Field Test Results of Automated Demand Response in a Large Office Building

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Abstract

Demand response (DR) is an emerging research field and an effective tool that improves grid reliability and prevents the price of electricity from rising, especially in deregulated markets. This paper introduces the definition of DR and Automated Demand Response (Auto-DR). It describes the Auto-DR technology utilized at a commercial building in the summer of 2006 and the methodologies to evaluate associated demand savings. On the basis of field tests in a large office building, Auto-DR is proven to be a reliable and credible resource that ensures a stable and economical operation of the power grid.

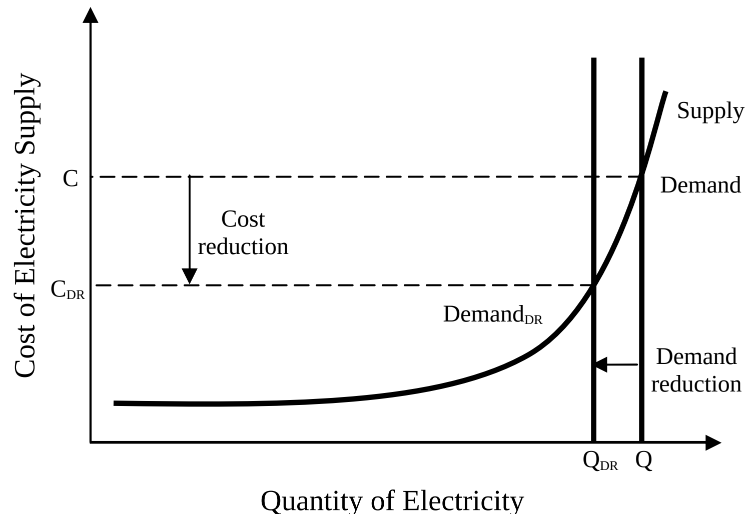
Keywords

Demand Response, Automated Demand Response, Critical Peak Pricing, Field Test

Introduction

As an essential of modern life, electricity is different from other commodities. It cannot be stored economically, and the supply of and demand for electricity must be balanced in real time. Mismatches in supply and demand can threaten grid integrity within seconds. Also, grid conditions can change significantly from day-to-day or hour-to-hour. Demand levels also can change quite rapidly and unexpectedly. Increasing grid capacity to maintain reserve margins sufficient for demand is possible but is not a good solution because the electric system is highly capital-intensive, and both generation and transmission system investments have long lead times.

Whereas the cost of electric power varies on a short time scale, customers generally face retail electricity rates that are fixed for months or years at a time, representing the average costs of electricity production (including transmission and distribution). This disconnect between costs of short-term marginal electricity production and the fixed retail rates paid by consumers leads to an inefficient use of resources. By contrast, Demand Response (DR) generally induces demand shedding, shifting or limiting during times when the electric grid is near its capacity, or when electric wholesale prices are high [1]. Under conditions of tight electricity supply, DR can significantly reduce peak price and, in general, electricity price volatility [2], as shown in Fig. 1. By improving electric grid reliability, managing electricity costs, and optimizing electric power resources, DR has been capturing worldwide interest in recent years.



(Source: U.S. Department of Energy)

Fig. 1 Impact of Demand Response on Electricity Supply Cost

In general, DR may be defined as short-term changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times when either of high wholesale market price or system reliability is jeopardized [3]. DR can be classified into two categories [2]: price-based DR and reliability-based DR. Price-based DR refers to customer reduction in demand when they receive signals indicating increased prices, in exchange for discounted retail rates during non-DR periods. Reliability-based DR refers to customer payments or preferential prices for non-DR periods derived from reduced electricity usage during periods of system need or stress.

Critical Peak Pricing (CPP) program is a price-based tariff. CPP provides for incentive-based lower energy rates on non-CPP event days in exchange for higher rates on up to 12 CPP event days during the summer months (from May 1 to October 31). The associated tariffs may vary for different utilities. An example of the CPP tariff structure for Pacific Gas & Electricity (PG&E) is illustrated in Fig. 2, which represents the electricity charge for usage rising by three times the customer's summer part-peak energy rate relative to the otherwise-applicable rate during the Moderate-Price period, and by five times the summer peak energy rate under otherwise-applicable rate during the high-price period.

