Dynamic Energy Management

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ABSTRACT

Dynamic Energy Management is an innovative approach to managing load at the demand-side. It incorporates the conventional energy use management principles represented in demand-side management, demand response, and distributed energy resource programs and merges them in an integrated framework that simultaneously addresses permanent energy savings, permanent demand reductions, and temporary peak load reductions. This is accomplished through a system comprising smart end-use devices and distributed energy resources with highly advanced controls and communications capabilities that enable dynamic management of the system as a whole. The components build upon each other and interact with one another to contribute to an infrastructure that is dynamic, fully-integrated, highly energy-efficient, automated, and capable of learning. These components work in unison to optimize operation of the integrated system based on consumer requirements, utility constraints, available incentives, and other variables such as weather and building occupancy. Dynamic Energy Management is not simply a repackaging of energy efficiency, demand response, and distributed generation practices. It is a framework that brings together these three practices in a manner that yields a higher and more sustainable magnitude of improved efficiency, both at the customer site and for the utility grid in general. This simultaneous implementation of measures sets this approach apart from conventional energy use management and eliminates any inherent inefficiencies that may otherwise arise from a piecemeal deployment strategy.

Introduction

This paper explores the concept of dynamic energy management as a future demand-side energy resource. It begins by summarizing the basic concept. It then steps back to look at current practices in energy use management and articulates how dynamic energy management is different by delineating specific characteristics of the dynamic energy management framework.

What Is Dynamic Energy Management?

Dynamic energy management is an innovative approach to managing load at the demand-side. It incorporates the conventional energy use management principles represented in demand-side management, demand response, and distributed energy resource programs and merges them in an integrated framework that simultaneously addresses permanent energy savings, permanent demand reductions, and temporary peak load reductions. This is accomplished through an integrated system comprising of smart end-use devices and distributed energy resources with highly advanced controls and communications capabilities that enable dynamic management of the system as a whole. This simultaneous implementation of measures sets this approach apart from conventional energy use management and eliminates any inherent inefficiencies that may otherwise arise from a piecemeal deployment strategy. It offers a no-regrets alternative to program implementers.

The Integral Components of Dynamic Energy Management

Dynamic energy management consists of four main components:

- Smart energy efficient end-use devices;
- Smart distributed energy resources;
- Advanced whole-building control systems; and
- Integrated communications architecture.

Figure 1 illustrates how these components act as building blocks of the dynamic energy management concept. The components build upon each other and interact with one another to contribute to an infrastructure that is dynamic, fully-integrated, highly energy-efficient, automated, and capable of learning. These components work in unison to optimize operation of the integrated system based on consumer requirements, utility constraints, available incentives, and other variables such as weather and building occupancy. Table 1 summarizes the predominant characteristics of each of these three components. The components and how they potentially interplay will be covered in greater detail later in this paper.

Figure 1. Building Blocks of Dynamic Energy Management

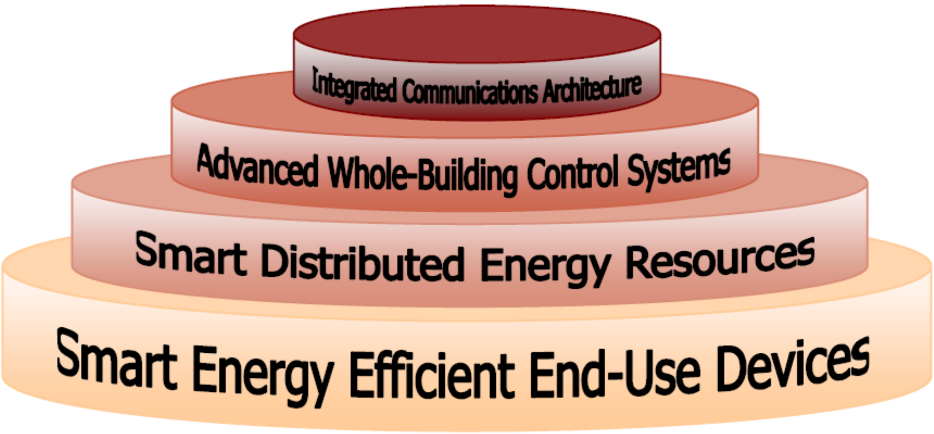
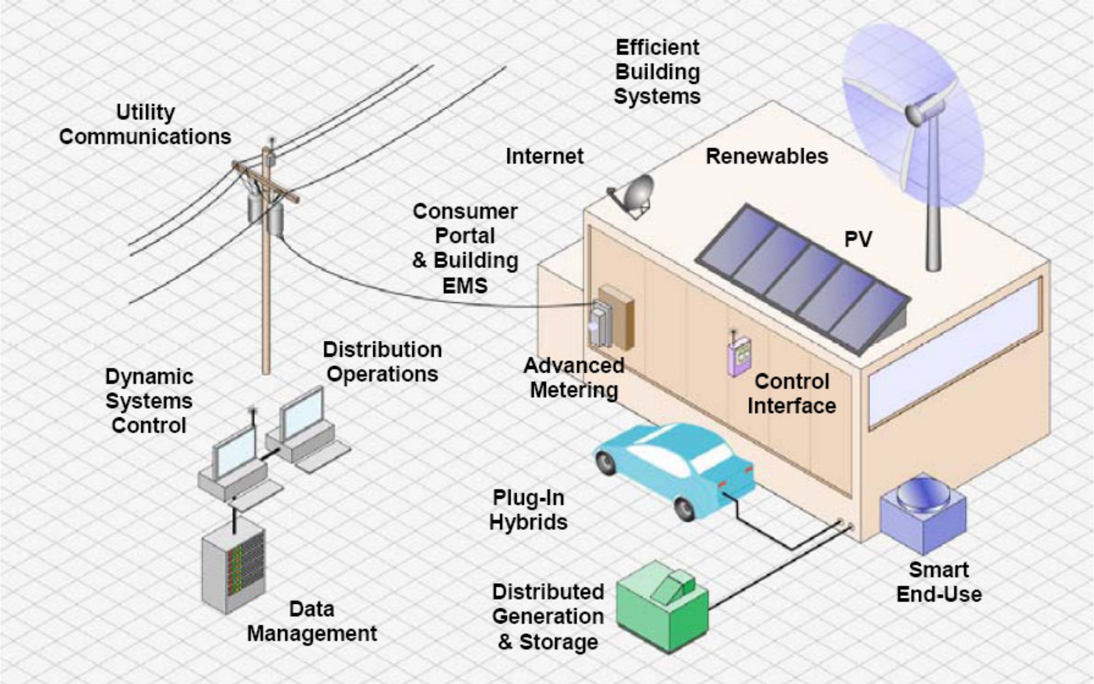


