Customer Energy Services Interface White Paper
Version 1.0

Smart Grid Interoperability Panel B2G/I2G/H2G Domain Expert Working Groups
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Abstract
The Energy Services Interface (ESI) is a concept that has been identified and defined within a number of Smart Grid domains (e.g., NIST Conceptual Model[1]). Within these domains, an ESI performs a variety of functions. The purpose of this paper is to provide a common understanding and definition of the ESI at the customer boundary through a review of use case scenarios, requirements and functional characteristics. This paper then examines the information that needs to be communicated across the ESI, and looks at the standards that exist or are under development that touch the ESI.

This white paper provides input to the Smart Grid Interoperability Panel (SGIP) as well as international efforts to understand grid interactions with the customer domain and the standards that govern those interactions. This in turn provides guidance in product and service development. A shared understanding of the requirements and architecture and standards framework of the customer interface will lead to improved interoperability and more effective integration of customer resources to meet the challenges of grid reliability.

1. WHAT IS AN "ESI"

A primary business requirement driving an Energy Services Interface is the need to effectively and efficiently enable customer energy assets (i.e., electrical loads, storage and generation) to actively participate in maintaining electric grid reliability while improving both grid and customer energy efficiency.

The ESI helps promote interoperability by providing an abstract interface between energy services providers (ESP) and energy customers. The foundational frameworks for achieving system-to-system interoperability are the GridWise Interoperability Context-Setting Framework (a.k.a. GWAC Stack)[2] and NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0[3].

An ESI is a bi-directional, logical, abstract interface that supports the secure communication of information between internal entities (i.e., electrical loads, storage and generation) and external entities. It comprises the devices and applications that provide secure interfaces between ESPs and customers for the purpose of facilitating machine-to-machine communications. ESIs meet the needs of today's grid interaction models (e.g., demand response, feed-in tariffs, renewable energy) and will meet those of tomorrow (e.g., retail market transactions).

This is a general definition of an ESI as applied to the customer boundary. Real implementations will have variations arising from complex system inter-relationships: diverse customer business and usage models with different types of assets in different types of customer facilities controlled by a range of energy management systems.

2. THE CUSTOMER DOMAIN

The NIST Smart Grid Conceptual Model provides a definition of the customer domain (see Figure 1):

"The customer domain is usually segmented into sub-domains for home, commercial/building, and industrial. The energy needs of these sub-domains are typically set at less than 20 kW of demand for home, 20-200 kW for commercial/building, and over 200 kW for industrial. Each sub-domain has multiple actors and applications, which may also be present in the other sub-domains. Each sub-domain has a meter actor and an ESI that may reside in the meter or on the energy management system (EMS) or in an independent gateway."