A key requirement for DR is the availability of interval meters. In order to encourage the participation of DR programs, PG&E currently provides free interval meters to consumers over 200 kW if they choose to participate in a DR program. The meter records 15-minute load data and provides daily transmission of measurements over a communication network to a central collection point. Lack of metering infrastructure may limit participation in a DR program, but equally constraining may be the lack of knowledge about how to develop and implement DR control strategies [4]. Manually managing and participating in DR programs can also be labor intensive. Automated Demand Response (Auto-DR) does not involve human intervention, but is initiated at a home, building, or facility through receipt of an external communications signal to execute pre-programmed demand response strategies. Auto-DR ensures a completely hands-off approach through automation of the entire process. When demand reduction is not desirable at a particular site, the Auto-DR system provides participants the choice to override DR events.

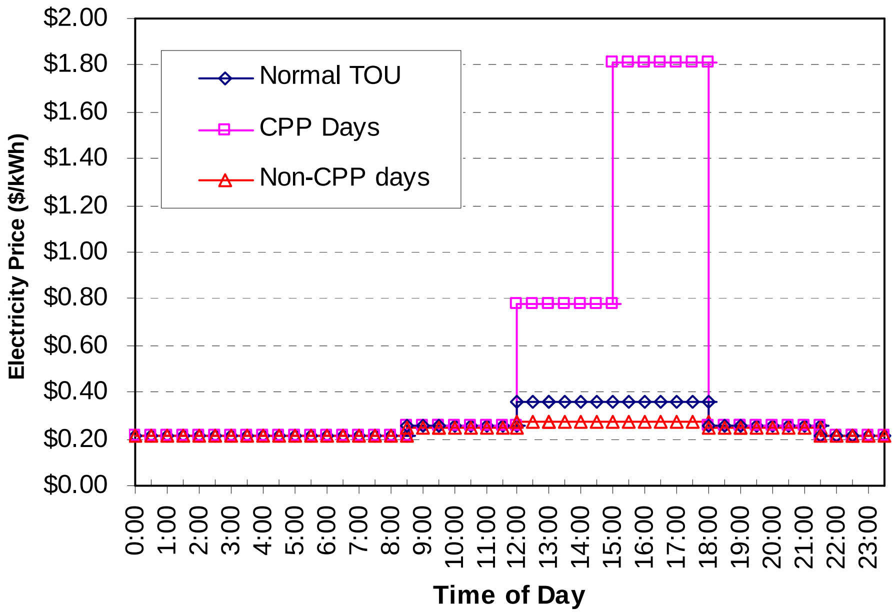


Fig. 2 Example of CPP Tariff Structure for PG&E

Automated Communication System

The Auto-DR system uses an XML-based Web Service Oriented Architecture (SOA) for platform-independent, interoperable systems. Auto-DR consists of two major elements formalized by the draft Open Auto-DR Communication Standards [5]. First, a Demand Response Automation Server (DRAS) provides signals that notify electricity customers of DR events. Second, a DRAS client is at the customer's site to listen and provide automation signals to existing pre-programmed controls. There are two types of DRAS clients:

1. A Client and Logic with Integrated Relay (CLIR) or a simple client for legacy control systems.
2. A Web Services software or smart client for sophisticated control systems.

As shown in Fig. 3, the steps involved in the Open Auto-DR process during a DR event are:

1. The Utility or ISO defined DR event and price/mode signals are sent to the DRAS.
2. DR event and price services are published on a DRAS.
3. DRAS Clients (CLIR or Web Service) request event data from the DRAS every minute.

4. Customized pre-programmed DR strategies determine action based on event price/mode.
5. Facility Energy Management Control System (EMCS) carries out load reduction based on DR event signals and strategies.

