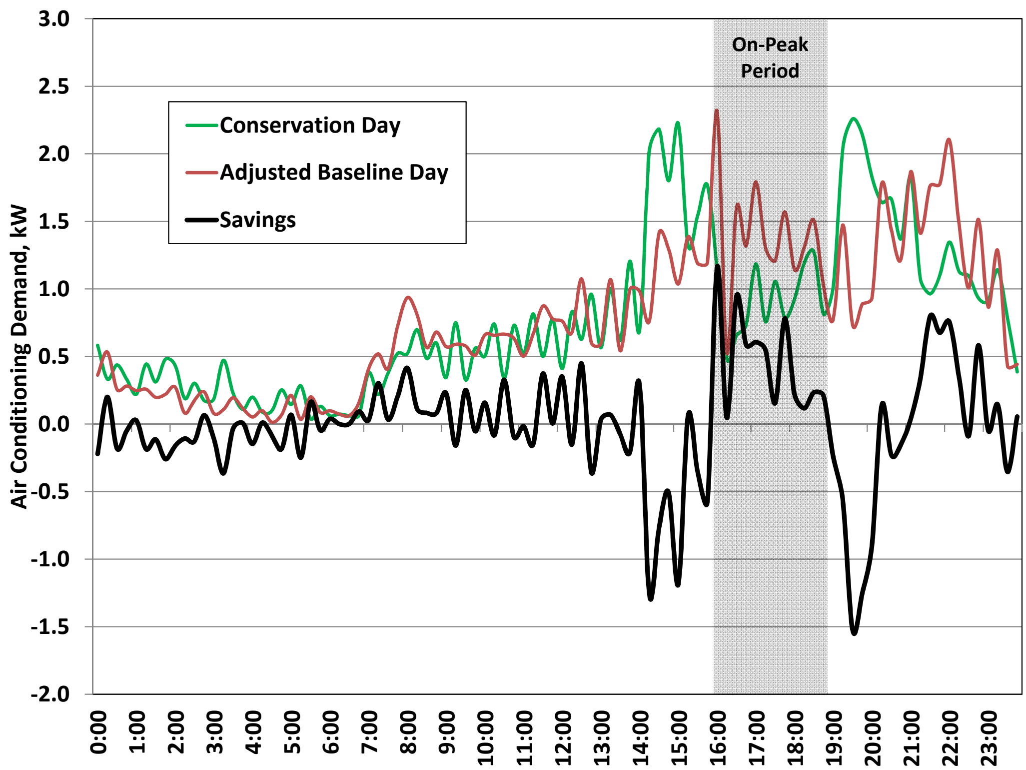

Figure 23 Average Air Conditioning Unit Profiles and Savings on Conservation Days.

The average values over the three hour on-peak period of 4:00 p.m. to 7:00 p.m. are presented in Table 4. There is a 28% savings during the on-peak period which corresponds to 0.35 kW in average demand savings and 1.05 kWh in energy savings. Additional air conditioning savings may be occurring on non-conservation days since the PCT is programmed to change the cooling set points but not as aggressively.

Table 4 Average On-Peak Period Demand per Air Conditioner.

	Value	Units
Average 3-hour Demand on Baseline Days	1.26	kW
Average 3-hour Demand on Conservation Days	0.91	kW
Average 3-hour Demand Savings	0.35	kW
Savings, %	28	Percent
3-hour Energy Savings per Conservation Day	1.05	kWh

The PCT data for the TOU-CPP rate customers were reviewed for the conservation days. The cooling set points were sometimes controlled according to the prescribed control schedule. Taking into account that the first three conservation days did not have pre-cooling applied, there was not consistent application of the pre-cooling set point. There appeared to be many instances where the temperature set points were not controlled as the plan scheduled. The occupants can override the control setting after it has taken place, but they cannot pre-emptively override the conservation day settings, so there should be a record of the system setting the temperature at 2:00 p.m., 4:00 p.m., and again at 7:00 p.m. Given the sparse data from the PCTs for the TOU-CPP rate customers and the eight conservation days there was no instance identified that could be shown to behave as the plan laid out and without alteration by the customer or the PCT. One instance was on September 12th for customer #S58. This case is shown Figure 24 where the temperature before the pre-cooling started was 82°F. The only deviation from the expected set point profile is that halfway through the on-peak period the temperature set point was lowered to the original temperature of 82°F for a few minutes before it was raised back up to 85°F.

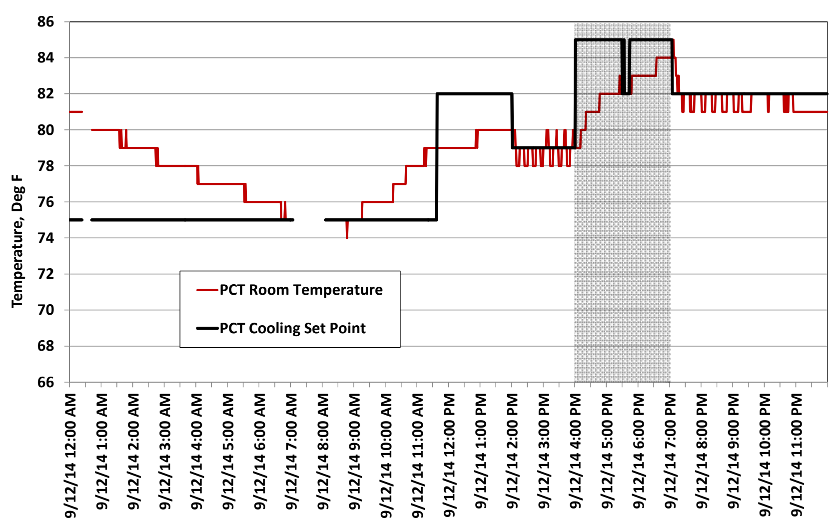

Figure 24 PCT Set Point Changes at 2:00 p.m., 4:00 p.m., and 7:00 p.m. for One Home on Sept. 12th a Conservation Day.

Three houses had an independent temperature logger mounted near the PCT thermostat to independently verify the PCT readings. Figure 25 shows three days of PCT temperatures along with the TandD temperature logger data. The TandD logger data are about two degrees higher than the PCT but correlate closely. The tracking and relative changes in recorded temperature are much more important than the absolute measurement in verifying the operation of the PCT.

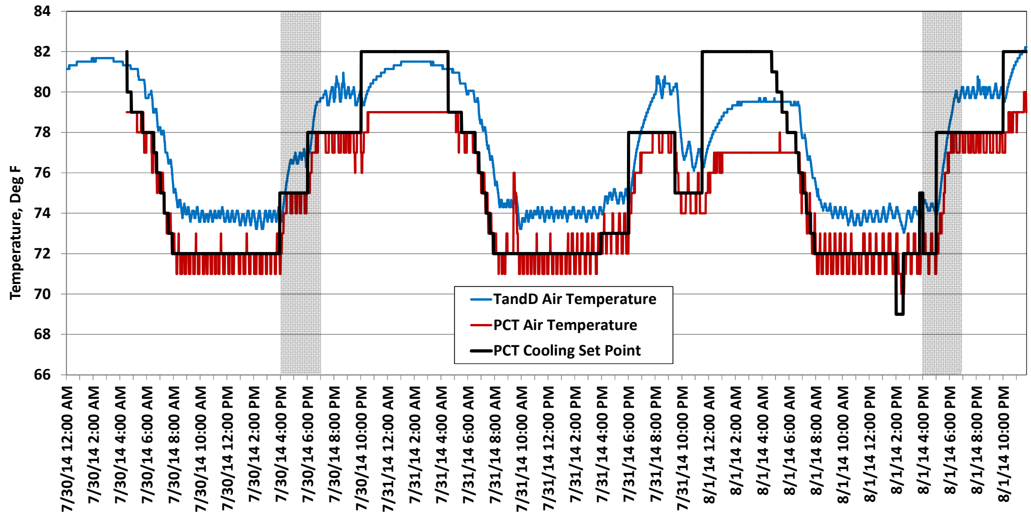

Figure 25 Three Days of PCT and TandD Temperature Data Comparisons.

July 30th was a conservation day and Figure 25 shows a 3ºF rise starting at 4:00 p.m. as expected, however there was no pre-cooling that took place as evidence by all three datasets. At one point during the on-peak period the cooling set point was raised another 3ºF, possibly by the customer. On August 1st the cooling set point was lowered 3ºF at 2:00 p.m. in accordance with the pre-cooling strategy, but about 30 minutes later the set point was returned to the original setting. This could have been a customer override of the pre-cooling. At 4:00 p.m. the cooling set point was raised 3ºF as expected, but a few minutes later the set point was brought back to the original setting of 72ºF. Again this could have been a customer override, however about an hour into the on-peak period the cooling set point was raised 6ºF, again unlikely that all three of these changes were customer overrides since some of them are contradictory. This example and the next two figures are from customer #S43.

More than a month later on September 12, another conservation day with similar thermostat activity occurred as seen in Figure 26. Although the timing of the changes differ from the previous example, the high frequency of changes suggests that another source in addition to the customer may be responsible for the adjustments.

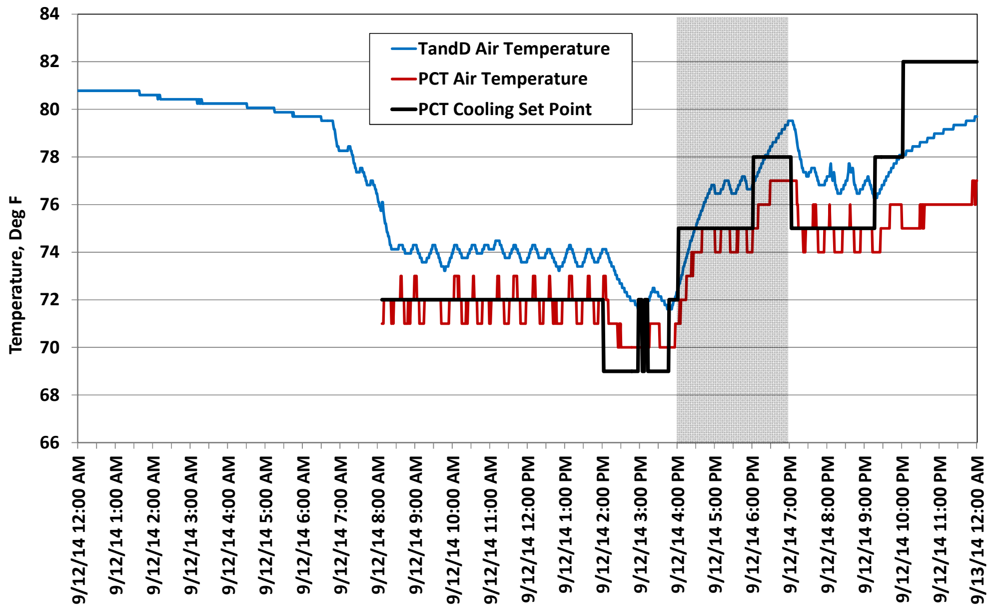

Figure 26 PCT and TandD Data from a Conservation Day, September 12.

The data from the PCT dataset listed the time as UTC (Coordinated Universal Time, also known as GMT, or Greenwich Mean Time). There were only a couple of units that the time settings could be independently checked. For them the date and time stamp was in local time until September 12 when it switched to UTC. There were other occurrences of the PCT clocks drifting 10 or more minutes and then realigning with the independent loggers. This occurred more than once prior to September 12.

On September 16, another conservation day, there were no set point overrides (see Figure 27). However, at the beginning of the on-peak period the set point was raised 6ºF above the original setting of 72ºF. The set point was also not returned to the original set point after the on-peak period was over. As evidenced by the data examined here, the ThinkEco thermostat response was not consistent or reliable. A utility program needs to be able to rely on devices for demand reduction when there is a call for conservation.

