Installation and Commissioning Automated Demand Response Systems

Sila Kiliccote, Mary Ann Piette
Lawrence Berkeley National Laboratory

Greg Wikler, Joe Prijyanonda
Global Energy Partners

Albert Chiu
Pacific Gas and Electric Company

Synopsis

From 2003 through 2006 Lawrence Berkeley National Laboratory (LBNL) and the Demand Response Research Center (DRRC) developed and tested a series of demand response automation communications technologies known as Automated Demand Response (Auto-DR). In 2007, LBNL worked with three investor-owned utilities to commercialize and implement Auto-DR programs in their territories.

This paper summarizes the history of technology development for Auto-DR, and describes the DR technologies and control strategies utilized at many of the facilities. It outlines early experience in commercializing Auto-DR systems within PG&E DR programs, including the steps to configure the automation technology. The paper also describes the DR sheds derived using three different baseline methodologies. Emphasis is given to the lessons learned from installation and commissioning of Auto-DR systems, with a detailed description of the technical coordination roles and responsibilities, and costs.

About the Authors

Sila Kiliccote is a Senior Scientific Engineering Associate in the Building Technologies Dept. at LBNL. She has a MS in Building Science in Architecture from Carnegie Mellon University and a Bachelor of Electrical Engineering Systems from the University of New Hampshire.

Mary Ann Piette is a Staff Scientist and the Research Director of the PIER Demand Response Research Center. She has an MS in Mechanical Engineering from UC Berkeley and a Licentiate in Building Services Engineering from the Chalmers University of Technology, Sweden.

Greg Wikler is a Vice President for Global Energy Partners (GEP), LLC. Mr. Wikler is involved in planning assessments and program design/implementation support for energy efficiency and DR initiatives. He received his BS degree in Energy Economics from the UC Davis and his MS in Economics and Urban Planning from the Univ. of Oregon.

Joe Prijyanonda is a Sr. Associate at GEP, LLC. He has a MS of Engineering in Energy Technology from the Asian Institute of Technology, a MBA from the Call State University at Hayward, and a BS in Mechanical Engineering from the University of California at Irvine.

Albert Chiu is a Program Manager in the DR Department at Pacific Gas & Electric (PG&E). In his 7 years in DSM, he has worked on the design and implementation of residential, low income, commercial and local government DSM programs for utility customers. He has a BS in Environmental Study from San Jose State University and concentrated in Energy Efficiency and Renewable Energy.

Introduction

Demand Response **(DR)** can be defined as actions taken to reduce electric loads when contingencies, such as emergencies and congestion, occur that threaten supply-demand balance, or market conditions raise supply costs. California utilities have offered price and reliability DR based programs to customers to help reduce electric peak demand. The lack of knowledge about the DR programs and how to develop and implement DR control strategies is a barrier to participation in DR programs, as is the lack of automation of DR systems. Most DR activities are manual and require people to first receive notifications, and then act on the information to execute DR strategies.

Levels of automation in DR can be defined as follows. Manual Demand Response involves a labor-intensive approach such as manually turning off or changing comfort set points at each equipment switch or controller. Semi-Automated Demand Response involves a pre-programmed demand response strategy initiated by a person via centralized control system. Fully-Automated Demand Response does not involve human intervention, but is initiated at a home, building, or facility through receipt of an external communications signal. The receipt of the external signal initiates pre-programmed demand response strategies. We refer to this as Auto-DR (Piette et. al. 2005). Auto-DR for commercial and industrial facilities can be defined as fully automated DR initiated by a signal from a utility or other appropriate entity and that provides fully-automated connectivity to customer end-use control strategies. One important concept in Auto-DR is that a homeowner or facility manager should be able to “opt out” or “override” a DR event if the event comes at time when the reduction in end-use services is not desirable. Therefore, Auto-DR is not handing over total control of the equipment or the facility to the utility but simply allowing the utility to pass on grid related information which then triggers facility defined and programmed strategies if convenient to the facility.

This paper presents the history of technology development for Auto-DR since 2003 and technologies and strategies that have been utilized by facilities. It also outlines the commercialization experience with PG&E including the various steps for technology installation, DR sheds achieved by various sites and results using three baseline methodologies. Emphasis is given to the lessons learned from installation and commissioning of Auto-DR systems with a detailed description the technical coordination concept as well as process and economics of utilizing this concept in 2007.

History of Auto-DR

The automated demand response project began in 2002 following California's electricity market crisis with the goal of addressing three key research questions. First, is it possible using today's technology to develop a low-cost, fully automated communication and controls infrastructure to improve DR capability in California? Second, how "ready" are commercial buildings to receive common signals? Third, once a building receives a signal, what type of strategies are available that can be readily automated?

