Linking Continuous Energy Management and Open Automated Demand Response

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Abstract

Advances in communications and control technology, the strengthening of the Internet, and the growing appreciation of the urgency to reduce demand side energy use are motivating the development of improvements in both energy efficiency and demand response (DR) systems. This paper provides a framework linking continuous energy management and continuous communications for automated demand response (Auto-DR) in various times scales. We provide a set of concepts for monitoring and controls linked to standards and procedures such as Open Automation Demand Response Communication Standards (Open Auto-DR or OpenADR). Basic building energy science and control issues in this approach begin with key building components, systems, end-uses and whole building energy performance metrics. The paper presents a framework about when energy is used, levels of services by energy using systems, granularity of control, and speed of telemetry. DR, when defined as a discrete event, requires a different set of building service levels than daily operations. We provide examples of lessons from DR case studies and links to energy efficiency.

1. INTRODUCTION

The objective of this paper is to explore a conceptual framework and a set of definitions that link building energy efficiency, control system features, and daily operations to electric grid management and DR. DR can be defined as mechanism to manage the electric demand from customers in response to supply conditions, such as through prices or reliability signals. We discuss how these relate to the GridWise® interoperability context [1]. Such concepts and definitions are needed as the building industry and the electric utility industry become more integrated in supply demand side operations. It is critical for the energy industry to more strongly link demand-side performance objectives with electricity supply-side concepts.

One motivation for this framework is to facilitate understanding of automation of DR in demand side systems. The examples in this paper draw from research on commercial buildings, though the concepts are relevant to industrial facilities and residential buildings. This framework also emphasizes existing buildings but the ideas are applicable to new buildings and may help guide concepts to move DR into building codes and standards.

A key theme of this work is to understand not just how much energy a building uses, but when it uses energy and how quickly it can modify energy demand. This is not a new concept, but as more sophisticated controls are installed in buildings, the opportunities to better link demand and supply side systems are improving. Previous papers have discussed definitions of energy efficiency, daily peak load management, and DR [2 & 3]. This paper discusses the different speeds of DR, automation basics, and related control system features and telemetry requirements.

One objective of this DR research is to evaluate building electric load management concepts and faster scale dynamic DR using open automation systems. Such systems have been developed by the California Energy Commission's Public Interest Energy Research Program (PIER). The PIER Demand Response Research Center (DRRC) has led this effort and developed and deployed systems throughout California and the Northwest in a technology infrastructure known as OpenADR [4]. The intention of the signaling infrastructure is to allow building and industrial control systems to be pre-programmed, enabling a DR event to be fully automated with no human in the loop. The standard is a flexible infrastructure design to facilitate common information exchange between utility or Independent Systems Operator (ISO), and end-use customer. The concept of an open standard is intended to allow anyone to implement the signaling systems, providing the automation server or the automation clients. These standardized communication systems are being designed to be compatible with existing open building automation and control networking protocols to facilitate integration of utility/ISO information systems and customer electrical loads [5].

The next section of this paper outlines the six key elements of the conceptual framework for traditional energy management and emerging demand responsiveness. This is followed by a section that discusses levels of building services in relation to the six key elements. This section also discusses control systems and the speed of telemetry.

Next we present an example of how this framework can be applied to advanced lighting controls and we reference the New York Times Building in New York as an example of an as-built advanced multi-functional lighting control system. We conclude with a brief summary and key research issues associated with the framework.