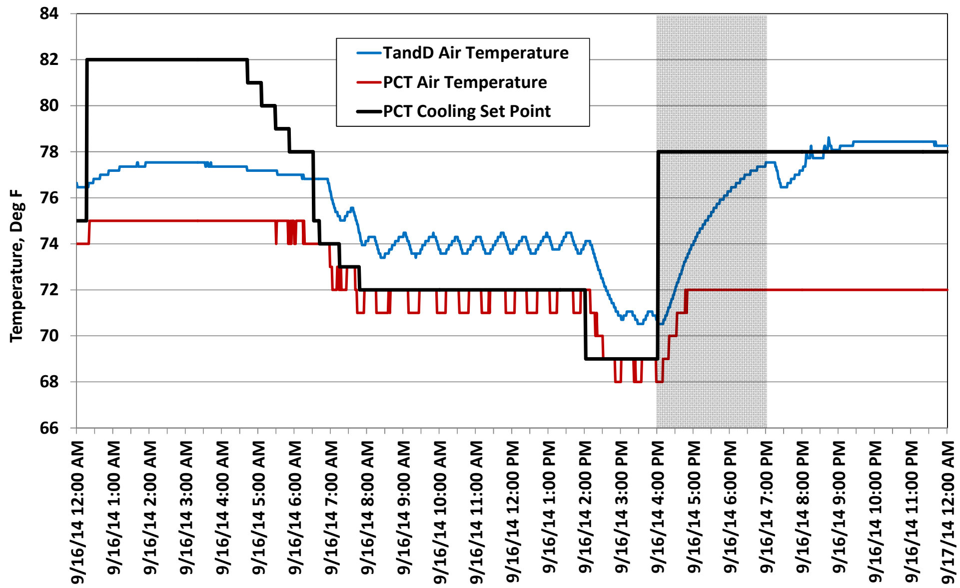

Figure 27 PCT and TandD Data for Another Conservation Day, September 16.

The conclusion is that although there is some savings associated with the conservation day setting of the PCT there is opportunity for more savings, better control as scheduled by the plan, and more consistent data retrieval and storage.

3.12 Modlet Load Shifting:

On conservation days the modlets were programmed to turn off the loads. Power data measured by the modlets and reported back to the portal were available for the 10 customers on the TOU-CPP rate. Each house had two modlets devices which the homeowners could plug into any duplex wall outlet of their choice in the house. The houses that documented the loads plugged into the modlets list the following appliances: printers, TVs, entertainment centers, cable boxes, laptop, iPad, phone, desk lamp, living room lamp, fan, and coffee maker. Each device has two outlets which are metered and reported separately. A total of four outlets in each house reported power measurements. The analysis was conducted by averaging the loads from all modlets at the 10 TOU-CPP customer's houses on all eight conservation days to develop a daily profile with 15-minute resolution. The loads from all the modlets at the 10 TOU-CPP customer houses were averaged for all non-conservation summer weekdays to also develop a daily profile with 15-minute resolution. These profiles are shown in Figure 28 and note that these are averages per outlet (not modlet). The average values over the three hour on-peak period of 4:00 p.m. to 7:00 p.m. are presented in Table 5. There is a 73% savings during the on-peak period which shows that the modlet effect is very discernable, but the magnitude of the savings is not as impressive. The average household energy use per outlet on a non-conservation weekday is 0.090 kWh while on a conservation day it is only 0.076 kWh. Over the course of all eight conservation days an average TOU-CPP rate customer would save $0.08 for all four controlled outlets over what a standard customer would pay on their rate and without loads being turned off. The operation of plug loads has a high variability and is dependent on what type and size of load is plugged into it. The conclusion is that the modlet is not cost effective for consumers that curtail only small loads on the TOU-CPP rate.

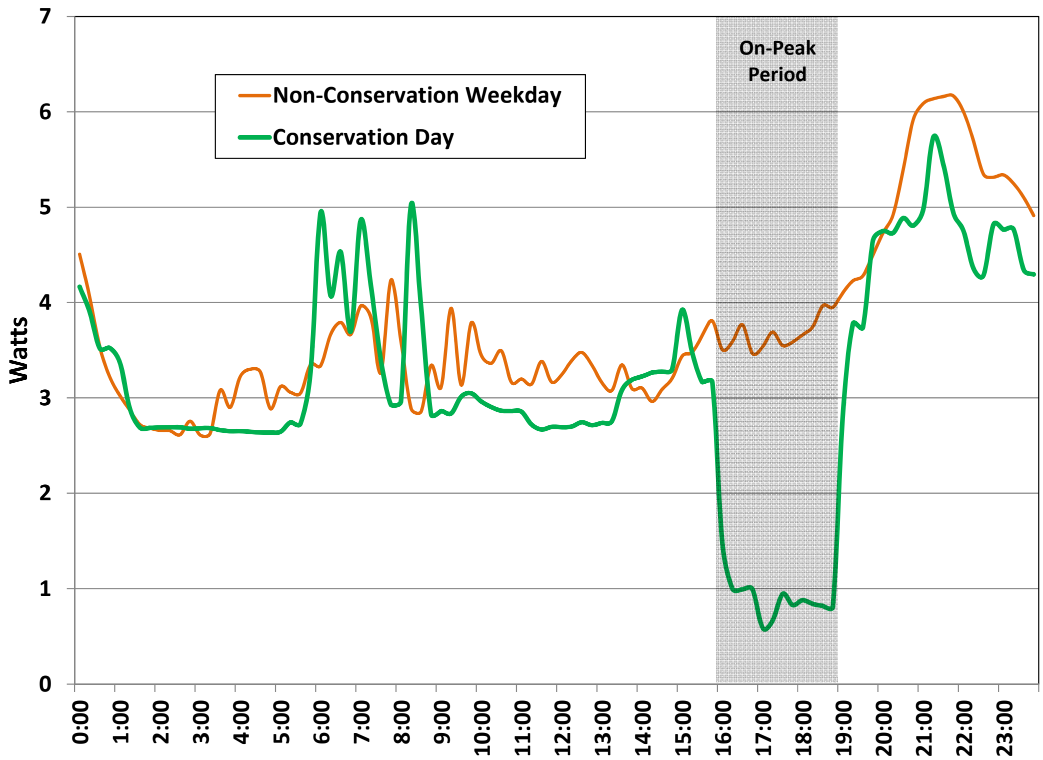

Figure 28 Average Modlet Power Profiles per Outlet.

Table 5 Average On-Peak Period Demand per Outlet

	Value	Units
Average 3-hour Demand on Non-Conservation Weekdays	3.72	Watts
Average 3-hour Demand on Conservation Days	1.02	Watts
Average 3-hour Demand Savings	2.70	Watts
Savings, %	73	Percent
3-hour Energy Savings per Conservation Day	0.0081	kWh

The question may be asked: why is the average outlet demand so low, about 4 Watts? Generally, the appliances plugged into the modlets were not large load items. But another major factor was the appliances were off or drawing 2 Watts or less 80% of the time.

4. Fleet Operation in Aggregate

Each SIS unit individually is small in capacity (4.5 kW and 11.7 kWh). Large numbers of them could have a more significant impact if they can be operated collectively as a fleet. The mechanics to conduct a coordinated fleet operation are not addressed in this report.

SIS Goals:

Demonstrate the ability to operate a group of SIS units in a coordinated fashion.

SIS Test Plan:

To operate a group of SIS units to demonstrate a targeted group dispatch. The plan is to dispatch for load shifting on a conservation day with 24 hour notice on a group of customers signed up of the TOU-CPP rate who have SIS units.

M&V Evaluation:

The previous section evaluated the average load shifting for the group of TOU-CPP rate customers with the SIS. The evaluation concluded that load shifting successfully occurred at the target group of houses. Therefore fleet operation in aggregate has been demonstrated. Figure 29 shows the IEMS load shifting for the fleet of 10 TOU-CPP rate houses on an average conservation day relative to no IEMS. The demand shifting peaks at 43.8 kW during the on-peak period.

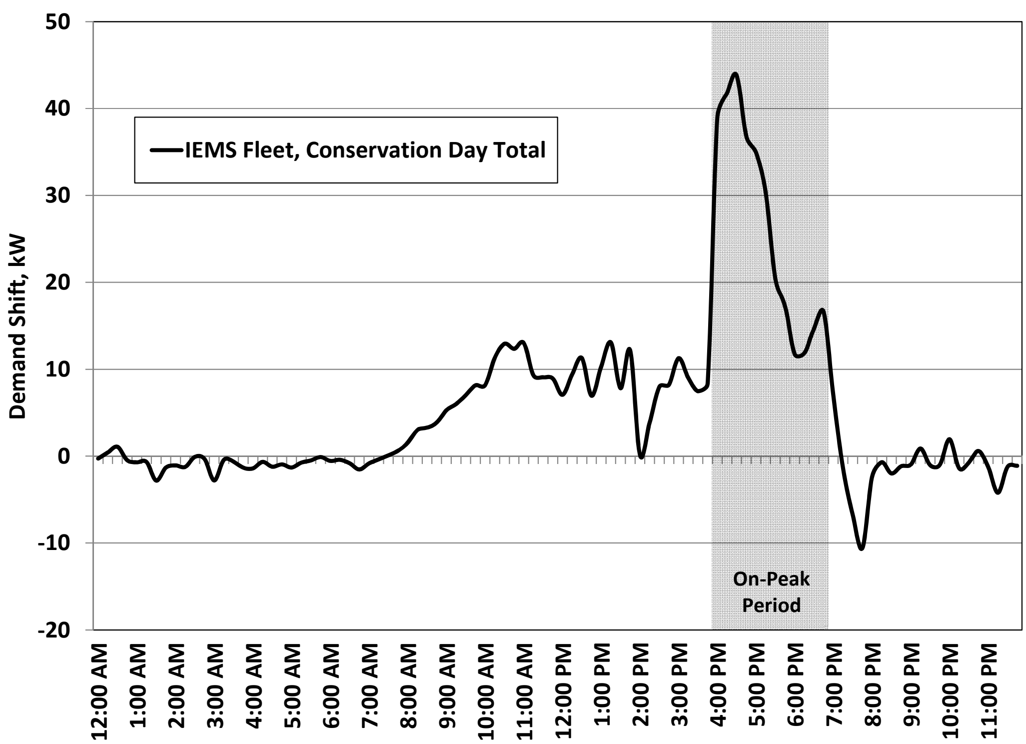

Figure 29 Total Fleet IEMS Load Shifting Profile for an Average Conservation Day.

5. UPS

The uninterrupted power supply (UPS) use case of the SIS is described in this section. The SIS contains batteries for energy storage. The inverter in the SIS transforms the DC (direct current) voltage of the battery system to AC (alternating current) voltage compatible with the power supplied by the utility grid. The 60 Hz frequency voltage produced by the inverter must match and synchronize with the grid frequency. The UPS capability is a feature of the SIS which most customers can easily understand when they are told that even if there is a power outage or blackout in their neighborhood the SIS will continue to power the critical loads in their house.

The critical load panels are connected to the SIS, such that the SIS can power it through battery, PV or grid. The SIS continuously monitors the grid in order to immediately provide power to the critical load panel if there is a grid outage or disturbance.

SIS Goals:

There are two goals of the UPS use case test listed here. The SIS is setup to reserve a majority of the battery capacity for UPS purposes.