Figure 2 shows an example of the dynamic energy management infrastructure applied to a generic building. In this example there are two-way communications via the Internet as well as via the power line. The building is equipped with smart energy efficient end-use devices, an energy management system, automated controls with data management capabilities, and distributed energy resources such as solar photovoltaics, wind turbines, and other onsite generation and storage systems. Thus, energy efficient devices, controls, and demand response strategies are coupled with onsite energy sources to serve as an additional energy *resource* for the utility. Not only do all of these elements contribute to the utility's supply-side by reducing building demand, the distributed energy resources can also feed excess power back to the grid.

Table 1. Main Characteristics of the Integral Components of Dynamic Energy Management

Smart Energy Efficient End-Use Devices
• Appliances, lighting, space conditioning, and industrial process equipment with the highest energy efficiencies technically and economically feasible
• Thermal energy storage systems that allow for load shaping
• Intelligent end-use devices equipped with embedded features allowing for two-way communications and automated control
• Devices that represent an evolution from static devices to dynamic devices with advancements in distributed intelligence; one example is a high efficiency, internet protocol (IP) addressable appliance that can be controlled by external signals from the utility, end-user, or other authorized entity
Smart Distributed Energy Resources
• Onsite generation devices such as photovoltaics, diesel engines, micro-turbines, and fuel cells that provide power alone or in conjunction with the grid
• Onsite electric energy storage devices such as batteries and fly wheels
• Devices that are dynamically controlled to supply base load, peak shaving, temporary demand reductions, or power quality
• Devices that are dynamically controlled such that excess power is sold back to the grid
Advanced Whole-Building Control Systems
• Control systems that optimize the performance of end-use devices and distributed energy resources based on operational requirements, user preferences, and external signals from the utility, end-user, or other authorized entity
• Controls that ensure end-use devices only operate as needed; examples include automatic dimming of lights when daylighting conditions allow or reducing outdoor ventilation during periods of low occupancy
• Controls that allow for two-way communications; for example, they can send data (such as carbon dioxide concentration in a particular room) to an external source and they can accept commands from an external source (such as management of space conditioning system operation based on forecasted outside air temperature)
• Local, individual controls that are mutually compatible with a whole-building control system; for example, security, lighting, space conditioning, appliances, distributed energy resources, etc. can all be controlled by a central unit
• Controls that have the ability to learn from past experience and apply that knowledge to future events
Integrated Communications Architecture
• Allow automated control of end-use devices and distributed energy resources in response to various signals such as pricing or emergency demand reduction signals from the utility; day-ahead weather forecasts; other external alerts (e.g., a signal could be sent to shut down the outdoor ventilation systems in the building in the event of a chemical attack in the area); and end-user signals (e.g., a facility manager could shut-down the building systems from an off-site location during an un-scheduled building closure)
• Allow the end-use devices, distributed energy resources, and/or control systems to send operational data to external parties (e.g., advanced meters that communicate directly with utilities)
• Communications systems that have an open architecture to enable interoperability and communications among devices

Figure 2. The Dynamic Energy Management Infrastructure Applied to a Generic Building



Current Practice in Energy Use Management

Current practice in the implementation phase of energy use management consists of several elements used alone or in combination to effect a change in energy use characteristics at a given site. In general, the elements can be divided into seven main categories:

