Preparing for the Utility of the Future

Jim Parks, Sacramento Municipal Utility District

ABSTRACT

Energy efficiency and demand response will play a strategic role in the grid of the future. With the advancement of distributed energy resources (demand response, renewables, electric vehicles, microgrids, energy efficiency and energy storage), smart grid technologies, competition and new policies, the utility industry is in the middle of the biggest changes since its inception. In conversations with others in the utility industry, some are questioning the role of energy efficiency and demand response in the utility of the future.

The Sacramento Municipal Utility District (SMUD) implemented a large smart grid project (SmartSacramento) that included the installation of advanced metering infrastructure across all customers. Using smart meter capability and data, SMUD performed a consumer behavior study (Smart Pricing Options) to test time of use (TOU) and critical peak pricing (CPP) rates with residential customers. Based on the results of the study (13% peak-period energy reduction for default participants and 90% customer satisfaction), SMUD is implementing TOU as the default rate for all residential customers beginning in 2018.

This paper will discuss several aspects of the SmartSacramento project as they relate to energy efficiency and demand response including the results of the consumer behavior study and how the study was used to justify implementation of full-scale TOU; how SMUD is using AMI meter data and other data sources to improve energy efficiency and increase demand response; how conservation voltage reduction can be used to improve building energy efficiency; and looking at ways to improve grid performance through focused energy efficiency and demand response initiatives focused at a micro level—a substation or feeder—to enable greater deployment of distributed energy resources in the future.

Introduction

In October 2009, SMUD received notice that it had been awarded a $127.5 million grant as part of the American Recovery and Reinvestment Act (ARRA). This grant facilitated a $308 million (over $162 million from SMUD, $18.3 million from partners) smart grid Project that was comprised of over 40 individual projects. Several of the projects were directly related to energy efficiency and demand response. These included:

- Smart Pricing Options – a time of use and critical peak pricing pilot
- Advanced Metering Infrastructure (AMI) – installation of smart meters over the entire service territory, laying the foundation for greater visibility of energy use patterns
- Conservation Voltage Reduction – reduce voltage at the grid level to achieve energy efficiency savings
- PowerDirect – a commercial demand response pilot using AutoDR
- PowerStat 1 and 2 – residential thermostat control demand response pilots: one that included pre-cooling, the other did not
- EV Innovators – time variant rates with direct load control for electric vehicles

- 2500 R Street – residential infill project including energy efficiency, photovoltaic systems, energy storage, time variant rates and net-zero design
- Advanced Controllable Lighting – demand response enabled, super-efficient lighting systems
- In Home Display (IHD) check out – customers could borrow IHDs from SMUD or from local libraries for a period of two months
- Building energy management system installations

Due to space constraints, this paper provides highlights of five of the initiatives listed above. Additional detail on these projects can be obtained at *smartgrid.gov* by searching on "SMUD reports". References to the final reports summarized in this paper are provided at the end of this paper.

The project, SmartSacramento®, created a greater awareness of the changes coming to the utility industry and the need to be fully engaged in advancing the utility of tomorrow. The project caused SMUD to closely consider the future of the grid and where it fits into that future. The vision for the grid of the future must be an evolving one. When SMUD received the Smart Grid Investment Grant 6 years ago, few could have imagined the technology potential we now see and the speed at which the utility industry is changing. SMUD's system is seeing increasing numbers of distributed energy resources (DERs) including electric vehicles, renewable generation, demand response, energy storage, micro grids and energy efficiency. It becomes more challenging to manage the grid as thousands of new, small, distributed resources are added to the distribution system. We see a future where we will need to optimize these resources to improve grid performance and meet customer needs—even when many of the DERs are intermittent in nature and cannot be dispatched as needed. The collective management of DERs is both a challenge and an opportunity for utilities.

