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ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Demand Response
Spinning Reserve Demonstration

Prepared for
Energy Systems Integration
Public Interest Energy Research Program
California Energy Commission

Principal Investigator
Joseph H. Eto, Lawrence Berkeley National Laboratory

Project Team
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Environmental Energy Technologies Division

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Abstract

The Demand Response Spinning Reserve project is a pioneering demonstration of how using existing utility load-management assets can provide an important electricity system reliability resource known as spinning reserve. Providing spinning reserve with aggregated demand-side resources such as those illustrated in this report will give grid operators at California Independent System Operator (CA ISO) and Southern California Edison (SCE) a powerful, new tool to improve system reliability, prevent rolling blackouts, and lower system operating costs.

The work completed to date to demonstrate the use of demand-response as spinning reserve has produced important programmatic and technical insights, including:

- **Target-marketing a utility's air-conditioning load-cycling program to customers served by a single distribution feeder can be a successful strategy.** SCE successfully recruited a high proportion (nearly one-third) of eligible customers to participate in the demonstration.

- **Repeated curtailment of these customers' air-conditioning in a manner similar to the deployment of spinning reserve can be accomplished *without a single customer complaint.*** SCE curtailed these customers' air-conditioning units 37 times during the final portion of Southern California's cooling season for durations lasting from five to nearly 20 minutes, and did not receive any customer complaints regarding the curtailments.

- **Real-time visibility of load curtailments can be achieved through an open data platform and secure website.** The project team demonstrated a highly flexible, open yet secure data-integration, archival, and presentation platform that allowed external audiences (e.g., electricity grid operators) to see curtailments in real time. Using such a platform and website could significantly lower the costs of this service relative to current practices.

- **Analysis methods developed for this project could one day be used to predict magnitude of load curtailments as a function of weather and time of day.** The project team developed statistical methods to estimate the load that would have been observed without a curtailment and means for comparing this estimated load to actual loads observed during curtailments. The team also conducted exploratory analyses that confirmed the existence of a relationship between the magnitude of the load curtailment, and ambient weather conditions and to a lesser, but still suggestive extent, time of day.

- **Load curtailments can be fully implemented much faster than ramping up of spinning reserve fro**m ther**mal generation**. The project team measured full load response in less than 20 seconds and identified technical opportunities to further increase the response speed.

Acknowledgments

This project was sponsored by the California Energy Commission (Energy Commission) Public Interest Energy Research (PIER) Program under contract #500-05-001. The project team gratefully acknowledges the support of Ron Hofmann, PIER Advisor, and Kristy Chew, PIER Contract Manager.

The project team also extends thanks to reviewers John Goodin, Walter Johnson, and Glen Perez of the California Independent System Operator (CA ISO); Roger Levy of Levy Associates; and Chuck Goldman of Lawrence Berkeley National Laboratory.

The project team is grateful for the support of the project Technical Advisory Committee: Bob Kinert, Pacific Gas and Electric Company (PG&E); Gary Tran, Southern California Edison (SCE); Patrick Harner, San Diego Gas and Electric (SDG&E); Clyde Loutan, CA ISO and Western Electric Coordinating Council (WECC); Fred LeBlanc, Western Area Power Administration (WAPA) and WECC; and Dorris Lam, California Public Utilities Commission (CPUC).

Finally, the team expresses its appreciation to David Hawkins and Tami Elliot of CA ISO for their contribution to coordinating this project.

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Acronyms

ACCP	Advanced Communication and Control Protocol
ACP	Autonomous Control Protocol
APS	Automatic Power Shift
CA ISO	California Independent System Operator
CMOPS	Compliance Monitoring and Operating Practices Subcommittee
CPUC	California Public Utilities Commission
DRSRP	Demand Response Spinning Reserve Pilot
ERCOT	Electric Reliability Council of Texas
ISO	Independent System Operator
ISO-NE	New England Independent System Operator
kWh	Kilowatt-hour
MORC	Minimum Operating Reliability Criteria Work Group
MW	Megawatt
NDFD	National Digital Forecast database
NTP	Network Time Protocol
NWS	National Weather Service
NYISO	New York Independent System Operator
OAT	Otherwise Applicable Tariff
PG&E	Pacific Gas and Electric Company
PIER	Public Interest Energy Research program
RAA	Remotely Alterable Address
SCADA	Supervisory Control and Data Acquisition
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric Company
SOAP	Simple Object Access Protocol
UCLT	Utility-Controlled Load Tests
WAPA	Western Area Power Administration
WECC	Western Electric Coordinating Council

Executive Summary

The Demand Response Spinning Reserve project is a pioneering demonstration of how existing utility load-management assets can provide an important electricity system reliability resource known as spinning reserve. Using aggregated demand-side resources to provide spinning reserve will give grid operators at the California Independent System Operator (CA ISO) and Southern California Edison (SCE) a powerful, new tool to improve system reliability, prevent rolling blackouts, and lower system operating costs.

Employing spinning reserve is an electricity system operator's first strategy for maintaining reliability following a major contingency, such as the unplanned loss of a large generation facility or critical transmission line. Operators protect system reliability by ensuring a continuous match between electricity generation and electricity consumption and by maintaining extra generating resources to respond to contingencies; these resources are known as spinning reserve. Spinning reserve is the most important contingency reserve because the generators that provide it are already running ("spinning") synchronized to the grid and can therefore respond immediately, either manually or automatically, to changes in system frequency. When spinning reserve is called into active service, the generator must ramp up output immediately and meet its full spinning reserve obligation within 10 minutes. CA ISO procures spinning reserves through competitive bids offered on its day-ahead and hour-ahead markets.

Using demand-side resources to provide spinning reserve would increase the total contingency reserve available to a system operator and might thus prevent situations in which operators might otherwise run short of generator-provided spinning reserve and have to call for rolling blackouts. The contingencies that trigger the need to call on spinning reserve occur infrequently (typically once or twice a month though sometimes more or less often). However, because triggering contingencies are unpredictable, the system operator must have pre-determined amounts of spinning (and other contingency) reserve available continuously. Ensuring that these reserves are available at all times is so important that rolling blackouts (i.e., the controlled curtailment of the loads of pre-defined geographic blocks of customers) are mandatory when these reserves run short. Intentionally curtailing customer loads may seem contradictory in this situation. However, by intentionally curtailing some customers' loads, operators ensure that the limited contingency reserve that is available remains adequate to ensure the reliability of the entire grid for the benefit of all customers.

The objective of this project is to demonstrate that spinning reserves can be provided using demand-side resources in a manner that is comparable to the current provision of spinning reserves using supply-side (i.e., generation) resources. We seek to demonstrate that it is both technologically feasible to provide spinning reserve using demand-side resources and that it may be preferable to do so because of inherent advantages of demand-side resources. These advantages include: 1) near-instantaneous response (compared to the 10 minutes allowed for full response from generators); and 2) responses that can be targeted geographically anywhere electricity is consumed within a utility's service territory (rather than responses that are restricted to the fixed location of the handful of generators that are contracted to provide contingency reserve services). These advantages are especially attractive because the curtailments required may not even be noticed by customers and reduce the likelihood that more dramatic curtailments, which customers do notice, will be needed.

In conducting the demonstration, we are beginning to address three critical institutional issues that currently hinder provision of spinning reserve with demand-side resources:

First and foremost, current Western Electric Coordinating Council (WECC) reliability rules preclude provision of spinning reserve from demand-side resources. Although these rules were not written to intentionally exclude demand-side resources, they consider only supply-side resources because no one had previously considered using demand-side resources for this purpose.

Second, as a result of the WECC rules, system operators do not have experience with relying on demand-side resources for spinning reserve. In addition to change in the rules, operators must develop confidence that providing spinning reserve from demand-side resources will be as reliable and effective as providing this service from generators.

Third, market rules related to aggregation, metering, load verification, and settlement must be reviewed and, where appropriate, modified so that aggregated demand-side resources can participate in CA ISO's wholesale markets where spinning reserves are competitively procured.

Finally, through the choice of technologies employed in this demonstration (SCE's 25+ year-old air-conditioning load-cycling program), we also show how a traditional utility load-management asset can be repositioned as a competitive asset whose value is established by wholesale markets for reliability services.[1] In doing so, we illustrate the potential that assets that have long been paid for by utility ratepayers can provide even greater value if the utility uses them to both improve reliability and lower the cost of securing reliability services. In this case, this would be accomplished as the utility either meets its own spinning reserve requirement or sells spinning reserve service directly to the competitive markets in which CA ISO procures spinning reserve.

The work completed to date in this project has produced important programmatic and technical insights, including:

Target-marketing a utility's air-conditioning load-cycling program to customers served by a single distribution feeder can be a successful strategy. SCE successfully recruited a high proportion (nearly one-third) of eligible customers to participate in the demonstration. This is a dramatic increase in participation from the typical one- to two-percent response rate that SCE obtains from its traditional mass-marketing approach for the load-cycling program. For this demonstration, the mass-marketing technique was

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[1] Many other demand-side technologies could provide spinning reserve in a manner comparable to that demonstrated in this project. These technologies include, in principle, other utility load-management assets as well as newer demand-response technologies, such as programmable communicating thermostats.

augmented with direct phone and door-to-door solicitations, endorsements from city officials, and marketing at community-based events. In the future, SCE can refine and use these targeted marketing approaches to capture additional location-specific benefits from customer demand-response programs.

Repeated curtailment of customers' air-conditioning in a manner similar to the deployment of spinning reserve can be accomplished *without a single customer complaint.* SCE curtailed the participating customers' air-conditioning units 37 times during the final portion of Southern California's cooling season for durations lasting from five to nearly 20 minutes. This is in contrast to "normal" curtailments for residential customers participating in the Summer Discount Plan, which are triggered by CA ISO-declared stage-two emergencies or local SCE transmission emergencies and can last one to four hours. After each normal curtailment event, SCE typically receives hundreds of requests by customers seeking to withdraw from the program. However, SCE received no complaints from the spinning reserve demonstration curtailments.

Real-time visibility of load curtailments can be achieved using an open platform and secure website. The project team demonstrated a highly flexible, open yet secure data integration, archival, and presentation platform that allowed external audiences (e.g., electricity grid operators) to view curtailments in real time. We maintain that viewing the aggregate behavior of the controlled loads on this feeder can be directly compared to viewing the performance of generators, which are routinely equipped with comparable telemetry. In the future, reliance on flexible, open platforms, such as the one demonstrated in this project, will lower the costs associated with ensuring that operators have real-time information about aggregated loads and with verifying the performance of these programs in real time.

Analysis methods developed for this project could one day be used to predict the magnitude of load curtailments as a function of weather and time of day. The project team developed statistical methods to estimate the load that would have been experienced without a curtailment and means for comparing this estimated load to actual loads observed during curtailments. The team also conducted exploratory analyses that confirmed a relationship among the magnitude of the load curtailment, ambient weather conditions, and, to a lesser but still important extent, time of day. The methods are all based on after-the-fact review of distribution feeder loads. Ultimately, it should be feasible to predict the magnitude of a load curtailment as a function of time of day and expected weather conditions. Additional curtailments under a wider range of weather conditions along with more information on the behavior of individual units will be required for this analysis.

Load curtailments can be fully implemented much faster than ramp-up of spinning reserve from thermal generation. The project team measured full load response in less than 20 seconds and identified technical opportunities to further increase response speed. This response is an order of magnitude faster than the spinning reserve response provided by thermal generators, which are allowed up to 10 minutes to provide full output. Moreover, the data collected suggest that it is technically feasible to further reduce the latencies associated with each step in the curtailment process and thus achieve full response nearly instantaneously. A separate California Energy Commission Public Interest Energy Research (PIER) project is beginning to examine the additional value to CA ISO of faster responding spinning reserve resources such as these.

The use of aggregated demand-side resources to provide spinning reserve is a powerful, new tool that California can use to improve system reliability, prevent rolling blackouts, and lower system operating costs. This research is an important first step toward realization of these goals.

1. Introduction

The Demand Response Spinning Reserve project is a pioneering demonstration of how existing utility load-management assets can provide an important electricity system reliability resource known as spinning reserve. Using aggregated demand-side resources to provide spinning reserve will give grid operators at the California Independent System Operator (CA ISO) and Southern California Edison (SCE) a powerful, new tool to improve system reliability, prevent rolling blackouts, and lower system operating costs.

Employing spinning reserve is an electricity system operator's first strategy for maintaining reliability following a major contingency, such as the unplanned loss of a large generation facility or critical transmission line. Operators protect system reliability by ensuring a continuous match between electricity generation and electricity consumption and by maintaining extra generating resources to respond to contingencies; these resources are known as spinning reserve. Spinning reserve is the most important contingency reserve because the generators that provide it are already running ("spinning") synchronized to the grid and can therefore respond immediately – either manually to a system operator's request or automatically – to changes in system frequency. When spinning reserve is called into active service, the generator must ramp up output immediately and meet its full spinning reserve obligation within 10 minutes. CA ISO procures spinning reserves through competitive bids offered in its day-ahead and hour-ahead markets.

Using demand-side resources to provide spinning reserve would increase the total contingency reserve available to a system operator and might thus prevent situations in which operators would otherwise run short of generator-provided spinning reserve and have to call for rolling blackouts. The contingencies that trigger the need to call on spinning reserve occur infrequently (typically once or twice a month, sometimes more or less often). However, because triggering contingencies are unpredictable, the system operator must have pre-determined amounts of spinning (and other contingency) reserve available continuously. Ensuring that these reserves are available at all times is so important that rolling blackouts (i.e., the controlled curtailment of the loads of pre-defined geographic blocks of customers) are mandatory when system operators run short of these reserves. Intentionally curtailing customer loads may seem contradictory in this situation. However, by intentionally curtailing some customers' loads, operators ensure that the limited contingency reserve that is available remains adequate to ensure the reliability of the entire grid for the benefit of all customers.

The objective of this project is to demonstrate that spinning reserve can be provided using demand-side resources in a manner that is comparable to the current provision of spinning reserve using supply-side (i.e., generation) resources. We demonstrate that it is both technologically feasible to provide spinning reserve using demand-side resources and that it may be preferable to do so because of inherent advantages of demand-side resources. These advantages include: 1) near-instantaneous response (compared to the 10 minutes allowed for full response from generators), and 2) responses that can be targeted geographically anywhere electricity is consumed within a utility's service territory (rather than responses that are restricted to the fixed location of the handful of generators that are contracted to provide contingency reserve services). These advantages are especially attractive because the curtailments required may not even be noticed by customers and reduce the likelihood that more dramatic curtailments, which customers do notice, will be needed.

In conducting the demonstration, we begin to address three critical institutional issues that currently hinder provision of spinning reserve with demand-side resources: First and foremost, current Western Electric Coordinating Council (WECC) reliability rules preclude provision of spinning reserve from demand-side resources. Although these rules were not written to intentionally exclude demand-side resources, they consider only supply-side resources because no one had previously considered using demand-side resources for this purpose. Second, as a result of WECC rules, system operators do not have experience with relying on demand-side resources for spinning reserve. In addition to a change in the rules, operators must develop confidence that providing spinning reserve from demand-side resources will be as reliable and effective as providing this service from generators. Third, market rules related to aggregation, metering, load verification, and settlement must be reviewed and, where appropriate, modified so that aggregated demand-side resources can participate in CA ISO's wholesale markets where spinning reserves are competitively procured.

Finally, through the choice of technologies employed in this demonstration (SCE's 25+ year-old air-conditioning load-cycling program), we also show how a traditional utility load-management asset can be repositioned as a competitive asset whose value is established by wholesale markets for reliability services.[2] In doing so, we illustrate the potential for assets that have long been paid for by utility ratepayers to provide even greater value when used by the utility to both improve reliability and lower the cost of securing reliability services. This would be accomplished as the utility either meets its own spinning reserve requirement or sells spinning reserve service directly to the competitive markets in which CA ISO procures spinning reserve.

This demonstration was designed to enable side-by-side comparison of the performance of demand-side and supply-side resources in providing spinning reserve service.

For the demonstration, we target-marketed SCE's air-conditioning load-cycling program, called the Summer Discount Plan, to customers on a single SCE distribution feeder and developed an external website with real-time telemetry for the aggregated loads on this feeder. We postulate that the aggregate behavior of the controlled loads on this feeder can be directly compared to the performance of generators, which are typically equipped with comparable telemetry.

During the demonstration, we conducted a large number of remotely controlled, short-duration curtailments (lasting approximately five to nearly twenty minutes each) of the

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[2] Many other demand-side technologies could provide spinning reserve in a manner comparable to what we demonstrated in this project. These technologies include, in principle, other utility load-management assets as well as newer demand-response technologies, such as programmable communicating thermostats.

air-conditioning units of participating customers on this feeder. These curtailments were similar in duration to CA ISO's historic deployments of spinning reserves.

To characterize the magnitude and predictability of the load response elicited during the demonstration, we used data recorded before, during, and after each curtailment. We augmented those data with high-time resolution metering information taken directly from a small number of individual air-conditioning units equipped with enhanced devices. These additional data supported detailed analysis of the timing latencies in SCE's air-conditioning load-cycling communication and control system and of the behavior of individual air-conditioning units.

We conducted this demonstration with explicit guidance from utility and regulatory staff. We reviewed the demonstration plan with: operations staff from CA ISO, utility participants on key WECC committees who would be involved in reviewing any proposal to change reliability rules to allow demand-side resources to provide spinning reserve service, representatives from California utilities involved in demand-response activities and grid operations, and staff from both the California Public Utilities Commission (CPUC) and the Energy Commission.

This report summarizes the first two years' accomplishments and findings from the Demand Response Spinning Reserve project. Following this introductory section, the remainder of the report is organized as follows:

In **Section 2**, we describe the rationale for providing system reliability resources, specifically spinning reserve, with demand-side resources.

In **Section 3**, we review the concerns expressed by CA ISO and others regarding the use of demand-side resources for provision of system reliability services and discuss how these viewpoints have been taken into consideration in designing and conducting this demonstration.

In **Section 4**, we describe the characteristics of the customers and aggregate loads in the geographic region targeted by this demonstration.

In **Section 5**, we describe SCE's air-conditioning load-cycling program, the Summer Discount Plan, the program enhancements that were made to conduct the demonstration, and the impact of delays in regulatory approval for these enhancements, which hampered recruitment of customers for the demonstration.

In **Section 6**, we describe the communication and control infrastructure that supports the Summer Discount Plan program and the modifications made in order to conduct the demonstration.

In **Section 7**, we describe the data integration, archiving, and presentation framework that we developed to provide, among other things, real-time telemetry on the feeder load in a manner comparable to that currently provided by large generators.

In **Section 8**, we describe the test curtailments that were conducted during the summer and fall of 2006.

In **Section 9,** we describe our findings from the test curtailments in 2006.

In **Section 10**, we summarize our accomplishments and findings from the work completed in 2006.

Appendix A is a technical review and assessment of the data integration, archiving, and presentation platform.

2. The Rationale for Providing Spinning Reserves with Demand-Side Resources

In this section, we describe the rationale for using demand-side resources as system reliability resources.[3]

We begin with a technical description of the role and function of the system reliability resource known as spinning reserve, focusing on the difference between the technical requirements of the service as specified in reliability rules, which require that it be available for up to two hours, and the way in which it is actually used by system operators, which is often for 10 minutes or less. This discussion illustrates why air-conditioning load and other demand-side resources that have some form of storage or inertia are well matched to the short time periods during which spinning reserve is actually utilized in practice. Compared to the very long curtailments (two to six hours) typically experienced by customers on traditional utility load-cycling programs, the far shorter curtailments associated with providing spinning reserve may be indistinguishable to these customers from the routine operation of their air conditioners.

We build from this basic insight to discuss other technical advantages that might accrue from use of demand-side resources to provide spinning reserve and end the section by reviewing the reliability rules that currently preclude this practice.

2.1 What is Spinning Reserve?

To assure reliable provision of electricity service, power system operators must have resources continuously poised, ready to respond immediately if a generator or transmission line fails. Without reserves to replace the lost generation (or the generation that the lost transmission was delivering), load would exceed generation, and the power system would rapidly collapse.

