Arnold Schwarzenegger
Governor

MAINTAIN, ENHANCE AND IMPROVE RELIABILITY OF CALIFORNIA'S ELECTRIC SYSTEM UNDER RESTRUCTURING

APPENDIX - XVII

CERTS Demand Response Project Plan for Summer 2005 Demand Response Test in Southern California Distribution Circuit

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:

Lawrence Berkeley National Laboratory

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

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California Independent System Operator

and

California Energy Commission
Public Interest Energy Research Program

CERTS Demand Response Project

Plan For
Summer 2005 Demand Response Test
on Southern California Edison Distribution Circuit

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1. Executive Summary

This report describes a plan for a precise, statistically significant test of demand response for a representative SCE distribution circuit. In the test, residential and commercial air conditioning will be curtailed using a dispatch signal from a central control location. The test has two basic goals:

1. 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.
2. 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.

The distribution circuit power level will be sampled via SCADA every 16 seconds. A group of local data loggers will also be installed during the test to increase the statistical precision of the data analysis. The rigorous, statistical approach taken for the design of this test is discussed in Section 3. For the purposes of this plan, the selected circuit will be called the Zin circuit. The Zin circuit has roughly 2350 residential accounts and 169 commercial accounts. Based on seasonal load profiles, there is approximately 850 kW of air conditioning load on this circuit.

SCE plans to implement a special contract for the test with 400 to 500 residential customers and 50 to 100 commercial customers. Residential customers will be curtailed with a local switch, commercial customers will be curtailed with a thermostat that will be programmed to actually curtail, not to just set back the temperature.

The curtailment durations will be set to twenty minutes. Twenty minutes is ample time to verify the exact amount of load that has been shed. Installed metering will also show how quickly it was shed. There will be 60 tests over July, August and September at random times between the hours of 2 pm and 6 pm. This large number of curtailments (60) is needed to obtain statistical accuracy.[1]

The circuit has a peak load of 9 MW. In the tests, we expect to curtail about one MW depending on time of day, temperature, and day of week. A rigorous statistical analysis has been performed in planning the number of customers under test, the number of tests, and the data acquisition system to ensure the results provide a relative precision of perhaps 15% at the 90% level of confidence. We expect the test to provide a benchmark for repeatable, precise, rapid demand response used as a reliability service.

[1] In the actual provision of reliability services, the curtailment durations would be longer. Longer curtailment intervals could be provided by simply dispatching a longer curtailment since the load management methods being tested provide direct control of the load. A longer curtailment duration would make it difficult to contract for this large number of tests because customers would be concerned about multiple air conditioning outages.

2. Test Plan

Objectives

- Demonstrate that demand response can provide the ancillary service of spinning reserve for system contingencies in a manner that will be adopted by system operators. This includes:
    - Building confidence among CAISO operators regarding the value of demand response as an alternative to traditional approaches for providing spinning reserve.
    - Setting the basis for modifying reliability rules to allow utilization of demand response for spinning reserve.
- Demonstrate and benchmark the reliability of large numbers of small responsive loads; compare this to the current responsiveness of generation.
- Demonstrate ability to target demand response to geographic sub-regions.
- Demonstrate to demand response providers and the CAISO that demand response can provide spinning reserve economically through modest enhancements to existing centralized systems. This includes both legacy load management systems that already control groups of end-use loads as well as newer systems developed for more recent demand response programs.
- Demonstrate to IOU distribution system planners the ability of demand response to influence the timing of distribution system upgrades.

Narrative

The initial plan is to equip a Southern California Edison distribution circuit with two types of demand response - controllable thermostats and contactors on air conditioning compressors.

The data collected by the project must have sufficient accuracy for statistical analysis. An important issue will be to synchronize the time stamping of the spot meter data; spot meters need not be monitored in real time. The time error (e.g. 5 seconds or less) and ranges of the data acquisition rate must be identified. We will determine the elapsed time durations starting when CAISO activates a call sign, to the duration for the call signal to reach the load, and how long it takes for the load to respond. The project must provide visual indication of the load response to the CAISO. Continuous monitoring of the shedding will be provided. The statistical analysis of the distribution circuit is discussed under Section 3. Statistical Plan. The data acquisition system is discussed below under Section 4. Data Acquisition.

SCE's existing substation SCADA system is expected to provide test feeder data with 16 seconds scan rate. Initially the SCADA data is recorded in 2-minute snapshots by SCE's eDNA Historian. Connected Energy will provision another eDNA server for the project. SCE will "push" preconfigured feeder data to this project eDNA server at Connected

Energy when new data is available. Connected Energy will further aggregate the feeder's data with recorded time-stamped dispatch events from Thermostat and AC cycling dispatch systems, real time weather data and spot meter data to provide a comprehensive monitoring and centralized data repository system for the project. The monitoring system delivers real-time displays, trend displays and tabulated reports for verification and analysis.

Connected Energy will time synchronize with the US Naval Observatory Master Atomic Clock reference. Static time errors between the SCADA system, eDNA Historian, AC Cycling Dispatch System, Thermostat Dispatch System, Thermostat time and the Spot Meters will be identified and compensated by Connected Energy. Error due to drifts will be periodically checked and compensated. Connected Energy will also recommend suitable electronic meters for use as project's verification spot meters. Connected Energy will also recommend options for installing the spot meters and retrieving spot meter data.

Test Plan Steps

1. Contract with residential and commercial customers and modify SCE Load Management and Demand Response systems to control air conditioning loads within the circuit.
2. Install sufficient numbers of two types of load control devices on this feeder to ensure interruptions can be observed statistically at the feeder. At time of device installation, record the size of the air conditioning compressor.
3. Install spot meters on a designated sample of the controlled units.
4. Assemble the data acquisition and communications system as described in Section 4.
5. Conduct a series of 20 minute duration demand response tests during July, August and September, 60 tests total.
6. Retrieve the spot meters and their data.
7. Corroborate load changes observed at the feeder with spot metering placed on a sample of controlled loads within the feeder; express findings statistically.
8. Measure load drop and response times, including latency in observability; express findings statistically.
9. Characterize load drops as function of relevant influences (temperature, time of day, day of week) with an eye toward extrapolation of findings to other feeders that having differing saturations of controllable end-use loads; express findings statistically to determine response confidence level.
10. Present and discuss results with stakeholders (IOU distribution system planners, IOU dispatchers, CAISO operators, relevant WECC/NERC committees) to confirm adequacy of present analysis and priorities for future research in this area.

3. Statistical Approach for Test Development, Prepared by R.L. Wright

The following is a concise list of some of the key assumptions and findings discussed in this report. The primary study goal is to demonstrate the value and practicality of AC curtailment for spinning reserve and feeder load relief. The plan will focus on 100% AC curtailment for 20 minutes, using either smart thermostats or residential switches. We are especially interested in the load response during the first 10 minutes of the curtailment.

We will focus on curtailments during periods of high AC load and high value of spinning reserve, between 2 pm and 6 pm weekdays. We will make as many 20-minute calls as necessary and practical, probably one per day for every weekday during July – September, e.g., about 60 calls.

We will pre-schedule the calls at specified times from day to day so that both systems can make simultaneous calls. We need to schedule the calls carefully so that we can create a baseline load for each curtailment day undistorted by prior curtailments.

A major concern is the lag of the load response following the curtailment call, especially within the first five or ten minutes after the call. The two separate dispatch systems are expected to have different lags in getting the signal out to the end users. There may be some added delay between the time that the thermostats and switches receive the curtailment call and actually cut off the AC units.

