Intelligent Buildings

Laboratory Tests of Integrated Controls of Residential and Small Commercial Buildings for Energy Management and Load Leveling

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Technical Update, January 2018

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NOTE

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ABSTRACT

The intelligent buildings annual research portfolio focuses on building controls to reshape load profile and enable flexible demand. The three major technical areas of Intelligent Buildings in 2016 and 2017 are developed around: Automation, Communication and Integration. The 2016 research was to demonstrate low-cost and easy-to-install connected devices packages to upgrade residential and small commercial buildings for IDSM. We demonstrated several system architectures to enable whole-building-level DR. For this 2017 project, the focus is on the controls integration of end-use load management, electric storage and solar PV. We conducted a comprehensive technology review to resolve the load ramping issues caused by higher penetration of solar PV, which include 1) state level policy drivers and national level initiatives/projects, 2) EPRI pilots in the area of integration of solar PV + storage + load management, 3) a summary of technology vendors in the market and finally 4) the value proposition to customers and utilities. EPRI is developing two initiatives – one is to co-develop an application programming interface to dynamically control a battery that can be coordinated and optimized with load management systems to balance PV; the other one is the enhanced customer engagement for home energy management and demand response. The voice interaction developed in 2017 is the very first Alexa Skill to enhance customer engagement through participation in DR events.

Keywords

Solar PV
Storage
Load Management
Enhanced Customer Engagement for DR

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1
INTRODUCTION

The Load Ramping Issue

The growing solar photovoltaic (PV) penetration and the non-dispatchable nature of solar have generated and are projected to create curvier load shapes and more balancing problems to grid operations. The most famous example is the significant load ramps (also known as the “Duck Curve”) that have been already observed in California, and the even deeper and steeper load curves that are observed in Hawaii. The California Independent System Operator (ISO) predicted the net load curves year-by-year and plotted in a chart (Figure 1-1) based on the forecasted total load and the expected electricity generation from all generation resources in California [1]. The non-controllable behind-the-meter PV generation creates three significant load ramps throughout a day, two upwards and one downwards, and the load ramps are expected to be deeper and steeper each year [1]. The first load ramp starts around 4:00 AM as people start the day and the load ramps up as more and more people start their daily routines. As the sun rises around 7:00 AM the behind-the-meter PV generation kicks in, which replaces the need of generators on the supply side and the net load curve starts to move downward. Thus, the net load curve finishes the first ramp and starts the second ramp, which continues until 3:00 PM or 4:00 PM until the sun starts to set and solar PV generation starts to drop. The third and the steepest load ramp starts as people get off from work and the PV generation lags with the increasing load. The net load curve then starts to drop again as soon as it reaches the peak as time gets later in the evening and loads begin to decrease. Referring to Figure 1-1, the daily load ramps are expected to increase in the next few years with each ramp in the scale of thousands of MWs, and each starting and finishing in just a few hours. These significant load ramps challenge the reliability of grid operation and need flexible and controllable resources on the demand side to flatten the load curve.

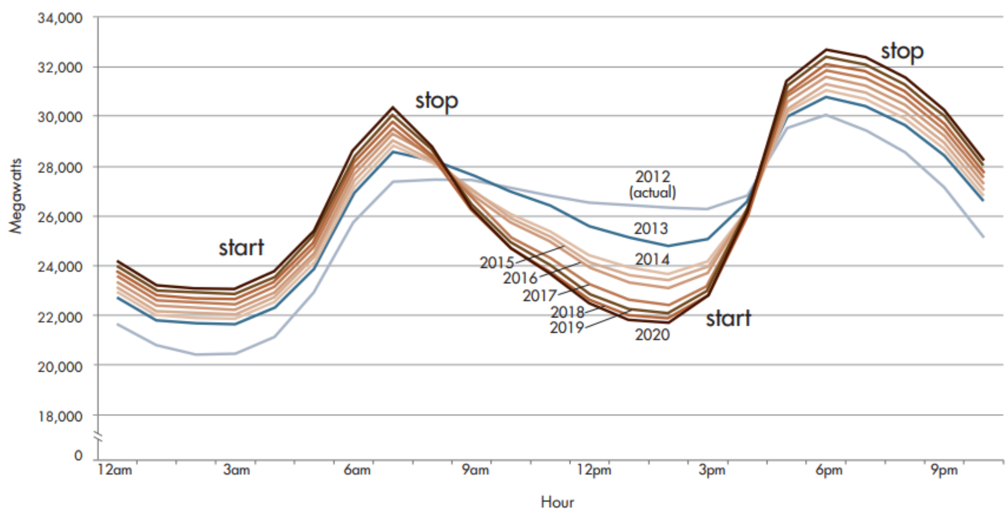


Figure 1-1
Predicted and Measured Net Load Ramps in California [1]

The U.S. grid-connected Solar + Storage is projected to be a 1.2 GW market in 2021, which would be more than 70 times of what was in 2015 [2]. The dramatically growing PV penetration will present significant challenges to the existing utility operations and business models. Recent initiatives and demonstrations are observed to be targeted on flattening the net load curve, driving standardization, repeatability and scalability. Technology development trends suggest expanding the existing pilots that have been focused on "Solar + Storage" or "Solar + Load management" to an all-inclusive "Solar + Storage + Load management" type of DER system. New concepts, such as "Smart Solar" and "Solar +" are developed to suggest a systematic solution that would be needed in order to balance such dramatic net load curves that are created by solar PV [3]. The proposed system requires that the demand-side resources can be integrated, orchestrated and optimized with utility system planning, investment and operations, as well as independent system operator (ISO) and distributed system operator (DSO) planning and operation. The drivers of solutions can be summarized into two buckets: 1) energy policy and market drivers, and 2) emerging technology trends. Although the development of this area is still at a very early stage and the implementation will be taking place in steps and in different timescales, the policy/market drivers and technology trends are moving to an integrated solution of demand-side resources that can maximize utility system benefits, reduce greenhouse gas emissions, harmonize the needs and wants of customers with system needs, and establish financial benefits/customer incentives to be integrated with ISO/DSO operations [5].

State Level Policy Drivers and National Level Initiative

The California Legislature has enacted legislation to further reduce greenhouse gas (GHG) emissions and deploy DERs. Senate Bill 350 commits to reduce 2030 GHG emissions by 40% below 1990 levels, increase to 50% of electricity generated by renewables, double EE savings in electricity and natural gas use, and encourage electric transportation and technologies for low-income/disadvantaged communities [6]. The Hawaii Legislature passed HB623, which sets Hawaii to lead the entire country as the first state to set a 100 percent renewable portfolio standard by 2045 [7]. Hawaii has recently planned to take one step further—pushing to extend the bill to cover 100 percent ground transportation to be fueled by renewable sources by 2045 [8].

In addition, the California Senate Bill requires implementation of an integrated resource plan (IRP) process to identify optimal portfolios of DER resources to achieve the GHG goals and to meet the challenge of renewable integration [6]. The bill recognizes the load ramping issue of high penetration of renewables, and has identified that demand-side resources need to play a more important role to balance solar PV. Thus, the California Public Utility Commission (CPUC) recently expanded the definition of Integrated Demand Side Management (IDSM). The new definition considers the initiatives of integration work on the customer side and made the transition to a broader integration of DERs to consider "the impact and interaction of such resources as a whole, and individual customer's energy usage and the environment" [5]. Here, the "integration of such resources" is defined as the integration of demand-side resources that include "distributed renewable generation resources, energy efficiency, energy storage, electric vehicles, and demand response technologies" [5]. Whereas, the previous definition of IDSM was more focused only on EE and DR, which stated that "Energy efficiency, energy conservation, demand response, advanced metering, and distributed generation technologies are offered as elements of an integrated solution that supports energy and carbon reduction goals immediately, and eventually water and other resource conservation goals in the future" [9]. In fact, EPRI has spoken with California and Hawaii Investor-Owned Utilities (IOU), and the current focus is still pushing on the coordination of internally-separated EE and DR programs/incentives to add a DR project with EE benefits, or vice versa. However, the dramatic renewable penetration in California requires more flexible loads with integrated controls, and thus needs the demand-side resources to be integrated and coordinated for load management. These state level policy drivers are expected to promote more pilot projects and demonstrations of the all-inclusive "Solar + Storage + Load management" type of DER systems.

