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Author

Kiliccote, Sila

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Field Testing of Automated Demand Response for Integration of Renewable Resources in California's Ancillary Services Market for Regulation Products

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Sila Kiliccote, Phil Price, Mary Ann Piette & Geoffrey Bell
Lawrence Berkeley National Laboratory

Steve Pierson & Edward Koch
Akuacom/Honeywell

Jeremy Carnam & Hugo Pedro
SolAspect & UC Merced/ UC San Diego

John Hernandez & Albert Chiu
Pacific Gas and Electric Company

Abstract

Increasing renewable generation resources supply electricity to 33% by 2020 in California will require solving several problems simultaneously. In California, 33% penetration of renewable generation resources propose four major challenges: 1) unpredictable and steep ramps; 2) making up for errors in forecasting these resources; 3)intra-hour variability; and 4) over generation in the middle of the night. Storage and demand response are being proposed as ways to address these challenges.

Following successful tests using demand response for non-spinning reserves in California Independent System Operator's ancillary services market, we explored the use of demand response for regulation up and down products in the same market. Regulation is the capability to inject or withdraw power from resources in response to automatic generator control signals to meet the Area Control Error needs of the Independent System Operator. Resources participating in regulation are characterized and certified to meet certain requirements. The objectives of this project were to evaluate if the demand response resources could meet the requirements to replace the generators in this market and if OpenADR would be able to meet the communication speed requirements. Three facilities were recruited to the project: two campuses and one agricultural pumping station. Each site was equipped with an OpenADR client that could receive the automatic generator control signals converted into OpenADR information exchange model. The results showed that 1) the pseudo generator model did not work well for demand response resources; 2) converting automatic generator control signals to OpenADR signals did not introduce significant communication delays; 3) accuracy of load forecasts may introduce significant problems with demand response participation; and 4) latencies due to the facility control system may be a major barrier.

Executive Summary

Introduction

In 2009, Lawrence Berkeley National Laboratory (LBNL) assisted Pacific Gas and Electric Company (PG&E) and Akuacom to demonstrate the technical feasibility of commercial and industrial (C&I) customers to participate in California Independent System Operator's (CAISO) non-spinning reserves products in the ancillary services market. During the same 2009-2011 demand response program cycle, PG&E had proposed to conduct a two-year pilot study on the use of OpenADR to automate DR with C&I customers so that DR resources could be used to mitigate the intermittency of renewable energy resources. The study was conducted in two phases. The first phase was a scoping study exploring the issues the CAISO is expected to face as the state moves towards achieving its 33% renewable portfolio standard (RPS) by the year 2020 and proposing demand-side resources to solve these issues (Kiliccote et al. 2010). The objectives of this second phase of the project were to evaluate if the demand response resources could meet the requirements to replace the generators in this market and if OpenADR would be able to meet the communication speed requirements.

Methodology

The methodology for this field study included site recruitment, control strategy development with the sites, resource characterization, automation system development, establishing communication, enabling data collection and evaluation of sites' participation in regulation. LBNL developed site recruitment criteria and worked with PG&E's account managers and industry leaders to recruit sites. As a results of this effort, three sites were recruited: University of California Merced (UC Merced), San Mateo Community College (SMCC) and West Hill Farms (WHF). Each site was equipped with an OpenADR client connected to the OpenADR server. The OpenADR server received setpoint instructions for each demand response resource, converted them into load levels to which the sites could respond. Each site preprogrammed demand response strategies within their energy management and control system to increase and decrease demand to respond to regulation down and regulation up, respectively. In the case of the agricultural pumping site, the control strategy resided in the cloud-based control system. For each demand response resource, forecast of loads for each day was developed by a third party and made available to the CAISO. Other information that was provided to the CAISO was the four-second data that was captured by the telemetry equipment installed at the facility. To evaluate the performance of the sites, their actual participation was to be compared with the characterization of the demand response potential. In addition, latencies of the communication to each site and latencies of the controls at each facility were measured. Finally, forecasts are evaluated using the average error, the median error, and the standard deviation of the error.

Results

The results were summarized in three categories:

1) *Forecast evaluations:* Relative Root Mean Square Error (rRMSE) for UC Merced, SMCC and WHF using all available data were high: 16.8%, 9.4% and 17.6%, respectively. Since the pseudo generation performance is evaluated using the load forecasts, these errors pose a significant barrier in DR participation in regulation. More information on the operation of the facility and other factors that affect the loads should be made available to develop more accurate forecasts. In addition, certainty around availability of resources can enhance the system operator's confidence in the performance of these resources.
2) *DR evaluations:* All three sites were less than ideal for this study. San Mateo's mild climate and difficulties with implementing lighting strategies were major challenges at SMCC. UC Merced's challenges were as follows: behind the meter solar resources caused large forecast errors; thermal storage system was excluded from tests; tests were only allowed to take place during times when solar resources were diminishing and the campus was transitioning out of the solar system; and data were missing during the tests which were not recovered. At WHF, once the frequent on/off control of pumps was rejected by the site, because of fear of soil and sand getting stuck in the irrigation pipes, a variable frequency drive was installed. However, because the meter was installed at a wrong location, the tests did not capture actual load drop data.
3) *Latencies associated with communicating ISO signals to OpenADR clients and control of loads:* Inserting an OpenADR server and clients to facilitate automation and convert ICCP to OpenADR using the public Internet added on average less than 2 second delay in the transmission of these signals to the facilities. Downstream from the OpenADR server, the latencies depended on the facilities' control and communication architecture and priorities within the sequence of operations. The latencies after the OpenADR clients received the signals and reached the loads ranged from two seconds to over two minutes.

Observations and Recommendations

Demand-side issues

- ***Customer education needed on ancillary services markets and regulation products***. The recruitment effort was able to capture some early adopters not on the customer side but on the controls vendor side. We observed strong involvement from each vendor.
- ***Limiting customers' regulation participation to certain hours***. While regulation products are used continuously by the system operators, putting boundaries for each DR resource improves recruitment of sites. Customers were more open to thinking about responding two to three hours during the day and/or at night when their end uses may be available for regulation participation.
- ***Switching off equipment vs. modulating equipment (equipment operation issues)***. The end use response can be abrupt by switching off loads or gradual by using variable frequency drives on the pumps and fans that are part of the facility loads. The wear and tear of the DR strategies on the existing building equipment was not considered in this project.
- ***Accuracy of forecasts***. DR resources are evaluated using the forecasted loads. Therefore, the accuracy of the forecasts influence the accuracy or certainty of the DR resources delivered.
- ***DR resources are not the same as generation resources***. DR resources are variable depending on the time of day, day of the week and season. However, they are controllable. The variability is due to the variability of loads that may or may not be controlled for DR purposes. In addition, the ramp up and ramp down times of these resources may vary depending on many factors such as the season, end uses being controlled, etc.

Communications

- ***Resource characterization parameters are inadequate for DR***. A single ramp rate and an offset to avoid negative values were major limitations of the characterization of DR resources. DR resources should have separate ramp-up and ramp-down rates as well as having the capability to have negative values.
- ***Slow DR communication infrastructures may not be able to meet the regulation latency requirements.*** We utilized the existing communication and control infrastructures within the facilities and the Internet to PUSH signals from the DRAS to the site. The results of the latency tests showed that depending on the communication and control infrastructure at each site, the latencies vary and may not meet the regulation requirements. Therefore, at each participating site, in addition to the resource characterization tests, communication latency characterization has to be conducted.
- ***A SOAP or REST based PUSH architecture requires alternatives in the long-term.*** While the project team decided to use this architecture to test the technical feasibility of responding within 4 seconds, alternative methods were also researched through the process. For Internet communications, "long polling" is suggested as an alternative. OpenADR may be utilized over other transports that have inherent capabilities dealing with signal latency and security issues. Research is needed consider other transports for this type of communication.

Controls

- ***Controls architecture has significant impact on communication latency.*** Once the signals reaches the facility, latency of the existing control system architecture is the constraint for this interaction. Since energy management and control systems are not initially designed to accommodate fast DR applications, it is important to characterize this latency before making the resources available for regulation products.
- ***Fans and pumps provide fast response when directly controlled.*** Within the HVAC system, there are some components that act faster than others. Sometimes this is simply because the sequence of operations for variable-air volume boxes slow the response as compared to directly controlling fans for ventilation. Of course directly controlling equipment outside of the system controls may have an adverse affect on the system.
- ***Some buildings may be able to take energy.*** When wind is available at night, and there is no load to take it, buildings may be able to take this excess energy and use it in a meaningful way. Whether it is night flushing the building, or pre-cooling, additional research is needed to provide guidance to building owners to how best utilize this inexpensive energy at night.

1 Background

In 2009, Lawrence Berkeley National Laboratory (LBNL) assisted Pacific Gas and Electric Company (PG&E) and Akuacom to demonstrate the technical feasibility of commercial and industrial (C&I) customers to participate in California Independent System Operator's (CAISO) non-spinning reserves products in the ancillary services market. Ancillary services are support services in the power system essential to maintaining power quality, reliability and security. There are four types of ancillary services products in CAISO's ancillary services. From the faster to the slower acting, these are: regulation up, regulation down, spinning reserve and non-spinning reserve.

The demonstration was set out to determine if the heating ventilation and air conditioning (HVAC) systems and related loads could deliver demand response that met the non-spinning reserves requirements. The two questions from the 2009 study were as follows:

- Can customers who have adopted Open Automated Demand Response (OpenADR) to participate in retail demand response (DR) seamlessly – without additional costs– participate in wholesale markets (Piette et al. 2009)?
- Can the Internet be used as a low-cost communication network to deliver non-spinning reserves signals?

The positive findings from this study on these questions were summarized by Kiliccote et.al. (2009).

During the same 2009-2011 demand response program cycle, PG&E had proposed to conduct a two-year pilot study on the use of OpenADR to automate DR with C&I customers so that DR resources could be used to mitigate the intermittency of renewable energy resources. The study was conducted in two phases. The first phase was a scoping study exploring the issues the CAISO is expected to face as the state moves towards achieving its 33% renewable portfolio standard (RPS) by the year 2020 and proposing demand-side resources to solve these issues (Kiliccote et al. 2010). The study identified the four challenges that the CAISO is expected to face with increased renewable resources on the electricity grid:

1. Unpredictable and steep ramps during times when wind and solar resources are ramping up or down;
2. Forecast errors associated with wind and solar resources that somehow has to be made up for in the real-time energy or ancillary services markets;
3. Intra-hour variability that may be caused by climate effects on renewable generation; and
4. Over generation due to wind that may coincide with low-load periods such as early mornings.

The scoping study pointed out that the key to addressing these challenges was to identify flexible C&I loads that may be available most of the year, if not year-round. Lighting loads were proposed as a primary candidate due to their availability year-round and HVAC loads as a secondary candidate for commercial buildings. For industrial facilities, refrigerated warehouses, wastewater treatment facilities and agricultural pumping were also identified. Finally, thermal energy storage systems behind the C&I facilities meters were proposed as candidate systems.

A follow on study conducted for the California Energy Commission (CEC) showed that in California, using the existing control capabilities in C&I facilities, there is 0.8 GW of automated DR capability on hot summer afternoons and 0.25 GW on cold winter mornings (Watson et al. 2011). If the control capability is doubled for refrigerated warehouses and increased by a factor of eight for agricultural systems, the capability increases to 1.8 GW and 0.4 GW, respectively.

This report is a summary of the second phase in evaluating the feasibility of using OpenADR for CAISO's ancillary services to mitigate the challenges faced by 33% RPS in California. The next introductory section summarizes the project goals, structure and process as well as describing the telemetry architectures. The ***Methodology*** section summarizes the tests conducted, data collected, and analysis methods used. The ***Results*** section summarizes the analysis results and evaluates the performance of the sites. The key findings and lessons learned are summarized in the ***Conclusions,*** which also includes a summary of challenges and shortcomings of this project.   Future plans are outlined in ***Next Steps***.

2 Introduction

The initial goal of the project was to automate DR loads identified in the scoping study to address challenges proposed by CAISO and identify and resolve communications and control challenges using DR for renewable resource integration. Further discussions with PG&E and CAISO led the project team to alter the scope to evaluate the feasibility of C&I loads participation in regulation up and down products in the ancillary services market. The change was to address the need that CAISO would need more regulation products (Venkataraman et al. 2010) in the ancillary services market.

Regulation energy is used to control system frequency that can vary as generators access the system. The resources must have continuous – 60 minutes for the day-ahead market and 30 minutes for the real-time market- energy requirement for regulation up and regulation down products. Resources providing regulation products are certified by the CAISO. CAISO tests to characterize a generator with its ramp rate and minimum and maximum operating limits. Generators must respond to automatic generation control (AGC) signals to increase or decrease their operating levels depending upon the service they provide, such as regulation up or regulation down.