The biggest factor of the statistical error associated with the SCADA data appears to be our ability to predict the baseline – the circuit load in the absence of curtailment. Using a simple 10-day average with true up and weather correction, we were able to predict the circuit load within about ±2% during most of the hours of interest. By smoothing out the random variability using the 10-minute rolling average as the measure of true load and taking advantage of the load of two adjoining feeders as well as the 15-minute weather data from Edison's Foothills weather station, we have generally been able to predict the circuit load within about ±1% during the most of hours of interest. We believe the base period can be reduced to three days so that we can avoid contaminating the baseline with prior curtailments.

We need to control enough air conditioners on the circuit so that the impact shows up significantly in the total load of the circuit. If we control about 100 commercial thermostats and 425 residential switches, we can expect to be able to estimate the impact within ±18% statistical precision at the 90% level of confidence.

Given available billing data for the accounts on the circuit, we may need to recruit about 80% of the commercial sites and about 50% of the residential sites with AC load. This will require aggressive marketing.

It is important to develop a load response model for predicting the expected kW load reduction as a function of day of the week, time of day and the weather on the control

day. Even with daily curtailments, the SCADA data will provide limited information about the full response function.

However since the units are 100% curtailed, the load reduction should be equal to the actual load of the controlled units, with any necessary adjustment for signal reception and take back from other AC units serving the same space. The actual aggregate load of the controlled AC units should be monitored using data loggers to record the amperage consumption of each of a sample of units on a five-minute basis. With a sample of 50 loggers we can expect about ±18% statistical precision at the 90% level of confidence. With 75 loggers this improves to ±15% precision. 150 loggers would be needed for ±10% precision.

By integrating the SCADA information from the curtailments and the logger data from all of the non-curtailment periods, we should be able to develop a reliable load response model. The loggers can also provide important information about signal reception and may provide some information about timing of response.

We recommend that a sample of 50 to 150 controlled units be monitored using battery powered loggers that can record and store amperage measurements for at least 110 days for 5-minute intervals throughout the summer. The loggers should be time synchronized at installation. We need to make sure that the drift of the timestamp in the loggers is negligible over the summer. The personnel installing the loggers should also verify that all AC units serving the site are controlled and verify other important information including the tonnage of the controlled units and the Carrier pin numbers of the smart thermostats.

Issues

In planning this study, we face a number of statistical issues:

- Is the selected circuit subject to frequent, unpredictable realignment of loads or other re-engineering activities?

- What is the topology of the circuit? Do we need to do sub-metering or take advantage of existing whole-premise load metering to isolate large loads that may be hard to predict?

- Can we characterize the customers served by the circuit to be used in the test using suitable billing data for each site? Are there enough suitable customers?

- What is the relationship between the number of controlled AC units and the expected statistical precision of the results? How many customers do we need to control to provide statistically reliable results?

- What about assessing the impact by time of day and by temperature? How many data loggers do we need?

- How do we estimate the baseline load of the circuit in the absence of control? Do we need to measure load more frequently than every two minutes? Can we gain statistical precision using the load of one or two other similar circuits?

Orientation

The test circuit has been given the fictitious name Zin. The circuit is in the Fontana area, east of Ontario. This is an area of relatively new building stock. See Figure 1.

Figure 1: Fontana area

Accounts on the Circuit

Figure 2 summarizes the accounts known to be on the circuit, by rate schedule and status code (1 = active, 4 = closed). We have 1,958 active residential accounts and 151 active commercial accounts, together with a relatively small number of inactive accounts.[2]

[2] Due to lag in data entry, some new accounts may have been omitted.

Count of Customer	Status Code		
Rate Schedule	1	4	Grand Total
D-APS	24		24
D-APS-E	19	1	20
D-CARE	474	90	564
D-CARE-APS	2	1	3
D-CARE-APS-E	4		4
DE	7	1	8
DE-APS-E	3		3
D-FERA	7		7
DMS-2	2		2
DOMESTIC	1,415	299	1,714
D-S	1		1
GS-1	85	14	99
GS-2	29	4	33
GS-2/GS1	19		19
GS2T	4		4
TC-1	7		7
TOU-GS-1	3		3
TOU-GS2-B	1		1
TOU-GS2-SP	2		2
TOU-PA-SOP-2	1		1
Grand Total	2,109	410	2,519
Residential	1,958	392	2,350
Commercial	151	18	169

Figure 2: Accounts on Circuit

Of course, many of these accounts may be poor candidates for AC load management because they don't have air conditioning or don't use it regularly. The monthly AC kWh consumption of each account can be crudely estimated by comparing the total billed consumption in summer versus winter months. Using this approach, we have identified the active accounts with estimated monthly AC use greater than various thresholds. How many kWh per month might a typical home use for AC? If we assume that a typical residential AC unit is three tons and has a demand of 3 kW and that the unit has a daily full load run time of about 3 hours, then this home would use 250 to 300 kWh per month more electricity in the summer than the winter. So this might be a minimal threshold for our purposes.

Figure 3 shows the results. The first column of Figure 3 shows the results for a threshold of 250 kWh per month. For these results we considered all accounts for which the average monthly summer use was at least 250 kWh greater than the average monthly winter use as indicated by the billing data. We found 60 such commercial accounts[3] and 857 such residential accounts.

[3] Typically a commercial account will have two AC units so it seems reasonable to expect about 120 controlled commercial AC units.

Count of Customer Name	Minimum AC kWh per Month						Total
Rate Schedule	250	300	350	400	450	500	Current
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

Figure 3: Number of Candidate Accounts

Considering the various thresholds, about 50 to 60 of the commercial accounts appear to be good candidates for AC load control. Depending on the selected threshold, anywhere from 300 to 850 of the residential accounts seem to be good candidates.

Circuit Load

SCE has provided SCADA load data for the Zin circuit for the four months of August through September, 2004. The file provided by SCE contained the voltage of the circuit (V), measured in kilovolts, the current of the three phases (l_a, l_b, l_c), measured in amps, and the total mega VARS reactive power ($MVAR$). The data was based on instantaneous measurements taken every two minutes. Each of the five values was actually recorded, along with the date and time of the measurement, only if the value changed from the value observed two minutes earlier.

To prepare an analysis database, we started by filling in the omitted values for each of the five fields. Then we calculated the MWatts real power using the equations

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

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

Figure 4 gives an overview of the load of the Zin circuit during the four months of June through September, 2004.[4] The load pattern indicates that this circuit was not affected by realignment of the accounts on the circuit.

Figure 5 shows the magnitude and time of the peak load in each week of the period. The overall peak was 9.38 MWatts at 3:58 PM on Tuesday, August 10. Most of the peak loads occurred in the afternoon on weekdays.