The SmartSacramento Project officially ended December 2014, but the project continues:

- Many of the pilot projects performed under SmartSacramento have been adopted as operational programs and are continuing to provide benefits to SMUD and its customers.
- The hardware and software projects that were implemented under the grant have been tested, commissioned and put into operation.
- Many hardware/software projects are being expanded.
- The creation of new data sources through SmartSacramento have created, and continue to create, new initiatives that improve grid performance and reliability, and provide new and improved services to customers.
- Time of use rates will be the default residential SMUD rate beginning in 2018 as the result of SmartSacramento's Consumer Behavior Study, Smart Pricing Options.

Projects

Smart Pricing Options

One of the key SmartSacramento projects focused on a consumer behavior study called *Smart Pricing Options*. This project tested combinations of time of use (TOU) and critical peak pricing (CPP) rates with SMUD's residential customers. Some customers self-selected the rate based on promotional materials (opt-in). Other customers were sent materials letting them know that they were going to be assigned a rate, but had the option to opt-out (default). Customers were selected randomly from approximately 50,000 SMUD customers that had at least one year's worth of smart meter data. This data was used to examine the pre- and post TOU/CPP rate impacts. Since SMUD's smart meter deployment was not complete when Smart Pricing Options started, only those with a year's worth of data were eligible to participate. Customers that were not selected for the dynamic rates made up the control group. Additional details on number of participants, recruiting methods, response rates, and more are available in the interim and final reports.

The CPP rate was significant due to the big difference between the peak and off peak prices. The critical peak rate was 75 cents per kWh while the off-peak price was just 7.2 cents per kWh—a pricing differential greater than ten-to-one between super peak and off peak. The TOU rate used a 3:1 differential; 8.5 cents per kWh off peak and 27 cents/kWh on peak. These rates were determined by SMUD's Rates group. Based on their analysis of industry trends and pricing policies, the Rates group believed a 3:1 and a 10:1 price differential would clearly demonstrate the benefits of TOU and CPP pricing. The CPP rate was used 12 times per summer season (June through September) during 2012 and 2013 for called events over a three-hour window from 4 to 7 p.m. SMUD promised participants that CPP events would be called no more than 12 times per summer season. Events were called day ahead based on forecasted weather and electrical load, and participants were notified via email, text and/or phone. The TOU/CPP rates are shown below in Table 1. The existing residential rates were two-tiered, with the first 1000 kWh per month costing approximately 10 cents/kWh and usage over 1000 kWh priced at 18 cents/kWh.

Table 1. Smart Pricing Options TOU and CPP rates

	On-Peak Prices Weekdays: 4-7 PM		Off-Peak (Tier 1) and Mid-Peak (Tier 2) Prices		Monthly Service Charge
Standard Residential CBS Rate	**Peak Price**	**Critical Peak Price**	**Tier 1**	**Tier 2**	
Time-Of-Use Peak Rate	\$0.27	\$0.00	\$0.0846	\$0.1660	\$10.00
Time-Of-Use with Critical Peak Pricing	\$0.27	**\$0.75**	**\$0.072**	\$0.1411	\$10.00
Critical Peak Pricing (Stand-Alone)	\$0.00	**\$0.75**	\$0.0851	\$0.1665	\$10.00

The results of the pilot were statistically significant according to multiple references in the *SmartPricing Options Interim Evaluation*. Opt-in customers generally reduced peak loads by about double the rate of default customers, but the savings from both groups were considered significant in terms of peak load reduction. Figure 1 shows the peak capacity reductions from the CPP participants. The *SmartPricing Options Interim Evaluation* provides details on the impacts of In Home Displays (IHDs) on the reductions.