Spinning reserves is the portion of unloaded capacity from units already connected or synchronized to the grid and that can deliver their energy in 10 minutes and run for at least 30 minutes. Non-spinning reserve is capacity that can be synchronized and ramping to a specified load within 10 minutes.

CAISO currently offers two programs for DR to participate in the wholesale market in California: Proxy Demand Response (PDR) and Participating Load (PL) programs. PDR is a load or aggregation of loads that are capable of measurable and verifiable electric energy demand reduction. These resources submit bids into the wholesale Day Ahead or Real Time energy markets and respond to CAISO dispatches. Verification is done using one of two types of customer baselines: 1) 10/10 baseline (average of load in the last 10 eligible days) or 2) an agreed upon baseline - in the case of PL, this was hourly forecasts of bids. . PL is a load that can provide energy and ancillary services. For PL resources, hourly forecast of bids are used for verification purposes. The difference between PDR and PL is the flexibility that PDR offers. Under a PDR program, only the net demand activity is scheduled and bid into the market. And PL, as mentioned, it's the entire load that needs to be scheduled and bid. Also, For PL only a load serving entity can participate - no other market participants can use the PL program.

2.1 Regulation Products in the CAISO's Ancillary Services Market

Regulation is a product in the ancillary services market whereby the provider of the service is equipped with automated controls that allows the system operator to request upward or downward changes in output. Regulation is used to track and balance system wide generator output with system wide load on a sub-minute by sub-minute basis (Heffner et al. 2007). CAISO has two separate products: a regulation up (generation resource delivers energy, loads reduce energy use) and a regulation down (generation resource reduced energy production, loads increase energy use) products. CAISO currently has a number of requirements for generators seeking to provide the ancillary service of regulation, including a direct communication and control system, which communicate key parameters and allows the generator to respond without operator intervention (Rubinstein et al. 2010). Generators have to provide characteristics including maximum (or high) operating limit (HOL), minimum (or low) operating limits (LOL), capacity available and ramp rate, which is determined as a part of the certification process to become a provider. CAISO also has a cerfication process[1], which has been designed for conventional generators and requires demonstration of the ability to ramp up and or down as quickly as their certified ramp rate.

In order for a resource to participate in the regulation ancillary services market it must interface to the CAISO's AGC system to receive dispatch instructions at up to 4 sec intervals and provide real time telemetry of its actual operating point, also at 4 second intervals.

While there has been discussion of using loads to provide ancillary services (Black et al. 2002, Callaway 2009, Eto 2002 and Kirby et al. 2008) and numerous market products enabling loads to participate in ancillary service markets the authors found few examples of loads participating in regulation markets in the literature (Rahimi 2009, Rebours et al. 2007, Reid at al. 2009, Spees at al. 2007). For example New York ISO (NYISO), Pennsylvania New Jersey Maryland Interconnection (PJM) and Midwest ISO (MISO) all have had programs where loads could bid into ancillary service markets for several years, but as of 2009 only MISO actually has loads participating in its market (Newell et al. 2010, NYISO 2009, PJM 2010).

To meet the regulation participation requirements, 4-second telemetry equipment had to be installed at each site. Through controls test, resource characteristics such as the ramp rate, HOL and LOL were identified for each participating site.

2.2 Site Selection and Recruitment

A set of target loads was identified during the phase one study (Kiliccote et al. 2010). Site selection started early March with an effort to find at least one refrigerated warehouse, one lighting system and one building with a behind-the-meter thermal energy storage system. To recruit at least one refrigerated warehouse, LBNL reached out to PG&E's account managers who serve this sector. These account managers proposed a few candidate sites. After site visits to three sites, one of the customers agreed to participate in the study. Towards mid-July, this customer had to drop out because their controls vendor was booked solid and would not be able to finish installation and enablement before October. LBNL also worked with several lighting controls companies. None of the companies were able to find a customer who agreed to participate in the study. One of the lighting controls companies offered their own facility but they were sharing a meter with other offices located in the same office complex and that sheds in lighting loads were so small compared to the whole building loads that the team was concerned these resource would not be visible. Finally, a few technologies and connections made through PG&E's permanent load shifting program led the team to several facilities where there were operational issues at each of these facilities. While the team thought these systems would have the flexibility required for regulation up and down participation, the operators at the sites were concerned that their time-of-use optimized systems worked so well that they did not want to deal with any changes to these systems.

[1] http://www.caiso.com/2b67/2b67e63955f10.pdf

PG&E provided the following incentives to the participants:

- **Participation incentives**: Customers earn $1000 for operational activities (during scheduled operations timeline) outside their normal day to day activity.
- **Performance Energy Incentives**: For any dispatch instructions made by CAISO or PG&E (test or event), resources are paid CAISO's Local Marginal Price for energy.
- **Time-of-use Rate Differential Incentive:** For any dispatch instructions or activities initiated by either the CAISO or PG&E (real events or tests) which prevent the customer from being able to operate under their "normal" conditions during the weekday 12 – 6 timeframe, the participant will receive credits.
- **Capacity Incentives**: Customers earn an incentive payment per KW of capacity provided. This varies by month according to the following schedule:

	May	**June**	**July**	**August**	**September**	**October**
IRR ($/ kW)	5.00	10.00	20.00	20.00	20.00	20.00

LBNL team also approached controls companies and aggregators to recruit their customers. As a result of the recruitment efforts, three sites were recruited into the study:

1. San Mateo Community College (SMCC): This is a campus of 19 buildings with varying sizes and uses, located in San Mateo, CA. 11 out of 19 buildings participated in the tests. The summer outside air temperature in 2011 was mild (with an average maximum outside air temperature of 81°F during the periods the site committed to participating in events). The control vendor of the campus, Schneider Electric, was instrumental in the recruitment of this site and the campus was supportive of the project and willing to experiment with both "take" (regulation down) and "shed" (regulation up) strategies.
2. University of California at Merced (UC Merced): This is a UC campus with 9 buildings and student housing on campus. The campus itself has a two million gallon chilled water thermal storage system that is operated during the day. In addition, the campus has solar generation that produced about 1 MW of electricity. The buildings all controlled from a central Automated Logic Corporation energy management and control system. LBNL has worked with this site on energy efficiency projects and had great support from the campus energy manager for regulation tests at this site.
3. West Hills Farms (WHF): This is a small pistachio farm located in WHF, CA participating in the California Peak Energy Agriculture Awards (PEAR) program[2] and working with an aggregator, M2M Solutions.

2.3 DR Strategies for Regulation

Each site was asked to consider shed strategies during the daytime and take strategies during the nighttime hours. In this document, we use the terms "shed" for decrease in demand and "take" for increase in demand to replace "regulation up" and "regulation down", respectively, while communicating with the sites.

[2] http://pearcalifornia.com/

Initial discussions with UC Merced led us to agree to keep the thermal energy storage out of the list of systems that would be involved in DR strategy development. While the team wanted to use a more stable period for DR, such as the 1 pm to 3 pm period, the site wanted to test the strategies between 5 pm and 8 pm. During this time, the sun starts to lower and set in the sky so the 1 MW generation also winds down. By using shed strategies during this period, the site was hoping to manage the solar ramp. Final strategy was set between 6 pm and 8 pm with temperature adjustments in all the major buildings connected to the central enterprise control system. Four strategies, each indicating a global temperature adjustment (Motegi et al. 2007), were programmed into the control system. The table below summarizes the strategies:

TABLE 1. DR SEQUENCES PRE-PROGRAMMED AT UC MERCED

Demand Response Sequence	
Name	**Operation**
DR0	Reset Global Temperature Setpoint to 74 DegF
DR1	Reset Global Temperature Setpoint to 75 DegF
DR2	Reset Global Temperature Setpoint to 76 DegF
DR3	Reset Global Temperature Setpoint to 78 DegF

San Mateo County Community College (SMCC) was open to experimenting with both shed and take strategies. The site designated 2 am to 4 am to experiment with take strategies and 1 pm to 3 pm to test shed strategies. Table below summarizes the DR strategies this site implemented.

TABLE 2. DR SEQUENCES PRE-PROGRAMMED AT SMCC

Strategy	Operations
Take1	Increase ventilation in buildings 5 & 10
Take2	Increase ventilation in buildings 8, 9, 35 and 36
Take3	Increase ventilation in buildings 1,2,3,16 and District Administration Building
Shed1	Global temperature adjustment of +2 DegF in buildings 5 and 10
Shed2	Global temperature adjustment of +2 DegF in buildings 8 and 9
Shed3	Global temperature adjustment of +2 DegF in buildings 35 and 36

West Hills Farm (WHF) is a pistachio grower's site with two pumps at the site. They installed a variable frequency drive on one of the pumps so that it could modulate between 20% and 100% of its output. A closer study of the pump and the requirement of the irrigation system revealed that the nominal run speed of the pump was between 57 -60 Hz producing a pressure range of 40-52 psi. For the the purposes of the project, the pressure could be lowered to 30 psi, yielding about 26 kW maximum.

3 Summary of communication and controls technology

Generators participating in CAISO's regulation products are connected to the Automatic Generation Control (AGC) within their Energy Management System (EMS). Generators establish communication with the AGC system through a secure private network using inter-control center communications protocol (ICCP) and adjust their power output in response to setpoint instructions from the AGC system. A similar architecture is being used for loads to participate in regulation products. AGC is sending setpoint instructions through a private network using ICCP. However, instead of directly to a generator, these setpoint instructions are being sent to a demand response automation server (DRAS). DRAS converts these signals to OpenADR information exchange model and pushes these signals to the software-based OpenADR clients located at each site. OpenADR clients receive these setpoint instruction signals and depending on the setpoint received, trigger preprogrammed DR strategies whose demand level (reduction or increase) correspond to the setpoint sent by the CAISO. In the past, PUSH architecture seem to propose security risks so over the years, OpenADR has been used with a POLL architecture to overcome the security issues. However, since four second communication was an important feature of these tests, to eliminate latencies, the communication was converted into a PUSH architecture for this project. Each site developed their own way of reducing risks to their existing information technology infrastructure. Figures 1 through 3 display the architecture of this system as implemented at each site. A separate path, which is displayed in the figures, is established for the communication of telemetry data for each site.

UC Merced worked with its enterprise controls vendor to develop a PUSH client and embed it to its existing ALC system. While the campus IT department was aware of this work, they did not object to it because the control and IT networks on this campus are separate. Upon the receipt of the setpoint instruction, which is a typical message sent to generators to instruct them on their operation (in kWs), UC Merced used its ALC system to convert this instruction to a pre-programmed DR strategy and send it to relevant controllers in associated buildings. The telemetry infrastructure, common to all sites in the study, used Code Division Multiple Access (CDMA) technology to communicate the four-second data back to the DRAS and the CAISO's AGC system operator.

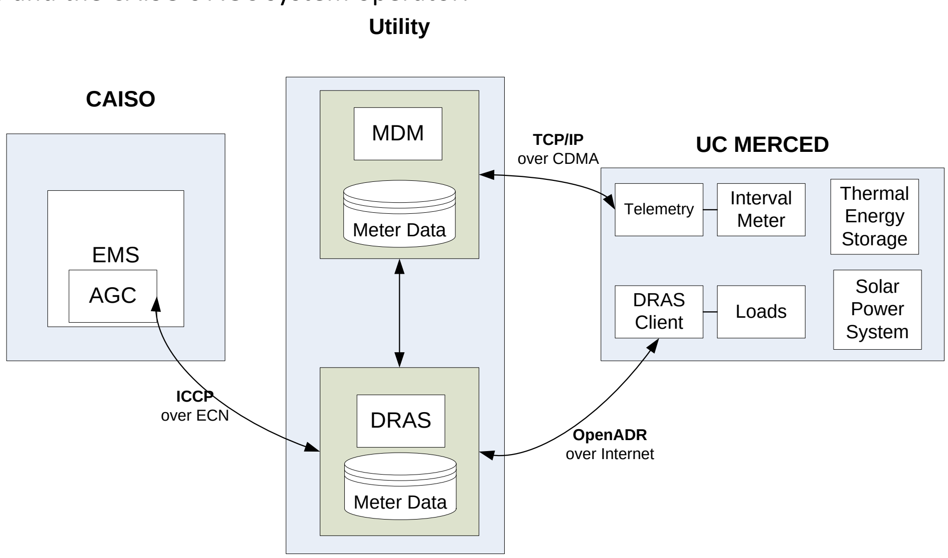

FIGURE 1. UC MERCED'S COMMUNICATION ARCHITECTURE

Since West Hills Farms was already participating in automated DR programs with an aggregator, M2M Communications, the AGC signals were being PUSHed to M2M's network operations center. These were then converted into proprietary signals and sent to the site using M2M's existing infrastructure.