- Provide backup power: Demonstrate the ability of the Sunverge SIS to provide backup power to a single home's critical load panel when the SIS is disconnected from the utility grid.
- Reconnect to the grid: Demonstrate the ability of the Sunverge SIS to reconnect to the utility grid in accordance with reconnection standards.

SIS Test Plan:

The UPS would ideally be conducted when an actual power outage occurs in the neighborhood. However, SMUD maintains a very reliable power source for its customers. In replacement of an actual power outage a simulated outage was conducted. The simulated outage was conducted at one of the houses by flipping the breaker off inside the SIS unit which connects it to the main house panel and therefore the utility grid.

Prior to flipping the breaker the Sunverge team ensured there was at least 500 W of load on the critical load panel. This was to provide a baseline prior to the event and also to improve the measurement accuracy as small loads have greater uncertainty in the SIS meter. In addition to a daytime simulated outage test, ADM requested that another simulated outage test be conducted either at night or by disabling the PV panel inputs. The intention of the additional test was to ensure that the critical load panel was indeed being powered by the grid prior to the start of the test. If the SIS was powering the critical load panel prior to the test, there would effectively be no instantaneous transfer of the power source from the grid to the SIS. Although this test has not been conducted, it is not necessary as the first test indicated that the power was originally being provided by the grid…

There were a total of four events to investigate for the UPS use case. They were as follows:

1. Customer #S43, Simulated Outage: Thursday, October 16, 2014. From 10:55:26 a.m. to 11:18 a.m.

2. Customer #S43, Simulated Outage: Thursday, October 16, 2014. From 11:45:50 a.m. to 12:00 p.m.

3. Customer #S46, Unintended power outage: Wednesday, October 29, 2014 at 11:16: a.m. to Thursday, October 30, 2014 at 8:34 a.m.

4. Nine Customers, Outage reported by SMUD system: Monday, September 8, 2014. From 18:46 p.m. to 19:15 p.m.

M&V Evaluation:

Three sources of data were available for the measurement and verification evaluation: Utility house meters, IEMS meters and system status, and evaluation contractor installed meters. The SMUD interval meter data could not be used for the simulated outage test since it has a minimum time resolution of 1-hour but the tests lasted less than 30 minutes.

The Sunverge SIS successfully provided continuous power to the critical load panels for all of the cases listed above. Following are additional details for each case.

1. The data from the meters in the SIS show that the power was out for 23 minutes and the SIS provided 0.37 kWh of energy to the critical load panel during that time. The ADM meters confirmed that the critical load panel received continuous power before during and after the event.

2. The data from the meters in the SIS show that the power was out for 15 minutes and the SIS provided 0.12 kWh of energy to the critical load panel during that time. The ADM meters confirmed that the critical load panel received continuous power before during and after the event.

3. The data from the meters in the SIS show that the power was out for 21.3 hours and the SIS provided 2.57 kWh of energy to the critical load panel during that time. The SMUD house meter also confirms there was no power delivery in either direction during that period.

4. Although SMUD reported there was an outage to nine of the homes in the development neither the SIS nor the ADM meters identified a power outage. In fact, the meters indicated that the SISs were connected to the grid the entire time.

6. Power Quality

The SIS contains an inverter which generates AC (alternating current) voltage and power compatible with the utility grid power. This section investigates the ability of the SIS to provide power to the grid at a quality acceptable to the utility. SMUD has interconnection guidelines for power generators to follow when providing power to the grid. SMUD's Document No.11-01 Interconnection Guidelines will be used to interpret SIS's ability to provide acceptable power quality when connected to the grid. In addition, this section evaluates whether the inverter in the SIS operates within the manufacturer's specifications

The parameters that will be checked for compliance with the interconnection guidelines are voltage, frequency and harmonics. Voltage on a nominally 120 Volt system must stay within the range of 106 V to 132 V. Momentary excursions beyond those limits are acceptable with certain limits but will not be investigated here because of metering limitations. The frequency must be maintained within the range of 59.3 Hertz to 60.5 Hertz. The generating facility must disconnect from the distribution system (grid) if the generation or the grid exceeds these limits. Harmonic distortion shall be in compliance with IEEE 519. The voltage total harmonic distortion (THD) should be maintained at 5% or less. Current THD limits vary depending upon the system and current loads and are not assessed here.

SIS Goals:

The goal is to demonstrate that the SIS system operates within acceptable ranges. When pulling power to or from the grid, the inverter matches the grid. When supplying power to the critical load, the inverter attempts to output power according to the inverter specifications. These specifications include the following:

- Voltage: Line to neutral (L-N) voltage should be 120 Vac ±3% [116.4 Vac to 123.6 Vac] and line to line (L-L) voltage should be 240 Vac ±3% [232.8 to 247.2 Vac].
- Frequency: Should be 60.0 ±0.1Hz
- Harmonic Distortion: Total Harmonic Distortion should be <5% at rated power.

The harmonic distortions will be observed for power flows in the following conditions:

1. Power from grid to loads via SIS pass-through. This will be used as a baseline reference.
2. Power from the SIS to grid out.
3. Power from SIS to critical load panel when load SIS is supporting loads, such as during Offset Demand mode.
4. Power from SIS to critical load panel during a UPS event.

SIS Test Plan:

Power quality testing generally is not event based so any period of available data can be investigated so long as the loads have a range of operation typical for the site. This is not to say that specific events could not happen which may produce results outside of expected limits. One event that is of interest is the UPS condition where the SIS becomes disconnected from the grid and is the sole source for maintaining power quality to the critical load panel.

M&V Evaluation:

For this measurement and verification evaluation ADM installed power meters capable of making the necessary measurements. These meters were installed at a sample of three customers (#S63, S71, & S43). There are three power measurement points for each house which are listed below and diagramed in Figure 30:

- AC power measurement from SIS to Critical Load Panel
- AC power measurement to and from Main Load Panel (Grid)
- DC power measurement from PV to SIS (no power quality assessment conducted)

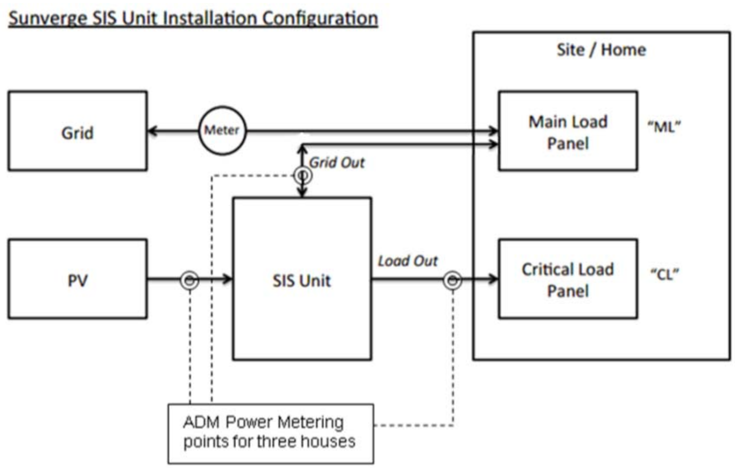

Figure 30 Configuration of Power Meters Installed by ADM at Three Houses.

Power quality measurements from the three houses were reviewed for the following periods based on requests for data by ADM during the project:

- Customer #S63: July 24, 2014 to August 25, 2014.
- Customer #S71: August 8, 2014 to August 27, 2014.
- Customer #S43: June 11, 2014 to August 25, 2014.
- Customer #S43 UPS Event 1: October 16, 2014 from 10:55 a.m. to 11:18 p.m.
- Customer #S43 UPS Event 2: October 16, 2014 from 11:45 a.m. to 12:00 p.m.

The ADM meters collected data on 1-second intervals. The data was processed into 15-minute intervals and the averages, minimums and maximums of these values are reported for each customer and each power distribution condition. In addition, the minimum and maximum 1-second values for each condition are also reported. Table 6 shows the results of the voltage power quality assessment including standard deviation of the 15-minute averages. The voltages for all conditions are well within the specifications for the interconnection guidelines. The voltages average above 123 Vac. Although the SIS inverter specification rates the maximum output as 123.6 Vac, the grid is often above that value. This forces the inverter to follow the grid precedence. During the UPS events when the inverter is disconnected from the grid the voltage supplied by the inverter generally averages below its upper voltage output rating, although the short term (1 second) values generally reach above the rated output to a maximum of 125.3 Vac. This should cause no problem for the customers or their equipment, but is only a notation on the SIS specifications.

Table 6 Voltage Power Quality Assessment Results, in Vac.

#	Condition	line	Voltage Average	Minimum 15 Minute Average	Minimum 1 Second Value	Maximum 15 Minute Average	Maximum 1 Second Value	Std. Dev.
S63	From Grid	V1	123.8	122.3	121.4	125.1	125.3	0.59
S63	From Grid	V2	123.6	121.6	120.8	124.9	125.2	0.61
S63	To Grid	V1	123.8	122.4	121.7	125.2	125.7	0.42
S63	To Grid	V2	123.6	121.9	121.1	125.1	125.7	0.52
S63	Critical Load	V1	123.6	121.4	119.8	125.2	125.8	0.61
S63	Critical Load	V2	123.9	122.3	120.1	125.5	126.0	0.56
S71	From Grid	V1	123.8	122.3	121.6	124.8	125.1	0.59
S71	From Grid	V2	123.4	122.2	121.5	124.6	125.0	0.50
S71	To Grid	V1	123.3	122.4	121.6	124.7	125.1	0.41
S71	To Grid	V2	123.2	122.3	121.5	124.5	125.0	0.41
S71	Critical Load	V1	123.7	122.4	121.2	124.9	125.2	0.56
S71	Critical Load	V2	123.4	122.1	121.5	124.6	125.1	0.48
S43	From Grid	V1	123.5	122.0	121.0	124.8	125.2	0.55
S43	From Grid	V2	123.6	122.0	120.9	125.0	125.3	0.65
S43	To Grid	V1	123.4	122.2	117.5	124.9	125.8	0.48
S43	To Grid	V2	123.4	121.9	117.8	125.0	125.6	0.48
S43	Critical Load	V1	123.7	121.9	119.7	125.1	125.9	0.62
S43	Critical Load	V2	123.4	121.7	119.8	125.1	125.9	0.53
S43	Critical Load UPS Event 1	V1	123.8	na	119.8	na	124.2	0.64
S43	Critical Load UPS Event 1	V2	121.1	na	120.3	na	121.3	0.14
S43	Critical Load UPS Event 2	V1	120.9	na	119.7	na	125.3	0.88
S43	Critical Load UPS Event 2	V2	120.9	na	120.1	na	124.4	0.50

It is common knowledge that the utility grid in the United States operates at 60 Hertz (Hz). There are clocks and other equipment that count the cycles and rely on the consistency of the grid to maintain calibration. The system can allow some leading or lagging in the number of cycles at any given time but by the end of the day the average is expected to be exactly 60 Hz. Table 7 shows the results of the frequency power quality assessment. During long term assessment, the frequency consistently averaged 60.00 Hz. All situations to and from the grid showed they were within the interconnection guidelines. The ±0.1Hz rating of the SIS did show times it was exceeded at the 1 second level. There were two occurrences where the maximum 1-second values reached 61 Hz, but those were only on the critical load panel. For customer #S43 the minimum 1-second value from the grid was as low as 59.84 Hz, which could have been grid driven.

Table 7 Frequency Power Quality Assessment Results, in Hertz.