The US Department of Energy (DOE) funded the "Beneficial Integration of Energy Storage and Load Management with PV" under DOE's Sustainable and Holistic Integration of Energy Storage and Solar PV (SHINES) program to provide scalable, reliable and cost-effective solutions to the dramatically increasing solar and storage resources added to the grid [2]. SHINES is the first funding program within DOE focusing exclusively on "Solar + Storage + Load Management" to address the significant load ramps caused by solar PV. The funded projects' developed solutions include: dynamic load management, advanced forecasting, utility communication, controls, smart buildings and smart appliances to meet both utility and customer needs [2]. The awardees and their projects are shown in Table 1-1.

Table 1-1
The DOE SHINES Projects to Exclusively Focus on Solar + Storage + Load Management on National Level

Awardee	Focused Customers	Objective
Austin Energy	Residential, Commercial	Demonstrate a solution adaptable to any region and market structure that offers a credible pathway to a LCOE of 14¢/kWh for solar energy when augmented by storage and other distributed energy resource management options.
Carnegie Mellon University	Residential, Commercial	Develop and demonstrate a distributed, agent-based control system to integrate smart inverters, energy storage, and commercial off-the-shelf home automation controllers and smart thermostats.
Commonwealth Edison Company (ComEd)	Microgrid Community	Address availability and variability issues inherent in solar PV technology by utilizing smart inverters for solar PV and battery storage and by working synergistically with other components within a microgrid community.
EPRI	Residential, Commercial	Design, develop and demonstrate technology for end-to-end grid integration of energy storage and load management with PV generation.

Table 1-1 (continued)
The DOE SHINES Projects to Exclusively Focus on Solar + Storage + Load Management on National Level

Awardee	Focused Customers	Objective
Fraunhofer Center for Sustainable Energy (CSE)	Commercial, Industrial	Develop and demonstrate a scalable, high-performance solution to manage the integration of commercial and utility-scale PV, energy storage, and commercial and industrial facility loads at the feeder level.
Hawaiian Electric Company	Residential, Commercial, Industrial	Demonstrate successful distributed photovoltaics (PV), energy storage, and dynamic load control deployments and show the system-level benefits of enhanced utility visibility and control of distribution system/edge-of-network electricity resources.

EPRI Pilots of Controls Integration of Load Management, Solar PV and Storage

In response to the state level policy drivers and the national level initiatives, EPRI has been taking the leadership in research, development, demonstration and deployment (RDD&D) and has gained significant achievements and experiences related to the integration of DERs, including solar PV, energy storage and load management.

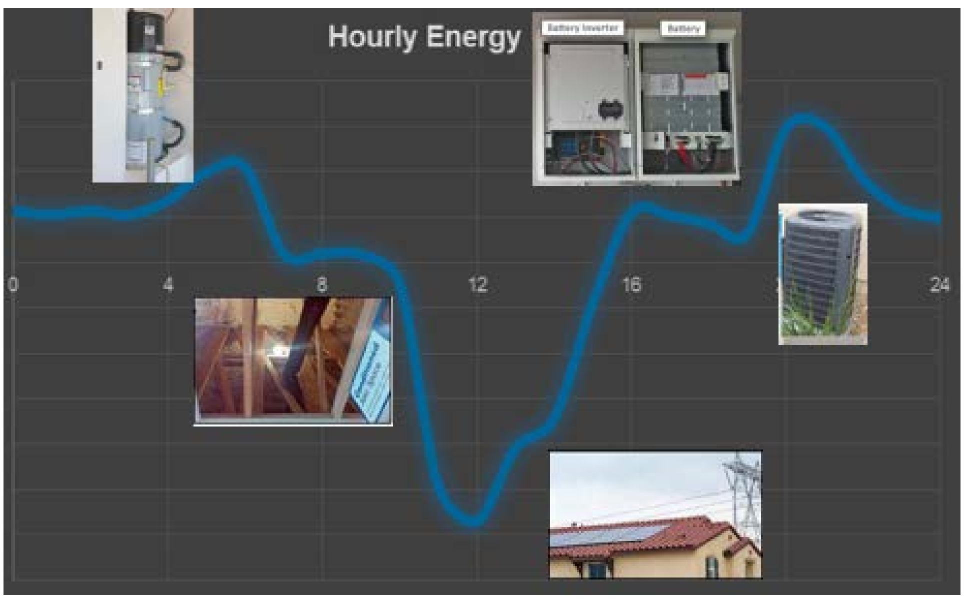


Figure 1-2
EPRI Field Demonstrations of Solar + Storage + Load Management in Fontana, CA

The first project was the demonstration of a near-Zero Net Energy home community to study the impacts on the local distribution systems and mitigation of the impacts using multiple strategies centered around load management and energy storage [10]. The project was completed in late 2016, and was funded by the CPUC under the California Solar Initiative (CSI) research development and demonstration (RD&D) program. The State of California has set ambitious targets for GHG emission reduction and energy efficiency improvement. One of the goals is that all new residential homes in California must be Zero Net Energy (ZNE) by 2020, which is defined as: the societal value of the energy consumed by the residential building over the course of a year must be less than or equal to the societal value of the on-site renewable energy generation. ERPI's demonstrations have shown that the load profile of a ZNE home is very similar to the "Duck Curve" in Figure 1-2, because the "Duck Curve" is essentially the accumulation of many buildings' net load curves. Referring to Figure 1-2, the EE measures substantially reduce energy consumption in the morning times until the early afternoon, and the energy storage flattens the load curve in the late afternoon hours. Soon after,the evening load kicks in and creates the last steep ramp until late evening hours. The daily load curve is typically observed to have multiple load ramps and very high backflow of power because of solar PV and the interactive and counteractive controls. After the completion of this project, EPRI still kept working with the product providers to continue the work of system integration One of the efforts is to work with battery management provider E-Gear to co-develop the Application Programming Interface (API) to manage battery and loads to balance with PV generation. The project in Fontana is the beginning, and EPRI continues the work of controls integration.

Another of EPRI's on-going projects is the DOE funded "Beneficial Integration of Energy Storage and Load Management with PV" under the SHINES program. The EPRI's SHINES project is set to demonstrate a path toward minimizing costs using load management, advanced forecasting techniques, and optimal control strategies through smart inverters and battery storage management [2]. The EPRI project designs a two-level control architecture—1) system controller to maintain wide area reliability and coordinate local controllers and distribution equipment; 2) local controller to optimize PV, storage, load management, smart inverters and solar/load forecasting, and respond to the system controller [2]. The project focuses on two university sites (one is at Case Western Reserve University and the other is at Queens College, University of New York), and two single families in Florida.

In addition, EPRI recently kicked off another project on PV + Storage + EMS in a commercial building, under the California Energy Commission's "Solar +: Taking the Next Steps to Enable Solar as a Distribution Asset". The project is aimed at the demonstration of integrated solar + storage with a smart inverter and load management to provide very cost effective solar integration through load management, energy storage and a smart inverter. The goal is to 1) reduce total lifecycle cost (capital cost, installation, O&M) for a behind-the-meter solar + storage systems by 10% through integration of disparate and independent EE technologies that connect to DERMS and EMS. 2) Demonstrate appropriate business models for Commercial Building Scale solar that meets both owner requirements for cost effectiveness and utility grid balancing needs. 3) Increase late evening energy availability and reduce peaks by 50%, especially for evening peaking buildings, through a combination of west facing solar, optimized energy storage operation, load management and smart inverter controls. 4) Work with the IOU on extending this research into their DRP areas and understanding how the results could be used for the Distributed Resource Planning process.

Technology Trends and Vendor Landscape

Our approach of research in 2017 started with a technology review. We had developed a long list of DER vendors, including smart thermostats, lighting and plug load controls, HVAC manufacturers, energy monitoring, Internet of Things (IoT) platforms, PV manufacturers, electric storage, battery management and electric vehicles. We scheduled conference calls and spoke with most of the technology providers in the market. Some of the product providers had been working with EPRI in the past or are still in on-going projects, and some of the product providers were new vendors to EPRI. We discussed with them their technologies and development plans under non-disclosure agreements (NDA). Overall, we found technology providers have very strong interest in the field of aggregation/integration of load controls and battery management to balance with PV generation. However, we found that most of the aggregations of PV, storage and load management are not yet developed on controls integration and initiatives that are focusing on controls/system integration are not yet ready for lab testing or field demonstration. For example, one of the technology providers has developed simulation models of solar + storage and is testing with the deployed fleet level load management internally. Another technology provider has been testing load controls based on the already deployed solar + storage systems, but the development is still in progress until late 2017. Table 1-2 lists the initiatives and publicly announced collaborations of solar, storage and home EMS. EPRI is currently collaborating with E-Gear to co-develop an Application Programming Interface (API) to dynamically control battery operations, which allows the optimization with load controllers to balance solar PV. Referring to Table 1-2, closer collaborations of solar PV providers and smart home providers have been observed. Mass market IoT providers, such as Nest and Nexia, are extending the energy service to Solar PV, and incorporating residential rooftop solar data on the user App as an expanded package for home EMS.