Figure 2-1 shows a plot of power system frequency during a major loss-of-generation contingency. In this case the reserve responded well, and system balance was successfully restored within 10 minutes.

Contingency response is not obtained from a single resource or even from a single service. Instead, a series of services (shown in figure 2-2) is coordinated to provide the required response speed and duration: spinning reserve is the “first responder” service, followed by non-spinning reserve and replacement reserve.

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[3] A more complete discussion of the overall topic can be found in *Demand Response For Power System Reliability: FAQ*, (B. Kirby, ORNL/TM-2006/565) from which much of the material in Section 2 was derived.

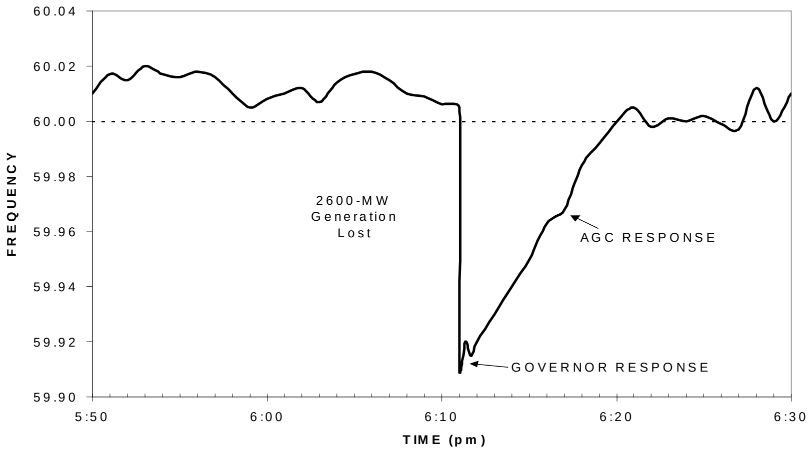

Figure 2-1. Power System Frequency During a Major Contingency. Reserves successfully restored generation/load balance within 10 minutes after sudden failure of two generators in Texas.

Spinning reserve must begin to respond immediately and be fully responsive within 10 minutes. To provide this service, spinning reserve must be already synchronized with the grid. *Non-spinning reserve* must also respond fully within 10 minutes but does not need to begin responding immediately. As a result, it does not need to be synchronized with the grid initially. *Replacement reserve* must respond fully within 30 minutes. California's real-time energy market, with its five-minute dispatch interval, can also be used by system operators to obtain response to contingency events.

Spinning reserve is the fastest-responding contingency reserve and thus the most critical for maintaining power system reliability. Spinning reserve is the service that arrests the dangerous frequency drop seen in Figure 2-1. WECC does not currently allow responsive loads to provide spinning reserve. Only generators that are on line and synchronized to the grid can supply spinning reserve.

2.2 Why Use Controllable Air-Conditioning Units For Spinning Reserve?

Advances in communications and control technology now make it possible to use aggregated groups of curtailable loads, such as air-conditioning units already equipped with load-cycling controls, as a spinning reserve resource that is potentially superior to relying on generators for this service. The natural response capabilities of these loads match the response speed, duration, and frequency required to support spinning reserve. The appropriateness of this match has been recognized by the Electric Reliability Council of Texas (ERCOT), which allows load curtailment to supply half of ERCOT's 2,300 MW spinning reserve requirement. The PJM Interconnection also recently changed its reliability rules to allow loads to supply spinning reserve.

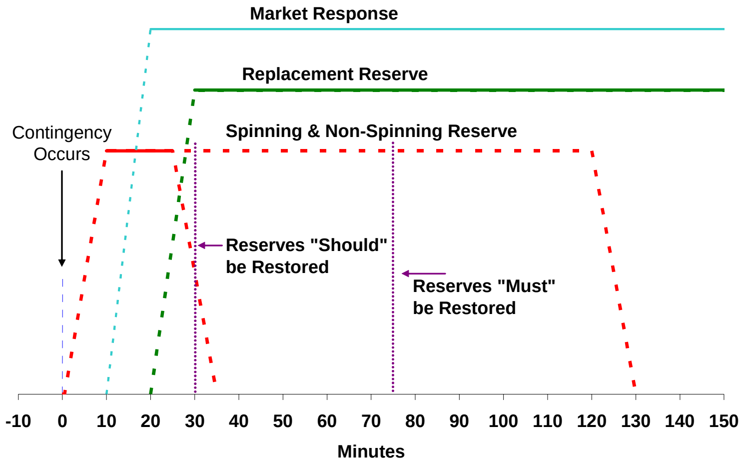

Figure 2-2. Coordinated Contingency Response. A series of reserve services provide coordinated contingency response.

In California, air conditioning is one type of curtailable load that has the capability to respond faster to system disturbances than generators can. Data gathered in the tests described in this report show that air-conditioning load can be dropped nearly instantaneously (in tens of seconds or less) in response to commands from a system operator. The rapid response possible from using air-conditioning load as spinning reserve could improve power system reliability; using air-conditioning load as demonstrated in this study would allow load response to be in place much more quickly than the 10 minutes currently allowed for generators who provide spinning reserve.

Spinning reserve is a good match to air-conditioning load-response capabilities for several reasons:

- *Deployment of spinning reserve is typically brief*: Total air-conditioning load can therefore be curtailed for the event duration; because the event is likely to be brief, customers are not likely to notice the curtailment.

- *Spinning reserve deployment is relatively infrequent*: Response is only required when a contingency occurs as opposed to, for example, being required every afternoon during a heat wave for peak reduction.

- *Air-conditioning response is reliable and robust*: Meaningful response is spread over thousands of small, independent units, so failure of a single unit to respond has no impact on power system reliability. In contrast, failure of a large generator to provide spinning reserve is a serious reliability event.

- *Air-conditioning response is generally available when needed*: Hourly spinning reserve market price history confirms that spinning reserve is in short supply (prices rise) when system load is high, which is the same time that air conditioning is loading the system.

2.2.1 Spinning Reserve Deployment Duration

As shown in Figure 2-3, spinning reserve events are typically quite short. The figure shows data for the ISO New England (ISO NE) and New York Independent System Operators (NYISO) and CA ISO. Longer reserve deployments are occasionally required and are extremely important for reliability, but, as shown in Figure 2-3, they are rare. Brief event duration is a perfect match for air-conditioning load curtailment because air-conditioning units can easily be curtailed for short periods, likely, with little or no comfort impact on occupants. Longer duration curtailments, too, are also possible. However, the comfort impacts would become more noticeable.

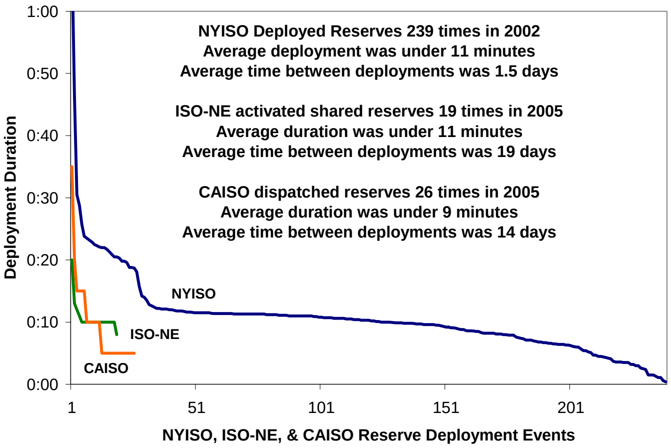

Figure 2-3. Duration of Spinning Reserve Deployment. ISOs differ in frequency of use of spinning reserve, but most deployments of spinning reserve are short in duration.

2.2.2 Load and Spinning Reserve Cycles

The daily and seasonal load cycles of air conditioning mean that it can supply spinning reserve when generator-supplied spinning reserve is most costly. Spinning reserve prices in California are shown in Figure 2-4 along with a typical air-conditioning load profile. The spinning reserve price is low overnight because there is ample partially loaded generation available to supply spinning reserve. The spinning reserve price rises near the load peak because generation is needed to serve load and is thus not available as reserve. So, although air-conditioning load is available at certain times and the power system need for spinning reserve is constant, there are low-cost alternative supplies available when air-conditioning load is not.

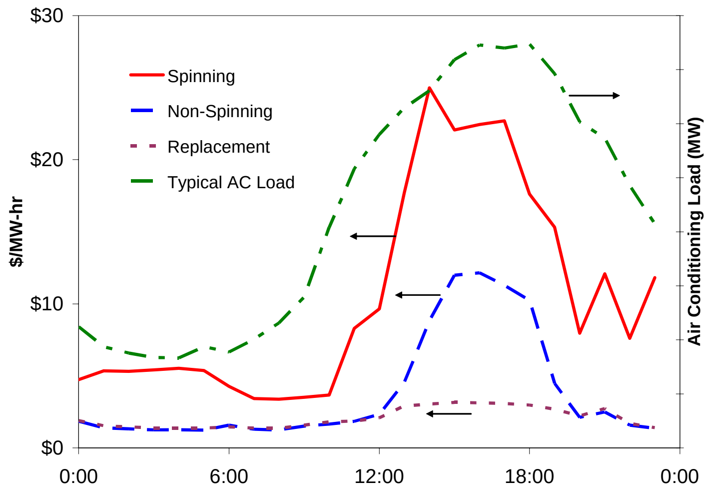

Figure 2-4. Correlation Between Air Conditioning Load Availability and Cost of Spinning Reserve. **Hourly prices show that the power system values spinning reserve the most at the same time that this service is available from air conditioning.**

Figure 2-4 also shows why load should be used to supply spinning reserve if possible rather than restricting load to supplying only non-spinning and replacement reserves: spinning reserve prices are typically three times higher than non-spinning and five times higher than replacement reserves. These numbers quantify the higher reliability value of spinning reserve to the power system. Expanding spinning reserve supply will both increase reliability and lower costs for all customers.

2.2.3 Load Response Reliability

Figure 2-5 shows that the response reliability of aggregations of small loads can be greater than the response reliability of a small number of large generators. This simple example compares the provision of contingency reserves from two sources.

First, we assume contingency reserves are supplied by six generators that can each provide 100 megawatts (MW) of response with 95-percent reliability. These assumptions produce a 74-percent chance that all six generators will respond to a contingency event and a 97-percent probability that at least five will respond. That probability indicates a significant risk that fewer than five generators will respond.

Second, we assume that contingency reserves are provided by many (1,200) smaller loads that, for illustrative purposes, are assumed to be individually less reliable (90-percent reliability) than the large generators.[4] This aggregation typically delivers 540 MW (out of the total possible 600 MW) of reserves but never delivers less than 520 MW (or 120 MW more than the large generators). This example illustrates that the aggregate load response

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[4] There would be many more (and smaller) air conditioners in a typical aggregation. This example used only 1,200 because of the limitations of the software program (Microsoft Excel) used to create the example. Larger numbers of smaller loads simply result in a more vertical aggregate response curve.

is much more predictable and the response that the system operator can “count on” is actually greater than is the case with the traditional strategy of relying on a few small generators for spinning reserve.

It is worth noting that this statistical analysis of response reliability may indicate that, if load response provides spinning reserve service, system operators would not have to conduct the detailed monitoring currently required when spinning reserve service is provided by a few large generators. System operators monitor large generators providing spinning reserve at the four- to 10-second Supervisory Control and Data Acquisition (SCADA) rate at least partially because there is some probability that the generator will not respond when required. The system operator can watch the response in real time and take alternative action in the rare (but important) event that a generator fails to move. With a large aggregation of independent loads, the system operator might only have to monitor the common communications system to make sure that the signal has been sent because the response reliability is sufficiently high to make continued monitoring unnecessary.

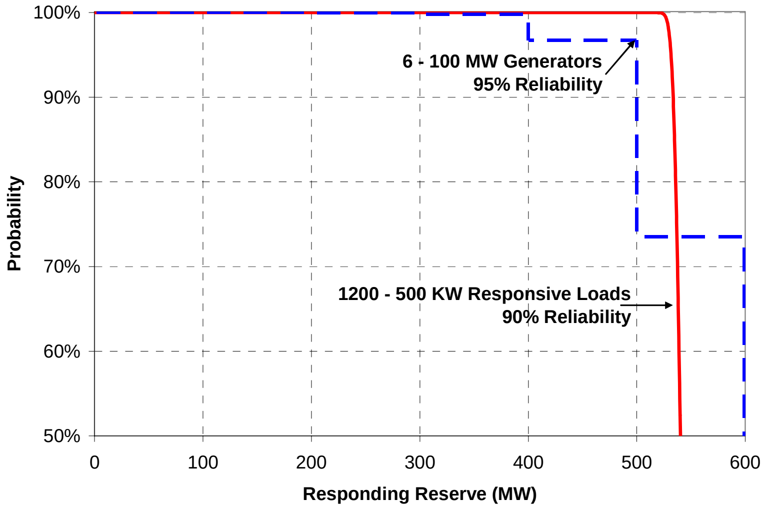

Figure 2-5. Reliability Comparison. Large numbers of individually less-reliable responsive loads can provide greater aggregate reliability than fewer large generators.

3. Concerns Regarding Provision of Spinning Reserve with Demand-Side Resources

ISO staff is justifiably cautious in evaluating new and unfamiliar approaches to managing reliability. In contrast to the supply-side resources that most ISOs currently rely upon to provide spinning reserve, the demand-side resources we examine in this study appear very different: they are small, geographically dispersed, essentially uncontrolled (at least by a system operator), and for all intents and purposes not individually observable.

This section reviews concerns that have been raised by CA ISO staff[5] and others regarding using demand-side resources to supply system reliability/spinning reserves and explains how these concerns can be answered and/or have been addressed in this demonstration project. The general areas of concern relate to: response duration, load cycles, response reliability, load geographic specificity, communication and monitoring infrastructure, power system stability, and ISO workload.

3.1 Response Duration

Response duration is often seen as an obstacle for air conditioning to supply spinning reserve. According to the reliability rules, spinning reserve may be deployed for up to two hours per event and there is no limit on the number of times it may be deployed. Thus, it is understandable that some might initially believe this service could not effectively be provided by air conditioners, which typically would object to regular curtailments of more than approximately 30 minutes. However, as noted in Section 2, in actual practice, spinning reserve is usually deployed for brief periods of time. See Figure 2-3. This is an example of the importance of fully understanding power system reliability requirements, data on actual power system behavior, and the response capability of a particular type of load in evaluating the potential suitability of a system reliability resource.

3.2 Load Cycles and Patterns of Spinning Reserve Deployment

Another apparent obstacle to the use of air conditioning for spinning reserve is the daily load cycle: spinning reserve capability is required 24 hours a day, but curtailable air-conditioning load is not always available (e.g., during the entire heating season or during the early morning hours of the cooling season). However, as described in Section 2, and shown in Figure 2-4, low-cost alternative supplies of spinning reserve are available when air-conditioning load is not. Moreover, air-conditioning load is available to serve as spinning reserve at the times when spinning reserve from other resources is most costly, so air-conditioning load is an economically advantageous resource for this purpose.

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[5] Perspectives and concerns expressed specifically by CA ISO and described in this section were identified in an earlier project that resulted in the “Demand Response Research Plan to Reflect the Needs of the California Independent System Operator,” prepared by John D. Kueck and Brendan J. Kirby, and published as ORNL/TM-2003/2, January 2004. That project was carried out under the auspices of the PIER Demand Response (DR) Program Plan under Contract # 150-99-003.

3.3 Reliability of Load Response

Fears of low response reliability are often raised as reasons that loads should not provide spinning reserve. However, as described in Section 2 and shown in Figure 2-5, aggregations of small loads may exhibit higher response reliability than small numbers of large generators, in part because the failure of individual units with a curtailable load to respond has far less impact on the overall response than does the failure of a single large generator. The risk of lack of response from one generator within a small number of spinning reserve generators is greater than the risks that enough small loads will fail to respond to actually impact on the load curtailment. As illustrated in Section 2, the aggregate load response is much more predictable and the volume of response that the system operator can “count on” is actually greater than is the case with the traditional use of a small group of large generators contracted to provide spinning reserve.

In California, demand-response programs involving shedding large blocks of load to address a system emergency have worked well. However, CA ISO, like many ISOs, does not have experience with precisely controlled, accurately dispatched demand response from aggregation of small loads. As noted earlier, demand response programs are now successfully supplying substantial levels of spinning reserve in some regions. For example, one-half of ERCOT’s total spinning reserve requirement is supplied using large loads. We believe that the demonstration described in this report shows that small loads can dependably respond in seconds to the need for spinning reserve. This is the kind of evidence that CA ISO and other system operators need if they are to gain confidence that curtailable load can reliably provide spinning reserves.

CA ISO has also raised the concern that demand response must not degrade an ISO’s ability to forecast load. Among the objectives of the Demand Response Spinning Reserve Demonstration project is development of a method for forecasting air-conditioning load and its response that is more accurate and has a higher confidence level than existing methods. This forecasting method, which is expected to be completed in future phases of this project will consider variables such as location, time of day, day of week, current weather pattern, and holidays. The project will provide test data for benchmarking the forecasting method. It is our hope that the method of forecasting response will have a confidence level of greater than 95 percent and an accuracy of greater than 90 percent, both of which are thresholds CA ISO has identified.

3.4 Geographic Specificity

CA ISO has pointed out that demand response must be location-specific to have real value. A method is needed that clearly conveys the value of location to regulatory bodies and customers. Could automated mechanisms be developed to pay for load response in specific locations? Could short-term zonal load forecasting be improved to reduce surprises? How can load aggregations deal with zones?   As a way to begin to address these questions, the Demand Response Spinning Reserve demonstration was performed on a single distribution circuit, which represents a relatively small, defined geographic location, and thus shows clearly the potential for targeted response from a typical SCE circuit with mixed residential and commercial load.

3.5 Communications, Monitoring, and Control Systems

CA ISO observes that for a demand response program to effectively provide reserve services, the price information that customers see must be something they can and will respond to, and the system operator needs to know what load response is potentially available in terms of location and type. What communications, monitoring and control are needed for these purposes? How much will they cost the system operator, the aggregator, and the customer? This demonstration has concentrated on the technically difficult task of communicating rapidly between the system operator and large numbers of responsive loads and will, by the time the project is complete, quantify the performance of the existing data acquisition and control system for the purpose of controlling a large number of small loads in near real time. The project will demonstrate whether existing systems are adequate or whether newer, faster systems must be installed. The project will also provide insight into residential customer needs and preferences for response duration, frequency, and time of day.

3.6 Power System Stability Impacts

Concerns have been raised that power system stability will be harmed if spinning reserve is supplied from responsive load rather than from generation because of the resulting reduction in generator inertia. A WECC stability study tested this concern and found that stability actually increased with load providing spinning reserve for the example run. See Figure 3-1. The reason for the improvement is that the load can respond fully much faster than generation can, and the faster response has greater benefit than the displaced generation rotating mass.

Under-frequency relaying will be a critical element of loads supplying spinning reserve. Although under-frequency events are relatively rare, they are large and pose a significant threat to system reliability. Fortunately, it is relatively easy to implement under-frequency response, so this capability has not yet been included in this demonstration project. With large aggregations of loads providing spinning reserve, it will be desirable for each unit to respond at slightly different frequencies and create an aggregate frequency droop curve that mimics the generator’s governor response.

3.7 Impact on ISO Workload

CA ISO staff feel strongly that, if demand response is to be successful as a reliability resource, it must be made to look like generation, so that deploying demand response will look to the system operator just like adding in the next 100 MW from the bid stack. How can the response supplier ensure that the response is observable and controllable? This demonstration project is designed to show conclusively that demand response can be dispatched just like generation, that the response times can be determined accurately, and that the response amount can be predicted with comparable accuracy to what is possible for spinning reserve provided by generators. As noted in Section 2, the response times for the air-conditioning load in this study is expected to faster than thermal generation, and the response reliability is greater than for a small group of large generators. The communication, control and verification functions that would be provided by the response supplier are also being clearly demonstrated in the project, as discussed in Section 6 of this report.