#	Condition	Frequency Average	Minimum 15 Minute Average	Minimum 1 Second Value	Maximum 15 Minute Average	Maximum 1 Second Value	Std. Dev.
S63	From Grid	60.00	59.95	59.90	60.05	60.10	0.016
S63	To Grid	60.00	59.96	59.92	60.04	60.07	0.014
S63	Critical Load	60.00	59.95	59.90	60.05	61.07	0.015
S71	From Grid	60.00	59.96	59.90	60.05	60.10	0.016
S71	To Grid	60.00	59.96	59.92	60.04	60.07	0.014
S71	Critical Load	60.00	59.96	59.90	60.05	60.10	0.015
S43	From Grid	60.00	59.95	59.84	60.05	60.10	0.015
S43	To Grid	60.00	59.96	59.86	60.04	60.11	0.014
S43	Critical Load	60.00	59.95	59.86	60.05	61.00	0.015
S43	Critical Load UPS Event 1	60.01	na	60.00	na	60.01	0.001
S43	Critical Load UPS Event 2	60.01	na	59.87	Na	60.02	0.008

Harmonic distortion is a measure of the 60 Hz signal from a pure sinusoidal wave. The distortion can be analyzed to separate it into a range of frequency components. Each frequency has a magnitude component associated with the distortion. The sum of the distortion for each frequency, generally up the 50^{th} harmonic of the fundamental 60Hz frequency is added and the result is the total harmonic distortion (THD) and is represented as a percentage. THD can be measured for voltage or current.

Table 8 shows the results of the voltage THD percent power quality assessment. During general operation both the voltage THD is within specifications for both the interconnection guidelines and SIS ratings. During the simulated UPS event when the SIS is disconnected from the grid, the SIS may have slightly exceeded the THD rating specification as measured by the independent meter, but the independent meter has a THD uncertainty specification of ±1% so the maximum measured value of 5.71 %THD is still within acceptable tolerance.

No power quality issues were seen at the beginning or end of the UPS simulated tests when the power supply transition occurred.

Table 8 Voltage Total Harmonic Distortion Power Quality Assessment Results, THD in %.

Customer #	Condition	line	THD% Average	Minimum 15 Minute Average	Maximum 15 Minute Average	Std. Dev.
S63	From Grid	V1	1.63	1.28	2.06	0.14
S63	From Grid	V2	1.69	1.31	2.23	0.17
S63	To Grid	V1	1.63	1.22	2.01	0.14
S63	To Grid	V2	1.77	1.31	2.20	0.17
S63	Critical Load	V1	1.75	1.34	2.26	0.17
S63	Critical Load	V2	1.63	1.22	2.07	0.15
S71	From Grid	V1	1.63	1.32	2.23	0.14
S71	From Grid	V2	1.69	1.39	2.31	0.15
S71	To Grid	V1	1.65	1.32	2.27	0.16
S71	To Grid	V2	1.74	1.41	2.41	0.17
S71	Critical Load	V1	1.62	1.27	2.27	0.15
S71	Critical Load	V2	1.71	1.38	2.42	0.16
S43	From Grid	V1	1.61	1.28	2.07	0.14
S43	From Grid	V2	1.56	1.21	2.01	0.13
S43	To Grid	V1	1.64	1.30	2.04	0.12
S43	To Grid	V2	1.57	1.19	1.95	0.12
S43	Critical Load	V1	1.55	1.15	1.99	0.13
S43	Critical Load	V2	1.63	1.28	2.10	0.14
S43	Critical Load UPS Event 1	V1	4.81	4.39*	5.31*	0.18
S43	Critical Load UPS Event 1	V2	5.18	4.77*	5.71*	0.19
S43	Critical Load UPS Event 2	V1	4.64	1.42*	5.35*	0.49
S43	Critical Load UPS Event 2	V2	4.99	1.87*	5.52*	0.39

* 1 Second Values (Minimum or Maximum per column designation).

7. PV Firming

PV firming is a term generally used to describe a process by which a storage system can be utilized to smooth the power output to the grid. The smoothing is intended to account for variations or fluctuations in the amount of solar insolation received by the PV panels.

Conventional solar PV systems immediately invert the power received by the panels and inject it into the grid. Sudden changes in cloud cover or available sunlight can quickly change the amount of power generation put onto the grid. For PV systems the sudden changes require the grid to compensate for either the sudden loss or sudden gain in power to the grid. A system such as the SIS with battery storage can be used to smooth the power being sent to the grid, thus maintaining a more stable grid system.

SIS Goals:

The goal as described by Sunverge is to demonstrate the ability of the SIS units to use storage to mitigate rapid output changes from the solar PV panels.

SIS Test Plan:

The SIS has the capability to automatically implement PV firming to smooth out rapid changes in PV power output. It is very dynamic and instantaneous.

Customers in the housing development who are not on the TOU-CPP rate have an operating schedule that sends PV power out of the SIS and incorporates PV smoothing to prevent drastic changes in power output. A range of PV smoothing can be selected, from low to high. The setting chosen for these units was to limit the maximum change in output allowed to 2250 W. The smoothing takes place over a 1-minute period during which the SIS uses the battery to absorb or inject power as needed.

M&V Evaluation:

For this measurement and verification evaluation ADM had to rely on data from the SIS units which have raw data intervals typically every 12-seconds. The PV metering which ADM used throughout the summer was set to collect on 1-minute intervals. The PV data were reviewed from the monitoring period and four days that had fluctuations in the PV panel power output indicating partly sunny / partly cloudy periods were selected.

The days selected for further investigation were August 11, August 22, September 18 and September 21. Data from 24 customers not on the TOU-CPP rate were provided by Sunverge for the review.

The typical record interval in the data set was 12 seconds. The data were analyzed by looking at the difference between the sum of the power on each of the two lines to the grid plus the critical load panel from one reading compared to a reading one minute later. Only periods when the SIS was in “send to grid PV only” mode were analyzed for the PV firming use case. Upon review of the data there were very few cases where the inverter output changed by over 2,200 Watts. There were not enough instances to statistically classify them as a threshold limit. There were a couple cases (see Figure 31) where the change exceeded the 2,250 Watt difference which the firming algorithm targeted. However, these could be explained by uncertainty in the multiple measurements that went into the total output estimation and clock timing, since the records are not at exactly the same time interval between each record. Our conclusion is that the PV firming functioning could be operating as programmed.

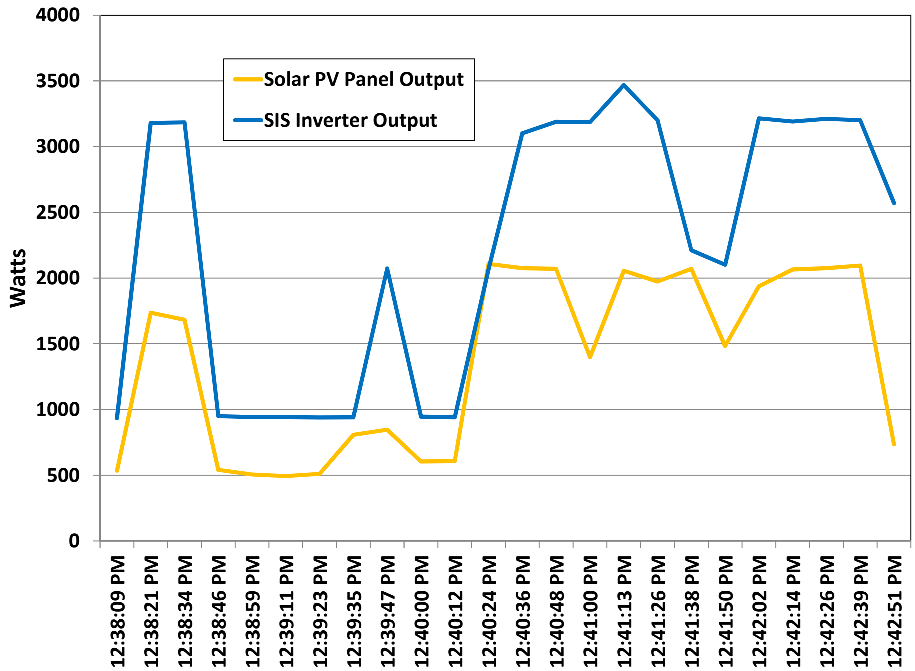

Figure 31 Largest SIS Power Output Changes Observed During "Send to Grid PV Only" Mode.

Another example of rapid solar insolation fluctuations is seen in Figure 32. In this example, the sun dances in between clouds over a 25 minute period. There are times in the chart that the inverter output is larger than the available PV output which is indicative of the inverter supporting the critical load panel using battery storage. Under the programming used in this test, the SIS was not expected to respond to these insolation fluctuations. However, it is recommended that these types of changes should be targeted for smoothing. It is also recommended that Sunverge work to develop more aggressive PV firming control settings in the future, if desired by SMUD.

On a portion of a sunny day the 100 Watt minimum steps that the inverter is allowed to change can be seen in Figure 33 as the solar only changes gradually.

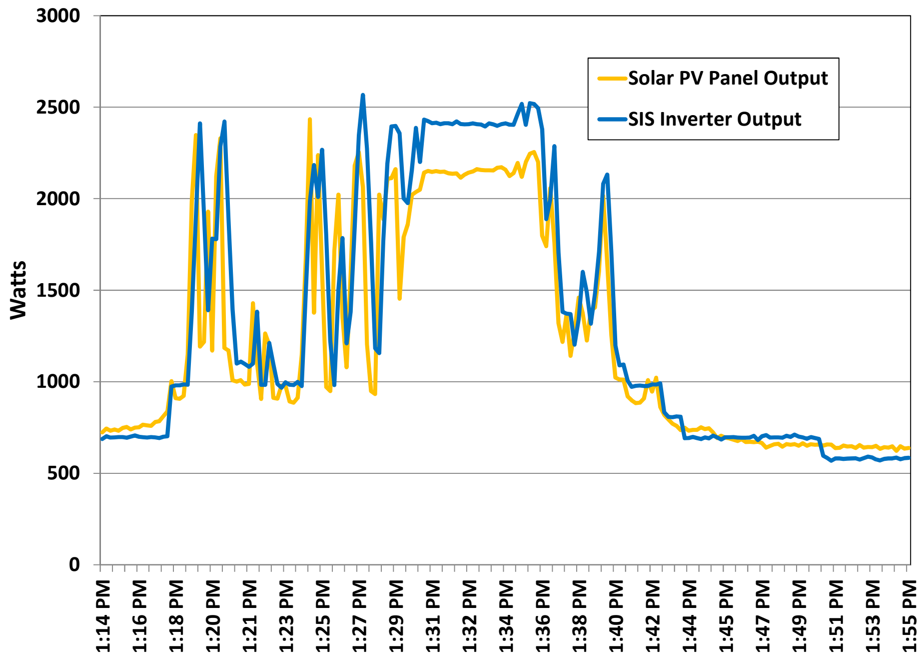

Figure 32 Rapid Changes in PV and SIS Power Outputs During Partly Cloudy Day.