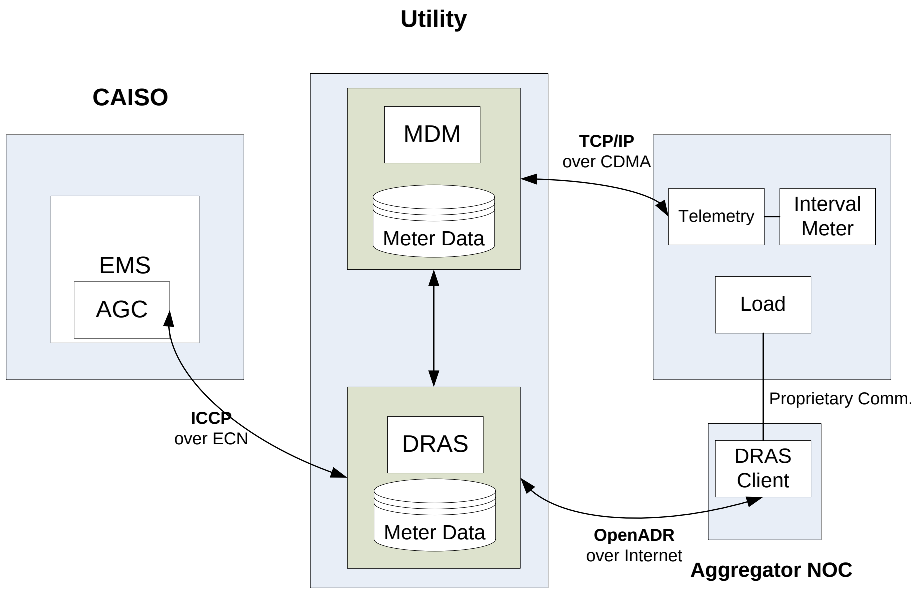

FIGURE 2. WEST HILL FARMS' COMMUNICATION ARCHITECTURE

The implementation at SMCC was a hybrid of the two systems described above. A DRAS client was developed and embedded in a server called GridView. A client called GridLink polls this server at significantly high rates and converts these signals to DR sequences pre-programmed into the Schneider system. While GridLink is located at the site, GridView is a server located in the cloud.

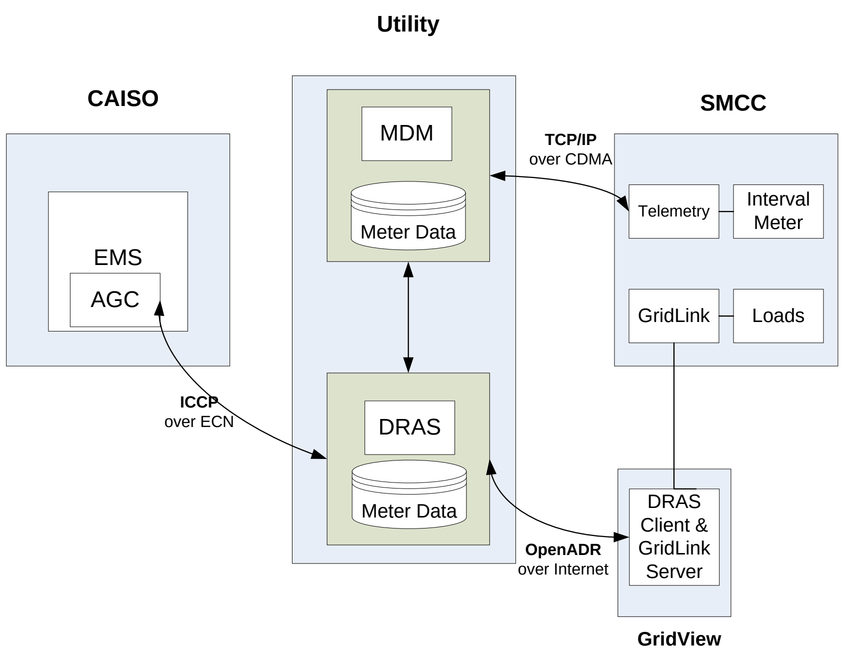

FIGURE 3. SMCC'S COMMUNICATION ARCHITECTURE

4 Methodology

This section outlines the data to be collected from each site participating in the project and the analysis that is completed for each site using the data.

For each site the following data are collected or calculated:

- 2 day-ahead forecast posted at 4 pm (5 min. interval)
- Day-ahead forecast posted at 4 pm (5 min interval)
- 3 hours-ahead forecasts (5 min interval)
- Whole facility power from telemetry equipment (4 sec)
- Whole facility power from revenue meter (5 min and 15 min intervals)
- Trend logs from building EMCS (various intervals)
- Time stamps of issue and receipt of communications (AGC, DRAS, DRAS clients)
- Pseudo generation calculated as:
  Pseudo generation = (Forecasted –Actual) + Offset[3]

Different methods to achieve different goals as outlined in the following sections are used for data analysis before, during and after the tests.

4.1 Before the test period

The goals of data analysis **before the test period** are:

- To evaluate the error of the forecast algorithms
- To determine the ramp rate and the response amount of the various DR strategies being implemented at each site
- To investigate communication latency issues and synchronization of the system and time stamp comparison

4.1.1 Evaluate the error of the forecast for non-DR test days.

Examination of the statistical distribution of forecast errors (defined as actual load minus forecast load) is required. The most basic statistics of interest are the average error, the median error, and the standard deviation of the error. If the average or the median error is substantially non-zero, this will represent *bias*; it may be easy to simply scale the forecasts to remove the bias if one is found. The standard deviation of the errors is a measure of precision of the forecast. If the standard deviation of the errors is not small compared to the DR load shed, it may not be possible to determine the DR effectiveness for each individual time interval, though it may be possible to determine the average DR effectiveness over a longer period.

In addition to the mean, median, and standard deviation of the forecast errors, the temporal behavior of the errors may be investigated (for instance, if the forecast is too low for one time period, it will likely also be too low for the subsequent time period). Temporal information may be useful for improving forecasts or for understanding the reasons for the errors.

4.1.2 Determine the ramp rate and size of response.

Control tests were used to determine how much and how quickly the load responds to the DR strategies. The facilities were monitored under normal operation; during DR period and the recovery period.

[3] Offset is greater or equal to the regulation down amount of the DR resource. This is so that the pseudo generation never goes to a negative value

Determining the ramp rate and amount of DR load shed involves subtracting the measured load from the predicted load under normal operation. The prediction could come from the forecast alone (see the section above), but the prediction could be improved post-facto by using additional information that was not used for the forecast. For instance, if the load is higher than was forecasted in the few hours before the intervention, the entire day's forecast can be scaled upwards to improve the fit. Or, if there was a linear trend in (measurements minus forecast) for the periods just before or after the intervention, a linear trend could be added to the forecast over the entire day. And of course, the forecasts were based on predicted outdoor air temperature, and could be modified once the actual air temperatures are known.

There are many possible approaches to improving the prediction of load shape under normal operation, given data observed before, during, and after the intervention; it is even possible that different approaches are appropriate for different facilities or types of facilities.

Some of the controls tests involved performing multiple DR approaches, or in the campus settings, multiple iterations on the number of buildings and DR strategies. Ideally, the control tests that relate to cooling or heating loads would be performed at days and times that cover a variety of outdoor temperatures, so the temperature-dependence of the load reduction could be quantified.

4.1.3 Synchronization of the EMS, DRAS and Telemetry equipment

For any latency calculations, all these systems should be synchronized.

4.2 During and after the test period

The goals of data analysis **during and after the test period** are:

- *To evaluate pseudo generation calculation*. Each site was modeled as the sum of a constant consumption plus a variable supply that can be either positive or negative. The variable supply was treated as a power generator that could be called upon to provide more or less power, with constraints on the ramping timescale and magnitude of the power changes. The attainable ramp rate and magnitude was estimated as described in the previous section, and compared to the actual values experienced on the test days.
- *To evaluate if and how the instruction levels were met and the effect of latency issues.* Collecting time stamps of information being sent out and received to calculate end-to-end latencies. Once the slowest communication was identified, ways of speeding up were considered.
- *To evaluate the overall impact of the tests on each site's energy consumption, load shaping and economics.* Each facility's participation in the IRR program resulted in changes in electric load compared to what would have occurred if the facility did not participate: at a given time, the electric load might be higher, lower, or the same as it would otherwise have been. The total energy consumption during a day could be higher or lower, and the peak load can be higher or lower. As a result, the facility's electric utility charge may be increased or decreased by participation in the program. For each event, for each site, the impact of DR strategies were evaluated and results are presented in the next section.

4.3 Description of Pseudo Generation concept

When a site responds to a traditional DR signal, the expectation is that the actual load consumed deviates from an established baseline to a lower level of power consumption. In typical modeling terms the difference between actual load and the modeled load, the baseline, can be thought of as the residual error, which the model fails to capture. While the baseline represents the amount of power that the ISO had planned to provide, if the difference between the actual load and the baseline is negative then there is some amount of power, which is now available to other loads. Shedding load in this manner makes the DR resource into a kind of generator, or a provider of pseudo generation. Conversely, if the residual is positive, the load can be thought of as a pseudo generator supplying down regulation, with less power available on the system. We define pseudo generation as:

$$pg = \hat{l} - l \qquad (1)$$

where pg represents the amount of pseudo generation, $\hat{l}$ is the forecasted or baseline load and l is the actual load. Pseudo generation is equivalent to the negative of the residual. Note that any large residual error may show up as pseudo generation. The methods to filter noise to capture actual pseudo generation are outside of the scope of this paper. However, an offset greater than or equal to the regulation down component of the pseudo generation is added so that the resource always has a positive value. The pseudo generation with offset is defined as:

$$pg_{offset} = (\hat{l} - l) + c \qquad (2)$$

where c is a constant greater than the maximum regulation down value of the resource. It is determined by testing regulation down strategies of the load. Figure below is a graphical representation of the pseudo generation concept.

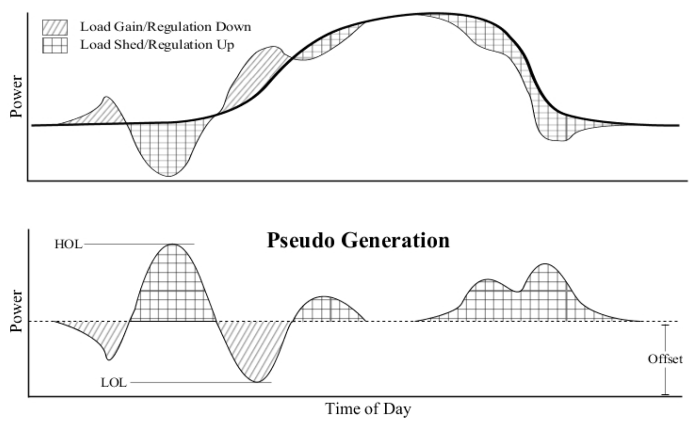

FIGURE 4. GRAPHICAL REPRESENTATION OF THE PSEUDO GENERATION CONCEPT

There are a several key distinctions between pseudo generation and conventional generation. A major distinction is that pseudo generation can be a negative value. If a participating facility increases its power consumption beyond the modeled baseline to respond to a regulation down instruction from the ISO, it begins to provide negative pseudo generation.

Other key distinctions involve the characteristics associated with regulation provider bids: HOL, LOL and ramp rate. For conventional generation both operating limits and ramp rate are established during the certification process to participate in the market, and these values typically change little as the provider supplies regulation. For pseudo generation, the operating limits are determined by the maximum take or shed for a facility. Pseudo generators are much more likely to have the HOL and LOL changing over time as both will depend on the state of the loads that contribute to power draw. Operation of many loads depends on the season of the year, day of the week and time of the day. Also, the ramp rate varies with operation and whether the load is moving up or down and which end uses are contributing to this movement. For loads, the ramp rate is determined by testing the DR strategy and observing the transient response of the system until the system reaches a steady state. Figure 2 displays a hypothetical baseline and load for a facility. Figure4 shows the negative residuals. Eliminating negative pseudo generation is accomplished by defining the maximum regulation down (maximum load gain while providing regulation) for a given facility and offsetting all the pseudo generation upward by this value with some additional buffer. However, if regulation down is a high value, this representation can provide mismatch in models and actual grid operations. Therefore, it is not a viable long-term solution to representation of loads.

4.4 Determining pseudo generation characteristics for each resource

To determine pseudo generation characteristics of the DR resources, the team conducted extensive control tests. These control tests were completed before the end-to-end communication was established and were typically completed manually. Several test days were selected based on weather temperature, the availability of the onsite personnel, and the availability of monitoring equipment. Figure 5 displays the results of take strategy tests on August 3rd. The graphic on the top displays the 2 am to 4 am test period where the ventilation was manually increased in growing number of buildings every half hour starting in 2 am. A closer evaluation of the load shape in the picture at the bottom of Figure 5 displays the difficulty of identifying the ramp rates in this noisy data environment. The blue line is selected as a conservative estimate of the ramp to calculate the ramp rate. After going through similar tests with each of the sites, the ramp rate calculations prove to be a simple estimation. Unfortunately, the pumping station never went through these tests. On days the tests were completed, the data was not available because the team realized that the meter was installed on the other pump on the site. Table 3 shows the pseudo generation characteristics of each of the sites. While these values were derived from tests at UC Merced and SMCC, the values for WHF were derived from engineering estimates. Compared to the single ramp rate that the generators are certified for, the DR resources have varying ramp rates depending on whether they implement take or shed strategies. This is indicated in Table 3 as separate ramp rates for SMCC.