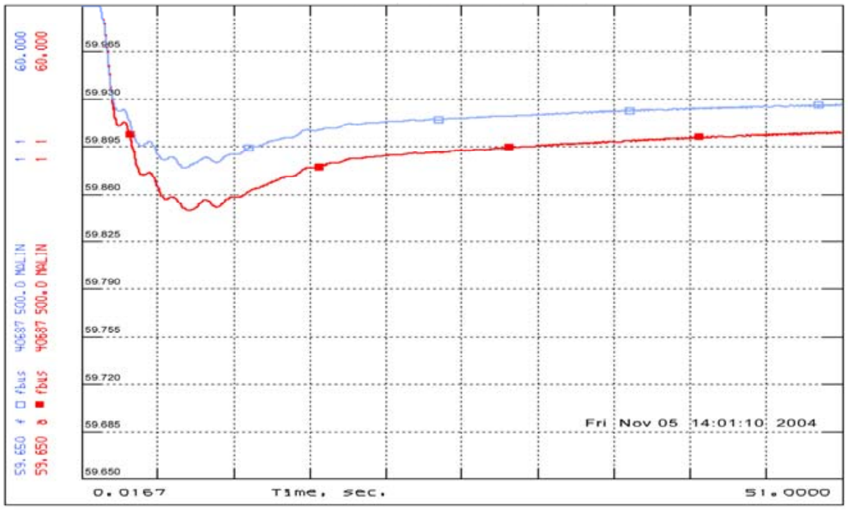

Figure 3-1. Effect of Load Response on System Stability. WECC system stability is enhanced when 300 MW of responsive load (upper blue curve) replaces an equal amount of generation (lower red curve). (Stability runs performed by Donald Davies of WECC).

4. Customer and Load Characteristics, Sample Selection and Statistical Analysis

This section describes the customers, distribution feeder location and loads and sample selection and statistical analysis issues associated with this demonstration.

4.1 Location Characteristics

The distribution feeder chosen for this project is in the hot climate region known as the Inland Empire, approximately midway between Los Angeles and San Bernardino. This is an area of relatively new building stock. The weather station used for the load analysis is at Mira Loma, approximately eight miles from the distribution feeder. See Figure 4-1.

Figure 4-1. Approximate Location of Distribution Feeder

4.2 Customers

The customers served on the demonstration project feeder are primarily residential and small commercial.

Table 4-1 summarizes the accounts known to be on the feeder by rate schedule. “D” rate schedules are used for residential customers. “GS” rate schedules are used for smaller commercial customers. “TOU” rate schedules are used for larger commercial customers. As of the end of 2004, there were 1,958 active residential accounts and 151 active commercial accounts on the feeder along with a relatively small number of inactive accounts.[6]

We conducted two analyses to determine whether the number of customers on the distribution feeder was adequate to support the objectives of this demonstration. First,

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[6] Because of a lag in data entry, some new accounts may have been omitted.

we reviewed records on monthly electricity consumption to determine how many customers were likely to have central air-conditioning units and hence would be eligible to participate in the demonstration. Second, we assessed the normal variability of the aggregate loads on the feeder and compared this variability to the expected variability of individual air-conditioning loads. This comparison enabled us to determine how well, from a statistical standpoint, we might be able to attribute observed changes in the feeder loads to the aggregate behavior of the controlled air-conditioning units. Finally, we expressed the statistical strength of this attribution as a function of the number of controlled air-conditioning units.

We also reviewed historic loads on the feeder serving all customers to understand the statistical significance of load reductions that we would observe at the feeder as a function of the number of customers participating in the demonstration. That is, the loads on the feeder, in addition to exhibiting a repeating diurnal shape, exhibit random variability on a minute-by-minute basis. It was essential to recruit sufficient numbers of customers for the demonstration so that the aggregated “signal” resulting from the simultaneous curtailment of their air conditioners would be distinguishable from the background “noise” that is inherent on all feeders.

Table 4-1. Accounts on Distribution Feeder

Rate Schedule	Customers
D-APS	24
D-APS-E	19
D-CARE	474
D-CARE-APS	2
D-CARE-APS-E	4
DE	7
DE-APS-E	3
D-FERA	7
DMS-2	2
DOMESTIC	1,415
D-S	1
GS-1	85
GS-2	29
GS-2/GS1	19
GS2T	4
TC-1	7
TOU-GS-1	3
TOU-GS2-B	1
TOU-GS2-SP	2
TOU-PA-SOP-2	1
Grand Total	2,109
Residential	1,958
Commercial	151

4.2.1 Identifying Customers with Central Air-Conditioning Units

We reviewed the customers' historic electricity consumption to identify a target population to which the SCE Summer Discount Plan program could be marketed (namely, customers with central air-conditioning units, as evidenced by higher-than-average electricity consumption during summer months).

Before recruiting customers from this feeder for the curtailment tests, we needed to ascertain which were good candidates for load control. We assumed that a typical residential air-conditioning unit is three tons and has a demand of 3 kW and that the unit has a daily full-load run time of about three hours. Such a home would use 250 to 300 kWh per month more electricity in the summer than the winter. We estimated the monthly air -conditioning kWh consumption of each account by comparing the total billed consumption in summer versus winter months.

Then we identified the active accounts with monthly air-conditioning use greater than various thresholds, as shown in Table 4-2. About 50 to 60 of the commercial accounts appeared to be good candidates for air-conditioning load control. Depending on the selected threshold, anywhere from 300 to 850 of the residential accounts appeared to be good candidates. Ultimately, we chose 250 kWh per month estimated air-conditioning usage as our cut off, giving us a pool of 857 residential and 60 commercial customers to recruit from.

Table 4-2. Number of Candidate Accounts

Count of Customer Name	Minimum AC kWh per Month						Total Current
Rate Schedule	250	300	350	400	450	500	
D-APS	14	13	10	8	6	4	24
D-APS-E	10	7	7	6	3	3	19
D-CARE	153	121	99	79	63	45	474
D-CARE-APS							2
D-CARE-APS-E							4
DE	4	4	4	4	4	4	7
DE-APS-E	2	1					3
D-FERA	5	5	3	3	2	1	7
DMS-2	2	2	2	2	2	2	2
DOMESTIC	667	554	455	374	291	235	1,415
D-S							1
GS-1	17	16	13	12	11	10	85
GS-2	24	23	21	19	19	18	29
GS-2/GS1	12	12	12	12	12	12	19
GS2T	4	4	4	4	4	4	4
TC-1							7
TOU-GS-1	1	1	1	1	1	1	3
TOU-GS2-B							1
TOU-GS2-SP	2	2	2	2	2	2	2
TOU-PA-SOP-2							1
Residential	857	707	580	476	371	294	1,958
Commercial	60	58	53	50	49	47	151
Grand Total	917	765	633	526	420	341	2,109

4.3 Characterizing Distribution Feeder Loads

SCE provided SCADA load data for the targeted distribution feeder for the four months of June through September, 2004. The file provided by SCE contained the voltage of the feeder (V), measured in kilovolts, the current of the three phases (I_a, I_b, I_c), measured in amps, and the total mega VARS reactive power ($MVAR$). The data were based on instantaneous measurements taken every two minutes. Each of the five values was recorded, along with the date and time of the measurement, only if the value changed from that observed two minutes earlier.

To prepare an analysis database, we filled in the omitted values for each of the five fields. Then we calculated real power (MW) using the following equations:

$$MVA = \frac{V\ I_a + V\ I_b + V\ I_c}{1000\ \sqrt{3}}$$

$$MWatts = \sqrt{MVA^2 - MVAR^2}$$

Figure 4-2 gives an overview of the distribution feeder during the four months of June through September, 2004.[7]

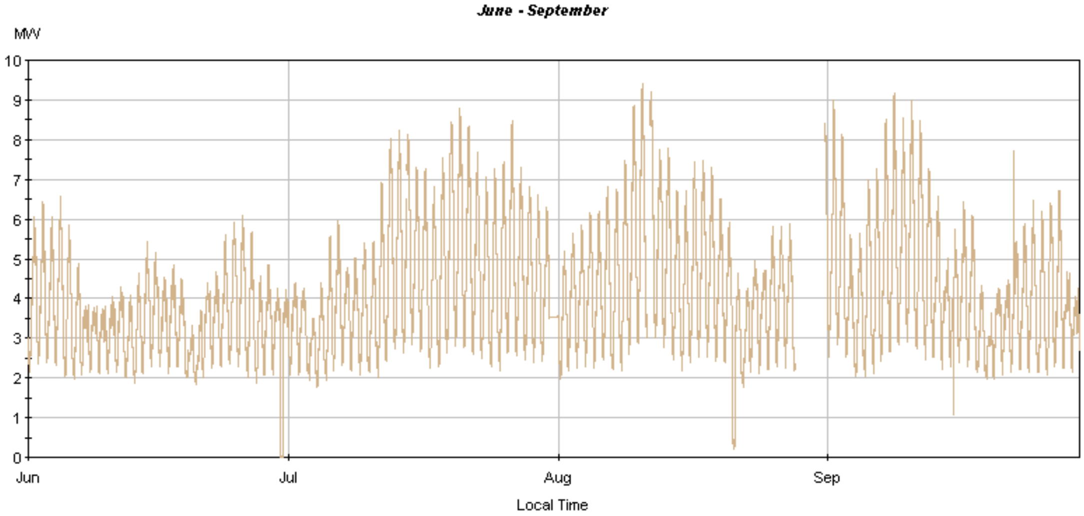

Figure 4-2. Overview of Feeder Load

Table 4-3 shows the magnitude and time of the peak load in each week of the period. The overall peak was 9.42 MW at 3:58 p.m. on Tuesday, August 10 (shown in bold). Most of the peak loads occurred in the afternoon on a weekday.

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[7] The total kWh use of the feeder is about 15 percent higher than the total kWh use of the accounts allegedly on the feeder during these months. This is consistent with distribution losses and billing cycle effects.

Table 4-3. Magnitude and Time of Weekly Peak Demands

Week Of	Peak	Peak At
6/6/2004	4.87	Sun Jun 6, 2004 6:10PM
6/13/2004	5.44	Mon Jun 14, 2004 4:36PM
6/20/2004	6.09	Fri Jun 25, 2004 5:24PM
6/27/2004	4.86	Mon Jun 28, 2004 2:56PM
7/4/2004	5.95	Tue Jul 6, 2004 3:08PM
7/11/2004	8.24	Tue Jul 13, 2004 4:38PM
7/18/2004	8.79	Tue Jul 20, 2004 4:18PM
7/25/2004	8.48	Mon Jul 26, 2004 4:20PM
8/1/2004	6.81	Fri Aug 6, 2004 5:08PM
8/8/2004	**9.42**	**Tue Aug 10, 2004 3:58PM**
8/15/2004	7.49	Tue Aug 17, 2004 5:10PM
8/22/2004	5.88	Fri Aug 27, 2004 4:14PM
8/29/2004	8.99	Wed Sep 1, 2004 4:10PM
9/5/2004	9.16	Wed Sep 8, 2004 3:48PM
9/12/2004	7.27	Sun Sep 12, 2004 3:36PM
9/19/2004	7.71	Wed Sep 22, 2004 10:38AM
9/26/2004	6.7	Mon Sep 27, 2004 4:44PM

Figure 4-3 shows the load profile for the peak week. Note the data gap on Wednesday, August 11 and the truncated load on Saturday, August 14. These gaps in the SCADA data are relatively rare but recurring problems. Similar events during the 2006 testing cycle resulted in lost data for six tests.

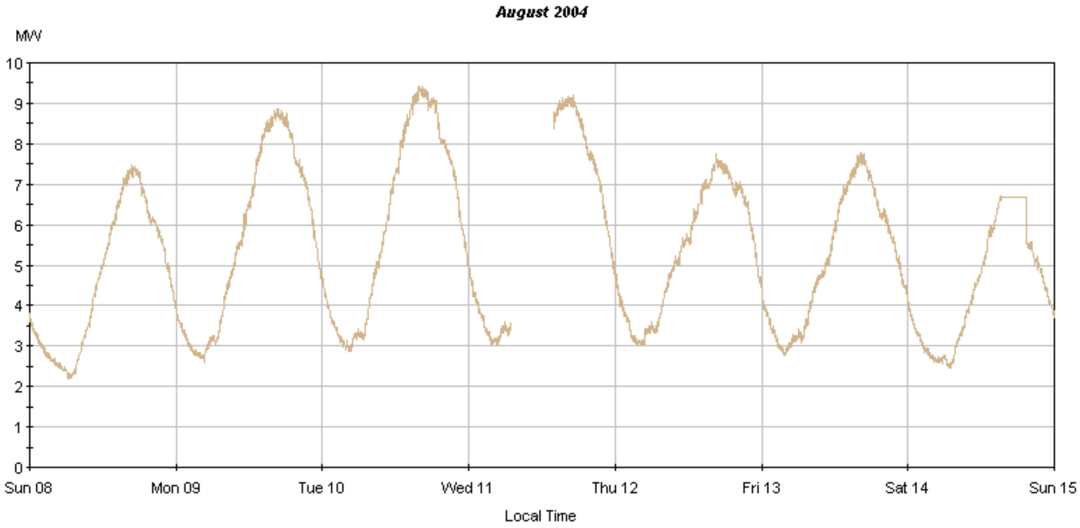

Figure 4-3. Circuit Load From August 8 Through August 14

Figure 4-4 shows the MW load of the feeder on the peak day, August 10. Load was quite high from 3:00 p.m. to almost 6:00 p.m., which indicated that curtailment tests during the summer would likely yield good results at any time during this timeframe.

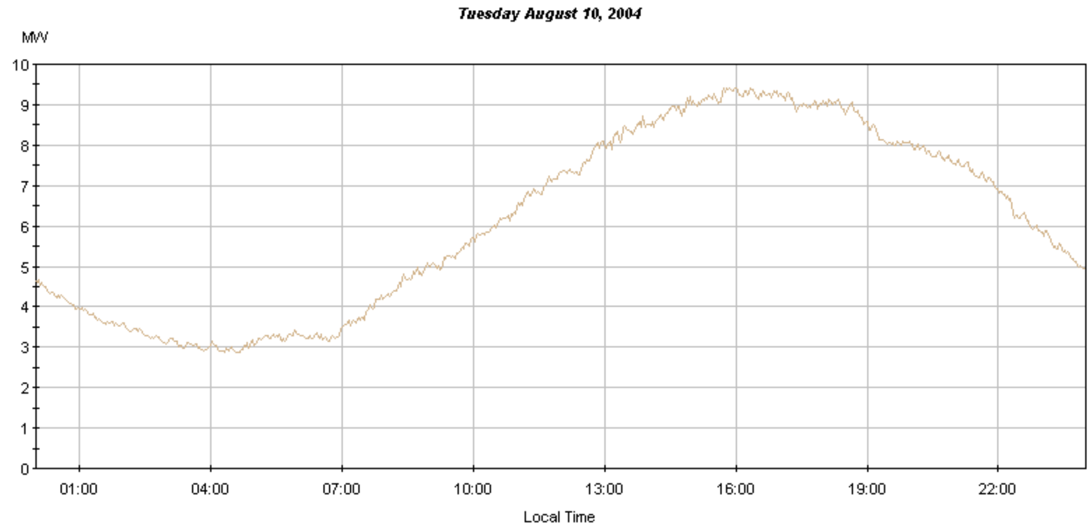

Figure 4-4. Feeder Load on the Peak Day of August 10

4.4 Uncertainty in Determining Load Curtailment Impact

Determining the impact of a curtailment call on the feeder involves two sources of uncertainty. The first can be seen in Figure 4-4, which shows instantaneous measurements taken every two minutes. From observation to observation, there is a significant amount of random variability or noise. This affects our ability to characterize the load on the feeder at any given point, including during a curtailment call. This source of uncertainty in turn affects our ability to pinpoint the load during the curtailment itself. Early in the project, we found this observation-to-observation noise to be roughly one percent of the feeder load.

The second source of uncertainty in measuring load drops is in characterizing what the size of the load would have been in the absence of a curtailment call. Having run a regression-based predictive model using previous-day temperature-adjusted data as a predictor of load, we estimated the standard deviation of our estimated load forecast to be roughly two percent of load.

Any statistically defensible reduction in load will therefore have to be of a magnitude significantly greater than the combination of these two sources of uncertainty. Thus, the standard deviation of any load drop estimate will be:

$$\sqrt{(.01 * Load)^2 + (.02 * Load)^2} = 0.022 * Load$$

or 2.2 percent of load. To overcome the uncertainty in the load at a 95 percent confidence level, the curtailment reduction must be greater than 1.96 * 0.022*Load = 4.3 percent of load.

4.5 Sample Size

In a preliminary study conducted in 2005, we used current loggers on 50 air conditioners in our test population to find that an air conditioner that was turned on (i.e., run at any time during the test period) drew an average of 1.5 kW. That is, the average air conditioner draws roughly 4 kW while operating, but only runs for 37 percent of any given hour. The standard deviation for this estimate was 1.37 kW. Table 4-4 shows our estimates of impact based on the assumption that 250 air conditioners are turned on, that the feeder load was running at 6 MW during the test period, and that the estimated 4.3 percent error for feeder load predictions holds true.[8] Table 4-4 shows the error bound on an estimate of feeder load under such conditions is 259 kW, and our estimate of impact from the curtailed units is 375 +/- 42 kW. Pooling the uncertainties, we would expect to see a 375-kW drop with a 95-percent confidence interval of +/- 262 kW. This means that we would see a drop in feeder load statistically significantly greater than the uncertainty in our estimates of the feeder load.

Table 4-4. Estimated Summer Load Impact with 95% Error Bounds of Currently Installed Units.

Source	Installed	Operating (n)	Unit Impact	sd	Impact Analysis	Standard Error	Err Bound	Rel. Precision
Feeder					6000	132	259	4.3%
Installed Switches	250	250.0	1.5	1.37	375	22	42	11.3%
Estimated Impact					375	134	262	69.9%

When we installed the current loggers for the 2005 tests, we also interviewed the homeowner and recorded any programmable thermostat settings. We collected these data from 49 homes and found that, during the summer, 75 percent of air conditioners are on during the peak hours (2 p.m. – 5 p.m.) of the day. If we extend this to our 250 switch-equipped units, as shown in Table 4-5, our estimate of impact drops to 281 kW with a 95-percent confidence interval of +/- 263 kW. Because the difference between the estimated impact and zero is greater than the error bound, we would still expect to see a statistically significant impact on warm days. However, the wide error bound, producing a 93.6 percent relative precision, indicates that although the drop in load would be significant, we would not be able to characterize its magnitude very precisely. Additionally, the difference between impact and the error bound is small enough that on milder days we would expect to see non-significant changes in load during curtailments.

Table 4-5. Estimated Summer Load Impacts with 75 Percent of Air Conditioners On

		% ACs On 75%	*Sample Size for % ACs On 49*					
Source	**Installed**	**Operating (n)**	**Unit Impact**	**sd**	**Impact Analysis**	**Standard Error**	**Err Bound**	**Rel. Precision**
Baseline					6000	132	259	4.3%
Installed Switches	250	187.5	1.5	1.37	281	25	49	17.4%
Estimated Impact					281	134	263	93.6%

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[8] The calculations presented in this section are based on an illustrative assumed population of 250 switches. In fact, 280 switches were installed for the test interruptions conducted in 2006.

Increasing the number of participants, which would increase the size of the impact, alleviates this imprecision somewhat. Table 4-6 shows that if an additional 150 customers were curtailed, we would estimate the impact to be 450 +/- 268 kW. The impact would be much more significant relative to the noise, but our estimate of its magnitude would still not be very precise.

Table 4-6. Estimated Summer Load Impacts of 400 Units with 75 Percent of Air Conditioners On

		% ACs On 75%	*Sample Size for % ACs On 49*					
Source	**Installed**	**Operating (n)**	**Unit Impact**	**sd**	**Impact Analysis**	**Standard Error**	**Err Bound**	**Rel. Precision**
Baseline					6000	132	259	4.3%
Installed Switches	400	300	1.5	1.37	450	37	72	15.9%
Estimated Impact					450	137	268	59.7%

A more exact estimate of impact could be achieved in one of two ways. First, if we could better characterize feeder load, we would reduce the main source of statistical uncertainty in our estimate and be able to predict impact with a narrower confidence interval. This could be accomplished by either pooling multiple feeders with similar characteristics and customers or by pooling days with similar weather and load patterns with tests conducted at the same time on each day. The alternative is to meter a sample of the curtailed units to find what their average load throughout each day is. This would remove the uncertainty of the feeder load from the equation entirely and leave only the uncertainty associated with projecting our sample up to the population of units. The project team hopes to explore these options in future research.

