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Publication Date
2023-12-11

Peer reviewed

LBNL-2001004

Lawrence Berkeley National Laboratory

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Energy Technologies Area

May 2016

Presented at 2016 ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, California

Disclaimer

Acknowledgement

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. We also thank the California Energy Commission Public Interest Energy Research Program.

Comparison of Actual Costs to Integrate Commercial Buildings with the Grid

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ABSTRACT

During the past decade, the technology to automate demand response (DR) in buildings and industrial facilities has advanced significantly. Automation allows rapid, repeatable, reliable operation. This study focuses on costs for DR automation in commercial buildings with some discussion on residential buildings and industrial facilities. DR automation technology relies on numerous components, including communication systems, hardware and software gateways, standards-based messaging protocols, controls and integration platforms, and measurement and telemetry systems. This paper discusses the impact factors that contribute to the costs of automated DR systems, with a focus on OpenADR 1.0 and 2.0 systems. In addition, this report compares cost data from several DR automation programs and pilot projects, evaluates trends in the cost per unit of DR and kilowatts (kW) available from automated systems, and applies a standard naming convention and classification or taxonomy for system elements. In summary, median costs for the 56 installed automated DR systems studied here are about $200/kW. The deviation around this median is large with costs in some cases being an order of magnitude greater or less than median. Costs to automate fast DR systems for ancillary services are not fully analyzed in this report because additional research is needed to determine the total such costs.

Introduction

During the past decade, the technology to automate demand response (DR) in buildings and industrial facilities has advanced significantly. As the field grows and deployment of DR technology broadens, it is important to understand the costs and benefits of automated DR systems (Piette et al. 2015). We initiated research to develop low cost DR automation more than ten years ago. But the question remains, what are low cost automation systems? This paper focuses on defining and discussing costs and covers two key areas. First, we present a common taxonomy or classification of the requirements, metrics, and costs associated with automated DR technology, including the costs of hardware, software, and installation, and maintenance. Second, we provide examples from automated DR programs and pilot projects and discuss the trends in the costs of automating DR. DR programs provide financial incentives for customers to modify electricity use when requested by a utility, third party, or grid operator. Historically, DR has been used on hot summer afternoon and cold winter mornings. Recently, with the increased renewable energy, DR is being used to help address the effects of variable generation on the grid. DR can address challenges associated with increased penetration of renewable generation (Kiliccote 2010a). Increased flexibility of demand-side resources and availability of real-time signals from the electricity grid are key ingredients for successful supply/demand interactions.

With automated DR playing a growing role in grid modernization, it is important to understand the costs of automating DR. This paper provides a taxonomy of key elements in automated DR systems to aid researchers and practitioners in documenting and describing costs of DR automation in a consistent and comparable manner. Our overall goal is to improve understanding of these data and help drive down first costs. Although the data in this report are mostly from automated DR systems in California, some data from field tests outside California are included. This paper describes cost data for automating DR systems and begins with an introduction to the elements of the components and costs for these systems. We then present actual data from several years of case study work and full scale DR programs, followed by a discussion on low-cost systems for fast telemetry and ancillary services. We discuss key trends and summarize future directions in research.

Demand Response and Automation Technology

DR programs are typically managed by utilities, independent system operators (ISOs), third-party aggregators, or program administrators. Automated DR programs typically cover the first costs to design, install and configuration of building or industrial electrical loads to shift or shed demand in response to a signal. Automated DR has three key operational elements: **communication**, **control**, and **telemetry** (Figure 1).