1. Energy audits and/or reviews of historical energy use characteristics to identify problem areas;
2. Improvements to the operation and maintenance of existing end-use devices and processes to reduce energy use, demand, and/or materials – this includes housekeeping and maintenance measures, heat recovery, energy cascading, material recovery/waste reduction, etc.;
3. Replacement or retrofit of existing end-use devices or processes with energy efficient devices to reduce energy use, demand, and/or materials as well as to improve productivity – this may also include fuel switching (e.g., from thermal processes to electrotechnologies);
4. Load shaping strategies such as thermal energy storage which shifts load to off-peak periods;
5. Installation of controls to turn end-use devices on/off or up/down as required or desired to reduce energy use and/or demand – this includes local controls and building energy management systems;
6. Demand response strategies to reduce peak demand temporarily; and
7. Use of distributed energy resources to replace or reduce dependence on electricity from the grid.

In some cases, the end-user takes the initiative to employ one or more of the elements listed above. Oftentimes, however, implementers of various energy use programs solicit participants. The elements are typically applied separately or in a piecemeal fashion, with the types of measures implemented being a strong function of the programs and incentives offered by implementers to program participants. Economic evaluations are also a key component to energy use management programs to quantify expected costs, savings, payback periods, and returns on investment.

All of these elements fall within the framework of demand-side management in its broadest sense. However, typical practice compartmentalizes the elements into three main types of programs. Specifically, the first five elements are conventionally considered to be encompassed in demand-side management programs, while the last two elements are often considered separately and fall within demand response and distributed energy resource programs, respectively.

Demand-Side Management

Clark W. Gellings of the Electric Power Research Institute (EPRI) coined the term demand-side management in the early 1980s. Perhaps the most widely accepted definition of demand-side management is as follows.

Demand-side management is the planning, implementation, and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape, i.e., changes in the time pattern and magnitude of a utility's load. Utility programs falling under the umbrella of demand-side management include: load management, new uses, strategic conservation, electrification, customer generation, and adjustments in market share.

However, demand-side management is even more encompassing than this definition implies because it includes the management of all forms of energy at the demand-side, not just electricity. In addition, groups other than just electric utilities (including natural gas suppliers, government organizations, non-profit groups, and private parties) implement demand-side management programs. Thus, the term demand-side management is extremely broad in its original intent. It can even be considered to encompass most of the essence of dynamic energy management. However, the two-way communications fundamental to the dynamic feature of dynamic energy management were not available during the inception of the demand-side management concept, and so they serve to update the demand-side management vision. Moreover, demand-side management does not inherently prescribe that the elements be implemented simultaneously as does dynamic energy management. Furthermore, despite its broad definition, demand-side management mainly results in the implementation of four main types of components in conventional implementation. These components include: 1) energy efficient end-use devices (which includes modifications to existing devices and processes as well as new energy efficient devices and processes); 2) additional equipment, systems, and controls enabling load shaping (such as thermal energy storage devices); 3) standard control systems to turn end-use devices on/off or up/down as required or desired, and 4) the potential for communications between the end-user and an external party (however, this is generally not employed to a great extent).

Oftentimes, the components are implemented separately rather than simultaneously. For example, an energy-efficient lighting program may offer incentives for conversion from T-12 lamps and magnetic ballasts to T-8 lamps and electronic ballasts, but it may not offer incentives for lighting controls or other measures. In addition, a water-heating program may offer incentives specifically for conversion from gas to electric water heaters or to heat pump water heaters. Still other programs offer incentives for whole-building energy savings, regardless of how the savings are achieved. All of these measures positively affect both the energy companies and the customers to some extent. However, if a building-wide program incorporating a variety of measures coupled with a dynamic link between the end-use devices, controllers, and energy suppliers were undertaken, the benefits would be optimized. This is where *dynamic* demand-side management, or the term we define in this paper—dynamic energy management—comes to play.

Demand Response

Demand response (DR) refers to mechanisms to manage the demand from customers in response to supply conditions, for example, having electricity customers reduce their consumption at critical times or in response to market prices. There has been a recent upsurge in interest and activity in demand response, primarily due to the tight supply conditions in certain regions of the country that have created a need for resources that can be quickly deployed. Demand response can broadly be of two types—incentive-based demand response and time-based rates. Incentive-based demand response includes direct load control, interruptible/curtailable rates, demand bidding/buyback programs, critical peak rebate programs, emergency demand response programs, capacity market programs, and ancillary services market programs. Time-based rates include time-of-use rates, critical-peak pricing, and real-time pricing. Incentive-based demand response programs offer payments for customers to reduce their electricity usage during periods of system need or stress and are triggered either for reliability or economic reasons. A range of time-based rates is currently offered directly to retail customers with the objective of promoting customer demand response based on price signals. These two broad categories of demand response are highly interconnected and the various programs under each category can be designed to achieve complementary goals.