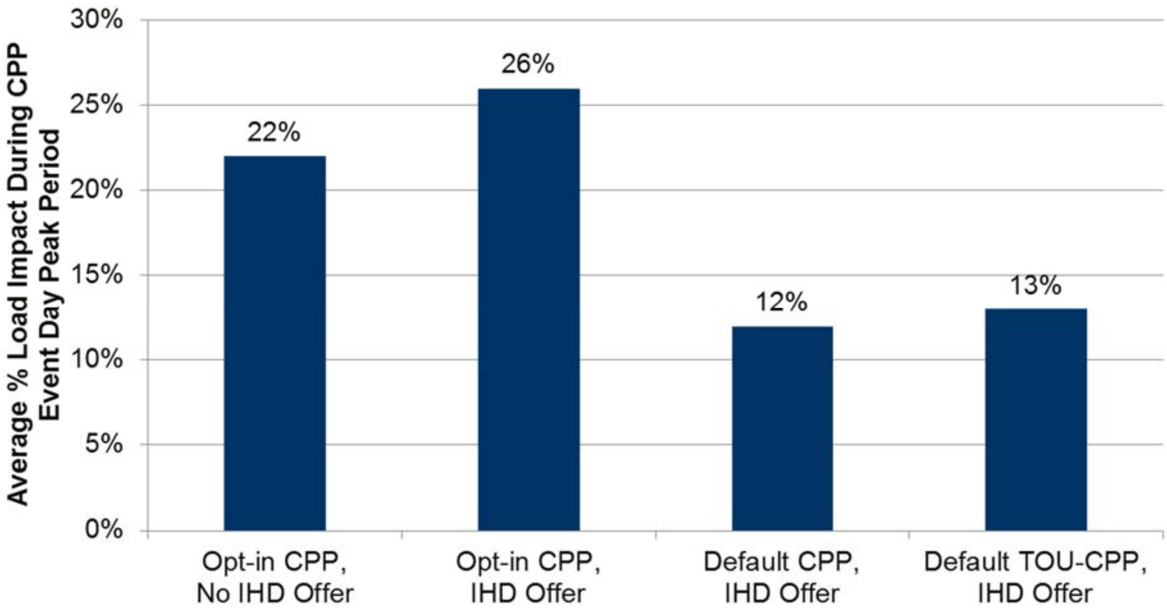

Figure 1. Peak kW (first year) reduction from Smart Pricing Options CPP rate

The first year TOU results yielded 10 to 13% peak reduction with opt-in customers and 6-8% reduction with default participants. Based on customer surveys, customer satisfaction with the rates was highest with the time varying rates (87%) and lowest with the default rate (80%). Based on these results, SMUD executives and the Board of Directors decided to pursue time of use rates as the default residential rate. This was announced through the 2014 SMUD Rate Proceeding with a plan to move gradually to TOU by retaining tiered rates from 2014 through 2016, moving to a flat, one-tiered rate in 2017 and to TOU in 2018. These are scheduled for full deployment in 2018. TOU rates are currently (2016) offered to a subset of customers. They will expand in 2017 to all customers that would like to opt-in and in 2018, all residential customers will default to the TOU rate, but will have the option to opt-out. Based on the Smart Pricing Options pilot, TOU customers reduced peak load by an average of 0.17 kW per customer. If extrapolated across the residential customer base, this could amount to approximately 90 MW of peak load reduction due to the TOU rate. The current TOU rate is shown below in Figure 2. The final 2018 residential TOU rate may change from what is shown in Figure 2, but is expected to be close.