[1] http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/IKBDomains

[2] http://www.gridwiseac.org/pdfs/interopframework_v1_1.pdf

[3] www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf

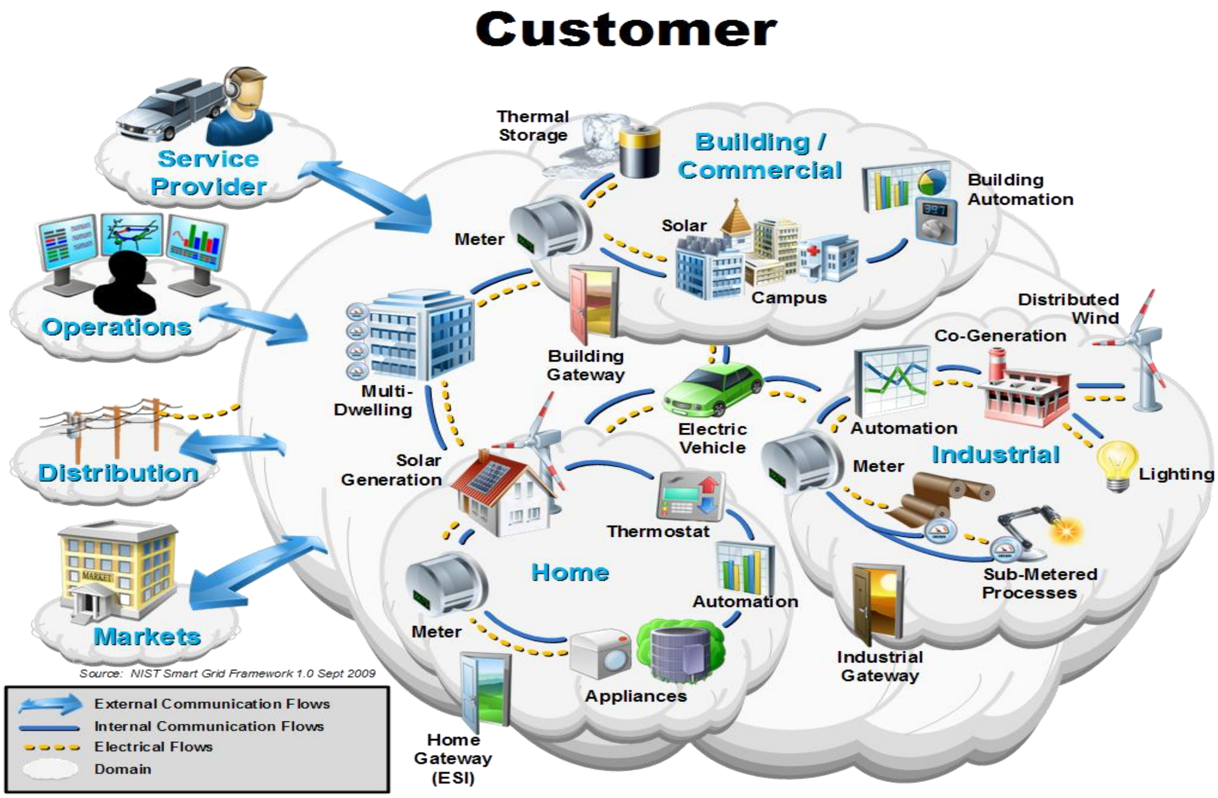

Figure 1 - Conceptual Reference Diagram for the Customer Domain (Source: NIST Framework, V2)

Table 1 Typical Energy Management Applications within the Customer Domain

Application	Description
Building/Home Automation	A system that is capable of controlling various functions within a building such as lighting and temperature control.
Industrial Automation	A system that controls industrial processes such as manufacturing or warehousing.
Distributed Generation	Distributed generation includes all types of generation (e.g., solar, wind, and hydro) that convert local energy to electricity, including within a customer location. These generators may be monitored, dispatched or controlled via communications.

The NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0, and Section 3.6 *Smart Grid Interface to the Customer Domain* provides an ESI description:

"The interface between the Smart Grid and the Customer domain is of special importance as the most visible part of this domain. The conceptual reference model depicts two distinct elements that together provide the interface to the Customer Domain:

• The Meter, and
• The Energy Services Interface (ESI), which serves as the gateway to the Customer Premises Network.

Through these interfaces, electricity usage is measured, recorded, and communicated; service provisioning and maintenance functions are performed (such as remote connection and disconnection of service); and pricing and demand response signaling occurs.

New and innovative energy-related services, which we may not even imagine today, will be developed and may require additional data streams between the Smart Grid and the Customer domain. Extensibility and flexibility are important considerations. The interface must be interoperable with a wide variety of energy-using devices and controllers, such as thermostats, water heaters, appliances, consumer electronics, and energy management systems. The diversity of communications technologies and standards used by devices in the Customer domain presents a significant interoperability challenge. In addition, ensuring cyber-security is a critical consideration." Typical applications within the Customer domain are listed in Table 1.

The diverse energy assets (i.e. loads, storage and generation) within the customer facility can be characterized by:

- **Electrical Capacity**
  Homes and small commercial and industrial (C&I) facilities typically have less than 20KW of demand and contain a relatively small number of low-power loads. Medium C&I facilities and multi-tenant residential customers are typically between 20KW and 200KW of demand. C&I customers typically contain significantly more diverse loads than multi-tenant residences. Large C&I facilities have greater than 200KW of demand and contain a large number of specialized loads.

- **Operational Characteristics**
  Most homes and commercial facilities currently have appliances and other loads but few have generation capabilities. Most facilities have heating, ventilation, air conditioning, lighting and general plug loads. In the future, more commercial facilities may have fuel cells or other backup generation. Large facilities and campuses may have distributed generation, backup generation, and cogeneration for power. This will evolve over time as innovation increases the economically-viable distributed energy options available to customers such as plugin electric vehicles (PEV) and renewables.