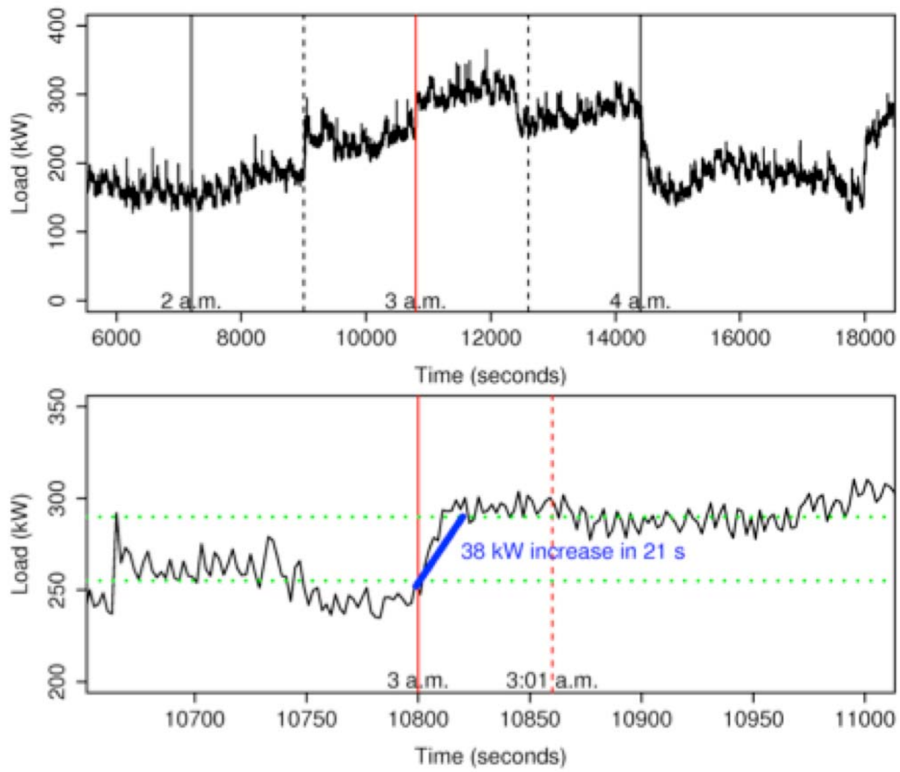

FIGURE 5. TEST RESULTS FROM SMCCD ON AUGUST 03, 2011

TABLE 3. PSEUDO GENERATION CHARACTERISTICS OF THE DR RESOURCES

Site	Available Capacity (MW)	Min. Operating Limit (MW)	Max. Operating Limit (MW)	Ramp Rate (MW/min.)
UC Merced	0.16	0	0.17	Reg up: 0.022 Reg down: 0.022
West Hill Farms	0.03	0	0.16	Reg up/down:0.03
SMCC	0.2	0	0.2	Reg up: 0.05 Reg down_1: 0.066 Reg down_2: 0.134

4.5 Description of the forecasting method

SolAspect employed a proprietary forecasting methodology, consisting of a multi-objective Genetic Algorithm (GA) overseeing the development of Artificial Neural Networks (ANNs). The GA controls the inclusion/exclusion and preprocessing of input variables in the predictive model. Input variables are also subject to optimizations through the GA. Once the data is preprocessed, multiple forecasting models are produced using ANNs. The forecasting models are then tested by the GA and ranked using the Root Mean Square Error (RMSE) between the forecasted and the measured values. The model with the lowest RMSE (the best result) was then used to provide the forecasted values.

4.5.1 Input Data

The first step to obtain the forecasting model was to collect historical demand data. Historical demand data was provided by PG&E, in five-minute intervals, from April 2009 to July of 2011, for San Mateo Community College and UC Merced, and in 15-minute intervals, from May 2010 to July 2011, for WHF.

The forecasting model for UC Merced also included hourly meteorological data obtained from the National Weather Service (NWS). Including NWS data for this site was motivated by the substantial demand impacts associated with UC Merced's 1 MW solar plant.

4.5.1.1 Data Cleaning and Data Splitting

Historical data 'outliers', such as blackout periods, were removed from the data sets. For San Mateo Community College, it was observed that after October 2010 (point A in Fig. 1), demand varies between two distinct modes: a "low demand" mode in which the demand varies between approximately 100 kW and 1000 kW, and a "high demand" mode with minimum demand of approximately 600 kW and maximum demand of 1300 kW.

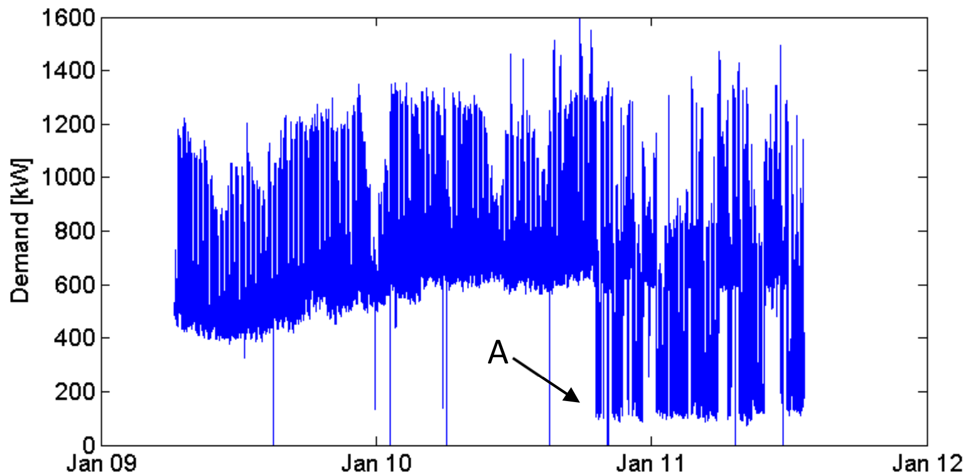

FIGURE 6: HISTORICAL DATA FOR SAN MATEO COMMUNITY COLLEGE

The reason why and when the mode change occurs is unknown and is unaccounted for in the forecasting models. Therefore, we opted to split the data set and create two different forecasting models (low demand and high demand). The data splitting is shown in Figure 2 for April to August of 2011. The switch between modes is done after visual inspecting the Metrum data, and therefore, larger errors are expected whenever such switches happen.

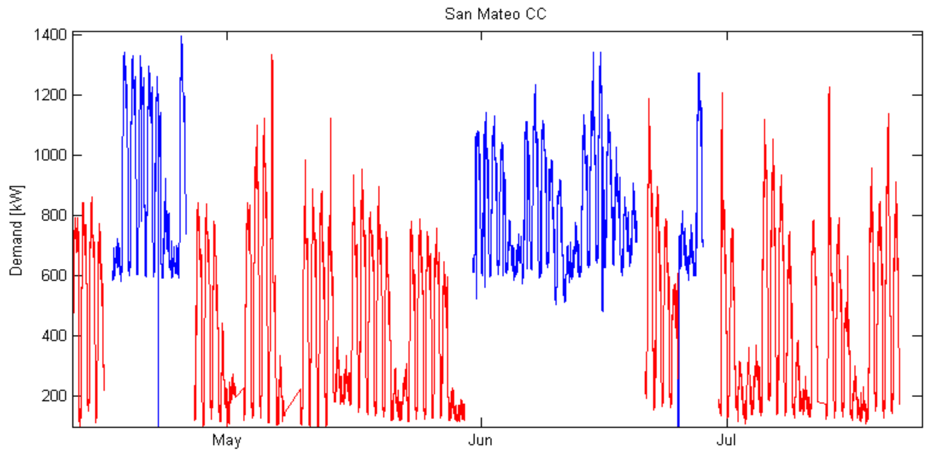

FIGURE 7: SAN MATEO COMMUNITY COLLEGE. HISTORICAL DEMAND FROM APRIL TO AUGUST 2011. "LOW" DEMAND MODE IS IN RED, "HIGH" DEMAND MODE IS IN BLUE.

4.5.1.2 Model deployment

Once the input data was processed, the forecasting model with the lowest RMSE was selected and used to determine the forecasted demand values. Daily forecasts were typically produced at the beginning of the day. Daily forecasts consisted of the forecasted demand values, calculated in 5 minute intervals for 5 days ahead at all three sites. When a DR test was scheduled, the daily forecast was typically updated one to two hours prior to the DR event in order to increase the accuracy of the forecasts.

4.6 Description of latency tests

4.6.1 Signal Latency Measurements

Signal latency was measured for each site by manually sending test setpoint signals and reading logs from the various computer systems involved in the process. For some tests (West Hill Farm), a commercially-available ICCP product was used to simulate the role of ISO, at the upstream end of the chain. Loss of key ICCP equipment forced other tests (UC Merced and San Mateo Community College) to use an automated test scheduler to inject setpoint numbers directly into the DRAS.

All three installations share a basic design of a custom OpenADR push listener that receives the IRR signal and then feeds the setpoint value into a more conventional demand response system which then sends appropriate control signals to load equipment. Times were recorded at the head-end ICCP input (when used), the OpenADR push from the DRAS, the IRR push listener, the conventional demand response system, and the final load destination.

It should be understood that this distributed system involves many different computers, so clock synchronization between the different systems is key. Clock differences were minimized but never completely eliminated in these tests.

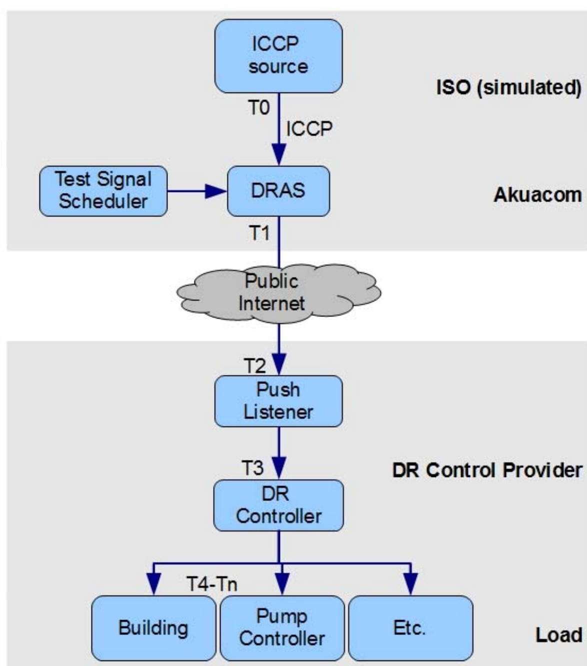

FIGURE 8. OUTLINE OF LATENCY MEASUREMENTS

T0: Setpoint value manually entered into ICCP table at simulated ISO.
T1: OpenADR event state pushed from DRAS to push listener.
T2: OpenADR event state received by IRR push listener.
T3: Setpoint value received by conventional demand response controller.
T4 – Tn: Control signal received at load (campus buildings, orchard pump, etc.)

4.6.2 ICCP signal transfer time

The ICCP protocol maintains a "bilateral table" of values between its two communication endpoints. Changes in either table are replicated in the corresponding remote table at regular intervals. In the case of this trial, the link between CA-ISO and the DRAS is configured to have a 2-second replication interval. This transfer time is reflected in the difference between T0 and T1.

4.6.3 Public Internet OpenADR push transfer time

The OpenADR push transaction over the public Internet consistently challenges the granularity of one-second-precision computer logging. Human observation and computer logging in tests when computer clocks are observed to be well synchronized consistently show a one or two second transfer time from DRAS to the push listener. Public Internet transfer time is reflected in the difference between T1 and T2.

4.6.4 On-site control system input

Once the OpenADR setpoint push is received, each site has a different architecture of queues and private networks through which control signals must pass. The initial link of this is from the IRR push listener to the main demand response system, and is reflected in the difference between T2 and T3. Then the signal must be dispatched to appropriate load equipment in various buildings, pumps, etc. This transfer time is reflected in parallel in the differences between T3 and one or more load controllers (T4 through Tn).

5 Results

5.1 Evaluation of forecasts

5.1.1 Demand Forecasting for San Mateo Community College

Demand forecasting at San Mateo Community College took place from 08/01/2011 through 10/31/2011. Input values consisted of the historical demand values and the time of day. Instantaneous demand values from the time of the forecasting creation up to 5 days ahead were provided in 5 minutes intervals. Figures 3-5 shows the monthly comparison of the measured with the most current forecasted demand at San Mateo Community College.