Table 1. History of Auto-DR

Year	# of Sites	DRAS	Site Communication	Utility
2003	5	Infotility	XML Gateway Software	None
2004	18	Infotility	XML & Internet Relay	None
2005	11	Akuacom	XML & Internet Relay	PG&E
2006	25	Akuacom	XML, Internet Relay, CLIR	PG&E, SDG&E

The 2003 automated DR technology development began with the design of a fictitious price signal and automation server that could represent price signals in XML (Extensible Markup Language) messages to support interoperable communications. Table 1 summarizes multi-year research and technology development efforts. Five facilities were recruited and each facility had an Energy Information Systems (Piette et. al. 2004), Energy Management and Control systems, technology gateways, and a variety of end-use load reduction strategies (Piette et. al. 2005).The test resulted in fully automated shedding during two events with an average peak reduction of about 10%. The 2004 design considered that many facilities may not have Energy Information System or Energy Management System (EMCS) so a low-cost internet relay was used to communicate with on-site equipment. The average demand reduction for these 15 sites was 0.53 W/ft^2 or about 14% of the whole building electric-peak demand. The relay was used for two years but replaced because of internet security concerns. It was replaced with a communications device called a Client & Logic with Integrated Relay (CLIR) box which is a self-configuring secure internet relay device.

In 2005 LBNL began a formal collaboration with the PG&E to offer Auto-DR as part of the Critical Peak Pricing (CPP) Program. LBNL worked with Akuacom to develop a new DR automation server (DRAS). For the eight sites that participated in the fully automated CPP event on September 29th, 2005 the average demand reduction ranged from 0 to 24% per site for the medium price period and 4 to 28% per site during the high price period, with an average of 9% and 14% overall for the two price periods. Following the pilot automated CPP test in 2005 LBNL began a more formal partnership with PG&E's Emerging Technologies Program. Among the twenty-five Auto-CPP sites, site responses to 125 events were fully automated and evaluated in this study. The average peak demand reduction was 14% of the whole-facility load based on the three-hour high-price period. (Piette et. al. 2006, 2007).

2007: Commercialization and Program Expansion

Following the hot summer of 2006 the California Public Utilities Commission requested the three California Investor Owned Utilities to partner with the Demand Response Research Center to begin using Auto-DR technologies. In 2007, PG&E started offering automated CPP program and Demand Bidding Program (DBP) and hired Global Energy Partners (GEP) to work with LBNL to commercialize the Auto-DR pilot efforts from previous years into 2007 and beyond. The PG&E Auto-DR goal for 2007 was to achieve 15 MW peak load reduction. GEP worked with a variety of subcontractors who played key roles in the project, including the Electric Power Research Institute (EPRI), and C&C Building Automation, Inc. PG&E directly contracted Akuacom, Inc. to continue maintaining the automation infrastructure for Auto-CPP and further expand the DRAS to automate the demand bid program. Figure 1 shows the vision for long-term commercialization of Auto-DR.

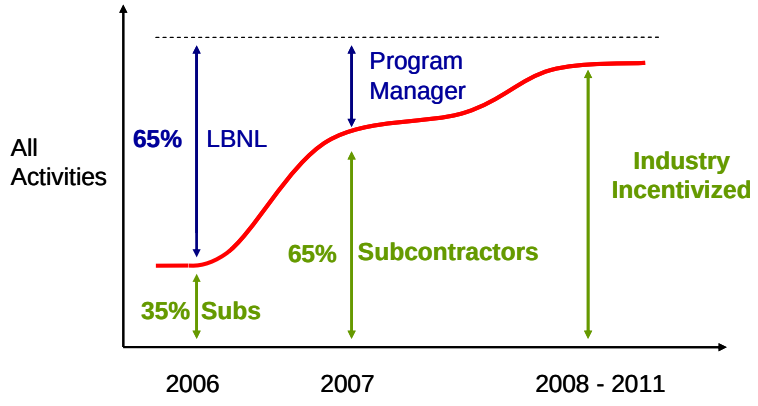

Figure 1. Long-term Vision for Auto-DR Commercialization

During 2007 PG&E's technology incentives (TI) program is used to finance the Auto-DR enablement and provided $300/kW for Auto-DR customers. Demand reduction (kW) is initially based on estimation and later corrected with actual participation. The TI incentive was designed into the following categories:

- **Recruitment**: Outside vendors were paid up to $40/kWto recruit viable Auto-DR customers. Customers were typically existing clients of the recruitment vendors.
- **Technical Coordinators** (TC): Trained energy management control system vendors were paid up to $70/kW for their services in conjunction with: (a) assisting the customer in understanding the selected Auto-DR control strategies for their facilities; (b) assisting the customer in selecting the equipment vendors; (c) participating in the verification of the installed Auto-DR equipment; and (d) maintaining contact with the customer during the DR season to ensure that the Auto-DR equipment was properly operating and that estimated load reductions were being realized.
- **Equipment**: Customers were reimbursed up to $140/kW for the costs associated with the design, procurement, and installation of the Auto-DR supportive technologies and

measures. In nearly all cases, this incentive covered 100% of the customer's Auto-DR project costs.

