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Facility Smart Grid Interface and a Demand Response Conceptual Model

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Abstract

Residential, commercial, and industrial facilities have potential to support electric grid reliability with demand response (DR) via use of facility energy management approaches. The ability of different DR approaches to successfully engage the maximum amount of customer response (and customer benefit in terms of energy and energy cost reduction) depends in part on proper selection of communication interfaces. This paper examines the impact of facility systems diversity on the communications interface, and analyzes use case requirements to derive basic use case classes and a resulting set of key information elements needed to support smart grid customer interface communications. The derived customer interface functional requirements are used to develop a “DR Conceptual Model” which provides a high-level view of the scope of DR interactions and guidance on the selection of communication interfaces.

Keywords: buildings, communications interface, customer, demand response, smart grid

Introduction

The United States and other nations have policies that are encouraging: renewable energy integration, CO2 reduction, building energy efficiency, and demand response (DR) for grid energy efficiency [1, 2, 3]. Meeting these policy goals while maintaining grid reliability represents a significant challenge. The combination of variable supply due to renewable generation and demand peaks due (primarily) to air-conditioning or heating loads has contributed to a move toward a paradigm where demand-side entities respond to supply-side conditions. Demand response has already been shown effective in managing load peaks. When facilities are taken together, they represent a viable resource to 1) offset peak loads through energy curtailment as well as 2) balance short-term supply and demand and aid the integration of intermittent renewables through ancillary services [4, 5].

However, DR as widely implemented today, utilizing DR event communications and direct load control (DLC), has only realized a fraction of the available demand response resource. It will be helpful to examine the reasons why this is true so as to better understand how demand response can be increased. Examining the diversity of the customer domain demonstrates the need for more abstract communication interfaces for achieving wide scale demand response. Use case analysis leads to understanding functional requirements for communications with the diverse customer domain and from which are derived use case classes. These classes are important for guiding the development of interface standards. Together, the results of these analyses lead to a higher-level view of DR interactions—a DR Conceptual Model. This DR Conceptual Model presents the range of DR interactions along with the drivers for adopting one DR approach versus another. The DR Conceptual Model is a tool for understanding the trade-offs among different DR approaches and options for implementing demand response.

As a first step, a working definition of the customer communications interface is presented. Following that, an analysis of customer domain characteristics is presented. These characteristics cover a diversity of business goals, customer loads (energy consuming systems and devices), and communication protocols used in different types of customer facilities. In order to realize the potential for DR, the customer communications interface design needs to account for this customer diversity.

Section four presents an analysis of the use cases for Smart Grid interactions between grid-side service providers and customer facility systems. These use cases reveal the functional requirements of the interface and basic information elements that must be communicated at the interface. The final section presents the DR conceptual model.

Baseline Definition of the Customer Communication Interface

The customer energy services interface (ESI) is a logical demarcation point at a facility asset ownership or operations support boundary that enables secure communication of information between entities internal to the customer domain (i.e., energy management systems, electrical loads, meters, storage and generation) and external entities (e.g., energy service providers, aggregators, and markets), Fig. 1. A clear demarcation point encourages market development of competitive devices, equipment and appliances that facilitate demand response, energy efficiency and energy management. The ESI comprises the devices and applications that provide secure interfaces between energy service providers and customers, facilitating machine-to-machine communications to support business processes [6, 7].

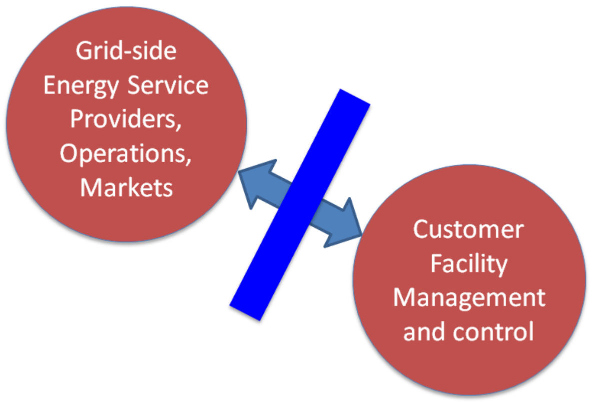

Fig. 1 Customer energy services interface (blue bar) as demarcation between independent domains.