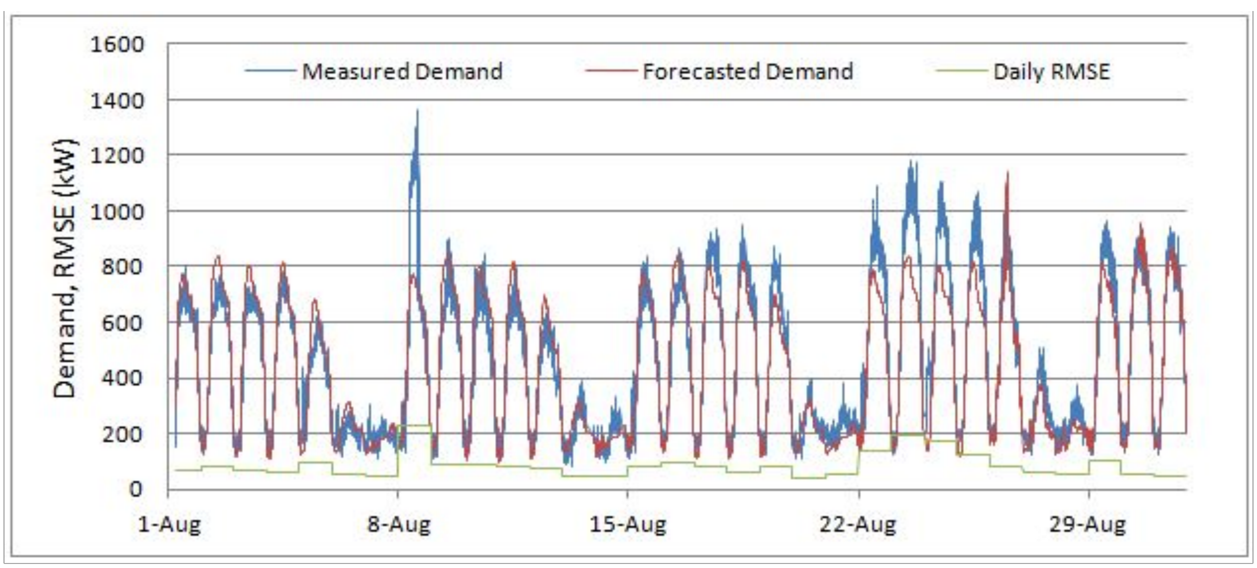

FIGURE 9: TIME SERIES COMPARISON OF MEASURED TO FORECASTED DEMAND AT SMCC FOR AUGUST, 2011

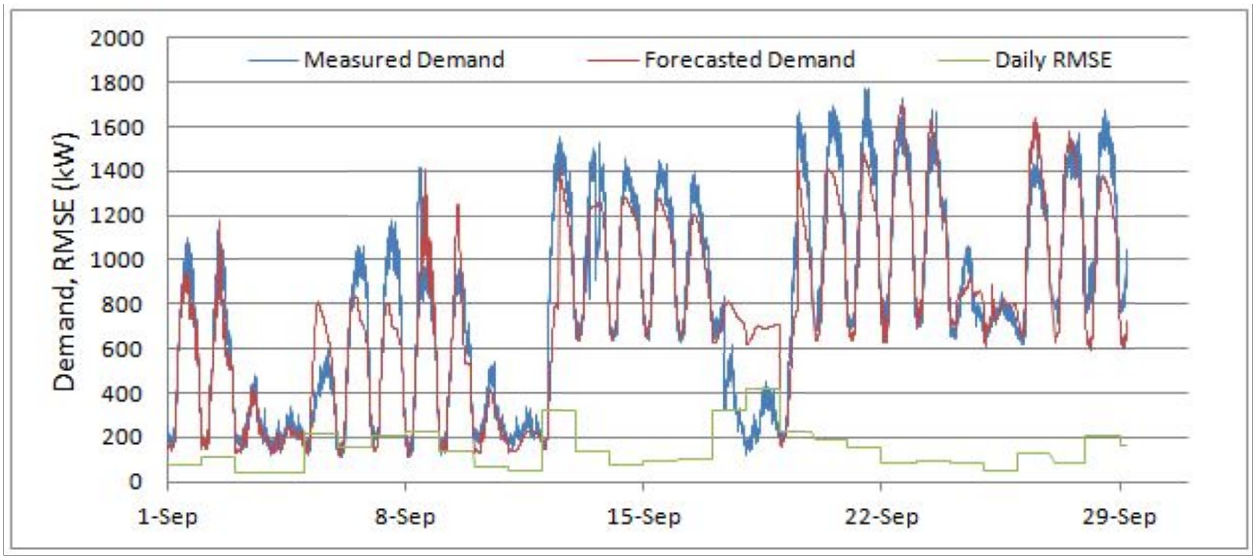

FIGURE 10. TIME SERIES COMPARISON OF MEASURED TO FORECASTED DEMAND AT SMCC FOR SEPTEMBER 2011

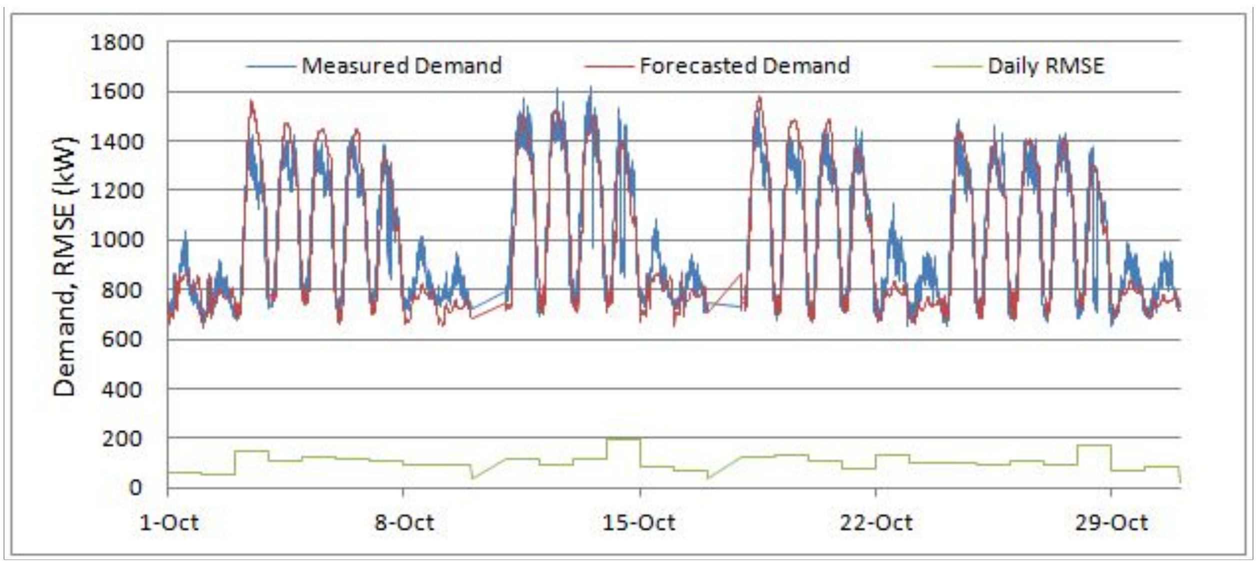

FIGURE 11. TIME SERIES COMPARISON OF MEASURED TO FORECASTED DEMAND AT SMCC FOR OCTOBER 211

5.1.1.1 Forecasting metrics for SMCC

	Using all available data	Excluding periods of unexpected changes in demand[4]
Mean Demand[5]	1,367 kW	1,367 kW

[4] For example, the co-generation malfunction of August 8, 2011

[5] Mean demand as listed in the irr information spreadsheet

Mean Biased Error (MBE)	11.1 kW	9.5 kW
Mean Absolute Error (MAE)	89 kW	85 kW
Root Mean Square Error (RMSE)	129 kW	128 kW
Relative RMSE (rRMSE)[6]	9.4 %	8.8%

5.1.1.2 Demand Response events

During the pilot period, Demand Response events occurred at San Mateo Community College on:

- 08/03/2011; 02:00 to 04:00
- 08/08/2011; 02:00 to 04:00
- 08/24/2011; 02:00 to 04:00
- 09/12/2011; 13:00 to 15:00
- 09/27/2011; 13:00 to 15:00

The following figure compares the measured demand against the forecasted demand during the Demand Response events.

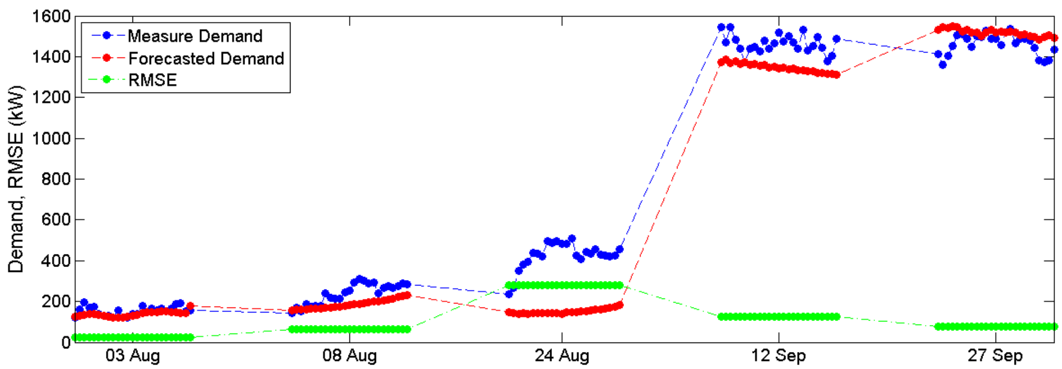

FIGURE 12. COMPARISON OF MEASURED AND FORECASTED DEMAND DURING DR EVENTS AT SMCC

5.1.2 Demand Forecasting for UC Merced

Demand forecasting at UC Merced took place from 08/01/2011 through 10/31/2011. Input values consisted of the historical demand values, the time of day, and atmospheric conditions (accessed from http://www.wrh.noaa.gov/). Instantaneous demand values from the time of the forecasting creation up to 5 days ahead were provided in 5 minutes intervals. Figures 7-9 shows the monthly comparison of the measured with the most current forecasted demand at UC Merced.

[6] The relative RMSE calculated with respect to the historical mean demand. The relative nameplate capacity RMSE, that is the RMSE relative to the maximum historical demand of 1774.1 kW, is 7.2% for all data points and 6.7% excluding periods of unexpected change in demand.