  The electrical energy consumption of homes is relatively predictable in the aggregate as compared to commercial and industrial customers. This is one of the reasons that residential electrical tariffs have been relatively simple and broadly applied.
  Energy consumption in commercial and industrial facilities tends to vary over time as large loads are activated and de-activated. This change in the demand for electricity can be unpredictable but needs to be balanced in real-time. C&I costs reflect this variability in more complex tariffs that separate energy costs from demand costs.

  Another aspect of variability relates to the timing of energy consumption of homes and C&I facilities. As a general rule, home energy consumption for non-stay-at-home families decreases while C&I consumption increases during the work day. During the weekends, commercial and industrial consumption decreases while residential consumption may increase.

  The electrical phase of loads also varies between home and C&I customers. C&I customers often employ large inductive loads which often require regulation through volt/VAR ancillary services.

- **Economic Impact on Customer**
  Electricity bills vary based upon the electrical consumption, demand, number and types of energy assets (loads, generation, and storage) and represent a portion of the overall costs of operating a home or business. As the relative economic impact of energy increases, more financial resources are applied to controlling costs based on return-on-investment. This is often reflected in increased expenditures for energy management and automation systems to help control energy costs.

  Positive economics for commercial and industrial customers have fueled the development of diverse and competitive control and automation industries. Historically, home automation has been limited to high-end homes due to cost. Use of home automation may increase over time as the relative economic impact of energy changes.

  Another factor affecting the economic impact is the financial responsibility of the customer for energy costs. Home residents are personally responsible for energy costs while commercial and industrial customers are not personally responsible but rely on business operating revenue to pay for energy costs.

- **Operational Flexibility of Customer**
  The capability for customers to react to opportunities and challenges that occur in the energy system (i.e. dynamic pricing, demand response events and retail energy transactions) is highly dependent upon the customer's flexibility given the constraints that are considered critical to the operation of the home/business.

  A commercial or industrial energy asset considered critical to producing revenue or ensuring health and safety will probably not be available for inclusion in energy transactions. A home energy asset, such as air conditioning for an elderly person, may also be considered critical and therefore not available. Flexibility is directly influenced by the capability of customer energy management systems to dynamically schedule and optimize the operation of energy assets.

- **Operational Impact on the Electric System**
  Customers can impact the power reliability, quality and stability of the electric system. Large, inductive industrial loads can have a direct impact while smaller home loads can have an indirect impact as they become aggregated into larger systems.

- **System Complexity of Customer**
  Customer facilities vary in complexity. In general, system complexity is minimal in residential buildings, increases in commercial facilities and is maximal within industrial facilities.

  At the low end is a simple residence with some appliances that can be cycled (e.g., air conditioning), load shifted (i.e., refrigerator defrost) or used for thermal storage (i.e., hot water heater). In the middle range are medium sized commercial properties or small industrial facilities that have simple control systems and multiple sub-systems (i.e., heating and cooling, lighting, thermal storage).

  Residential homes have simple devices, and simple requirements with minimal interactions between devices. There is commonly no energy management system in a home. The heating, ventilation and air conditioning (HVAC) system operates independently from the refrigerator, washer, and hot water heater and has the simple goal to maintain temperature. The HVAC system may be externally controlled to limit peak demand with acceptable impact on customer comfort. The electric hot water heater may be externally controlled to turn off heating during peak hours and to turn on heating at night. Energy service providers have, and will continue, to implement demand response programs based on these scenarios. Protocols, such as Smart Energy Profile (SEP), may be used to implement this control, while giving customers freedom to override control actions. It should be noted that external control is not the only approach and may not be the most desirable approach from the points of view of the consumer and energy service provider based on convenience to the customer and cost to the service provider.
  At the high end are large commercial and industrial campuses that operate many large, complex, interrelated energy and manufacturing processes. These facilities must meet a wide range of business and safety priorities (e.g., sub-system performance, business objectives for process management, occupant comfort, energy cost management, demand response, etc.).

  Some large commercial and institutional customers have energy management systems. Industrial customers may also have sophisticated distributed control systems but, in general, electrical loads cannot simply be turned off and on by an external entity that does not understand the facility's complexity. Energy management involves not only electricity, but also gas, oil, chilled water, steam, air quality, and tradeoffs among these.

- **Level of Customer Automation**
  Customer facilities vary greatly in the scope and capability of the automation systems that monitor and control facility functions. 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.