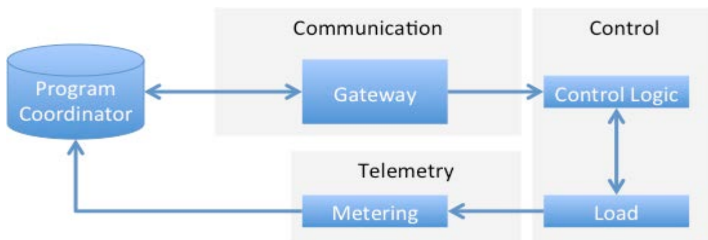

Figure 1. A common architecture of automated DR systems

Communication of Demand-Response Signals

Open standards allow multiple vendors to develop interoperable systems while minimizing the use of propriety standards that may result in vendor lock in. These open standards can lower the cost for technology by allowing a open completive market for technology. Experience with the development of OpenADR is described in Piette et al. (2010). Today, two main open communication standards are used for DR automation in California: Open Automated Demand Response (OpenADR 1.0 and 2.0) and the Smart Energy Profile (SEP 1.0 and 2.0) (Zigbee Alliance 2011, Piette et al, 2009, OpenADR Alliance 2013. These standards are propriety systems in use by aggregators, direct load control system developers, and technology vendors.

Demand Response End-Use Load Control

DR control occurs after a building receives a signal from the DR communication system through a gateway device and translates the signal into a control action, such as an electrical load shift or shed. In the case of residential or small commercial buildings with split systems or rooftop air-handling units, control strategies can include a relay that temporarily disables the compressors. Another option is installation of a “smart” programmable thermostat that can increase zone temperature set point for the duration of a DR event. Other cases include systems in which HVAC equipment is outfitted with control logic hardware capable of receiving remote messages and translating them to “low-power” operating modes. Where there are local relays or programmable thermostats, installed gateways are not always necessary because the devices can communicate via local Wi-Fi networks or other physical interfaces (e.g., ZigBee, cellular).

Demand-Response Measurement and Telemetry

The third group of elements in the DR automation system encompasses the electric meter, measurement systems, and communication of measured data. In most of California, DR automation costs do not include the meter or telemetry because most electric utilities have advanced meters and interval data that are collected for all customers (both those in DR programs and those that are not). Some DR programs require near-real-time power measurements, often called power measurement telemetry. Telemetry requirements for automated DR systems range from fast (such as four-second, real-time power measurements over dedicated system-operator networks) to slower, monthly electricity data from utility meters. There are three telemetry specifications for DR systems: measurement accuracy, communications speed, and data granularity (such as time stamps).

Characteristics that Impact Costs for Enabling Automated DR Systems

This section discusses costs of automated DR system for OpenADR 1.0 and 2.0 systems.

Communication Software - Stand-alone hardware and software are often required to receive DR signals. Many OpenADR communication systems use gateway boxes. Some control systems come with an embedded OpenADR software client where no additional hardware is needed. Early OpenADR systems used customers' existing Internet for communications. In other cases, new DR communications includes installing new or dedicated Internet connections.

Controls - One element that contributes to cost of DR automation is the purchase of control hardware or software. During the first few years of OpenADR field trials, most test sites incurred no extra costs for controls because existing controls were used. Programming was needed, which entailed labor, but no additional control systems were installed. Recently, many utility DR programs have covered costs for control system upgrades. Software programming costs are entailed in automating most DR systems.

Labor - Labor costs to design and configure OpenADR communications and DR control system logic can include up-front engineering, installation by a technician, and commissioning tests. In some cases, the hardware contractor is qualified to make changes to controls. In these cases, a control expert must be retained to program the changes to the building control sequences.

Telemetry – Telemetry for some DR programs is a smart meter. In California's ancillary services market, DR resources need to connect to the California ISO (CAISO) energy controls network (ECN) with a network service connection contract (Kiliccote et al, 2014). A schematic of this system is shown in Figure 2. Cellular data services can be an attractive option for telemetry. Cellular data can allow a utility or energy service provider to provide a DR enabling package (e.g., ship a "connected switch for the building occupant to install) (Cadmus 2013) that is "plug and play," requiring no setup. Examples of these costs are shown below. Cellular telemetry is economically attractive when network connectivity is not available at the point of install for the DR telemetry device. Using OpenADR 2.0b over a cellular data connection is relatively data intensive for ancillary services applications. Smart meters are capable of providing 10-second data to an SEP device, and these data can be ported over to an aggregator. The Open smart energy gateway (OpenSEG), linking to the smart meter, is an open-source data platform designed to work with ZigBee SEP 1.x to provide consumers with access to the most recent 48 hours of their data (Page et al. 2015). Data are stored locally in a circular cache. These systems may cost less than $100 to install.