Demand response functions are often applied to standard end-use devices, with local control systems and one-way or basic two-way communications. Currently, demand response enabling technologies have limitations in terms of system scaling and interoperation with other similar systems that impair their ability to be scaled up to serve the entire industry. Also, the individual demand response enabling technology components are oftentimes implemented in a piecemeal fashion without integration of the different technology components. This results in demand response programs falling far short of the anticipated potential benefits associated with an integrated strategy to manage load.

Distributed Energy Resources

In their most general sense, distributed energy resources include technologies for distributed generation (non-renewable and renewable), combined heat and power, energy storage, power quality, and even demand-side management and demand response. Since demand-side management and demand response have been treated separately herein, the current scope of distributed energy resources includes energy generation and storage technologies, including the generation of heat and power, and the storage of electricity. Distributed energy resources can be applied at the utility-scale where they feed into the distribution system, or they can be applied at the building level. The focus here is building-level distributed energy resources since they can be considered a demand-side alternative.

Current use of building-level distributed energy resources mainly relies on local control systems and basic communications. Enhanced communications and controls such as offered in a dynamic energy management framework would increase the ease in which customers integrate their distributed energy resources into the grid.

Main Limitation of Current Practice

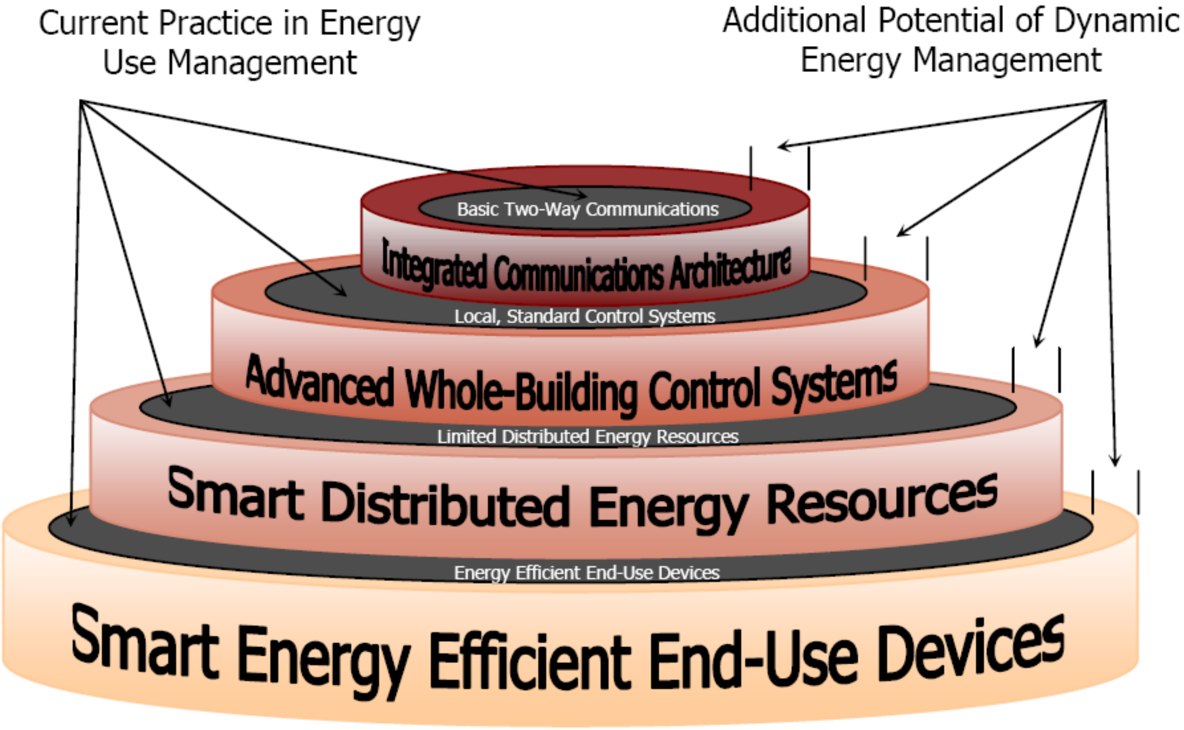
In current practice, customers are often offered individual programs instead of a single service offering comprising different options to manage their electricity load. Very rarely do energy service providers talk about integrating energy efficiency and demand response into a single offering, much less coupling the offering with distributed energy resources. Virtually all energy efficiency programs help to lower system peaks, even if peak reduction is not the primary program goal. Distributed energy resources have the same effect. In an analogous manner, participation in demand response programs can often yield energy savings in addition to peak demand reductions. Consideration of the interplay of energy efficiency, demand response, and distributed energy resources is lacking in current practice. A dynamic energy management system, as envisioned here, is likely to fill in this gap with a comprehensive and integrated service offering to the end-use consumer that combines energy efficiency, demand response, and distributed energy options as a unified demand-side energy resource.

How Is Dynamic Energy Management Different?

