Fast Demand Response Technologies and Demonstration at SDG&E Energy Innovation Center using OpenADR

Prepared for

SAN DIEGO GAS & ELECTRIC COMPANY

Christopher M. Roman
Project Manager

Prepared by

Rongxin Yin and Douglas Black, Ph.D.

LAWRENCE BERKELEY NATIONAL LABORATORY
Berkeley, CA

Michel Kamel, Ph.D.

MelRok, LLC

Santa Ana, CA

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Disclaimer

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Acronyms

- AutoDR	Automated Demand Response
- AMI	Advanced Metering Infrastructure
- BMS	Building Management System
- CAISO	California Independent System Operator
- DRAS	Demand Response Automation Server
- DR	Demand Response
- EIC	Energy Innovation Center
- HVAC	heating, ventilation and air conditioning
- IOU	Investor-owned Utility
- ISO	Independent System Operator
- kW	kilowatt
- kWh	kW hour
- LBNL	Lawrence Berkeley National Laboratory
- OpenADR	Open, standards based, internet protocol for implementing AutoDR
- RPS	Renewables Portfolio Standard
- SDG&E	San Diego Gas & Electric

Executive Summary

Demand response (DR) – allowing customers to respond to reliability requests and market prices by changing electricity use from their normal consumption pattern – continues to be seen as an attractive means of demand-side management and a fundamental smart-grid application that links supply and demand. Fast DR is defined as demand-side resources that respond to the signals without advanced notification and with fast response time (seconds to minutes). The major challenges fast DR enablement are the response speed of controllable end-uses to the fast DR signal and the measurement of response capacity.

CAISO's fastest ancillary service product is frequency regulation, which requires a 4-second response time. Automation and appropriate communication infrastructure between responding customers and grid operators is required to enable 4-second response. AutoDR is machine-to-machine enablement of DR in response to grid signals without a human in the loop (Piette et al., 2005). Fast load response through the building management system (BMS) is a critical component in fast DR. AutoDR is implemented as OpenADR (Open Automated Demand Response, a nationally recognized communication standards), an Internet protocol that is used to communicate with demand-side end-uses to automatically reduce demand during DR program events.

Kiliccote et al. (2014) developed fast DR measurement and communication technologies, which are scalable cost-effective demand response tools with sufficient reliability for real-time control and monitoring of loads over the Internet. The fast DR test demonstrated 4 seconds regulation services a synchronized load control and the results showed that fast DR is capable of control to response in 4 seconds and load complete transition in seconds to less than one minute depending on load type. MacDonald et al. (2014) demonstrated commercial building loads providing ancillary services in the PJM market. However, from the perspective of the DR market, current fast DR systems are expensive due to extreme reliability constraints in telemetry, control, and metering. The typical cost of enabling a site for fast DR participation in regulation services range from $50k to $80k (Kiliccote et al., 2014), which is too high for small loads to participate in high-value grid services.

In this study, we demonstrated a fast DR system architecture for DR resources participation in ancillary services using the OpenADR 2.0b. One objective was to measure if response time would be 4 sec or less, with response time defined as time to send signal, get response, and communicate back to server. This project examined the following performance characteristics of the DR resource: the speed of response, communication latencies in the architecture, and the accuracy of response.

The test site was the SDG&E Energy Innovation Center (EIC), a retrofit of a 1950s era building that earned the LEED Platinum® certification in 2012. It is a showcase facility where residential and business customers can learn about efficiency, the Smart Grid, and clean generation[1]. Key features at the center include highly efficient lighting, advanced control of HVAC systems, solar photovoltaic (PV) generation, and battery storage in the energy technology areas. The facility's ADR platform is embedded with OpenADR 2.0b and energy monitoring capability.

The project focused on the following:

[1] SDG&E Unveils Energy Innovation Center in San Diego, http://www.sdge.com/eic

- Demonstrating how OpenADR can automate and simplify interactions between buildings and OpenADR providers (OpenADR cloud server);
- Automating building control systems to provide event-driven fast demand response, and, in this case, with OpenADR signals;
- Providing fast DR solutions (less than 4 seconds) to customers that enable participation in ancillary services using the OpenADR 2.0b protocol.

Methodology

This project demonstrated a fast DR test of fans and AC units through the OpenADR 2.0b protocol and investigated a variety of issues that arose in the field test planning and execution. The methodology for this demonstration project included a site audit, control strategy development, automation system deployment, and performance evaluation of the site's participation in fast DR test events.

Results

- SDG&E EIC was enabled to respond to DR events and day-ahead hourly prices using OpenADR protocols.
- During the Fast DR test, response times of less than 4 seconds were measured.

Recommendations and Future Directions

Based on the test results observed here and anticipated near term market changes, additional fast DR tests should include DR integration with other resources (e.g. solar and storage) at the site. A next step to this project would be to demonstrate a variety of transactions between the demand-side resource and different DR market products, such as capacity reserves, frequency regulations, and real-time electricity price. With respect to the OpenADR 2.0b, there are still a few features to be demonstrated in the future tests, especially the reporting of energy use through OpenADR.

Introduction

Background

Across the US electrical market, the survey results show that the total potential demand response resource contribution from existing programs is estimated to be about 37,500 MW. In recent years, demand response has begun to be considered to directly supply reliability services to the power system with the advanced communication and control system. California market electricity structure provides several mechanisms intended to encourage customers to reduce their impact on the grid through DR. Such mechanisms include demand response programs, load shifting incentives, and curtailment programs. As of December, 2015, the DR capacity of all DR programs for California investor-owned utilities (IOUs) was about 2200 MW (CPUC, Demand Response Monthly Report)[2].

Today, the California Renewables Portfolio Standard (RPS) requires investor-owned utilities (IOUs), electric service providers, and community choice aggregators to increase procurement from eligible renewable energy resources to 33% of total procurement by 2020. Among those, percentage of RPS procurement provided by SDG&E will be 38.8% by 2020. The use of flexibility of demand-side resources and availability of real-time signals communication in the electricity grid addresses major challenges related to renewable generation penetration: over generation during low-load hours; steep and unpredictable ramps; forecast errors associated with renewable generation; and intra-hour variability of renewable resources (Kiliccote et al., 2010; Olsen et al., 2013). Some studies (Kirby, 2007; Callaway, 2009) have argued that a number of small DR resources are well suited to provide ancillary services to the grid. And, a number of field studies have been conducted to show DR capability for providing ancillary services (Eto et al., 2007; Kiliccote et al., 2009; Eto et al., 2012; Ma et al., 2013; Sullivan et al 2013). California ISO has proposed the proxy demand resource product that enables aggregators to offer demand response resources directly into the wholesale energy and ancillary services market and allow non-generator resources to bid their 15-minute capacity into the regulation market as well [3]. There are various types of ancillary services, including frequency control, voltage control, spinning reserve, standing reserve, operating reserve, black start capability, remote generation control, grid loss compensation and emergency control actions. Among these, two types of ancillary services products that DR is particular suited to are contingency and operating reserves.

Fast DR is defined as demand-side resources that respond to signals without advanced notification and with fast response time (seconds to minutes). Some major challenges of fast DR enablement are response speed of controllable end-uses to fast DR signals and the measurement of response capacity. CAISO provides specific telemetry requirements that include remote measurement and communication response times, the shortest being four seconds for regulation up and down ancillary services. The fast response requires the automated demand response (AutoDR) action on the demand side resource and the communication infrastructure between customers and grid operators. AutoDR is machine-to-machine enablement of DR in response to grid signals without a human in the loop (Piette et al., 2005). Fast load response through the building management system (BMS) is a critical component in fast DR. OpenADR (Open Automated Demand Response Communication Standards) is an Internet protocol that

[2] California Public Utilities Commission, Demand Response Monthly Report, http://www.cpuc.ca.gov/
[3] California ISO, http://www.caiso.com/informed/Pages/StakeholderProcesses/DemandResponseInitiative.aspx

is used to communicate with demand-side end-uses to automatically reduce demand during DR program events (OpenADR Alliance; Piette et al., 2009; Ghatikar et al., 2014).

Current fast DR systems are relatively expensive due to extreme reliability requirements in telemetry, control, and metering. The typical cost of enabling a site for fast DR participation in regulation services range from $50k to $80k, which is too high for small loads to participate in high-value grid services. Kiliccote et al. (2014) developed fast DR measurement and communication technologies, which are scalable cost-effective demand response programs with sufficient reliability for real-time control and monitoring of loads over the internet. The prototype system combined all three elements (communication, control, and telemetry) into a single package. The cost of the total package is about $100. The fast DR test demonstrated 4 seconds regulation services a synchronized load control and the results showed that fast DR is capable of control to response in 4 seconds and load complete transition in seconds to less than one minute depending on load type. MacDonald et al. (2014) demonstrated commercial building loads providing ancillary services in the PJM region. In this study, the following performance characteristics of the DR resource were examined: the speed of response, communication latencies in the architecture, and the accuracy of response.

The goal of this study was to demonstrate a low cost fast DR system architecture for DR resources participation in ancillary services using the OpenADR 2.0b protocol and to prove the capability for 4 second or shorter response time (including time to send signal, get response, and communicate back to server). The test site was SDG&E Energy Innovation Center (EIC), a retrofit of a 1950s era building that earned the LEED Platinum® certification in 2012. It is a showcase facility where residential and business customers can learn about efficiency, Smart Grid, and clean generation[4]. Key features at the center include highly efficient lighting, advanced control of HVAC systems, solar photovoltaic (PV) generation, and battery storage. The ADR platform used in the demonstration has the integrated OpenADR2.0b client and energy M&V capabilities.