The ESI may be instantiated in many forms, running different application services, implemented in different devices, at different levels of a hierarchy (e.g., with an aggregator), even multiple ESIs within a single system interacting with different outside parties. It may be owned and operated by either an energy services provider or customer. Real-world implementations will need to support operational variations among customers to account for diverse customer business models with different types of assets in different types of customer facilities controlled by a range of automation.

Considering general interface principles, a standardized interface defines what and how specific information is transferred through the interface but not how that information is processed nor what functions and features are provided by systems that implement the interface [8]. Vendors in the market do not compete on the standard interface, but rather on the products, systems and services that implement and use the information transferred to provide enhanced customer value through innovation. An interface that promotes both interoperability and innovation needs to provide separation between the systems that interact. This shields one side of the interface from changes that occur on the other, thus improving system robustness and stability.

Customer Domain Characteristics

It is important to recognize the customer facility (home, commercial, industrial) as a separate domain of the smart grid, as shown in Fig. 2, and as acknowledged by smart grid architectural efforts [7, 9]. The customer domain is segmented into separate sub-domains for home, commercial/institutional, and industrial (Fig. 2). Each sub-domain has a diverse set of actors, applications and technology. This diversity results in a challenge for grid-side service providers to engage with a range of customer systems and devices, managed for different purposes, using a wide variety of communication protocols. The customer interface needs to accept and adapt to this customer diversity in order to achieve scalability and a high level of acceptance.

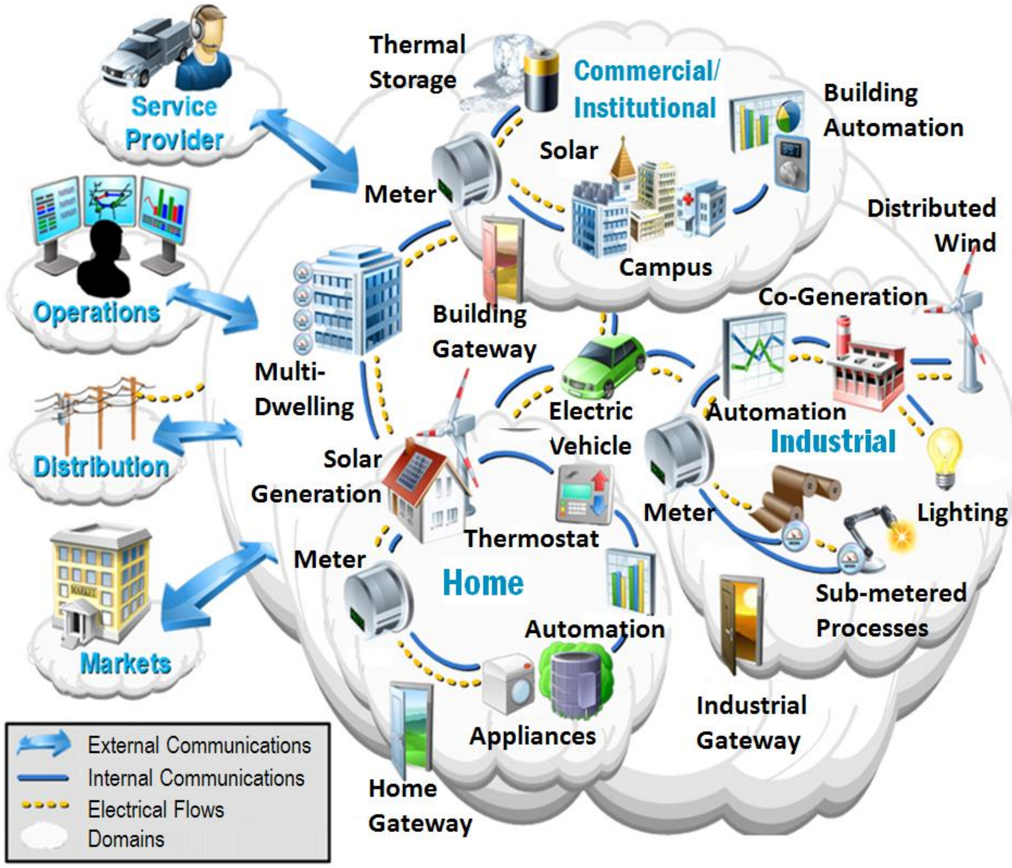

Fig. 2 Conceptual Reference Diagram for the Customer Domain (Source: adapted from NIST Framework, 2.0 [7]).