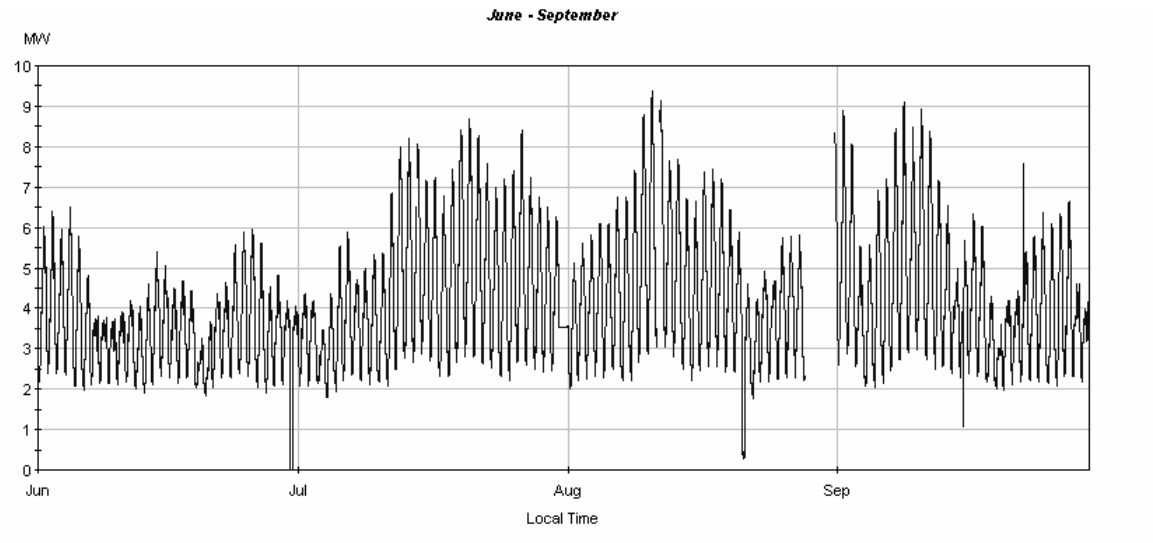


Figure 4: Overview of the Zin Load

Week Of	Peak	Peak At
6/6/2004	4.79	Sun Jun 6, 2004 5:48PM
6/13/2004	5.39	Mon Jun 14, 2004 4:38PM
6/20/2004	5.96	Fri Jun 25, 2004 5:26PM
6/27/2004	4.81	Mon Jun 28, 2004 3:52PM
7/4/2004	5.88	Tue Jul 6, 2004 3:08PM
7/11/2004	8.19	Tue Jul 13, 2004 5:14PM
7/18/2004	8.67	Tue Jul 20, 2004 4:24PM
7/25/2004	8.42	Mon Jul 26, 2004 4:26PM
8/1/2004	6.76	Fri Aug 6, 2004 5:12PM
8/8/2004	**9.38**	**Tue Aug 10, 2004 3:58PM**
8/15/2004	7.44	Tue Aug 17, 2004 5:10PM
8/22/2004	5.82	Fri Aug 27, 2004 4:18PM
8/29/2004	8.89	Wed Sep 1, 2004 4:52PM
9/5/2004	9.11	Wed Sep 8, 2004 3:48PM
9/12/2004	7.16	Sun Sep 12, 2004 3:42PM
9/19/2004	7.59	Wed Sep 22, 2004 10:44AM
9/26/2004	6.64	Mon Sep 27, 2004 4:24PM

Figure 5: Magnitude and Time of Weekly Peaks

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

Figure 6 shows the load profile for the peak week. Note the data gap on Wednesday August 11 and the truncated load on Saturday, August 14. The data will eventually have to be cleaned up, but we haven't taken the time to do this yet. At this point we believe the problems are rare enough not to substantially affect our analysis.

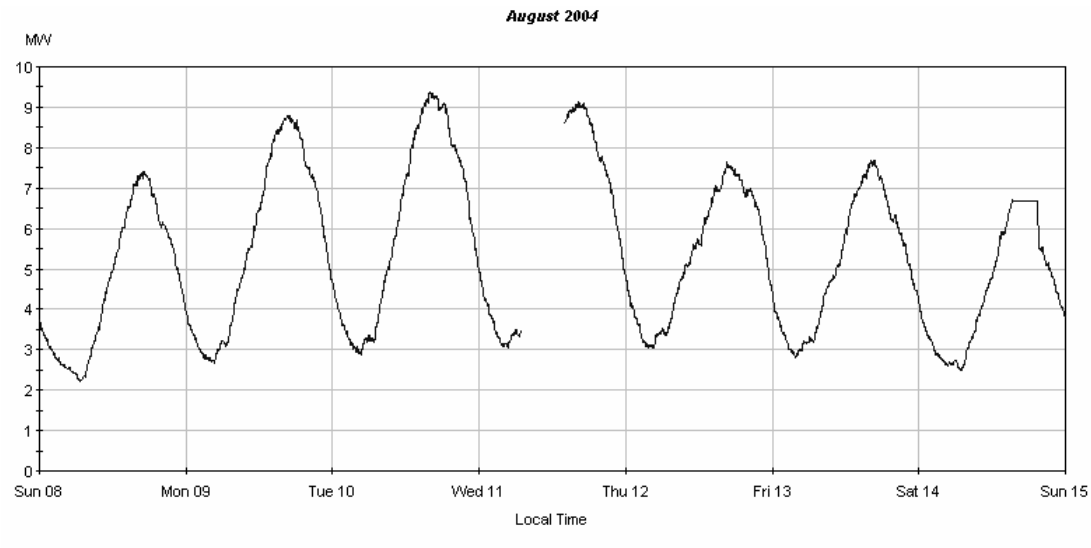


Figure 6: Zin Load from August 8 through August 14

Figure 7 shows the MWatt load of the Zin circuit on the peak day of August 10. This shows that the load was quite high from 3 pm to almost 6 pm. So a three hour curtailment may be required to significantly reduce the peak load on this particular day.

Figure 7 also shows that the load is relative smooth. Remember that the underlying data are instantaneous measurements taken every two minutes. The graph clearly shows random variability from observation to observation, but the amount of the variability is very small –about ±1% of the load.[5] G*iven the small amount of variation from one two-minute period to the next, it appears that there would be little value in collected these data more frequently than every two minutes.*

[5] To quantify this we calculated the standard deviation of the 2-minute measurements around the 10-minute rolling average. The standard deviation was 0.043 MW or just over 1% of the average load of 4.1 MW.

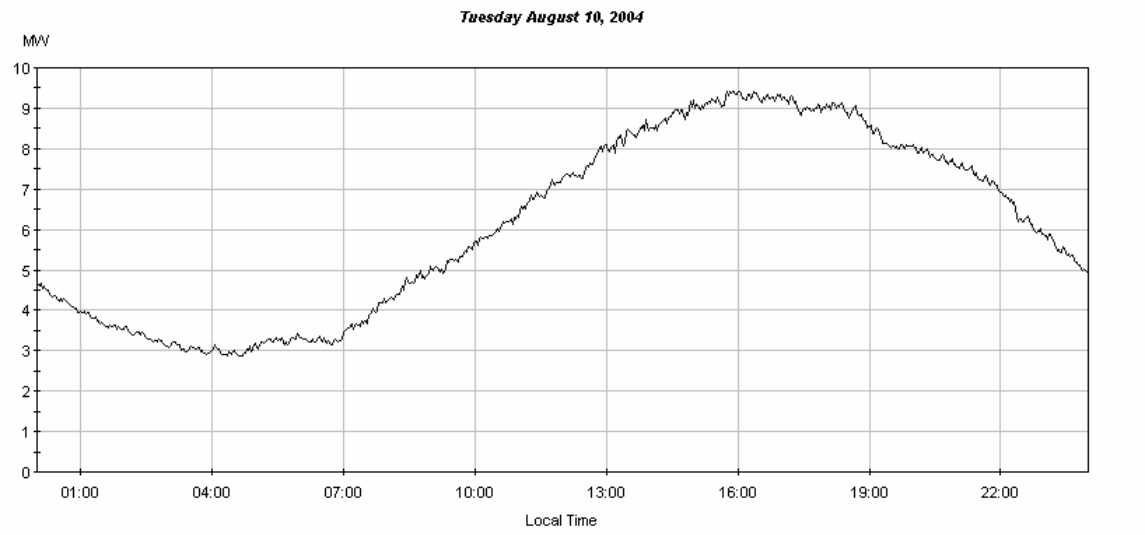


Figure 7: Zin Load on the peak day of August 10

Temperature

In this section we will take a brief look at how the exterior temperature might have affected the Zin load. We have used the 15-minute dry bulb temperature and humidity data from Edison's Foothills weather station. We used interpolation to convert the 15-minute measurements into 2-minute measurements to integrate these data with the load data. We used dry bulb temperature and humidity to calculate the enthalpy during each period. For this discussion we will focus on the dry bulb temperature, but we also used the enthalpy in the statistical model.