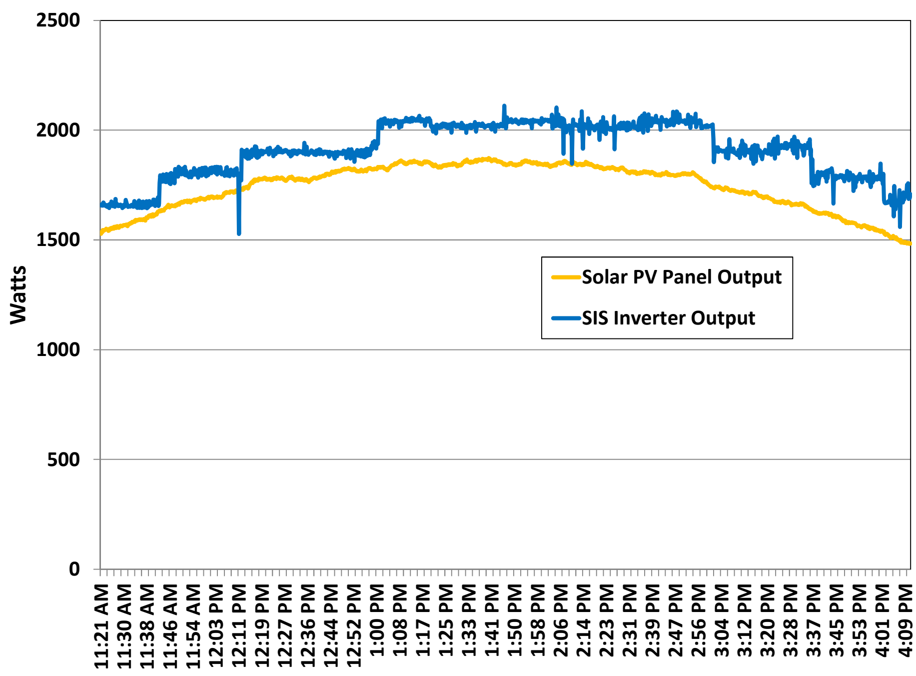

Figure 33 Example of the Inverters 100 Watt Step Minimum Change.

8. Regulation

Regulation is directed by the utility to provide balance on the grid between power generated and power used. Maintenance of line frequency and interchange of power between grid operators are also brought into the equation for regulation. Some power generators are selected to assist in balancing the grid. To accomplish regulation SMUD uses an application called Automatic Generation Control (AGC). The AGC measures line frequency and bias, and calculates the change of power being injected onto the grid to correct for frequency deviation. The AGC monitors the flow of power on tie lines and compares total delivered or received power to scheduled interchange deliveries with WAPPA, CAISO, etc. The difference in the interchange schedule versus actual is added to the frequency deviation, creating the Area Control Error (ACE). To correct for the ACE, the AGC sends out a pulse signal to generators that are in load following mode. Generators in load following mode have a base load they are scheduled to deliver and that base load is then adjusted for ACE resulting in an adjusted load delivery. Each generator has a response time and rate associated with the physical limitation of the system which is provided to the AGC for modeling. The AGC runs a model every four seconds to assign load adjustments to each generator operating in load following mode based on response rates and demands of the grid system. The pulse signal to each generator could request a specified increase or decrease in load output. If no change is needed then there is no signal sent to that generator.

SIS Goals:

The goal is to demonstrate the ability of the SIS units to respond to a simulated regulation pulse signal. Future tests are expected to integrate with actual AGC signals from SMUD.

SIS Test Plan:

The simulated regulation pulse signal will be sent from Sunverge to the SIS units. SMUD provided a file containing a real pulse signal sent from the AGC to a generator. The file was modified in two ways to use as a simulated signal for the regulation test. The magnitude of the load adjustment requests were changed by dividing by 10,000 to accommodate the capacity of the SIS units. The units were changed from MW to Watts. The file was also modified to contain a pulse signal every four seconds to make it easier to send the simulated signal. Zero wattage adjustments were inserted where the original file skipped intervals because no adjustment to the load was requested. The resulting file was the target regulation pulse signal used for the test. The regulation test period was two hours long and was preceded by a five minute period where the SIS was set to output 495 W to the grid.

Sunverge ran tests using laboratory SIS units prior to conducting the tests on units installed at the project housing development to ensure nothing would be done to compromise the operation of the SIS units or impact the customer's power supply. These tests took longer than expected but were successfully completed in time to run one actual simulated regulation test so the results could be included in this report. Initially the test plan called for conducting two sets of tests.

A computer at Sunverge held the target file. A program was used to send the simulated pulse signals from the computer to the Sunverge Cloud Application Programming Interface (API) every four seconds. This part of the plan did not go as smoothly as expected. There were intermittent delays in the signal uploading to the API. This should not be a problem with a real test using the AGC pulse signal since the problem arose on the sending side rather than the API receiving side. The simulated regulation signal was sent to 33 SIS units. This test is another example of fleet operation of the SIS units.

M&V Evaluation:

ADM had PEL loggers collecting measurements of power output by the SIS to the Grid (main panel) in one second intervals. These were active for two of the SIS units in the test. The PEL clocks were instructed to synchronize with the laptop clocks, which had already been synchronized with NIST[8]. Synchronizing the clocks on the PEL loggers was not completely successful. ADM verified the clocks on the PEL loggers updated but were not exactly synchronized. The clock on the PEL for customer #S63 was verified to be four seconds fast during the regulation test and the PEL for customer #S71 was verified to be three seconds fast during the regulation test. The test was conducted on December 5, 2014 starting at 2:30 p.m.

Figure 34 shows the targeted simulated regulation signal versus actual simulation signal. The intent was for the targeted simulated regulation signal to be sent to the SIS units. However, an issue with the simulator used for this testing resulted in the time shift shown in Figure 34. The actual simulated regulation signal is the one controlling the SIS load output.

Figure 35 shows the measured and test signal loads during the regulation test for customer #S63. The chart was similar for customer #S71. The chart does not show the requested load adjustment but rather the accumulated requested load adjustments. The PEL measured load to the main grid generally showed a similar change relative to the actual simulated regulation signal anywhere between two seconds before to three seconds after. Further testing may be needed to understand why the timing sometimes showed the measured response before and other times after the actual simulation regulation signal. In any case the response to the regulation signal was fast and less than four seconds. A scatter plot of measured power differences versus simulated regulation signal power differences when there is a request for a load change is shown in Figure 36. Although not every simulated regulation pulse signal requesting an adjustment showed a measured change in the load output. Twenty-nine percent of the simulated regulation pulse signals requesting an adjustment had a measured change of less than 10 W, which for practical purposes is no load change because of the uncertainty. The responses were within 100 W of the requests.

It is recommended that additional regulation testing should be conducted to verify responses although this first test shows very promising results. ADM suggests that larger requested changes in the load be requested by the pulse signal. The responses were within 100 W of the requests. This may suggest that when there is a small request for load adjustment only a subset of the units should be designated to respond rather than the entire fleet.

[8] National Institute of Standards and Testing website http://www.time.gov/widget.html

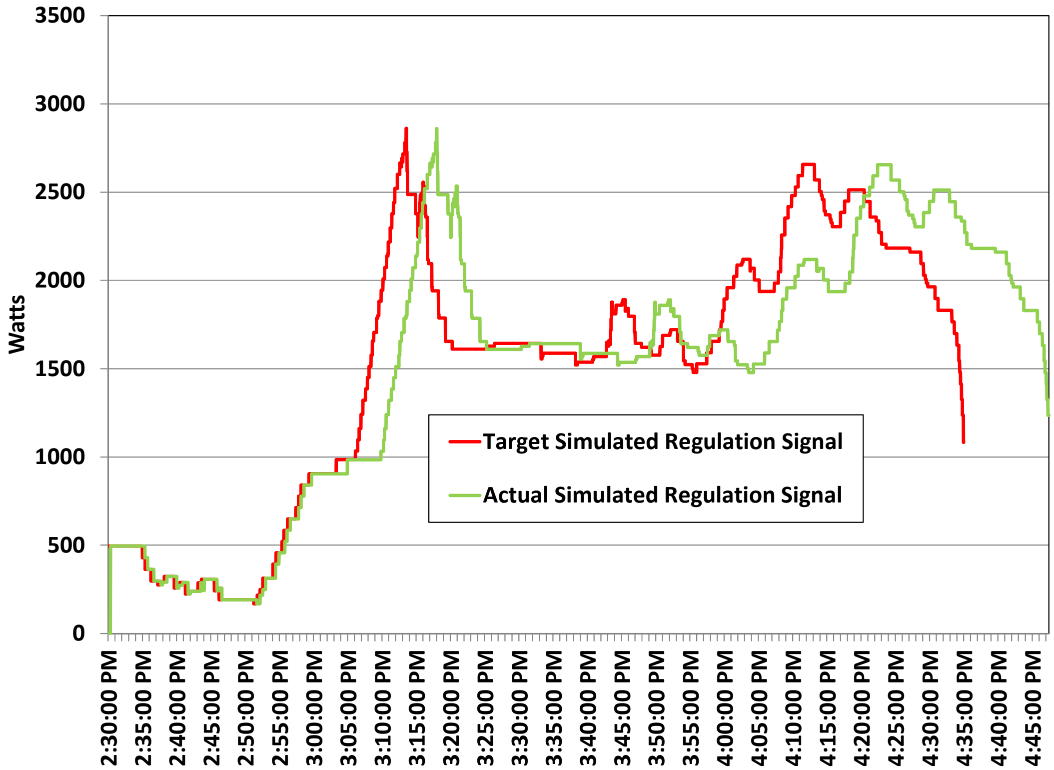

Figure 34 Target and Actual Simulated Regulation Signal.

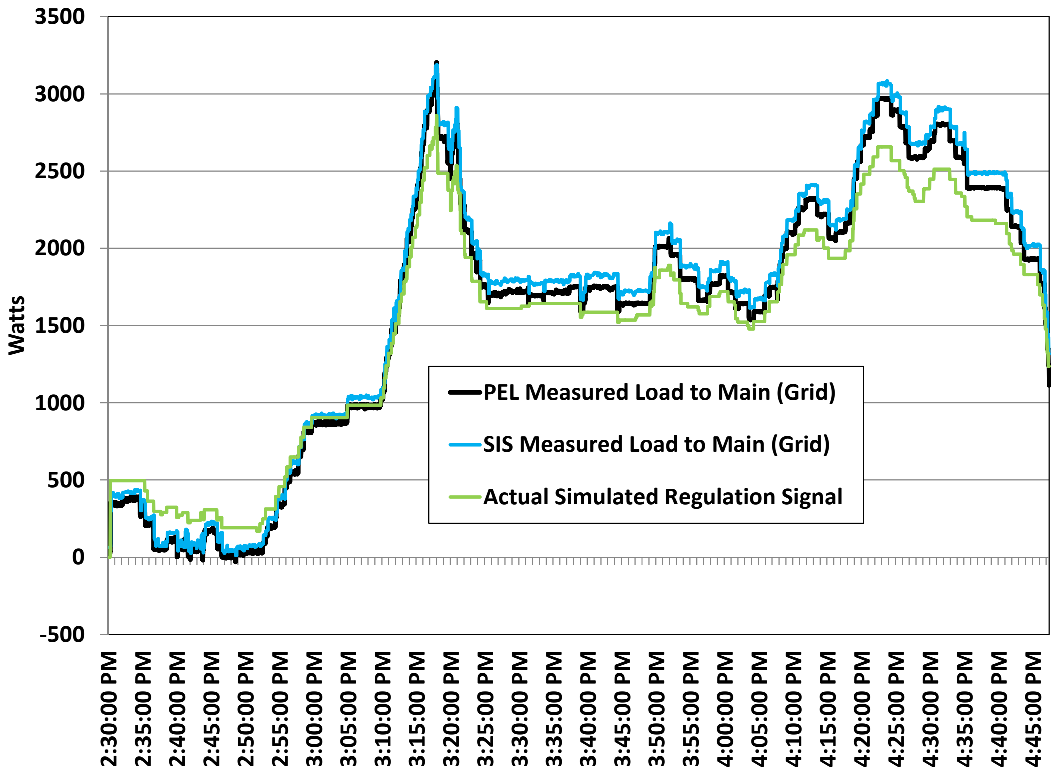

Figure 35 Regulation Test Loads for One SIS Unit.