Customer diversity can be categorized based upon differences associated with: 1) business values and business priorities, 2) system complexity and 3) communications technology.

Diversity of Business Values and Priorities

A discontinuity exists between the business values and priorities surrounding grid operations and those of customers. Each has different policies and regulations, different business models, drivers, processes and procedures, and different but complex information models and technologies.

Grid operations are typically focused on actively managing and controlling the delicate balance between the energy produced and energy consumed on the grid in real-time. Minimizing operational risk is a very high priority due to the costly impact of electric system instability or collapse. Minimizing risk often entails minimizing complexity and options. Customers are viewed through this lens.

Customers on the other hand are not focused on the grid but rather on achieving a totally different set of wide-ranging business objectives such as: profitably operating a large manufacturing business, maintaining a comfortable environment for customers in a retail store, or enjoying home entertainment. Maintaining profitability and comfort are high priorities. These customer objectives typically assume the continued availability of reliable and relatively inexpensive electricity.

Diversity of System Complexity

In general, system complexity is minimal in residential buildings, increases in commercial facilities and is greatest within industrial facilities. Most homes have appliances, air conditioning, lights, home entertainment and other loads but these typically operate independently as stand-alone devices. Integrated home automation systems are installed in a small percentage of the residential market.

Most commercial facilities have heating, ventilation, air conditioning, lighting and general plug loads along with specialized loads such as kitchen equipment or data processing equipment. Larger facilities and campuses may have distributed generation in the form of backup generators or combined heat and power (CHP) cogeneration power plants. In addition, equipment within larger facilities and campuses is often monitored and controlled by distributed building automation systems.

Industrial facilities typically include an even wider range of highly specialized equipment monitored and controlled by automation systems using distributed programmable logic control systems designed for operation in harsh conditions and with critical timing constraints. Manufacturing operations in larger industrial enterprises are often integrated with business systems and enterprise resource management to optimize efficiency and profit.

The capability for customers to react to opportunities and challenges that occur in the electrical system (i.e., dynamic pricing, demand response events and retail energy transactions) is highly dependent upon the customer’s flexibility to dynamically schedule and optimize the operation of energy assets which is impacted by the level of automation [10] and operational constraints. As an example, an energy asset considered critical to producing revenue or ensuring health and safety will probably not be available for rescheduling.

Automation systems represent significant capital investments and on-going operational expense. They are typically implemented based on the control system’s ability to address operational and business challenges while providing a return on investment measured against the costs of manual operation. Typically, the benefits of automation increase as the complexity and costs of a task increase.

Diversity of Communications Technology

Communication protocols have been developed in the customer sub-domains to meet the economic and technical requirements indigenous to each sub-domain. Home technologies are very cost sensitive and targeted at a limited range of relatively simple applications while commercial and industrial technologies must meet more demanding requirements associated with performance and reliability in a broader set of complex applications. This has led to a diversity of protocols which must interact with an ESI. The development of the Facility Smart Grid Information Model standard [11, 12] provides a common information model for smart grid interactions with the customer domain, and which in turn aids in defining standard interfaces to diverse customer domain protocols [13].

Communications between grid-side service providers and customers should accommodate customer diversity, to the degree possible, in order to enable innovation through thriving product markets while limiting diversity and risk in grid operations. Achieving this requires that the information elements that flow between the domains be limited to: 1) what is required to satisfy the use cases and 2) the overlapping information that links the different domain models together. In general, a given interface will be more broadly useful to a diversity of devices/systems if the information communicated across the interface is more abstract, exposing fewer system-specific details. The level of abstraction provided by an interface should vary based on the business and application requirements.