Table 1-2
Technology Vendor's Initiatives and Collaborations in the Solar + Storage + Home EMS Field

Solar + Load Management	Solar + Storage + Load Management
SunPower and **Ecobee** help homeowners to control electricity costs [11]	
SunPower will license its Energy Services Management to **Tendril**. The SunPower platform provides solar related data to Tendril and will allow development to a broader set of consumers and utilities [17]	
Vivint Solar and **Vivint Smart Home** will provide a single unified control of both solar PV and smart home technology [18]	
Sunverge Energy Platform operates energy storage to balance rooftop solar PV and provide some grid services [21]	
SolarCity's platform will integrate with **Nest** and the customer will get a free Nest Thermostat when they choose SolarCity for PV [12]	**SolarCity** is launching a Solar + **Tesla Powerwall** + **Nest thermostat** package to manage energy and reduce grid dependence [16]

Table 1-2 (continued)
Technology Vendor's Initiatives and Collaborations in the Solar + Storage + Home EMS Field

Solar + Load Management	Solar + Storage + Load Management
Enphase collaborates with **Nexia** Home Intelligence to integrate solar energy production data and monitoring into Nexia's platform for homeowners [14][15]	**Enphase** Home Energy Solution combines solar PV, energy monitoring, storage into one platform and is compatible with **Nest** thermostats [13]
	E-Gear EMC optimizes Solar PV, home energy monitoring, Time-of-Use load management, Time-of-Export optimization and grid support capabilities [19]

In the residential EMS market (technologies also apply to most small commercial space), partnerships currently are only established between some of the end-use devices, such as thermostats, lighting and plug loads through gateways. The development trend is observed to expand the ecosystem to incorporate energy consumption, storage and on-site generation, and to cover more controllable loads on top of smart thermostats (e.g., pool pumps, water heaters, heat pumps) to deliver expanded customer values and grid values. Although PV and storage are considered different types of DERs than end-use controls in terms of operations and grid impacts, customers consider rooftop PV as an EE measure and a part of an energy improvement package along with smart home IoT ecosystems. The trend is that energy generation and consumption data are to share the same platform/dashboard for data visualization, controls, fault detection and diagnostics (FDD).

Technology providers that focus on fleet level management of DER resources are also expanding from their historically focused areas, whether that is PV + storage or load management, to expand into an all-inclusive DER management system (DERMS). For example, retail electric customers are encouraged to bid in wholesale markets for DR. Examples include CAISO's rule 24/32 and PJM's rules of DER participation for DR. EPRI is developing practices and methods to enable prosumers (consumers that can produce electric energy from DERs) to trade the excess generation with the grid or other prosumers, and maintain reliable operations with high penetration of DERs under the new construct of the Distribution System Operator (DSO).

Referring to Figure 1-3, technology providers are categorized depending on their primary/historical focus area, either PV + storage or load management, and either the product focused on fleet level or individual premise level. This graph is generated based on the products that are considered relevant to the solar PV + storage + load management field, but does not cover all products that the technology providers can deliver to the market. The intent of Figure 1-3 is not meant to define which quadrant that a product provider should belong to, but rather to show the overall technology development trend of convergence and integration.

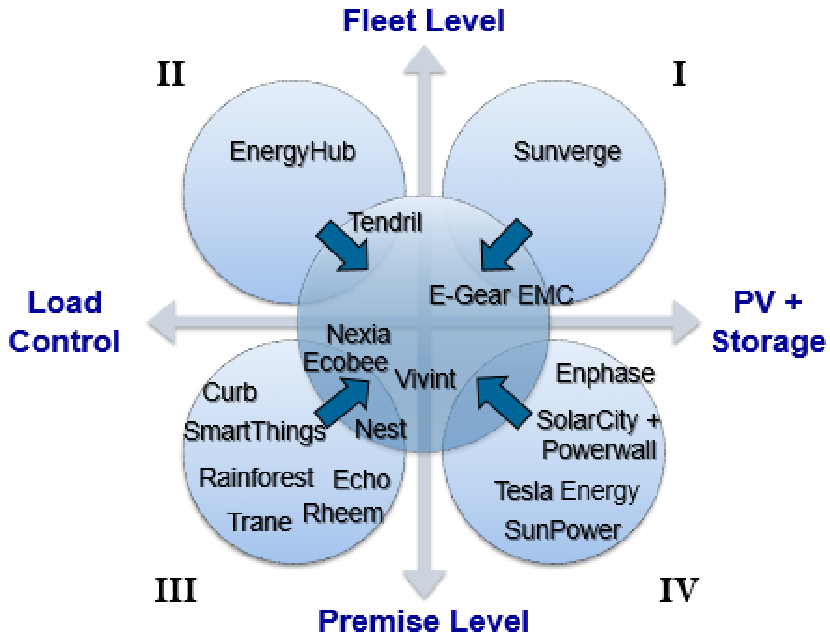


Figure 1-3
Technology Trends of the Solar + Storage + Home EMS Field

- Quadrant I is for technology providers that primarily focus on PV + Storage but now are integrating controls for load management, and whose focus is to aggregate a fleet of DERs.
- Quadrant II is for technology providers that primarily focus on fleet level load management (primarily for DR, such as the Bring-Your-Own-Thermostat (BYOT) program, and are now adding more controllable loads and integrating with solar PV and storage.
- Quadrant III is for technology providers that are targeting the very competitive smart home market. Focuses of these technology ecosystems have been security, energy monitoring, comfort, energy saving, convenience and may extend to DR capabilities. These technology providers are observed to be adding PV and storage as part of the home digitization and deliver energy use visualizations in a unified user interface.
- Quadrant IV is for technology providers who primarily focus on premise-level PV and storage markets. These providers have already announced collaborations to share data with some mass market IoT providers. For example, the collaborations listed in Table 1-2.

Connected Building Control Technologies

Referring to Figure 1-3, quadrant III covers more technology providers than any other quadrants, and it is the most competitive market space. In addition, the EPRI Program 170 focuses on energy end-uses so quadrant III and II are the focused areas of utility members. Thus this research delved deeper into the “Load Control” side of Figure 1-3 (i.e., quadrant II and III) to plot the vendor landscape that covers each subclass of technology and their customer values and grid values in Figure 1-4. This research adopts the sub-classes defined in an EPRI report that focuses on technology and market characterization of connected home market [20]. In that EPRI report, connected home products are defined into nine subclasses to target opportunities of both premise level and fleet level. Examples of technology providers are explored in that report [20]. The subclass definitions are listed in the following.