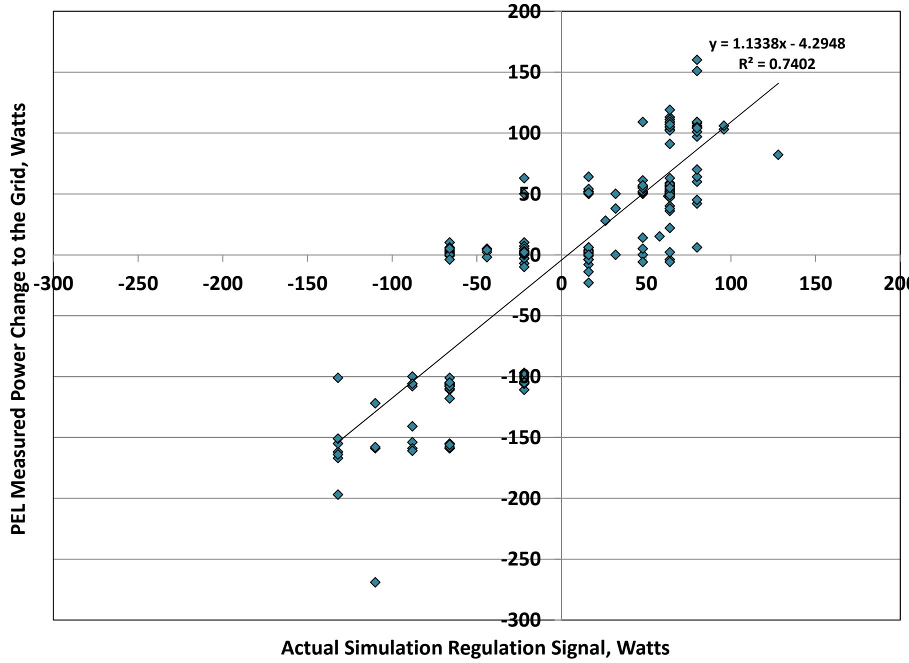

Figure 36 Measured Power Differences Versus Simulated Regulation Signal Power Differences.

9. Validation of Sunverge and ThinkEco Data

The original intent was to collect data from all the houses using the SIS and ThinkEco systems. ADM would provide a validation of the data using independent meters and then proceed to use it for the analysis. This approach was not relied upon due to issues with the data.

The SIS can collect data as frequently as every four seconds, although throughout most of the summer data was collected in approximately 12 second intervals. Sunverge provided 15 minute data for all the sites so that a comparison could be made with the independent meters. Some of those independent meters were the utility meters. At three houses additional meters were added to verify and validate the meters for the critical load panel and the lines between the SIS and main house panel (grid from the perspective of the SIS).

The power measurements for the lines between the house panel and SIS showed high correlation and would be acceptable for use in analysis of the systems. The comparison between the PEL meter and the SIS meter for the house panel total load for customer #S43 is shown in Figure 37. The other two show similar characteristics. Linear regression trend lines were added to provide statistical comparison. The slopes range from 1.014 to 1.038 with offsets ranging from -13 to -19 Watts. The R squared correlations were all at least 0.999. These comparisons were within the target range of less than ±5% difference.

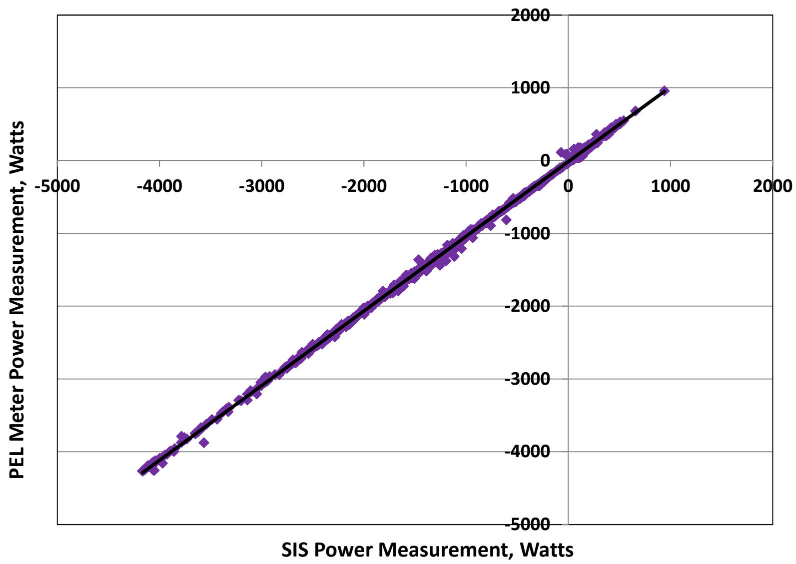

Figure 37 House Panel (to Grid) Power Measurement Comparison of Two Meters.

The power measurements for the critical load panel did not show as high of a correlation and would not be acceptable for use in analysis of the systems. The comparison between the PEL meter and the SIS meter for the critical load panel for customer #S43 is shown in Figure 38. The other two show similar characteristics with a significant amount of scatter in the comparison. The slopes range from 0.84 to 0.97 with offsets ranging from -17 to -38 Watts. The R squared correlations ranged from 0.74 to 0.90. These comparisons were not within the target range of less than ±5% difference.

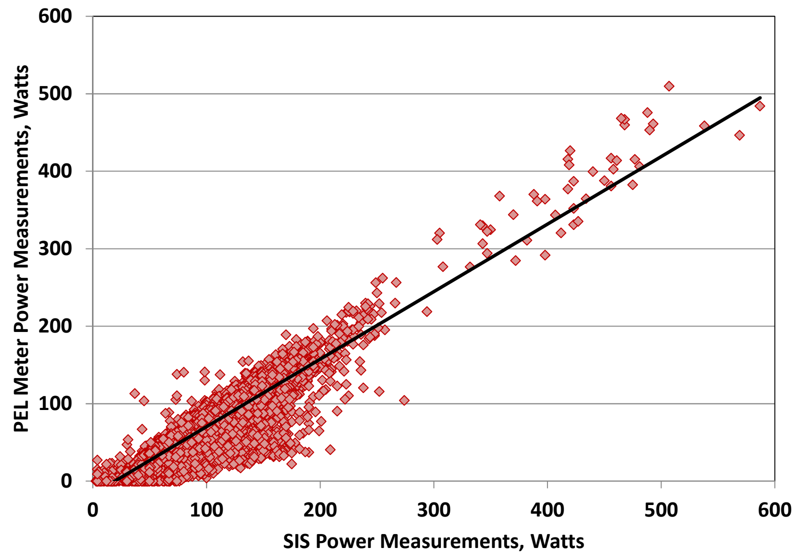

Figure 38 Critical Load Panel Power Measurement Comparison of Two Meters.

The SMUD meter data were compared to the whole house data collected by the SIS. Both sets have records for energy delivered to the house from grid and received by the grid from the house. For the comparison, the net energy delivered to the house was calculated and aggregated into daily values. Only days with full data sets were compared. In general the SIS meter data were highly comparable with the utility meter data. See Figure 39 for a sample.

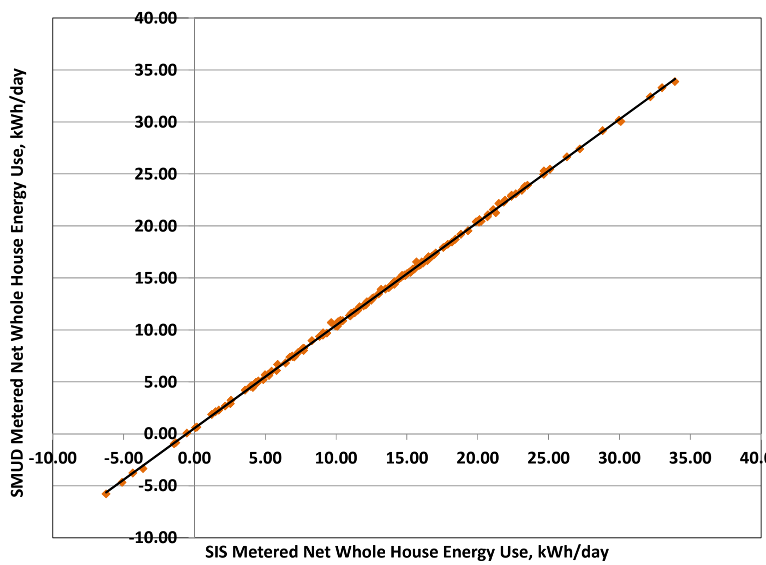

Figure 39 Sample of Daily Energy Use Comparison for Customer #S72.

However there were four houses of the 34 which did not match. This is more than 10 percent of the sites. There were two houses from the SIS dataset that were low by a factor of approximately four, which could be explained if the values provided were Wh rather than W, since the data was in 15-minute intervals. For another house, the power in and power out columns appeared to have been swapped. The four houses had unknown reasons for not matching although some of the power out data from the SIS was higher than the SIS rating. The issues with using the SIS data for these four houses may not have been identified without the comparison to the utility data. There was another reason the whole house data were not used as a primary source of data. In the original dataset from Sunverge, there were numerous gaps ranging from hours to days which often only impacted a subset of the total number of houses. This makes it very difficult to generate profiles for baseline days which only have a limited number of points going into the average even with a clean dataset.

The 30 houses with good SIS comparisons to the utility data support the general quality of the meters as long as an offset is taken into account. The slope of the dataset for these 30 homes ranged from 0.978 to 1.008 with an average of 0.990. The intercepts ranged from 0.14 to 0.63 and averaged 0.45 kWh/day. This means that if the SIS data were to be used, about 19 Watts should be subtracted from the power readings before analyzing. The R squared correlations were all at least 0.996.

PV power output measurement data from three systems were compared between the values provided by the SIS and the measurements independently made by ADM. The R squared correlations were very good with the lowest being 0.9967. The slopes ranged from 0.9482 to 0.9871 and averaged 0.9715. Since there is no precedence in which meters were the most accurate the difference was split. A slope of 0.985 and offset of zero was used to correct the SIS PV data. See Figure 40 for an example of the PV power output comparisons.

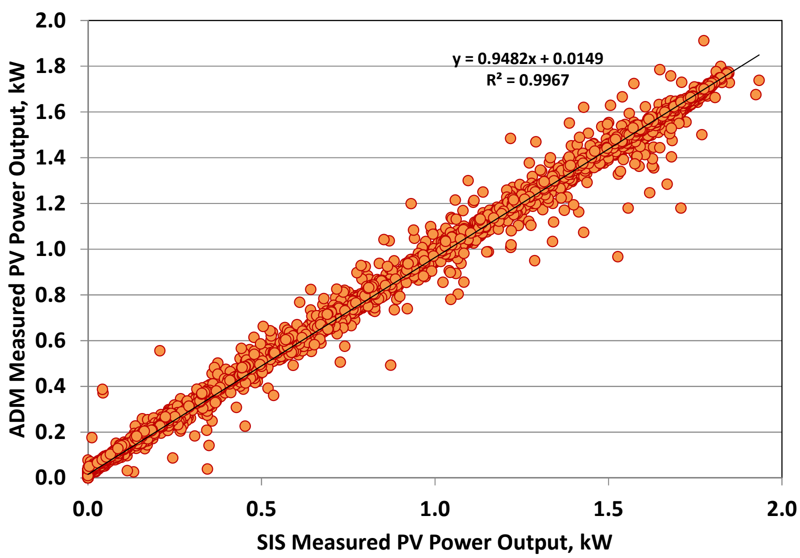

Figure 40 Sample of PV Power Output Comparison for Customer #S43.

Three houses had an independent temperature logger mounted near the PCT thermostat to independently verify the PCT readings. Figure 41 shows three days of PCT temperatures along with the TandD temperature logger data. The TandD logger data is about two degrees higher than the PCT but tracks very well. The tracking and relative changes in recorded temperature is much more important in verifying the operation of the PCT than the absolute measurement.