Table 1 Customer Interface Use Cases and Corresponding Information Elements

Use Case Classes	Description	Customer Interface Required Information Elements
Energy Market Transactions	Balancing and trading power, externally with electricity, gas and other energy markets, and internally balancing energy sources.	Energy supply cost data (including electricity price forecasts), market transactions (indications of interest, bids, and trans-actions). Demand forecasts also require weather forecast data.
Demand Response	Demand Response: Day ahead capacity DR and Day-of DR; Fast-DR (ancillary services); and price communications. Includes event communications, supporting services, feedback, and measurement and verification (M&V).	DR event information (start time, duration, and level/amount), price and product, event status, market context, resource ID and service location. Support information includes: registration, opt in/out, availability, event response and meter data for M&V.
Direct Load Control (DLC)	Direct control of facility loads.	Commands to turn on/turn off end node, or more sophisticated generator/storage control signals.
Facility Energy Management (FEM)	Energy management of facility loads, storage and generation which includes monitoring, planning and control of facility energy use, emissions, and power quality.	Validated meter (energy usage) data, energy cost data (including electric price forecasts), emissions data and weather forecasts.
Remote System Monitoring and Management	Monitoring and management of system health by service providers to allow system diagnostics and remote energy management.	High-frequency meter data, power quality data and sub-system status. Remote FEM may require additional building system data (occupancy and process schedules, business planning, etc.)
Integration of Customer Distributed Energy Resources	Exchange of grid and distributed energy resource (DER) status.	Grid power voltage and quality forecasts, generation and storage status (available power, charge level, ramp rates, availability schedule, priority, present demand, forecast demand, etc.). Alternatively, DER integration may be enabled via market transactions or DR signals.
Emergency Notification	Notification that a power disruption is imminent.	Alerts and warnings of power system degradation or failure.

Use Case Analysis for Interface Information Requirements

In this section the various smart grid use cases involving customer interactions are distilled to common use case classes and the information elements from these common classes are then identified. These key information elements serve as the building blocks for cross-domain interface standards. A given interface standard must define communication protocol messages for relevant information elements which are themselves represented according to some data model. Use case classes help to define the protocol messages and the information elements that need to be exchanged.

Significant effort has been expended over the last decade to collect use cases for electric grid interactions, of which some apply to customer-to-grid service provider interactions [14, 15, 16, 17]. The use cases cover a wide range of smart grid interactions, with emphasis on different domains and applications for grid service providers and customers. Many of these use cases include communication of information elements across the ESI, and these use cases in turn can be summarized in a small set of use case classes that are presented in Table 1. Abstracting away some of the use case details and combining them in this way helps to clarify the capabilities needed in an ESI.

The information elements in the right hand column of Table 1 may be reduced to a set of key elements, as given in Table 2. These information elements represent key functions of the interface that must be supported by interface standards in order to meet use case requirements. One important observation is that there is a limited set of information elements that together satisfy the needs of a large set of use cases. The use case classes (Table 1) cover essentially all of the envisioned smart grid interactions that enable customer load and distributed energy resources (DER) support of grid reliability to achieve smart grid goals.

Another observation is that significantly different types of DR interactions appear in Table 1. DLC requires low-level control interfaces that will be limited in application to specific types of devices and perhaps only certain customer groups. DR event signals can be more broadly disseminated, but may be implemented at different levels of abstraction with more or less visibility into customer sub-systems. Energy market transactions represent a fully decoupled interaction with the customer.

Table 2 Key Information Elements for the ESI

1	Price and product information (real-time and forecasts)
2	Market transaction data (bids, indications of interest, transactions)
3	DR signals (events and support services: registration, availability, opt-in/opt-out, feedback)
4	Energy usage information (meter data) including demand forecasts
5	Direct control signals
6	Weather forecasts
7	Power quality
8	Emissions data
9	Generation and storage status data
10	Emergency notifications

Table 1 use case classes have been presented in terms of abstracted applications on the grid side and customer side. For example, one does not see “distribution system management” or “electric-vehicle management”. Instead, one sees the more abstract classes of demand response and customer DER integration. Also, Table 1 includes the abstract customer application of facility energy management. Please note that the information elements in the right hand column are only those which cross the ESI, and not all information needed for facility energy management or any other customer or utility application.