- **Participation and Performance**: Customers were qualified for a participation incentive of up to $50/kW for their participation and validated performance during the DR-event period (May 1, 2007 through October 31, 2007).

Over 22 MW were recruited into the program in 2007. The majority of participants used lighting and HVAC loads for demand reduction during DR events. Industrial customers, who provided the majority of demand reduction, adjusted their process loads to accommodate the DR events. The types of control strategies that were adopted included the following:

- **Global temperature adjustment:** Existing EMCS received the DR event signal in the form of a dry contact from the DRAS. Once that signal was received, the EMCS would raise the cooling setpoint to a setting predetermined by the facility operator (usually in the range of 2 to 8 ^{o}F) for a period of time.
- **HVAC equipment duty cycling**: For buildings that had multiple packaged HVAC systems, select units were configured to receive the DR event signal from the DRAS. Once that signal was received, compressor units were shut off for a subset of the building's systems during an acceptable period of time. Additional signals were then sent to cycle through the units.
- **Other HVAC adjustments**: Other shed strategies that were employed included decrease in duct pressures, auxiliary fan shutoff, pre-cooling, variable frequency drive limits and boiler lockouts.
- **Switching off lights:** Various lighting circuits were wired to receive the DR event signal from the DRAS. When signaled, these loads would be tripped for the entire duration of the DR event. Typically these were for lighting applications in common areas with sufficient natural light or for task applications that could accommodate full shutoff given the proximity of other lighting in the area.
- **Other lighting and miscellaneous adjustments:** Other shed strategies that were employed included bi-level switching and motor/pump shutoff.
- **Process adjustments:** Given the varying nature of industrial processes, the strategy for each customer was tailored to their particular process. The most common Auto-DR strategy employed was production equipment sheds when there was sufficient storage capability such that the customer could accommodate complete equipment shutdowns during DR events and catch up production later in the day or the following day.

Figure 2 summarizes how the different facilities in different DR programs utilized global temperature adjustment strategy (Motegi et.al. 2006). Whether the adjustment is one-level or two-level, the average adjustment is about 2 degrees over 2-3 hours. The figure also shows that government facilities have higher temperature setpoints for normal operations and majority of customers with office spaces seem to be able to set up temperatures to around 78 ºF. In addition, in the Auto-DR sample, CPP sites have a lower operational setpoint than the DBP sites.