Figure 8 shows the recorded temperature during these four months.

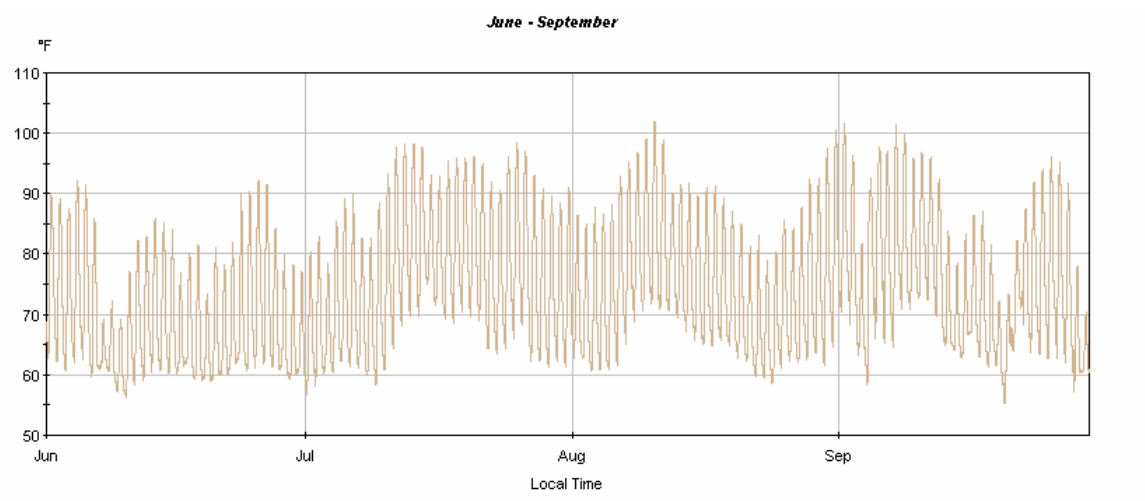


Figure 8: Recorded Temperature at the Mira Loma Substation

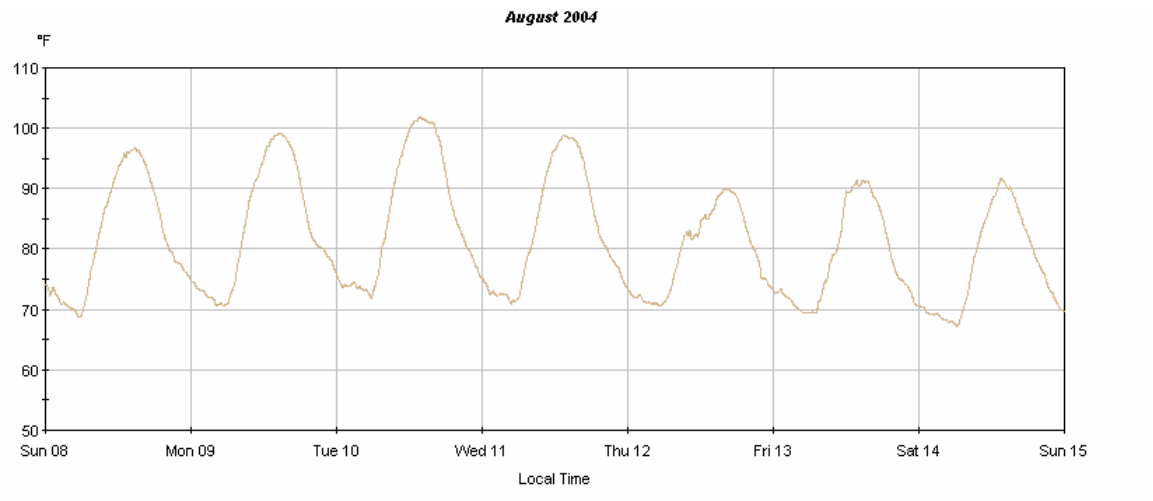


Figure 9: Recorded Temperature from August 8 through August 14

Figure 9 shows the temperature in the week of the peak load. During this week, the temperature generally reached a peak in the mid afternoon as might be expected. The beginning of the week was much hotter than the end of the week.

Figure 10 shows the weekly maximum temperatures as well as the time of the peak. The hottest recorded temperature of the summer was on Tuesday, August 10 with a recorded high of 102 F. This was also the day of the peak demand.

Week Of	Peak	Peak At
6/6/2004	85.97	Sun Jun 6, 2004 1:46PM
6/13/2004	85.90	Sun Jun 13, 2004 2:32PM
6/20/2004	92.09	Fri Jun 25, 2004 2:46PM
6/27/2004	84.20	Sun Jun 27, 2004 1:32PM
7/4/2004	93.27	Sat Jul 10, 2004 2:18PM
7/11/2004	98.30	Mon Jul 12, 2004 1:02PM
7/18/2004	96.20	Tue Jul 20, 2004 2:32PM
7/25/2004	98.39	Sun Jul 25, 2004 2:16PM
8/1/2004	95.09	Sat Aug 7, 2004 1:46PM
8/8/2004	**101.89**	**Tue Aug 10, 2004 1:46PM**
8/15/2004	91.27	Tue Aug 17, 2004 2:16PM
8/22/2004	92.38	Sat Aug 28, 2004 1:18PM
8/29/2004	101.60	Wed Sep 1, 2004 2:32PM
9/5/2004	101.40	Tue Sep 7, 2004 2:02PM
9/12/2004	92.40	Sun Sep 12, 2004 1:32PM
9/19/2004	96.20	Sat Sep 25, 2004 1:32PM
9/26/2004	95.20	Sun Sep 26, 2004 1:32PM

Figure 10: Weekly Maximum Temperatures

Figure 11 combines the information from Figure 10 and Figure 5, showing both the peak temperatures and the peak loads in each week. The table shows that in many weeks the peak temperature and load occurred on the same day. Otherwise, the peak load was often within one day of the peak temperature.