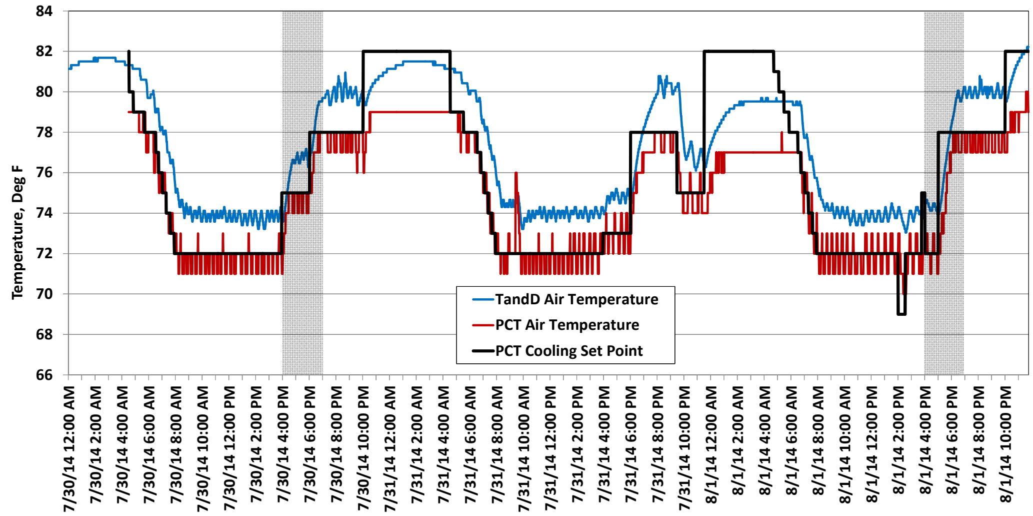

Figure 41 Three Days of PCT and TandD Temperature Data Comparisons

The modlets were independently monitored only for a short time (5 days) and only with small loads. Figure 42 and Figure 43 show the comparison of the independent WattNode power measurement versus the power measured by the modlets for a fan and a printer. The units are average Watts over 15-minute intervals. The trend lines were setup with the intercept at zero. The slopes are near one and the R-squared is good the limited number of points available. The conclusion is that the ThinkEco modlet power readings are acceptable for use in this report.

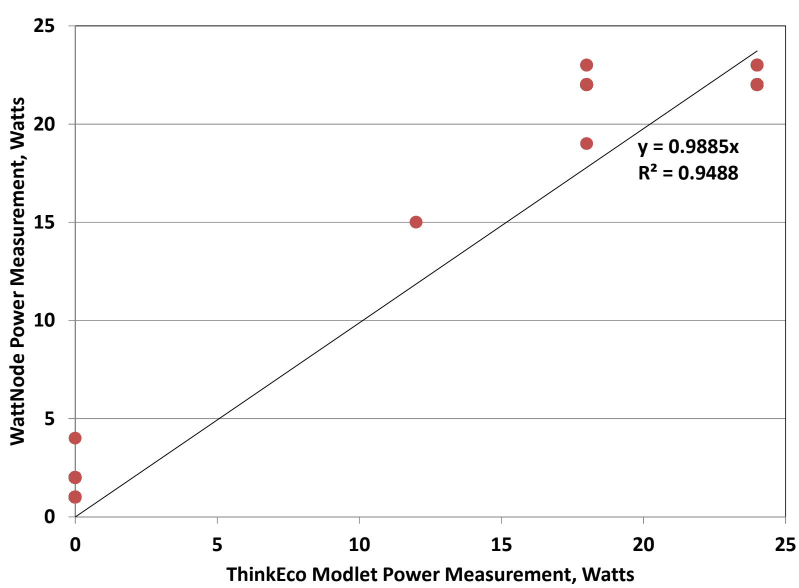

Figure 42 Comparison of WattNode versus Modlet Power Measurements of a Fan.

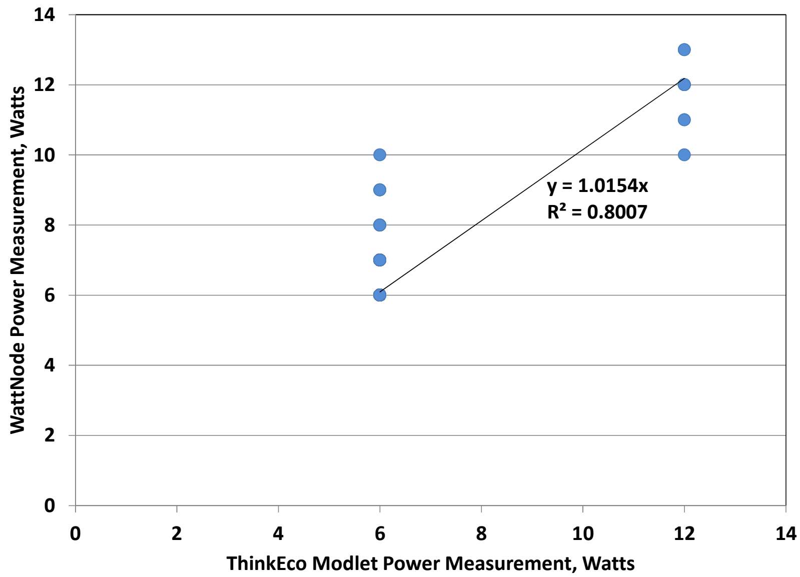

Figure 43 Comparison of WattNode versus Modlet Power Measurements of a Printer.

10. Discussions

This section addresses some supplementary issues.

The PV firming algorithm functioned as Sunverge expected. More significant benefit to the grid could be obtained by the program implementer, such as SMUD, coordinating system settings with Sunverge to avoid rather rapid changes in power fluctuations to the grid. A longer smoothing period is suggested for the future. The duration of an improved smoothing setting may better be answered by grid operators. The change in power to the grid from a single SIS would not greatly impact the grid, however the impact would increase with a larger fleet and as more are added to the grid. It is recommended that Sunverge could take greater advantage of the SIS's ability to provide value and mitigate a grid problem caused by standard PV systems. One mechanism that grid operators might consider is, a financial incentive to encourage systems such as the SIS to provide firming that is in the best interest of a stable grid.

Another use case that may be of interest but was not included in this phase of the project is spinning and non-spinning reserves. Further mode operation of the SIS and additional settings would need to be agreed upon prior to the operation of this mode.

Many of the SIS use cases have competing resources or goals. For the purposes of this evaluation, testing for each use case was conducted independently. The SIS does have the capability to operate multiple use cases simultaneously through layering of programs based on priority and the ability to reserve portions of the battery for different use cases. When establishing the operation of the SIS, a strategy must be developed to identify which are the most important or financially rewarding to the invested party. How to decide on which modes a SIS or fleet of SIS should operate was not in the scope of this project.

Another set of information added to this report is the average energy from SMUD per household. The average net utility meter energy use by month is shown in Figure 44. The number of occupied homes by rate type is listed above each bar. Prior to June all customers were on the non-TOU-CPP rate. The energy usage shown here does not correspond directly to the customer's energy bills and savings.

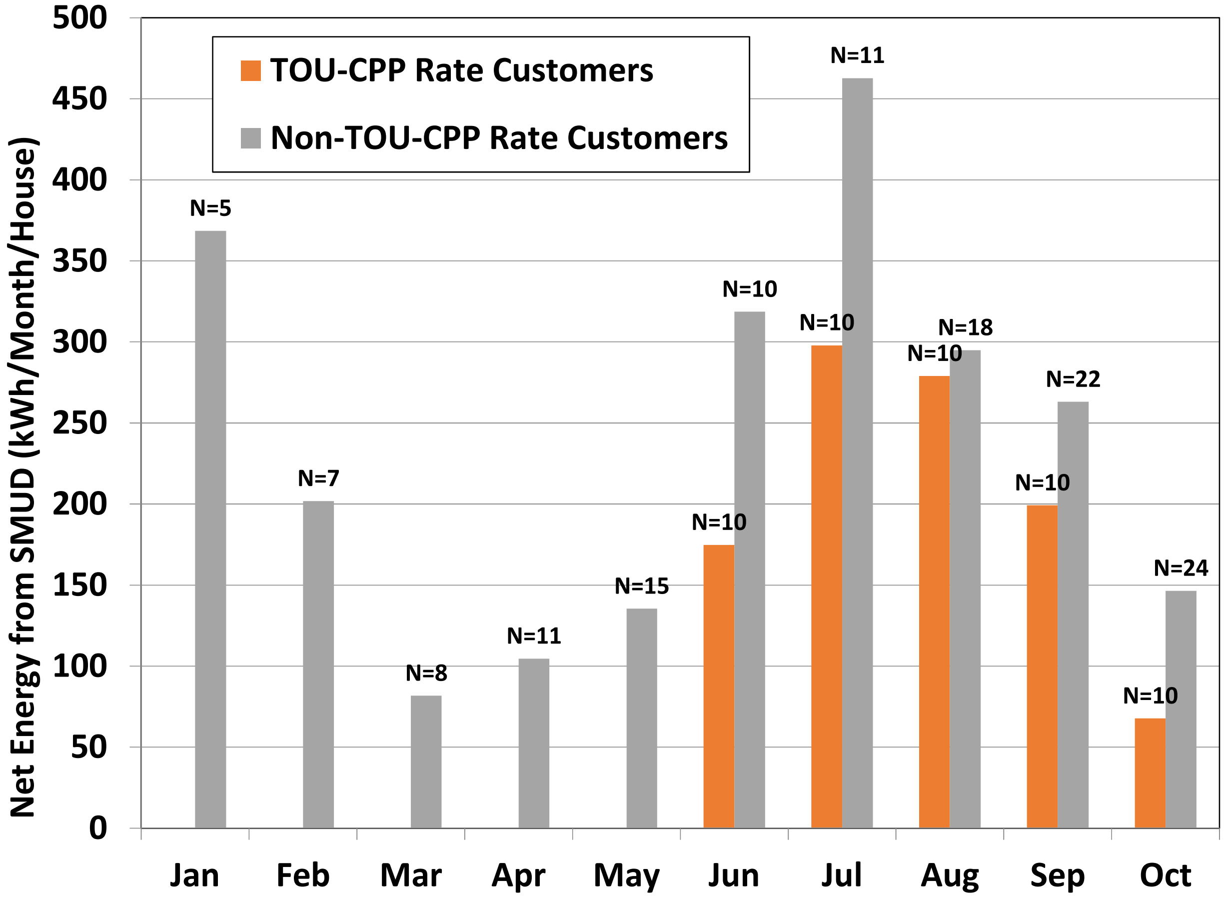

Figure 44 Average Household Net Energy Supplied by SMUD by Month.

11. Conclusions

The objective of the study was to verify that the SIS and IEMS could be controlled to provide energy flow to the customer and the grid in pre-defined modes of operation that are beneficial to the utility and the customer. The various modes are classified as use cases and include: Load Shifting, Fleet Operation in Aggregate, Uninterruptable Power Source (UPS), Power Quality, PV Firming, and Regulation.

Load shifting on conservation days at the participating homes was achieved through the following series of activities:

- Using the SIS to store PV power during mid-day and sending this power to the grid during the on-peak period;
- Using the PCT settings to pre-cool the house;
- Raising the cooling set point during the on-peak period to reduce air conditioning use; and
- Using the modlets to turn off power to selected loads.