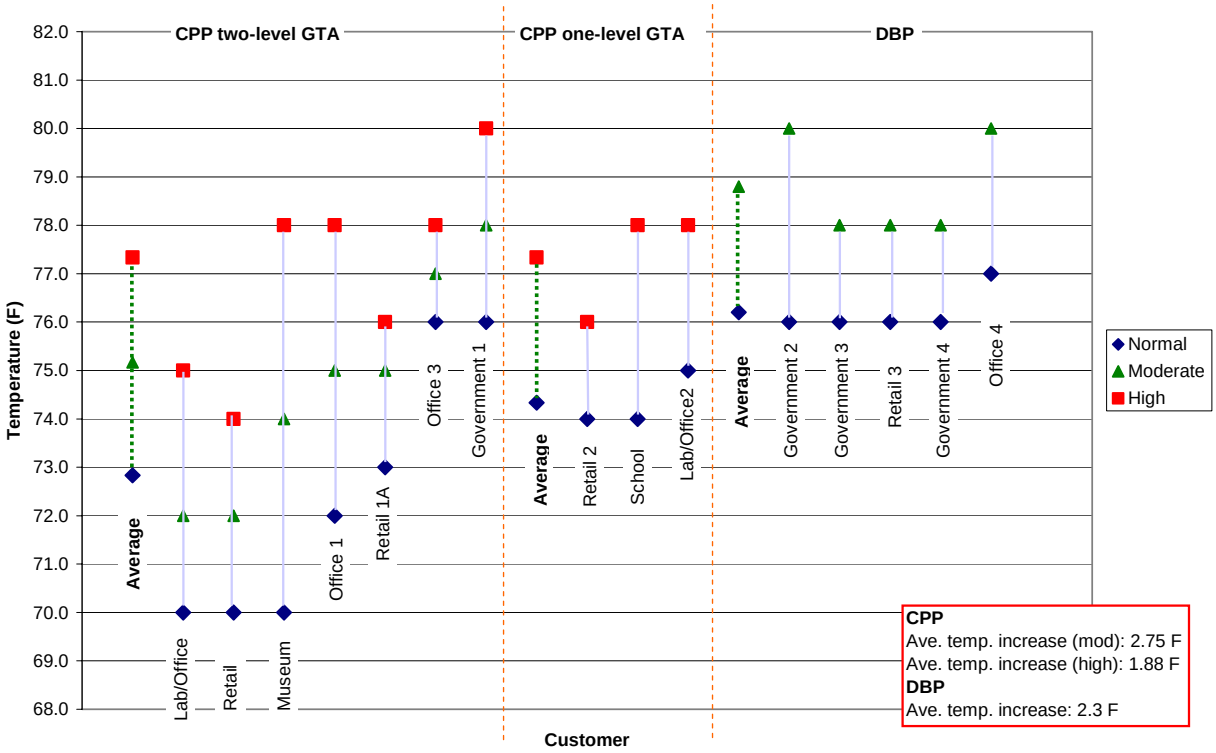

Figure 2. Global Temperature Adjustment for 2007 Auto-DR Sites

Auto-DR Communications Infrastructure

PG&E's Auto-DR system is built using Service Oriented Architecture (SOA) and XML (eXtensible Markup Language). The architecture consists of two major elements: demand response automation server (DRAS) and DRAS clients. There are two types of DRAS clients that communicate with the DRAS and initiate pre-programmed DR strategies:

1. Hardware clients: Client and Logic with Integrated Relay (CLIR) for legacy control systems that need hardware and software for their internet connectivity.
2. Software clients: Web Services (WS) software for control systems that are already linked to the Internet and have the capability to react on the signals sent by DRAS.

Auto-DR communications infrastructure for PG&E is illustrated in Figure 3. The steps involved in the Auto-DR process during a DR event include:

1. PG&E's DR event notification system calls for a DR event (typically triggered based on forecasted high temperatures or ISO grid conditions.
2. PG&E's InterAct Curtailment system sends these signals to the DRAS.
3. DR event and price information are published on the DRAS.
4. DRAS clients (CLIR or WS) request real-time event data from the DRAS every minute.
5. Customized pre-programmed DR strategies determine load shed actions in customer's facility based on event price/mode.

6. Facility Energy Management Control Systems (EMCS) or related controls carry out load reductions based on DR event signals and strategies. Customers can opt-out before or during the event.

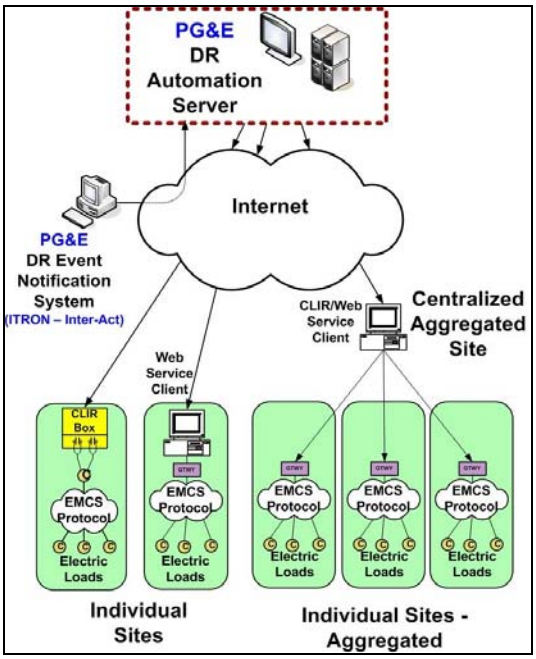

Figure 3. PG&E Auto-DR Technology Architecture

Auto-DR and Technical Coordination

Over the years, when Auto-DR was being tested and piloted, LBNL was instrumental in recruitment and technical assistance to each site. Researchers provided assistance in information technology (IT) related issues, communication set-up and DR strategy development, commissioning and optimization for each site. Three types of data were collected: interval meter data, trend logs of control points related to DR strategies and surveys with building operators. As the commercialization of the project was considered, it became clear that a group that had knowledge in both IT and building systems controls had to take over these responsibilities. For the sustainability of the Auto-DR enablement, the goal was to create a market for and interest in Auto-DR for the controls vendors to take over IT and building systems related tasks.