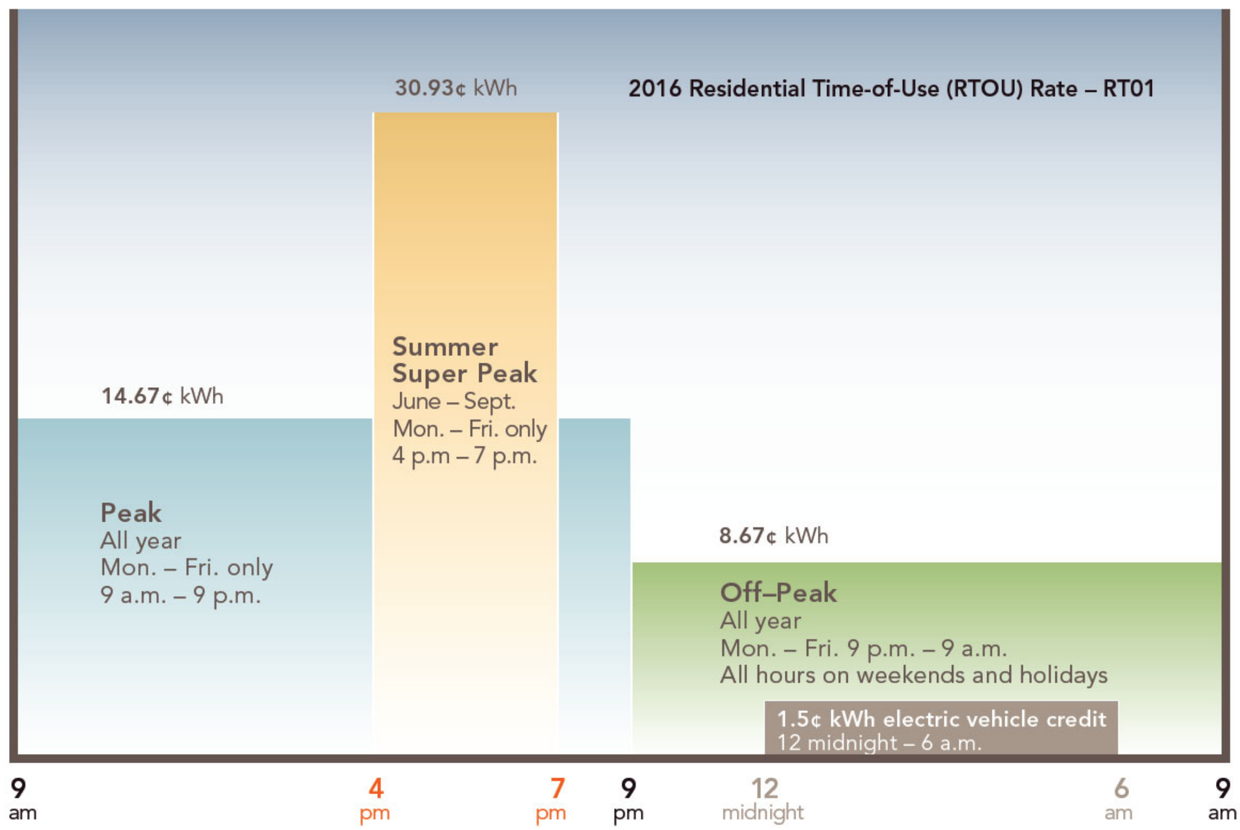

Figure 2. Proposed SMUD TOU rates with electric vehicle credit

Advanced Metering Infrastructure

SMUD installed 620,000 smart meters (100% of customers, less approximately 385 customers that have opted out of smart meters) and associated hardware and software to allow meters to be read automatically, accurately and frequently. The smart meters are the technology that enables SMUD to implement TOU rates. Electromechanical meters are good for once a month reads, but do not have the built-in intelligence to enable time varying rates.

From a data collection perspective, smart meters provide a trove of data that if used correctly, can help in the development of tools that can improve grid performance and reliability and provide customers with detailed information that can help them proactively manage their energy use. Through smart meters, SMUD collects hourly usage reads for residential meters and 15-minute reads for all commercial/industrial customers. In addition, SMUD collects hourly voltage reads so it can 'see' if there are voltage issues on the system.

As a result of installing smart meters and other 'smart' technologies, SMUD's data storage needs have increased dramatically. Moving from monthly reads to hourly reads on the residential side increased data storage needs by 720 times. By adding voltage reads to the equation, storage needs jump again. By moving from tiered rates to TOU rates, storage needs increase again. SMUD currently doubles its data storage capacity every 18 months and maintains servers to store the data. A data governance group establishes criteria for using the data and different groups within SMUD use the data based on their respective needs.