It should be noted that a service provider of “Remote System Monitoring and Management”, may be either an energy provider or third party. Also, the “Integration of Customer DER” use case class calls for communication of DER status information. This may be communicated by a low-level control protocol or a higher-level DR protocol. “Integration of Customer DER” also includes grid power voltage and quality forecasts which provide grid status information from an energy service provider to the customer. Similarly, the “Emergency Notification” use case class acknowledges the need for alerts to warn customers of imminent disruptions so that appropriate actions may be taken.

The DR Conceptual Model

Demand response refers to changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized [18].

The electric industry has implemented various methods of demand response. ISO/IEC 15067-3 [19] divides these methods into direct and indirect load control that may convey control and price signals. Considering the use case classes of Table 1 leads to further refinement of these two levels into four levels. These methods can be viewed as four distinct hierarchical levels of interactions as presented in the "DR Conceptual Model" of Fig. 3.

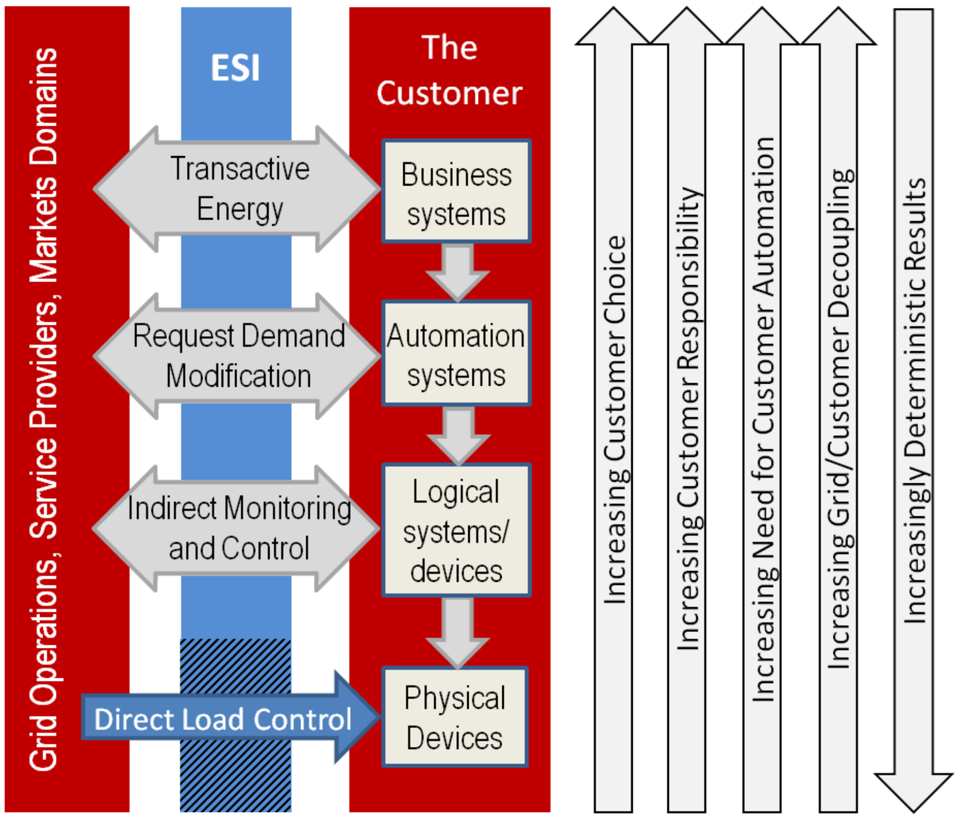

Fig. 3 Levels of Abstraction: DR Conceptual Model.

The DR Conceptual Model illustrates a range of service provider-to-customer interactions, from business level transactions down to direct load control. It defines four levels of abstractions from the perspective of the service provider: 1) Transactive Energy, 2) Request Demand Modification, 3) Indirect Monitoring and Control and 4) Control Physical Devices.

The DR Conceptual Model also shows the hierarchy of control that exists in any customer facility, depending on the level of automation present. Within the Customer Domain, customer business decisions provide input to energy management and control systems which interface to lower level system controls and finally to control actions at the physical device level. External grid service providers or markets can interact with the Customer Domain at the customer enterprise, facility, system or device levels, entering the Customer Domain control hierarchy at different points with different effect and implications as discussed below.