In 2006 after developing a qualifications procedure and interviewing several controls vendors, LBNL hired C&C Building Automation to start transferring expertise. Initially C&C Building Automation was referred to as the DR Integration Services Company, or DRISCO. Since the legacy customers from previous years were already set up, the DRISCO only assisted in the enablement of new customers. When the DRISCO was contracted, new customers were at various stages of recruitment and enablement. For a short period of time, the DRISCO shadowed LBNL to fully understand the recruitment, technology set up and participant feedback issues.

After this orientation, the DRISCO was asked to work directly with the customers and complete Auto-DR enablement.

In 2007, the DRISCO concept was replaced by technical coordination (TC) firms who were trained to help customers with Auto-DR enablement. Among the tasks identified by the team for successful commercialization of Auto-DR enablement, the following tasks, which were previously undertaken by LBNL researchers, were envisioned to be transferred to interested controls vendors which are trained and certified by the Auto-DR team to conduct these tasks:

- Conduct Auto-DR technical assessments and formalize customer participation
- Oversee and coordinate Auto-DR systems installations and process customer incentives
- Validate and test Auto-DR system installations
- Assess the results and make recommendations for future improvements

The involvement of control vendors into the Auto-DR enablement process was expected to develop a concept called "Hands-on TCs", where the TC in charge of installation coordination is also the control vendor for the site. By developing this concept, we expected to achieve efficiency in installation and reduction in overall costs as well as educating controls vendors in the field on DR issues and strategies. By contrast a "Hands-Off" TC does not directly touch or interact with the control systems.

TC Training Process

Eight TC firms went through a two-day Auto-DR training in May 2007. The DRISCO from 2006 pilot study was one of these firms. Except for one industrial controls company, all of the TC firms were commercial building controls contractors with varying building controls company affiliations. The first day covered PG&E's DR programs, rules, baseline models, plus estimated and actual reduction calculations which many of the TC incentive payments are based. The incentive structure was design to encourage continuous communication between the TCs and the customers through the summer DR season to ensure maximum demand reductions. A maximum of $70/kW was offered in three installments based on time and material cost for each site with the following payment structure:

- Equipment Installation: TCs receive their fist payment (subject to a $30/kW cap), after the Auto-DR equipment is installed and its operation is validated.
- First DR Event: After the customer has successfully participated in its first DR event of the season, the second part of the TC costs (subject to a $20/kW cap) is paid.
- End of Year: At the end of the DR season, the customer's actual performance is calculated and the third part of the TC costs (subject to a $20/kW cap) is paid.

The second day of training concentrated on technical aspects of the Auto-DR architecture and technology. Steps for delivering, installing and configuring software and hardware clients at each site were covered so that TCs could coordinate the installations and troubleshoot systems. TCs had a chance to work with CLIRs and learned about DRAS operations, especially how the DR signals are mapped for CPP and DBP.

Results of Working with TC Firms

On August 30th, 2007, PG&E called a CPP event and a test DBP event. Seventeen sites participated in Auto-CPP between noon and 6 pm and delivered about 600 kW of demand reduction. Eleven sites participated in the Auto-DBP test event between 2 pm and 6 pm and delivered about 10.7 MW of demand reduction. Figure 4 shows the aggregated load profile of the 28 automated sites that participated. The reduction was dominated by one site in the DBP program that delivered 9 MW of load reduction. The electric loads decrease at noon because the site that shed 9 MW starts an automated DR sequence 90 to 120 minutes before the event start time.

Three baselines were used to evaluate the demand reductions. For the Demand Bidding Program the baseline is called "3-10 baseline". PG&E looks at the last 10 business day (excluding holidays, weekends and DR event days) and picks the three days with the highest energy consumption during the DR period and averages them to calculate this baseline. LBNL calculates two additional baselines: 3-10 with morning adjustment and outside air temperature (OAT) regression baselines. The morning adjustment occurs when the baseline is lower than the actual load in the morning on the day of the event. In that case, a multiplier is applied that moves the baseline to the actual load level. This multiplier is the morning adjustment factor. OAT regression baseline incorporates the weather sensitivity of the facility into the baseline calculation method. (Coughlin et. al. 2008).