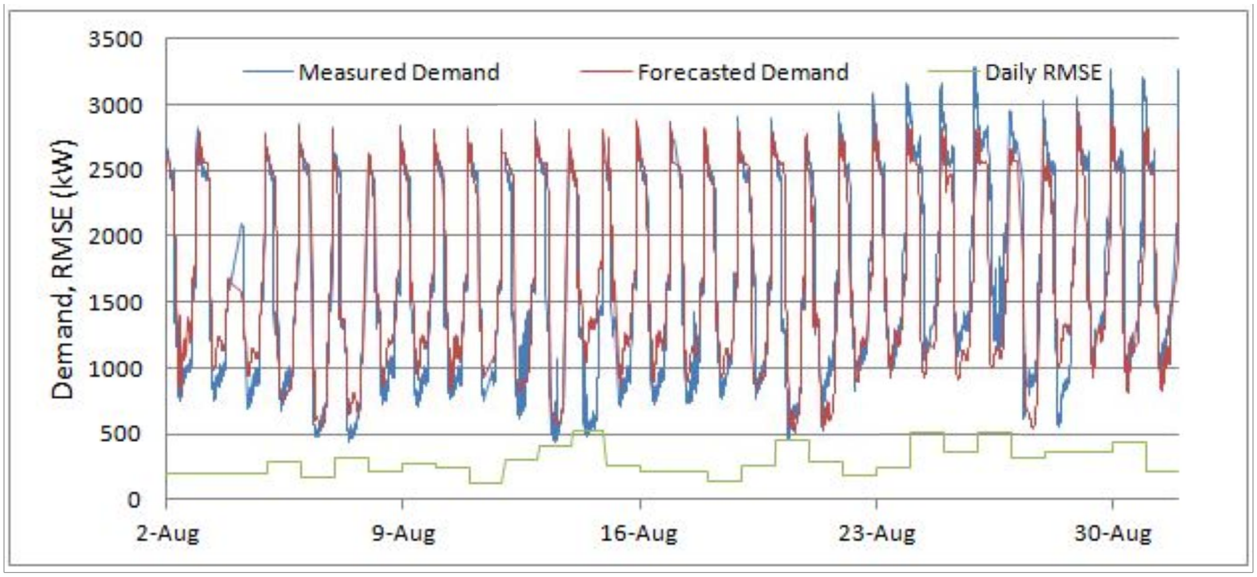

FIGURE 13. TIME SERIES COMPARISON ON MEASURED TO FORECASTED DEMAND AT UC MERCED FOR AUGUST, 2011

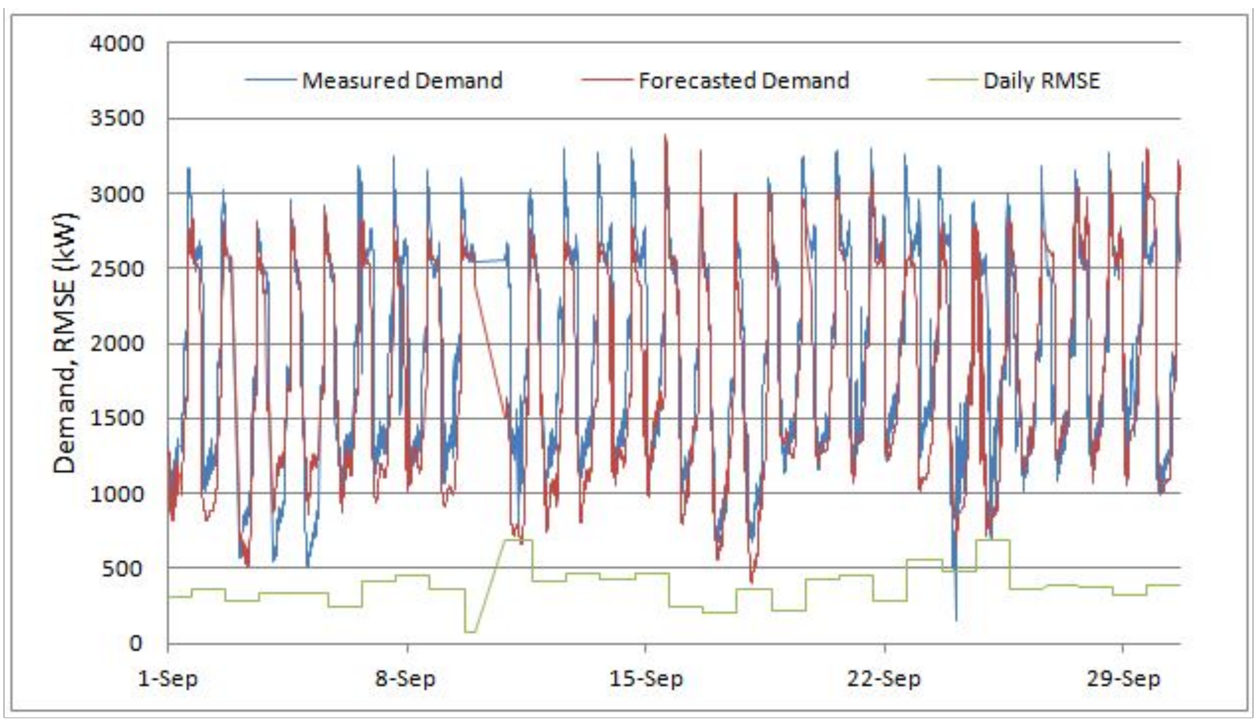

FIGURE 14. TIME SERIES COMPARISON ON MEASURED TO FORECASTED DEMAND AT UC MERCED FOR SEPTEMBER, 2011

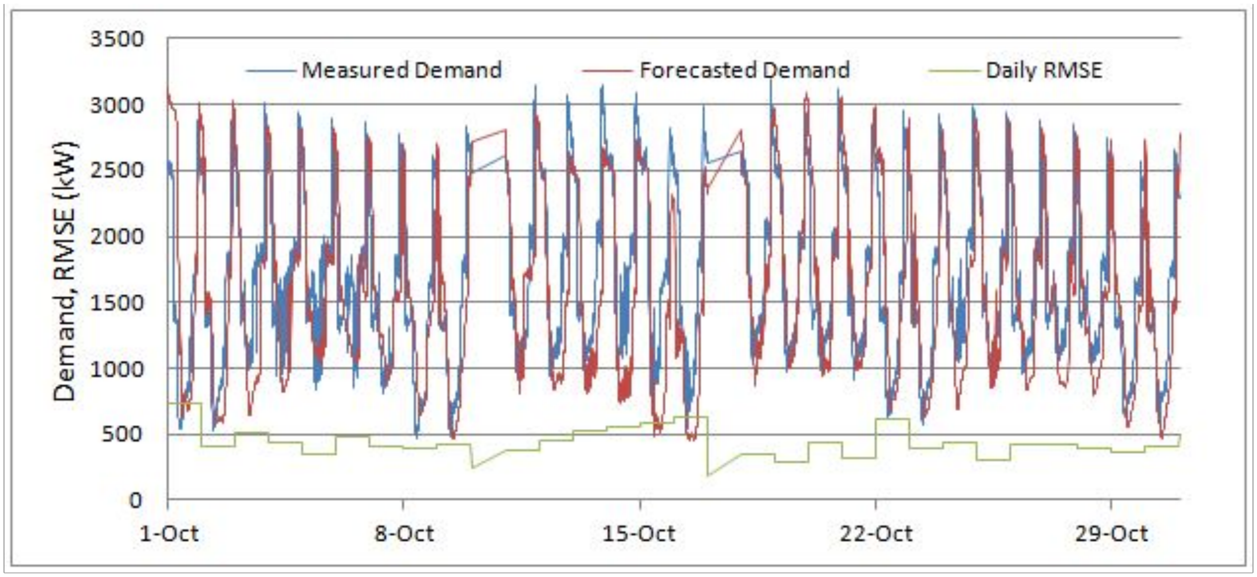

FIGURE 15. TIME SERIES COMPARISON ON MEASURED TO FORECASTED DEMAND AT UC MERCED FOR OCTOBER, 2011

5.1.2.1 Forecasting metrics for UC Merced

Mean Demand[7]	2,348 kW
Mean Biased Error (MBE)	90.3 kW
Mean Absolute Error (MAE)	276.25 kW
Root Mean Square Error (RMSE)	395.90 kW
Relative RMSE (rRMSE)[8]	16.8 %

5.1.2.2 Demand Response events

During the pilot period, Demand Response events occurred at UC Merced on:

- 8/04/2011; 17:00 to 19:00
- 8/16/2011; 17:00 to 19:00
- 8/31/2011; 19:00 to 21:00 (Note: Measured Demand data missing from 19:00-20:15)
- 9/8/2011; 17:00 to 19:00
- 9/13/2011; 17:00 to 19:00

The following figure compares the measured demand against the forecasted demand during the Demand Response events:

[7] Mean demand as listed in the irr information spreadsheet

[8] The relative RMSE calculated with respect to the historical mean demand. The relative nameplate capacity RMSE, that is the RMSE relative to the maximum historical demand of 3303.7 kW, is 11.9%.

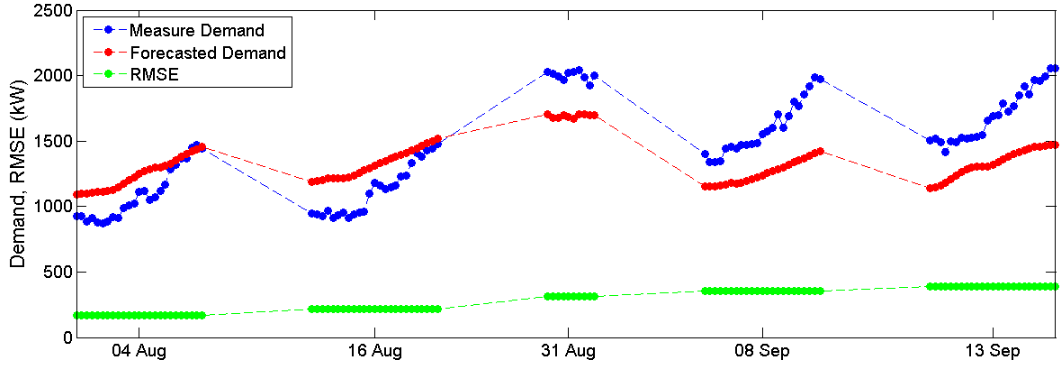

FIGURE 16. COMPARISON OF MEASURED AND FORECASTED DEMAND DURING DR EENTS AT UC MERCED

5.1.3 Demand Forecasting for WHF

Demand forecasting at WHF took place from 08/01/2011 through 09/02/2011. Input values consisted of the historical demand values and the time of day. Instantaneous demand values from the time of the forecasting creation up to 5 days ahead were provided in 5 minutes intervals. Figure 7 shows the comparison of the measured with the most current forecasted demand at WHF.

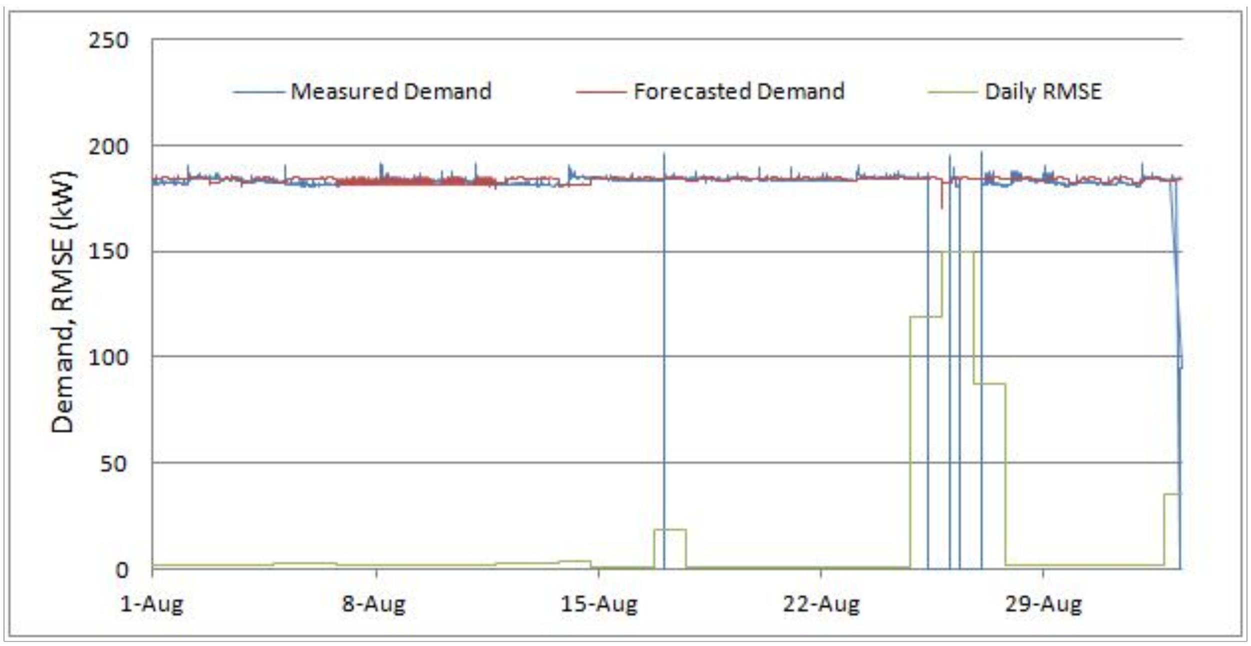

FIGURE 17. TIME SERIES COMPARISON ON MEASURED TO FORECASTED DEMAND AT WHF FOR AUGUST 1 TO SEPTEMBER 2, 2011

5.1.3.1 Forecasting metrics for WHF

	Using all available data	Excluding periods of unexpected changes in demand[9]

[9] For example, periods when the pumps were shut off without prior notice

Mean Demand[10]	196 kW	196 kW
Mean Biased Error (MBE)	-7.08 kW	-0.7 kW
Mean Absolute Error (MAE)	7.95 kW	1.5 kW
Root Mean Square Error (RMSE)	34.5 kW	4.3 kW
Relative RMSE (rRMSE)[11]	17.6 %	2.2 %

5.2 Factors that affected the forecasting results

Missing Data

Missing measured demand from the Metrum database adversely affected the forecast results, as the forecasting models rely on the most recent data (usually the last 24 hours) to determine the forecasted values. The models were designed to tolerate up to 20% missing data in the 24 hours preceding the forecasted value. However, there were several occasions, most notably for UC Merced (as shown in Figure 12) where the percentage of missing data was higher than this threshold. Unfortunately, the actual impact of the missing data on the accuracy of the forecasted values cannot be assessed without re-running the models for the complete data set.