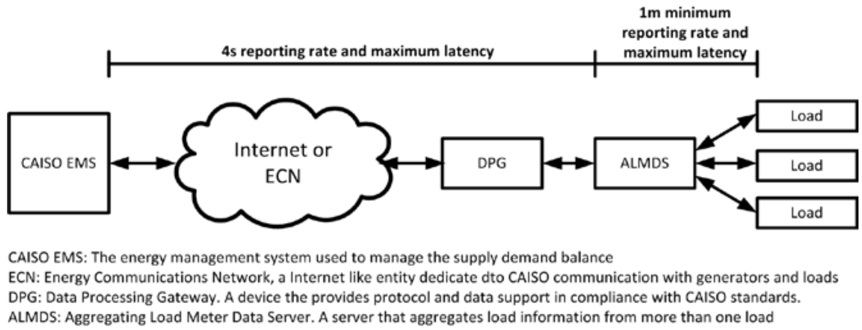

Figure 2. CAISO communication latency and reporting requirements for aggregated loads

An Accounting Framework for Automated Demand-Response Costs

Given the highly variable nature of the costs of enabling AutoDR, it is important to develop a framework that can help program administrators compare and contrast these costs among various programs. Table 1 shows 11 categories of costs that might be involved in automating a DR system. These costs encompass first costs of installing and configuring the AutoDR application and do not include program administration or system maintenance costs. In general, it is less expensive to automate DR in newer buildings that have newer control systems.

Table 1. Proposed accounting framework for cost of enabling AutoDR capability

	Price	Quantity	Total Cost
System Evaluation, Design, Commissioning			
Labor	$x/hr	y - hrs	xy
Communication			
Communication Service	$x/year	yr	xy
Hardware (Gateway)	$x	y	xy
Software (Client)	$x	y	xy
Configuration Labor	$x/hr	y - hrs	xy
Controls			
Equipment	$x	y	xy
Installation Labor	$x	y	xy
Controls Programming	$x/hr	y - hrs	xy
Telemetry			
Hardware (meters, meter comm.)	$x	y	xy
Installation Labor	$x/hr	y - hrs	xy
Configuration Labor	$x/hr	y - hrs	xy

Field Data on Costs of Automated Demand-Response Systems

For this study, we reviewed cost data from several DR pilot programs carried out during the past 10 years. These programs ranged from residential direct load control to enabling AutoDR in small and large commercial buildings. The biggest challenge in making these comparisons is the variation in what is included in the costs. Where possible, we reference the categories shown in Table 3. Table 4 gives data on the cost of enabling AutoDR from six sources. The costs vary by more than a factor of 5, from $73/kilowatt (kW) to $373/kW. We briefly summarize each of the data sources. To improve our ability to compare, we have converted the data to 2015 constant dollars. This is about a 13% increase for the 2007 costs to 2015 values. The values were converted from the published cost in their respective project year to January 2015 dollars using the Consumer Price Index (CPI)[1].