This report is organized as follows: In the methodology section we describe site information, the Auto-DR system architecture, and all details relating to site enablement and testing. In the test design section, we describe the test case matrix of fast DR and coordination with SDG&E and Melrok. In the results section we describe our fast DR communication results as well as load shed analysis, and feedback from the site. Finally, we conclude with a summary of project findings, and next steps for research.

Goals and Objectives

From January 2015 to December 2015, the Lawrence Berkeley National Laboratory (LBNL), San Diego Gas & Electric (SDG&E), and MelRok conducted a demonstration project enabling Fast DR at SDG&E Energy Innovation Center (EIC).

The project focused on following objectives:

- Demonstrating how OpenADR can automate and simplify interactions between buildings and OpenADR providers (OpenADR cloud server);
- Automating building control systems to provide event-driven fast demand response, and, in this case, with OpenADR signals;

[4] SDG&E Unveils Energy Innovation Center in San Diego, http://www.sdge.com/eic

- Providing Fast DR solutions (less than 4 seconds) to customers by participation in ancillary services using the OpenADR 2.0b.

Project Partners

The project team was comprised of the San Diego Gas & Electric (SDG&E), Lawrence Berkeley National Lab (LBNL), and MelRok LLC. LBNL managed the project including site audit analysis, fast DR control strategy development, and analysis of results. MelRok provided the OpenADR 2.0b client used on site, a high resolution multi-channel Energy Meter used to measure the load shed at 1 Hz sampling rate, and all OpenADR 2.0b demand response automation server (DRAS) software, services and support. MelRok also served as the installation coordinator and provided technical expertise for site enablement through hardware installation, control sequence programming, on-site support, system commissioning, and interactions with building and lighting controls vendors.

Methodology

Site Information

SDG&E's Energy Innovation Center (EIC) is a working showcase that demonstrates smart energy initiatives and green building practices. The 27,000 square foot LEED Platinum center is a unique mix of technologies suitable for participation in energy markets through renewable energy generation and load automation enabling, in the case of this study, fast DR.

Figure 1: Energy Innovation Center at SDG&E

Metering Infrastructure

There are eight smart meters installed at the EIC to measure the power demand of lights, rooftop units (RTUs), mechanical equipment, smart home, site lights, and solar generation. A central device was installed to collect data from existing submeters using the Modbus RTU protocol, collect data from the SDG&E utility meters using ZigBee SEP, as well as communicate control signals to the energy management system using BACnet/IP. Figure 2 shows the schematic diagram of OpenADR communication, control and data acquisition systems in this demonstration.

A multi-meter device was installed to measure the specific loads that were being shed during the ADR tests in this study. The specific loads being controlled were: exhaust fans 6, 9, 10, AC-9 and lights in the demonstration and kitchen areas. As described below, control of lights was not established during these tests. The additional metering was needed to provide high kW resolution measurements at the 1 Hz frequency needed to confirm the response time of the system, expected to be in seconds. Table 1 is an image of the panel schedule of Panel L1 that feeds the specific loads that were shed in this study.

Table 1: End-uses on Panel L1 at EIC

PANEL 'LI'

MOUNTING: FLUSH
ENTER CABINET AT: TOP
VOLTAGE: 120/208V. 3ø 4W

MAIN: 225A/3P BKR
TYPE: BOLT–ON
BUSSING: 225AMP AIC: 10K

LOCATION	VOLT–AMPERES øA	VOLT–AMPERES øB	VOLT–AMPERES øC	LTG	REC	MIS	BKR. AMP	BKR. POLE	ABC	ABC	BKR. POLE	BKR. AMP	MIS	REC	LTG	VOLT–AMPERES øA	VOLT–AMPERES øB	VOLT–AMPERES øC	LOCATION
SOLATUBES	1300					13	20	1	1	2	1	20	1			1000			2ND FLOOR POWER
EF–9		100				1	20	1	3	4	1	20	1				1000		2ND FLOOR POWER
EF–6			696			1	20	1	5	6	1	20	1					1000	2ND FLOOR POWER
EF–10	696					1	20	1	7	8	1	20			15	703			LIGHTS
SPARE							20	1	9	10	1	20			16		1088		LIGHTS
SPARE							20	1	11	12	1	20			21			1428	LIGHTS
SPARE							20	1	13	14	1	20			25	708			LIGHTS
SPARE							20	1	15	16	1	20	1				696		EF–8
SPARE							20	1	17	18	1	20			15			697	LIGHTS
SPARE							20	1	19	20	1	20	1			100			SPARE
GEN RECS		720			4		20	1	21	22	1	20							SPARE
ROOM 106			900		5		20	1	23	24	1	20							SPARE
ROOM 107	820				4	1	20	1	25	26	1	20							SPARE
SYST. FURN		600				1	20	1	27	28	1	20							SPARE
SYST. FURN			600			1	20	1	29	30	1	20							SPARE
SPARE							20	1	31	32	2	40	1			3240			AC–9
SPARE							20	1	33	34	–	–					3240		–
ROOF RECS			900		5		20	1	35	36	2	40	1					3240	AC–10
CDP–1	200					1	20	1	37	38	–	–				3240			–
AHU–3		2280				1	25	2	39	40	2	40	1				3240		AC–11
.			2280				–	–	41	42	–	–						3240	–
SUBTOTAL	3016	3700	5376													8978	9264	9605	SUBTOTAL

TOTAL VOLT–AMPERES/PHASE øA= 11994 VA øB= 12964 VA øC= 14981 VA

TOTAL PANEL VOLT–AMPERES: 39939 VA + LCL 9985 VA= 49924 VA AMPS= 139

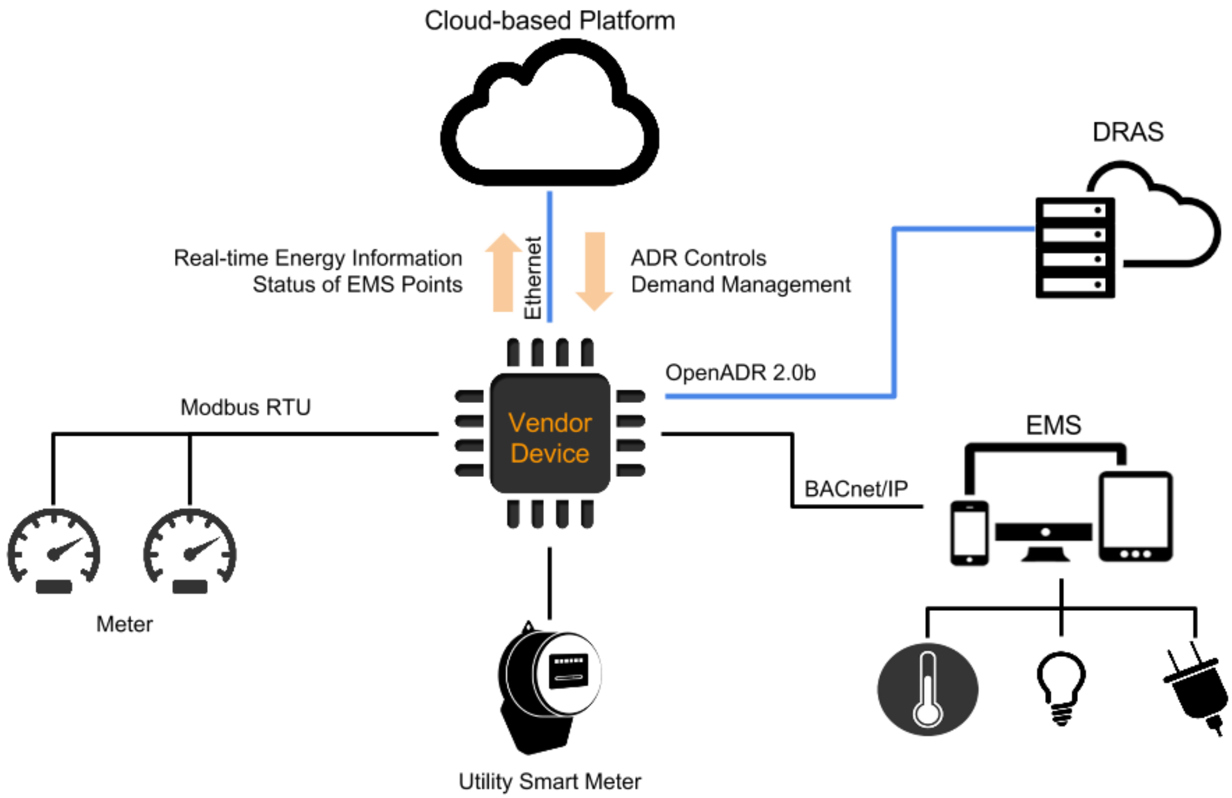

Figure 2: Schematic of communication, control and data acquisition provided by the Vendor's Platform.

