Facility Interface to the Smart Grid

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Keywords: buildings, communications, interface, Smart Grid, standards

Abstract
Homes, buildings and industrial facilities together represent nearly 100 % of the load on the electric grid. Beyond load, these facilities comprise a significant amount of electricity generation and thermal storage. These customer-owned load, storage and generation resources must be made responsive to needs of the electric grid in order to enable the Smart Grid. At issue is the best way to accomplish this. What is the proper relationship of the facility, whether home, commercial or industrial, to the grid? Is the facility a "demand response" resource best controlled by the grid operations domain, or is it an autonomous entity that responds to signals from a grid-side service provider? This paper presents some governing principles and a conceptual architecture for a facility to Smart Grid interface based on these principles. Communications across this interface are examined in the context of the standardization work underway as part of the NIST Smart Grid effort priority action plans.

1. INTRODUCTION

Smart Grid has entered the national vocabulary along with its association to smart meters. However, very few Americans understand the complexities of the current electric industry and why the buildings we live and work in have an important role to play in the future Smart Grid. The fact is that residential and commercial buildings together consume 73 % of our electricity [1]. Some major goals for the Smart Grid will fail to be achieved without successful integration of smart buildings and distributed energy resources (DER) [2]. Among Smart Grid experts there exists a philosophical divide concerning *how* the facility and its resources should be integrated into the Smart Grid. Those on the electric service provider side tend to view the building as a grid resource, while those from the consumer side (particularly commercial buildings and industrial community) regard the building/facility as an autonomous intelligent entity that can provide a service to support the grid. The latter perspective is appropriate for buildings with intelligent control technologies, is consistent with building ownership, and is thus the end goal.

In a July 2009 statement to Congress, the Institute of Electrical and Electronics Engineers (IEEE) identified the following benefits (among others) of the Smart Grid. (1) Real-time pricing of electricity will allow consumers to make informed decisions about their energy usage and reduce their energy costs. (2) Providing the information and control needed to better manage electrical demand will help facilitate the integration of alternative energy sources by providing a means to help mitigate the variability caused by their intermittency. And (3) greatly expanding the connection of end user loads to grid information and control will facilitate energy efficiency improvements [3].

These three points highlight the important role of intelligent facilities. The first point recognizes the necessity of communicating the real-time value of electricity to motivate and direct the consumer toward effective energy management. The communication of a simple price signal will transform the role of the facility in the grid, as the facility acts on behalf of the consumer to reduce or shift energy use at peak, while storing energy when price is low. This benefit ties to the second point above—with a price signal there is an economic driver for the use of intelligent controls and, in turn, for the installation of local generation and storage. The facility, with local generation and storage (primarily thermal), and automated controls, can then serve to support the intermittency of large-scale wind and other alternative energy sources. The third point above makes clear that Smart Grid is more than a tool for grid reliability and grid efficiency—it in turn supports energy efficiency as building owners gain insight into their energy use and tools for intelligent control.

Given the importance of the facility in the Smart Grid, it is necessary to properly understand the facility-to-grid interface. The facility interface has two components to match the two fundamental planes of the Smart Grid: power flow and information flow. The meter serves as the power interface—it measures electron flow and serves as the demarcation point between the distribution grid and facility ownership. A logically separate information communication interface handles control and business level interactions. This paper focuses on the information communications interface and the information flowing through that interface. This interface must be properly designed to meet the requirements of security and the ownership boundary, as well as to comply with principles that promote the development and success of the Smart Grid.

The U.S. government's push for Smart Grid has led to significant collaborative efforts to address standards associated with the facility interface. The efforts of the National Institute of Standards and Technology (NIST) [4] have advanced this topic, and this paper serves to consolidate our collective understanding within the context of this effort.

2. FACILITIES AND THE GRID TODAY

Today, the integration of facilities into the grid is at a nascent stage. Although various demand response (DR) programs have been tested and implemented in different forms by many utilities (retail electricity level) and Independent System Operators (ISO, at the wholesale level) for many years, there have been no standards, and the emphasis has been on dispatchable resources. If the end goal is real-time pricing to the customer (and there are many pilots demonstrating the effectiveness of price-based DR [5, 6]), there are very few real-time price tariffs available nationwide. In essence, we have no DR standards and a poor grasp of collaborative DR (or "collaborative energy" [7]).