Table 2. Summary of $/kW for AutoDR systems, in 2015 constant dollars

	Avg $/kW	# of sites	Type of automation and sites
PG&E 2007*	$108	82	School, Retail, Commercial, Industrial (OpenADR 1.0)
Bonneville Power Admin- Seattle City Light 2009	$117	5	Small/Large Commercial Buildings (OpenADR 1.0)
New York State Energy Research and Development Authority 2013	$373	4	Large Commercial / High Rise (OpenADR 1.0, Unique Platform)
PG&E 2013-2015	$362	25	Small Commercial / Large Commercial (OpenADR 2.0)

Pacific Gas and Electric Company 2007

Previous study described the categories of costs involved in installing and commissioning OpenADR systems (Kiliccote et al, 2008a). Those costs included labor, hardware, software, and configuration. Most of the sites used automation existing controls using an early low-cost gateway. Figure 4 and Table 5 show the cost data for these sites. At the time of this program, up to $300/kW was available to install DR automation, to cover the following types of costs:

- **Up to $40/kW for Recruitment –** For a recruiter as an incentive to participate.
- **Up to $140/kW for Installation –** This covered hardware and software.
- **Up to $70/kW for Technical Coordination –**The TC worked vendors as needed.
- **$50/kW Payment to the Customer –** Customers were paid a one-time incentive.

Recruitment and installation costs were paid based on an estimated demand reduction. Portions of technical coordination (TC) (30%) and customer (50%) payments were based on actual demand reduction. Figure 4 shows data for 23 AutoDR sites from a paper published by Kiliccote et al. (2008). The data here are in the original year's dollars (2007). The X axis in Figure 4 is a log scale. One large site provided a 10-megawatt shed at a single site. The costs can be grouped into three main categories: 1) CLIR box installation, 2) DR shed strategy development and programming, and 3) installation of new equipment or upgrade of old equipment to accommodate automation. Median total cost of automation was $71/kW. Installation costs were lower for new industrial customers (median $37/kW) and higher for new commercial customers (median $94/kW). These costs are all below the $140/kW limit set by the DR program. Legacy customer installation costs were compiled from 2005 and 2006 pilot studies. TC costs from 2007 were added to calculate the total cost of automation. Overall, automation for all the sites was installed and enabled within the $210/kW allocated by PG&E's technical audit and technical incentive program. We have found that many of the providers organized the installations to take greatest advantage of the technical audit and incentive payments, making it difficult to understand the range of costs required to install the automation.

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[1] All costs in Table 4, Fig. 7, 8 and 9 are converted to 2015 cost, other graphs and tables taken directly from previous papers are historical values. For 2015 data we used most recent published value when the data were collected, which was January 2015 CPI.