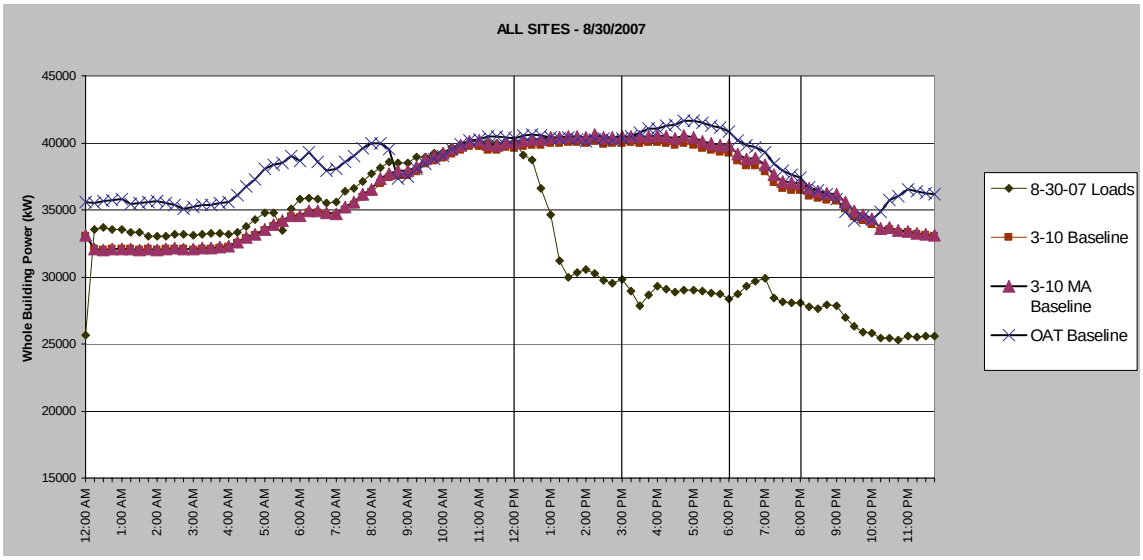

Figure 4. Results from August 30th, 2007

TC firms were instrumental in recruiting and enabling the sites for PG&E's Auto-DR program. Of the $70/kW total enablement budget provided to them, on average they used up 34% of the total available to them. Table 2 summarizes the TCs' involvement with Auto-DR sites in 2007. Of the eight firms that were qualified, four were assigned to customers. Assignments depended on the TCs' proximity to customers and their expertise on specific control systems. Some of the

TCs recruited their customers into the program and became "Hands-on TCs" while others were simply assigned to work with existing or newly recruited customers. Some TC's had many smaller sites each requiring individual attention and therefore increased the TC costs. Others worked with industrial sites that required additional expertise that made their services more expensive, but the concentrated effort for such high demand reduction resulted in less costly enablement.

Table 2. Summary of Technical Coordination Work

				DR Program			Client	
TC Firm	kW Enabled	$/kW	Number of Sites	CPP	DBP	CPP & DBP	CLIR	WS Client
TC1	2982	29	41	17	22	1	15	2
TC2	15175	4	3		3		3	
TC3	1568	42	13		12		3	1
TC4	2874	70	25		25			1
Total	**22599**	**19**	**82**	**17**	**62**	**1**	**21**	**4**

Table 2 outlines the TC enabled DR , cost of each enablement per unit demand (kW), number of sites each TC coordinated, DR programs which the customers were enrolled and the type of client installed at each site. Because of their industrial controls experience, TC2 was assigned to industrial sites which delivered large load reductions. TC4 worked with a retail chain to recruit, coordinate and enable their automation and used the maximum out of each pocket for TI funds. TC1 had the most sites because of their location and relationship with the legacy sites since they were the DR integration service company (DRISCO) in 2006. Overall, 21 CLIR boxes are installed at customer locations. Some customers use one CLIR box to control many of their sites. Other customers used one Web Services Client to control many sites together. In the case of TC4, they used one Web Services client to control 25 retail stores.

Table 3. Effort per Unit Demand by Customer Type

Customer Type	Shed (kW)	TC hours	Hr/kW
All Customers	22642	2159	0.10
New Industrial	15175	449	0.03
New Commercial	6116	1637	0.27
Legacy Industrial	100	5	0.05
Legacy Commercial	1251	68	0.05

TC effort by customer type is summarized in Table 3. After the new industrial customers, the legacy customers took the least time to coordinate and enable because they already had automation technologies in place from previous years. The additional time spent in 2007 was to update the existing systems with the newest CLIR box. New commercial customers require the most time to configure because they need assistance throughout installation and testing (and sometimes re-testing). New industrial sites have proven to be the least costly to automate for unit demand reduced because of the large demand reduction per site. Figure 5 displays the total cost per kW including the TC and installation costs (notice the x axis is logarithmic). The dashed line marks the upper limit for funds available from the program ($210/kW). In the future the program is expected to be more cost effective if sites are screen for delivery of the highest demand reduction with minimum installation effort. Thus, facilities toward the right of the x axis and

bottom of the y axis yield high demand reduction with less than average cost per demand reduced. Notice that some legacy customer Auto-DR installations have relatively high costs because either the systems did not operate as planned due to issues with the facility operators or the sites did not implement the appropriate strategies. Some of these sites had problematic baseline issues in measuring the demand response.