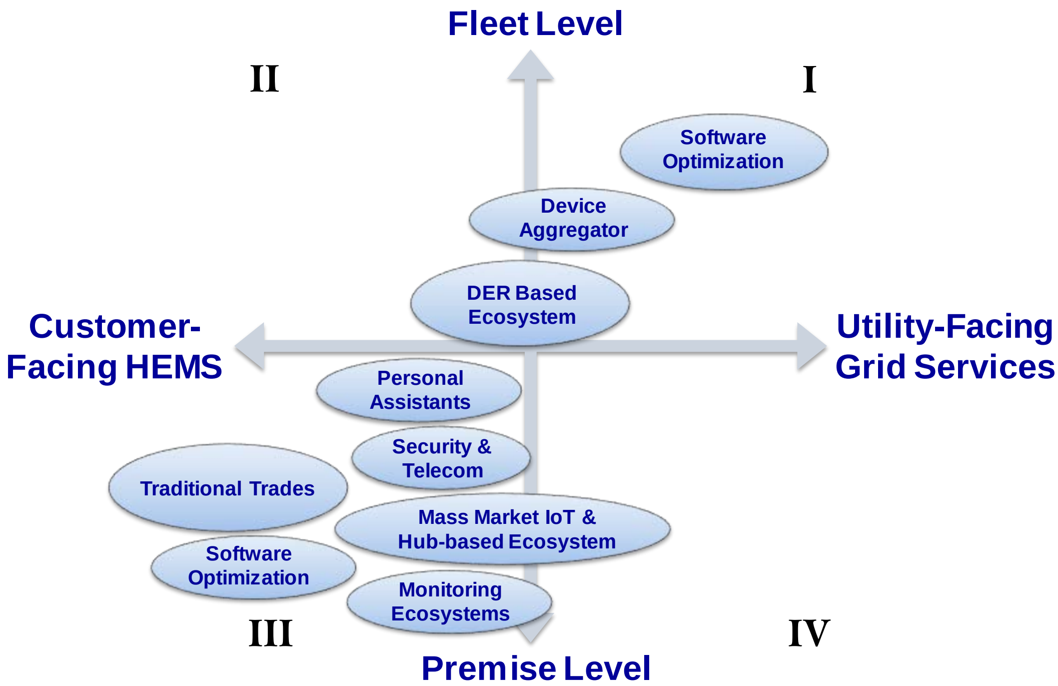


Figure 1-4
Vendor Landscape of Connected Building Control Technologies

- Personal Assistants: ecosystems that use natural voice commands to take controls of multiple end-use devices of an ecosystem.
- Security and Telecom Providers: ecosystems that are designed for home security.
- Device Aggregators: Aggregation platforms that control ecosystems of loads, mostly for utility DR programs.
- Mass-Market IoT Platforms: Leveraging a center piece of device (typically the thermostat) to focus on premise level energy use through compatible devices
- Hub-Based Mass Market Ecosystems: A centering hub is needed to establish ecosystem
- Traditional Trades: Conventional HVAC and water heating products are upgraded with interoperability, automation and integration features.
- Monitoring-Focused Ecosystems: Load disaggregation of premise level data, or circuit level metering.
- DER-based Management Ecosystems: Control of customer-side solar, inverter, storage and load management.
- Software-based Optimization Providers: Software-based control platforms or dashboards to provide Software-as-a-Service.

The "Load Control" (i.e., connected building controls technologies) side of Figure 1-3 (The connected building controls) covers a vast amount of technology vendors in the market and they can be summarized into nine subclasses. Figure 1-4 shows the landscape of technology providers' targeted customers and benefits only in technology subclasses but does not discuss any particular products.

The product providers are roughly distributed on a linear regression curve in quadrant I and III, which means that if a technology provider focuses on a fleet of customers, the technology is very likely targeted on utility-facing grid services; whereas, if a technology provider focuses on end-uses within a premise, the technology is more likely to only focus on customer facing benefits, such as comfort, convenience, security and energy savings.

The enablers of expanding customer-facing technologies for utility services are not limited to technology, but also the necessary assistance and incentives for customers to participate. For example, leveraging a smart thermostat for both EE and DR (i.e., both customer and utility facing benefits) would need customer's central air-conditioning, broadband internet access, and an open router port to connect the device. In addition, utilities also need a program that combines EE and DR benefits together to incentivize customers to participate.

We also have to agree that customer needs and utility needs are not necessarily aligned, so not all subclasses need to push to expand functionalities to meet the needs of one more quadrant in Figure 1-4. However, EPRI does observe several technology subclasses that are pushing their boundaries to cover both customer and utility benefits. These subclasses are ecosystems and platforms that aggregate and orchestrate end-use devices (and DER resources) and leverage energy data to optimize for customer and utility benefits. The core functions of these ecosystems and platforms are summarized in Table 1-3.

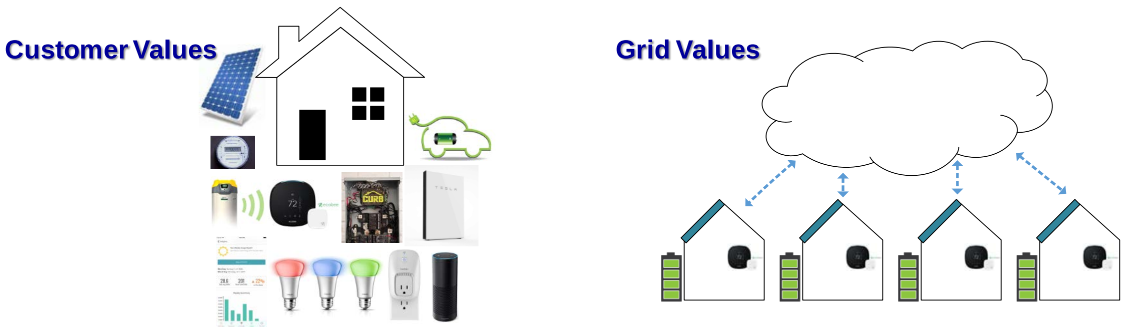
Table 1-3
Core Functions of Ecosystems and Platforms

	Optimization	Orchestration	Aggregation
Definition	Use of data and customer inputs to provide autonomous programming and response targeted for a specific need	Coordinated programming and response of end-use loads within a premise	Grouping of end-use loads, typically of the same end-use, to respond to particular utility controlled signals
Examples	Whisker Labs and Nest Labs	Amazon Echo, Samsung SmartThings	EnergyHub, Tendril, AutoGrid

Value Proposition

Currently many products in the market are providing both customer-focused and grid-related values. Products focused on premise level are more towards customer values. For example, voice assistant products like Amazon Echo and Google Home can aggregate end-use loads and enhance customer engagement for energy management. Products like Curb and Bidgely are energy monitoring focused, which allow low-cost access to circuit level metering and improve customer energy awareness to manage energy cost. Ecosystems like Works with Nest and SmartThings are mass-market IoT platform that allow integration of many types of loads to provide whole-home level energy management.

Platforms focused on fleet level are more towards grid-related values. For example, Wiskerlabs and Tendril partner with product providers to collect and provide additional data parameters to optimize operations of a portfolio of end-use devices (primarily thermostats). Sunverge and E-Gear partner with third party product providers, including solar, inverter and storage providers, to monitor and control for grid and customer benefits.



- Personal assistants for enhanced control, improved comfort and convenience
- Energy management for improved energy efficiency
- Load monitoring and bill management

- Optimization and aggregation of DER
- Grid reliability and power quality in areas of high DER generation
- Peak load reduction for distribution referral
- Resource adequacy and flexibility

Figure 1-5
Customer-Focused and Grid-Related Values

The value proposition of customer-focused and grid-related features are listed in Table 1-4 and Table 1-5. The customer-focused values are considered to benefit in four key areas: savings, convenience, security and comfort. Similarly, the grid-related values are considered to benefit in three key areas: EE, DR and DER integration. These key areas are the pillars of customer-focused and grid-related values. We then delved deeper and listed the potential values for both customer side and grid side. Some values satisfy one category of the key areas but some others satisfy multiple ones. The pillars are color-coded in Table 1-4 and Table 1-5 to show each value proposition's beneficial key areas. The definitions of the benefit features are defined in Table 1-6, and the improvement of the future and utility initiatives are discussed in a related EPRI report [20].