SMUD has used the data to develop new initiatives and continues to look for additional uses of the new data sources. Elements include:

- Provide personalized program offerings based on energy use patterns
- Enable development of micro programs that focus on specific areas of the grid that may need support from demand response or energy efficiency
- Improve customer participation by better understanding customer behaviors
- Help customers engage through the provision of more detailed energy information and provision of tailored recommendations
- Improve the advanced operating system that enables CVR and improves outage response times
- Enable demand response reconciliation
- Implementation of revenue protection improvements
- Improvements in photovoltaic integration, monitoring and forecasting
- Improvements in the outage management and outage communication systems
- Development of a digital wall map for utility operators
- Development of a situational awareness program that uses data from meters and the distribution system to provide utility operators with tools to improve utility performance

Conservation Voltage Reduction

SMUD installed automation technologies on over 118 feeders (a distribution line generally serving around 1000 customers, 18% of SMUD feeders) of the distribution system to improve the 'visuals' of the circuits through installation of equipment and communication technologies. The feeders were equipped with capacitor banks, motor operated switches, reclosers and two-way communication. This equipment enabled volt-var optimization—the ability to control voltages on the distribution grid. Voltages are generally higher at the substation and gradually drop as the distance from the substation increases. Utilities are required to provide voltages within a bandwidth of plus or minus 5%, so voltages should not be too high at the substation nor too low at the end of the line. By installing and controlling capacitors and other equipment, voltages can be boosted at critical points on a feeder, ensuring that voltages stay within the required bandwidth. Once mid- and end of line voltages have been boosted, voltage across the entire feeder can be reduced, saving energy. This is called conservation voltage reduction or CVR.

Figure 3 shows how this works. The blue line shows the voltage drop from the substation to the end of the line without volt var optimization. The green line shows what happens when volt var optimization is implemented—voltages are boosted at selected points on the feeder, providing a somewhat level voltage profile. Once the voltage is levelized across the feeder, the voltage across the entire feeder can be reduced as shown in the red line. This saves energy based on the equation P=IV (Power (watts) = Current (amps) x Voltage (volts)). When the voltage is reduced, power is also reduced. Unlike conventional utility energy efficiency programs, the energy savings are invisible to the customer. Customers save energy but do not know they are saving energy. The slight decrease in their electricity bills probably goes unnoticed.