Week Of	Peak Temp	Peak At	Peak Load	Peak At
6/6/2004	85.97	Sun Jun 6, 2004 1:46PM	4.87	Sun Jun 6, 2004 6:10PM
6/13/2004	85.90	Sun Jun 13, 2004 2:32PM	5.44	Mon Jun 14, 2004 4:36PM
6/20/2004	92.09	Fri Jun 25, 2004 2:46PM	6.09	Fri Jun 25, 2004 5:24PM
6/27/2004	84.20	Sun Jun 27, 2004 1:32PM	4.86	Mon Jun 28, 2004 2:56PM
7/4/2004	93.27	Sat Jul 10, 2004 2:18PM	5.95	Tue Jul 6, 2004 3:08PM
7/11/2004	98.30	Mon Jul 12, 2004 1:02PM	8.24	Tue Jul 13, 2004 4:38PM
7/18/2004	96.20	Tue Jul 20, 2004 2:32PM	8.79	Tue Jul 20, 2004 4:18PM
7/25/2004	98.39	Sun Jul 25, 2004 2:16PM	8.48	Mon Jul 26, 2004 4:20PM
8/1/2004	95.09	Sat Aug 7, 2004 1:46PM	6.81	Fri Aug 6, 2004 5:08PM
8/8/2004	**101.89**	**Tue Aug 10, 2004 1:46PM**	**9.42**	**Tue Aug 10, 2004 3:58PM**
8/15/2004	91.27	Tue Aug 17, 2004 2:16PM	7.49	Tue Aug 17, 2004 5:10PM
8/22/2004	92.38	Sat Aug 28, 2004 1:18PM	5.88	Fri Aug 27, 2004 4:14PM
8/29/2004	101.60	Wed Sep 1, 2004 2:32PM	8.99	Wed Sep 1, 2004 4:10PM
9/5/2004	101.40	Tue Sep 7, 2004 2:02PM	9.16	Wed Sep 8, 2004 3:48PM
9/12/2004	92.40	Sun Sep 12, 2004 1:32PM	7.27	Sun Sep 12, 2004 3:36PM
9/19/2004	96.20	Sat Sep 25, 2004 1:32PM	7.71	Wed Sep 22, 2004 10:38AM
9/26/2004	95.20	Sun Sep 26, 2004 1:32PM	6.70	Mon Sep 27, 2004 4:44PM

Figure 11: Peak Temperatures vs. Peak Loads

Figure 12 shows both temperature and load for the entire period. These results also indicate that there is a rather strong association between temperature and load. All of these results indicate that the Zin feeder has substantial air conditioning load and is a good candidate for this study.

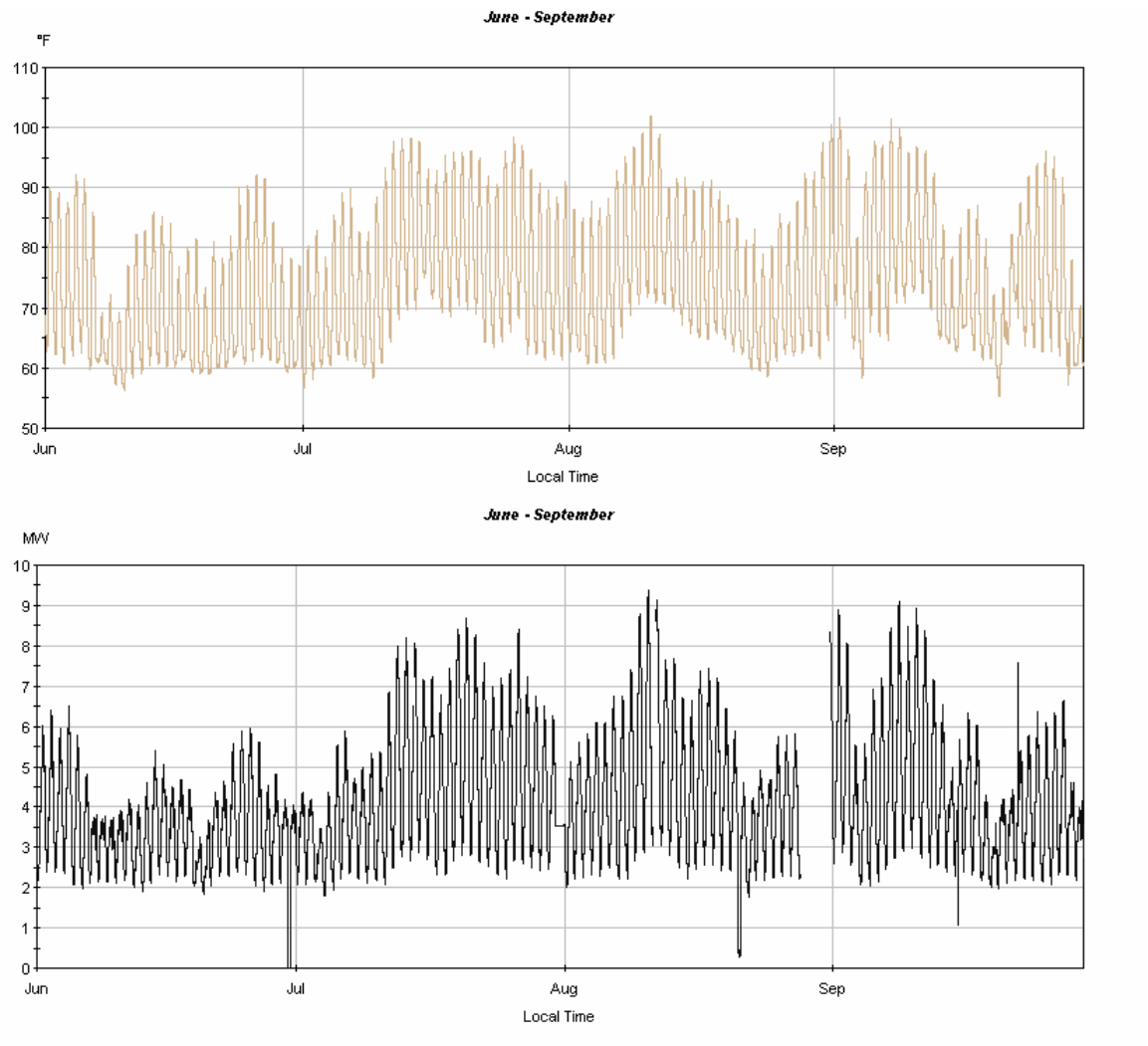


Figure 12: Temperature (top) versus Load (bottom)

Test Plan

The goal is to test two technologies, AC cycling and smart thermostats, at a selected number of homes and small businesses. One of the first questions is how many of each technology do we need to install and control to obtain statistically reliable results. To get at this question, we need to consider the following issues:

1. What is the estimated impact per unit for each of the two types of control device?
2. How variable is the impact from unit to unit?
3. How accurately can we predict the circuit load in the absence of curtailment?

We will consider each of these issues in the following subsections.

Impact of Control Devices

During the past several summers Edison has carried out a large scale test of smart thermostats in small businesses. As part of the study, about 100 AC units were end-use metered. The metering recorded the kWh consumption of each using every five minutes. Figure 13 shows the impact of a 4-degree curtailment that was called on September 7, 2004 from 2 PM to 4 PM. The high on September 7 was 94.0 degrees, and the average high on the control days was 92.4 degrees. The graph shows a direct comparison of the averaged load/ton of the end use metered units on September 7 (blue line) to the averaged load/ton for non-controlled comparison days (red line). The impact is the difference between the two curves.

As shown in Figure 13, the impact was greatest at the start of the control period. The peak load reduction was over 0.51 kW per rated AC tonnage but dropped by about half by the end of the two-hour period.

Averaging curtailments on eight different days, the maximum kW reduction in each curtailment was 0.49 kW per rated ton of the AC unit. The average kWh savings was 0.33 kWh per ton during the first hour of the curtailment and 0.21 kWh per ton during the second hour of the curtailment. In the prior study, the average size of the controlled AC units was about 4 tons. Using this figure, we can expect a maximum impact of about 2 kW per AC unit for smart thermostats installed in small commercial buildings using a temperature offset control strategy.