Automated Demand Response System

Prior to this project, the EIC did not have the capability to respond to machine-readable DR signals. During the site enablement process, a Router with built-in OpenADR client was installed to receive the DRAS cloud server generated DR signals using OpenADR 2.0b protocols. Upon receiving an event signal, the OpenADR client translated this message into a series of BACnet® messages sent to the EMS overriding the settings in the EMS to Turn OFF and ON the specific loads.

DR Control Strategies

In the commercial building sector, heating, ventilation, and air-conditioning (HVAC) systems have been proven to be excellent DR resources for several reasons: (1) HVAC systems account for a substantial electric load in commercial buildings, often more than 1/3 of the total; (2) The "thermal flywheel" effect of indoor environments allows HVAC systems to be temporarily unloaded without immediate impact to the building occupants; (3) It is common for HVAC systems to be at least partially automated with energy management control systems. In addition, lighting systems offer great promise as a resource for DR shed savings for several reasons: (1) Lighting systems create a substantial electric load in commercial buildings, often more than 30% of the total; (2) Lighting has no rebound effect during the transition from DR events to normal operations; (3) The lighting systems in many California commercial buildings already have bi-level switching in place. Beyond that, exhaust fan ventilation systems are a good candidate for fast DR. A number of field studies (Kim et al., 2013; Piette et al., 2008) show that shutting off exhaust fans in unoccupied spaces, such as mechanical rooms or electrical rooms (as long as it would have negligible impact on safety), for short periods is also effective for fast and reliable demand reduction. .

Previous study has identified DR opportunities in different spaces at EIC: (1) seminar and lobby, (2) smart home and training home, and (3) demonstration kitchen. Table 2, Table 3, and Table 4 present the highlights of end-uses' capabilities in each space.

Table 2: End-uses at conference room & lobby area

Load	Equipment	Panel	Panel Location	Total Volt-Ampere
A/C	AC 1-8	H1 (All)	Roof	86.4 kVA
Ventilation	CF1+small fans	L4 (10, 26)	Storage west	1.0 kVA
Lighting	Seminar lighting	L4 (even, 14-24)	Storage west	7.4 kVA
	Lobby lighting	L3 (8, 10)	Training room	2.1 kVA
Plug loads	Seminar/lobby	L4 (odd, 1-31)	Storage	13.9 kVA

Table 3: End-uses at Smart Home & Training Home

Load	Equipment	Panel	Panel Location	Total Volt-Ampere
A/C	AHU 1-2/HP 1-2	SH (even, 2-20)	Smart home	16.1 kVA
Ventilation	Kitchen fan	SH	Smart home	?
Lighting	Lighting SH	SH (odd, 25-27)	Smart home	2.0 kVA
Plug loads	Smart home	SH (odd, 1-23, 24)	Smart home	10.9 kVA

Table 4: End-uses in the demonstration Kitchen

Load	Equipment	Panel	Panel Location	Total Volt-Ampere
A/C	AC 9-11	L1 (even, 32-40)	Kitchen space	19.4 kVA

Ventilation	EF 1-5	H2 (odd, 1-29)	Electrical room	14.9 kVA
Lighting	MAU 1-5	H2 (even, 2-30)	Electrical room	12.2 kVA
	Demonstration lights, kitchen	L1 (even, 8-14)	Kitchen space	3.9 kVA
Plug loads	Kitchen	K1-4 (all)	Kitchen space	175.4 kVA

Previous Recommendations: The space of Smart Home & Training Home were initially recommended for the field test of DR at EIC. In these spaces, HVAC and electrical load are isolated from the rest of the building and offer an easy access to monitor and control. Other loads for DR are identified as follows:

- Site lighting: Metered on Panel SL and SL2
- Restroom ventilation: Metered on Panel L1, Branch 5
- Office heating/cooling load: Produced by rooftop condenser units (CU 1-3) and distributed by fan coils and AHU (FC 1-2, AHU3). Metered on L1 (even 32-42), L2A (even 10-24) and ER (21, 23) panels.
- The rooftop PV and battery systems should be monitored and implemented for demand response, independently of the zone chosen for measurement.

A multi-meter device was installed on the EIC electric panel L1 for high resolution monitoring of exhaust fans (EF-06, 09, 10), lighting, and air-conditioning units (AC-09) at the millisecond interval.

Table 5: Controlled End-use Equipment and strategies for Fast DR

Load	Equipment	Panel	Control Option	Other control options
A/C	AC 9	L1	On/off	Thermostat setpoint adjustment
Ventilation	EF 6, 9, 10	L1	On/off	None
Lighting	Demonstration lights, kitchen	L1	On/off	Dimming

Site Programming, Trend-logging and Commissioning

The control vendor programmed the proposed control strategies into the Cloud platform using a web-based interface. After then, the control strategies were translated into a series of BACnet control commands to be sent to the EMS. The onsite OpenADR client downloads from the Cloud platform the map of control strategies (ADR levels and policies) and corresponding BACnet control commands on a minute-by-minute basis. The onsite OpenADR client also checks with the DRAS server every minute to download new or updated schedules of ADR events.

SDG&E and LBNL oversaw this activity and coordinated logistics with MelRok to ensure the appropriate demonstration of fast DR. With respect to the performance of each fast DR test, the central device logged a record of the time stamps of each test control point. After each test event, the logs were downloaded and checked against control points to confirm that the BMS responded to OpenADR signals as programmed. The multi-meter device made one-second interval demand measurements of the loads targeted for ADR.

The OpenADR client has the capability to access to the control of AC units and exhaust fans through the EIC's BMS BACnet server. Unlike the control of AC units and exhaust fans, the lighting control system at EIC is provided separately by a separate network lighting control technology that integrates time-based, daylight-based, sensor-based, and manual lighting controls. At the EIC, the lighting control system is enabled through a virtual BACnet server. During the test phase of ADR controls, MelRok found that the virtual BACnet server was just a portal with read-only access and wasn't capable of being reprogrammed through the virtual server. Therefore, the fast DR enablement of the lighting system was not included in this study.

Test System Configuration

The fundamental problem to be solved by the pilot project is to show that through the OpenADR 2.0, the fast DR participation from each end-use can be achieved to provide ancillary services in the market. Key issues need to be answered by this pilot study: (1) communication infrastructure between the ancillary service providers and the OpenADR client, (2) characterize each type of end-use capability for providing ancillary services, (3) fast DR performance objectives and metrics.

Figure 3 shows the schematic diagram of the communication architecture for the fast DR test at the SDG&E EIC. MelRok has setup a Demand Response Automation Server (DRAS) at their facility (https://openadr.melrok.com/) to send OpenADR 2.0b signals to the OpenADR client[5] at the test site (EIC). The server used an implantation of EPRI's VPN DRAS version 0.9.3. There is only one VEN (virtual end node) ID for the client at EIC and no resource IDs are associated with the end-use equipment being controlled. For the AutoDR signals sent from the DRAS, three levels of signals are defined to activate different groups of control strategies: low, medium, and high (e.g. different values of this field will trigger each test case' pre-defined control strategies).

[5] OpenADR certification obtained 8/27/2015.

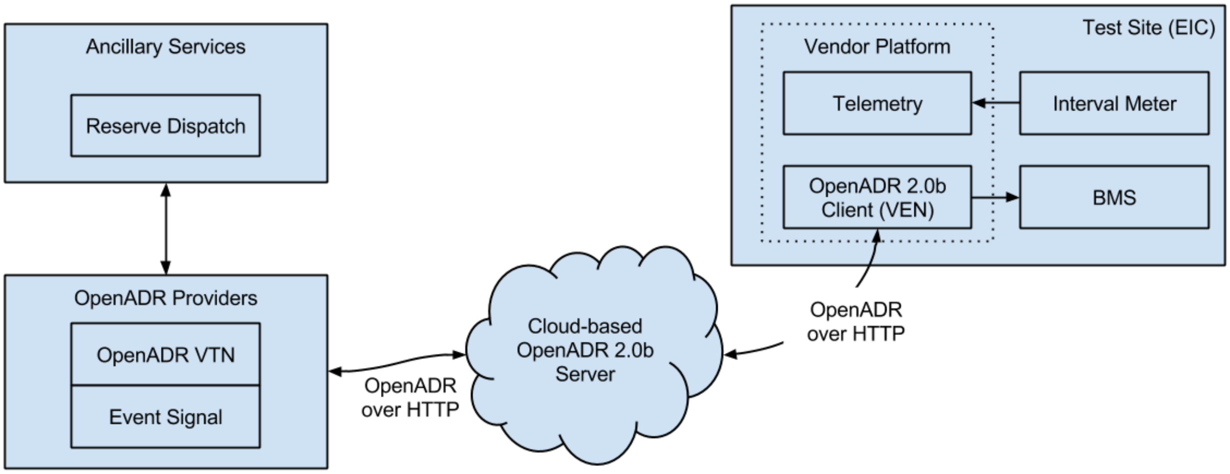

Figure 3: Communication Architecture of Fast DR Test at the Test Facility

Synchronous Reserve Test Setup

As the curtailment service provider (CSP), the OpenADR provider uses the OpenADR 2.0b server to create an event and push over HTTP from the provider's OpenADR 2.0b server to cloud-based server, from a VTN to VTN. The server is polled every 15 to 20 seconds by the receiving client onsite, which is connected to the Internet via a cellular network or ware-connected.