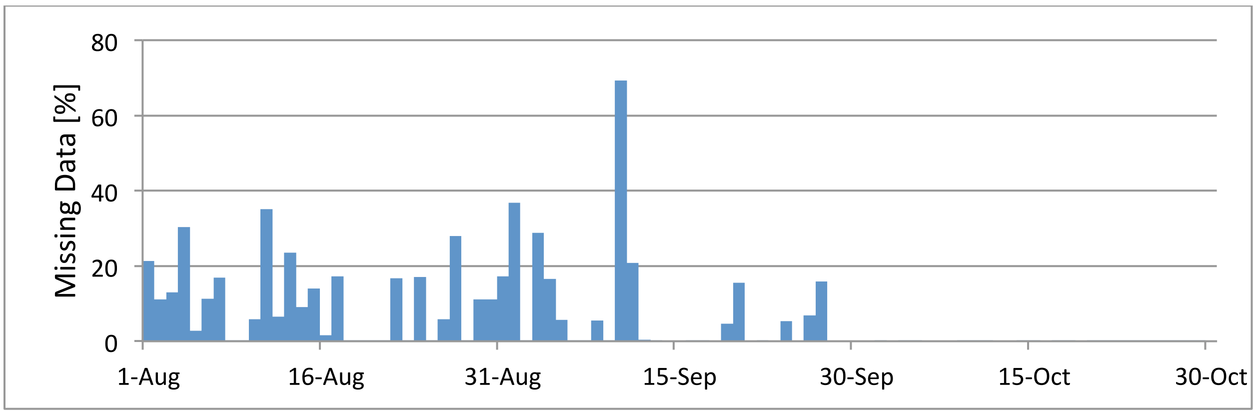

FIGURE 18. PERCENTAGE OF MISSING DATA POINTS ON A DAILY BASIS FOR UC MERCED

5.2.1 Timestamp Discrepancies

Forecast error calculations were determined by calculating the difference between the measured and the forecasted demand value for the corresponding timestamp. Forecast error calculations assume that both the forecasted value and the measured value for the instantaneous demand are available for a given timestamp. However, the timestamps from the Metrum's database did not match the timestamps for the forecasting data. In certain cases the closest timestamps in the Metrum database could be 10 seconds off from the timestamp for the forecasting. When timestamp discrepancies occurred, the closest Metrum values were used.

[10] Mean demand as listed in the information spreadsheet

[11] The relative RMSE calculated with respect to the historical mean demand. The relative nameplate capacity RMSE, that is the RMSE relative to the maximum historical demand of 197.2 kW, is 17.5% for all data points and 2.2% excluding periods of unexpected change in demand.

Given that we are working with instantaneous values of demand, differences can be substantial if the timestamps mismatch just by a few seconds. Figure 13 shows instantaneous demand values in 1 minute intervals, 5 minute intervals, and 5 minute averaged invervals of demand over a randomly selected, one hour period at SMCC. Figure 14 shows the same for UC Merced.

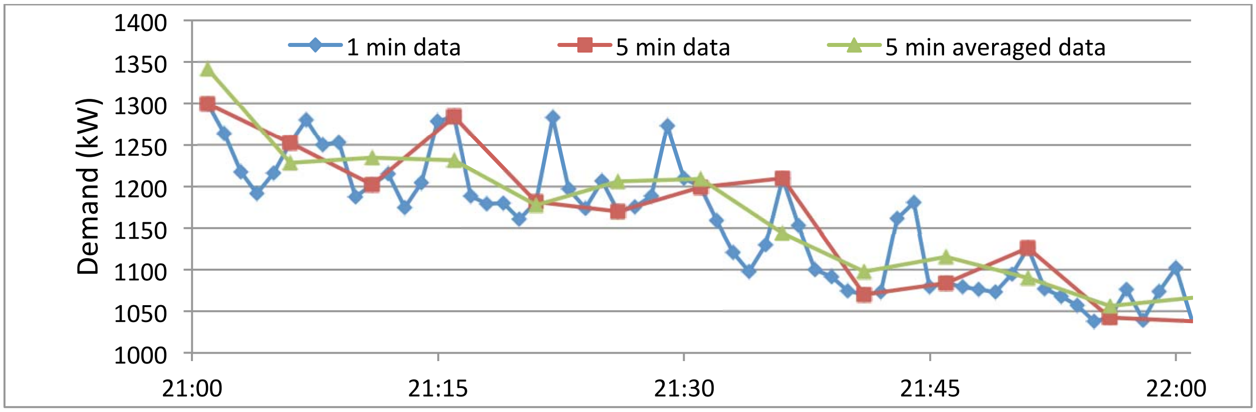

FIGURE 19. REAL-TIME DEMAND VARIABILITY ON SEPTEMBER 20, 2011 AT SMCC

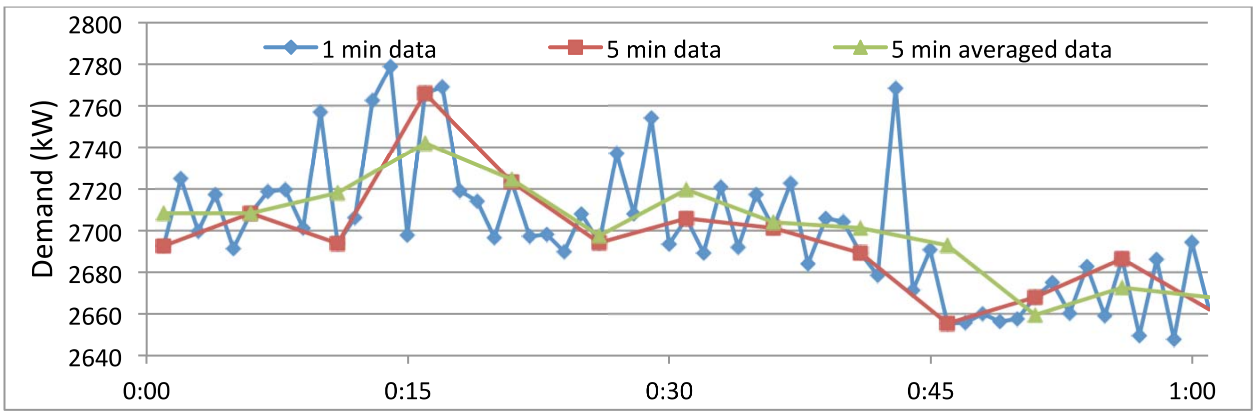

FIGURE 20. REAL-TIME DEMAND VARIABILITY ON AUGUST 28, 2011 AT UC MERCED

The variability of the demand within a 1 minute period can be close to 100 kW, the difference between the measured and forecasted timestamps could have a large impact in the error observed for the forecasting. One way to possibly mitigate this issue is by forecasting the 5 minute average demand. This would solve problems with timestamp mismatching and most likely would improve the forecasting quality. Moreover, as Figures 9 and 10 illustrate, the 5 minute averaged data better reflects the 1 minute demand trend than the 5 minute instantaneuous data (the green curve fits the 1 minute data much better than the red curve).

5.2.2 Unknown changes in the demand regime

The historical data shows that SMCC has two modes of operation, a "low demand" mode ~[150,1000] kW and a "high demand" mode ~[600,1400] kW. During the pilot period, the demand mode changed on three instances: 09/12, 09/17 and 09/19. Without prior knowledge of when these mode changes occur, the forecasting error will increase substantially.

5.2.3 Unexpected changes in site operation

Changes in operations or operational scheduling affected the forecasting results at both SMCC and UC Merced demand at the start of the school year (the week of 08/22). The forecasting models for both sites were retrained with data from the last week of August to reflect the associated change in demand.

Unexpected or unexplained changes in site operations also affected the forecasting results. At SMCC, the on-campus cogeneration malfunctioned and went offline on 08/08, resulting in a sudden demand spike. At UC Merced, variability in the scheduling of the chillers resulted in sudden changes in the demand regime. At WHF, the industrial pump was turned off unexpectedly on several occasions, namely: on 8/17/11 from 7:00 to 7:10, from 8/25/11 14:00 to 8/26/11 6:10, from 8/26/11 14:00 to 8/27/11 6:05 and on 9/2/11 at 12:25, which resulted in an immediate reduction in demand.

5.3 Performance of the DR resources

Coordination of the DR strategies and the enablement of all the sites took about three months. All three sites were less than ideal for this study. San Mateo County's willingness to experiment with reducing air conditioning loads proposed a few challenges because of the mild climate the campus is located. Initial discussions around lighting strategies were not realized due to budget and time constraints. UC Merced was not willing to experiment with the thermal storage system and wanted to use DR during the times when solar resources were diminishing and the campus was transitioning out of the solar system. WHF had one pump that could be on or off but they were not willing to turn it on and off frequently because if the fear of soil and sand getting stuck in the irrigation pipes.

Cooler than usual summer in northern California, coupled several issues with site enablement including installation of a meter on the wrong pump and missing data from UC Merced each time tests were conducted, unfortunately, led to few meaningful tests. In addition the resources were too small to actually participate in the CAISO's ancillary services market as regulation resources. Therefore, the tests conducted were initiated by the operator of the DRAS and were called "middle-to-end" tests. Table 4 summarizes the sites, test dates, test periods and the results of the site's participation. SMCC participated most with three take tests and two shed tests. Each time, each resource was instructed to deliver a certain load whether it was a take or a shed signal. A shed signal was indicated with a positive number and a take signal was indicated with a negative number. The most successful events were the regulation down tests conducted with SMCC. Unfortunately, because this site is located in a mild climate, the shed tests on warm weather did not yield large savings. Only one day of data was captured from UC Merced. Four-second data were missing on all other tests dates just around the test times. Because the data were missing just around the test dates, the team has been investigating the missing data issue more closely to understand if the telemetry equipment was somewhat effected by the tests. WHF was the only site at which we could not conduct any events. By the time the meter was moved and the communication was established, the site stopped operating the pump.

TABLE 4. SUMMARY OF TEST EVENTS

Site	Test Date	Test Period	Shed(+)/Take(-) per hour and total (kWh)
SMCC	8/3/11	2-4 am	-20, -16, **-36**
SMCC	8/8/11	2-4 am	-34, -80, **-114**
SMCC	8/24/11	2-4 am	-274, -279, **-599**
SMCC	9/12/11	1-3 pm	No visible response
SMCC	9/27/11	1-3 pm	67, 44, **153**

UC Merced	8/16/11	2-4 pm	325, 238, **563**
UC Merced	8/31/11	6:30-7:15 pm	missing data
UC Merced	9/8/11	6-8 pm	missing data
UC Merced	9/13/11	7-8 pm	missing data
WHF	No shed tests	-	-

While all the test events for SMCC and UC Merced are presented in Appendices A and B, for the rest of this section, two days that seem like the highest performance days are described in detail to point out some of the issues.

SMCC performance on August 24, 2011

The take tests in general were successful at this site. On this particular date, the take event scheduled between 2 am and 4 am, is clearly visible from the five-minute load shape. The smooth (blue) line indicates the forecast. Forecasted load is lower than the actual load in general but especially during the period before the tests so the take calculation is over estimating the actual load increase. When considering only the pseudo generation picture however, because of the error in the forecast, the site seems to deliver a similar pseudo generation amount between 8 am and 8 pm without being instructed. More discussion on this issue is included in the conclusion section.

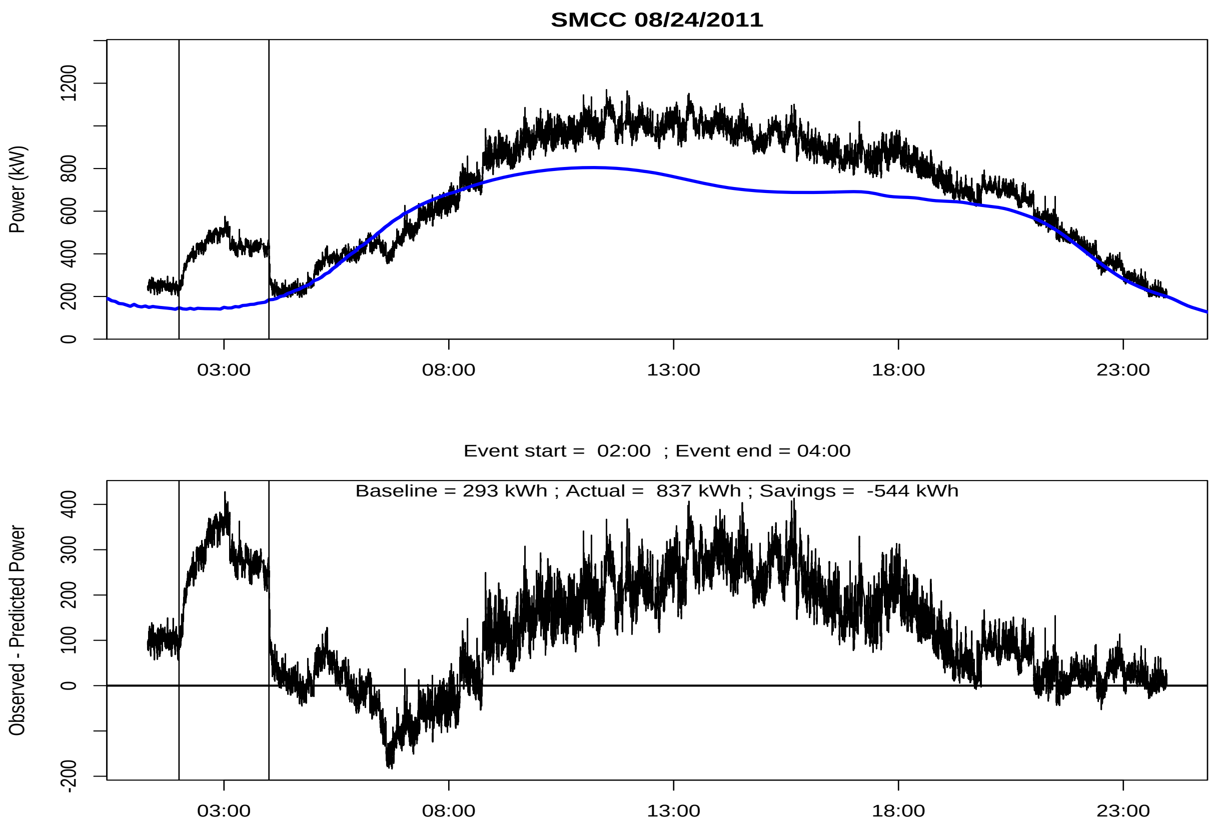

FIGURE 21. LOAD AND PSEUDO GENERATION PROFILE OF SMCC ON AUGUST 24, 2011.