There is significant potential to increase the functionality of typical demand-side management measures, typical demand response strategies, and typical implementation of building-level distributed energy resources by combining them in a cohesive, networked package that fully utilizes smart energy efficient end-use devices, advanced whole-building control systems, and an integrated communications architecture to dynamically manage energy at the end-use location. Figure 3 illustrates the additional potential for functionality offered by dynamic energy management relative to conventional energy management practices. It transforms the energy efficient end-use devices and processes associated with typical demand-side management into smart, highly energy efficient end-use devices and processes. It transforms the standard distributed energy resources associated with typical practice into smart, environmentally-friendly onsite energy resources that are leveraged to their maximum potential to benefit the end-user, the utility, and the environment. It transforms the local, standard controls associated with conventional energy management into advanced, building-wide controls that are mutually compatible and capable of learning. Finally, it transforms the basic communications associated with typical demand response and typical distributed energy resources into an advanced integrated two-way communication architecture that networks the end-use devices, distributed energy resources, and control systems with each other and with the utility or other external entities to manage and optimize energy use dynamically.

A dynamic energy management system is a demand-side energy resource that integrates energy efficiency and load management from a dynamic, whole-systems or networked perspective that simultaneously addresses permanent energy savings, permanent demand reductions, and temporary peak load reductions.

Figure 3. Additional Potential of Dynamic Energy Management Beyond Current Practice in Energy Use Management



Overview of Dynamic Energy Management System Operation from an Integrated Perspective

A dynamic energy management system is comprised of highly efficient end-use devices equipped with advanced controls and communications capabilities that enable the devices to communicate dynamically with external signals and to adjust their performance in response to these signals. This marks an emergence from static to dynamic end-use devices with advancements in distributed intelligence. In addition to end-use devices, a dynamic energy management system also includes distributed energy resources such as solar photovoltaic systems, diesel generators, and fuel cells. The performances of these distributed energy resources are also programmed to operate in an integrated manner with end-use devices at the facility so as to optimize overall system performance. The energy efficient end-use devices along with distributed energy resources are together referred to here as *smart devices*.

These smart devices have a built-in programmable response and control strategy whereby users are able to program the device and set optimal performance levels based on a variety of parameters such as external ambient conditions, time of year, consumer habits and preferences, etc. The devices are also able to communicate with external signals including electricity prices, emergency events, and external weather forecasts. A two-way communications infrastructure with enabling devices such as advanced meters will be required in order for this communication to take place. The communications capability will give the energy service provider direct access to information on the smart devices in the building and the ability to control them.

Depending on the hourly electricity price or other external parameters and based on the pre-programmed control strategy, the smart devices equipped with the responsive controls automatically respond to the external signals and optimize entire system performance within the user comfort range to minimize electricity costs. For the dynamic energy management system to operate autonomously in response to electricity price or other external signals, it must be capable of very abstract decision making, ranging from turning an air conditioner on or off to determining the best cost vs. comfort tradeoff for current conditions. Information on different parameters, including temperatures throughout the building, outside weather conditions, occupancy, appliance use, and power consumption, may allow for targeted control and may be able to deliver predictable performance and energy costs to the occupants.

The response strategy of each individual smart device is networked and interacts with the response strategies of other devices in the system so as to optimize entire system performance. Networking among devices allows internal communications and interactions among devices. The system should be able to execute a fully automated control strategy with override provisions. In a fully automated system, the control and communications technology listens to an external signal, and then initiates a pre-programmed control strategy without human intervention. The control devices have real-time control algorithms in their gateway devices and automatically control without manual operation. For example, they are enabled to respond to curtailment requests or high-energy prices from the energy service provider and then to deploy specific control strategies automatically to optimize system operation and avoid high energy costs.

Even though the system is able to control multiple devices, user preference may be to control some devices directly (e.g., heating, ventilating, and air conditioning (HVAC) equipment), while for others (e.g., copiers and fax machines) direct control is probably not practical. For devices that are indirectly controlled, the actuation of response could be occupant-assisted through signaling the occupant via some kind of notification method (e.g., red-yellow-green signals) that tell occupants when the time is propitious to run these appliances. Furthermore, an intelligent dynamic energy management system will contain learning functionalities with learning logic and artificial intelligence in order to be able to learn from prior experiences and incorporate these lessons into future response strategies. For example, if an occupant attempts to lower the temperature set point at a time when electricity is expensive, a confirmation will be required for the action to take effect. The fact that the occupant confirmed that a lower set point was desired even though it would be costly to achieve becomes part of the learning process. The measure of success for the learning functionality is that occupants override the system less over time.

Characteristics of Key Components

Smart energy efficiency end-use devices and distributed energy resources (together referred to as smart devices). The main characteristics of smart devices are listed below.

- Smart devices comprise very high efficiency end-use devices and a variety of distributed energy resources.
- Smart devices are equipped with highly advanced controls and communications capabilities.