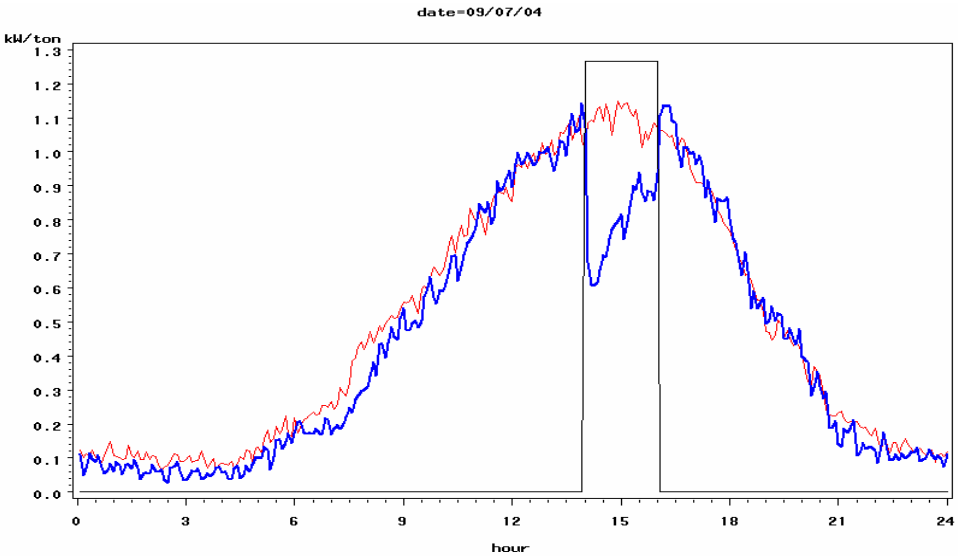


Figure 13: Impact of a Smart Thermostat Curtailment on a Hot Day

In these prior smart thermostat studies, the load was curtailed by raising the temperature set point of the thermostat a set amount, usually 4 degrees. If the AC had been operating and maintaining the indoor temperature at the original set point, then it would be idle for a period of time until the indoor temperature rose to the new set point. During this period of time, the AC would be effectively curtailed unless the customer chose to override the curtailment. But as units came back on, the impact of the curtailment would be diminished. In the test, we will not be using a setback, but an actual curtailment of the compressor.

In the present study, the smart thermostat will order the AC to be totally off during the entire curtailment period, i.e., for 20 minutes from the start of the curtailment. Therefore, assuming that the unit receives the curtailment signal, we can assume that the impact is to reduce its load to zero from its expected load during the period. In other words, assuming that the signal is received, the load reduction is equal to the load in the absence of curtailment.

We can estimate the expected load as the product of the probability that the unit will be operating during the period and the load of the unit when it is operating. We have estimated the latter to be 1 kW per ton. For example, consider a commercial 4-ton AC and assume there is a 0.7 chance that it is operating during the curtailment period. Then its expected load would be 2.8 kW and this would also be the expected impact of curtailing the unit.[6] .

Moreover, as long as the curtailment signal is received and properly interpreted, the AC load should be zero throughout the curtailment period. Therefore the impact should not change materially during the curtailment period in our application.

There may be some lag in getting the curtailment signal to the thermostats or switches. In principle, however, the signal should be received simultaneously by each of the thermostats and each of the switches. Therefore we can monitor the lag by installing a thermostat and switch at the substation and logging the time that the signals are received by each of the two devices.

There may also be some lag between the time that a thermostat or switch receives the signal and actually curtails the AC load. We should see the aggregate effect of this lag in the SCADA data itself.

A similar reasoning applies to AC switches installed in homes. For the sake of planning we probably can assume that the operating load per ton is about the same as for smart thermostat, i.e., 1 kW per ton. We have assumed that the average residential central AC unit is a 3 ton unit. If we assume a duty cycle of 0.5 we can expect the impact of a residential switch to be about 1.5 kW per AC unit. A key difference is that the impact is generally fairly constant over the control period.

[6] In other words, we are assuming that the duty cycle is 0.7.

Variability of the True Impact

The impact of either type of control will vary from one unit to another and from one day to another. The primary source of variability will be whether the unit is running or idle at the time of the curtailment. This will depend on the sizing of the unit and the weather conditions. We can estimate the standard deviation of the impact from the equation: $kW\ \sqrt{p(1-p)}$. Here kW is the operating load of the unit and p is the probability that it is operating at the time of the curtailment. We have assumed that the operating load is 1 kW per ton. For example, consider a 4 ton commercial AC and assume that the probability that it is operating is 0.7. Then the operating load is 4 kW and the standard deviation has been taken to be $4\ \sqrt{0.7(1-0.7)} = 1.8\ kW$.

We can assume that the true impact of each unit is statistically independent from unit to unit. Then the standard deviation of the total impact is the square root of the number of units times the standard deviation of each unit.

Predicting the Circuit Load

In order to determine the impact of a curtailment we need to predict the load of the circuit in the absence of the curtailment. In other words we need to establish a baseline similar to the red line in Figure 13. In developing our predictive model, we have made the following assumptions:

1. The load control will probably occur between 2 pm and 6 pm on a weekday,
2. The curtailment might be called at the start of any half hour during these hours and will last for 20 minutes,
3. During this period the controlled unit will be completely curtailed,
4. Participants will not anticipate the load control by pre-cooling or otherwise changing their load prior to 2 pm, and
5. There will not be material interactions between the controlled AC units and other loads at the site. In particular, non-controlled AC units will not pick up the load of the controlled units in sites with more than one AC unit.

We developed predictions for the load in each 2-minute interval from 2 pm to 6 pm on weekdays. Our predictions were informed by the following information:

1. The average load in each interval during prior weekdays,[7]
2. The actual measured load of the circuit just prior to the start of the curtailment,
3. The current temperature and enthalpy in the curtailment period and the average temperature and enthalpy in the same interval over the prior weekdays, and
4. The load of two adjoining feeders during the curtailment period.

[7] We have experimented using 1, 2, 5 and 10 prior weekdays. Although a 10-day average appears to give somewhat more accurate predictions, we would prefer to use fewer days (e.g. 3 days) to simply the scheduling of the trials to avoid contamination from prior curtailments.

Then we calculated the errors of our predictions in each interval by comparing the actual recorded load to the prediction. Finally we calculated the average load and the standard deviation of our predictions in each weekday from 2 pm to 6 pm. From this analysis, we found that we could generally predict the load of the circuit with a standard error of about one percentage point.[8]

Expected Statistical Precision

Now we can combine these results to shed some light on the question of how many controllers should be installed. Figure 14 summarizes one set of assumptions. From the billing data discussed earlier, we have assumed that the there are 120 candidate commercial units and 850 candidate residential units. We have assumed that 80% of the commercial units participate in the program and 50% of the residential units participate, giving 96 commercial units and 425 residential units in the program. We have assumed that the average size is 4 tons for a commercial unit and 3 tons for a residential unit and that the operating load of each is 1 kW per ton. Finally we have assumed that 70% of the commercial units would have been in use during the curtailment. For the residential units, we assumed this to be 50%. In addition, we have assumed that we can predict the baseline load with a standard error of ±1%.

Source	N	In Prog	n	Size (Tons)	In Use
Baseline					
E$T	120	0.8	96	4	0.7
Switches	850	0.5	425	3	0.5

Figure 14: Case A: Assumptions

Figure 15 shows our analysis of Case A. The first column shows the estimated impact per unit calculated as previously discussed. The next column shows the expected standard deviation of the impact of a single unit.