In the synchronous reserve test, the controlled lights will be shut off in response to the synchronous reserve events. The exhaust fan will respond to the signal by switching off the breakers. The HVAC system will respond to the signal through the on/off control command and/or setpoint adjustment by 2~4 °F. Meter data will be collected at one-second intervals and aggregated to one-minute intervals via a telemetry link to the VEN client at the EIC. From this data, we can see load shed and the amount of time before load responds to the signal.

The communication infrastructure between the VTN Demand Response Automation Server (DRAS) and the client VEN on the site was tested. During the test, the following data will be recorded.

- Communication Latency
- Speed of Response
- Accuracy of Response (not our focus of this test)

In addition, switching on/off the client VEN system will be conducted to validate the VEN registration. The following data will be collected for evaluating OpenADR applications for Auto-DR and ancillary services.

1. Communication latency: timestamp when an event signal is created by the DRAS cloud server, and the timestamp when OpenADR event arrives at the VEN client.
2. Speed of Response: the timestamp when the signal arrives at the client and the timestamp when the change in power reading by the meter.
3. Accuracy of Response: based on the power readings from the meter, the end-uses that respond to the signal will be identified to validate the proposed control strategy.

Frequency Regulation Test Configuration

The frequency of variable frequency drives (VFDs) can be controlled to provide a DR load shed. Normalized regulation signals are sent via OpenADR and translated into the frequency range in which the device operates. During the tests, it was found that the AHUs under the OpenADR client control platform don't have the capability to control the VFDs because there was no control point programmed into the list of BACnet control points. In future tests, we suggest using the same communication, control, and telemetry infrastructure system to test the frequency regulation on the devices with VFDs when that control capability is enabled.

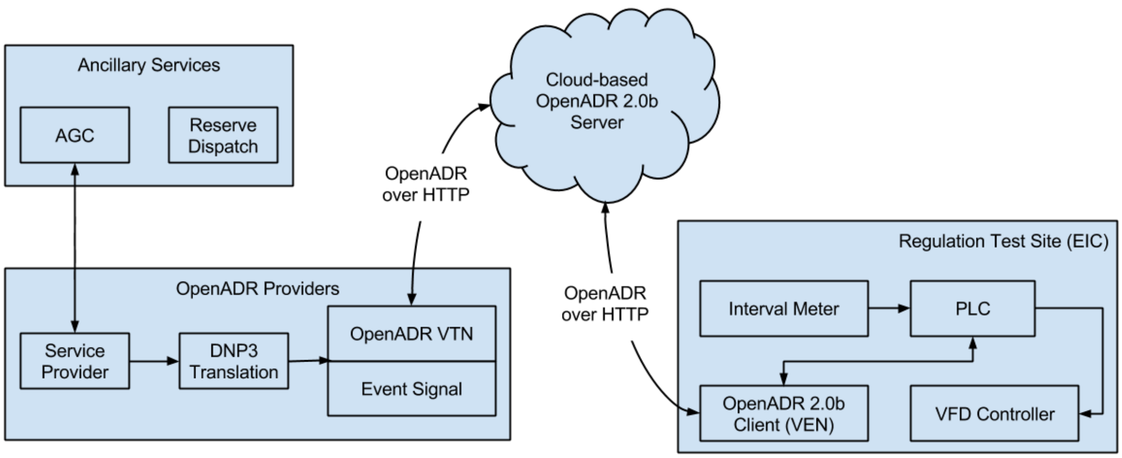

Figure 4: Communication Architecture of the Regulation Reserves Demonstration

Performance Metrics

There are three metrics for evaluating the performance of OpenADR test for ancillary services, which are listed as follows.

- Communication Latency
- Speed of Response
- Accuracy of Response (not our focus of this test)

Test Case Matrix Development

A primary objective of these tests is to measure the communication time delay between an OpenADR signal source and to the response of the end-use load being controlled as a DR resource. As shown in Figure 5, CAISO requests the DR resource by sending the signal to the OpenADR server. The OpenADR server dispatches the OpenADR signals to the OpenADR client over the Internet. The DR controller translates the OpenADR signals and activates the pre-defined DR control strategies through the BMS. There will be time delays at each step of the signal communication process. The fast DR test at the EIC simulates CAISO control in the system architecture via a signal sent via OpenADR to the client directly from a DRAS.

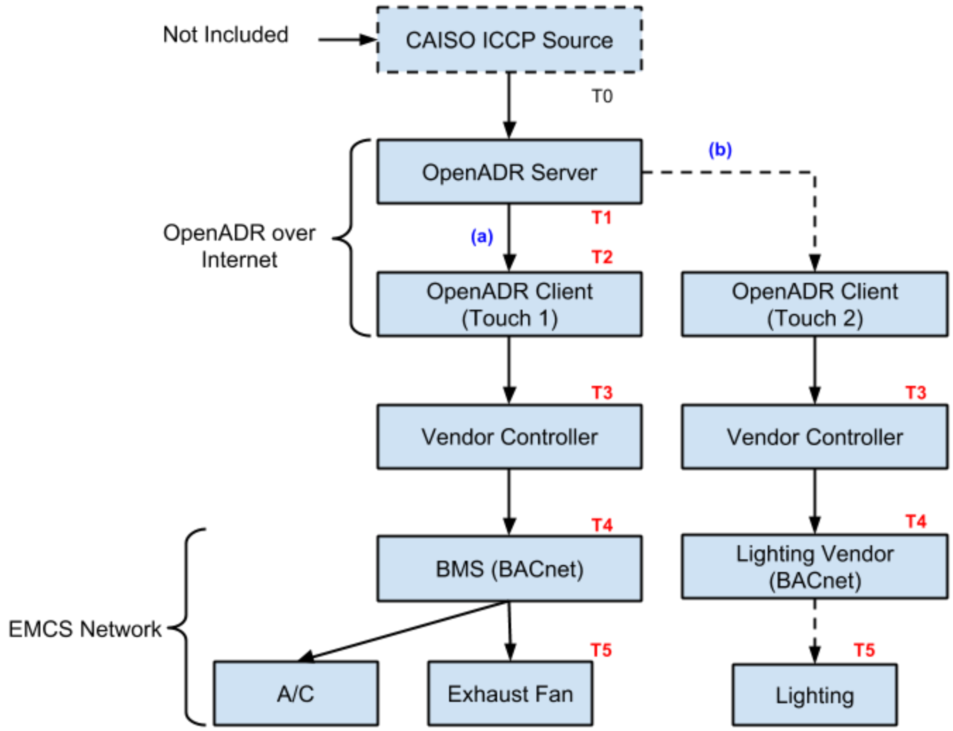

Figure 5: Schematic Diagram of Communication Latency: (a) DR control via BACnet, (b) Additional lighting control via the lighting control system.

To evaluate the fast DR test performance, the timestamps shown in Figure 5 and described in Table 6 were monitored to measure the communication latency and response time of each fast DR test case. With a focus on the communication latency, time is calculated as the time delay between the T1 when the DRAS sends the DR signal and T5 when the end-use load response is observed.

Table 6: Description of timestamp during the process of each step

Timestamp	Description	Notes
T1	Timestamp when DRAS sends the OpenADR signal (test VTN push and VEN pull mode)	Long time for the pulling mode from VEN
T2	Timestamp when the OpenADR client receives the signal	
T3	Timestamp when the DR controller on the OpenADR VEN client device receives the signal to activate the control action	The controller is embedded in the ADR client.
T4	Timestamp when the BMS sends the control signal of each BACnet point	

T5	Timestamp when the load response is observed from the high resolution monitoring system	Timestamp when the demand starts to change (up/down)

Test Case Matrix of Fast DR

All the fast DR tests were performed in September and October 2015. Eight test cases were proposed to test the fast DR capabilities at EIC, which included the A/C 09 test and exhaust fan tests (EF 6, 9, 10). Planned lighting tests using the lighting control system could not be completed due to our inability to convey the OpenADR signal via that system. The Fast DR test days and events scheduled for these tests are listed in Table 7.

Table 7: Test Case Matrix of Fast DR Test in September

Test Case	Test Date	Test Time	End-uses	Control Strategies	Assigned Signal Mode
TC-1	9/2/2015,	11:00AM~11:10AM	Lighting	Switch on/off	Low
TC-2		11:20AM~11:30AM	EF 6, 9, 10	Switch on/off	Medium
TC-3		11:30AM~11:40AM	EF 6, 9, 10 AC-9	Integrated	High
TC-4		11:50AM~12:00PM	EF 6, 9, 10 AC-9	Integrated	High
TC-5	9/14/2015,	3:00PM~3:10PM	Lighting	Switch on/off	Low
TC-6		3:20PM~3:30PM	AC-9	Switch on/off compressor	Medium
TC-7		3:30PM~3:40PM	EF 6, 9, 10 AC-9 (Lighting)	Integrated	High
TC-8		3:50PM~4:00PM	EF 6, 9, 10 AC-9 (Lighting)	Integrated	High

Notes: High-resolution monitoring devices are installed on the Panel L1. All the listed end-uses for test control are on the panel L1. The status of each controlled load were checked (e.g. on/off, setpoints) before the test event to ensure the load response when the control sequence was triggered.

Notes:

- The 2nd test phase may require the re-installation of the monitoring devices to measure the new controlled equipment (e.g. AHU-3).
- The control actions will be re-programmed to response the OpenADR signals (Low, Medium and High).