  Levels of automation (up to 10 levels[4]) describe different degrees of autonomy or decision-making capability between humans and machines. At the lowest levels, all decisions are made by humans and at the highest levels all decisions are made by machines.

  Simple, single-variable control loops are the easiest and least expensive to automate. The costs and difficulty of automation increases as operational and system complexity and coupling between variables increases.

  The level of automation within a customer facility will directly impact its ability to understand and respond to dynamic grid signals such as dynamic pricing and emergency events.

- **Customer Sustainability Needs**
  The social values of the customer may have an effect on the electrical equipment and energy content required by a customer. A customer may decide to consume only green (renewable) or low emission power even if the cost of this energy is higher than traditional energy. This energy may be produced on-site or by the energy service provider.

- **Energy Assurance Needs**
  While the vast majority of customers consume their power from the electrical grid, a small set of customers are only occasional energy consumers. To reduce the

[4]Mica R. Endsley, David B. Kaber, Level of automation effects on performance, situation awareness and workload in a dynamic control task (ERGONOMICS, 1999, VOL. 42, NO. 3, 462 ± 492)

dependence upon traditional energy service providers, some customers have decided to build Net Zero Energy (NZE) and Zero Energy (ZE) buildings. NZE customers provide electricity to the grid when they produce more than they consume and draw power from the grid when there is a shortfall. To reduce their risk of an energy failure, zero energy customers interconnect to the electrical grid and draw power only during emergencies.

3. BUSINESS CONSIDERATIONS

The business case is the core driver of system functionality by defining "why" a system should be built. It defines a system's scope, costs and benefits. Defining system scope requires a clear understanding of the business requirements, functional requirements, and quality requirements.

Functional requirements derive from the business and system use case scenarios and define the system functionality or "what the system must do." Quality requirements, in general, define the constraints and quality attributes such as security and performance that are placed on the system or "what performance the system must support." Once the system requirements are clearly understood, high-level system architecture can be developed that defines the components along with their behavior and interactions or "how the system will be structured". The business cases therefore directly impact and help define an ESI because they are the economic drivers for the specific use cases, requirements and architectures that deliver the business benefits to a specific customer or set of customers.

New business cases will be developed as standards and innovative technologies are developed, existing technology becomes more cost effective and enabling policy and regulations are enacted. Examples of this include increased micro-grid and customer participation in retail and wholesale energy transactions.

As a baseline set of business models for ESI demand response interactions, the Federal Energy Regulatory Commission (FERC) has defined the following fourteen demand response (DR) program categories in the FERC DR Assessment and Action Plan Summary[5]: Direct Load Control, Interruptible Load, Critical Peak Pricing with Load Control, Load as a Capacity Resource, Spinning / Responsive Reserves, Non-Spinning Reserves, Emergency Demand Response, Regulation Service, Demand Bidding & Buy-Back, Time-of-Use Rate, Critical Peak Pricing, Real Time Pricing, Peak Time Rebate and System Peak Response Transmission Tariff. (See Appendix 10.1 for more detail) These programs are supported by existing business cases and growth in their deployment is expected to continue.

4. INFORMATION EXCHANGE AT THE INTERFACE

The Energy Information Standards (EIS) Alliance Customer Domain Energy Services Interface (ESI) Requirements[6] provide a foundation for defining the functionality of the ESI. This document defines what information is processed by the ESI, based on use case. The use cases can be collected into a number of general categories as outlined below.

Energy Information Standards (EIS) Alliance Use Case Categories

- Demand response: load shed and shift, to minimize cost and to meet contractual obligations.
- Energy management of complex facilities with storage and generation: This expands the demand response and dynamic pricing use cases to include more detailed monitoring and planning of energy use, production and storage to balance energy costs with operational and production energy needs.
- Demand forecasts provided to the energy service provider: conveys expected power usage, after the customer has examined energy price forecasts and local energy needs.
- Balancing and trading power: an energy manager can choose to buy power from one or more energy suppliers, or to store or generate on site. One may also trade-off between on-site fuel sources for heating or electricity generation needs. The energy manager can choose to generate on site for sale in energy markets if the prices are advantageous.
- Measurement, validation and display: Sub-metering (or metering on individual devices) allows for better tracking of energy consumption, allocating energy costs, display of equipment power usage and costs, calculation of emissions, energy benchmarking, monitoring of power quality, and validation against energy supplier energy usage data. This may include the monitoring of facility emissions for benchmarking, market trading, or reporting purposes and enabling the monitoring of grid emissions for facility reporting purposes.