2. LINKING ENERGY EFFICIENCY AND DEMAND RESPONSE

We provide a brief description of six energy and demand management concepts. The first three concepts we classify as "traditional" energy management. The second three concepts are "emerging" demand responsiveness. Following each of the six concepts is a comment on the role of automation and timescales. These six sections are:

- **Traditional Energy Management**
  - Continuous energy minimization
  - Monthly peak demand management
  - Daily time-of-use energy management
- **Emerging Demand Responsiveness**
  - Day-Ahead demand response (Slow DR)
  - Day-of demand response
  - Ancillary services demand response (Fast DR)

2.1. Traditional Energy Management

2.1.1. Continuous Energy Efficiency

Energy efficiency can be defined as providing some given level of building services, such as cooling or lighting, while minimizing energy use. A strategy or technology that provides the same amount of service with less energy is a more efficient technique. A good example is to compare the lumens per watt of a fluorescent versus incandescent light. At the whole building level a more efficient building is one that provides HVAC, lighting, and miscellaneous plug load services using less energy for the same services than a comparison building. To actually achieve high levels of energy efficiency in a complex commercial building requires energy efficient components combined with well commissioned controls and good operational practices.

The key point about energy efficiency is that building control strategies and operations should be optimized with energy use minimized every hour of the year for the given "service" the building is providing at any moment. Our success in reducing energy use in commercial buildings is strongly linked to our improved ability to measure the services the buildings systems provide while ensuring that energy waste is reduced as much as possible. We need to reduce heating, cooling, ventilating and lighting of spaces that are unoccupied.

Automation – The automation of continuous energy management is provided by energy management and control systems (EMCS).

Timescale – Thousands of hours per year

2.1.2. Monthly Peak Electric Demand Management

The majority of large commercial buildings in the US pay peak electric demand charges. These charges often represent about one-third of the monthly electricity costs, yet they are not as well understood or as well managed as total (monthly or annual) electricity use. Peak electric demand charges typically have a time period they are associated with, such as the afternoon from noon to 6 pm. Some tariff designs have peak demand charges that apply to the monthly peak during on, partial or mid-peak, and off peak periods. Others have demand ratchets that may result in a peak demand that occurs in one month to set charges for 12 months. The key issue here is it is not how much energy is used, but when the most demand for electricity occurs. Efforts to reduce these charges require understanding rates, building controls, weather sensitivity and occupancy patterns.

Automation - Historically many energy management systems have offered demand-limiting features to reduce the peak demand by "limiting" electricity use when demand is high. While these are in limited use, they are available in many EMCS platforms and they require integrating whole-building electric use data with the EMCS.

Timescale – A few hours per month

2.1.3. Daily Time-of-Use Management

Similar to the presence of peak electric demand charges, most large commercial buildings have time-of-use (TOU) charges where electricity during the day time hours is more expensive than nighttime use. TOU energy management techniques involve careful consideration of scheduling equipment to reduce use of expensive electricity if possible.

Automation – Most EMCS provide scheduling of HVAC and lighting systems including programming of demand shifting strategies. As mentioned below most buildings do not use thermal storage so they do not "charge" energy systems during off peak periods. Some facilities do, however, modify energy use patterns to reduce expensive on-peak energy.

Timescale – Key periods of the day

The above three basic concepts are applicable to most commercial buildings with TOU and peak demand charges.

We have not, however, described more advanced strategies such as thermal storage or pre-cooling that allow for variations in charging and discharging of thermal systems. To optimize building performance we will want to consider what we are trying to minimize. Optimal control strategies to minimize energy costs may differ from strategies to minimize total energy use or CO_2 emissions (as CO_2/kWh may vary between the day and night). Ideally one can achieve both low energy use and low energy costs!

2.2. Emerging Demand Response Management

As we move toward a future in which the electric grid has greater communication with demand-side systems, it is useful to define and explore the time-scales of energy management and DR.

2.2.1. Day-ahead ("Slow" DR)

Day-ahead DR involves informing a demand-side customer the day before a DR event that the DR is pending the following day. In the case of manual DR this notification allows the facility manager to prepare a facility to participate in DR for the given schedule. Day-ahead real-time pricing can be an example of Day-ahead DR. Some RTP designs issue 24 electricity prices for each hour of the following day. This allows facility managers to schedule their loads and manage their electricity costs.[1]

Automation – Most DR in US commercial buildings is manually initiated. However efforts to develop and deploy open DR automation standards have shown that most buildings with EMCS are good candidates for DR automation. Day-ahead signals allow the EMCS to schedule next-day DR events and are sometimes used to automate pre-cooling [6]. The DR program evaluations in California showed that about 15% of the time the person responsible for the manual response did not act [7].