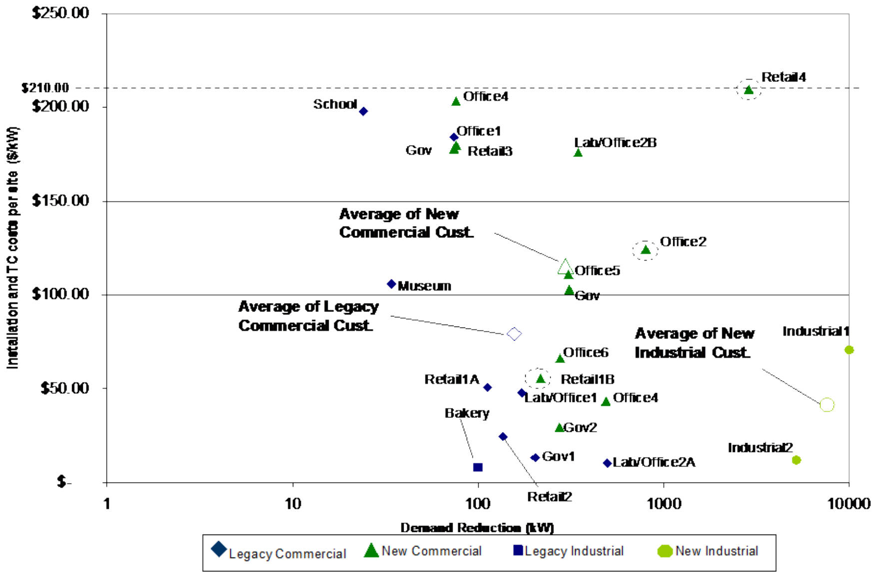

Figure 2. Costs for automated DR systems for 23 facilities in 2007 dollars

Table 3. Summary of $/kW for early PG&E AutoDR programs, in 2007 dollars

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

Bonneville Power Administration - Seattle City Light Study AutoDR Project 2009

In 2009, we worked with the Bonneville Power Administration (BPA) to enable AutoDR in five commercial buildings in the Seattle City Light (SCL) territory, with the goal of reducing cold-winter-morning and hot-summer-afternoon peak electricity demand. Table 4 shows the reported costs, which included labor, hardware, software, and configuration. The project started with cold-winter-morning DR. The table shows two sets of costs, winter (highlighted) and summer, for each building. The pilot program offered incentives for fully automated DR. The project partner, McKinstry, recruited customers with energy management control systems that were also already on SCL's MeterWatch meter data collection and monitoring system, so no telemetry costs were incurred. The costs of programming the BAS are included in the controls costs. These would have been lower if the winter and summer DR strategies were pre-programmed at the same time.

Table 4. Costs for AutoDR Systems in Bonneville Power Administration - SCE Study.

Site	Controls Vendor	Controls Cost	Material	Electrical Labor	Commissioning DR Strategies	Total	Total ($/kW)
McKinstry	ATS	$ 3,780	$ 1,064	$ 1,005	$ 1,071	$ 5,915	282
		$ 2,470	$ 200	$ 609	$ 1,530	$ 4,200	105
Seattle Municipal Tower	Siemens	$ 4,007	$ 1,500	$ 1,005	$ 1,071	$ 6,578	13
		$ 6,800	$ -	$ -	$ 1,530	$ 8,330	46
Target (both stores)	ALC	$ 6,500	$ 1,582	$ 2,000	$ -	$ 8,082	40
		$ 2,850	$ -	$ -	$ -	$ 2,850	10
Seattle University	ESC	$ 2,783	$ 1,000	$ 1,005	$ 1,071	$ 4,854	40
		$ 6,975	$ 927	$ 2,438	$ 1,530	$ 9,432	269

Highlighted rows indicate winter costs.

The costs vary from $10/kW to $282/kW. The cost for the Target stores was among the lowest for all of the sites described in this report because Target had OpenADR 1.0 available in their automated logic control system. Because Target had extensive experience with OpenADR in other buildings, it was easy to configure the buildings for this demonstration. The overall program costs ranged from $76/kW for winter DR to $108/kW for summer.

Table 5. Costs for AutoDR Systems in the BPA – Seattle City Light Study, in 2009 dollars

	Winter	Summer
Average demand reduction (kW) for each DR event	767 kW	338 kW
Total energy savings from four DR events (kWh)	8,589 kWh	6,455 kWh
Average per customer cost for control and commissioning	$4,057	$4,962
Average control and commisionning cost per kW (one time)	$76/kW	$108/kW

New York State Research and Development Authority Automated DR Project

Between 2011 and 2013 we worked with the New York State Energy Research and Development Authority (NYSERDA) to demonstrate AutoDR project in large commercial buildings in New York City, using OpenADR communication protocols. As part of the demonstration, facility managers for four buildings in New York City were given granular, equipment-level, opt-out capability to ensure full control of their sites during the AutoDR implementation. The expected bill savings ranged from 1.1% to 8.0% of the total dynamic pricing bill. The automation and enabling costs ranged from $70 to $725 per kW shed. The costs in one of the buildings were unusually high because it was an educational facility, and managers were never able to perform full-scale load-sheds because of conflicts with classroom schedules. It is likely that the university and colleges will need more time to develop shed strategies because of their complex schedules.

Pacific Gas and Electric 2013-2015

Lawrence Berkeley National Laboratory (LBNL) collaborated with PG&E from 2013 to 2015 to track AutoDR implementation costs in several commercial buildings. Figure 5 shows the costs per kW of enabling AutoDR, plotted against the kW of load-shed enabled. These costs include labor, hardware, software, and configuration and may be higher than at some of the previously described sites for two reasons. First, these are the first data collected for OpenADR 2.0, which is more sophisticated than OpenADR 1.0. We expect costs to install these systems to come down as more experience is gained. Second, as shown in green in Figure 7, several of these sites undertook control upgrades in response to incentives for upgrades that would reduce overall energy use. The blended costs at these sites make it difficult to compare AutoDR costs only.