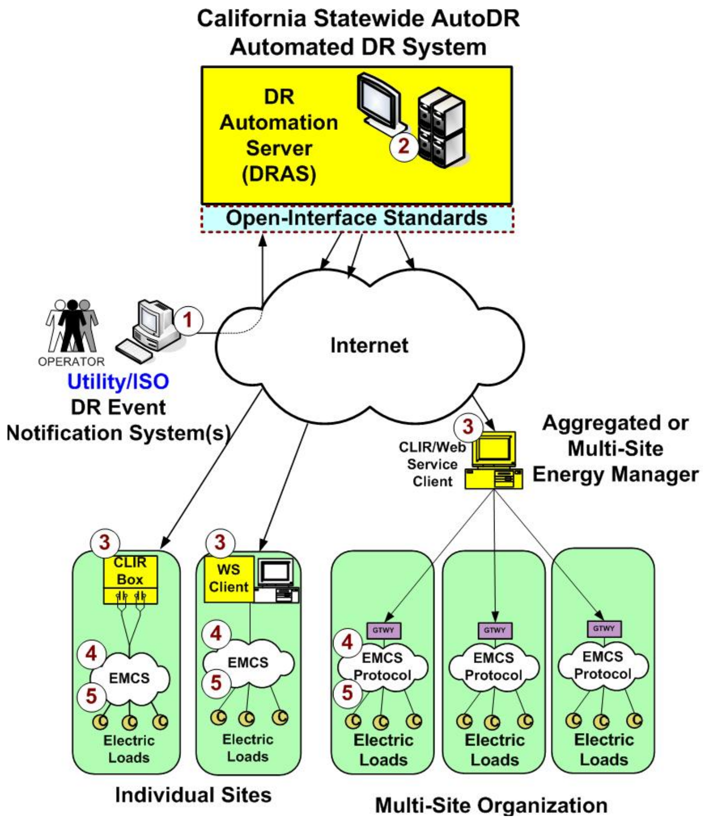


Fig. 3 Generic Automated DR Open-interface Standard Architecture

Field Test

Background

The Demand Response Research Center (DRRC), launched by the California Energy Commission's Public Interest Energy Research (PIER) program, has conducted DR research since 2003. A series of Auto-DR field tests have been carried out since then. Three-hour tests were conducted at five sites in 2003 and at eighteen sites in 2004, whereas six-hour tests on a pilot DR program were carried out at twelve sites in 2005. The average demand savings were 8%, 7% and 9%, respectively [6, 7, 8].

In 2006, a new secure, pre-configuring Client and Logic with Integrated Relay (CLIR) was developed. The CLIR enables the Energy Management Control Systems (EMCS) of the facility to receive Auto-DR signals over the Internet to trigger pre-programmed DR strategies and to reduce peak electric loads. Here, we present results of field tests for a building (in Martinez, CA) that participated in the Auto-DR pilot DR program in 2006 [9].

Field test object

Building Martinez (referred to below as Martinez) is a county government office building. It is a four-floor, 131,000 ft^2 building located in Contra Costa County, California. The building has five 60-ton rooftop package units. The ventilation system is single duct variable air volume (VAV) with a perimeter reheat air handler system delivering conditioned air to the whole building in the summer. The cooling set point during normal operation is 76°F. Separate direct fired natural gas rooftop packages provide heating in winter. The building has a digital direct control (DDC) system. The peak load of the whole building in the previous year (2005) was 528 kW.

Martinez participates in PG&E's CPP program. A total of eleven CPP events were called based on the weather forecast in Northern California in 2006. Event days and the maximum outside air temperature (OAT), as well as the average maximum OAT on three CPP baseline days, are shown in Table 1. Field tests at Martinez were carried out on all of these event days.

Table 1 Peak OAT on DR Event Day and Average maximum OAT on CPP baseline days

DR event day	6/21	6/22	6/23	6/26	7/17	7/18	7/20	7/21	7/24	7/25	7/26
Max. OAT on DR day (°F)	100	103	96	97	105	98	100	106	108	107	96
Average max. OAT on CPP baseline days (°F)	92	92	92	92	91	91	91	91	91	91	91

DR strategies

Martinez executed a global temperature adjustment (GTA) strategy [10] to reduce demand in response to the rising price signals during the CPP events. GTA increases the HVAC zone temperature set points for an entire facility. Martinez increased the zone temperature set point from 76 °F to 78 °F during the moderate-price period, and by an additional 2 °F during the high-price period. At an event's finish, the system needs to return to normal operation. To avoid rebound which is the load spikes up right after resetting back the operation, Martinez released the VAV boxes one-by-one over a short time interval. These strategies were pre-programmed and dispatched to the building EMCS.

Field Test Results

Evaluation Methodology

To determine demand reduction, a baseline is needed to estimate what the load would have been on the DR event day in the absence of DR strategies. Three baseline models [11] were used to evaluate demand reduction during event hours. The 3/10 baseline is the 15-minute-average based on the three days with the highest total kilowatt-hour usage during the program hours of the immediate past ten days (excluding weekends, holidays and other DR days). The 3/10 baseline is used by utilities in California to calculate demand reduction. A 3/10 baseline with morning adjustment (3/10_MA) model adjusts the 3/10 baseline by a morning adjustment multiplier (r_a) for each hour. The factor r_a is defined as the ratio of the actual to the predicted load in the three hours prior to the event period, as shown in Equation 1. The Outdoor Air Temperature regression with morning adjustment (OAT_MA) baseline model uses a weather regression model with morning adjustment. The weather regression model estimates load by the OAT linear regression based on the past twenty uncurtailed business days. In the OAT regression model, predicted load $L_{p,h}$ can be calculated by equation 2. Therefore, the OAT_MA can be calculated from $L_{p,h}$ by multiplying by the morning adjustment factor r_a.