During the testing period, the building manager received notification that included operational mode for each testing period on the test day. The building managers were able to opt out of test events via the BMS at EIC.

Follow-up Discussion and Test Plan Modification

Follow-up discussions between LBNL, SDG&E and MelRok reviewed the Auto-DR tests, DR strategies, and any reported building occupant comfort issues. Additional information about effectiveness of the OpenADR 2.0b communication, shed strategies, and issues that arose as a result of the tests were obtained from MelRok after the test was completed.

Two fast DR test events were conducted on 9/2/2015 (11AM to 1PM) and 9/14/2015 (3PM to 4PM). During the first test event, it was observed that the AC-09 unit didn't respond to the DR signal as expected. The BACnet command to the AC-09 unit gave no impact on the operation status, which required additional review of the BACnet system command and re-configuration in the VEN client. It is recommended that a commissioning process need to be followed after the Auto-DR enablement at the site. It involves manually triggering of OpenADR signals to confirm the BMS response from each controlled end-use. The control point for switching on/off the AC-09 was not activated in the initial control commissioning. With the widespread adoption of using building HVAC for Fast DR, it may require a new procedure of commissioning to confirm the response from end-uses.

The 2nd test phase cases presented in Table 8 weren't tested as proposed due to the following reasons. It was found that the BMS system could not control the fan frequency for AHU-3. Noticed that there was no BACnet control point for adjusting AHU-3 fans' speed. If the Variable Frequency Drive (VFD) on the supply fan was appropriately installed, the commissioning of the fan control needs to be conducted to confirm the existence of control points in the BMS. Thereby LBNL proposed to reset the fan static pressure instead to minimize the effect of the frequency control, however, there was no control point for the static pressure setpoint either on the BACnet control list as shown in Figure 6. Tests using the lighting control system could not be completed using the lighting vendor's virtual BACnet server because access was read-only. The control of the lighting system can be achievable through the re-programming in the lighting vendor's virtual server, however this configuration is not compatible with the implemented fast DR control platform. It is possible to implement a separate OpenADR 2.0b client to interact with the lighting vendor's virtual BACnet server. A list of certified OpenADR 2.0 a/b server and clients is provided in the Appendix B. Also, the proposed reset of the thermostat setpoints to cycle on/off the AC units did not work as planned because of milder than expected weather conditions that caused the AC systems to run inconsistently. The implementation of the thermostat setpoints adjustment may not provide the desired fast DR under mild weather conditions.

Table 8: Proposed Test Case Matrix that were not Performed in this Study

Test Case	End-uses	Control Strategies	Notes

TC-9	AHU-3	Reduce the fan frequency by 5 HZ	Frequency Regulation
TC-10	Lighting	Dimming the lights by 50%	
TC-11	AC-9	Raise the thermostat setpoint by 2F	Response speed from temperature reset
TC-12	AHU-3 Lighting AC-9	Integrated	

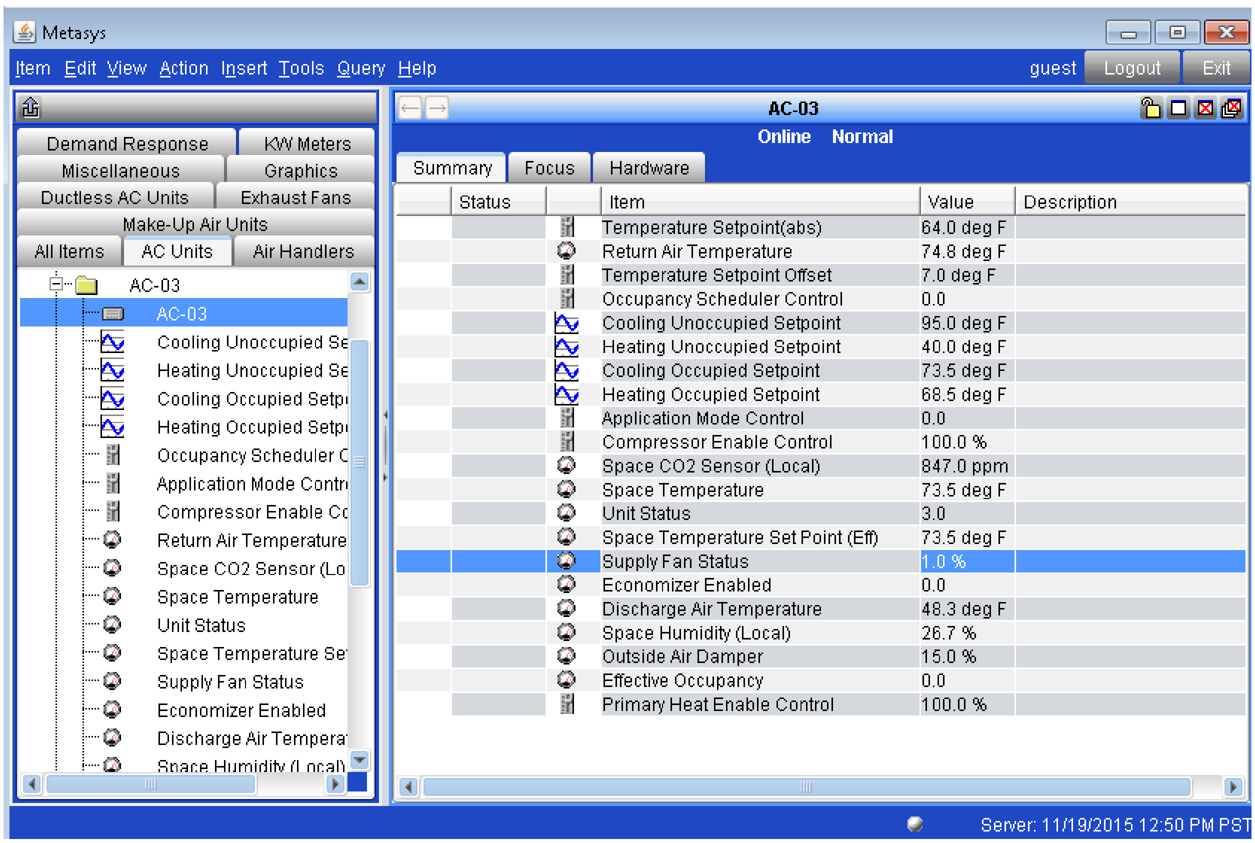

Figure 6: Screenshot of BACnet Control Points for AC-03

Two test events successfully demonstrated fast DR capabilities using the OpenADR 2.0b protocol at the EIC. The focus of the test was to quantify the round trip latencies from the dispatch of the OpenADR signal on the cloud to the observation of the load response at the test facility. The pre-programmed strategies were successfully implemented through the VEN client over the BACnet. Future work can include the fast DR test of the lighting control system and examine different BMS systems and relevant control protocols.

Results

Fast DR Test I

Evaluation of Fast DR Performance

For all test events, the following timestamps were recorded: Polling time, acknowledge time, delay time, BACnet command time, BACnet confirm time. The total response time was calculated as the duration from the start polling timestamp T_1 and the load response timestamp T_5 (see Table 6). The response time of all test events on 9/2/2015 are summarized in Table 9. The event data log is provided in Appendix A.

Table 9: Definitions of Time Stamp in the Trend Log

Timestamps	Total Time (ms)
Polling Time	Round trip to poll & get events. Varies based on Internet connection. The VEN device is set to poll every 15 seconds, but OpenADR2.0b protocol allows the DRAS to over write the device
AckTime	Acknowledge time, feedback from the device to DRAS confirming the Event was accepted
DelayTime	Time to process the event within the VEN device and send command to the building management system
BACnetCommandTime	Time to write the command on the BACnet controller
BACnetConfirmTime	Time to resend command & confirm the change of value was successful
Total Time	Equals the difference between EndConfirmingBACnetCommand and the StartPollingTime. It should be noted that the total time is not necessarily the sum of each time step reported as some of the processes happen in parallel

The load response time was not recorded in the event trend log. Rather it was calculated from the trend log of individual sub-meters for each end-use. The clock on the multi-meter is synchronized with NIST NTP time servers through the Cloud platform, and the clock of the OpenADR client and controller synchronizes directly with NIST NTP time servers. It was assumed that both clocks are thus synchronized with each other. As presented in Table 10, all five test events on 9/2/2015 took 4 seconds or less to respond to the OpenADR 2.0b signals. Since exhaust fans were controlled by the on/off command, the load response reached to the full power of exhaust fans without any ramping delay.

Table 10. A Summary of Response Time of Fast DR Test Events on 9/2/2015

End-use	Sensor ID	Start Polling Time	Total Time (ms)	Timestamp of Load Response	Response Time (s)
Exhaust Fan	8898/8899	11:04:24 AM	4106	11:04:27 AM	3
		11:16:49 AM	3157	11:16:52 AM	3
		11:32:19 AM	2987	11:32:23 AM	4
	8899	12:17:12 AM	3625	12:17:16 AM	4
		12:32:27 AM	3298	12:32:31 AM	4

Figure 7: Exhaust Fans' Power Demand on the Test Day, 9/2/2015

Figure 8 shows the electric power demand of AC-09 unit on test day 9/2/15. It shows that AC-09 unit operated on multiple stages of the compressor along with the outdoor and indoor environment. As scheduled in the test plan, AC-09 unit was supposed to turn on/off in response to the same OpenADR signal as exhaust fans. However, AC-09 unit kept running during the test period, which indicated that the pre-programmed BACnet command didn't go through the on/off control of AC-09 unit. To solve this issue, the team reviewed the BACnet control point and enabled the control of AC-09 unit by changing the occupied setting to unoccupied. This indicated that the control point in the BMS system might not have been assigned to the right command for external control. It brings attention to the value of vendor commissioning work after BMS programming is completed.