If we examine DR implementation and standards work, we see a significant divergence between residential and large commercial & industrial (C&I) customers. In response to federal and state mandates, electric utilities are investing billions of dollars in smart meters to address residential DR. Requirements and communication specifications are being developed (e.g., OpenHAN [8], ZigBee Smart Energy Profile [9]) that essentially extend utility management into the home. The smart meter is part of the Advanced Metering Infrastructure (AMI), and the meter itself serves as the communications portal to the home. Local distribution utilities have historically offered demand-side management programs that provide them limited direct control over certain home appliances: thermostat, water heater, heat pump, and other appliances that consume large amounts of electricity. These programs are voluntary and in return for signing up for the program, the homeowner receives an electricity bill credit.

In the C&I sector, there is a different dynamic at work. Although there are contractual agreements between the utility and large C&I customers to allow the utility to invoke direct control (known as "curtailable load"), there are other approaches for large buildings with in-house energy management that allow for EMS control and flexible implementation of energy management strategies.

A large building or industrial process is complex, with many sub-systems to provide facility management in line with occupant needs and process schedules. Energy management itself involves not only electricity, but also gas, oil, chilled water and steam, air quality, and tradeoffs among these. For this reason, utilities and ISOs have used many different methods for communicating DR signals to large customers. One communication protocol worthy of note is the Open Automated DR (OpenADR) signaling specification developed by Lawrence Berkeley National Laboratory [10]. This work has been proposed as the basis for an industry standard as discussed below.

What we have then are different approaches for addressing residential and C&I facilities, with different gateways to the home/facility, a legacy of direct load control, and multiple forms of DR and market communications that have not been standardized. We lack a thoughtfully designed facility interface that addresses higher architectural principles and the use cases of the Smart Grid.

The work underway in the NIST Smart Grid effort seeks to remedy this situation. Progress has been made on developing use cases, a Smart Grid architecture, and initiating critical standards efforts. The most important standards effort to note related to the facility interface is the effort underway now in the Energy Interoperation Technical Committee (EI TC) of the Organization for the Advancement of Structured Information Standards (OASIS) [11] and coordinated within the NIST DR/DER Standards Priority Action Plan [12]. The result of this work should be a standard that is adopted by utilities and ISOs nationwide to support DR programs and to address collaborative market interactions. The charter of the OASIS Energy Interoperation TC calls for a standard to address all energy interoperation communications across the facility interface. This scope includes the collaborative demand response signals in typical DR programs where a utility sends a request for load shed and the customer responds per contract with the choice to opt out. More importantly, Energy Interoperation is addressing price, bid, and other market interactions that promote collaborative participation of buildings in the Smart Grid.

The following section examines the NIST Conceptual Model for the Smart Grid and high-level architectural principles, and then proposes a facility interface consistent with these constraints.

3. FACILITY INTERFACE DESIGN PRINCIPLES

The traditional utility model is that of bulk generation feeding power to the transmission and distribution grids ending at the customer facility. For the past century the customer has been viewed simply as a load at the end of the wire and provided with no information regarding the health of the grid nor the instantaneous value of the electricity consumed. Markets have existed at the wholesale level alone. The advent of the Internet, digital controls and the prospect of significant amounts of consumer-owned distributed generation and storage is changing the picture.

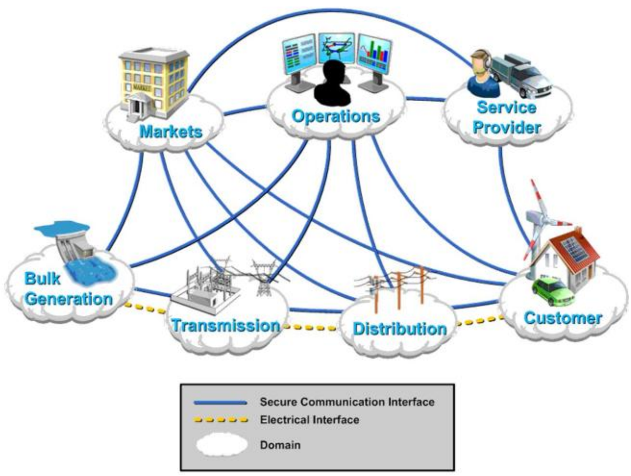

Figure 1 Seven domains of the Smart Grid with communication and electrical flows between them.