5. Southern California Edison's Summer Discount Plant Program Analysis

This section describes SCE's air-conditioning load-cycling program, the Summer Discount Plan; the program design enhancements that were made in order to conduct this demonstration; and the impact of delays in regulatory approval for these enhancements, which hampered customer recruitment for the demonstration.

SCE's air-conditioning load cycling program dates back to the first generation of California utility load-management programs in the early 1980s. Some of the customers that participated in our demonstration had air conditioners equipped with load-cycling devices that were initially installed more than 20 years ago. The load-cycling program was revitalized in 2000 as part of the state's response to the electricity crisis that had begun earlier that summer. In 2005, in preparation for the conducting the spinning reserve demonstration in summer of 2006, SCE conducted a first-ever target marketing campaign for the Summer Discount Plan to customers on the distribution feeder that had been selected for the demonstration. At the same time, SCE sought regulatory approval to modify the basic tariff for the Summer Discount Plan to permit the large number of short-duration curtailments envisioned by the demonstration, including authorization for additional payments to these customers as compensation for their participation. Final CPUC approval for the modification was not received until late June, 2006, however, which limited customer recruitment for the demonstration to the last few months of the 2006 cooling season. Still, by the start of the test curtailments in September, nearly 300 customers had agreed to participate in the demonstration.

5.1 Size of the Program

SCE's central air-conditioning load-cycling program, the Summer Discount Plan, has two elements. The "base" program dates back to the first generation of load-management programs developed by California utilities and is available to both residential and small commercial customers. An "enhanced" program that relies on the same load-cycling technology but has slightly different program elements was authorized in response to the summer 2000 electricity crisis. Together, the programs enable SCE to curtail more than 400 MW of load.

5.1.1 The Base and Enhanced Summer Discount Plans

The base air-conditioning cycling program was established in 1983 to provide load relief during excessive peak demand. The program targets residential and commercial customers who agree to have their air conditioning cycled intermittently when necessary to control peak demand. In return, customers receive a credit on their electricity bills from the first Sunday in June through the first Sunday in October, which defines the summer season. Customers are not charged for installation of the cycling devices.

From 1983 to 1985, customers could choose 50 percent, 67 percent or 100 percent cycling strategy levels. Starting in 1986, only the 100 percent level was offered to new participants. On April 10, 1996, the program was closed to new customers. Resolution E-3688, dated August 3, 2000, approved SCE's Advice Letter 1464-E, which authorized the reopening of the Residential Automatic Power Shift (APS) rate for customers with existing air-conditioning cycling devices, including the 50 percent, 67 percent, and 100 percent cycling strategies. Decision 01-04-006 reopened the program to all residential customers effective April 14, 2001.

The incentives that customers receive for participating in the program vary according to the cycling strategy they choose and each customer's tariff. Table 5-1 shows the bill credits given to the different types of customers according to their levels of participation, per ton of air conditioning per day or month, depending on the corresponding tariff (residential or one of two categories of commercial).

Table 5-1. Incentives for Summer Discount Plan Customers, Base Program

Participation Level	**Residential Customer Bill Credit (per ton of air conditioning per summer season day)**	**Commercial (GS-1 or TO U-GS-1 rates) Customer Bill Credit (per ton of air conditioning per month)**	**Commercial (GS-2, TOU-GS-2, or TOU-8 rates) Customer Bill Credit****
100%	18 cents	20 cents	$6
67%	10 cents	NA	NA
50%	5 cents	7 cents	$2.10
40%	NA	no longer available to new customers	no longer available to new customers
30%	NA	1.4 cents	42 cents

Currently, the Summer Discount program is triggered either by CA ISO following declaration of a Stage-2 emergency or by SCE grid operators in response to a local emergency condition. Cycling events are limited to 15 per summer season with each event not to exceed six hours. Multiple events may be called on a single day.

Decision 01-04-006, dated April 14, 2001, approved SCE's Advice Letter 1530-E establishing a Residential and Non-Residential Air Conditioning Cycling Enhanced Program. The differences between the base and enhanced programs are that the credit is doubled and the number of cycling periods is unlimited during the summer season. For example, residential customers who participate in 100-percent cycling under the enhanced program receive a credit on their bill of 36 cents per ton of air conditioning per summer season day. At the 67 percent level, they receive a credit of 20 cents per ton of air conditioning per day, and at the 50 percent level, they receive a credit of 10 cents per ton of air conditioning per summer season day.

5.1.2 Summer Discount Plan Program Participation and Events

Table 5-1 summarizes Summer Discount Plan program participation in 2005 and 2006. The total potential interruptible load represents the nameplate rating of air-conditioning units equipped with switches that enable curtailments. The actual total MW interrupted depends on the number of air-conditioning units actually running at the time of a curtailment. The number of units actually running in turn depends on both occupant behavior, i.e., whether the unit is in operation, and, if it is, how it is being operated (whether it currently cycled on or off).

Table 5-2. Summer Discount Plan Participation and Potential Interruptible Load

	2005		**2006**	
	Number of Customers	**Total Potential Interruptible MW**	**Number of Customers**	**Total Potential Interruptible MW**
Residential – Base	80,299	153	76,235	145
Residential Enhanced	83,310	156	121,211	232
Total Residential	163,609	309	197,446	377
Non-Residential – Base	1,905	35	2,050	37
Non-residential – Enhanced	550	8	1,429	14
Total Non-Residential	2,455	43	3,4,79	51
Total Program		352		428

There were four air-conditioning cycling events in 2005. The ISO declared one transmission emergency and two Stage-2 events (operating reserves less than five percent), and SCE declared one distribution-relief event.

There were two air-conditioning cycling events in 2006. SCE declared these distribution relief events for six districts.

5.2 Summer Discount Plan Modifications for Spinning Reserve Demonstration

To participate in the spinning reserve demonstration, customers on the selected distribution feeder had to both be enrolled on the Summer Discount Plan and, if enrolled, had to agree explicitly to participate (and be compensated for participation). Nearly 70 customers on the targeted distribution feeder were already participating in the Summer Discount Plan program, but the project team recognized (based on the analysis presented in Section 4) that many more customers were needed for the demonstration. As a result, SCE initiated a supplementary marketing campaign targeting customers on the selected distribution feeder. Next, SCE obtained CPUC approval for a revised tariff that would compensate customers for participating in the demonstration. SCE then recruited participants for the revised tariff and at the same time continued to recruit new Summer Discount Plan and demonstration participants on the selected distribution feeder. Unfortunately, CPUC approval arrived late, so recruitment into the demonstration reduced the amount of time available for the demonstration, itself.

5.2.1 Target Marketing of Summer Discount Plan and Demonstration

To get high enrollment on the selected demonstration distribution feeder, SCE augmented its routine mass-mailed letter invitation to join the Summer Discount Plan with targeted marketing activities. The targeted marketing consisted of outreach at a local community fair for the city served by the distribution feeder, a letter signed by the mayor endorsing the effort that was sent to customers on the feeder, a concerted phone solicitation of customers on the feeder, and some door-to-door solicitation. These efforts began prior to and continued through the summers of 2005 and 2006.

Target marketing proved very effective in recruiting participants for the Summer Discount Plan. By the time testing began in fall 2006, nearly 300 customers on the demonstration distribution feeder had been recruited for the Summer Discount Plan. Of these, approximately 70 customers had already been participating in the program, so the target marketing during May-July 2005 produced a net increase of about 230 participants. The nearly 300 participating customers served by the distribution feeder represent more than 25 percent of the total number of eligible customers (i.e., those deemed in Section 4 to be eligible for participation based on having higher average monthly summer electricity consumption than winter consumption).

5.2.2 CPUC Approval of Modified Tariff

SCE had to file a modified tariff specifically designed to enable the research team to conduct a large number of short-duration curtailments for the demonstration project. SCE's modification addressed a previously approved tariff that had become dormant. As noted, CPUC gave final approval for renewing this tariff in mid-summer of 2006.

On October 26, 2005, SCE proposed additional changes to the Experimental Schedule, Utility-Controlled Load Test (UCLT) to implement the Demand Response Spinning Reserve Pilot (DRSRP) on one feeder in the City of Fontana.[9] The proposed changes allowed SCE to collect data regarding the load-control equipment that was already installed and operational on approximately 500 customers' air-conditioner compressor units. These data were necessary to understand the effectiveness and impact of the load-control equipment during distribution feeder load relief periods – i.e., the degree to which air conditioner load could act like spinning reserve. SCE observed how rapidly air-

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[9] In May 1976, the CPUC approved SCE's Advice Letter 422-E, implementation of Experimental Schedule UCLT. This experimental schedule was originally developed to facilitate the Powershift Valencia test program, a program that ran from 1976 through 1980, and was very similar to SCE's current Summer Discount Plan. The Powershift Valencia test program was specifically designed to compensate participants on a per-test basis whereas SCE's current Summer Discount Plan gives bill credits throughout the summer season whether the program is activated or not.

On October 16, 1978, SCE filed Advice 474-E, revising the dormant Experimental Schedule UCLT to eliminate the termination provision which, if it had been retained, would have resulted in the termination of Schedule UCLT on June 1, 1979. In addition to minor text changes, SCE proposed to extend Experimental Schedule UCLT indefinitely, thus allowing for its use in any future tests. The CPUC approved Advice Letter 474-E on November 15, 1978.

conditioner load control devices are activated upon dispatch, an important variable in determining the impact the test program would have on SCE’s system.

The following changes to the Experimental Schedule UCLT were approved by the CPUC on June 27, 2006 with an effective date of November 25, 2005:

- RATES: “The rates, as applicable under the customer’s Otherwise Applicable Tariff (OAT), including any applicable credits under an Air Conditioner Cycling program (APS), shall apply except the customer shall receive an annual monetary payment or bill credit for its active participation on this program.”
- SPECIAL CONDITIONS: Compensation – replaced with Test Events - “The maximum accumulated minutes of all test events combined shall not exceed 400 minutes in a calendar year, with the maximum duration of a single test event not to exceed 60 minutes” with the understanding that the average test event will last between 5 and 10 minutes in duration with a weekly average of 20 minutes.
- SPECIAL CONDITIONS: This change addresses the time period during which a customer could participate under this tariff schedule. Although tests at individual sites will not exceed a period of three years, the language needed to be modified to ensure an ending date for testing that did not mandate removal of hardware used for ongoing Summer Discount Plan participation.

5.2.3 Additional Marketing of Modified Tariff

The final marketing step was to solicit customer participation in the demonstration project. Target marketing was again employed, consisting of a letter sent to customers outlining the demonstration program and the incentives that would be paid for participation and of a concerted telephone solicitation effort.

By and large, the recruitment efforts were excellent for residential customers but less successful for commercial customers, in part because of the more extensive requirements for commercial customers. When the recruitment campaign was finished, SCE had enrolled 279 service accounts/devices in the demonstration project.

6. Communication and Control Infrastructure for the Summer Discount Plan

This section describes the communication and control infrastructure that supports the Summer Discount Plan program and the modifications that were made to conduct the spinning reserve demonstration. Although some load-cycling controllers installed on air-conditioning units were relatively old, the communication and control infrastructure that supports the program has been regularly upgraded.

SCE centrally dispatches the Summer Discount Program from a single control center that can be programmed to interrupt pre-selected groupings of customers within SCE's service territory. This feature enabled the demonstration to curtail only those customers who agreed to participate in the demonstration.

The signal to interrupt is transmitted to switches installed on customers' air conditioners via a radio tower owned by SCE. The switches feature functionalities that were used in the demonstration, such as the ability to adjust the delay from the time an curtailment is ended to the time the air conditioner is allowed to restart. Early testing of this system in the fall of 2005 and in 2006 led SCE to enhance the system to reduce latencies in the transmitted signal. For summer 2006, SCE also intended to deploy, for a statistically selected sample of customers, a specially enhanced switch with two-way communication of high-time-resolution information on switch status and load drawn by the air-conditioning unit's compressor. The switches would have provided micro-level information on the individual air-conditioning units' performance. However, only six of the enhanced switches could be installed in time for a final set of tests; as discussed in Section 8, these switches produced mixed results.

6.1 Major Communications and Control Hardware Elements and Control System Infrastructure

The SCE control system has been continually upgraded to incorporate the latest technology available. In 2006, 10 new, fully redundant servers were added, and new functionality allows the grid control dispatcher to shed individual substation load. The control system is also time synchronized with the Network Time Protocol (NTP) server.

6.1.1 Transmitters

SCE has a 50,000-square-mile service territory covered by 21 utility-owned transmitters with redundant coverage for all regions. All transmitters have either fiber or microwave connections directly to SCE's control system.

6.1.2 Air-Conditioner Load-Control Switches

Autonomous Control Protocol (ACP) load control switches are used for the nearly 200,000 residential participants in the Summer Discount Plan. These switches receive a "begin-curtailment" signal, and curtailment of air conditioner load continues until the switches receive an "end-of-curtailment" signal from SCE or until 60 minutes passes without a begin-curtailment signal. Upon receiving the end-of-curtailment signal, SCE allows air conditioners to restart after a randomly determined time delay of 12 to 18 minutes. This load-return delay is adjustable through SCE's control system and was set to zero for most of the tests conducted in 2006. When the tests started in 2006, there were 244 switches installed on the distribution feeder used for this project. Of these, 211 were ACP switches, and 33 were an older switch technology, Remotely Alterable Address (RAA), which functions slightly differently. (SCE plans to replace the remaining RAA switches prior to any demonstration tests in 2007). A few switches were added in September 2006 so that, by October, there were 268 switches on the feeder: 233 ACP, 29 RAA, and six new enhanced switches described below.

6.1.3 Enhanced Air-Conditioner Load Control Switches

Six enhanced switches were installed at the end of October 2006 that feature two-way communication with system servers, load monitoring of the air-conditioning unit through a current transducer, switch-closure monitoring for refining the characterization of response timing, and time synchronization with SCE servers to ensure that the time stamps are consistent with one another and with the dispatch system. These devices also perform all the functions of the ACP switches that execute the Summer Discount Plan for most customers.

6.2 Steps in a Curtailment Event

Curtailment events for the demonstration project are initiated using a dispatch application that targets the switches installed on the demonstration distribution feeder. (See Figure 6.1). Once an event is launched, there are five steps:

1) The control system sends a command to the Broadcast Master Controller, which identifies the transmitter(s) that will broadcast the event commands.
2) The Broadcast Master Controller sends the commands to the appropriate Port Expander. Each port has a direct fiber or microwave connection to a Remote Site Controller at the transmitter site.
3) The Remote Site Controller signals the transmitter to broadcast event commands to the switches at customer sites.
4) The switches located on each customer's condenser open following a two-second latency period from the time the event was dispatched.
5) Once the switch is open, the power to the air conditioning is cut off, and load drops instantaneously.

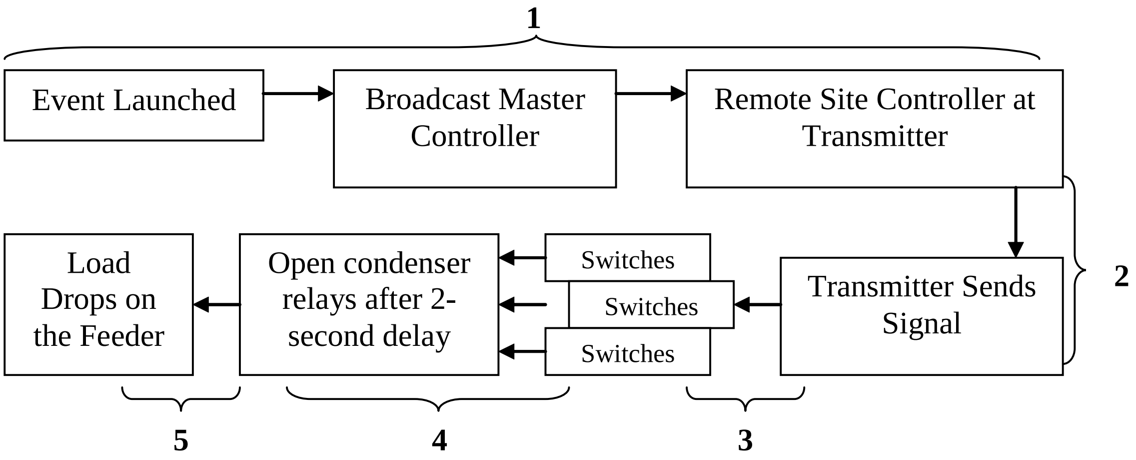

Figure 6-1. From Event Initiation to Feeder Load Response

7. Communication and Aggregation Framework for Real-time Telemetry and Load Monitoring

This section describes the data integration, archiving, and presentation framework that was developed to provide real-time telemetry of the feeder load for this demonstration project in a manner comparable to that currently provided by large generators. A key feature of the demonstration is giving electricity system operators real-time displays of the performance of demand-side resources comparable to the displays operators can access to view the performance of supply-side resources.

Currently, operators observe the performance of large generators via secure, internal monitoring systems that provide snapshots of generators' output, which are updated and refreshed every four to 10 seconds.

The spinning reserve demonstration built on a software design developed originally for the U.S. Department of Energy (DOE) that is based on open protocols, and is extensible and scalable. A technical assessment of the system is included in Appendix A.

Data on the total load on the demonstration feeder are extracted directly from SCE's internal monitoring system at the same rate that they are collected and transmitted internally within SCE's system, i.e., every four to 10 seconds. The data are viewable in real time on a secure website by any external entity that is given access. For this demonstration, the website was accessible to CA ISO, California utilities, WECC committees, the Energy Commission, CPUC, and the research team.

The system also archives these and other data [e.g., weather data from the National Weather Service (NWS)] for analysis. The system was configured to collect and display the real-time data generated by the six enhanced switches described in Section 6. However, the connectivity required to enable this functionality was not completed by SCE's vendor before the end of the summer 2006 cooling season, so the data collected from the small number of enhanced switches that had been installed were archived.

Providing usable, real-time telemetry of the target load in a manner comparable to existing solutions for large generation resources poses a design problem because of the diversity of data sources involved -- feeder data, weather station data, end-use metering data, shed-signal origination data -- and the need to aggregate, manipulate, and present these monitored data in real time. The problem is further complicated by the need to use existing technology platforms (e.g., SCE's internal monitoring system) and to rely on the public internet for communication in order to reduce the total initial cost of the solution. The solution also needs to be reusable, expandable and scalable to address the barriers to large-scale and ready adoption.

These challenges were addressed by adopting a multi-layered, framework implementation of the Advanced Communication and Control Protocol (ACCP) architecture developed in a multi-year, multi-member, DOE-sponsored co-operative research study (Connected Energy 2007).[10] Custom interfaces were added to SCE's SCADA data store (so that the

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[10] Connected Energy's platform is known commercially as *COMSYS.* ™.

program could access the total load on the demonstration feeder), NWS observations, and enhanced load-control switch data.

7.1 Use of ACCP System Architecture to Support this Project

Several attributes of the ACCP architecture were instrumental to the success of this demonstration program.

First, ACCP uses a multi-layered architecture that allowed the project team to archive meter data for aggregation and analysis at a later stage. Second, the architecture uses an IEEE 1547.3 - recommended, open, XML-based protocol to communicate through all logical interfaces of the system, [11] which allowed for seamless integration of vendor-specific metering data and NWS weather data. Third, the platform's push-based and event-driven components result in rapid transmission of data; latencies – time lapses from the time data are received until the time they are presented for display on a website -- are on the order of 1 to 6 seconds, which allowed the project team to provide real-time visibility of demonstration status. Fourth, ACCP architecture also supports real-time data analysis and roll up for immediate presentation.