Table 1-4
Potential Customer Value Propositions

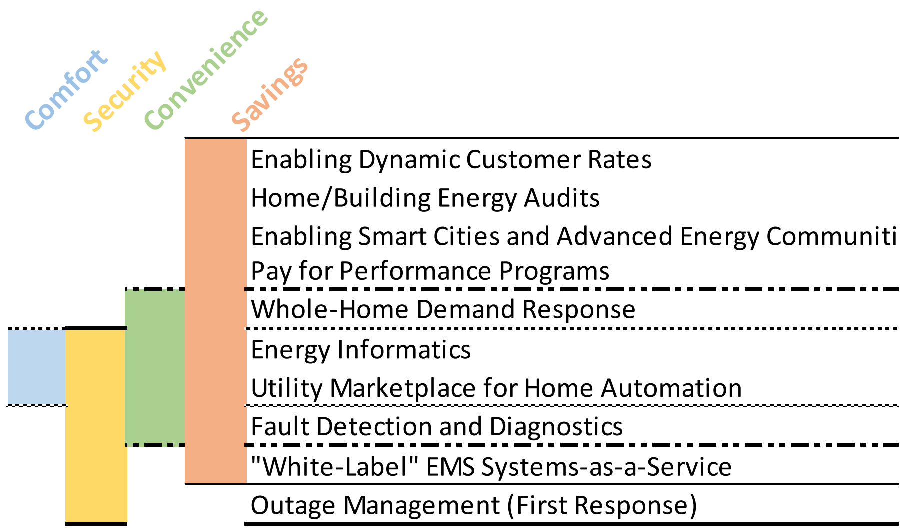


Table 1-5
Potential Grid Value Propositions

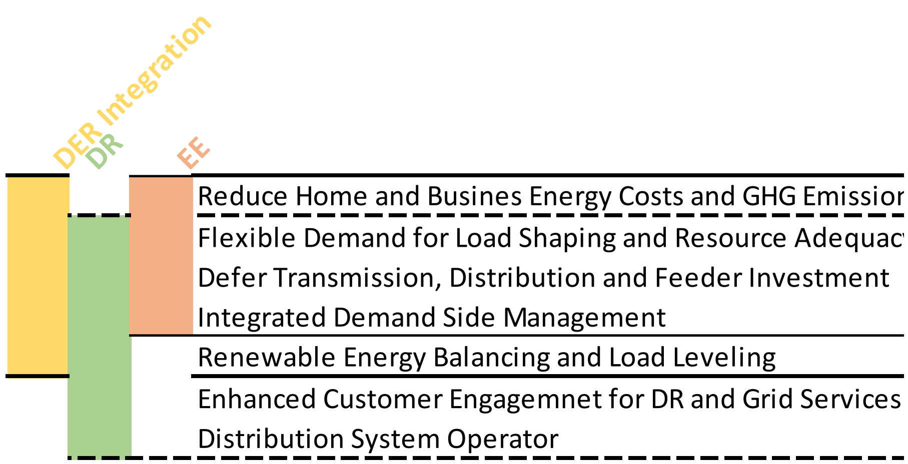


Table 1-6
Definitions of Potential Customer and Utility Value Propositions

Customer and Utility Values	Definitions
Whole-Home Demand Response	DR where multiple end-use systems within a premise are triggered by a single DR signal delivered by the utility through an in-home gateway. Will define this as both aggregation and orchestration of control of 2 or more end-use loads within a premise
Enabling Dynamic Customer Rates	Using connected ecosystems to enable both monitoring, control and/or optimization of connected devices in a dynamic utility rate environment (ToU, CPP, RTP, demand, etc.)
Home/Building Energy Audits	Using environmental, occupancy, customer preference and other available data to determine building characteristics enabling programs such as home weatherization.
Fault Detection and Diagnostics	Using ecosystems to identify instances where systems, appliances and devices within that system are not functioning as intended based on operational history and signal patterns compared to nominal system expectations
Pay for Performance (P4P) Programs.	Replacement of traditional utility incentives based on deemed values and/or energy calculations w/ an incentive structure based on savings estimated through data collection during a performance period.
Utility Marketplaces for Home Automation	Using infrastructure provided by connected home ecosystem providers, webpages and/or phone applications that allow for a utility customer to procure connected systems or components of a connected ecosystem. In certain cases, provides automatic program enrollment and associated incentives.
Energy Informatics	Using data and communication capabilities of connected ecosystems to provide energy information—utility facing and otherwise
“White-Label” EMS Systems as a Service	Partnerships with connected home ecosystem providers to provide home automation and energy management
Outage Management	Use of connected ecosystems to help manage device response in the event of a utility system failure
Enabling Smart Cities and Advanced Energy Communities	Use of data and controls to provide coordinated responses to community-level events such as emergency notification.

Table 1 6 (continued)
Definitions of Potential Customer and Utility Value Propositions

Customer and Utility Values	Definitions
Flexible Demand for Load Shaping and Resource Adequacy	Load shaping is to achieve six objectives: peak shaving, valley filling, load shifting, flexible load shape, strategic conservation and strategic load growth. The first four objectives focus on Power (kW) adjustments and the last two objectives focus on Energy (kWh) adjustments. Customers are motivated in demand response or dynamic pricing programs to participate.
Reduce Home and Business Energy Costs, and GHG Emissions	Use of advanced controls to optimize operations and shut off appliances when not used to improve energy efficiency, and thus reduce GHG emissions.
Enhanced Customer Engagement for DR and Grid Services	Use of customer interfaces, dashboards, voice commands to enhance customer engagement to DR events and grid services. Customers need the necessary technology for easier visuals to understand these programs and convenient interfaces to participate.
Defer transmission, distribution and feeder investment	Demand side management (DSM) and distributed energy resources (DER) are considered customer side non-wire solutions that can defer transmission and distribution (T&D) build out and upgrades.
Integrated Demand Side Management	Integration of demand side resources such as EE, DR, renewable energy sources and energy storage into a package for aggregated energy management.
Renewable Energy Balancing and Load Leveling	Use of energy storage and aggregation of controllable and flexible loads to balance large load ramps caused by renewable energy sources, such as solar and wind.
Distribution System Operator	The DSO interfaces the bulb power system operator (balancing authority, ISO/RTO) and the owners/operators of demand side resources (microgrid, building energy management system and DER aggregators)

2
IDENTIFICATION OF PRODUCTS AND APPROACHES FOR LABORATORY TEST

Research Scope

The intelligent buildings annual research portfolio focuses on building controls to reshape load profile and enable flexible demand. The three major technical areas of Intelligent Buildings in 2016 and 2017 are developed around: Automation, Communication and Integration. The 2016 research was to demonstrate low-cost and easy-to-install connected devices packages to upgrade residential and small commercial buildings for IDSM. We demonstrated several system architectures to enable whole-building-level DR. The lab test showed that the automation and communication can be established through 1) a physical gateway and AMI metering-based architecture, 2) a CTA-2045 standards based architecture or 3) a cloud based API-integration architecture. The lab tests in 2016 allowed us to deploy the controls in three customers' homes to demonstrate the idea of "whole-home DR", which leverages controls integration that controls an aggregate of loads through a central energy management system for DR.

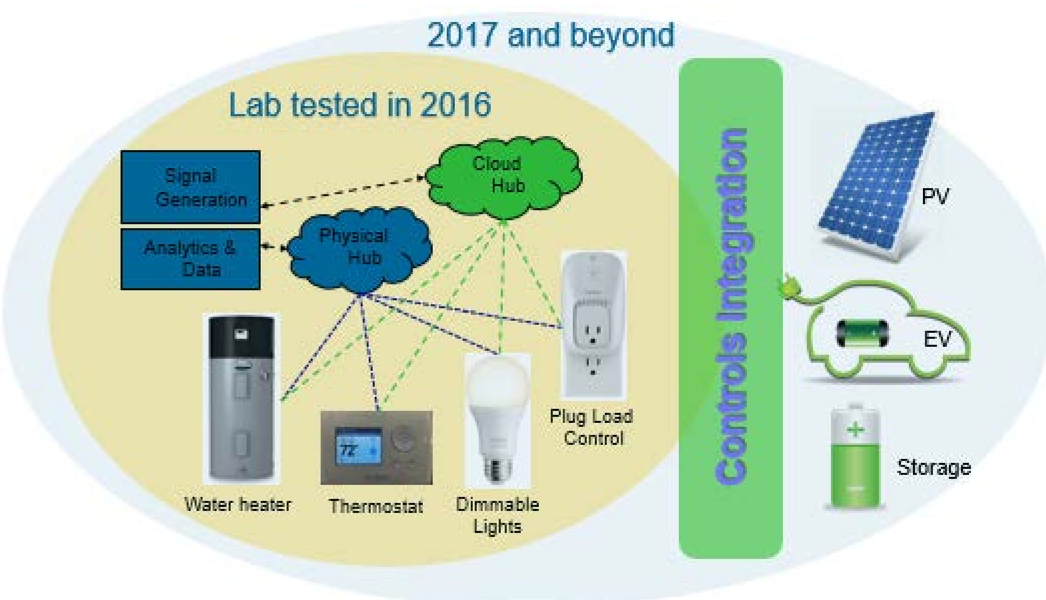


Figure 2-1
Research Scope of Intelligent Buildings ARP

The 2016 research showed the controllability of the aggregated loads on the whole-home level. The research plan for the 2017 project was to explore the demonstrations of aggregated loads to solar PV and electric storage sincethe higher solar PV penetration to the grid has introduced the curvier load shapes. Energy storage is not enough to completely flatten the load ramps and it is not economically feasible to use an over-sized battery to balance the entire load ramps. Thus controllable, interoperable and flexible ecosystems of loads are needed in order to completely mitigate the load ramps.

The Advanced Energy Communities (AEC) group of EPRI has been leading on quite a few initiatives and projects with the focus of aggregation and orchestration of connected devices in the residential and small commercial space, and pertains to the demonstration of whole-home/building level energy management for EE, DR and renewable generation balancing, and requires the development of an aggregation platform that integrates major end-use appliances via individual product provider's Application Programming Interface (API). Two key research areas are identified for this 2017 Intelligent Buildings ARP—1) dynamic battery management and 2) enhanced customer engagement for DR.