The NIST Smart Grid top-level Conceptual Model [13] is shown in Figure 1. The Smart Grid envisions the customer not only connected to the distribution domain via the meter, but also to the markets, grid operations, and customer service provider domains via communication networks. Are there to be four separate gateways to the facility, or is there a better architecture for customer communications?

There are two fundamentally different philosophies driving communications across the facility interface. The first is tied to the need for grid stability and reliability—the need for grid operators to have capacity and reserves on hand to meet demand, with the need for reserves to be available increasing as wind and other variable renewable energy sources are brought into the system. The second is tied to the promise of Smart Grid to enable new technologies and new business models to engage the consumer in ways that meet the needs of the future grid. This philosophy demands collaboration across the interface and excludes direct control. To a great extent, the latter dynamic will provide for grid stability. We already see demand response being bid into the forward capacity markets [14], and pilots demonstrating the capability of buildings to participate in the reserves market with 5 minute response times via OpenADR signaling [15]. These efforts begin to show automated building participation in grid operations delivering demand reduction during critical periods without direct load control.

To successfully unleash the potential of buildings in the Smart Grid, the facility interface must be a clear demarcation point between grid operations and facility operations. To successfully enable markets, motivate customers, optimize assets and enable efficient grid operations [16] we must adhere to the following architectural principles [13].

- *Loose coupling* describes a resilient relationship where each end of a transaction makes its requirements explicit with minimum knowledge of the other side of the interface.
- *Composition*, the building of complex interfaces from simpler interfaces, enables diversity. Composition also means that the base, simpler services are available, and, hence, can be repurposed and recomposed—the simpler services become your toolkit.
- *Layering* denotes separation of function and loose coupling between them. A layer has a general function and provides services to the layer above while receiving services from the layer below. A communication stack is composed of layers, just as a protocol standard is composed of simpler component standards.
- *Scalability*. The Smart Grid applications, components, and participants are expected to grow rapidly as standards mature and infrastructure is modified or added. System performance should not be detrimentally affected as components and capabilities are added.
- *Security* enables protected interaction, and is fundamentally concerned with managing risk. Security must be commensurate with application vulnerabilities and exposures, as evaluated by domain experts at the time application requirements are developed. Security of the marketplace requires transactional *transparency* to ensure auditable and traceable transactions.

The facility interface must conform to these architectural principles to meet the goals of the Smart Grid to enable innovations, ensure interoperability and grid reliability. Security demands a limited number of connections into the facility. Collaborative interaction requires simple data exchanges with minimal need for knowledge of how that information is used or what protocols exist on the other side of the interface. The interface that is developed must meet the needs of today’s demand response models as well as those of tomorrow’s market interactions. Fortunately, most demand response today is “collaborative demand response,” where a facility (or home) is sent a request to shed load at a specific time per contract. This approach is not direct load control, and it can be implemented while still adhering to the principles above.

4. FACILITY INTERFACE MODEL

Figure 2 presents a conceptual design for the facility interface that is consistent with the principles above. The facility domain, which is equivalent to the customer domain in Figure 1, has two primary gateways: the electrical gateway at the meter (with its distribution domain communications), and the communications gateway at the energy services interface (ESI). The facility domain interacts with the service provider domain to exchange DR program and other energy interoperation signals. This figure shows the logical separation of the ESI and meter. While the ESI could be realized at the meter (as it is currently for some residential DR programs with AMI meters), this approach is only one implementation of the more general architecture shown in Figure 2.

The ESI is a gateway to the building domain and, as such, serves a security function. However, no specific network architecture is implied. The ESI may provide a direct connection to some device (such as the energy management system, EMS) or forward external service provider signals, as appropriate, to satisfy multiple services. There may be a hierarchy of ESIs, with the building ESI beneath a campus or microgrid ESI.