Source	Unit Impact	sd	Impact Analysis	Std Error	Err Bnd	Rel Prec
Baseline			9,000	90	148	2%
E$T	2.8	1.8	269	18	30	11%
Switches	1.5	1.5	638	31	51	8%
Impact			906	97	159	18%

Figure 15: Case A: Analysis

The third column shows the estimated impact. We have assumed that the circuit load would have been 9,000 kW in the absence of the curtailment. We would expect the smart

[8] The predicts were more accurate at the start of the 20-minute curtailment and less accurate at the end of the period. At 10 minutes into the curtailment the standard error was typically about ±1%

thermostats to reduce the load by 269 kW and the switches by 638 kW for a total reduction of 906 kW.

Next we have calculated the expected standard error associated with each element of the impact analysis. The standard error of the baseline reflects our ability to predict the baseline during a curtailment. We have taken it to be 1% of the expected circuit load in the absence of curtailment, or 90 kW.

There is also a standard error associated with the total impact of the smart thermostats, calculated from the equation $\sqrt{96}\,1.8 = 18$ kW in this case, and a standard error associated with the switches, 31 kW. The standard error associated with the estimated impact is calculated from these components using the equation $\sqrt{90^2 + 18^2 + 31^2}$ and is found to be 97 kW.

The error bound is simply the standard error times 1.645, the normal coefficient associated with the 90% level of confidence. The relative precision is the error bound divided by the estimate. In this example, the estimated impact is 906 kW ±159 kW. This gives an expected statistical precision of ±18% at the 90% level of confidence.

Figure 16 and Figure 17 shows the analysis assuming a smaller number of participants. In this case we have assumed participation rates of 50% for commercial and 25% for residential, thereby reducing the expected number of smart thermostats and switches. We have kept the remaining parameters the same. As shown in Figure 17, in this case we would expect the impact to be 487 kW with a statistical error bound of ±154 kW. So the expected relative precision would only be ±32%.

Source	N	In Prog	n	Size (Tons)	In Use
Baseline					
E$T	120	0.50	60	4	0.7
Switches	850	0.25	213	3	0.5

Figure 16: Case B: Assumptions

Source	Unit Impact	sd	Impact Analysis	Std Error	Err Bnd	Rel Prec
Baseline			9,000	90	148	2%
E$T	2.8	1.8	168	14	23	14%
Switches	1.5	1.5	319	22	36	11%
Impact			487	94	154	32%

Figure 17: Case B: Analysis

Scheduling the Curtailments

The preceding analysis indicates that we should install the cycling and smart thermostats respectively on about 525 air conditioners at homes or small businesses. We are primarily interested in demonstrating the value and reliability of AC load control as spinning reserve. Typically, spinning reserve is especially valuable during periods of high AC load. Moreover the calls on spinning reserve are typically rather short, usually 10 to 30 minutes in duration.

For the sake of planning we can assume that we will make one curtailment call each weekday, with a duration of 20 minutes, at a prescheduled (but unannounced) time between 2 pm and 6 pm. The following factors should be considered in scheduling the time of the curtailment:

- The curtailments should be uniformly distributed across the time of the day, between 2 pm and 6 pm.
- We do not want the participants to anticipate the curtailment so they should be difficult to predict.
- We do not want to make it unduly difficult to estimate the baseline load in the absence of the curtailment.

The last point will require some more investigation. One of the important inputs to our predictive model is the average load of the circuit on several weekdays immediately preceding a particular curtailment day. We must make sure that this baseline load is unaffected by prior curtailments.[9] The critical period is from just prior to the curtailment through any snapback following the curtailment, e.g. during the following forty minutes.

Use of Loggers

An important goal of the study is to reliably predict the magnitude of the potential impact as a function of the time of day and the temperature. Since we are planning 100% curtailments, the potential impact at any point in time should be directly related to the total load of the controlled units. This leads us to the idea of estimating total load of the controlled units by end-use monitoring a sample of the units.

The key planning question is the number of loggers that are needed. We have carried out an analysis under the assumptions shown in Figure 14. In particular we have assumed 96 smart thermostats and 426 residential switches in the program. We have regarded these

[9] Because of this consideration we are reluctant to calculate the baseline load from the average load on the ten prior weekdays since this means that we need to avoid this type of conflict on all ten prior days together with the curtailment day itself. If we calculate the base load from the average on three prior weekdays, we only need to avoid conflict on four days which should be manageable.

units as the target population and sought to estimate their total AC load from a stratified sample. As in our prior analysis, we would estimate the total load of these units to be 906 kW. What can we say about the expected statistical precision under these circumstances?

Figure 18 shows the new analysis. We have assumed a logger sample of 150 units. We have allocated 32 of the units to the smart thermostats and 118 to the switches.[10] Our analysis indicates that with this sample we can expect to estimate the total controlled AC load with a statistical precision of ±10% at the 90% level of confidence. With a sample of 75 loggers, the expected statistical precision would be of ±15% at the 90% level of confidence. With a sample of 50 loggers, the expected statistical precision would be of ±18% at the 90% level of confidence.

	Assumptions, Case A				Analysis			
Source	N	Unit Impact	sd	n	Total Load	Std Err	Err Bnd	Rel Prec
E$T	96	2.8	1.8	32	269	25	42	16%
Switches	425	1.5	1.5	118	638	50	82	13%
Impact	521			150	906	55	91	10%

Figure 18: Expected Statistical Precision of Logger Sample, Case A

Based on our experience, we would recommend the use of a battery-powered logger that can record and store the amperage of the AC unit during each 5-minute interval for 110 days. Because of the concern about timing, the time clocks of the logger should be accurately synchronized at the time of installation and we should take care that they have negligible drift during the study period.

We at RLW Analytics are working with a logger that meets these specifications. This logger can be purchased for under $300 per unit with an appropriate current transformer. Our field staff can install and retrieve these loggers and collect the added site information discussed below for about $500 per unit.

Related Information

The preceding analysis, e.g. Figure 15, indicated that the success of the study will be heavily dependent on curtailing sufficient load. In particular, our analysis of the smart thermostat program has shown that the impact of curtailment at a site may be significantly diminished if the space is also served by an uncurtailed AC unit at the site. Therefore whenever the control device is installed, the installer should ensure that all air conditioning units serving the site are under control.

Our prior analysis also has shown the importance of accurate information about the tonnage of the controlled AC units and the Carrier PIN numbers for the smart thermostats. We recommend that this type of information be collected when the

[10] Under standard assumptions this is the optimal allocation for estimating the total load of all controlled AC units.

thermostats or switches are installed. We recommend that these data be carefully verified for all of the sites included in the end use monitoring at the time that the loggers are installed.

Statistical Analysis Conclusions

Based on this analysis, we suggest the following conclusions:

- The Zin circuit does not seem to be affected by periodic realignment of the end users served by the circuit.

- The peak load generally occurs in the afternoon, e.g., between 2 PM and 6 PM and the load is rather temperature sensitive, indicating substantial AC load on the circuit.

- The maximum daily temperatures range from 80 to 100 and higher. In 2004 the hot days occurred from mid-July through mid-September.

- The load varies randomly by about ±1% from one 2-minute period to the next. There may be relatively little value in collecting load data more frequently than every two minutes. In fact it may be beneficial to smooth the existing instantaneous 2-minute load measurements over a rolling ten-minute window.

- We can improve the statistical reliability of the results by smoothing the load of the circuit using a 10-minute rolling average, and by using the load of similar circuits to help estimate the base load of the controlled circuit.

- It may be necessary to control about 525 AC units to obtain statistically significant results at the circuit level.

- Given the focus on spinning reserve, we recommend calling a 20-minute curtailment each week day, following a specified schedule. The schedule must avoid contaminating the baseline load since an accurate baseline is crucial for impact assessment.