EPRI Development One: Dynamic Battery Management

EPRI collaborated with E-Gear on battery management in the project of demonstration of near-Zero Net Energy home communities. However, currently E-Gear's battery management system is not optimized to coordinate with load controls, and is only controlled by fixed charging/discharging rules with solar generation. Therefore, the solar generation is not as much coordinated with battery storage, which results in the ramping net load curves (Figure 1-2). After completion of the project in Fontana, CA, EPRI has been continuously monitoring and analyzing the energy generation and consumption data to understand customer behavior. The ramping net load curves are observed on a daily basis. Thus, EPRI and E-Gear have planned to co-develop an API that allows EPRI to dynamically control the charging/discharging of the battery to coordinate with loads to balance PV generation. The development is still in progress. The first step is to use excess solar PV generation (i.e., generation greater than home loads) to charge the battery and then discharge the battery when solar PV generation is less than home loads. The future steps can integrate whole-home DR, solar prediction, and optimization of customer comfort, convenience and energy saving goals. Figure 2-2 shows the topology of E-Gear's Energy Management Controller (EMC). The API is used to allow EPRI to leverage the control system functionalities to dynamically respond to any customized energy systems of solar PV, storage and load management.

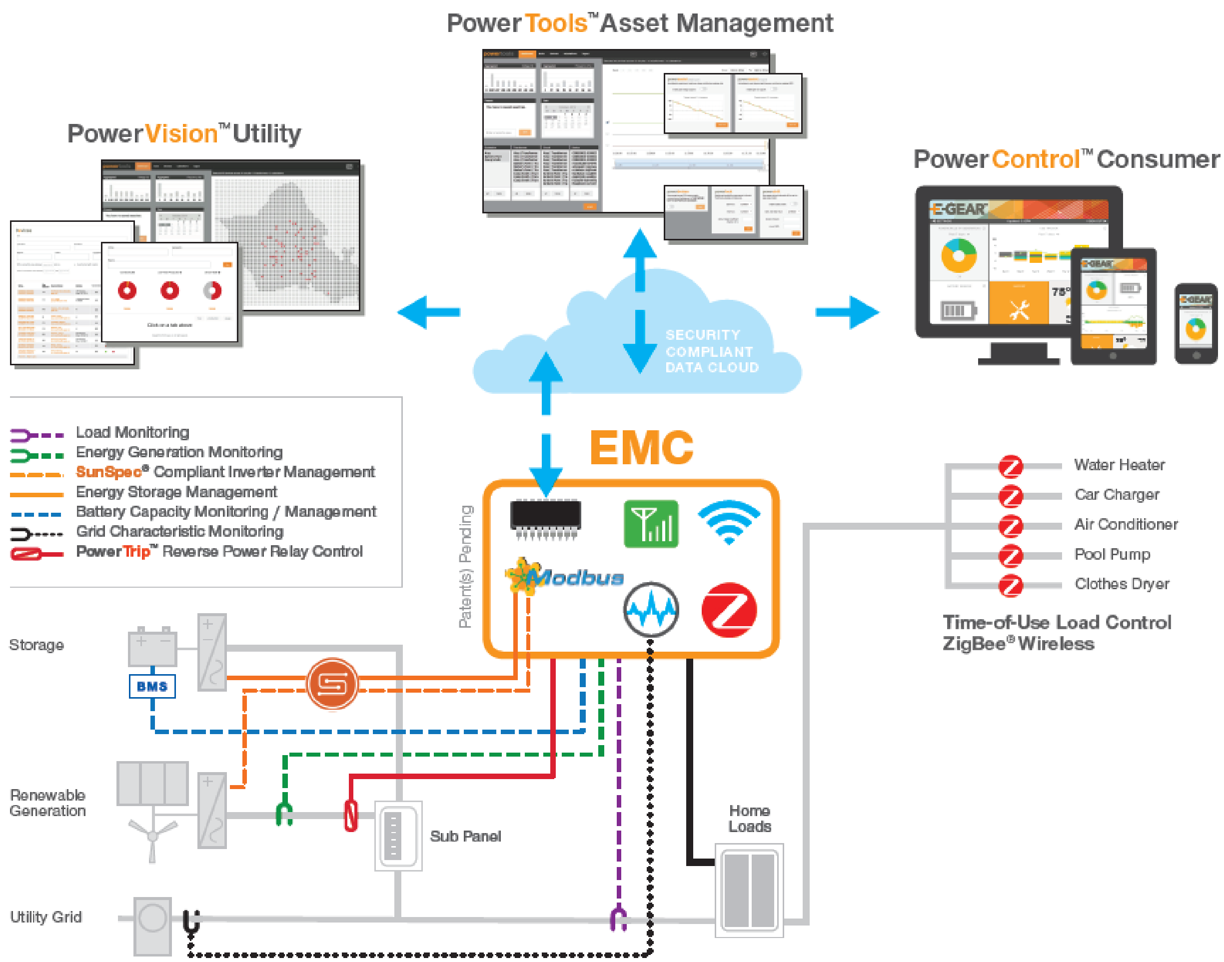


Figure 2-2
E-Gear EMC for Control of Solar PV, Storage and End-Use Devices (Courtesy of E-Gear)

EPRI Development Two: Enhanced Customer Engagement for DR

Customer engagement is one of the most challenging barriers of residential and commercial DR programs. In 2016, EPRI tested controls for EE and DR with various architectures, and these ecosystems can be summarized into two architectures: cloud-to-cloud communications (Figure 2-3) and central Hub communications (Figure 2-4). EPRI has improved based on what we have tested and has added voice commands, which can be translated by the voice assistant (i.e., Amazon Echo) to actionable commands to end-use loads. The Amazon Echo Alexa expands the controllability to schedule loads via occupant's voice. Echo has already established voice commands to schedule individual loads, such as "Alexa, lower the temperature by 2 degrees" and "Alexa, turn off the lights in living room". This allows verbal communications for DR events without logging into an website or clicking an App, thus removing certain layers to engage customers. The development is to develop a specific Alexa Skills for voice command to enable DR events. The future steps will be to use voice control check, accept/reject of an aggregation of end-use loads for DR, and to add the voice functions to validate load sheds after the DR events. The voice commands shall also be expanded to check premise level energy production/consumption, and allow the use of the fully integrated and coordinated PV, storage and loads ecosystem to provide further grid services.

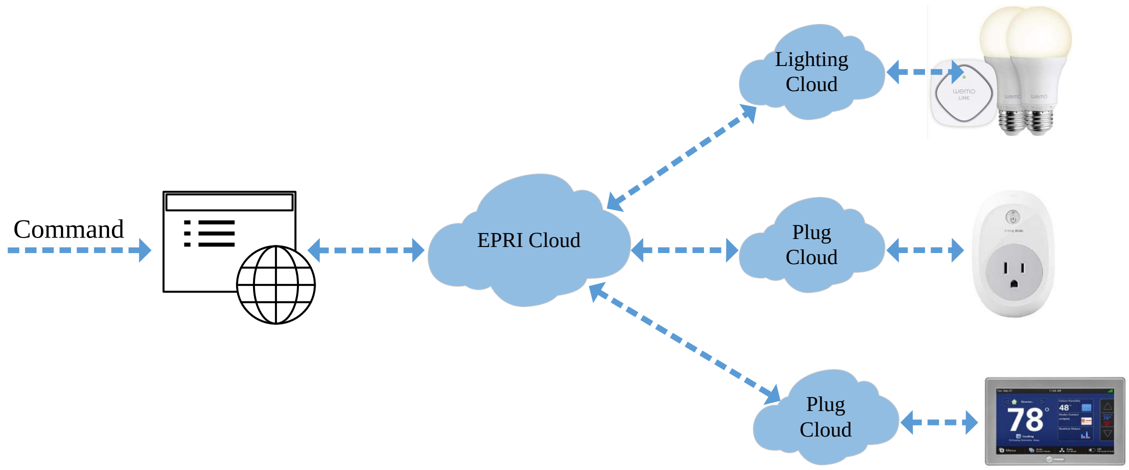


Figure 2-3
DR through an Aggregation of Loads via Cloud-to-Cloud Communications

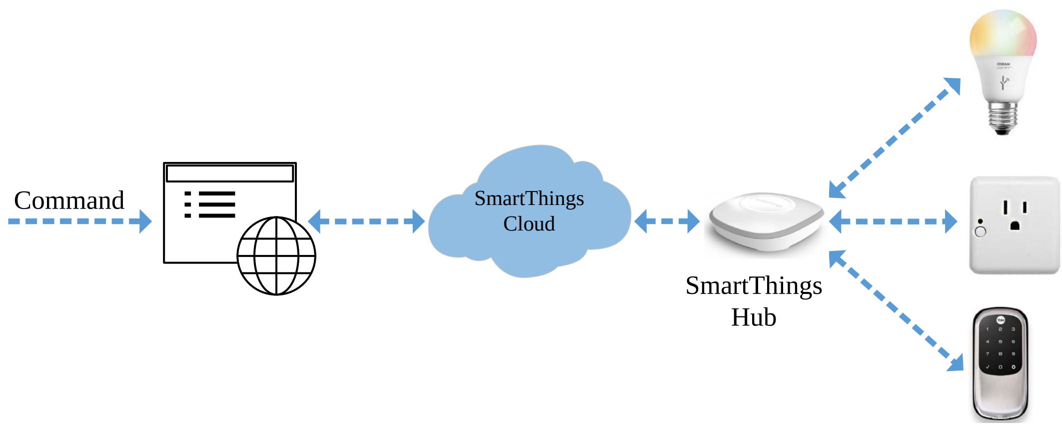


Figure 2-4
DR through an Aggregation of Loads with Connections through a Central Hub

The voice command is developed based on the cloud-to-cloud controls architecture (Figure 2-3) and adding Amazon Echo and Ecobee 4 (with built-in Alexa) for voice commands. The three controls paths are shown in Figure 2-5.