UC Merced Performance on August 16, 2011

Figure 22 displays the load and pseudo generation profile of UC Merced on August 16, 2011. The smooth (blue) line is the load forecast. Typically, there is a lot of variation in loads during morning and evening ramp periods and this day is no exception. However, on this day, the forecast is higher than the actual loads making it difficult to calculate the actual savings from the shed event. While the pseudo generation profile indicates a reduction in loads because the load reduction is not differentiable during the event period, it is not considered a reliable shed event.

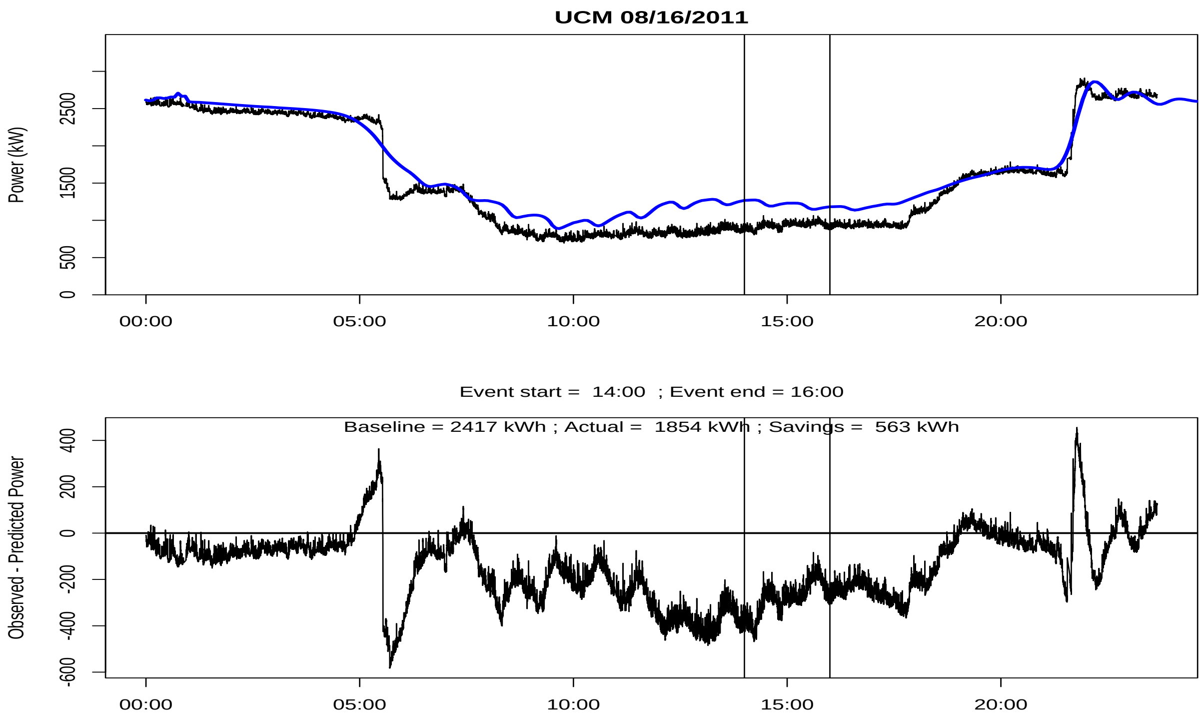

FIGURE 22. LOAD AND PSEUDO GENERATION PROFILE OF UC MERCED ON AUGUST 16, 2011

5.4 Results from latency tests

The following timing information was collected for the three participating sites following the latency test outlined in section 4.6.

West Hill Farms November 8, 2011

Table 5 displays the results of the latency tests conducted with WHF. When a setpoint instruction of 100 kW was sent to the site, it took 1 minute and 5 seconds for the site to receive and respond to the instruction. Similarly, on the same day, less than 10 minutes later, when a setpoint instruction of -100 kW was sent to the site, it took 2 minutes 6 seconds for the site to respond. In both tests, the largest delay happens between the DR controller and the loads, indicating that the limiting factor is the architecture that is being used by the aggregator to communicate with the pumps.

TABLE 5. RESULTS OF THE LATENCY TESTS AT WHF

Setpoint	T0	T1	T2	T3	T4	End to End
100	3:48:00	3:48:03	3:48:08	3:48:09	3:49:05	1:05

0	3:45:00	3:53:03	3:53:08			
-100	3:55:00	3:55:03	3:55:08	3:55:08	3:57:06	2:06
0	3:58:00	3:58:03	3:58:08			

UC Merced, December 5, 2011

The results from UC Merced were more encouraging but unfortunately cannot be directly compared with WHF. Table 5 displays the results of the latency tests at UC Merced. The T3 through T6 are all on the same clocks at the participating site. T2 and T7 are on different clocks. There are clearly differences between the clocks, as T2 (first arrival at the site) shows receipt of the signal three seconds before T3, which is impossible. There is also a considerable apparent signal delay reaching T7 (a different building on a different clock.) The longer latency reaching T7 may or may not be real. Also note that the ICCP infrastructure necessary to simulate the 2 to 3 second latency between ISO and the DRAS was not available for this test. Instead, setpoint instructions were injected directly into the DRAS. Overall, we estimate that end-to-end latency was between 2 to 11 seconds excluding any latencies between CAISO and the DRAS.

TABLE 6. RESULTS OF THE LATENCY TESTS AT UC MERCED

Setpoint	T1	T2	T3	T4	T5	T6	T7	End to End (sec.)
100	10:50:05	10:50:10	10:50:07	10:50:07	10:50:09	10:50:07	10:50:16	2 to 11
0	10:51:04	10:51:10	10:51:05	10:51:05	10:51:06	10:51:05	10:51:14	1 to 10
200	10:55:01	10:55:06	10:55:03	10:55:03	10:55:05	10:55:03	10:55:12	2 to 11
0	10:56:01	10:56:06	10:56:03	10:56:04	10:56:04	10:56:03	10:56:12	2 to 11
300	11:00:04	11:00:10	11:00:05	11:00:05	11:00:07	11:00:05	11:00:14	1 to 10
0	11:05:01	11:05:06	11:05:03	11:05:03	11:05:05	11:05:03	11:05:12	2 to 11

San Mateo Community College, December 19, 2011

A series of middle-to-end tests (from the DRAS to the site) with synchronized clocks showed that the OpenADR push gets to the GridLink box in San Mateo in one second (including a detour through Dallas, TX), except for sometimes when the relay from Dallas to San Mateo takes 20 seconds for unexplained reasons.

This only represents the first leg of the trip, and does not include on-site latency as the signal works its way through the building management system to the destination load. On-site latency, as seen in the tests with WHF, may add a major delay in the signal propagation depending its architecture and communication bottlenecks that are not necessarily observable through daily operations.

TABLE 7. SAMPLE COMMUNICATION TIMESTAMPS FROM SMCC

Setpoint	ICCP Entry	PUSH	Dallas	San Mateo	EMCS
	T0	T1	T2	T3	T4
150	14:41:00	14:41:03	14:41:00	14:41:06	NA
150	14:59:00	14:59:04	14:59:05	14:59:05	NA

300	15:03:00	15:03:04	15:03:07	15:03:27	NA
0	15:10:00	15:10:03	15:10:04	15:10:19	NA
10	15:14:00	15:14:04	15:14:05	15:14:06	NA
20	15:16:00	15:16:05	15:16:05	15:16:05	NA
30	15:18:00	15:18:04	15:18:05	15:18:04	NA
40	15:22:00	15:22:03	15:22:04	15:22:05	NA
50	15:29:00	15:29:04	15:29:04	15:29:18	NA
60	15:33:00	15:33:04	15:33:04	15:33:05	NA

6 Observations and Recommendations

This section summarizes the lessons learned and recommendations about site selection and end-uses, communication and controls.

6.1 Demand-side issues

- ***Education on ancillary services markets and regulation products***. Customers have no knowledge of how the wholesale market in California operates, what ancillary services markets do and how regulation products work. Over 20 customers were approached and individually educated on the wholesale market operations in California. In addition, LBNL held a training session to all the controls vendors associated with these customers. In general, customers resisted any implementation without quantifiable benefits. The recruitment effort was able to capture some early adopters not on the customer side but on the controls vendor side. We observed strong involvement from each vendor.
- ***Limiting customers' regulation participation to certain hours***. While regulation products are used continuously by the system operators, putting boundaries for each DR resource improves recruitment of sites. Customers were more open to thinking about responding two to three hours during the day and/or at night when their end uses may be available for regulation participation.
- ***Switching off equipment vs. modulating equipment (equipment operation issues)***. The end use response can be abrupt by switching off loads or gradual by using variable frequency drives on the pumps and fans that are part of the facility loads. The wear and tear of the DR strategies on the existing building equipment was not considered in this project. This was partly because there were limited number of events with short durations.
- ***Accuracy of forecasts***. DR resources are evaluated using the forecasted loads. Therefore, the accuracy of the forecasts influence the accuracy or certainty of the DR resources delivered. In this study, simply considering the pseudo generation calculation for the DR period would be misleading.
- ***DR resources are not the same as generation resources***. DR resources are variable depending on the time of day, day of the week and season. However, they are controllable. The variability is due to the variability of loads that may or may not be controlled for DR purposes. In addition, the ramp up and ramp down times of these resources may vary depending on many factors such as the season, end uses being controlled, etc.

6.2 Communications

Communication evaluation included what is being communicated and how it is being communicated. In the case of regulation, first each resource had to be characterized with a ramp rate, high operating limit and low operating limit. Then, during the dispatch period, a setpoint instruction, which is a certain load level that the resource has to deliver through shed or take actions, was communicated to each site. In this section we comply our observations on both the resource characterization and the setpoint instructions.

- ***Resource characterization parameters are inadequate for DR***. A single ramp rate and an offset to avoid negative values are major limitations of the characterization of DR resources. DR resources should have separate ramp-up and ramp-down rates as well as having the capability to transmit negative values. This is a substantial change since the resource characterization changes will cause additional changes in the AGC system and the development of a resource integration process (akin to the certification process for the generators).
- ***Slow DR communication infrastructures may not be able to meet the regulation latency requirements.*** We utilized the existing communication and control infrastructures within the facilities and the Internet to PUSH signals from the DRAS to the site. The results of the latency tests showed that depending on the communication and control infrastructure at each site, the latencies vary and may not meet the regulation requirements. Therefore, at each participating site, in addition to the resource characterization tests, communication latency characterization has to be conducted.
- ***A SOAP or REST based PUSH architecture requires alternatives in the long-term.*** While the project team decided to use this architecture to test the technical feasibility of responding within 4 seconds, alternative methods were also researched through the process. For Internet communications, "long polling" is suggested as an alternative. OpenADR may be utilized over other transports that have inherent capabilities dealing with signal latency and security issues. Research is needed consider other transports for this type of communication.

6.3 Controls

The initial recruitment goals for the project included more variety of end uses and larger loads. Nevertheless, the final recruited sites provided information on the use of pumps and role of enterprise controls systems. Here, we summarize these observations as follows:

- ***Controls architecture has significant impact on communication latency.*** Once the signals reaches the facility, latency of the existing control system architecture is the constraint for this interaction. Since energy management and control systems are not initially designed to accommodate fast DR applications, it is important to characterize this latency before making the resources available for regulation products.
- ***Fans and pumps provide fast response when directly controlled.*** Within the HVAC system, there are some components that act faster than others. Sometimes this is simply because the sequence of operations for variable-air volume boxes slow the response as compared to directly controlling fans for ventilation. Of course directly controlling equipment outside of the system controls may have an adverse affect on the system.
- ***Some buildings may be able to take energy.*** When wind is available at night, and there is no load to take it, buildings may be able to take this excess energy and use it in a meaningful way. Whether it is night flushing the building, or pre-cooling, additional research is needed to provide guidance to building owners to how best utilize this inexpensive energy at night.

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