Transactive Energy

Transactive energy is the highest level of abstraction. At this level, a service provider interacts with the customer through business processes communicating business value. By interacting at the business process level, the service provider views the customer as an autonomous decision-making entity that is capable of optimizing its internal behavior in response to grid signals. The customer determines and performs all control actions.

The interface can represent a facility or enterprise (e.g., multiple facilities) and the data transferred across the customer interface may include energy price quotes, market-based tendered energy bids and resulting transactions, weather and weather forecasts, system status information and notifications of imminent grid disruption. The service provider does not have visibility beyond the interface although sufficient information is available at the interface to enable both customers and service providers to execute specific use cases.

At this level, the customer or customer's automation systems decide on the optimum course of action to achieve the best economic and performance results. The customer has a choice on how, or whether, to respond and the service provider is not impacted by internal system changes that occur on the user side. More advanced automation strategies may be required to take advantage of time-variant prices while minimizing risk.

Request Demand Modification

At this level, the focus is on "what" needs to be achieved, while the customer retains control of "how" to respond. The service provider specifies and conveys the desired results and the user decides how to achieve those results, e.g., "Reduce load by 10 kW." The customer or the customer's automation systems decide on the optimum course of action, based on an analysis of the tradeoffs, to achieve the desired results with the minimum negative operational impact and maximum positive impact on the facility. The service provider does not require knowledge of the exact details of how the user will respond internally, only the overall result. This also minimizes the impact of system changes that occur on the customer side.

A service provider should not expect all customers to fully comply with a reduction request. However, depending upon the contractual relationship, the customer may be fully responsible for achieving the agreed upon results and may risk penalties if they fail to achieve the requested results.

Indirect Monitoring and Control

At this next level of abstraction, service providers interact with "logical" systems or devices, not physical ones. There is control logic between the service provider and the load; the service provider requests an action to occur on a logical device or system. For example, a service provider might send a command to a thermostat setting a specific set point. Higher priority requirements in the control logic may override the signal from the service provider, e.g., overrides related to safety or equipment reliability.

Indirect monitoring and control provides indirection and decouples the customer's internal physical systems and devices from the service provider permitting changes (e.g., device replacement) to occur on either side of the interface. The logical devices can implement and expose consistent behaviors to the service provider. All physical control actions, manual or automatic, are performed by the customer and can be overridden by the customer. Service providers do not require full knowledge of the devices in the customer domain, because the automation system ensures that appropriate facility and equipment constraints are maintained.

Data transferred across the customer interface may include demand response signals or set points commanding certain indirect actions (e.g., reduce consumption to baseline, increase temperature 2 degrees, charge/discharge storage), meter readings, power quality, emissions, availability of load reduction or generation for DR, DR feedback for measurement and verification, fault detection, power quality monitoring, etc.

Some example applications that use indirect monitoring and control are: 1) contracted DR programs, 2) external equipment monitoring, 3) DR feedback and 4) measurement and verification.

The customer requires some level of automation capability depending upon what devices are being controlled. This may increase cost if new automation equipment is required. Addressing the associated risks related to security and privacy concerns may also result in additional costs.

Service providers gain more granular interactions but may be impacted by changes in the customer's automation equipment if the changes are not performed in a coordinated and safe manner. In addition, the customer is only responsible for doing what was requested and not for whether the request is sufficient to achieve the needed demand reduction.

Currently, service providers wishing to communicate at this level must interface with a number of well-established protocols used by existing automation systems.

Control Physical Devices

At the lowest layer of abstraction, the service provider directly controls the power to loads through the command and control of physical systems or end devices within a customer facility. This normally involves service providers sending commands to start and stop physical devices and query device value and status information. An important requirement is that all controlled devices are the same or very similar.

All decision making and automation is performed by the service provider with little or no involvement by the customer. The customer has no risk or responsibility for whether the load is actually controlled as directed by the service provider. The service provider however must understand exactly how the load operates in order to turn power on and off directly and how this affects safety, reliability, environment, comfort, etc. As such, it is most appropriate for interfacing simple devices that control simple static loads that don't change over time. Low-level physical control is often the lowest cost in the absence of existing automation equipment.