Path 1 (blue dotted line) is the same as the cloud-to-cloud communications in Figure 2-3—the load control command is sent via a webpage to the EPRI cloud to control loads. The goal is to control an aggregate of end-use devices. Smart thermostats, lighting and plug loads are the largest three loads in residential and small commercial buildings, and are the focus on controls retrofits for EE and DR. We propose Path 2 and Path 3 the architecture for voice control.

Path 2 (orange dotted line) requires an Amazon Echo to take in voice command and pass on to the Alexa cloud, which may either 1) directly go to the individual device's cloud for load control, or 2) go to the EPRI cloud to schedule an aggregation of loads—which will be the same as Path 1 once the control command reaches the EPRI cloud.

Path 3 (green dotted line) employs Ecobee4, which has a built-in Alexa, to replace an Echo to take in a voice command and pass the command to the Alexa cloud. In this case, the Ecobee thermostat is not just a load and taking controls, but also needs to communicate with other loads for DR.

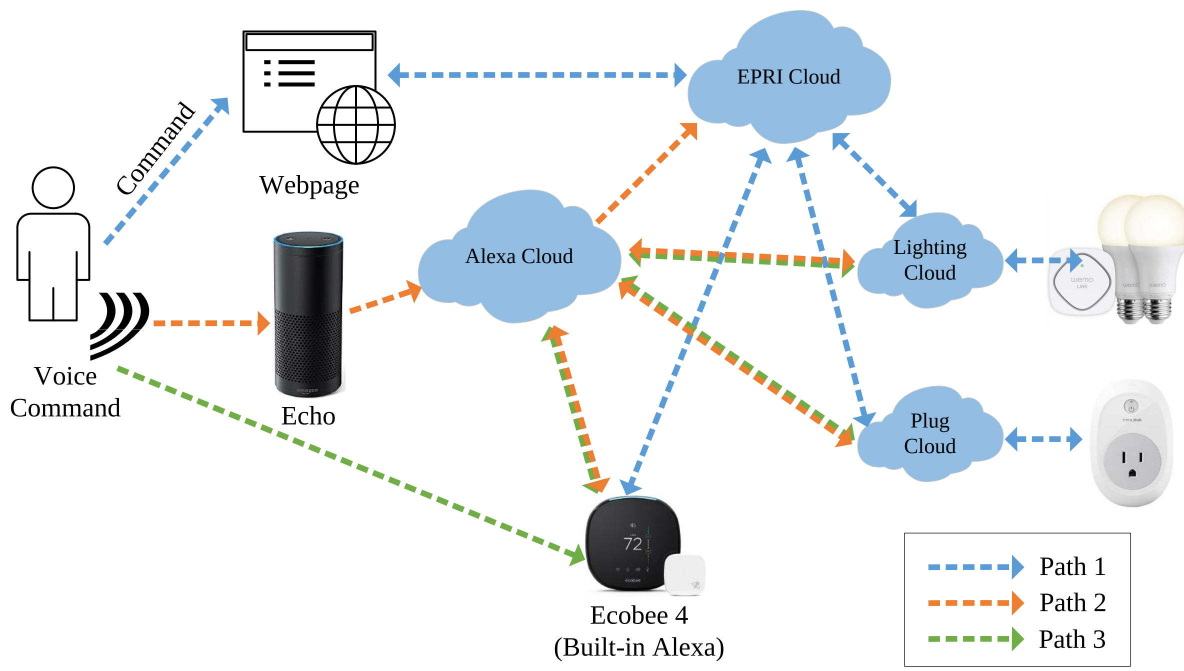


Figure 2-5
Voice Command Architecture to Enhance Customer Engagement for DR

3
VOICE INTERACTION DEVELOPMENT AND LABORATORY TESTS OF VOICE COMMAND FOR DR

Amazon Echo can already integrate an impressive list of home energy devices, such as smart home hubs, lighting, switches, dimmers, locks, cameras, home security, thermostats, and ventilation controls [22]. What really expands the voice assistant's capability is Alexa's Skill Kit, which is a collection of self-service APIs, tools, documents and code samples that enable personalized Skills to expand functions using voice interactions [23]. The development of an Alexa Skill is a three-step process—design, build/test and launch (Figure 3-1). The detailed design guide is available on Amazon Alexa website [24].

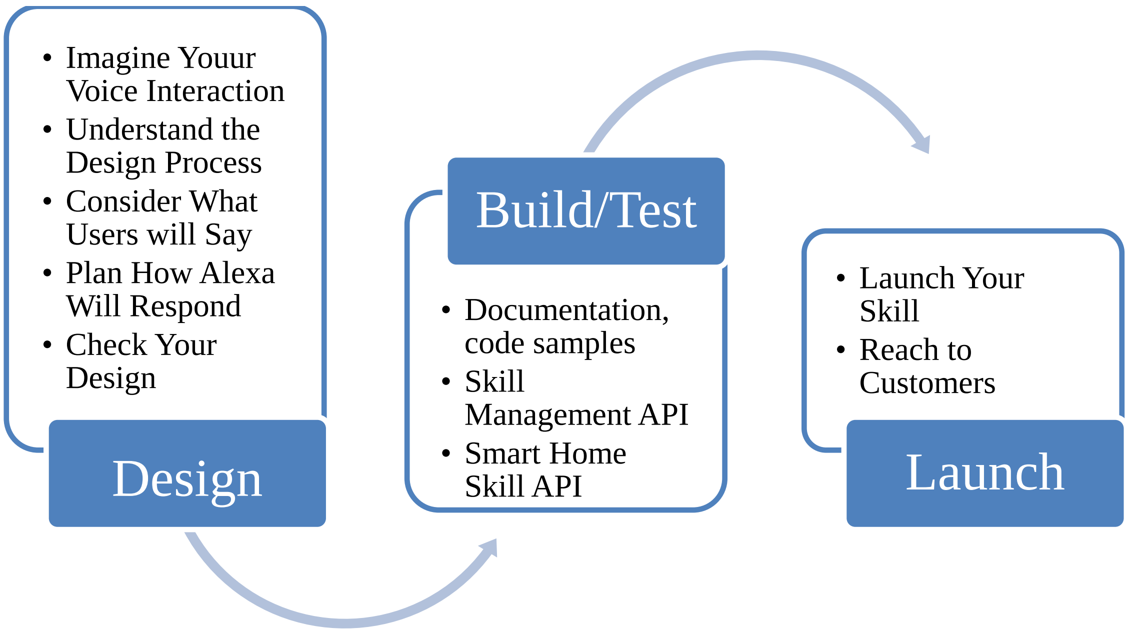


Figure 3-1
Alexa Skill Development Process

Design

EPRI designed the "EPRI Utility Program" to interact between users and Alexa to check, accept and reject DR events. The idea is to use simple verbal commands to check if DR events are available for the day, and ask what time the event will occur and for how long. The user can then decide to accept or reject the events based on the needs of the home or business. Figure 3-2 shows the interactions between users and Alexa. This is the very first Alexa Skill to allow voice assistant functions to engage customers for utility DR programs as far as we know. But it is also the very beginning to unlock the potentials of leveraging Alexa's Skills to engage residential and commercial customers for a broader set of utility services and energy management needs.