Finally, ACCP allows monitored data to be delivered in multiple ways that are compatible with the user's analytical requirements. The presentation layers used in the demonstration included this demonstration included real-time viewing of data on the website, nightly delivery of aggregated data for analysis purposes, delivery of pre-defined reports and summaries, and real-time trending of historical data. The platform's data storage design uses both relational and dedicated time-series data repositories.

7.2 Integrating Data Sources

The four sources of real-time data for SCE's system are SCADA feeder data, current and predicted weather data, telemetered data from the enhanced switches that were installed at a few customer sites (as described in Section 6), and control center data on load-shed event signal status.

7.2.1 Feeder-level Data from SCE's SCADA Data Stores

These data are retrieved via an eDNA data-bridge between symmetric eDNA server installations at SCE and Connected Energy's data center. The data are collected at four-second intervals and posted without any system delays. The following parameters are monitored for the target feeder as well as two adjoining feeders:

- current phase A
- current phase B
- current phase C
- reactive power – 3 Phase
- feeder voltage
- temperature

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[11] Connected Energy's XML protocol is known commercially as ener*TALK.* ™

7.2.2 Current and Predicted Weather Data

A custom web service client retrieves weather data for a representative weather station within the target territory. Data for the Ontario International Airport generated by the NWS-hosted Current Observations server and the National Digital Forecast database (NDFD) are used. In addition, data were collected from weather stations at SCE's Mira Loma and Colton offices. The following weather data parameters were monitored:

- current temperature
- relative humidity
- current pressure
- predicted daily maximum temperature
- predicted daily minimum temperature
- predicted hourly temperature (in three-hour segments)
- predicted relative humidity

7.2.3.Telemetered Data From Radio-Controlled, Enhanced, Load-Shed Switches

A custom integration component was developed for retrieving telemetered data from the enhanced switches described in Section 6. The following parameters from each switch were configured for monitoring:

- feeder Amperage
- feeder Voltage
- relay status
- load-shed event signal status

The following control center load shed event signal status was also monitored.

Data from first the three real-time sources above moved through the analytical layers of the platform, archived in time series and relational databases, and prepared for presentation.[12]

The data path and primary components that make up the communication system are illustrated in Figure 7-1.

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[12] Connected Energy's presentation engine is known commercially, as ener*VIEW* ™.

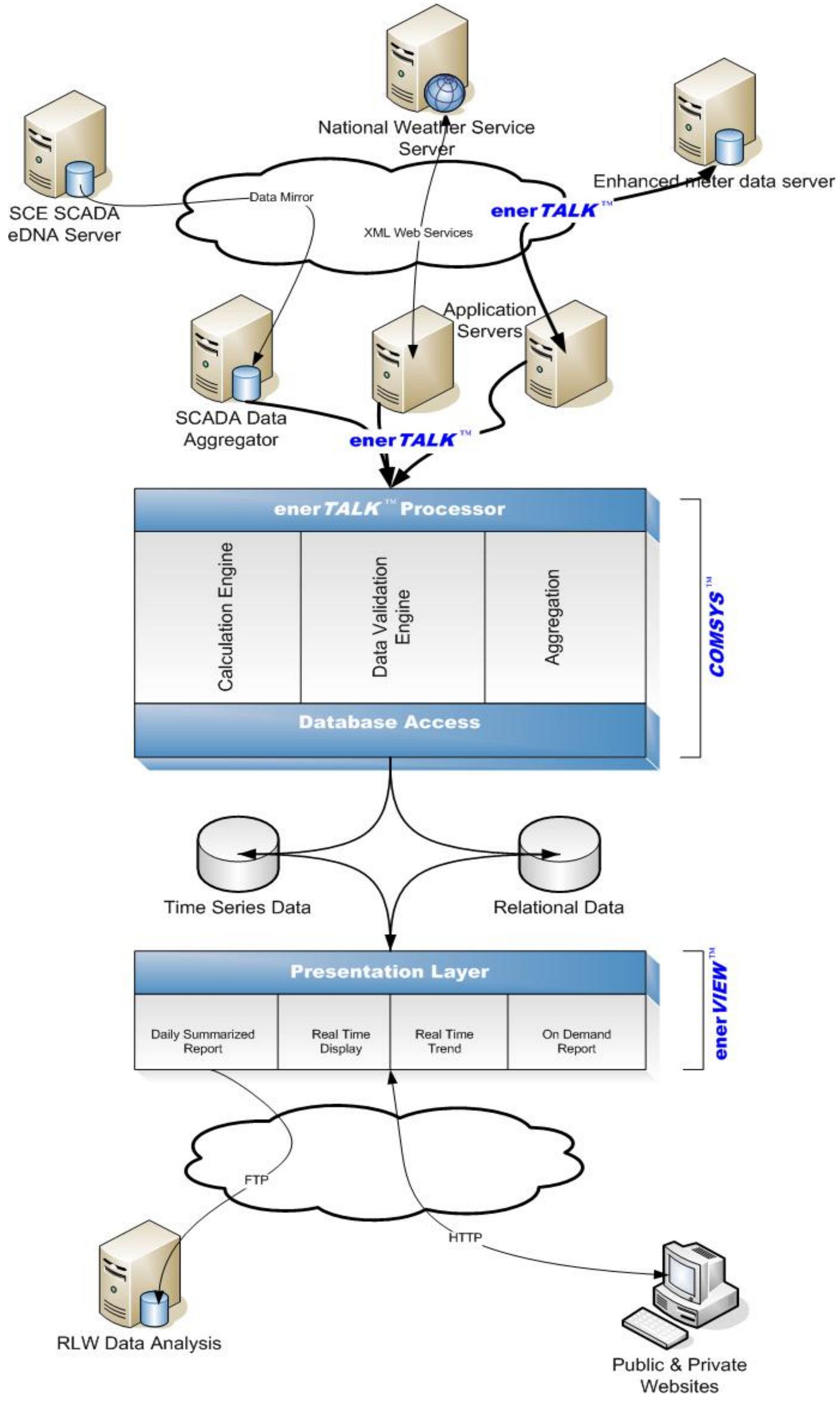


Figure 7-1. Communication & Data Aggregation Framework: Technology Stack

7.3 List of Platform Elements

The major system components used in the demonstration project and their primary attributes are as follows.

The implementation framework is an IEEE 1547.3 standards-driven open, public protocol. It is an extensible markup language (XML)-based protocol built on regular HTTP transport mechanism (as used by web browsers) and a message-driven architecture. A technical assessment of the protocol is provided in Appendix A.

The SCADA data aggregator component of the platform extracts data from the SCADA data holding server and marks it up for integration with the platform. It creates a common interface for all feeder data stored in SCE's eDNA Server and can interoperate with SCE's internal repository. The data aggregator is event-driven and forwards data to the platform without any structured delays. It is designed to run within or outside of a shared security zone. Data are transported via XML over HTTP.

The National Weather Service data aggregator is an event-driven and configurable custom component that uses a Simple Object Access Protocol (SOAP) client as well as an HTTP request-response client to access weather data from NWS data servers and post them to the platform via the public protocol described above.

The enhanced switch data aggregator was specifically designed to aggregate data from the enhanced radio-controlled switches deployed on the demonstration feeder. It uses a timer-based "pull" mechanism to continuously query enhanced switch data servers for data updates from field-deployed switches.

The data processor is a common interface for all custom data aggregation components and a single point of interoperation for data sources. All data presented to the system are parsed via this common interface so that they are readily available for integration. This abstract layers allows for the necessary decoupling of data sources from the data analysis, storage, and presentation components.

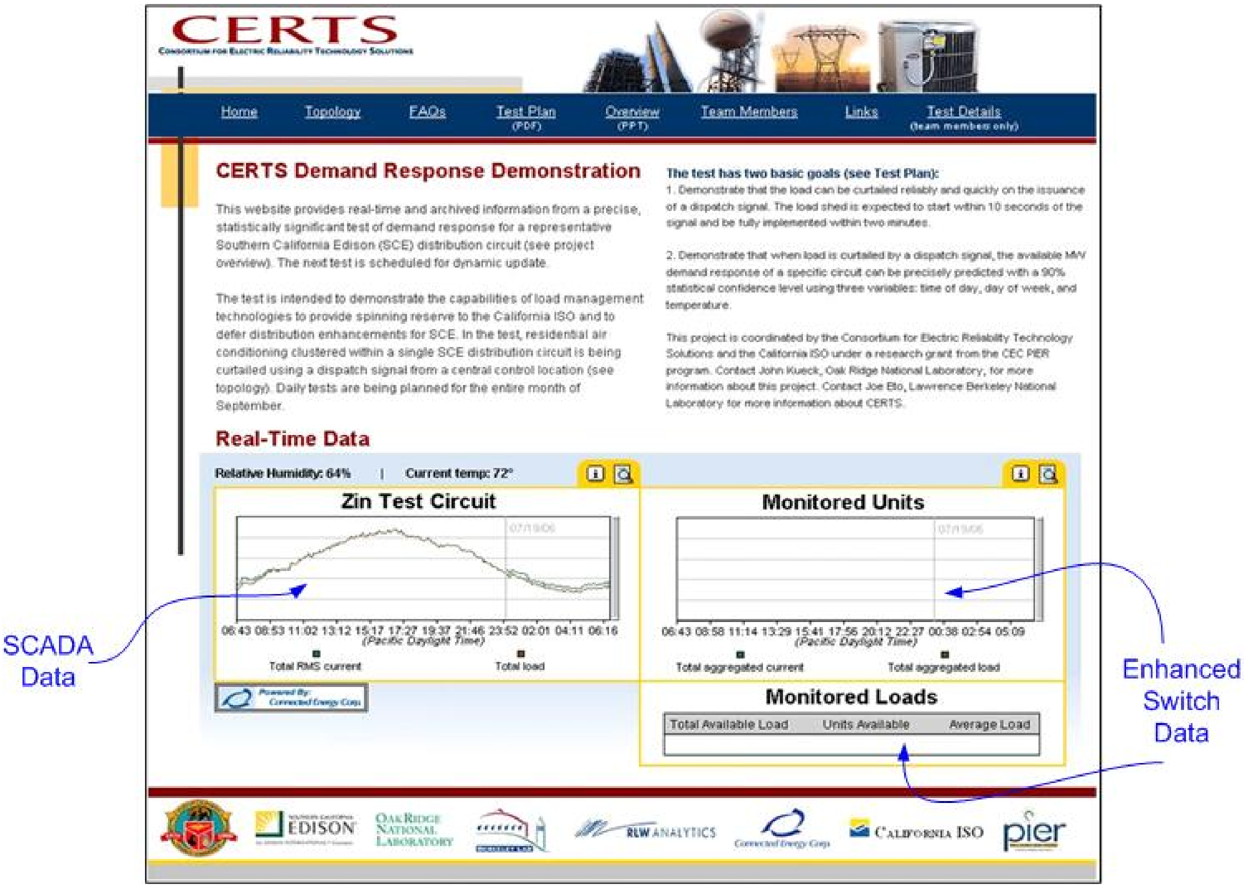
Other platform components provide the necessary in-line analysis functionalities and include:

- The calculation engine that performs event-triggered calculations on real-time data, e.g., total power for target feeder;
- The data validation engine, which checks for consistency of all inbound data;
- The aggregation engine, which provides real-time summary and data roll-up analysis, e.g., aggregated load shed by enhanced switches relative to their relay state at the start of a load-shed event;
- The time-series data store, which stores real-time data streams using specialized data structures and optimized interface;
- The relational data store, which stores contextual meta-data, summarized characteristic data, and batch-processed data-mining analytics for end-user applications;
- The suite of presentation layer applications that allow delivery of monitored data over multiple mechanisms, aggregations, and views including:

- Daily summarized reports, which are generated nightly from mined data for all data streams, time synchronized, interpolated as needed, packaged, and delivered via ftp to researchers for analysis;
- Real-time views, which present monitored and calculated data for web-based delivery in real time;
- Live trends, which show real-time trending of historical data;
- On-demand reports, which are pre-defined reports available on demand that can be configured to summarize shed events.

7.4 Real-Time Websites for Data View

The public project website is hosted at Connected Energy Corp.'s Data Center (https://www.enerstage.com/DRdemo/) and was developed to display real-time feeder load and switch data during a load-shed event and to show test-specific information for general use. The website is accessible via secured HTTP. Figure 7-2 displays the first page of the public website.



CERTS Demand Response Demonstration

This website provides real-time and archived information from a precise, statistically significant test of demand response for a representative Southern California Edison (SCE) distribution circuit (see project overview). The next test is scheduled for dynamic update.

The test is intended to demonstrate the capabilities of load management technologies to provide spinning reserve to the California ISO and to defer distribution enhancements for SCE. In the test, residential air conditioning clustered within a single SCE distribution circuit is being curtailed using a dispatch signal from a central control location (see topology). Daily tests are being planned for the entire month of September.

The test has two basic goals (see Test Plan):

1. Demonstrate that the load can be curtailed reliably and quickly on the issuance of a dispatch signal. The load shed is expected to start within 10 seconds of the signal and be fully implemented within two minutes.

2. Demonstrate that when load is curtailed by a dispatch signal, the available MW demand response of a specific circuit can be precisely predicted with a 90% statistical confidence level using three variables: time of day, day of week, and temperature.

This project is coordinated by the Consortium for Electric Reliability Technology Solutions and the California ISO under a research grant from the CEC PIER program. Contact John Kueck, Oak Ridge National Laboratory, for more information about this project. Contact Joe Eto, Lawrence Berkeley National Laboratory for more information about CERTS.

Real-Time Data

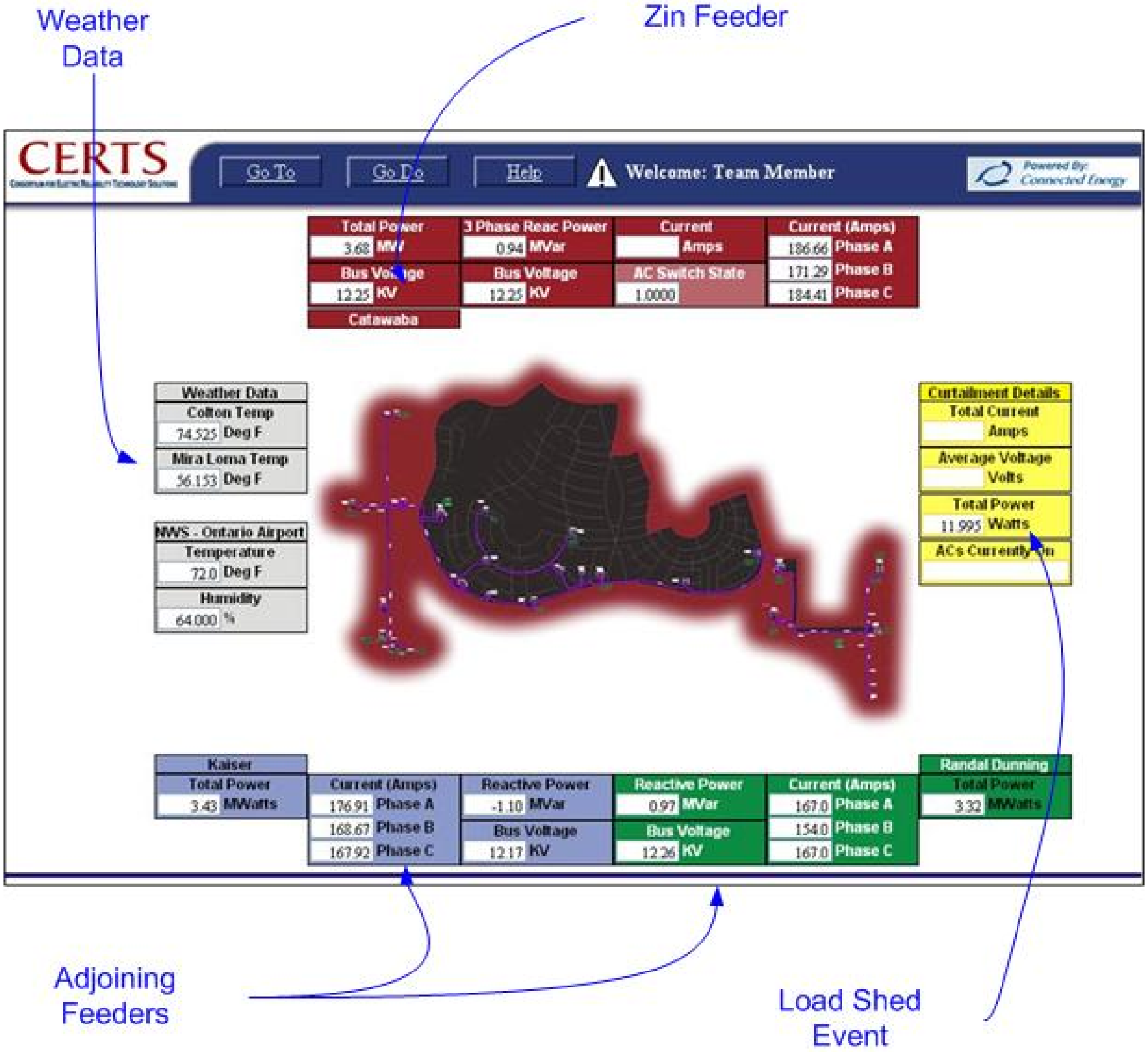
Relative Humidity: 64% | Current temp: 72°

Monitored Loads

Total Available Load	Units Available	Average Load

Figure 7-2. Public Website

The internal project website is hosted at Connected Energy Corp.'s Data Center (https://www.enerstage.com/) and was developed to display all archived project data and analysis for use by the project team. The website is accessible via secured HTTP and protected username and password credential. Figures 7-3 and 7-4 display the two aggregated view pages of the website.