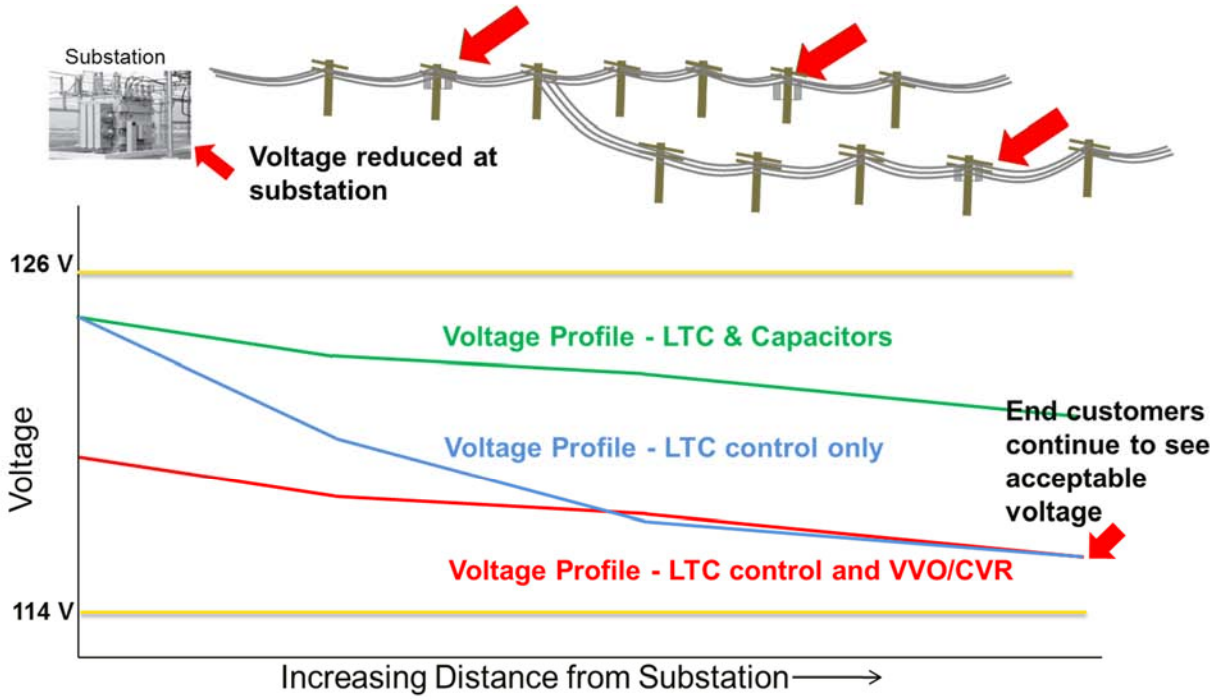

Figure 3. Volt Var Optimization and Conservation Voltage Reduction

When voltages are reduced, energy savings can be calculated and the CVR factor is determined by substation (a substation has one or more feeders). The CVR factor is based on the savings at a particular substation and the number is different across substations based on the types of load, age of equipment, size of distribution wire and many other factors. The CVR factor is useful in documenting the savings you will achieve depending on the percentage reduction in voltage. SMUD performed CVR at 14 substations (approximately 40 circuits) and the CVR factors generally ranged from 0.3 to 0.9 and averaged 0.6. This means for every percent voltage reduction, energy savings equaled 0.6%, so a 2% voltage reduction would yield 1.2% energy savings on average. The CVR factor is simply multiplied by the percent voltage reduction to determine the savings. Figure 4 depicts how the load shape looks with and without CVR. The dotted lines at the top show the pre-CVR voltage (red) and the voltage during CVR (blue). The solid lines show the load profile pre-CVR (red) and with CVR (blue). The white area between the two load profile curves represents the energy savings due to CVR. The data was collected on a reference day with similar characteristics to the test day. A regression analysis was performed to estimate the CVR savings.