Comparison of Costs for AutoDR Systems for Seasonal Grid Stress

In this section we describe how the costs to install automated DR systems compare among projects from BPA, NYSERDA, and PG&E. Figure 5 shows the data from 56 individual building and industrial facilities. The X-axis of kW shed for each site uses a log scale to accommodate the large 10 MW site. As previously mentioned, the newer PG&E data show higher $/kW. There are two elements to this. First, these sites use the newer, more sophisticated OpenADR 2.0. It is likely that the costs to install these systems will decrease over time because we anticipate more competition on the market for these products. Second, a number of these systems include energy efficiency control system upgrades as part of their project. As mentioned before, the BPA's Target sites had low costs because the DR automation was available through the control system and Target had prior experience with OpenADR. The NYSERDA costs are relatively high because of complexities of the New York buildings and the structure of the incentives. One trend we see is lower $/kW for larger systems. In general if a DR load-shed is large, the total $/kW is likely to be lower because the cost for audits, labor, gateways, and configuration are similar regardless of the size of the load. In order to have a more realistic assessment of the DR cost, we trimmed the cost outliers in two ways. In the first case, the outliers are defined as the five highest $/kW and five lowest $/kW. In the second case, the outliers are defined as four highest $/kW and four largest kW. Figures 9 show the cost data for with trimmed data set with the high kW shed sites removed. The trends show the strong reduction $/kW with shed size. However it is worth noting that all of the more recent OpenADR 2.0 sites did not provide reductions greater than 300 kW, so the data sets cover different ranges of shed capabilities. The summary statistics of the entire data set and the trimmed data sets are shown in Table 6 and Figure 5. The average cost reduced from $355/kW to about $260/kW after trimming the outliers in both methods. There's still a wide range within the cost data, but the standard deviation is reduced almost in half. The median costs for DR automation are about $200/kW with all three samples.

Table 6. Costs for AutoDR Systems in BPA– SCL Study, in 2009 dollars

Number of Observations	48
Average ($/kW)	260
Minimum ($/kW)	8
Maximum ($/kW)	980
Stand Deviation ($/kW)	254
Median ($/kW)	200

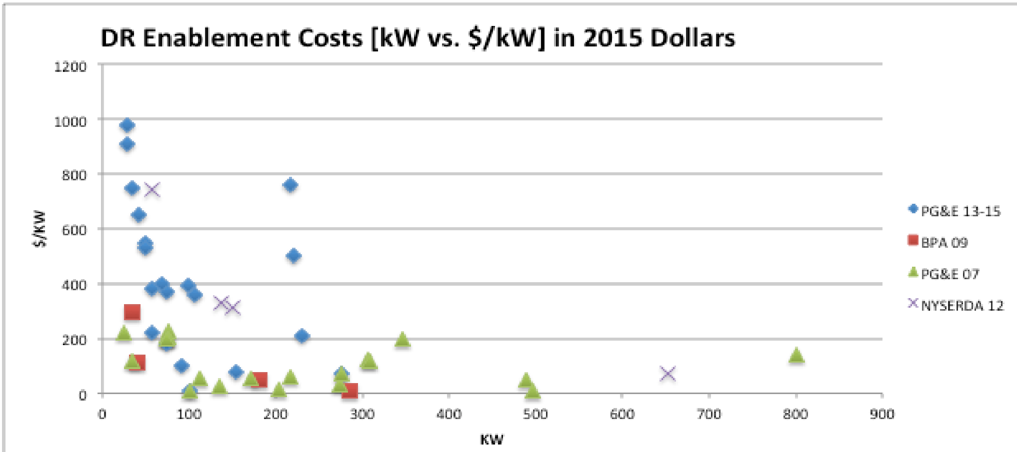

Figure 5. Costs for AutoDR systems from 2007 to present from PG&E, NYSERDA, and BPA