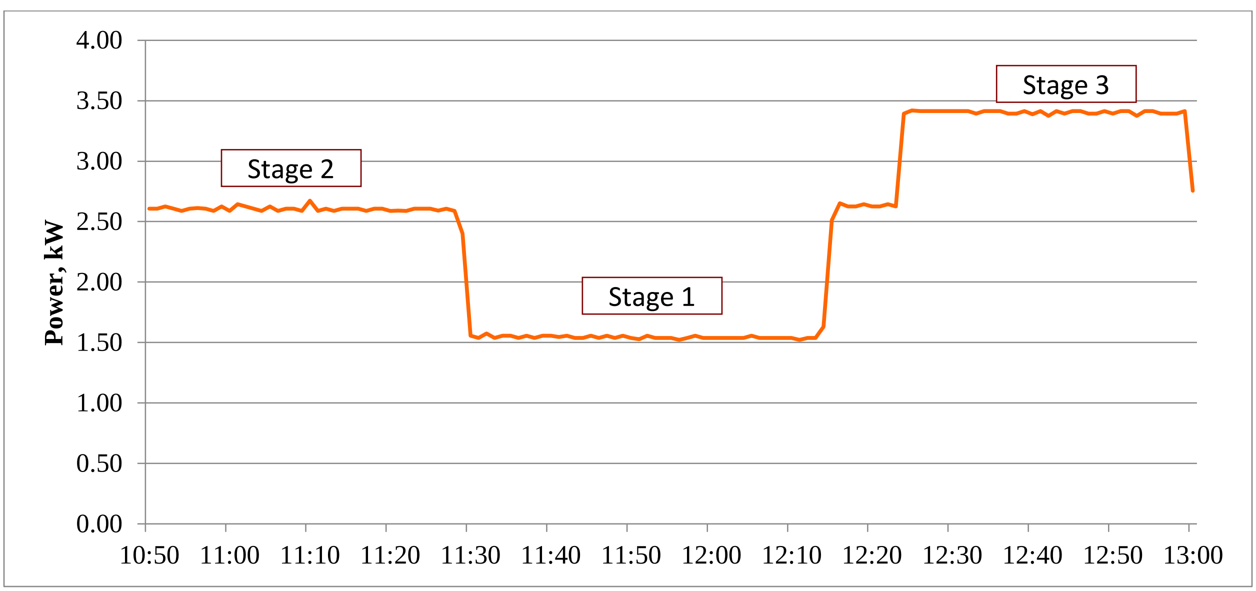

Figure 8: AC-09's Power Response on the Test Day, 9/2/2015

Lessons Learned from Test I

OpenADR signals can either be "pushed" or "polled" between the DRAS and the OpenADR client. Pushing or polling lead to different communication time periods between the DRAS VTN (virtual top node) and the client VEN. The push mode from the server to the client avoids the polling time from the client to the server, which usually is configured to occur every 15 seconds. OpenADR 2.0b protocol allows the DRAS on the cloud to overwrite the client device. During the first test event, the following issues were identified.

- Control command to turn on/off AC unit didn't work. Vendor specified the control point for AC unit on/off may not be overwritten via the BMS. As pointed above, the list of control points in the document may not be assigned to the control sequence of the device. For the AC-09 unit, the control point for switching the compressor on/off was the "occupied/unoccupied" command. This command point was used to turn the AC-09 unit on/off in later tests.
- The trend log collection in Test 1 was stopped before the event end signal was sent. As a result, the time for the controlled loads to return to normal status was not recorded. At the beginning of the testing, the trend logs were only created to track the response timestamp when the control device received the OpenADR signal. It was assumed the round trip of the OpenADR signal communication was the same between the on/off mode switch. The trend log was re-configured to record the full time series of each status change in the OpenADR signal flow in the system for Test II.

Test I demonstrated the importance of commissioning building management systems and Auto-DR control. A few issues were identified that include mismatched and missing control points in the BMS. In considering more wide spread Auto-DR implementation, increased application of standard practices of controls commissioning may increase overall Auto-DR program performance and decrease cost of enablement.

Fast DR Test II

Evaluation of Fast DR Performance

On 9/14/2015, the second fast DR test was conducted using the first test strategies and the "lessons learned" modifications from the first test event. The focus of the second test was to evaluate the response time of the AC unit on/off mode switch since the control of the AC-09 unit didn't work on the first test event. As presented in Table 11, the response time of switching the exhaust fan off was 4 seconds (see Fig 10), which was the same as was measured in the first test event. In this test, the metric of full load response time was added. The time for the AC-09 load to fully shed was longer than the time it took for the exhaust fans load to fully shed. This was caused by an additional layer of control sequence in the AC unit. Repeating the same test on the AC unit resulted in a response time of 6 seconds (see Fig 10) with an additional 6 seconds to reach the full load shed. The load shed delay was due to the AC-09 unit going through multiple stages of compressor operation.

Table 11: A Summary of Response Time of Fast DR Test Events on 9/14/2015

End-Use	Start Polling Timestamp	Total Time (ms)	Timestamp of load Response	Response time (s)	Timestamp of Full Load Response	Full Response time (s)
AC unit	3:01:15 PM	3814	3:01:21 PM	6	3:01:27 PM	12
Exhaust fan	3:01:15 PM	3814	3:01:19 PM	4	3:01:20 PM	5
Lights and Fan	3:25:06 PM	4368	3:24:22 PM	Null	3:24:22 PM	Null
AC unit	3:45:14 PM	2986	3:45:22 PM	8	3:45:25 PM	11
AC unit Recovery	3:54:37 PM	2972	3:57:01 PM	144	4:01:01 PM	240

For exhaust fans, there was no difference in the response times for each test. However, the AC unit's recovery time from "off" status to normal status was nearly 4 minutes, as shown in Figure 9. It can be explained that the operational stage control of AC unit's compressor requires additional control logic based on zone temperature. The significant rebound delay of the AC unit would be problematic for participating in ancillary service markets requiring 4 second response.