Some example applications include: 1) remote cycling of air conditioning (AC) units, 2) remote cycling of water heaters, and 3) remote operation of back-up generation units. An example of remote cycling is the use of a radio frequency signal to trigger relays on air conditioning units in the summer.

The term "direct load control" (DLC) is often used to refer to a DR service provider directly switching on or off customer systems, devices, or appliances. DLC is widely used with residential customers and ISO/IEC 15067-3 defines DLC in the residential context as "remote control of one or more appliances by a utility or third-party service provider" [19].

Cross-Cutting Issues of the DR Conceptual Model

The drivers for moving up or down the DR hierarchy in Fig. 3 are represented in the arrows on the right side of the figure. This section examines each of these.

Increasing Customer Choice

From the perspective of the service provider, higher abstractions result in greater dependence upon the customer to perform as requested. This requires greater customer technical and decision-making capability which includes automation systems. This results in greater complexity for the customer and requires investment in automation systems that must be justified as they require up-front capital and on-going maintenance investment.

Increasing Customer Responsibility

At lower levels of customer interaction, the service provider is responsible for installation and maintenance of equipment and connections used to control the system response. The service provider is also responsible for all demand reductions which are achieved or not achieved as a result of system problems. At higher levels of demand response interaction, responsibility for installation and maintenance of facility equipment that is used to control the response shifts to the customer. The financial benefits and risks of participating in the program also shift to the customer.

Increasing Need for Customer Automation

At lower levels of interaction, the customer is not required to have any automation equipment since the service provider directly controls whether power is allowed to flow to the load. The need for automation increases at higher levels of interaction. At the level just above Control Physical Devices, this may be as simple as a thermostat. Higher levels of interaction may require a building management system, energy management system, or even some type of enterprise level system that considers tradeoffs between energy prices and other business considerations.

Increasing Grid/Customer Decoupling

The customer domain diversity section earlier demonstrated the benefits of a more abstract interface that can interact with a wider range of customer devices and systems. Lower levels of interaction require detailed knowledge of devices or systems on the customer side of the ESI and make such an interaction more end-system specific and less scalable and reusable. The interface used for a specific application use case should be at as high level as possible but matched to, or balanced with, required application functionality. If an interface provides insufficient functionality, techniques may be implemented to circumvent or bypass the interface, resulting in decreased interoperability. If the interface provides excessive functionality, the costs to implement and maintain the interface increase [13]. Conformance to this important abstraction principle will help achieve the interoperability and reliability goals of the smart grid and enable future innovations by hiding complexity and enabling independent development within domains.

Increasingly Deterministic Results

At lower levels of interaction, the resulting response can be very deterministic since the service provider is directly disconnecting the power to the load. At the higher levels of interaction, the resulting response is more indeterminate unless aggregation of numerous resources is included. Aggregation converts a collection of indeterminate resources into a determinate resource for the grid.

Independence of Quality-of-Service Requirements

This paper has focused on functional requirements at the customer interface, as seen in Table 1. Each use case also has a range of non-functional quality-of-service requirements: message transport, network performance, security and privacy, scalability, etc. Here we specifically note that while quality-of-service requirements are important in interface implementations, they are also orthogonal to the DR Conceptual Model. Any level of the DR Conceptual Model may be implemented with any given set of quality-of-service requirements. The important corollary is that one should implement an interface in such a way that the messages that communicate the information elements are separated from the transport, security and other quality characteristics.

Conclusion

Demand response implementation has largely focused on what can be accomplished to manage customer load during grid demand peaks. There has not been a careful examination of the nature of the customer domain and associated use cases. This paper has presented the diversity of the customer domain and an analysis of smart grid customer interaction use cases from which were deduced a set of use case classes and key information elements crossing the customer energy services interface. This analysis was used in the development of a DR Conceptual Model which presents the range of DR interactions along with the drivers for adopting one DR approach versus another. Customer domain diversity emphasizes the need for broadly applicable interfaces using more abstract communications and minimal information for a given application. Use case classes and derived key information elements guide development of more broadly applicable interface standards.

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