Comparison of Costs for AutoDR Systems for Ancillary Services

Reporting the cost of AutoDR systems for ancillary services participation is even more complicated than reporting cost as described previously for straightforward DR participation. There are additional set-up and ongoing operational costs for a load-serving entity or scheduling coordinator; these are approximately $25,000 for the former, and $2,000 to 10,000 for the latter, for Proxy Demand Resource (Kiliccote et al. 2015). For the Participation Load model or Non-Generating Resource, there are varying telemetry requirements, so the customer will incur additional telemetry installation and configuration costs and the requirements for the speed of the telemetry change for different services. In addition, there are monthly secure communication connection costs. In a study funded by the US DOE Advanced Research Projects Agency-Energy, we evaluated the costs of participating in ancillary services markets using cellular data networks to pass data to the ISO or program coordinators. The team evaluated two cases: participation in regulation markets that require four-second telemetry and participation in spinning reserve markets that require one-minute telemetry. Table 7 shows the data required for regulation and spinning reserve services in California when using OpenADR 2.0b, and it also shows the data cost and typical compensation values for the services. The last line of the table shows the data cost divided by the compensation, which indicates a break-even point for the minimum load under control, for the given participation payments and data transmission costs.

Table 7. Costs of automating DR for regulation and spinning reserve products

	Regulation (4s)	**Spinning Reserve (1m)**
Data/hour (in megabytes [MB][1]	15 MB	1 MB
Cellular data cost / h[2]	$0.73	$0.05
Compensation[3] /kW per hr	$0.007	$0.004
Minimum load under control	420 kW	49 kW

[1] Based on measured results using OpenADR2.0b HTTP method; XMPP is ~25% better. [2] Cellular data costs using $5x10^{-8}$/B from Verizon; public data show $4x10^{-7}$/B, [3] MacDonald et al. 2012.

As part of the project, an LBNL-led team developed a series of pilot deployments that demonstrated the low-cost potential of an integrated AutoDR solution using OpenADR small loads and buildings. The prototype system combined all three elements – communication, control, and telemetry – into a single package and showed how such a system could be deployed and controlled by DR program operators. Of note, the system leveraged the home area network available in PG&E smart meters for telemetry (4-second readings), and combined an embedded PC with a thermostat to offer both communication and control. Tables 8 describes the cost of the prototype and the communication, control, and telemetry.

Table 8. Costs of DR automation: ancillary services for small commercial buildings

Electric Meter			Use smart meter connection such as OpenSEG		
	LBNL Prototype	**Engineered System [2]**		**LBNL Prototype**	**Engineered System [2]**
Elec Meter Hardware	$700	$200	Meter Connectivity	$50	Included in thermostat
Embedded PC	$50	Included in thermostat	Embedded PC	$45	Included in thermostat
Wi fi Thermostat	$200	$100	Wi-fi Thermostat	$200	$100
3G modem	$400	Included in thermostat	3G modem	$400	Included in thermostat
Installation[1]	$1,200	$1,200	Installation	$200	$200
Total	**$2,600**	**$1,500**	**Total**	**$895**	**$300**
Enablement $/kW [2]	**$170**	**$100**	**Enablement $/kW [1]**	**$60**	**$20**

Discussion and Trends in Costs for DR Automation

This study shows that data on the costs of automating DR systems are complex and affected by a number of factors, such as the requirements of the program, existing conditions, and ease of installation. In this analysis, costs are also influenced by the fact that many providers organized installations to take greatest advantage of utility incentives, which made it difficult to understand the costs required to install the automated systems in that program. Some projects in that same program also included control system upgrades that saved energy beyond the automated DR capabilities; in those cases, it was difficult to separate the AutoDR costs from the overall retrofit costs. From a building owner's perspective, the goal of such a project is to reduce utility bills, so the owner has no motivation to distinguish between energy-efficiency and DR costs. Another factor is that we are only beginning to see with the deployment of OpenADR 2.0 is the difference in costs between OpenADR 1.0 and OpenADR 2.0, with higher costs for OpenADR 2.0. This is likely to be related to the larger variety of available systems and greater variety of control upgrades in OpenADR 2.0. The costs for the automated DR systems are related to the scope of the DR automation, size of load reduction, version of OpenADR protocol, and typeof DR.