Load shifting on non-conservation weekdays provided 1.35 kW of savings on average from the IEMS. The average incremental IEMS demand savings peaked at 2.80 kW during the first hour and averaged 1.31 kW for the entire on-peak period on conservation days compared to non-conservation weekdays for the participating houses. The average total IEMS load shifting on conservation days compared to no IEMS peaked at 4.38 kW and averaged 2.66 kW for the entire on-peak period. The peak and average demand savings during the on-peak period for different day types per control strategy are presented in Table 1.

Table 9 Average Demand Savings On-Peak Period by Control per House

	Non-Conservation Day Demand Savings, kW	Incremental Conservation Day Demand Savings, kW	Total Conservation Day Load Shifting, kW
IEMS, Maximum	1.68	2.80	4.38
IEMS, Average	1.35	1.31	2.66
SIS & PV, Maximum	1.49	2.27	3.87
SIS & PV, Average	1.26	1.07	2.47
PCT, Maximum	na	1.16	1.16
PCT, Average	0.09	0.35	0.19
Modlet, Maximum	0.00	0.003	0.004
Modlet, Average	0.00	0.003	0.004

Although operation of the PCTs did shift air conditioning load, review of control system data showed that the cooling set points were not always set as scheduled, and significant blocks of data were missing. Modlets provided very small savings due to the low load appliances plugged in and variability of use of these loads.

Fleet operation was confirmed, as all 10 participating customers were operated as a fleet. Analysis showed that they all contributed to the average load shifting savings on conservation and non-conservation days.

A critical load panel in the house is wired so the SIS can maintain power to some of the homeowner's loads in the event of a grid power failure. As no confirmed grid power outages occurred prior to the scheduled testing, the uninterruptable power source mode was tested by simulating a grid power failure. When the breaker connecting the SIS to the grid was disconnected, the critical load panel appliances continued to operate. After the scheduled simulation, one other successful use of the UPS occurred when service was disconnected from one home after a customer did not pay their electric bill.

The SIS maintained power quality to the grid in accordance with SMUD interconnection guidelines. The only minor deviation from the power quality guidelines occurred during the UPS test when the SIS was disconnected from the grid and the voltage total harmonic distortion parameter was slightly exceeded, although this deviation is not conclusive since it was within the uncertainty of the measurement error bounds.

The SIS is functioning according to Sunverge's algorithm to provide PV firming. However, the possibility of using PV firming more aggressively to smooth and level out the power flow to the grid during times of partly cloudy / partly sunny conditions should be explored in conjunction with SMUD. This would ensure that the SIS units are providing SMUD with as much value in PV firming as desired. The current controls provide firming on the time frame of one minute.

Only one simulated regulation test occurred prior to the deadline of this report and it showed very promising results. The simulated regulation test signal had some timing problems due to the simulation tool. Despite this issue, it appeared that the response time of the SIS units were less than four seconds. The responses were within 100 W of the requests. However, it is recommended that additional regulation testing should be conducted to verify responses.

Many of the SIS use cases have competing resources or goals. For the purposes of this evaluation, testing for each use case was conducted independently. The SIS does have the capability to operate multiple use cases simultaneously through layering of programs based on priority and the ability to reserve portions of the battery for different use cases. Some modes of operation have competing interest in the use of battery storage allocation. When establishing the operation of the SIS, a strategy must be developed to identify which modes are the most important or financially rewarding to the invested party.

Recommendations

The following recommendations are provided for consideration.

- Further investigate the PCTs to determine whether they are able to schedule the control of the cooling set point in a reliable manner.
- If possible, consider providing a complete and time-consistent dataset of the PCT cooling set points for analysis.

- Work with Sunverge to develop more aggressive PV firming control settings if desired by SMUD.
- Identify if there are any standards for PV firming.
- Conduct additional regulation testing to verify responses and consider approaches for providing larger requested changes.
- Determine the priority level of these use case strategies.
- Investigate the spinning and non-spinning reserve capability the SIS has and conduct tests to verify.

12. Appendix A: Monitoring Instrumentation

Monitoring Instrumentation

Since long term monitoring was proposed, the monitoring equipment was selected and combined to allow remote data collection. The communications were centralized in a laptop computer at each of the three houses with detailed monitoring. Loggers were either connected to the laptop by a USB or Ethernet cable. Since multiple Ethernet cable loggers were in use, a hub was supplied to expand the number of ports available on the laptop. The laptop was connected to the internet via an Ethernet cable to a router at the house. The laptop was setup for secure remote login and access. It was operated from ADM's office to manually initiate data downloads to the laptop. Synchronization of the data files to a central network computer was automated.

AEMC PEL 103 Power Energy Loggers were used to measure ac power output from the inverter and from the grid to the critical load panel. The PEL 103 is a meter and logger. Voltage, current, and true rms power on each line (120 V), between the lines (240 V), and neutral (0 V) were recorded on 1-second intervals. The meter recorded bidirectional flow of power (as either + or -values). The PEL also records line frequency and total harmonic distortion of voltage and current power factor, kVA and kVar. Energy was recorded in 15-minute intervals. Data are stored on an SD card which will holds approximately 15 days of 1-second resolution data.

Other power measurements were made with WattNode® pulse outputting watthour transducers from Continental Controls. Model WNB-3Y-208-P WattNodes® were used. These are measurement devices only and do not log or record. The pulse output is proportional to the energy measured. There were two 20 Amp high accuracy CT's (Continental Controls model ACT-0750-020) connected to the WattNodes for the air conditioner monitoring. The modlets were monitored using a plug-in appliance logger containing a WattNodes® and a HOBO State logger (model UX90-001M). The plug-in appliance loggers were the only devices that were intended for short term data collection and were manually retrieved to download the data.

TandD brand wireless loggers were used to collect pulses from the WattNodes® and room temperature from within the houses. A model RTR-500NW base station was located next to the laptop and received the 900Mhz signals from the model RTR-505-P pulse loggers and RTR-501 temperature loggers. At 1-minute recording intervals they will hold 11 days of data. The loggers have extended battery packs which will allow for over two years of operation.

Two battery operated Onset HOBO® data loggers were installed in the enclose holding the laptop, PEL loggers, and TandD base station. One (model U12-014) was simply used to monitor the temperature inside the enclosure. The other is a 4-channel analog logger, model UX120-006M. Although both of these are battery operated, they are permanently connected to the laptop via a USB cable which powers them, so the batteries only act as backup power for the loggers. The 4-channel analog logger collects data from a precision voltage divider for the dc line from the PV panel and a CT (current transducer) on the dc line from the PV panel. The CT is a model DLTB-420-24L-U-SP from NK Technologies with a 4-20 mA output and is rated at 50 Amps dc.

ADM also relied on SMUD-installed Smart meters at the houses to measure and record electrical energy use delivered to and received from the customer. SMUD provided hourly average kW (kWh) data for all the houses from the time they were occupied until October 31, 2014.

Monitoring Equipment Accuracies

PEL 103 loggers: The combined meter and sensor accuracies for the ac power measurements are ±1.5% for the equipment and ±2% for positioning. Resolution of AC measurement is 0.001W. AC voltage and current harmonic distortion measurements have an uncertainty of ±1%. The ac frequency measurement resolution is 0.01 Hertz.

The WattNode® power accuracy rating is ±0.5% at 5% to 100% of full scale. High-accuracy split-core current transducers (CTs) were used which have an accuracy of ± 0.5% from 1% to 100% of full scale.

DC power measurement accuracies are ±1.2% for the current, ±0.3% for the voltage and ±2% for positioning. Resolution of dc measurement is approximately 0.001W

The TandD pulse logger is has a resolution of 1 pulse and the clocks are automatically synchronized with the web available NIST clock weekly. The temperature logger has an accuracy of 1ºF and a resolution of 0.2ºF.

The Hobo loggers have a clock accuracy of 1 minute per month. The clocks resynchronize when they are launched or re-launched.

13. Appendix B: Additional Details

This appendix includes additional details of the evaluation which are not included in the main body of the text to avoid distraction from technical details.

Load Shifting

The following table (Table 10) contains a list of the three hottest days prior to an event which were used to generate the baseline day.

Table 10 List of Three Hottest Eligible Days Used to Generate Baseline for Conservation Days

	July 1	July 25	July 29	July 30	Aug 1	Sept 11	Sept 12	Sept 16
Day 1	6/20	7/14	7/14	7/14	7/24	8/28	8/28	9/1
Day 2	6/23	7/15	7/24	7/24	7/28	9/1	9/1	9/4
Day 3	6/30	7/24	7/28	7/28	7/31	9/10	9/10	9/10

Figure 45 shows the hourly savings profiles for all eight of the conservation days relative to non-conservation days for the TOU-CPP rate participating customer homes. This profile was developed from the SMUD hourly meter data.

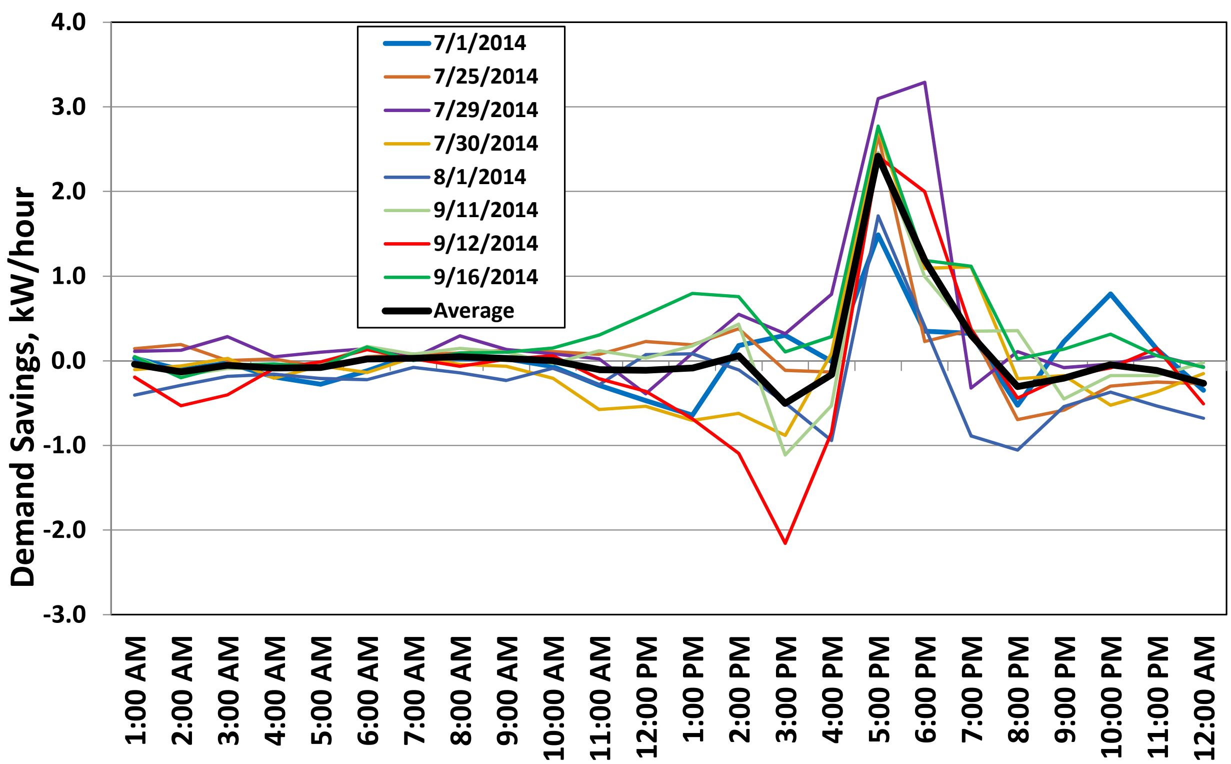

Figure 45 All Eight Conservation Day IEMS Savings Profile for Participating Homes.