$$r_a = (L_{a,9}+L_{a,10}+L_{a,11})/(L_{p,9}+L_{p,10}+L_{p,11}) \quad (1)$$

Where, r_a is the morning adjustment factor,
$L_{a,9}$, $L_{a,10}$, $L_{a,11}$ are the actual hourly average loads on DR day at the hour's start at 9:00am, 10:00am, and 11:00am, respectively; and
$L_{p,9}$, $L_{p,10}$, $L_{p,11}$ are the predicted load by CPP baseline at the hour's start at 9:00am, 10:00am, and 11:00am, respectively.

$$L_{p,h} = a_h + b_h * T_h \quad (2)$$

Where, $L_{p,h}$ is the predicted load at the time *h*,
a_h, b_h are the linear constants at time *h* which can be calculated by the twenty pairs of past actual load/OAT data, and T_h is the OAT at time *h*.

Demand reduction

As an illustration of how DR strategies affect actual load profile in Martinez, Fig. 4 shows the time series whole building power (WBP) and baselines of the first test on June 21, 2006. The zone temperature of a 2 °F increase at 12:00pm caused demand to drop from 432 kW to 350 kW in 30 minutes before the load slowly recovered over time. At 15:00, an additional 2 °F increase caused almost 100 kW demand drop in about 15 minutes. The rebound strategy successfully prevented load from spiking at the end of the event.

Table 2 shows results for average demand reduction using three different baselines. Based on OAT_MA, six-hour-average demand reductions range from 14% to 29% of WBP. The average demand savings for OAT_MA of the eleven DR events was 96 kW, accounting for 19% of total demand. The maximum three-hour-average demand reductions during the moderate-price and high-price period were 132 kW and 178 kW, accounting for 25% and 34% of WBP, respectively. Based on 3/10_MA, the six-hour-average demand reductions ranged from 7% to 21% of WBP, and averaged 14% of WBP. However, based on the 3/10 baseline, the six-hour-average demand reductions were in the range of -11% to 13% of WBP, with an average of 3%. Negative sheds were shown on several DR days characterized by maximum OAT of over 100°F. The 3/10 baseline tends to under-estimate shedding on high OAT days preceded by relatively cooler days. In Fig. 4, the maximum OAT on June 21 is 100°F whereas on three baseline days, the highest temperatures were 93°F, 85°F, and 98°F, with an average of 92°F.