Weather Data

Zin Feeder

Adjoining Feeders

Load Shed Event

Catawaba
Total Power 3.68 MW
3 Phase Reac Power 0.94 MVar
Current Amps
Current (Amps) 186.66 Phase A, 171.29 Phase B, 184.41 Phase C
Bus Voltage 12.25 KV
Bus Voltage 12.25 KV
AC Switch State 1.0000

Weather Data
Colton Temp 74.525 Deg F
Mira Loma Temp 56.153 Deg F

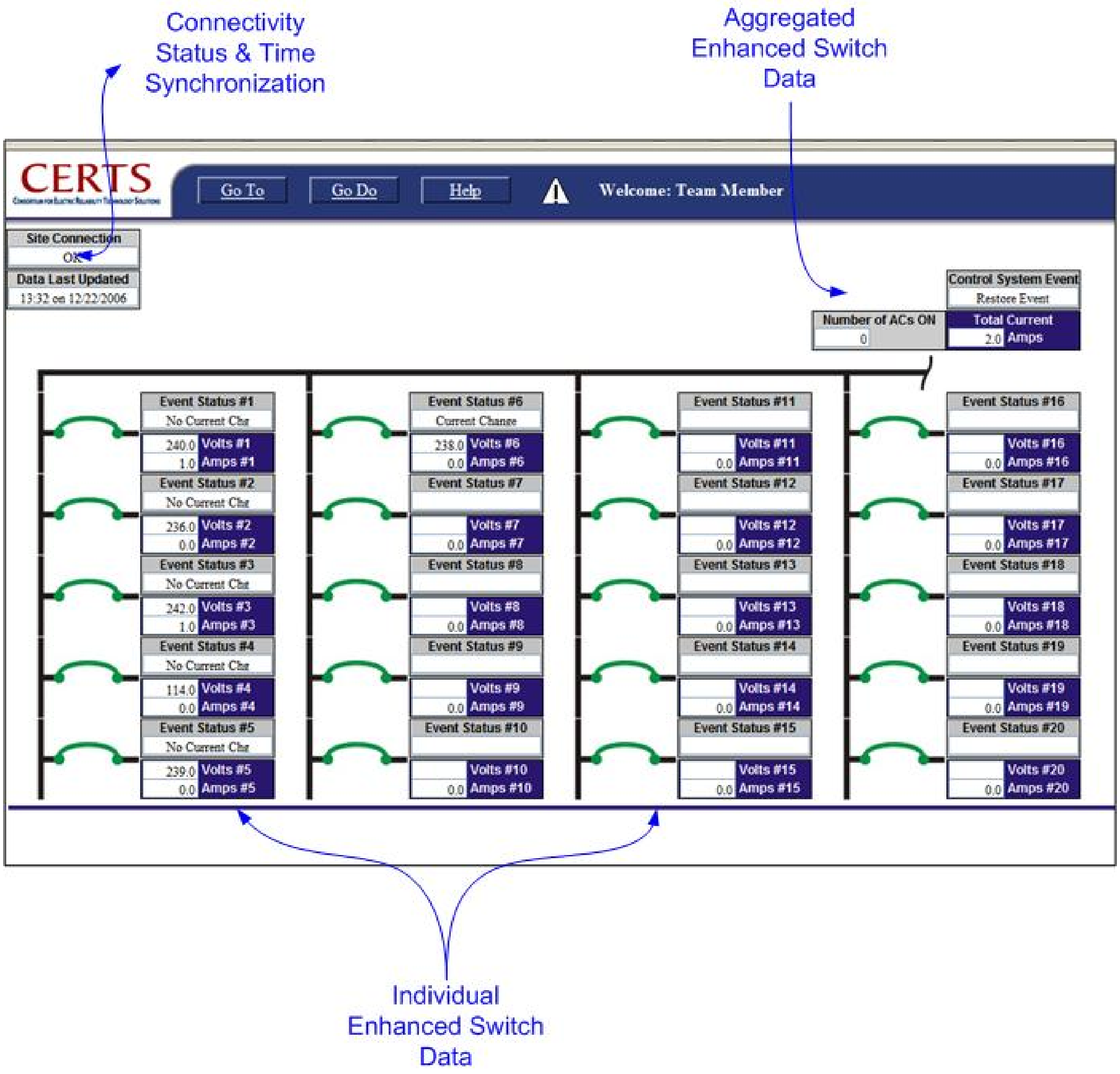
NWS - Ontario Airport
Temperature 72.0 Deg F
Humidity 64.000 %

Curtailment Details
Total Current Amps
Average Voltage Volts
Total Power 11.995 Watts
ACs Currently On

Kaiser
Total Power 3.43 MWatts
Current (Amps) 176.91 Phase A, 168.67 Phase B, 167.92 Phase C
Reactive Power -1.10 MVar
Bus Voltage 12.17 KV

Randal Dunning
Total Power 3.32 MWatts
Reactive Power 0.97 MVar
Bus Voltage 12.26 KV
Current (Amps) 167.0 Phase A, 154.0 Phase B, 167.0 Phase C

Figure 7-3. Internal Website – Feeder-Level Aggregated View



Connectivity Status & Time Synchronization

Aggregated Enhanced Switch Data

Site Connection
OK

Data Last Updated
13:32 on 12/22/2006

Control System Event
Restore Event

Number of ACs ON
0

Total Current
2.0 Amps

Event Status #1
No Current Chg
240.0 Volts #1
1.0 Amps #1

Event Status #2
No Current Chg
236.0 Volts #2
0.0 Amps #2

Event Status #3
No Current Chg
242.0 Volts #3
1.0 Amps #3

Event Status #4
No Current Chg
114.0 Volts #4
0.0 Amps #4

Event Status #5
No Current Chg
239.0 Volts #5
0.0 Amps #5

Event Status #6
Current Change
238.0 Volts #6
0.0 Amps #6

Event Status #7
Volts #7
0.0 Amps #7

Event Status #8
Volts #8
0.0 Amps #8

Event Status #9
Volts #9
0.0 Amps #9

Event Status #10
Volts #10
0.0 Amps #10

Event Status #11
Volts #11
0.0 Amps #11

Event Status #12
Volts #12
0.0 Amps #12

Event Status #13
Volts #13
0.0 Amps #13

Event Status #14
Volts #14
0.0 Amps #14

Event Status #15
Volts #15
0.0 Amps #15

Event Status #16
Volts #16
0.0 Amps #16

Event Status #17
Volts #17
0.0 Amps #17

Event Status #18
Volts #18
0.0 Amps #18

Event Status #19
Volts #19
0.0 Amps #19

Event Status #20
Volts #20
0.0 Amps #20

Individual Enhanced Switch Data

Figure 7-4. Internal Website – Enhanced Switches Aggregated View

8. Overview of Test Curtailments Conducted in 2006

This section describes the test curtailments conducted during the late-summer cooling season of 2006. Because of the late regulatory approval for the demonstration, scheduling the test curtailments involved a trade-off between allowing additional time for recruiting demonstration participants and reserving enough time to conduct a sufficient number of tests before the end of summer 2006 cooling season in southern California (typically mid- to late October). Ultimately, 37 tests were conducted between mid-September and the first week of November. The tests were scheduled at different times on weekday afternoons when the weather was expected to be hot. Each test was scheduled to last five minutes. Early review of data revealed problems in SCE's control software that resulted in the initial tests lasting longer than five minutes (in one case as long as 17 minutes). These software problems were corrected for the remaining 28 test curtailments.

8.1 Participant Recruitment Delayed Test Curtailments

As described in Section 5, recruitment for the demonstration project began in July 2006 following regulatory approval in late June. Both customers already enrolled in the Summer Discount Plan program and those who were not already enrolled were recruited for the demonstration. By mid-August a significant number of customers already enrolled in the Summer Discount Plan had agreed to participate in the demonstration. However, efforts to enroll new customers in both the Summer Discount Plan and the demonstration were significantly less successful. Taking into account extensive marketing of the Summer Discount Plan to customers on the demonstration feeder that had taken place during the prior summer (2005), the SCE marketing staff concluded that they had reached the point of diminishing returns for recruiting new customers, so the project team began preparations for testing. SCE staff shifted their efforts to completing written participation agreements with customers and scheduling the installation of switches for new customers on the demonstration feeder. Ultimately, 286 customers on the Summer Discount Plan agreed to participate in the demonstration.

8.2 Testing Conducted between Mid-September and Early November

Prior to and during the summer of 2006, the project team developed several schedules for test curtailments designed to cover a wide variety of conditions, including time of day, day of week, and temperature. Because of the number of customers participating in the demonstration and because the time available for testing was limited to the last two months of the summer cooling season, the team adopted a pragmatic, iterative approach.

A small number of once-per-day, five-minute curtailments were scheduled for early September to assess the system's function. Rapid analysis of these early tests identified several important issues, including conventions used to time-stamp events in the curtailment process, signaling delays by the communication towers, and the need to modify control software commands for initiating and ending curtailments. These issues and their resolution are described in Section 9.

Because these issues had to be addressed at the same time weather in southern California was beginning to cool, the team's approach for scheduling the remaining tests involved approximately weekly conference calls to discuss the results of the previous week's tests and the status of steps to address issues identified and to develop a testing schedule for the coming week based on a review of forecasted weather. The team targeted days when weather was predicted to be hot and times of day when loads on the distribution feeder would be highest, to maximize the likelihood that the effect of the simultaneous curtailment of participating air-conditioning units would be discernable from the "noise" created by random fluctuations in the total loads on the distribution feeder. This led to scheduling the majority of tests at 4 p.m. on weekday afternoons.

Throughout September, no more than one test per day was conducted. After modifications to the SCE control system were completed at the end of September, testing was increased to as many as three tests per day. All tests were scheduled to last five minutes.

In October, SCE received six enhanced switches from its vendor. Following successful internal acceptance testing of the units, these switches were installed on air-conditioning units in the distribution feeder during the last week of October. A specially designed, two-day test was conducted in late October to gather high-time-resolution information from these switches. Customers that received enhanced switches were contacted by SCE and asked to ensure that their units were operating during the testing period. Five curtailments were conducted on the first day and four curtailments on the second day of this special test period for the enhanced switches. Each curtailment lasted five minutes.

In early November, a weather forecast predicted additional hot weather, so a final set of tests was conducted.

A total of 37 test curtailments were conducted between mid-September and early November. Table 8-1 summarizes all tests conducted, including the date, scheduled and actual curtailment start and duration, peak daily temperature from the nearby weather station, and number of switches by type that were targeted by the curtailment.

Table 8-1. Summary of 2006 Test Interruptions

Date	Scheduled Start Time (PM PDT)	Actual Start Time (PM PDT)	Scheduled Event Duration	Actual Event Duration	Peak Temp. (F)	Switches Installed		
						RAA	ACP	Enhanced ACP
9/12/06	4:00	4:06:00	5 min.	0:07:00	92	33	204	0
9/13/06	4:00	3:59:29	5 min.	0:07:29	87	33	211	0
9/18/06	4:00	3:57:10	5 min.	0:08:54	94	33	211	0
9/19/06	4:00	4:04:06	5 min.	0:07:13	90	33	216	0
9/20/06	4:00	4:01:06	5 min.	0:08:43	82	33	216	0
9/21/06	4:00	4:04:06	5 min.	0:17:43	82	33	216	0
9/26/06	4:00	4:01:06	5 min.	0:08:42	86	34	216	0
9/27/06	4:00	4:04:06	5 min.	0:08:49	91	34	216	0
9/28/06	4:00	4:01:05	5 min.	0:05:44	93	33	215	0
9/29/06	4:00	4:01:06	5 min.	0:05:43	91	33	215	0
10/3/06	Test	2:29:50	5 min.	0:04:50	81	33	227	0
10/3/06	Test	3:49:20	5 min.	0:05:00	81	33	227	0
10/19/06	12:00	12:03:10	5 min.	0:05:00	80	29	233	6
10/19/06	2:00	1:51:00	5 min.	0:05:02	82	29	233	6
10/19/06	4:00	4:00:00	5 min.	0:05:00	83	29	233	6
10/20/06	1:30	1:30:01	5 min.	0:04:59	85	29	233	6
10/20/06	2:30	2:30:00	5 min.	0:05:00	88	29	233	6
10/20/06	3:30	3:30:00	5 min.	0:05:00	87	29	233	6
10/23/06	2:00	2:03:00	5 min.	0:05:00	88	29	233	6
10/23/06	3:00	3:00:00	5 min.	0:05:00	90	29	233	6
10/23/06	4:00	4:00:00	5 min.	0:05:00	89	29	233	6
10/26/06	12:45	12:45:00	5 min.	0:05:01	80	29	233	6
10/26/06	1:30	1:30:00	5 min.	0:05:01	79	29	233	6
10/26/06	2:15	2:15:00	5 min.	0:05:00	80	29	233	6
10/26/06	3:00	3:00:00	5 min.	0:04:59	80	29	233	6
10/26/06	3:45	3:45:00	5 min.	0:05:01	79	29	233	6
10/27/06	12:45	12:44:59	5 min.	0:05:01	84	29	233	6
10/27/06	1:30	1:33:00	5 min.	0:04:59	84	29	233	6
10/27/06	2:15	2:15:00	5 min.	0:04:05	85	29	233	6
10/27/06	3:00	2:59:59	5 min.	0:05:01	85	29	233	6
10/27/06	3:45	3:45:00	5 min.	0:05:00	85	29	233	6
11/6/06	1:00	1:00:00	5 min.	0:05:01	91	29	233	6
11/6/06	2:00	2:01:01	5 min.	0:05:01	91	29	233	6
11/6/06	3:00	3:00:00	5 min.	0:05:01	90	29	233	6
11/7/06	1:00	1:20:59	5 min.	0:05:01	93	29	233	6
11/7/06	2:00	2:00:00	5 min.	0:05:00	93	29	233	6
11/7/06	3:00	3:00:01	5 min.	0:04:59	93	29	233	6

9. Findings from Test Curtailments Conducted in 2006

This section describes preliminary findings from the test curtailments that were conducted during the summer of 2006. The findings are drawn from four general areas of analysis.

First, we compare temperatures from the test period to temperatures from the entire cooling season and confirm that our tests were conducted during a comparatively cool period compared to the hotter weather normally experienced by customers on the feeder.

Second, we discuss the magnitude of the aggregated loads curtailed during each test curtailment and the analysis procedures that we employed to eliminate unusable data and to measure the difference between pre- and post-curtailment loads.

Third, we discuss initial efforts to characterize and extrapolate from the test curtailments to develop prototype "nomograms" describing the amount of load curtailment that is available as a function of both time of day and temperature.

Fourth, we review the time-stamped information for each step in the curtailment process and the corresponding feeder loads to assess the latencies associated with each step in the process. (Analysis of these latencies led to modifications of SCE's control software during the testing process.)

9.1 Test Curtailments Conducted During Comparatively Cool Period of Summer

To understand the context for the load impacts of our test curtailments, we compare daily high temperatures from the test period to daily high temperatures from an entire summer. This comparison shows that the time period of our test curtailments was a comparatively cooler period of the summer. We estimate that the load curtailments that we might have observed had tests been conducted during hotter periods of the summer would have been significantly higher than those that we observed during the testing period of mid-September to early November 2006. (As noted earlier, the timing of the tests was determined in large part by the timing of regulatory approval for them.)

Table 9-1 shows the distribution of days by high temperature range during the summer of 2004. These results suggest that very cool days are uncommon in the summer, but the four higher temperature bins are about equally likely.

Table 9-1. Number of Summer Days in 2004, by Daily High Temperature.

Daily High			Days
Up	to	80	6
80	to	90	24
90	to	95	20
95	to	100	17
100	and	up	21

Table 9-2 shows the temperature during the 37 curtailment tests conducted in September-October 2006. Most of the tests took place when temperatures were in the range of 80 to 90 degrees Fahrenheit; the highest temperature on a test day was 94 degrees. The results of these tests are therefore likely to understate the load reductions achievable during the other hotter months of the summer. Figure 4-2 shows that the peak summer 2004 load was roughly 9 MW compared to the 7 MW on the peak day of the 2006 tests. This difference is accounted for because the 2004 peak likely occurred on a 100+ degree day, but the peak temperature during the 2006 tests was only 94 degrees.[13]

Table 9-2. Number of Tests in 2006, by Daily High Temperature.

Test Temperature	Frequency
Up to 80	2
80 to 90	22
90 to 95	13
95 and up	0

9.2 Variable Magnitude of Load Impacts

As discussed in Section 4, the load impacts from the test curtailments must be distinguishable from the stochastic variations in load that are inherent to the total load served by the distribution feeder. We first reviewed the test curtailment data to determine which data could be used for our analysis. This procedure led us to eliminate data from seven curtailments because of problems (described in the next paragraph below), so our analysis used data from only 30 curtailments. We then developed a statistical smoothing technique to estimate the load before and after the start of a curtailment. We attribute the difference between these two estimates of load to the impact of the curtailment. Using this technique, we found load impacts ranging up to almost 10 percent of the total load on the distribution feeder.

For each day with a test event (there were total of 17 weekdays when we conducted curtailments, as noted in Section 8), we collected 10-second average load data from SCE's SCADA system. As noted above, seven of the tests were dropped from the analysis because the data were flawed. The flaws were as follows: the September 12 test data were recorded in the wrong time resolution (one-minute instead of 10-seconds), and during the three October 20th tests and three of the October 27th tests, the SCADA data system was malfunctioning.

The 30 remaining tests occurred on 15 separate weekdays. Table 9-3 shows the distribution of these tests by week.

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[13] If our roughly 300 switches (about 15 percent of the population on the feeder) make up about 15 percent of the total air-conditioning load, and assuming that the two-MW difference is predominantly due to air conditioning (a reasonable expectation given the large temperature difference and the fact that most other residential loads in the summer are fairly temperature-independent), we would expect to see an additional 300 kW = 15 percent * 2MW load drop on the warmest days of the summer over the 500 kW seen on the warmest day of our test.

Table 9-3. Tests with Usable Data, by Week.

Week	Tests
Week of 9/11/06	1
Week of 9/18/06	4
Week of 9/25/06	4
Week of 10/2/06	2
Week of 10/9/06	0
Week of 10/16/06	3
Week of 10/23/06	10
Week of 10/30/06	0
Week of 11/06/06	6

The moment-to-moment variability of the feeder load makes characterizing the absolute size of the load drop difficult for two reasons: first, we must characterize what load would look like in the absence of the curtailment, and, second, we must eliminate the observation-to-observation noise to ascertain the post-test load.

The first of these issues can be resolved in a number of ways. We could overcome noise by averaging a period of time prior to the test event and using that average as the “jumping- off point” for comparison with a similar average of periods after the test event. To get 30 observations and have a relatively precise average, we would need five minutes’ worth of data. This would work fine during periods of flat load where one five-minute-period’s load is indicative of the load of the subsequent period. However, during periods of increasing load, this would tend to understate the load curtailed, and during periods of decreasing load it would tend to overstate the curtailment. This is shown clearly in Figure 9-1 where there is a downward trend in the data that direct averages would misinterpret as a load curtailment.

Thus, we chose to resolve this issue by using regression analysis to characterize the load in the absence of the test. For the 15 minutes before each test, we estimated a regression line through the data (we did this individually for each test). Based on the results of those regressions, we projected the load forward into the test period, creating an estimate for each 10-second observation of load data. For each observation during the test period, we could then estimate the amount of load curtailed by subtracting observed load from the load predicted by the regression analysis.

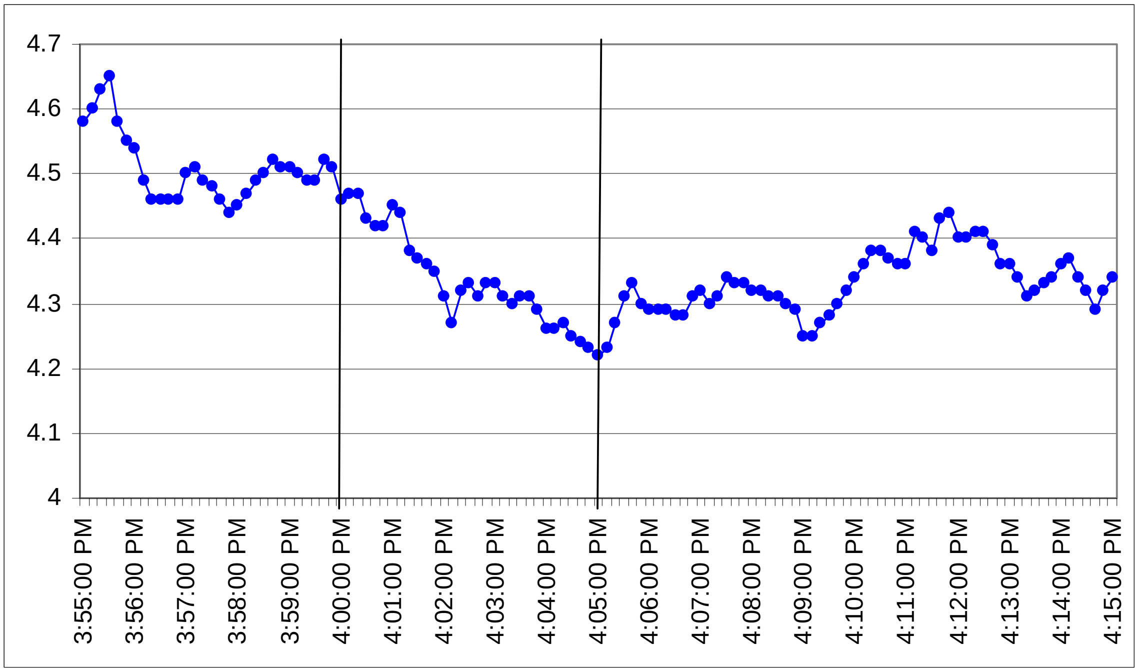

Figure 9-1. October 23 4:00:00 Test Load Profile

We addressed the issue of the observation-to-observation variability of the post-test system load itself by averaging these estimated load curtailments over the five-minute period of the test. To avoid capturing any transitional effects in this estimate, we created a 30- to 40-second "buffer zone" after the test call by dropping the four observations following a test call (or the three observations following the call and the observation concurrent with the call in cases where the call came on an even 10-second interval). We also ignored the last observation of the period. Figure 9-2 illustrates schematically how we estimated the magnitude of the load curtailment.