- It is important to supplement the information from the experimental curtailments using end-use loggers. Depending on the desired statistical precision, the sample size should be anywhere from 50 to 150 units.

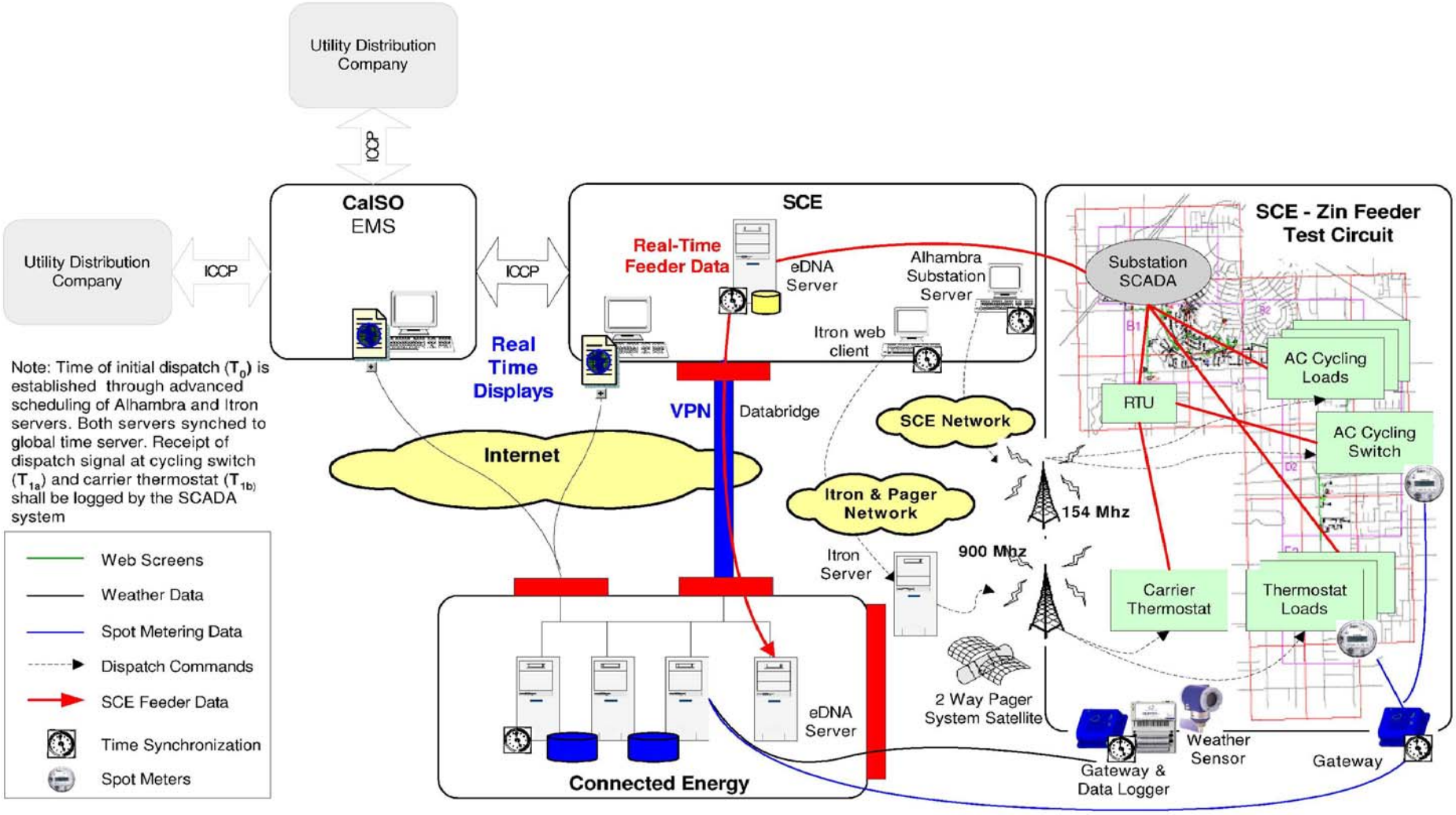
- The success of the experiment depends on getting the maximum impact from each curtailment. This means that we must mitigate take back from any uncontrolled AC units serving the same space as the controlled units. To take advantage of the run time and logger data we also need accurate information about the size and connected load of the controlled units. These activities should be included in the work plan.

4.Data Acquisition and Flow Details

	Type of Data	Reason for Sending Data	Origin	Target	Mechanism	Trigger
1.	Real Time Feeder Data	For real time monitoring of the test feeder circuit. This data will be used for load profile projection as well as to monitor the result of a dispatch command	eDNA server collocated with SCE SCADA System	A pre-configured eDNA server at Connected Energy.	Databridge will be used for data replication over a vpn.	Predefined interval commensurate with SCADA data scanning interval (16 secs)
2.	Spot Metering Data	To sample a representative sample of participating thermostats and AC cycling devices for verification of response to dispatch event. May also be used to predict available capacity before a dispatch event is called	On location Spot meters on dispatchable thermostats and AC cycling units.	Connected Energy's Data aggregation system.	Connected Energy gateway devices. Data gathering mechanism is yet TBD.	Pre-configured Spot meter scan rate.
3.	Weather Data	Will be used to gather real time weather data as an input to the load profile projection equations.	SCE operated Weather sensors located within the test circuit area	Connected Energy's data aggregation system.	Connected Energy gateway devices and network.	Pre-configured scan rate

4.	Dispatch Event Data	To measure elapsed latency time between dispatch and each of the end device paths (switch and thermostat)	SCE operators at Alhambra radio system (switches) and SCE operators of the Itron paging thermostat system.	A target AC Cycling switch and a carrier thermostat in the test circuit that are connected to a data gathering RTU	SCE's 154Mhz network for the AC Cycling dispatch signal. Itron and 900Mhz Pager network for dispatch signals to the thermostats	Predefined schedule. Each system must dispatch the signal at exactly the same time (synched via a time server)

See Data Acquisition and Flow Diagram
On Following Page


Utility Distribution Company
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SCE
Real-Time Feeder Data
eDNA Server
Alhambra Substation Server
Itron web client
Real Time Displays
VPN
Databridge
Internet
SCE Network
Itron & Pager Network
154 Mhz
900 Mhz
Itron Server
2 Way Pager System Satellite
eDNA Server
Connected Energy
SCE - Zin Feeder Test Circuit
Substation SCADA
AC Cycling Loads
RTU
AC Cycling Switch
Carrier Thermostat
Thermostat Loads
Weather Sensor
Gateway & Data Logger
Gateway
Note: Time of initial dispatch (T_0) is established through advanced scheduling of Alhambra and Itron servers. Both servers synched to global time server. Receipt of dispatch signal at cycling switch (T_{1a}) and carrier thermostat (T_{1b}) shall be logged by the SCADA system
Web Screens
Weather Data
Spot Metering Data
Dispatch Commands
SCE Feeder Data
Time Synchronization
Spot Meters

5. Long Term Objectives

1. Conduct tests on other feeders to validate and further refine initial findings.
2. Test approaches for triggering staged interruptions on multiple feeders such that their aggregate behavior replicates that of frequency responsive spinning reserves with a frequency droop characteristic.
3. Evaluate the system (and distribution system planning) impact resulting from explicitly targeting interruptions to specific feeders or regions within the SCE service territory.
4. Explore options for providing visibility directly to CAISO through the existing ICCP link with the SCE EMS/SCADA system.
5. Work with WECC and NERC committees to modify current rules prohibiting use of load to provide spinning reserve.