For most customers the ESI connects only to service providers, whether that is the utility providing distribution grid management, or an aggregator providing load aggregation for wholesale market interactions. However, the model presented in Figure 2 is flexible. For example, while the large C&I customer may interact directly in the wholesale markets, so the small customer may interact directly in some future local market implemented by the "service provider." That market may, for example, be part of a campus microgrid.

Note the dashed line from grid operations directly to a distributed energy resource in the facility domain, indicating a "back-door" direct load control (DLC) connection. There may continue to be viable reasons to hard-wire certain facility resources to the distribution grid. Although this approach may be necessary for integration of facility resources as spinning reserve (where response times need to be on the order of one second), properly implemented networks can nonetheless easily meet these latency requirements with communications via the ESI.

Concerning the Energy Management System (EMS), it is worth noting that for some buildings the function of the EMS could be handled by an external service provider. This approach may become more common for the small commercial market. There is also some similarity between this method and AMI for residential. However, with AMI, the utility is not performing energy management as much as demand management.

Returning to the issue of ownership, the ESI stands as the gateway to the building domain. For example, the fact that a building automation system implements BACnet for energy management is not visible to the outside. This separation implies that the signals on one side of the interface are communicated via a different protocol than the other side. OpenADR (or now Energy Information eXchange, EIX protocol) messages arrive via web services in eXtensible Markup Language (XML) on the outside and are mapped to whatever internal control protocol is in use for the facility. The EIX signals may be passed from one ESI to the next and mapped to multiple internal protocols at multiple internal sub-systems. Simple signals make for simple translation. The goal, then, is to reduce information communication to its bare essence.

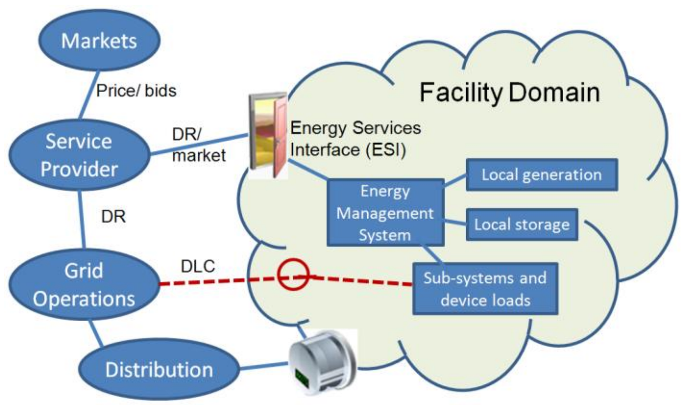

Figure 2 The Facility interface conceptual model

5. FACILITY TO GRID COMMUNICATIONS

The facility interface must support communications associated with the services of today and tomorrow. These communications have been identified in the form of use cases for demand response and distributed energy resource integration as part of the NIST Smart Grid workshops process [13]. Currently the North American Energy Standards Board (NAESB) is preparing requirements documents for DR and price communications [17] which will provide input to standards development in the OASIS Energy Interoperation TC. The goals of this section are to classify communications through the ESI, associate information elements with those communications, and point out where work is being done to further define the information elements used in various use cases.

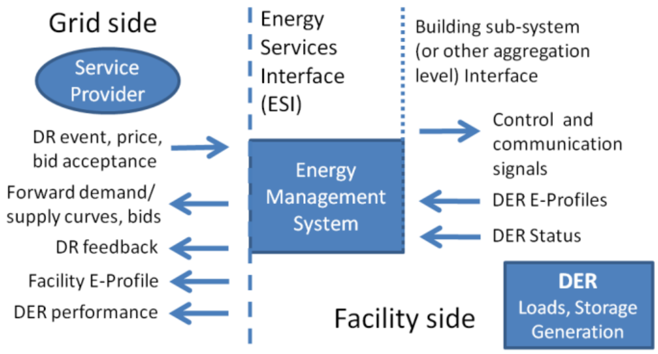

Figure 3 Information elements for communications at the Energy Services Interface and within the facility.