- Smart devices, embedded with microprocessors, allow incorporation of diagnostic features within the devices based on critical operating variables and enable the devices to undertake corrective actions.
- Distributed energy resources with intelligent controls are able to synchronize their operation with end-use devices in order to optimize system performance. They are also enabled to feed back power to the grid automatically based on overall system conditions.
- Communications features for these devices need to be set up based on open architecture to enable interoperability.
- Smart devices contain microchips that have IP addresses to allow external control of these devices directly from the Internet or through a gateway. It is desirable to have TCP/IP[1] communication protocol so that the system can be set up and managed using common network management tools.
- Smart devices have learning logic built into them (artificial intelligence, neural networks) to improve on future performance based on past performance experience, including learning how energy usage relates to parameters such as building cool-down and heat-up rates, occupant habits, outside temperature, and seasonal variables.

Advanced whole-building control systems. Advanced whole-building control systems will need to incorporate the following functionalities.

- Receiving and processing information from sensors;
- Sending actuation signals for control of devices;
- Learning physical characteristics of the building from sensor information;
- Managing time-of-day profiles;
- Displaying system status to occupants;
- Obtaining command signals and overrides from occupants;
- Learning the preferences and patterns of the occupants; and
- Receiving and displaying external signals, such as price information from the utility.

In order to attain the integrated functionalities associated with a dynamic and networked system as envisioned in a dynamic energy management framework, the building system will need to be enabled with a web-based energy management and control system (Web-EMCS). A Web-EMCS should be able to:

- Monitor and control building systems at the component-level by communicating with EMCS or similar technology via the Internet;
- Integrate multiple building systems such as HVAC, lighting, generation, and security using a gateway or similar technology; and
- Control building systems automatically according to user-programmed algorithms; this implies that the system can be programmed to modify thermostat settings, reduce chiller

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[1] Transmission Control Protocol/Internet Protocol (TCP/IP) was developed by the Advance Research Projects Agency (ARPA) and may be used over Ethernet networks and the Internet. Use of this communications industry standard allows Design and Deployment Concept (DDC) network configurations consisting of off-the-shelf communication devices such as bridges, routers, and hubs. Various DDC system manufacturers have incorporated access via the Internet through an IP address specific to the DDC system.

or fan loads, and dim lighting automatically in response to external signals such as when a curtailment call is received from the utility.

Integrated communications architecture. An integrated communications architecture will need the following characteristics:

- The dynamic energy management system will need built-in notification methods for communications with external signals. For example, hourly electricity price notification can be sent through a price-signaling device with green/yellow/red stoplights. These colored lights indicate the price level changes. If a light is on continuously, it indicates the current price. If it is flashing, it indicates the future price within a period of, say, ½ hour. So two lights may be on at a time – one continuous and one flashing. There can also be an emergency light that indicates a crisis event within the electricity supply system. It may mean that critical peak pricing is in effect, or it may be used just to enlist occupant cooperation to avoid a brownout.
- Multiple sensors and actuators are required to manage all significant appliances in the building (e.g., relays to control on-times of HVAC equipment and appliances, power sensors, temperature and occupancy sensors, and signaling devices to inform occupants about external signals such as electricity prices and the consequences of decisions). These will be spread about the building, with many being away from convenient access to power mains or communications cabling. This suggests the need for a distributed system with wireless communications infrastructure or networking over power lines.
- An enabling technology for distributed sensing and actuation will be low-power, low-cost wireless communication. Wireless communication will avoid the substantial cost of running power and communication wires. Another alternative could be to use power line communications (PLC) in place of wireless networking.
- Smart metering with communications is likely to be a key infrastructure requirement. Advanced metering systems apply advances in communications technology (e.g., Internet, PLC, and wireless) to meter reading. Communications technologies use open standards like IP and the public infrastructure, where possible, for interfacing between the meter, smart devices, and the existing utility information technology (IT) infrastructure.

Key Features of a Dynamic Energy Management System

End-user flexibility. Customers should have numerous options for participating in a dynamic energy management system. They should have the ability to use custom business logic that is applicable to their own operations.

Simplicity of operation. For easy user adoption of a dynamic energy management system, the user interface for the system will have to be concise and intuitive for non-technical people. It will need to behave autonomously based on effective initial defaults and machine learning, with minimal or no programming requirements.

Standard IT platforms. One of the most important ways to keep costs low will be to leverage existing IT trends. The public Internet and private corporate local area networks (LANs) or wide area networks (WANs) are ideal platforms for controls and communications due to their ubiquity, especially in large commercial buildings. In addition, the performance of IT equipment (e.g., routers, firewalls, etc.) continues to improve and equipment prices continue to drop. Dynamic energy management systems based on standard IT platforms will also tend to be more scalable and secure than special purpose systems developed specifically for the purpose.

Open systems architecture and universal gateways. An important concept in the dynamic energy management system architecture is that the layers of protocols across all the systems are common, and that seamless communication and control activity can occur. An open systems architecture is essential in integrating the system operation. Also, monitoring and controlling different devices from a central location or from anywhere in the network can be done only if a universal gateway is used. Communication between devices and the Internet is accomplished through standard communications pathways including Ethernet, telephone line, or wireless communication.

Integration with existing building energy management system. It will be advantageous for dynamic energy management systems to have tight integration with any existing EMCS and energy information system (EIS) and enterprise networks within buildings. This strategy maximizes the performance, distribution, and availability of the building data, while minimizing the installation and maintenance costs.