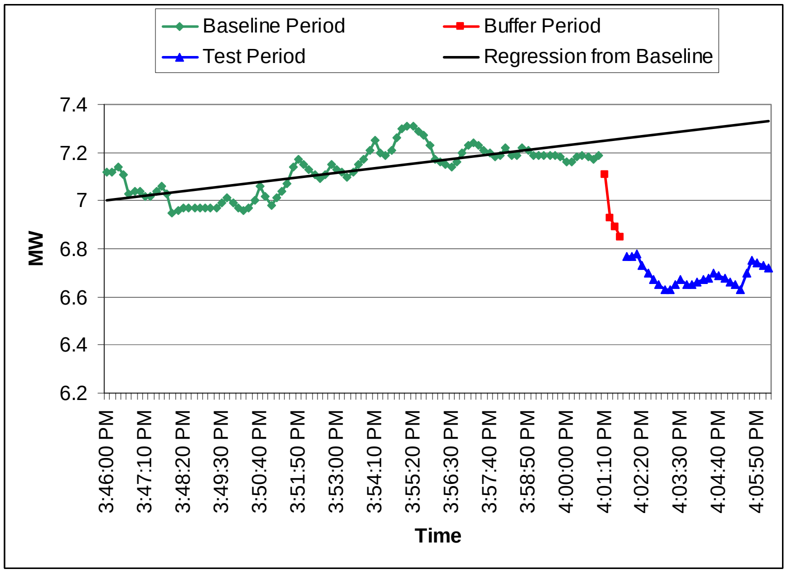

Figure 9-2. Estimation of Magnitude of Load Curtailment

Figure 9-3 shows the results of this analysis. The load curtailments range from negative (load after curtailment averaged higher than what would have been expected) to 610 kW from the September 13 test.

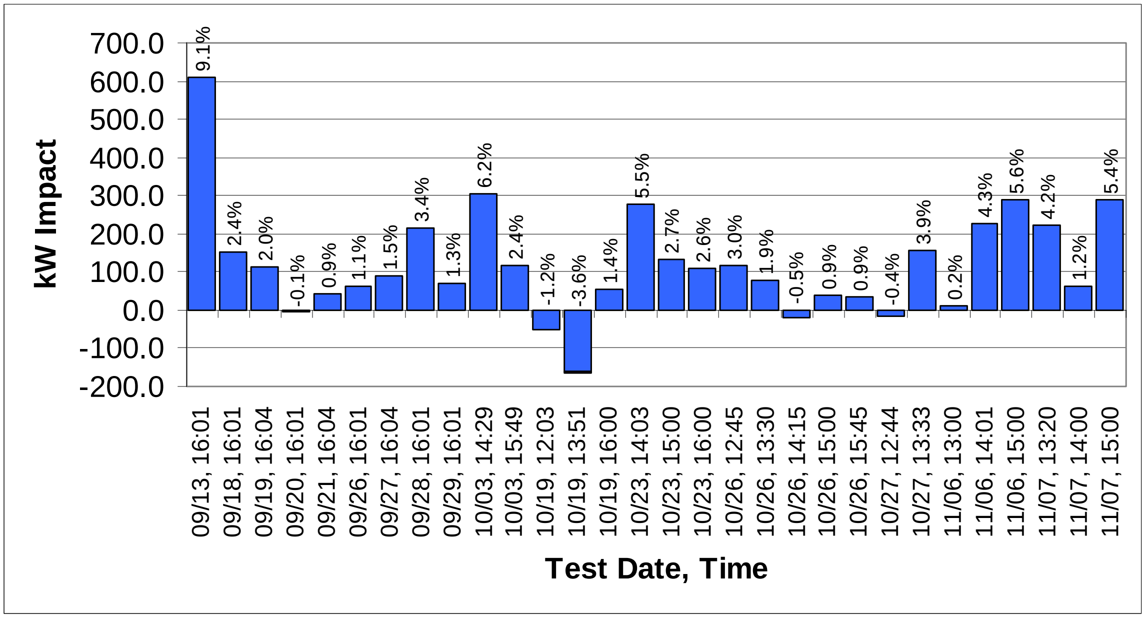

Figure 9-3. Estimated Load Curtailments by Test Date/Time

The results are highly variable, showing the sensitivity of using only distribution feeder load data—which itself is highly variable—to characterize load curtailments. In Table 9-3, the groups of tests that occur on a single day illustrate this variability most vividly. We would expect the load curtailed to increase as the system load (and by proxy the air-conditioning load) increases, and then to see a smaller curtailment once load begins to abate in the late afternoon. This pattern holds true only for the November 6 test day. On November 7, the 1:20 p.m. load curtailment of 221 kW is higher than the 2:00 p.m. load drop of 61 kW, which is followed by a much higher 3:00 p.m. curtailment of 291 kW. In part, these results are due to conducting our tests during the relatively mild late-September to early-November period; when the tests are run with the larger air-conditioning loads typical during the summer, the impacts should be considerably greater. This finding also highlights the need for using sampled unit-level data that allow us to see the effect of a curtailment isolated from other factors rather than seeing load data in which variability among a multitude of end-uses other than our curtailed air conditioners confounds attempts to isolate the load response attributable to the curtailment.

9.3 Correlation of Load Impacts with Temperature and Time of Day

We used the results to conduct a preliminary characterization of the relationship between time, temperature, and expected load curtailed.[14]

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[14] Because the data used to derive these estimates are entirely from the September (second half of the month), October and November, the results only apply to that time of the year.

Figure 9-4 shows the results of the 30 test events plotted against the time of the event. From 12:00 p.m. until 3:00 p.m., there is a clear trend upward in the data, with the average load curtailed increasing as the afternoon progresses. At 4:00 p.m., however, the results are more mixed. There is a cluster of 4:00 p.m. events with low load curtailments but also a handful of events with 200-kW curtailments, and this group includes the largest curtailment of 610 kW. This range reflects less the nature of load curtailments at 4:00 p.m. than it does the range of days over which we conducted 4:00 p.m. tests versus tests at other times of the day. The earliest set of tests, when we were conducting only one curtailment per day, all occurred near 4:00 p.m. This resulted in a mix of temperatures for the 4:00 p.m. tests, ranging from 82 degrees on 9/20 to 94 degrees on 9/18. The 1:00-3:00 p.m. tests, by contrast, were only performed on the warmer days when multiple tests were performed per day.

Figure 9-5 shows the prominence of temperature as a driving factor in load curtailed. There is a very clear and consistent relationship between the temperature in the hour of the test event and the load curtailed during that event. All but one test conducted when the temperature was below 86 degrees had a load reduction of less than 200 kW; several had negative “reductions.” On the contrary, no tests conducted when the temperature was above 90 degrees resulted in a negative load reduction.

We developed a model that simultaneously addressed the impact of both of these effects on load curtailed. We regressed estimated load curtailed against temperature and time of day using the equation:

$$LoadDrop = b_0 + b_1 * HrsSince12 - b_2 * HrsSince12^2 + b_3 * Temperature$$

where LoadDrop is the estimated load drop of each test measured in kW, HrsSince12 is the number of hours past 12:00 p.m. when the test occurs, and Temperature is the average temperature during the hour of the test. The HrsSince12 term is included to account for the fact that, after a certain time in the afternoon, load curtailed will decrease rather than increase with time.

The resulting model is:

$$LoadDrop = -801.3 + 120.2 * HrsSince12 - 20.9 * HrsSince12^2 + 9.07 * Temperature$$

which has an R-squared of 0.1994, meaning that it captures roughly 20 percent of the variation in the load drops. This model provides a blueprint for developing a model of the average load curtailment achievable at a given time of day and a given temperature.

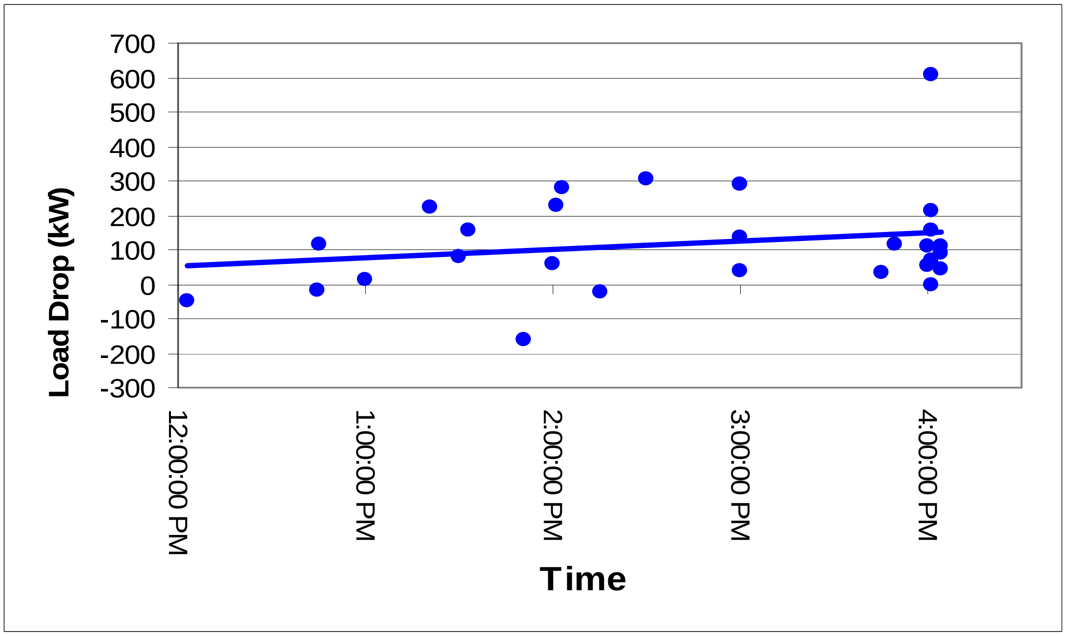

Figure 9-4. Estimated Load Drop by Time of Day

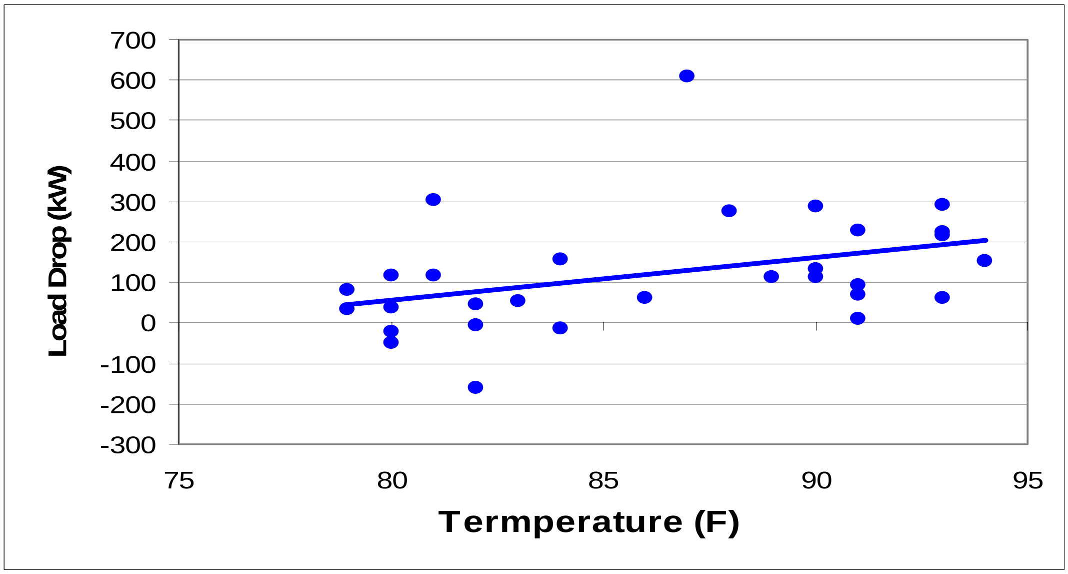

Figure 9-5. Estimated Load Drop by Temperature

Figure 9-6 shows the results of plugging various load and temperature numbers into the above model to yield load-curtailed-by-time-of-day curves for temperatures between 80 and 110 degrees. The right axis translates these results into per-unit estimates based on the 268 switches installed on the feeder for these tests.

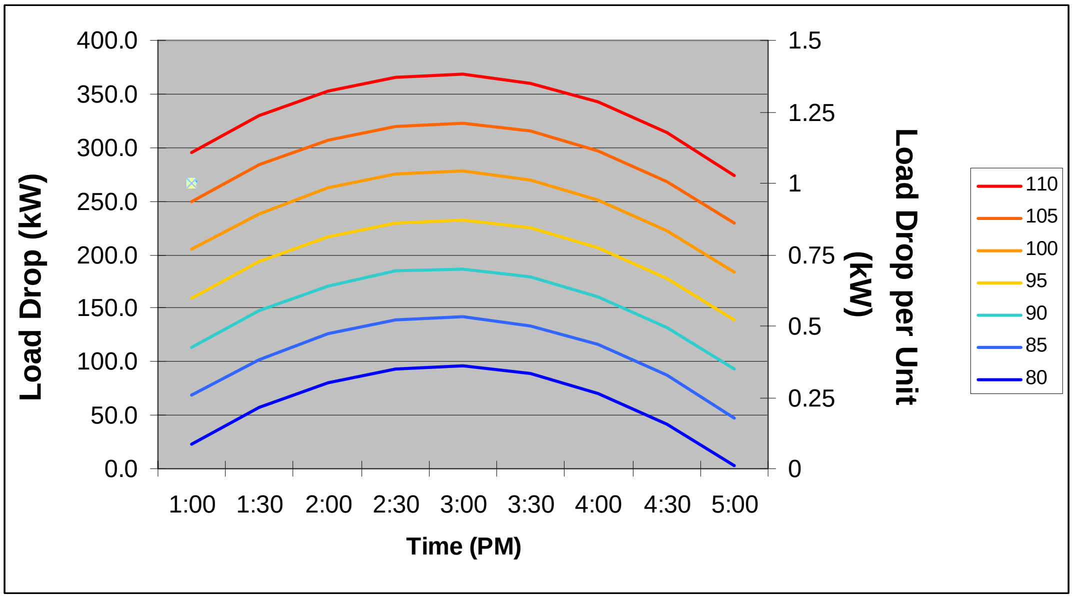

Figure 9-6 Estimated Load Drop by Time and Temperature

9.4 Load Response Faster than Thermal Generator Response; Potential to Increase Response Speed

Using the original configuration of the SCE demand-response system, there could be as much as a three-minute delay between initiation of a test event and sending of the curtailment signal to the switches installed in the demonstration.[15] This delay was caused by the signal tower's broadcast window, which occurred only once every three minutes. For the first 10 tests in 2006, this timing meant that whenever a command was given to begin a test, the system had to wait for a broadcast window to initiate the curtailment. After the third test, SCE ceased recording the time of test initiation and instead recorded the broadcast time as the test start time. Table 9-4 shows the timing of the signal relative to the logged test times. Note that all of the first tests were "4:00 p.m." tests and thus broadcast during the 4:01:06 or 4:04:06 p.m. broadcast window.

After September, SCE's new command system software allowed test curtailment signals to be sent from the tower at whatever moment the curtailment call was initiated. Table 9-5 shows the timing information for these tests. The software update effectively removed the command-structure delay in load response.

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[15] There are technically two towers to which the switches in the demonstration were set up to respond. In practice, during both the October 13, 2005 test and during the initial tests in 2006, the units only responded reliably to one of these towers.

Table 9-4. Timing Information for Tests Conducted Before System Software Update

Test	Date	Test Initiated	Signal Sent
	9/12/2006	4:06:00 PM	4:07:06 PM
1	9/13/2006	3:59:29 PM	4:01:06 PM
2	9/18/2006	3:57:10 PM	4:01:06 PM
3	9/19/2006	Not Recorded	4:04:06 PM
4	9/20/2006	Not Recorded	4:01:06 PM
5	9/21/2006	Not Recorded	4:04:06 PM
6	9/26/2006	Not Recorded	4:01:06 PM
7	9/27/2006	Not Recorded	4:04:06 PM
8	9/28/2006	Not Recorded	4:01:05 PM
9	9/29/2006	Not Recorded	4:01:06 PM

Table 9-6 is taken from the 2005 analysis of the October 13, 2005 pilot curtailment tests. It shows the timing of three air conditioners' responses to the curtailment calls when the air conditioning was set to run at full output all day. The timestamps are from four-second data loggers and mark the time that the load was first recorded as zero. All three air conditioners responded completely (i.e., their loads dropped entirely to zero) to all four tests within 15 to 19 seconds after the signal was sent.

Table 9-5. Timing Information for Tests Conducted After System Software Update

Test	Date	Test Initiated	Signal Sent
10	10/3/2006	2:29:50 PM	2:29:50 PM
11	10/3/2006	3:49:20 PM	3:49:20 PM
12	10/19/2006	12:03:10 PM	12:03:10 PM
13	10/19/2006	1:51:00 PM	1:51:00 PM
14	10/19/2006	4:00:00 PM	4:00:00 PM
	10/20/2006	1:30:01 PM	1:30:01 PM
	10/20/2006	2:30:00 PM	2:30:00 PM
	10/20/2006	3:30:00 PM	3:30:00 PM
15	10/23/2006	2:03:00 PM	2:03:00 PM
16	10/23/2006	3:00:00 PM	3:00:00 PM
17	10/23/2006	4:00:00 PM	4:00:00 PM
18	10/26/2006	12:45:00 PM	12:45:00 PM
19	10/26/2006	1:30:00 PM	1:30:00 PM
20	10/26/2006	2:15:00 PM	2:15:00 PM
21	10/26/2006	3:00:00 PM	3:00:00 PM
22	10/26/2006	3:45:00 PM	3:45:00 PM
23	10/27/2006	12:44:59 PM	12:44:59 PM
24	10/27/2006	1:33:00 PM	1:33:00 PM
	10/27/2006	2:15:00 PM	2:15:00 PM
	10/27/2006	2:59:59 PM	2:59:59 PM
	10/27/2006	3:45:00 PM	3:45:00 PM
25	11/6/2006	1:00:00 PM	1:00:00 PM
26	11/6/2006	2:01:01 PM	2:01:01 PM
27	11/6/2006	3:00:00 PM	3:00:00 PM
28	11/7/2006	1:20:59 PM	1:20:59 PM
29	11/7/2006	2:00:00 PM	2:00:00 PM
30	11/7/2006	3:00:01 PM	3:00:01 PM

Table 9-6. Timing Results from the Analysis of the October 13, 2005 Test

Test Initiated	2:00:01	2:58:30	3:59:45	4:59:29
Signal Sent	2:01:10	3:01:10	4:01:10	5:01:10
Units Responded	*All Powersight Values +/- 2 Seconds*			
Powersight 1	2:01:29	3:01:25	4:01:25	5:01:25
Powersight 3	2:01:29	3:01:25	4:01:25	5:01:25
Powersight 4	2:01:27	3:01:27	4:01:27	5:01:27
Avg Response Delay (sec)	**18.33**	**15.67**	**15.67**	**15.67**

As explained in Section 6, "enhanced" air-conditioner cycling switches were installed on six participating air conditioners. These switches have one-second current loggers on them that report results in real time to a central server. We hoped to use this real-time capability to capture the timing of the test events. The switches were installed in late October. During the October 26 and 27 tests, SCE asked the customers with those switches to turn on their air conditioners for the entire day so that we could see the timing of the load drop on those units. However, the data indicate that only one of the six air conditioners was running on the 26th and none were running on the 27th.[16]

Five curtailments were conducted on the October 26 to test the response time of the enhanced-switch-equipped air-conditioning units. For three of the tests, the air conditioner that had non-zero data (i.e., the unit that appeared to be running) turned off between three and five minutes before the test actually began. SCE has been in communication with its vendor to identify what may be causing this error, but, as of the date of this report, the cause is unknown. The remaining two tests on the unit corroborate the results seen on the meters during the preliminary tests conducted in October 2005. Figure 9-7 shows the second-by-second current of the unit beginning at the time of the signal of the 12:45:00 p.m. test. At 19 seconds, 70 percent of the unit's load has been dropped. By 21 seconds, the unit bottoms out at two amps and remains there for the duration of the test event.[17] The results from the 3:00 p.m. test are similar (not shown). These results indicate, like the October 2005 results, that this one unit responded to a curtailment call within roughly 18 to 19 seconds. At most, we can conclude only that the enhanced switches appear to take a few seconds longer than the non-enhanced switches to respond; the project team is conferring with SCE's vendor regarding why this might be.