[5] http://www.ferc.gov/legal/staff-reports/06-17-10-demand-response.pdf

[6] http://www.oasis-open.org/committees/download.php/38460/EIS%20Alliance%20Interface%20Requirements%20V2.pdf

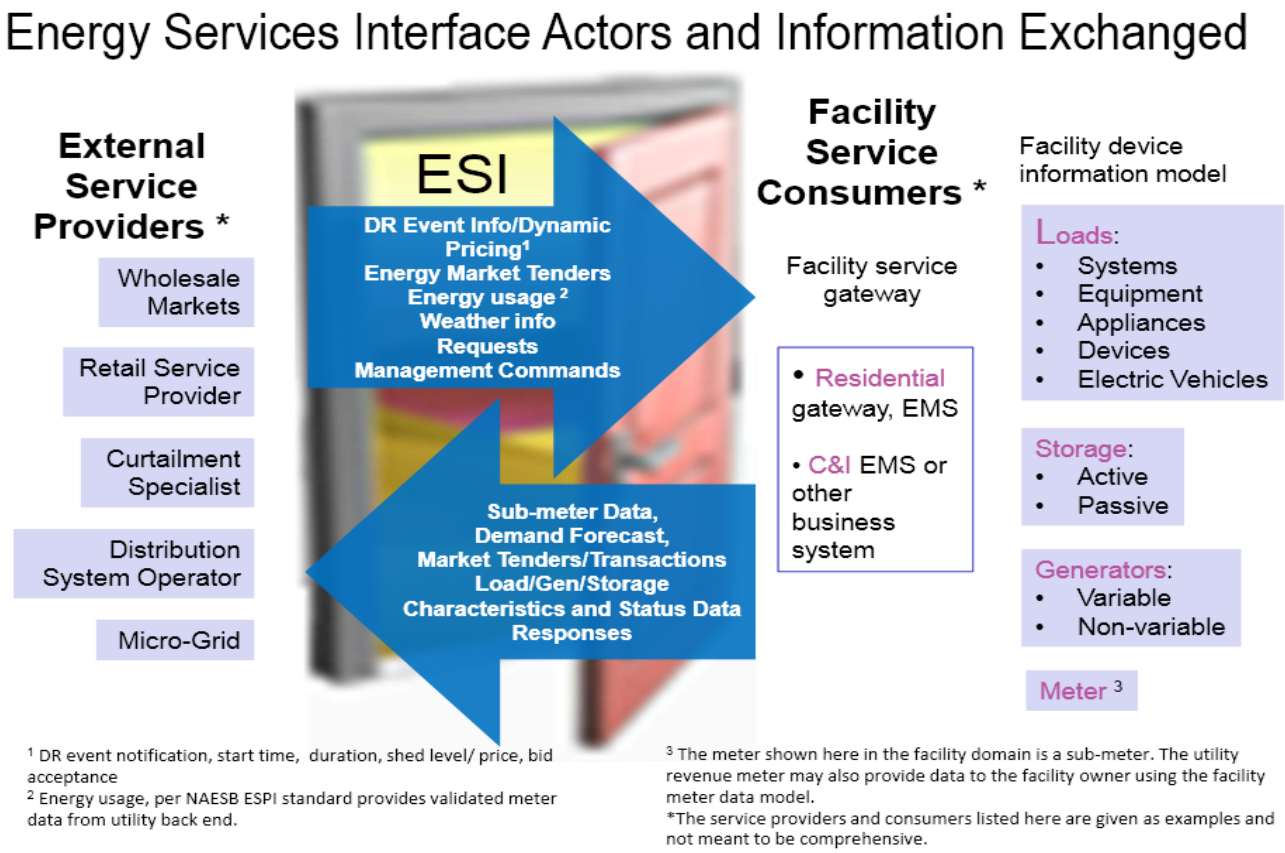

Figure 2 – Information Exchange between the Grid and Customers (Source: B2G DEWG)

- Exchange of grid and distributed generation (DG) status: enables the facility to learn about upcoming grid outages for planning purposes and to inform the energy service provider about the status of DG.
- Direct load control
- Monitoring and management of system health by service providers: allows for business models such as; 1) leasing of DG, storage and other distributed energy resources, 2) the proactive remote analysis and management of energy assets such as appliances and equipment, 3) the capability to interface to building/home energy management systems for the purpose of detecting operational efficiencies and anomalies and 5) the ability to monitor facility energy producing equipment that may affect the safety of grid maintenance personnel.