Open standards and interoperability. For flexibility and future proofing, dynamic energy management systems should use open standards wherever possible. Unlike proprietary systems, truly open systems are interoperable. In other words, a device from one company (e.g., Cisco) will easily and naturally reside on a network with products from other companies (e.g., Nortel). Communication using the TCP/IP protocol will ensure that the system can be set up and managed using common network management tools.

Flat architecture for robust, low-cost systems. To be as robust and low-cost as possible, a dynamic energy management system should have a flat architecture with a minimum number of layers of control network protocols between the front-end human machine interface (HMI) and final control and monitoring elements such as actuators and sensors.

Illustrative Example: Dynamic Energy Management in an Office Building

A dynamic energy management system is likely to have a much larger impact on a building's electricity consumption and demand than just implementing energy efficiency and/or demand response on their own. This section presents an example to illustrate this point.

Modeling Scenarios and Assumptions

In this example, a DOE-2 model of an office building is simulated under several different scenarios in order to evaluate the building's electricity consumption and demand under each scenario relative to the Base Case, which represents business as usual. The scenarios are: 1) the Energy Efficiency Scenario, which represents the installation and implementation of energy efficiency measures that are typically promoted in utility demand-side management programs; 2) the Demand Response Scenario, which represents the implementation of manual demand response strategies during extremely warm summer days; 3) the Combination Scenario, which represents the simultaneous implementation of both energy efficiency and demand response as defined by #1 and #2 above; and 4) the Dynamic Energy Management Scenario, which represents the implementation of dynamic energy management technologies and strategies.

The building modeled is a large, newly constructed office building located in Albuquerque, New Mexico. The base case building meets current energy standards. Table 2 summarizes the strategies that were modeled in each of the scenarios.

Modeling Results

Table 3 provides the modeling results for the different scenarios. The electricity savings and demand reduction relative to the Base Case are presented for each scenario. Note that the potential energy savings and demand reduction estimates represent the maximum technical potential of the various strategies and do not take into account financial or market considerations.

The results indicate that implementing the Energy Efficiency Scenario would yield electricity savings of 23% and a peak demand reduction of 22% relative to the Base Case. Implementing the Demand Response Scenario would result in a peak demand reduction of 15% relative to the Base Case. Energy savings due to demand response strategies are considered negligible because demand response actions are implemented during only a few emergency events throughout the year. Using this same assumption, implementing the Combination Scenario would yield the same amount of electricity savings as the Energy Efficiency Scenario (23%), but peak demand reduction would increase to 34% relative to the Base Case. Implementing the Dynamic Energy Management Scenario would achieve higher levels of energy savings and demand reduction than implementing energy efficiency or demand response alone (or even the combination of the two). Indeed, implementing dynamic energy management would result in an electricity savings of 36% and a peak demand reduction of 51% relative to the Base Case.

Figure 4 depicts the additional energy savings and demand reduction achieved by the Dynamic Energy Management Scenario. An extra energy savings of 13% and an extra demand reduction of 17% are attributable to dynamic energy management strategies. The important point here is that dynamic energy management serves to fill in the gap and captures additional energy savings and demand reduction potential that would not otherwise be captured by implementing traditional energy efficiency and demand response alone. The additional potential is enabled by the integration of smart devices, advanced controls, and a communications architecture.

Conclusions

This paper has introduced EPRI's new concept of dynamic energy management. It has explained how dynamic energy management is distinctly different from current practices, and not simply a repackaging of demand-side management, demand response, and distributed energy resource practices. Dynamic energy management is a framework that brings together these three practices in a manner that yields a potentially higher and more sustainable magnitude of improved efficiency, both at the customer site and for the utility grid in general. Future work should address the national potential for energy savings and demand reduction associated with dynamic energy management. In addition, a plan should be developed to identify how this potential could be realized in the form of utility-sponsored dynamic energy management programs and initiatives.

Table 2. Specific Strategies Modeled Under Different Scenarios for the Office Building