The majority of the field data evaluated in this study are based on programs that are providing DR for seasonal grid stress, such as hot summer days or cold winter mornings. We did find that the winter DR was similarly priced as the summer DR automation. The DR for ancillary services requires more sophisticated systems with higher costs. One of the original goals of the DRRC's DR automation research was to develop interoperable software to reduce the costs of automated DR systems. If OpenADR is included in a building or facility native control software systems, no additional hardware is required to automate DR. Some of the lowest costs per kW observed in these data sets is the BPA Target site where the DR automation was available in the native control system. The BPA data were OpenADR 1.0 systems. We have yet to seen this cost reduction in OpenADR 2.0. As noted previously, the newest version (2013) of the California Building Code, Title 24, which took effect in 2014, requires AutoDR capabilities for lighting; HVAC; and electronic messaging centers (CEC 2014). The cost to automate DR in buildings that comply with the 2013 building code may be far less than the costs required for retrofitting an existing building. This is a new requirement and there are minimal data on the cost savings for the code requirements compared to retrofits of automated DR systems. In regards to ancillary services, while the opportunity to develop low-cost, fast DR automation is clear, there is little experience with these systems at scale because the DR markets are just emerging. Initial products tests show that these systems can be developed for less than $100/kW, compared to the current costs which can be a factor of ten higher. Set up costs for California's Proxy DR program in the Intermittent Renewable Management Pilot Phase 2 (IRM2) are about $25,000 per site. A site can produce 100 kW or 1 MW. Thus the 100 kW site is already requiring $250/kW just for the scheduling coordinator (Kiliccote et al, 2015). Through the experience gained from recent pilots of fast DR systems, we are moving from understanding feasibility and controls and communications issues to quantifying costs. PG&E's IRM2 pilot is the first in which the costs related to CAISO participation are reported. That pilot provided capacity payments, and the utility covered the scheduling coordinator costs to incentivize participation while also reporting on the scheduling coordination costs.

Summary and Future Directions

To drive broad adoption of automated DR systems, it is important to understand the costs associated with their installation. This paper compares cost data from several DR automation programs and evaluates trends in the costs per kW of load-shed. We summarize the types of costs entailed in installing and enabling AutoDR systems, documenting widely varying costs in several pilot projects and utility programs. Median costs are about $200/kW with more than a factor of 10 difference in minimum and maximum costs from the field data. The wide range is a result of the variety in the systems, including system capabilities, age of controls, scope of communication systems, complexity, and other factors. Future research should explore the total cost to install, operate, and maintain these systems. Ownership and operational costs of these systems should include the building or facility manager's costs as well as those of the utility or third-party program manager. Cost comparisons can only be made if there are standard methods of defining the costs for hardware, software, installation, configuration, and commissioning. We propose adoption of a standard accounting practice that will enable comparison of the costs of enabling AutoDR and allow for analysis to identify the category of building stock best suited for AutoDR systems. The lowest cost sites are those with DR automation software embedded in controls. These lower costs may continue to become common as standardization in DR automation continues and vendors provide native DR in software. Similarly, the existence of new building code requirements for DR automation may reduce costs. Further work is needed to better understand the costs to automate demand response. This study provides an initial framework for this topic. More data from a broad set of utility programs should be collected.

Acknowledgments

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Office, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. We also thank the California Energy Commission Public Interest Energy Research Program.

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