Timescale – 50-100 hrs/yr (though day-ahead hourly real-time prices can be continuous, high price events are fewer hours per year.)

2.2.2. Day-of DR

Day-of DR can be defined as DR events that occur during the day when the event is called. These DR events typically have a scheduled time and duration. Day-of DR may also be an hour-ahead or 15-minute ahead real time price. A facility manager has less notice to prepare to participate in such events.

Automation – Similar to Day-Ahead DR, Day-of DR is often initiated manually. The more "real time" the DR, the more compelling is the need to automate DR because the notification for a person in the loop is more problematic with faster time scales of DR. Pre-cooling may not be possible in "Day-of" DR events.

Timescale – 30-60 hrs/yr (though hour-ahead real-time prices can be continuous, high price events are fewer hours per year.)

2.2.3. Fast DR

A third class of DR is ancillary services. There are several classes of ancillary services such as load following systems, spinning and non-spinning reserves, and regulation capability [8]. Fast DR can be thought of DR that is available quickly and the DR may not last long but it can be harvested quickly. The DR event may only be five minutes in duration. There are several recent research projects that have explored such "fast" DR [8].

Automation – Fast DR requires automation because people often cannot "jump" to action when notified of a fast DR event. These fast DR events may not last long. The electric loads are often restored within five to ten minutes of when they were curtailed [8]. The existing Internet-based DR automation systems are being considered for their speed and applicability to this class of DR.

Timescale – 5-10 hrs/yr

3. SERVICE LEVELS, CONTROLS AND TELEMETRY

There are three key features of demand-side systems to consider as commercial buildings begin to participate in all six of the electricity value chains listed above. These are, Levels of Service, Granularity of Controls, and Speed of Telemetry.

3.1. Levels of Service

There is a tremendous opportunity to better link DR and energy efficiency by improving understanding of the levels of service provided by existing buildings and building end-use systems. Take the example of an office building which is designed to provide ventilation to support good indoor air quality, indoor climate control, lighting, and other services such as hot water, office equipment plug loads, and vertical transport (elevators). Good energy management practices assume that there is not much energy wasted. The building is heated, ventilated, lit, and cooled at optimal levels to provide comfort, but energy waste is minimized.

Given this as the baseline, to participate in DR requires that the service level that is provided in normal operations is minimized. Common examples are to change temperature set points or reduce lighting levels. Better measurement and monitoring of actual temperatures and lighting level distributions will improve our ability to change service

1 In California "Day-ahead" DR has been referred to as price

levels since we want to ensure "optimal energy efficiency" as the starting point for DR.

3.2. Granularity of Advanced Controls

Similar to the desired ability to "measure" levels of services provided in a building is the desire to "control" the level of service. To participate in DR events we do not want to simply "turn off" a service, rather we'd like to "reduce" the service. This ability to improve control can provide features important for continuous energy management, monthly peak demand management, and daily TOU control. Further examples are provided below.

3.3. Speed of Telemetry and Response

This final category of infrastructure moves us from manual DR to fully automated systems. Research and automated DR programs in California have shown that existing Internet systems are fast enough to provide a signaling infrastructure for Day-ahead and Day-of DR [9]. Research is beginning to explore the capabilities of such systems for fast DR.

Table 1 below summarizes the key concepts explored in this framework

Table 1: Summary of demand-side systems features to electricity value chains

Concept	Automation	Time Scale	Level of Service	Speed
Continuous Energy Management	Provided by EMCS	1000s hrs/yr	Optimize each hr	Slow
Daily TOU Energy Management	Provided by EMCS	Select time of the day	Optimize for TOU	Slow
Monthly Peak Demand Management	Provided by EMCS	Few hours/ mo	Minimize demand charges	Slow
Day-ahead DR	Can be automated	50-100 hrs/ Yr	Temp reduced	Medium
Day-of DR	Can be automated	30-60 hrs/ Yr	Temp reduced	Medium-Fast
Ancillary Services	Requires automation	5-10 hrs/ yr	Temp reduced	Fast