It is useful to evaluate additional trends in the data. Three of the sites shown with the circled dashed line were the "Hands-on" TCs (Retail1B, Retail4 and Office2. Retail4 is the cumulative demand reduction for 25 retail chain stores and the TC was the aggregator for the customer. For the other two participants, Retail1B and Office2, the cost of enablement and installation were $55/kW and $124/kW, respectively. Retail1B used a CLIR box to communicate with the DRAS while the Hands-on TC for Office2 had to develop a software client. At both sites the Hands-on TC concept worked and the project took less time than average to complete with less TC cost ($4/kW for Retail1B and $11/kW for Office2) than the average of $35/kW for new commercial buildings. The two government accounts, namely Gov1 and Gov2, have costs of less than $50/kW because they did most of their DR programming in-house.

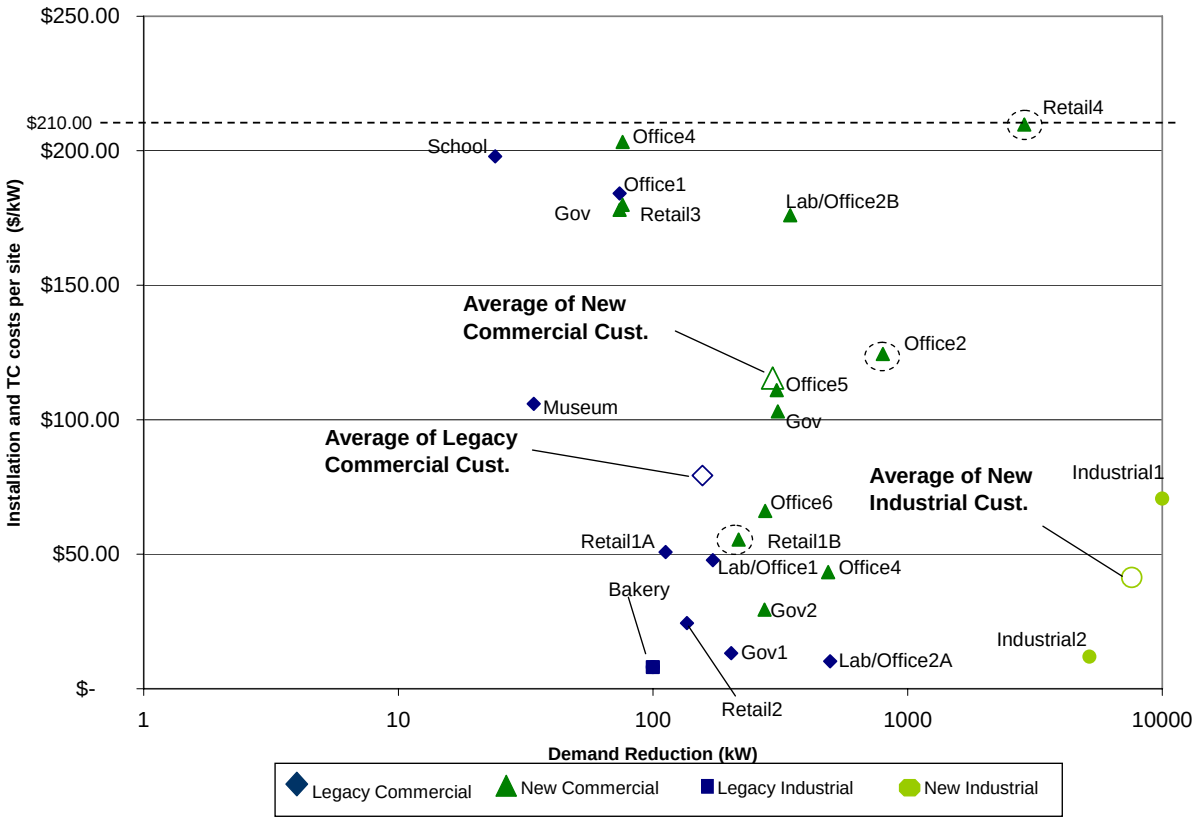

Figure 5. Cost per Demand Reduction ($/kW) by Facility Type

Customers who joined the Auto-DR programs were reimbursed up to $140/kW for the costs associated with the design, procurement, and installation of the Auto-DR supportive technologies

and measures. The costs can be group under three main areas: 1) installation of a CLIR box, 2) DR shed strategy development and programming, and 3) installation of new equipment or upgrade of the old equipment to accommodate automation. Table 4 summarizes the TC, installation and total costs. Median total cost of automation was $71/kW. The installation costs were lower for new industrial customers (median $37/kW) and higher for new commercial customers (median $94/kW). These costs are all within the $140/kW boundary set for installations from TI funds. Legacy customer installation costs were compiled from 2005 and 2006 pilot studies and TC costs form 2007 were added to calculate the total cost of automation. Overall, automation for all the sites were installed and enabled within the $210/kW allocated by PG&E's TA/TI program.