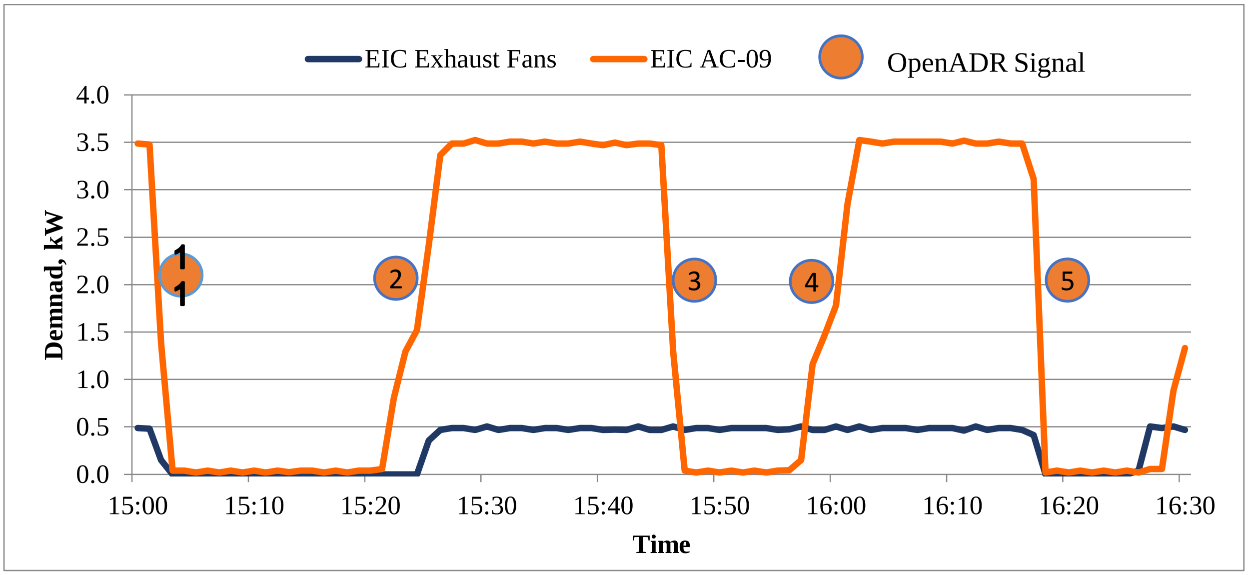

Figure 9: Exhaust Fan and AC Unit's Power Response on the Test Day, 9/14/2015

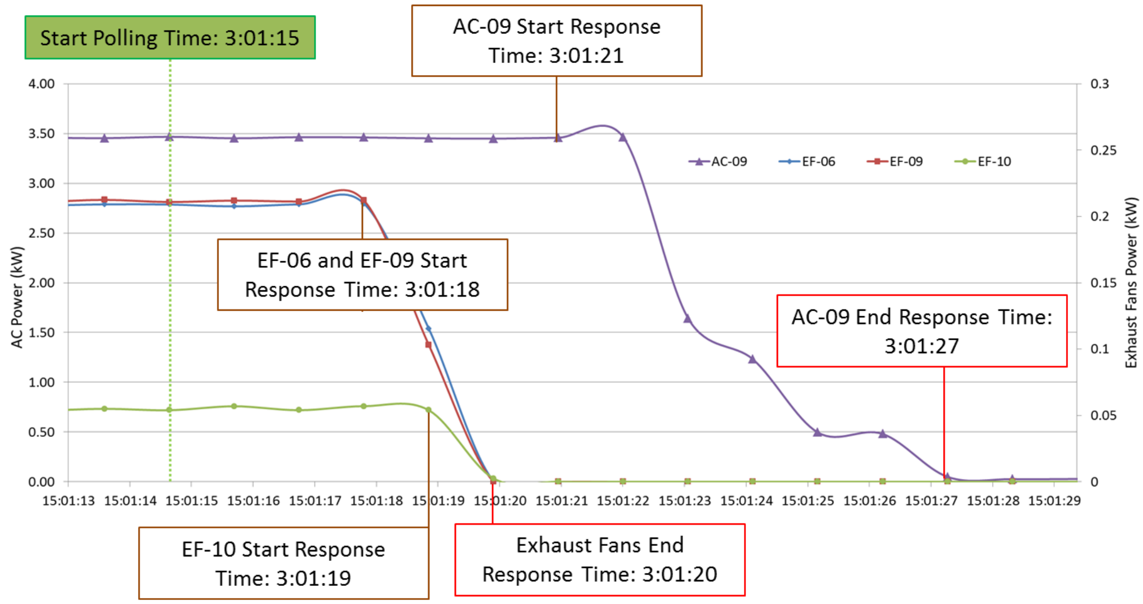

Figure 10: Details of timeline at ADR event initiation at 3:01:15 PM on 9/14/2016 with data collected using the multi-meter sampling at 1 Hz.

Table 12: Timestamps of each sent signal in the OpenADR xml Profile

End-Use	Start Polling Time	Sending Post Request Time
AC unit	3:01:15 PM	Null
Exhaust fan	3:01:15 PM	Null
Lights and Fan	3:25:06 PM	Null
AC unit	3:45:14 PM	3:45:14 PM
AC unit	3:54:37 PM	3:54:37 PM

Lessons Learned from Test II

After the re-configuration of the command control of AC-09 unit, all the controlled end-use loads responded to the OpenADR signals successfully. With a focus on the response time for each test event, internet communication “congestion” was considered by conducting two test events at different times—in the morning and in the afternoon. There was no observed impact on the communication time from the cloud server to the client at either time of day.

AC units and exhaust fans exhibit different load shed response times due to the nature of their hardware and not due to communications delays. As demonstrated in the test, exhaust fans responded to the OpenADR signal within 4 seconds and reached to the full load response in 4 to 5 seconds. AC units took about 6 seconds to start shedding the load and needed an additional 6 seconds to reach the full load response.

Conclusions and Recommendations

In this study, a demonstration project was conducted to enable fast Automated Demand Response (ADR) in the Energy Innovation Center located in San Diego, CA using OpenADR communication protocols. In particular, this project focused on measuring communication and equipment response times with signals generated by an OpenADR server and received by building end-use loads. The measured response time ranged from 3 to 5 seconds for the DR strategy of shutting down exhaust fans, and from 5 to 12 seconds for the DR strategy of shutting down AC (Air-Conditioning) units. During the first test, it was found that control command of turning on/off an AC unit didn't work, even though the site programming followed the control vendor's specific control points. After the re-configuration of control points on the controlled AC unit, it took 6 seconds to observe the load response from AC load shed and 11 to 12 seconds to reach the full AC load shed capacity. Overall, the results show that OpenADR and a DR strategy of turning off fans (exhaust fans in the test case) can facilitate the automation of fast DR response at the test facility and deliver fast DR capability of the implementation to meet the requirement of DR products for ancillary services in the CAISO electricity market.

Results from two fast DR test events indicate that metering and visibility of load response from end-uses meet the requirement of telemetry rate (4 seconds in CAISO). However, this study only demonstrated the DR strategy by switching on/off end-uses such as fans and AC units. It is definitely suitable for both spinning reserves and non-spinning reserves by providing fast DR to the ancillary service market. For regulation reserves, the CAISO operates two capacity markets for regulation service, upward and downward Regulation Reserve. Previous experience indicates that variable-speed drive devices (e.g. VFD fans, pumps) can be good candidates to provide this type of ancillary service. Fast DR test for regulation service could be included in future work by using the current telemetry system with additional telemetry devices such as the data processing gateway required by CAISO. Finally, it was found that the lack of controls commissioning can be a barrier to implementing Auto-DR. With the increasing use of building HVAC systems for providing fast DR products, it is recommended that a commissioning process be followed to enable Auto-DR control.

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Appendix A

EIC OpenADR Trend Log (9/2/2015)

EIC ADR Test DRAS Log: 9/2/2015: 11:00 AM to 1:00 PM.

Legend:

Polling Time: Round trip to poll & get events. Varies based on Internet connection. The VEN device is set to poll every 15 seconds, but OpenADR2.0b protocol allows the DRAS to over write the device.

AckTime: Acknowledge time, feedback from the device to DRAS confirming the Event was accepted

DelayTime: Time to process the event within the VEN device and send command to the building management system.

BACNetCommandTime: Time to write the command on the BACnet controller.

BACNetConfirmTime: Time to resend command & confirm the change of value was successful.

Total Time: equals the difference between EndConfirmingBACnetCommand and the StartPollingTime. It should be noted that the total time is not necessarily the sum of each time step reported as some of the processes happen in parallel.

Event Logs:

```
EventID: 9dccc867958560caa2f5 , ModNumber: 0, StartPollingTime: 2015/09/02
11:04:24:001 AM PDT, EndPollingTime: 2015/09/02 11:04:25:004 AM PDT,
StartAckEventTime: 2015/09/02 11:04:25:977 AM PDT EndAckEventTime: 2015/09/02
11:04:27:232 AM PDT, StartSendingBACNetCommand: 2015/09/02 11:04:27:196 AM
PDT,EndSendingBACNetCommand: 2015/09/02 11:04:28:099 AM PDT,
EndConfirmingBACNetCommand: 2015/09/02 11:04:28:107 AM PDT, PollingTime: 1003
ms,SaveEventTime: 973, AckTime: 1255 ms, DelayTime: 1219 ms, BACNetCommandTime: 903
ms, BACNetConfirmTime: 8 ms, TotalTime: 4106 ms.

EventID: 946a30717462a87686cd , ModNumber: 0, StartPollingTime: 2015/09/02
11:16:49:009 AM PDT, EndPollingTime: 2015/09/02 11:16:50:060 AM PDT,
StartAckEventTime: 2015/09/02 11:16:50:985 AM PDT EndAckEventTime: 2015/09/02
11:16:52:276 AM PDT, StartSendingBACNetCommand: 2015/09/02 11:16:51:167 AM
PDT,EndSendingBACNetCommand: 2015/09/02 11:16:52:159 AM PDT,
EndConfirmingBACNetCommand: 2015/09/02 11:16:52:166 AM PDT, PollingTime: 1051
ms,SaveEventTime: 925, AckTime: 1291 ms, DelayTime: 182 ms, BACNetCommandTime: 992 ms,
BACNetConfirmTime: 7 ms, TotalTime: 3157 ms.

EventID: aae0b534a5b9d7df646b , ModNumber: 0, StartPollingTime: 2015/09/02
11:32:19:373 AM PDT, EndPollingTime: 2015/09/02 11:32:20:504 AM PDT,
StartAckEventTime: 2015/09/02 11:32:21:413 AM PDT EndAckEventTime: 2015/09/02
11:32:22:711 AM PDT, StartSendingBACNetCommand: 2015/09/02 11:32:21:678 AM
PDT,EndSendingBACNetCommand: 2015/09/02 11:32:22:356 AM PDT,
EndConfirmingBACNetCommand: 2015/09/02 11:32:22:360 AM PDT, PollingTime: 1131
ms,SaveEventTime: 909, AckTime: 1298 ms, DelayTime: 265 ms, BACNetCommandTime: 678 ms,
BACNetConfirmTime: 4 ms, TotalTime: 2987 ms.

EventID: cdbee340dcb6d0b48612 , ModNumber: 0, StartPollingTime: 2015/09/02
12:02:11:678 PM PDT, EndPollingTime: 2015/09/02 12:02:12:902 PM PDT,
StartAckEventTime: 2015/09/02 12:02:13:827 PM PDT EndAckEventTime: 2015/09/02
12:02:15:162 PM PDT, StartSendingBACNetCommand: 2015/09/02 12:02:14:908 PM
PDT,EndSendingBACNetCommand: 2015/09/02 12:02:14:918 PM PDT,
EndConfirmingBACNetCommand: 2015/09/02 12:02:14:934 PM PDT, PollingTime: 1224
ms,SaveEventTime: 925, AckTime: 1335 ms, DelayTime: 1081 ms, BACNetCommandTime: 10 ms,
BACNetConfirmTime: 16 ms, TotalTime: 3256 ms.
```

EventID: c6d139e96570fd74d902 , ModNumber: 0, StartPollingTime: 2015/09/02 12:17:12:123 PM PDT, EndPollingTime: 2015/09/02 12:17:13:291 PM PDT, StartAckEventTime: 2015/09/02 12:17:14:311 PM PDT EndAckEventTime: 2015/09/02 12:17:14:673 PM PDT, StartSendingBACNetCommand: 2015/09/02 12:17:15:473 PM PDT,EndSendingBACNetCommand: 2015/09/02 12:17:15:743 PM PDT, EndConfirmingBACNetCommand: 2015/09/02 12:17:15:748 PM PDT, PollingTime: 1168 ms,SaveEventTime: 1020, AckTime: 362 ms, DelayTime: 1162 ms, BACNetCommandTime: 270 ms, BACNetConfirmTime: 5 ms, TotalTime: 3625 ms.