4. LINKS TO GRIDWISE

The GridWise® interoperability framework [1] was developed to facilitate integration and information exchange among participants. The integration of technologies to link energy efficiency and OpenADR must meet the requirements of the electricity value chains and key features of demand-side systems, namely levels of service, granularity of controls, and speed of telemetry. These technology requirements vary based on the type and use of energy management. For example, the EMCS and technologies used for continuous and TOU energy management and peak demand management can be well integrated and interoperate with the needs of OpenADR. Subsequently, the same OpenADR system infrastructure could be integrated and enhanced to meet the requirements of ancillary services. This essentially means that the underlying technology should be designed to meet the context-setting framework of varied demand-side requirements. The figure below (Figure 1) show linkages between the electricity value chains and their key features those are necessary for a robust technology framework.

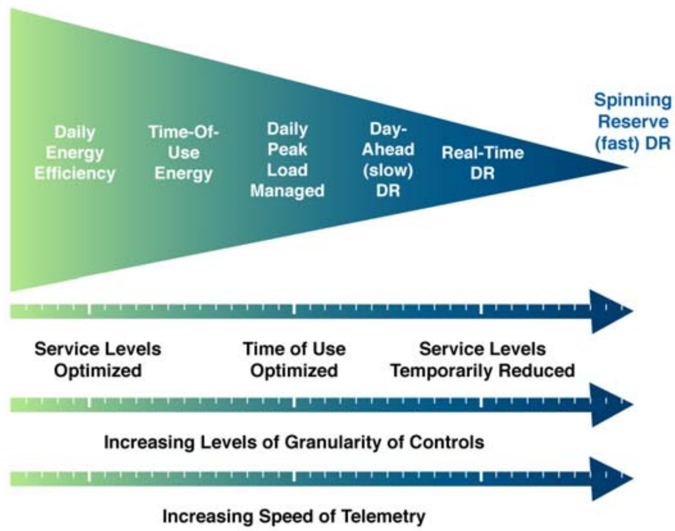

Figure 1: Service levels, controls, and telemetry in electricity value chain

The left side of the figure above (Figure 1) is meant to show that most hours of the year we are concerned with continuous energy efficiency. Each hour energy use can be optimized relative to the energy services begin delivered. As we move to the right, few hours of the year are included and we begin to reduce building service levels in DR periods.

The second bar in the figure above (Figure 1) adds a level of describing control system granularity. Our ability to provide fine grain controls into end-use building systems improves both energy management and demand responsiveness. Further examples are provided below using dimming lighting and DR capabilities.

The final bar in the figure adds a third layer to describe telemetry. As we move to the left toward faster DR systems, increasing speeds of telemetry are needed to initiate the DR. While this paper does not go into the details of all of the functional requirements of such systems, we acknowledge that the end-use controls within the building become a key component of the end-to-end system for DR.

The use of Internet-based signals and IT with a Service Oriented Architecture (SOA) using web services and well-designed IT systems for DR can meet the demand-side systems' needs in relation to the electricity value chain. SOA, which uses eXtensible Markup Language (XML), a widely accepted standard for communication, and an Internet-based platform, can facilitate communications interoperability and ease of sharing structured data among complex systems. Such interoperability needs are in use by the Building Automation and Controls Network (BACnet) protocol in form of BACnet web services (BWS) [10]. Thus, the OpenADR standards that delivers both price and reliability signals, are an important step toward integration and automation of DR. The context-setting framework defined by GridWise to meet technical, informational, and organizational requirements for interoperability within DR systems is well studied and developed for OpenADR and is being commercialized throughout California. While OpenADR primarily facilitates technical and informational needs among DR systems (both Human to Machine and Machine to Machine), the information model also considers facility or end-user's needs when signals and data pertaining to DR events are sent and the facility determines the optimal DR strategy based on that information. OpenADR is also being evaluated for ancillary services in new research efforts on Fast DR.