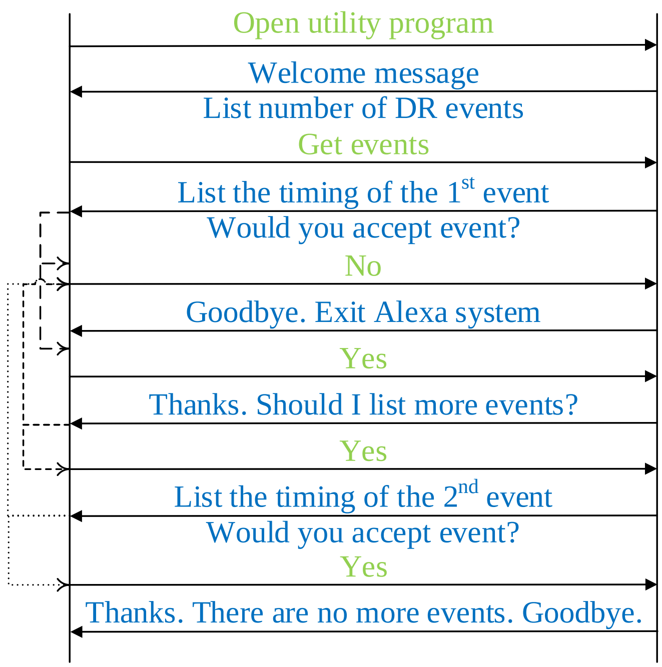


Figure 3-2
Design Interactions between Users and Alexa for the Amazon Alexa Skill for DR

Build and Test

The Skill is built based on the interactions designed, shown in Figure 3-3. It is more specific on what the responses would be for each request from the user. The Skill is designed to turn on and off an end-use device (e.g., thermostat and light bulb) when a DR event is started, but the ecosystem can be expanded for whole home/premise DR.

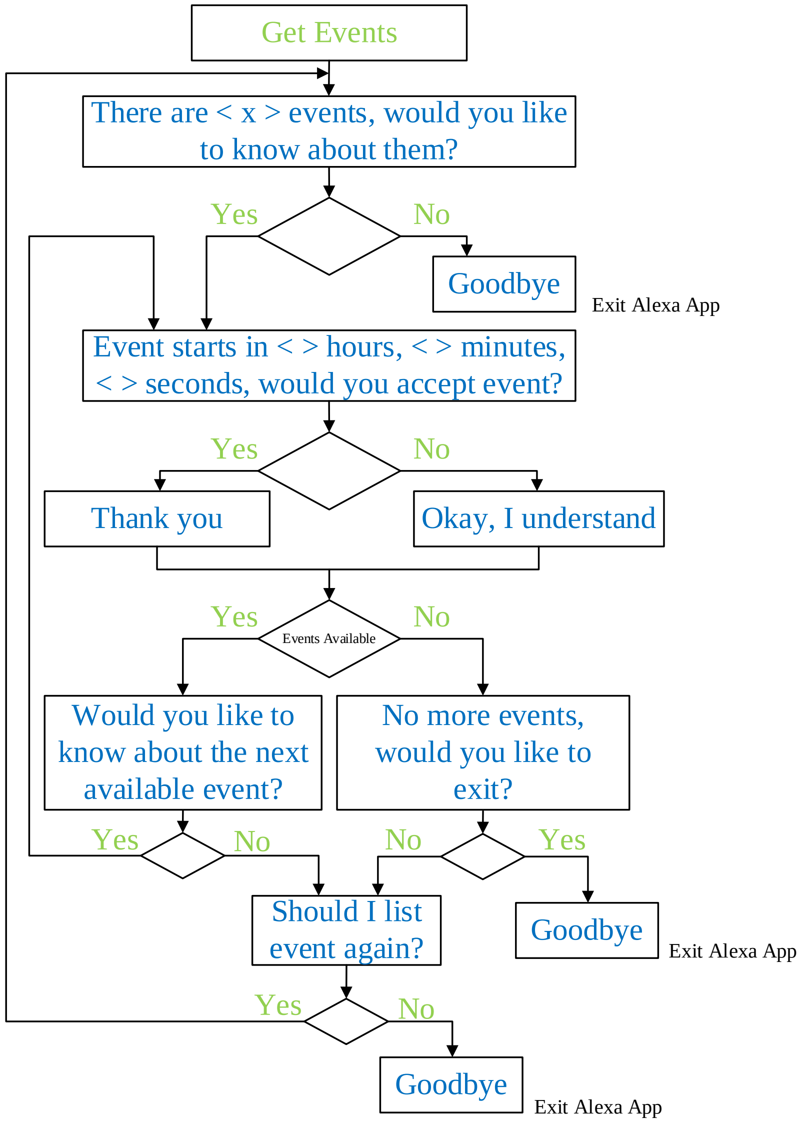


Figure 3-3
Build Verbal Interactions of EPRI Utility Program for DR

The laboratory tests are shown in Figure 3-4. The picture on the left is the Alexa Testing Interface to take in voice command, and the picture on the right shows the laboratory tests using Echo to run the EPRI utility program. The tests were successful, and we covered all possible scenarios as far as the interactions designed for the Skill. It is a voice-based tests but we were able to record a video to demonstrate the interactions with Alexa. We are still developing the functions and will not finally launch the Utility Program Skill until we find a test set for field demonstrations with customers.

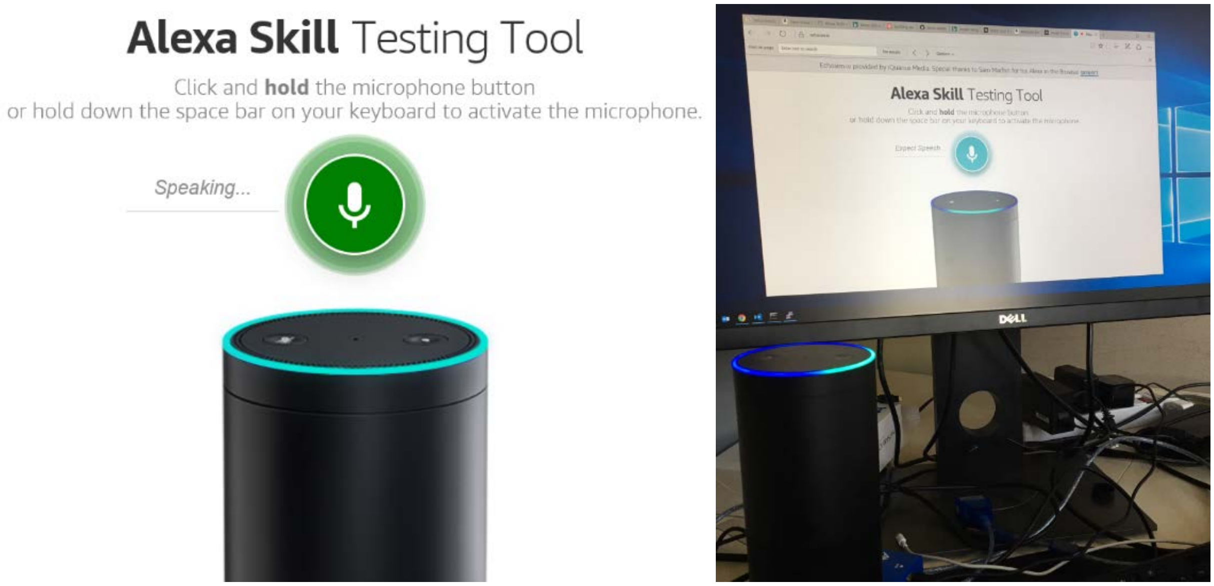


Figure 3-4
Alexa Skill Testing Interface and the Laboratory Test

4
SUMMARY AND NEXT STEPS

This report focused on the controls integration of end-use load management, electric storage and solar PV. We conducted a comprehensive technology review to resolve the load ramping issues caused by higher penetration of solar PV, which include 1) state level policy drivers and national level initiatives/projects, 2) EPRI pilots in the area of integration of solar PV + storage + load management, 3) a summary of technology vendors in the market and finally 4) the value proposition to customers and utilities. EPRI is developing two initiatives—one is to co-develop an API with E-Gear to dynamically control batteries to be coordinated and optimized with load management systems to balance PV; the other one is the enhanced customer engagement for home energy management and demand response. The Alexa Skill, EPRI Utility Program, is the very first one to use Amazon Echo to engage customers to participate for DR events. The work done in 2017 suggests the next steps in the Intelligent Buildings ARP in 2018:

1. Expand Alexa Skills. Two potential developments to improve the EPRI Utility Program: 1) expand to whole-home DR by aggregating multiple types of end-use devices into the ecosystem. 2) expand the Alexa Skill functions to enable renewable balancing needs, such as fast DR and flexible DR.

2. Continued investigation of the technology convergence trend. With the emergence of renewable energy integration, microgrids, Software-as-a-Service building energy management systems, Zero Net Energy buildings, smart home ecosystems and customers more actively engaged as “Prosumers”, the distribution system operator (DSO) structure is the trend to support the new paradigm of “Transactive Energy”. EPRI will need to continue to closely watch the technology trend.

3. Analysis of data collection and aggregation of end-use devices, and PV and storage is a good proxy of where orchestration and optimization happens within an integrated energy management system.

5
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