Figure 3 presents a more information-focused view of Figure 2.The ESI is a dashed vertical line marking the boundary with grid on the left and facility on the right. Internal to the facility, the EMS receives messages from the ESI and communicates to internal sub-systems. External communications are between the ESI and Service Provider, as in Figure 2. The information elements shown here attempt to summarize the energy interoperation communications that involve both the grid and building.

The communications at the ESI can be loosely classified into *market* interactions and *DR* interactions. Market interactions can be separated into simple forward *price* only, as distinct from buy and sell *bidding* transactions. DR programs are varied but follow a consistent model—a DR event signal is passed to a customer and the customer acts on that signal.

NIST has initiated a priority action plan to address a standard definition of price [18]. That plan tasks NAESB to coordinate preparation of a requirements document that will be passed to the newly formed OASIS Energy Market Information Exchange Technical Committee (EMIX-TC). EMIX is focused on a standard definition of electricity price with associated context, e.g., schedule, quality, reliability, and generation source. EMIX will address clear and consistent semantics for communication of energy prices, bids, and energy characteristics that will apply to Smart Grid transactions [19]. The definition of price, in turn, becomes input to the Energy Interoperation EIX standard as a data element for DR communications. The price signal itself, at its core, is an array of prices associated with a schedule of future time intervals. A common standard for schedules is the subject of another NIST priority action plan [20]. As noted in Figure 3, bids are submitted by the facility to the markets and bid acceptance (or rejection) notice is received back. The customer independently receives the purchased power (for bid to buy) or delivers the load reduction or generation (for bid to sell). These market signals will be integrated into the Energy Interoperation EIX protocol.

Also shown in Figure 3 is the "forward demand/supply curve." A forward demand curve is a prediction of future energy use (expected demand in kW) for future time intervals, and may be generated by analysis of past use, facility schedules, weather, and sub-system status. Rather than deal directly with a market, the facility may send these forward demand estimates (or supply in the case of potential demand reductions or generation/storage resources) to an aggregator who then bids this demand or supply resource into a wholesale market. Accurate estimation of sub-system demand may rely in part on sub-system energy profiles. Energy profiles may serve not only for configuration purposes (e.g., identifying sub-system load shed capabilities) but also as a resource for dynamic status: operational mode, faults, power level, storage status, etc. The subject of energy profiles is a topic of ongoing research.

For demand response, the DR event signal contains: mode (e.g., high/ medium/ low, or pricing level), date and time of event notice, and date and time of event start. There may be other optional elements such as location. The notice will include customer and utility account and DR program specific data. The event is understood in the context of that program, and, for automated DR, the response to the signal is pre-programmed such that facility response meets expected load reduction. There may be some opt-in/ opt-out response. There may be some feedback signal to indicate status/performance of the facility in meeting the requested shed, although retail settlement (payment to the customer or penalty for non-compliance) is judged based on measurement and verification at the meter. The Energy Interoperation TC efforts are awaiting NAESB input to validate the details of a generic DR signaling protocol that can serve these functions and more fine-grained use case requirements.

6. CONCLUSION

We are in the midst of a transformation of the relationship between buildings and the grid. The convergence of automated controls in buildings, information technology, and national impetus to address electric grid weaknesses (reliability, energy source and need for DER integration) has created the environment for accelerated standards action. Work is proceeding on DR signals and market transaction communication standards even as we develop our vision for the integration of buildings in the Smart Grid. In fact, the standards development process coordinated by NIST has become a social and political, as much as technical, effort that is stretching the vision of all stakeholders and coalescing the understanding of what the facility interface *should* be. Facility interactions with the grid should occur at a secure interface that also serves as a demarcation point of ownership at the domain boundary. Communications across the interface should be collaborative in nature, with simple data exchanges that require minimal knowledge of how that information is used or what protocols exist on the other side of the interface.

This paper has presented a conceptual design for a facility interface that is consistent with these principles. The communications crossing the interface were examined with reference to the standardization work underway as part of the NIST Smart Grid effort priority action plans.

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