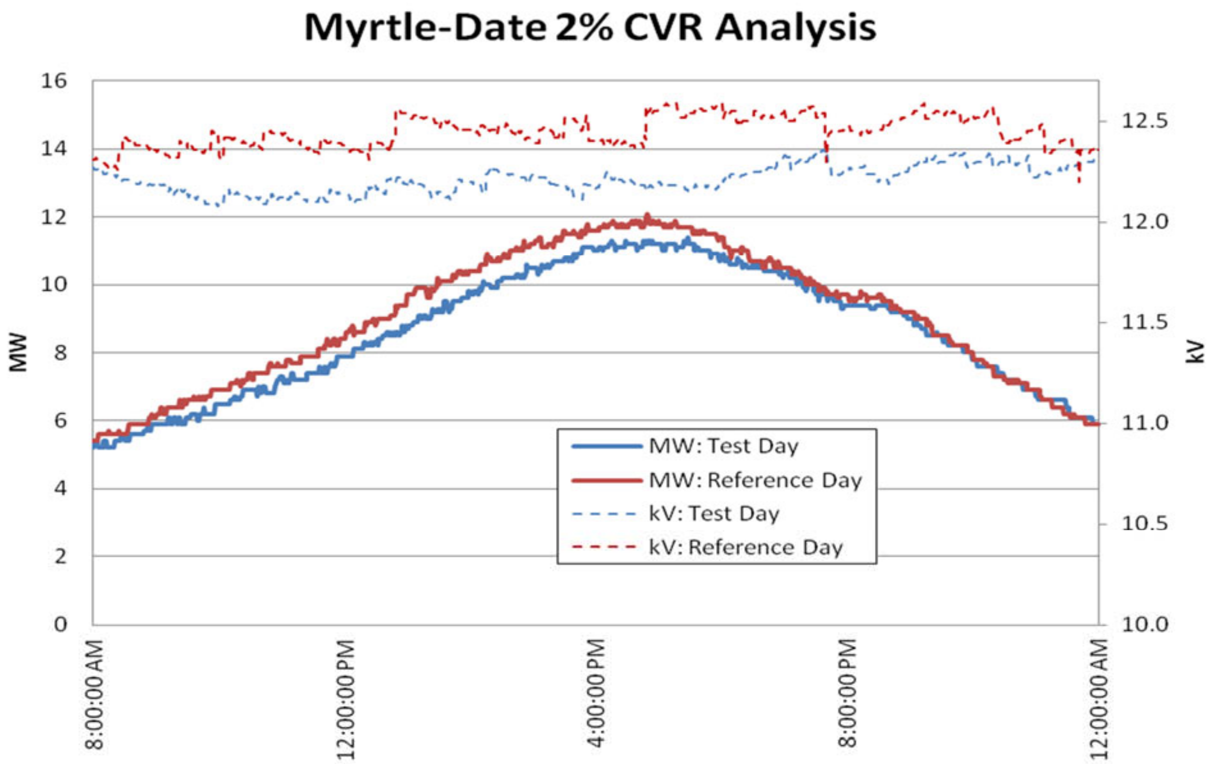

Figure 4. CVR load profiles

Commercial Demand Response

As part of SmartSacramento, SMUD developed an AutoDR commercial demand response (DR) pilot called PowerDirect®. The intention was for the pilot to eventually roll out as SMUD's long term commercial DR program.

The program was designed to encourage maximum performance, offer ease of compliance and provide reliable, predictable and sustainable load reduction. The pilot also provided a manageable, cost-effective and high quality settlement process through the demand response management system. The program featured automated notification, dispatch and settlement.

Customers pre-selected loads they were willing to curtail and SMUD could call on those loads as needed to reduce system peaks, for economic dispatch and to improve system reliability. Nine customers participated in the pilot and all included HVAC, either chillers or package air conditioners, as all or part of their load reduction. Some participants included fans, air handlers, pumps and lighting as part of their proposed load shed. AutoDR (the ability to implement demand response automatically through the use of controls) enabled the loads to be automatically dispatched, but customers were notified of events and could opt-out if needed.

During the summer of 2013, the pilot delivered effective performance of 91% compared to expectations, and achieved energy savings of 41,500 kWh and peak load reduction of 3.4 MW during 10 called events. Based on the pilot results, PowerDirect became the operational commercial DR program at SMUD. It is currently unclear how much the program will be expanded in the near term. In the past, SMUD consistently experienced 2% growth in electricity use per year. In recent years the growth has flattened, reducing the need for additional demand response programs.

The final report for the project: *2013 PowerDirect Medium and Large Commercial Automated Demand Response Pilot Program Report* contains many additional details including recruiting information, pilot design, program economics, energy savings and peak load reductions achieved by event.

Residential Demand Response

The residential demand response pilot was called PowerStat. PowerStat was designed to reduce residential air conditioning loads through temperature set back of programmable communicating thermostats and the use of time of use rates, critical peak pricing, and/or direct load control.

Two studies were performed: one that precooled participant homes prior to called DR events (summer 2012), and the other without precooling (summer

2013). Figure 5 shows the levelized results of the precooling pilot at different temperatures. The key features in Figure 5 are the increased energy use prior to the DR event due to the temperature setback and increased air conditioner on time; the significant savings during DR events; and the rebound after the event due to air conditioners coming on after the DR event.