EventID: ff91a29bf42e2ffb6a5a , ModNumber: 0, StartPollingTime: 2015/09/02 12:32:27:710 PM PDT, EndPollingTime: 2015/09/02 12:32:28:947 PM PDT, StartAckEventTime: 2015/09/02 12:32:29:997 PM PDT EndAckEventTime: 2015/09/02 12:32:31:350 PM PDT, StartSendingBACNetCommand: 2015/09/02 12:32:30:328 PM PDT,EndSendingBACNetCommand: 2015/09/02 12:32:31:003 PM PDT, EndConfirmingBACNetCommand: 2015/09/02 12:32:31:008 PM PDT, PollingTime: 1237 ms,SaveEventTime: 1050, AckTime: 1353 ms, DelayTime: 331 ms, BACNetCommandTime: 675 ms, BACNetConfirmTime: 5 ms, TotalTime: 3298 ms.

Appendix B

List of OpenADR Client Service providers

OpenADR is a worldwide-adopted Internet messaging protocol used by many utilities to communicate with equipment at customer facilities to automatically drop demand during DR program events. Utilities send OpenADR signals to customers' Energy Management System (EMS) through Demand Response Automation Server (DRAS). To receive OpenADR signals, customers must install and configure an OpenADR "client". This client logs into DRAS server and maintain an ongoing connection. Whenever utilities initiate a DR event, the DRAS server sends the event signal to installed client. Once the client receives the signal, it implements the response that customers have programmed into it.

- **Server**: Cloud Based, Cloud Based Control, and Stand-Alone.
- **Client**: BMS, Cloud Based Control, Controller, EMC, EMS, Gateway, HVAC, Lighting, Refrigeration, Thermostat.
- **Business Type**: Agricultural, Commercial, Industrial, Residential, and Small/Medium Business (SMB).
- **OpenADR Profile**: OpenADR 2.0a, OpenADR 2.0b, and OpenADR 2.0a/b

OpenADR Alliance provides an OpenADR certified product database for utility and customer's selection of VTN/VEN service providers. Table 13 and Table 14 summarize the existing OpenADR 2.0a/b certified products on the market, in terms of OpenADR profiles and client types.

Table 13: List of Certified VEN Service Providers

OpenADR 2.0 Certified	OpenADR Profile	Client Type	Description	Company
Acuity Controls/LC&D ADR/dADR	2.0a	BMS, Controller, EMC, EMS, Gateway, Lighting	Automated Demand Response Controller	Acuity Brands, Inc.
Automated Logic Corporation/WebCTRL OpenADR Add-on	2.0a+b	BMS, Controller, EMC, EMS, Gateway	WebCTRL Automated Demand Response Add-on	Automated Logic Corporation
Alstom	2.0a+b	Stand Alone	Demand response management systems	Alstom Grid, Inc
AutoGrid	2.0a+b	Cloud Based	AutoGrid DROMS (Demand Response Optimization and Management System)	AutoGrid Systems Inc.
Byucksan Power	2.0a+b	Stand Alone	Energle DRAS	Byucksan Power Company, Ltd.

Electric Power Research Institute	2.0b	Cloud Based Stand Alone	Open-source implementation of OpenADR 2.0b	Electric Power Research Institute (EPRI)
EnTouch 360 DR	2.0a	Cloud Based Control	Proprietary wireless facility automation system coupled with a cloud-based control	EnTouch Controls, Inc.
Fujitsu Limited/ALOX Demand Controller	2.0b	Stand Alone	DR automation server software/system	Fujitsu Limited
Hitachi Demand Response Automation Server	2.0b	Stand Alone	Demand Side Management (DSM), Demand Response and Virtual Power Plant (VPP)	Hitachi, Limited
Honeywell (Akuacom)/DRAS	2.0a+b	Stand Alone	Demand Response Automation Server	Honeywell (Akuacom)
I-ON Communications/DRMS	2.0a+b	Stand Alone	DRMS (Demand Response Management System)	I-ON Communications Co., Ltd.
Institute for Information Industry/SAVE	2.0a+b	Stand Alone	SAVE (Smart and Valid Energy) server	Institute for Information Industry
IPKeys	2.0a+b	Cloud Based	IPKeys' Energy Interop Server & System (EISS)	IPKeys Technologies, LLC.
Lockheed Martin/SEEload	2.0a+b	Stand Alone	SEEload, a single advanced load management platform	Lockheed Martin
Mitsubishi Electric Corporation/BLEnDer DR	2.0b	Stand Alone	BLEnDer DR Server	Mitsubishi Electric Corporation
NEC Engineering/NECE-DR-CA	2.0b	Stand Alone	Demand Response application service platforms	NEC Engineering, Ltd.

NTT Smart Community Platform	2.0a+b	Cloud Based Control	Smart Community Platform	NTT
Olivine DER	2.0a+b	Cloud Based, Stand Alone	Olivine DER, distributed energy resource management system	Olivine, Inc.
Siemens/DRMS	2.0a	Cloud Based	DRMS (Demand Response Management System)	Siemens AG
Sumitomo Electric Industries/EI-VTN	2.0a+b	Stand Alone	VTN modules (SEI-VTN 2.0b)	Sumitomo Electric Industries, Ltd.
TOSHIBA	2.0a+b	Stand Alone	Demand Response Server software	Toshiba Corporation
Wooam/SmartDRMS	2.0a+b	Cloud Based, Cloud Based Control, Stand Alone	Smart DRMS (Demand Response Management System)	Wooam, Inc.

Table 14: List of Certified VTN Service Providers

OpenADR 2.0 Certified	OpenADR Profile	Service Type	Description	Company
Advanced Institutes of Convergence Technology	2.0a+b	Cloud Based Stand Alone	National Virtual Power Plant (NVPP) Business Platform	Alstom Grid, Inc.
Alstom	2.0a+b	Stand Alone		
AutoGrid	2.0a+b	Cloud Based	AutoGrid DROMS (Demand Response Optimization and Management System)	AutoGrid Systems Inc.
Byucksan Power	2.0a+b	Stand Alone	Energle DRAS	Byucksan Power Company, Ltd.
Electric Power Research Institute	2.0b	Cloud Based	Open-source implementation of	Electric Power Research

		Stand Alone	OpenADR 2.0b	Institute (EPRI)
EnTouch 360 DR	2.0a	Cloud Based Control	Proprietary wireless facility automation system coupled with a cloud-based control	EnTouch Controls, Inc.
Fujitsu Limited/ALOX Demand Controller	2.0b	Stand Alone	DR automation server software/system	Fujitsu Limited
Hitachi Demand Response Automation Server	2.0b	Stand Alone	Demand Side Management (DSM), Demand Response and Virtual Power Plant (VPP)	Hitachi, Limited
Honeywell (Akuacom)/DRAS	2.0a+b	Stand Alone	Demand Response Automation Server	Honeywell (Akuacom)
I-ON Communications/DRMS	2.0a+b	Stand Alone	DRMS (Demand Response Management System)	I-ON Communications Co., Ltd.
Institute for Information Industry/SAVE	2.0a+b	Stand Alone	SAVE (Smart and Valid Energy) server	Institute for Information Industry
IPKeys	2.0a+b	Cloud Based	IPKeys' Energy Interop Server & System (EISS)	IPKeys Technologies, LLC.
Lockheed Martin/SEEload	2.0a+b	Stand Alone	SEEload, a single advanced load management platform	Lockheed Martin
Mitsubishi Electric Corporation/BLEnDer DR	2.0b	Stand Alone	BLEnDer DR Server	Mitsubishi Electric Corporation
NEC Engineering/NECE-DR-CA	2.0b	Stand Alone	Demand Response application service platforms	NEC Engineering, Ltd.
NTT Smart Community Platform	2.0a+b	Cloud Based Control	Smart Community Platform	NTT

Olivine DER	2.0a+b	Cloud Based, Stand Alone	Olivine DER, distributed energy resource management system	Olivine, Inc.
Siemens/DRMS	2.0a	Cloud Based	DRMS (Demand Response Management System)	Siemens AG
Sumitomo Electric Industries/EI-VTN	2.0a+b	Stand Alone	VTN modules (SEI-VTN 2.0b)	Sumitomo Electric Industries, Ltd.
TOSHIBA	2.0a+b	Stand Alone	Demand Response Server software	Toshiba Corporation
Wooam/SmartDRMS	2.0a+b	Cloud Based, Cloud Based Control, Stand Alone	Smart DRMS (Demand Response Management System)	Wooam, Inc.