5. ADVANCED LIGHTING SYSTEM EXAMPLES

Today's dimming lighting systems are perhaps the best example of an advanced emerging technology that provides daily continuous energy minimization with excellent DR capability. By drawing less when there is abundance of daylight or reducing electricity from the grid when electricity costs are highest, dimming ballasts are an enabling technology that allows building lighting loads to become more elastic. Concerns for electricity disruptions and power outages have stimulated the industry to re-examine and re-design dimming controls to implement DR and energy efficiency measures. Advances in lighting technologies coupled with the pervasiveness of the Internet and wireless technologies have led to new opportunities to realize significant energy saving and reliable demand reduction using intelligent controls [11].

Many manufacturers now produce electronic lighting control equipment that are wirelessly accessible and can control dimmable or multilevel lighting systems while complying with existing and emerging communications protocols. These controllers are well-suited to retrofit applications where it may be less cost-effective to add wiring to communicate with downstream lights. The lighting industry has also developed new technology with improved performance of dimming lighting systems. The system efficacy of today's dimming ballasts compare well with non-dimming ballasts, where historically there was an energy penalty for dimming.

As a result, from an energy efficiency perspective, dimming ballasts can provide seamless integration of indoor lighting and daylighting delivering continuous low energy use with optimized lighting levels. From a DR strategies perspective, dimmable ballasts can be utilized for demand limiting and demand shedding. Often times, even when dimming strategies are detectable, they can still be acceptable by the occupants [12]. In the newly built New York Times building, the installation of individually addressable dimming ballasts provides highly flexible lighting systems which can minimize energy use for lighting when there is adequate daylight. Advances in lighting control algorithms also facilitated demand shedding of lighting loads to allow good participation in regional DR programs [4].

The process to develop an automated DR strategy based on which lighting control features and layout one has in their building is summarized in figure 4 below. A building operator can use either a manual or automated approach. If central control of lighting is available, the next step is to evaluate the "granularity" of the lighting control which is determined through a set of yes/no questions. Advanced lighting controls and increased levels of granularity allow us to define explicit steps in building lighting that can potentially be exercised during DR events.

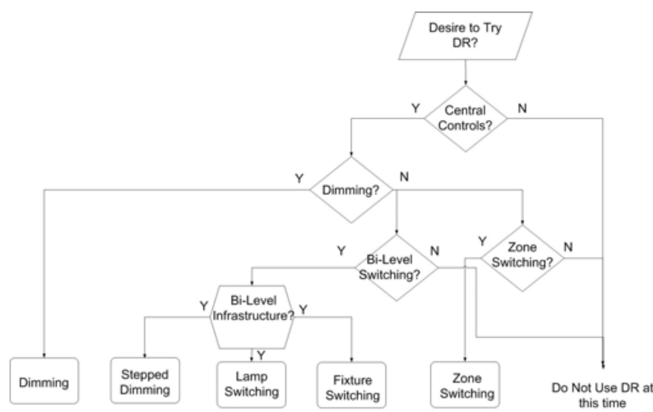

Figure 2: DR decision tree for lighting strategies

Research is also beginning to explore the possible role of dimmable lighting for regulation capacity. Regulation capacity is generation that is on-line, and synchronized with the ISO so that the energy generated can be increased or decreased instantly through automatic generation control (AGC). While there are many technical challenges this research will address, the main objective is to explore whether the reserve markets may be better served if the ISO can obtain small load reductions from many distributed loads, rather than megawatts of power from a few generators.

6. DISCUSSION AND RESEARCH NEEDS

As we begin to explore the functional requirements for linking buildings to the electric grid we must ensure that we understand the fundamental concepts to support optimal and continuously monitored energy efficiency. Many of the technologies required for DR can benefit energy efficiency and advances in controls and service level monitoring will provide greater flexibility in energy management. As energy markets become more complex and there is a growing urgency for greater levels of energy efficiency, facility managers will need to explore better control of demand-side systems.