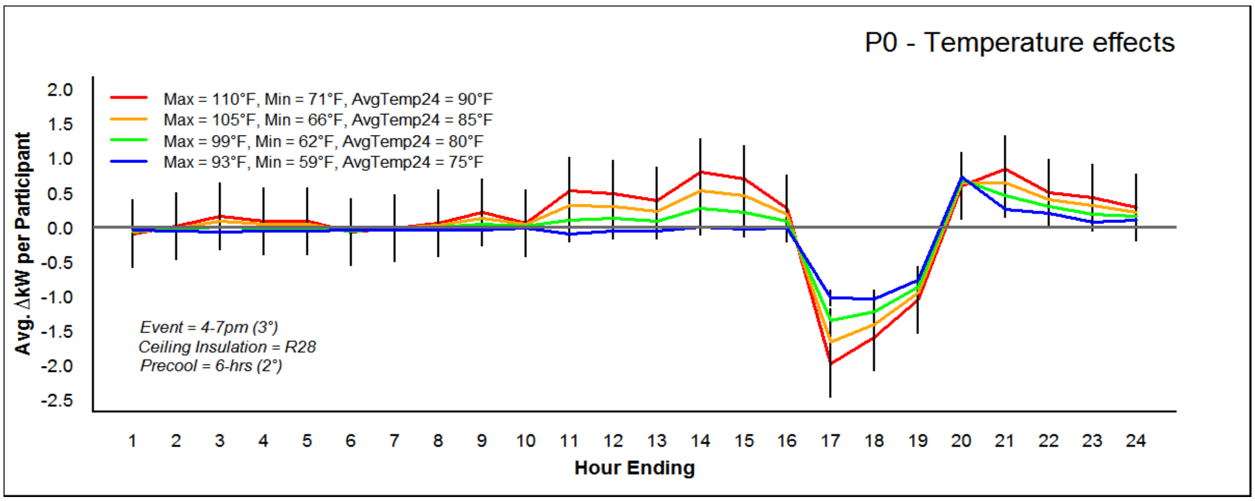

Figure 5. Levelized load profile showing precooling energy use, demand response and rebound from page 47of *2012 Residential Direct Load Control Precooling Study*

The average peak load reduction during the 4-7 p.m. window was 1.45 kW. Customers were very satisfied with the program and PowerStat (without precooling) has become the new residential DR program for SMUD. Many additional details are available in the reports referenced in this paper.

Next Steps

DERs are going to play a much larger role in the future of the electric grid and building energy efficiency, grid efficiency, and demand response will be key elements. The potentially negative impacts of increasing numbers of non-dispatchable renewable resources such as wind and photovoltaics can be mitigated through the proper application of demand response, energy efficiency and energy storage. As new loads are added to the grid and new infrastructure such as substations and grid upgrades are needed, DERs will be considered as an alternative to expensive infrastructure upgrades.

As an example, SMUD has a customer that is planning to expand operations which will require SMUD to install a new bulk substation in order to meet the expected load. In preparation for this, SMUD is analyzing alternative measures that might delay the need for the substation. Consideration will be given to micro energy efficiency and demand response programs that reduce loads at specific locations and optimize existing resources to delay the capital outlay required for the project. Programs can be marketed to specific zip codes or customers and the program benefits will be focused where they are needed.

This type of thinking needs to become commonplace among utilities. The typical model of central station power plants delivering energy to load centers is gradually giving way to a model of distributed resources, mostly on the distribution side, supplying energy from multiple points and causing two-way power flows. There is a place for energy efficiency and demand response in the new model, but there will be changes. Utilities will start claiming energy efficiency and DR credit for grid-related initiatives as well as through conventional utility energy efficiency programs. As buildings become more efficient, the grid will provide higher percentages of efficiency and programs will focus more on areas where grid reliability can be improved and/or certain infrastructure can be deferred or eliminated.

SMUD has several planning efforts underway to help prepare for the future. Plans include:

- Grid Modernization 3-Year Plan—itemizes the short term hardware and software needs to continue moving towards a smarter grid
- Distributed Energy Resource Plan—highlights the grid changes required to better integrate and utilize the increasing number of distributed energy resources (energy efficiency, demand response, renewables, energy storage, electric vehicles, and micro grids) on the grid
- Energy Research and Development Strategic Plan—sets the direction for R&D efforts to continue moving SMUD towards the grid of the future
- Smart Grid Roadmap—analyzes the projects performed under SmartSacramento and makes recommendations for expanding those projects
- Grid 3.0 Plan – combines the plans above into a single plan that lays out direction for the future

Several things are converging that will continue to drive change in the utility industry. These include smart meters and the large amounts of data that can be used to effectively develop future programs both on the grid side and the customer side; increasing numbers of DERs that drive utilities to strengthen their systems in order to accommodate the increase; communications on the grid side allowing for near real time knowledge of grid systems; and the increasing number of new products and services that help optimize assets, improve reliability and increase efficiency. Energy efficiency and demand response will continue to play a key role in the future.

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