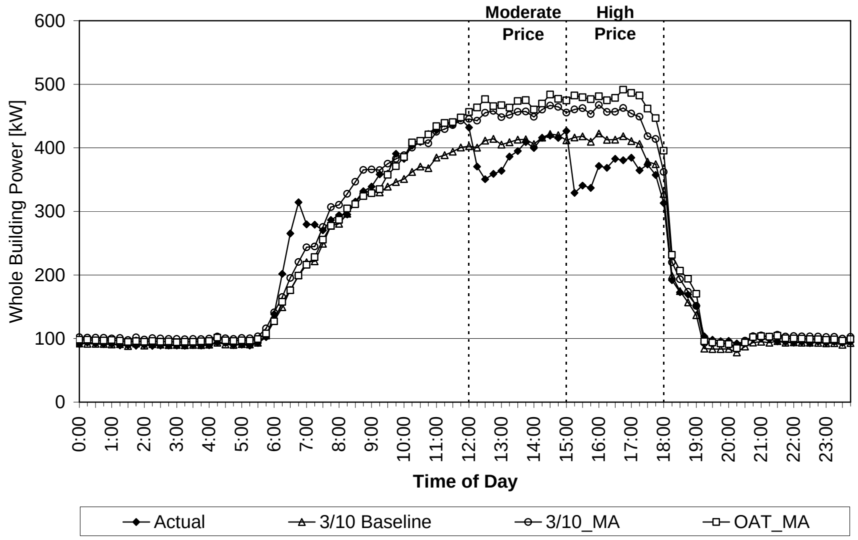


Fig. 4 Whole Building Power and Baselines on DR Event Day of June 21, 2006

Table 2 Demand Reduction Evaluation by Three Baseline Models

Baseline	Time \ date		6/21	6/22	6/23	6/26	7/17	7/18	7/20	7/21	7/24	7/25	7/26	Average
3/10 baseline	12:00-6:00	kW	28	-4	54	32	-41	17	47	19	-46	-19	48	12
	Average	%	7%	-1%	13%	8%	-10%	4%	11%	4%	-11%	-4%	11%	3%
	12:00-3:00	kW	20	1	39	11	-65	-5	34	11	-60	-35	35	-1
	Average	%	5%	0%	9%	3%	-16%	-1%	8%	3%	-14%	-8%	8%	0%
	3:00-6:00	kW	37	-9	70	52	-16	39	59	27	-32	-3	61	26
	Average	%	9%	-2%	18%	13%	-4%	10%	14%	7%	-8%	-1%	15%	6%
3/10_MA	12:00-6:00	kW	71	66	72	102	86	94	67	34	38	37	72	67
	Average	%	16%	14%	17%	21%	16%	19%	15%	8%	7%	8%	16%	14%
	12:00-3:00	kW	64	72	57	83	64	74	56	26	26	23	59	55
	Average	%	14%	15%	13%	17%	12%	15%	12%	6%	5%	5%	13%	11%
	3:00-6:00	kW	79	59	88	121	108	115	79	42	49	52	85	80
	Average	%	18%	13%	21%	26%	21%	24%	18%	10%	10%	11%	19%	17%
OAT_MA	12:00-6:00	kW	93	78	91	155	101	101	89	67	89	89	97	96
	Average	%	20%	16%	21%	29%	18%	21%	19%	14%	16%	17%	20%	19%
	12:00-3:00	kW	79	84	77	132	82	81	78	56	67	65	78	80
	Average	%	17%	17%	17%	25%	14%	16%	16%	12%	12%	12%	16%	16%
	3:00-6:00	kW	106	73	106	178	120	122	101	78	111	113	115	111
	Average	%	23%	15%	24%	34%	22%	25%	22%	17%	20%	21%	25%	23%

Discussions

Many baseline methods can be used to evaluate and measure demand reduction. In this work, three baselines were used for evaluation. The 3/10 baseline is the simplest and easiest to calculate. It is reliable when applied to non-weather-sensitive buildings. However, it tends to underestimate actual demand reduction for weather-sensitive buildings because DR events are more likely to be called on the hottest days. Since DR program administrators have a strong preference for simpler calculation methods with limited data requirements, the 3/10 baseline was chosen by PG&E for demand reduction evaluation. Here, the highest OAT on event days were in the range of 96°F to 108°F, whereas the average of the highest OAT on three baseline days for each event were either 91°F or 92°F, as shown in Table 1. Because Martinez is a large office and a weather-sensitive building, the 3/10 baseline generally underestimates actual demand reduction. Existing research [12] indicates that application of a morning adjustment factor significantly reduces bias and improves the accuracy of baseline models. Compared to the 3/10 baseline, accuracy of 3/10_MA baseline is improved in most cases. However, 3/10_MA is not applicable for sites at which pre-cooling strategy is used. The OAT_MA baseline is accurate but complicated. It requires not only the interval load data, but also local hourly OAT data which can be obtained from a nearby weather station that is currently active and maintained by either a state or a federal agency. In this research, the weather data at a local airport, one mile away from the building, was used. Variation in climate between weather station and site may also influence the nature of building response.

It is important to choose an appropriate baseline to calculate DR reduction. An accurate baseline can evaluate the actual demand reduction fairly whereas a biased baseline could either under- or overestimate the actual demand reduction. Here, the 3/10 baseline clearly under-estimates the demand reductions during the event hours.

Conclusions

The primary goal of this research was to examine the use of an automated communication system for DR and to evaluate the savings potential in actual CPP events at a large office building. Auto-DR field tests demonstrate the reliability of the communication system. Demand savings were significant and reliable through the automated system even during a heat wave. Baseline selection was proven to be important to measure the demand reduction. In this study, because the object is a high weather-sensitivity building, OAT_MA is the best baseline.An average 19% of demand savings during six event hours on eleven CPP event days was delivered through automation. Through field tests, Auto-DR was proven to be a reliable and credible resource that reduces peak demand and ensures stability of the power grid. Auto-DR implementations can cut back the high costs of peak demand, lower the average wholesale power price, and eventually deliver benefits to all of electric customers.

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