Table 4. Comparison of TC and Installation Costs

Customer Type	All Customers (N=82)	New Industrial (N=2)	New Commercial (N=66)	Legacy Industrial (N=1)	Legacy Commercial (N=13)
Shed (kW)	22642	15175	6116	100	1251
TC Cost ($)	$357,075	$59,021	$286,215	$800	$11,039
Installation ($)	$1,390,240	$709,706	$629,878	$0	$50,656
Av. TC $/kW	24	5	35	8	12
Min. TC $/kW	-	3	4	8	-
Max. TC $/kW	70	7	70	8	47
Med. TC $/kW	11	5	32	8	9
Av. Inst. $/kW	69	37	88	-	67
Min. Inst. $/kW	1	5	33	-	1
Max. Inst. $/kW	187	68	180	-	187
Med. Inst. $/kW	71	37	94	-	45
Av. Total $/kW	96	41	123	8	79
Min. Total $/kW	8	12	29	8	10
Max. Total $/kW	210	72	210	8	198
Med. Total $/kW	71	41	118	8	49

TC Plans for 2008

As part of the assessment of the Auto-DR program, one of the program partners at EPRI conducted a survey of the TC firms to determine their interest in this new technical service. The results of an informal survey indicate that all of the TCs would like to participate in the 2008 program. The knowledge gained by the TCs in 2007 will benefit future Auto-DR programs and future customers.

Conclusion and Future Directions

This paper summarizes the Auto-DR design and development between 2003 and 2006. It then describes PG&E's commercialization effort in 2007, Auto-DR technology being used, DR strategies being implemented by customers, and results from customer participation. It concentrates on the enablement process by describing the role of the Technical Coordination firms, and costs associated with the Auto-DR system enablement and automation installation costs. The key findings are:

- **TCs have been instrumental in achieving Auto-DR goals for 2007**. As the pilot program moved towards actual implementation, there was a need to find the appropriate market participants to take over the technical coordination role which was previously

provided by LBNL researchers. Selected and trained control vendors not only assisted in the enablement of their assigned sites but also made an effort to bring their customers into the Auto-DR programs.

- **TA/TI fund distribution was sufficient to fund TC activities.** TA/TI funds offered $70/kW and $140/kW to cover the TC and installation costs respectively. Median cost of TCs and installations were $11/kW and $71/kW respectively.

- **Hands-on TC Firms' involvement in installing and configuring the Auto-DR systems leads to efficiency in installation and reduction in overall costs as well as education of controls vendors in the field on DR issues and strategies**. During the course of the DR season, TCs worked closely with the customers, assisting them in defining control strategies for DR events. As these strategies were implemented and tested, TCs observed the customers reaction through follow-up interactions. They reported that some customers were keen in implementing an overall low power mode for their facilities which they could use at times other than DR events.

The Demand Response Research Center will continue to conduct research to facilitate broader implementation of Auto-DR systems in commercial and industrial facilities. The long term vision is to embed the automation clients and DR shed modes into new construction for inclusion in building codes. There is a need to educate building operators, plant managers, controls engineers, manufacturing engineers and control companies on the concepts of DR and the opportunities with automation. As utilities, ISOs, and energy service providers become more familiar with DR, moving towards automated DR will help improve making the demand side reductions more reliable and repeatable load reductions from their customers. Facility operators and engineers will turn to their controls vendors to deliver additional capabilities to the existing EMCS. The DRRC is working with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), National Institute of Standards and Technologies (NIST) and other organizations to build a de facto standard for DR event propagation based on the communication foundation of Auto-DR. Work is underway to develop a BACnet® (ANSI/ASHRAE Standard 135-2004) Web Services client that works with the proposed DR communication infrastructure for implementation in energy management systems. This effort is part of a broader plan to evaluate the feasibility of requiring this communications capability into new commercial buildings through California's Energy Efficiency Standards for Residential and Non-residential Buildings (Title 24) in 2011.

Another important element of future work on Auto-DR and technical coordination is to better integrate installation of automation systems with commissioning and retro-commissioning programs and processes. Proper selection of DR strategies and installation of automation equipment requires a good knowledge and understanding of building controls. Furthermore there is a need to retro-commission first to ensure HVAC and other building systems are operating as efficiently as possible prior to DR strategy implementation. Proper pre-DR commissioning should improve the performance of DR strategies because of better HVAC balancing, optimized comfort, and ideal equipment scheduling.

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