Facility engineers will need tools and systems to understand their existing systems and how it can participate in these new DR markets. Many energy markets will see dynamic prices and DR programs that provide economics incentives for facilities that can modify their end-use loads.

As we enhance our experience and understanding with the dynamic energy management concepts described above, our next technical challenge will be to quantify the performance metrics associated with each of the domains. For example, whole-building energy benchmarking is widely practiced and well understood process. Whole-building peak demand benchmarking is not! Electric load factors that compare average energy use and peak demand help characterize how "peaky" a building load shape is. Such load factors could be developed for different times of the day. Beyond the whole-building benchmarks are the opportunities to move into end-use benchmarks. Lighting system benchmarks are likely to be more straightforward than HVAC because of the lack of climate sensitivity.

7. SUMMARY

This paper has described a framework for characterizing energy use and the timescales of energy management for both energy efficiency and DR. This work builds on our experience using a standard set of Internet signals to trigger DR events in buildings. The development of advanced controls for energy management has also helped improve the ability of commercial building loads to be good DR resources. Further work is needed to develop tools and methods to help building owners and facility managers evaluate investments in advanced controls for both energy efficiency and DR.

8. ACKNOWLEDGEMENTS

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References

[1] The Gridwise Architecture Council (GWAC). *GridWise® Interoperability Context-Setting Framework*, March 2008.

[2] Kiliccote S., M.A. Piette, and D. Hansen. *Advanced Controls and Communications for Demand Response and Energy Efficiency in Commercial Buildings*. Proceedings of Second Carnegie Mellon Conference in Electric Power Systems, Pittsburgh, PA. LBNL Report 59337. January 2006.

[3] Kiliccote S., M.A. Piette, D.S. Watson, and G. Hughes. *Dynamic Controls for Demand Response in a New Commercial Building in New York*. Proceedings, 2006 ACEEE Summer Study on Energy Efficiency in Buildings. LBNL-60615. August 2006.

[4] Piette, M.A., S. Kiliccote and G. Ghatikar. *Design and Implementation of an Open, Interoperable Automated Demand Response Infrastructure*. Presented at the Grid Interop Forum, Albuquerque, NM. November 2007. LBNL-63665.

[5] Holmberg, D.G., S.T. Bushby, and J.F. Butler. *BACnet® for Utilities and Metering*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE) Journal, Vol. 50, No. 4, PP. 22-30, April 2008.

[6] Xu P. and L. Zeagrus. *Demand Shifting with Thermal Mass in Light and Heavy Mass Commercial Buildings*. LBNL-61172. 2006.

[7] Quantum Consulting Inc. and Summit Blue Consulting, LLC. 2004. *Working Group 2 Demand Response Program Evaluation – Program Year 2004 Final Report*. Prepared for Working Group 2 Measurement and Evaluation Committee. Berkeley CA and Boulder CO, December 21.

[8] Eto, J., J. Nelson-Hoffman, C. Torres, S. Hirth, B. Yinger, J. Kueck, B. Kirby, C. Bernier, R. Wright, A. Barat, D. Watson. *Demand Response Spinning Reserve Demonstration*. LBNL-62761. May 2007.

[9] Piette, M.A., G. Ghatikar, S. Kiliccote, E. Koch, D. Hennage, and P. Palensky. *Open Automated Demand Response Communication Standards: Public Review Draft 2008-R1*. LBNL number forthcoming. May 2008.

[10] ANSI/ASHRAE 135-2001. *BACnet: A Data Communication Protocol for Building Automation and Control Networks*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). June 2001; REPLACED by ANSI/ASHRAE 135-2004.

[11] Rubinstein F. and S. Kiliccote. *Demand Responsive Lighting: A Scoping Study*. DRRC Report to California Energy Commission (CEC). LBNL-62226. May 2006.

[12] Newsham G. *Detection and Acceptance of Demand Responsive Lighting in Offices with and without Daylight.* Leukos, Vol. 4, No. 3, pp 139-156. January 2008.

Biography

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