This timing can be further corroborated by visual inspection of the system load data. For the tests with a sizeable load drop, a graph of the system load profile, as in Figure 9-8, shows that the first observation after the test is initiated (in this case four seconds after the test begins) is still at the same level as the observation before. At the next observation, 14 seconds into the test, system load has begun to drop. By 24 seconds, system load has bottomed out and continues to bounce around this lower level until the

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[16] The project team is looking into this and other data "anomalies" (e.g., some air conditioners display a non-zero current that doesn't change (out to 0.001 amps) from minute to minute) but have not, as of the date of publication of this report, fully resolved this issue.

[17] The enhanced switch logs compressor current using a current transducer. It is also set up to completely interrupt compressor current during a curtailment event. The fact that the unit drops to 2 amps instead of 0 not only contradicts the supposed design of the unit but also the 50 loggers of field data we collected during the October 2005 test. SCE's vendor has been asked about this issue but has not yet responded.

end of the test. All of the tests with visually clear load curtailments like this support the conclusion that a15- to 19-second response time is accurate. Within less than 20 seconds from the beginning of a curtailment call, the system load has responded completely.

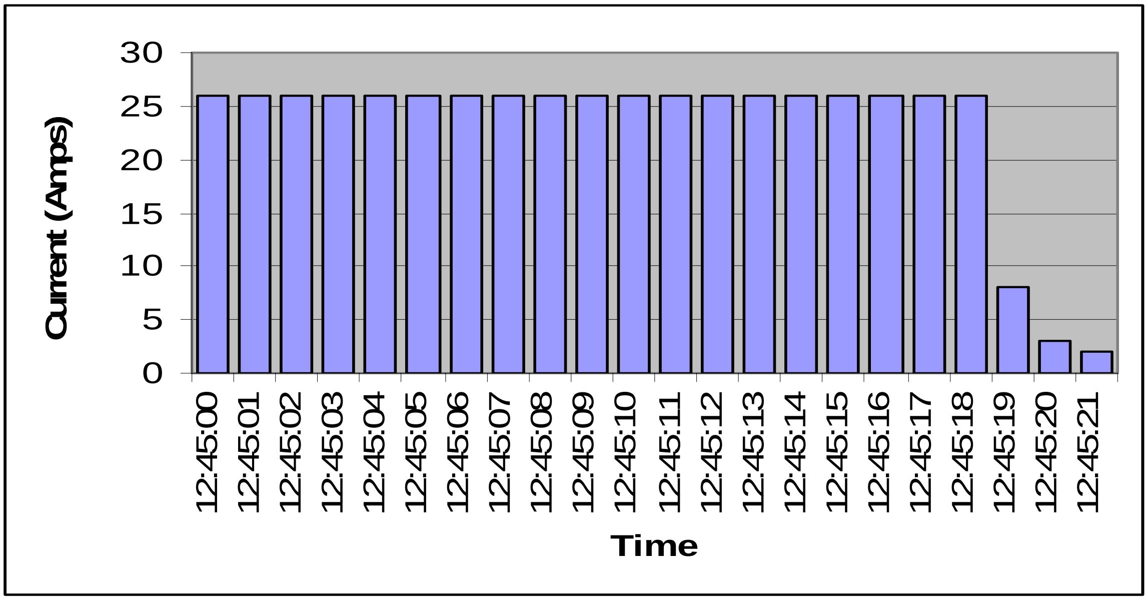

Figure 9-7. Current Draw of Enhanced-Switch-Equipped Air Conditioning During Oct 26, 2006 12:45:00 p.m. Test

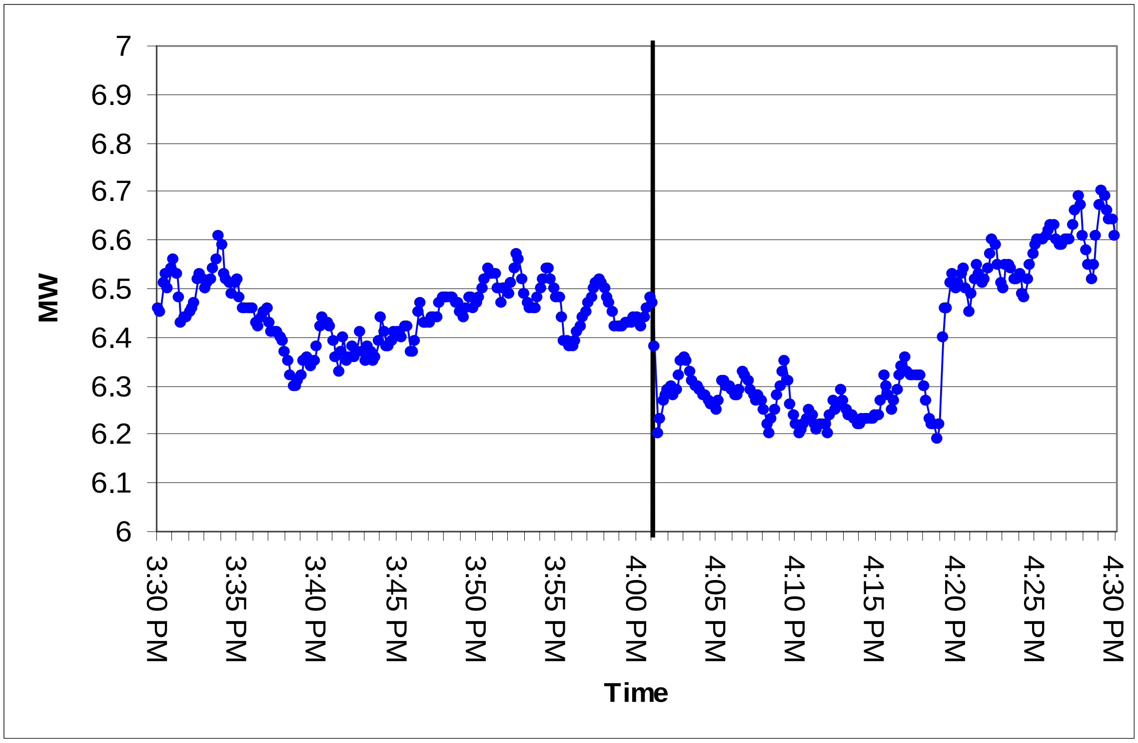

Figure 9-8. September 18, 2006 4:01:06 p.m. Test Load Profile

What happens during the 15 to19 seconds before load drops in response to a curtailment call, and what can be done to reduce this time delay further is still unknown and worthy of investigation. Referring to the steps in Figure 6-1, it is unlikely that there is any significant time spent in steps 1, 3, or 5 as these are near-instantaneous electric signals. Further, SCE's new software has effectively removed the delay between the Remote Site Controller giving the order to signal a curtailment and the communication tower being able to issue the signal. This narrows us down to two possible sources of the time lag between test initiation and system response: step 2 or step 4.

Step 2 is the step between the order to send the signal and the signal actually being sent to the switches. The communication towers' broadcast window is 15 seconds long; perhaps the switches do not respond until the 15-second transmission is complete. Or perhaps the curtailment call packet is not sent until the very end of the 15-second window. Digging further into SCE's system and its capabilities will be necessary to identify what the timing of a generalized spinning-reserve curtailment system would be like.

The delay in step 4 between the switch receiving the signal and the relay opening may also account for the delay in load response. SCE believes this delay to be two seconds, but it is possible that the mechanism of the relay or the programming of the switch result in a longer delay.

Regardless of the reasons for this timing, the findings from the past two years of testing indicate that the maximum time between curtailment call and system response is 15 to 19 seconds, and it is possible that this time could be shortened.

10. Summary of Accomplishments and Findings

The objective of this project was to demonstrate that spinning reserve can be provided using demand-side resources in a manner that is comparable to the current provision of spinning reserve using supply-side generation resources. This section of the report summarizes the most important insights from the work completed to date and relates them to issues we hope to address in future work.

Finding #1: Targeted marketing of load response programs to customers in a particular area could give system operators the option of using load responses for location-specific load shedding.

Our work to date demonstrates successful target-marketing of an air-conditioning load-cycling program (SCE's Summer Discount Plan) to customers served by a single distribution feeder. We postulate that the aggregate behavior of the controlled loads on this feeder can be directly compared to the performance of generators, which are routinely equipped with comparable telemetry. SCE's recruitment of customers for the Summer Discount Plan has traditionally been conducted via mass-marketing techniques. For this demonstration, these techniques were augmented by direct phone and door-to-door solicitations, endorsements from city officials, and marketing at community-based events. Ultimately, nearly one-third of eligible customers agreed to participate on both the Summer Discount Plan and demonstration project. This is a dramatic increase in participation from the one- to two-percent response rate that SCE typically obtains from its traditional mass marketing approach. Going forward, refinement and application of these target-marketing approaches will enable SCE to capture additional location-specific benefits from its customer demand response programs.

Finding #2: Load response can be used as spinning reserve without inconvenience to customers.

SCE curtailed the participating customers' air-conditioning units 37 times between mid-September and early November and received *no customer complaints*. These curtailments were designed to be similar in duration to CA ISO's historic deployment of spinning reserve service. "Normal" curtailments for customers participating on the Summer Discount Plan, which are triggered by CA ISO-declared stage-two emergencies or local SCE transmission emergencies, can last one to four hours, in contrast to the typically brief windows (10 minutes or less) during which spinning reserve is employed. After each normal Summer Discount Program curtailment event, SCE typically receives hundreds of requests by residential customers seeking to withdraw from the program. Using aggregated loads, such as customers' air-conditioning units, to provide spinning reserve would not only increase the contingency reserves available to the CA ISO and reduce the likelihood of stage-two emergencies (and the need for long curtailments), but would also likely be more popular with customers than the Summer Discount Program approach to reducing load.

Finding #3: Open data platforms can be used effectively to display real-time information.

The project team demonstrated a highly flexible and open data integration, archival, and presentation platform that, among other things, provides real-time visibility of loads on the distribution feeder to external audiences through a secure website. The standard real-time communication channel between CA ISO and generators and load-serving entities is, by contrast, very inflexible, dedicated, and based on proprietary protocols. Going forward, reliance on flexible, open platforms, such as the one demonstrated in this project, will lower the costs associated with providing real-time visibility of aggregated loads to system operators or others with a need to verify the performance of these programs in real time.

Finding #4: Analysis methods developed for this project could one day be used to predict the magnitude of load curtailments as a function of weather and time of day.

The project team developed statistical methods to detect and determine the magnitude of the aggregated load curtailment solely through after-the-fact review of distribution feeder loads. We used distribution feeder data recorded before, during, and after each curtailment to characterize the magnitude and predictability of the load response. We also conducted exploratory analyses that confirmed a relationship between the magnitude of the load curtailment, ambient weather conditions, and, to a lesser but still suggestive extent, time of day. Ultimately, we believe it will be feasible to predict the magnitude of a load curtailment as a function of time of day and expected weather conditions. Additional curtailments under a wider range of weather conditions along with more information on the behavior of individual units will be required for this analysis.

Finding #5: Load response can be achieved in less than 20 seconds, i.e., more rapidly than the 10 minutes allowed for the spinning reserve response of generators.

The project team determined that load curtailments could be fully implemented in less than 20 seconds. This response is an order of magnitude faster than the spinning reserve response provided by thermal generators, which are allowed up to 10 minutes for full response. Moreover, the data collected on the latencies associated with each step in the curtailment process suggest that it is technically feasible to reduce these latencies and achieve full response nearly instantaneously. A separate PIER project is examining the potential additional value to CA ISO of spinning reserve responses.

Providing spinning reserve with aggregated demand-side resources such as those studied in this project is a powerful, new tool to help to prevent rolling blackouts and improve system reliability. The research conducted to date is a first step toward the realization of this goal.

WECC reliability rules do not currently allow responsive loads to supply spinning reserve. However, they have been considering such a change for a number of years; but they are (correctly) being deliberate. The *November 2005 Frequency Response Standard Reserve Issues Task Force White Paper* states:

> A number of pilot programs have been proposed to demonstrate load management technologies that would enable load to be responsive to frequency on par with generation. At such time when these technologies are satisfactorily demonstrated, the prohibition on load as spinning reserve may be rescinded.

The Demand Response Spinning Reserve Demonstration project is one such test, and it clearly indicates the feasibility and advantages of using air-conditioning loads to provide spinning reserve. When complete, we expect that the Energy Commission and CA ISO will present the results of this demonstration project to WECC in partial support for changing the reliability rules, as has been successfully done elsewhere. As previously mentioned, ERCOT now obtains half of its spinning reserve from responsive load, and loads are ready to supply considerably more of ERCOT's spinning reserve needs. PJM has also changed its reliability rules to allow loads to supply spinning reserve.

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Appendix A.
Technical Evaluation of Advanced Communication and Control System

Introduction

This appendix provides a technical evaluation of the Advanced Communication and Control Project (ACCP) system used in this project. While the main body describes the functionality and effectiveness of this system in the project, this appendix focuses on technical attributes of the system that would become important if the system were scaled up for use in future projects.

Executive Summary

Connected Energy Inc. provided a central server (COMSYS), gateway devices (CENTRYwcc) and other components to create an end-to-end demand response system. Upon initiation by the utility, Southern California Edison, the system caused air-conditioning units in residences within the demonstration feeder to temperately turn off, thereby reducing electric load on this feeder. In addition to shed control functionality, extensive data logging capabilities were incorporated into the system.

Though the project was for research purposes, the Connected Energy system was built to the high standards typically used in commercial production systems. With minimal modifications, the system could be ready for larger scale pilots and deployments. The system is designed to be flexible, open, secure and scalable. Specifically, the system has the following features:

- Communication protocol embraces object modeling.
- Open. Application programmer’s interface to the two logical system interface points (CENTRYwcc and COMSYS) is published.
- Abstracts detailed data structures from a variety of protocols (MODBUS etc.).
- EnerTALK communication protocol is open and public
- CENTRYwcc devices are enabled to be managed using (standard) Simple Network Management Protocol (SNMP).
- Advanced security measures are built into the ACCP system. Software virtual private networks (VPN) are established between CENTRYwcc devices and the COMSYS. The VPN tunnel uses secure shell (SSH) encryption. Public key infrastructure (PKI) technology is used to authenticate CENTRYwcc devices. Access to the user interface via the COMSYS is password protected.
- The ACCP system uses Network Time Protocol (NTP) for time synchronization.

Evaluation Method

The framework through which the ACCP system was evaluated in this report was developed by the IntelliGrid Consortium. The IntelliGrid Consortium was created to help the energy industry pave the way to the power grid of the future. The consortium includes utilities, manufacturers and public sector partners. Their vision is “A new electric power delivery infrastructure that integrates advances in communications, computing and electronics to meet the energy needs of the future”18.

The authors of this report believe that the IntelliGrid Conformance Specification provides a relevant framework for evaluating complex demand response control and monitoring systems such as described in this report. However, it should be noted that the concepts described in this framework are a subset of IntelliGrid work and are somewhat generic. These concepts are generally accepted by other profession organizations as well.

The following attributes have been identified as important by the IntelliGrid Consortium:

- Support object modeling,
- Employ self description,
- Support the concepts of common services and generic interfaces,
- Based on open, published standards,
- Well defined interfaces and points of interoperability,
- Facilitate device and network management,
- Permit the implementation of adequate security policy, and
- Implements time synchronization.

Within this framework, the ACCP will be evaluated. In this project, the ACCP system was created by Connected Energy Inc. using their COMSYS back office system and CENTRYwcc gateway products.

System Design Attributes

The building blocks (hardware, firmware, software, middleware) of a well-designed and implemented system have the following attributes. The inclusion of these attributes (or lack thereof) are described with regard to the Advanced Communication and Control Project (ACCP) system used in this research project.

Object Modeling

The object modeling requirement means that the data attributes and methods of a device can be described by an abstract model of that device. A compliant device will be accompanied by documentation of its capabilities using such an object model. The communications protocol(s) used by that device should also use an object oriented model approach that preferably directly implements the object model.

The communication protocol used in the ACCP, Connected Energy enerTALK embraces object modeling. The enerTALK system supports IEEE 1547.3 data object models. In addition, enerTALK is capable of supporting the relevant sub-set of another object modeling standard, IEC 61850. These objects are supported by wrapping them within enerTALK messages.

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[18] IntelliGrid Website: http://www.epri-intelligrid.com/intelligrid/about/vision_mission.html 2/27/06

Self Description

This requirement refers to the ability for an external client to interrogate the device and discern its object model (e.g. the attributes the device supports, their types, and other information about the underlying object model). This capability is also referred to as meta-data.

The CENTRYwcc gateway devices currently ship with a pre assigned authentication key. Upon interrogation by the Authentication server, the CENTRYwcc devices identify themselves and send applicable self-description information back to the COMSYS.

Common Services and Generic Interfaces

This requirement refers to the device supporting an abstract definition of its underlying functionality and interfaces in such a way as to facilitate separating technology specific implementation of the devices capabilities from its internal logical construction from an application point of view. For example, this design methodology is supported by standards such as IEC 61850 (via the Abstract Communication Service Interface – ACSI), IEC 61968 (via the Common Information Model) and IEC 61970 (via Generic Interface Definition – GID).

One of the key functions of the ACCP system is to abstract detailed data structures from a variety of protocols (MODBUS etc.) and communicate back to the back office system, using a common schema and protocol (enerTALK). The application programmer's interface to the two logical system interface points (CENTRYwcc and COMSYS) is published. Common services such as "shed peak load" are available within the enerTALK protocol.

Open, Published Standards

This requirement is generally self explanatory. A compliant device or system will utilize methods and technologies published by recognized standards organizations such as the IEEE, IEC, ANSI, ASHRAE, ISO, IETF, W3C, and others.

EnerTALK is open and public and conforms to W3C standards for XML. It has unique features functions and capabilities that are not available in any other open standard. However, enerTALK is designed to be flexible so as to be compatible with devices that use well-established standards such as IEC 61850.

Well Defined Interfaces and Points of Interoperability

Even if a devices implements its basic interface using a standards based approach, interoperability is not achieved unless there are well defined points within the overall system where interoperability is expected to be achieved. These points should be well documented, and the specific standards used to implement the interfaces at these points of interoperability must be defined.

The application programmer's interface to the two logical system interface points to the ACCP system (CENTRYwcc and COMSYS) is published. If the COMSYS were removed from the system, another back office system could be created to interface with the CENTRYwcc field devices. If the CENTRYwcc were replaced with a different gateway, the COMSYS could interface to the new devices. Examples of both of these scenarios have been implemented in other projects.

Facilitate Device and Network Management

A compliant device or system will take into account the need for external systems to manage that device or system by exposing standard methods of management such as the Simple Network Management Protocol.

CENTRYwcc devices are enabled to be managed using Simple Network Management Protocol.

Permit the Implementation of Adequate Security Policy

A compliant device will support security features necessary to implement corporate security policy appropriate for the environment in which the device of system is to be implemented. This includes the mechanisms necessary to implement authentication, authorization, auditing, confidentiality, integrity, and availability.

Advanced security measures are built into the ACCP system. Software virtual private networks are established between CENTRYwcc devices and the COMSYS. The VPN tunnel uses secure shell encryption. Public key infrastructure technology is used to authenticate CENTRYwcc devices. Access to the user interface via the COMSYS is password protected. Multiple password levels are provided (e.g., monitoring only, setpoint adjust access etc.). For highly sensitive data, the system can also use a hardware USB security key for user access.

Implements Time Synchronization

Time synchronization has been identified as a key attribute for proper operation of utility field devices and systems and is especially important for auditing to facilitate after the fact analysis of anomalous events. A compliant device or system will be synchronized to Universal Coordinated Time using one of several available methods (e.g. NTP, SNTP, GPS, IRIG-B, etc.) with a resolution and uncertainty appropriate for the application and compliant with relevant security policy.

The ACCP system uses Network Time Protocol for time synchronization.