Measure/ Strategy	Scenario			
	1. Energy Efficiency (EE)	**2. Demand Response (DR)**	**3. EE + DR**	**4. Dynamic Energy Management**
A. Lighting	Involves implementing typical lighting measures such as T-5 lamps, super T-8 lamps, compact fluorescent lamps, task lighting, occupancy sensors, and time clocks and controls.	Includes manually turning off lights completely in unused areas and manually turning off a portion of lights in other areas ("bi-level switching") during a DR event.[a]	Same as Strategies #1 and #2 combined.	Involves implementing typical lighting measures such as T-5 lamps, super T-8 lamps, compact fluorescent lamps, task lighting, dimmable ballasts, occupancy sensors, and time clocks. Additionally, advanced lighting controls are used to integrate daylighting into lamp dimming schemes. Also the advanced lighting controls will automate the process of dimming and/or turning off lights during 10 critical peak pricing and/or DR events throughout the year.[b]
B. Cooling	Involves installing a higher-efficiency chiller than standard practice.	Involves manually setting the cooling setpoint to 79°F during a DR event.[c]	Same as Strategies #1 and #2 combined.	Involves installing the highest-efficiency chiller available and manually setting the cooling setpoint to 79°F during 10 critical peak pricing days and/or DR events throughout the year.
C. Envelope Insulation	Involves installing a higher-efficiency ceiling and roof insulation than standard practice.	NA	Same as Strategy #1.	Same as Strategy #1.
D. Windows/ Glazing	Involves installing Low-E glazing.	NA	Same as Strategy #1.	Same as Strategy #1.
E. Other	Includes optimizing set points of zone thermostats and cooling system operation schedules.	NA	Same as Strategy #1.	Includes optimizing set points of zone thermostats and cooling system operation schedules, automation of the chilled water and condenser water reset functions, and automation of pre-cooling the building in anticipation of warm days throughout the year. During 10 critical peak pricing and/or DR events during the year, the control system will also automatically implement the following strategies: increase thermostat set points (as described in B above), increase duct static pressure, increase chilled water temperature, and limit the distribution variable speed drive (VSD) fan speed.[d]

Notes: a. Assumes that 15% of lighting power can be reduced by implementing these strategies.
b. Assumes that 30% of lighting power can be reduced by implementing these strategies.
c. Assumes that 10% of an office building's total demand can be reduced by implementing this strategy.
d. Assumes that 15% of an office building's total demand can be reduced by implementing these strategies.

Table 3. Modeling Results for the Office Building

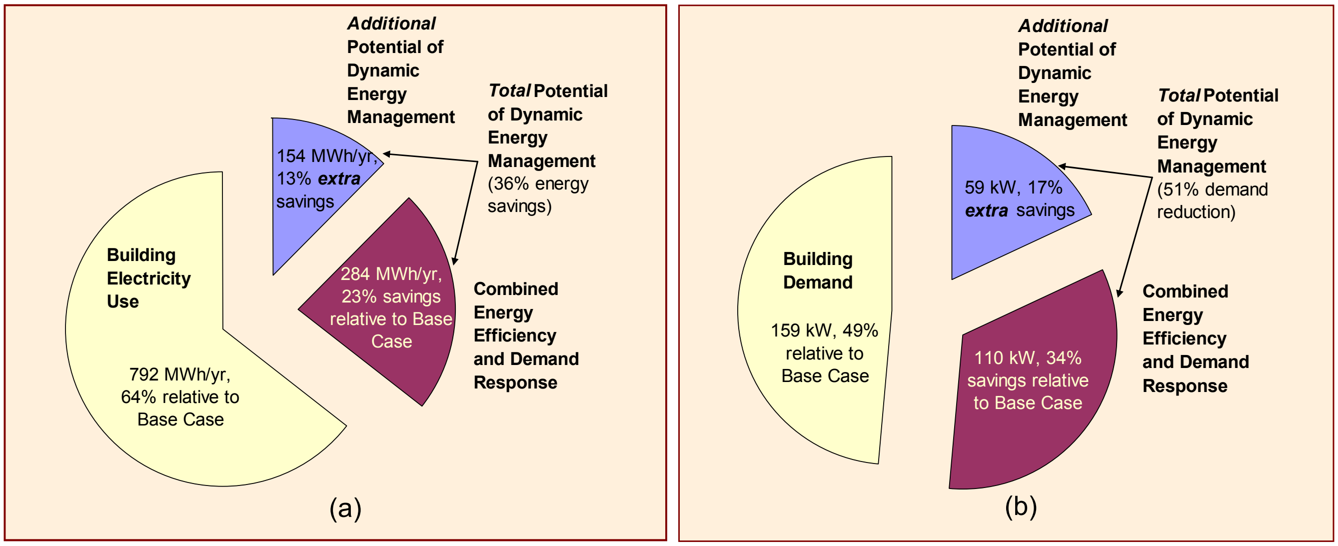
Scenario	Energy and Demand for Base Case		Energy and Demand for Given Scenario		Savings			
	kWh/yr	kW [a]	kWh/yr	kW [a]	kWh/yr	%	kW [b]	%
1. Energy Efficiency	1,229,995	328	946,331	256	283,664	23%	72	22%
2. Demand Response	1,229,995	328	1,229,995 [c]	278	0 [c]	0%	50	15%
3. EE + DR	1,229,995	328	946,331 [c]	218	283,664 [c]	23%	110	34%
4. Dynamic Energy Management	1,229,995	328	791,712	159	438,283	36%	169	51%

Notes: a. This is the average electricity demand of the entire building during the three warmest weekdays of the summer (July 29-31 of the typical meteorological year [TMY] climate data) between the hours of 2pm and 5pm.

b. This is the average electricity demand reduction of the entire building during the three warmest weekdays of the summer (July 29-31 of the TMY climate data) between the hours of 2pm and 5pm.

c. Assumes that the energy savings due to demand response measures are negligible.

Figure 4. Potential for (a) Energy Savings and (b) Demand Reduction due to Dynamic Energy Management Applied to an Office Building



(a) (b)