Each of the above use cases, if implemented, requires certain supporting information to be communicated across the ESI. Information elements include: weather, power quality, pricing information, energy emissions, present demand of the site, present demand of sub-loads, available shed-able load, critical loads, load state change interval, existing demand thresholds, onsite generation capabilities and availability, onsite energy storage and availability, historical interval power usage, loads to shed, demand forecast, facility report of common data, historical demand of loads and distributed generation, storage status, or appliance system health data. These information elements served as an important contribution to the development of the ASHRAE/NEMA 201P[7] Facility Smart Grid Information Model standard. However, the information communicated for any specific ESI implementation will depend upon the business case that is being satisfied.

An ESI is characterized by both the internal and external energy asset-related information processed and the functions provided by the interface (Figure 2). Energy asset information includes demand response event information,

[7] http://spc201.ashraepcs.org/pdf/SPC201-045_Meter_Model.pdf

dynamic pricing, energy transactions, energy usage, weather data and control signals.
The extent of the information processed by an ESI is dependent upon the type of service program the interface is facilitating. For this reason, there will be a range of interfaces along with systems that implement the interfaces. As an example, a price-responsive DR program may utilize a different interface than a remote asset monitoring program.

Some example ESI use cases scenarios are provided below to provide more insight into the information that may be communicated across an ESI. These are intended to reinforce and augment the EIS Alliance use cases listed above. The specific use case scenarios summarized below represent residential, multi-tenant residential, small and large commercial as well as small and large industrial facilities. Each scenario outlines how the ESI is realized.

Renewable Balancing
Balancing operations have traditionally relied upon the addition and subtraction of incremental generation. The integration of intermittent renewable resources will increase the volatility of supply by introducing intra-hour variability, forecast errors, over-generation and steep ramping rates. Demand side resource management can augment traditional generation and help mitigate the intermittency of renewable generation on the electricity grid. However, management of demand side resources must be predictable and transparent in order to be effective for this purpose. The grid operators may need to know the following information about the participating assets:

- What are its capabilities and limitations?
- How much, how often, and how long could it be made available (to consume and/or to export back to the grid)?

Residential Facility Participating in Ancillary Services
FERC (Federal Energy Regulatory Commission) defines ancillary services as "those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system." and identifies six different kinds of ancillary services: scheduling and dispatch, reactive power and voltage control, loss compensation, load following, system protection and energy imbalance.[8]

In addition to traditional day-ahead DR, residential facilities can provide fast-acting appliances and equipment, such as electric hot water heaters, that are capable of participating in ancillary services. The grid operators may need to know the following information about the participating assets:

- What are its capabilities and limitations?
- How much, how often, and how long could it be made available?

Large Commercial Buildings with Multiple Tenants Participating in Demand Response
This use case illustrates multiple tenants using a multi-ESI hierarchical network. Unique information requirements at the ESI include the ability to bill tenants for their power use.

Industrial Facility with On-Site Generation and Storage Capability Participating in Dynamic Pricing
Selling industrial cogeneration power to the wholesale market when the day-ahead market price is advantageous, and shedding load (adjusting process scheduling) based on a real-time market contract. Large industrial facilities may represent energy sources that can directly impact both the bulk electric system and industrial operations. For reliability and safety reasons, this may require a closer coupling of customer operations management systems with grid operations resulting in a more granular information flow for the purpose of properly characterizing operational context.

Remote Monitoring
A facility, whether it be residential, commercial or industrial leases out space (within the facility, on the rooftop or land) to a service provider who installs solar, wind, other distributed generation (DG) resources, storage equipment, plugin electric vehicles (PEV) charging stations or other appliances/equipment that act as a load. The resource is located behind the meter but the service provider takes responsibility for the monitoring and operation and/or maintenance of the resource.

[8] U.S. Federal Energy Regulatory Commission 1995, *Promoting Wholesale Competition Through Open Access Non-discriminatory Transmission Services by Public Utilities*, Docket RM95-8-000, Washington, DC, March 29.

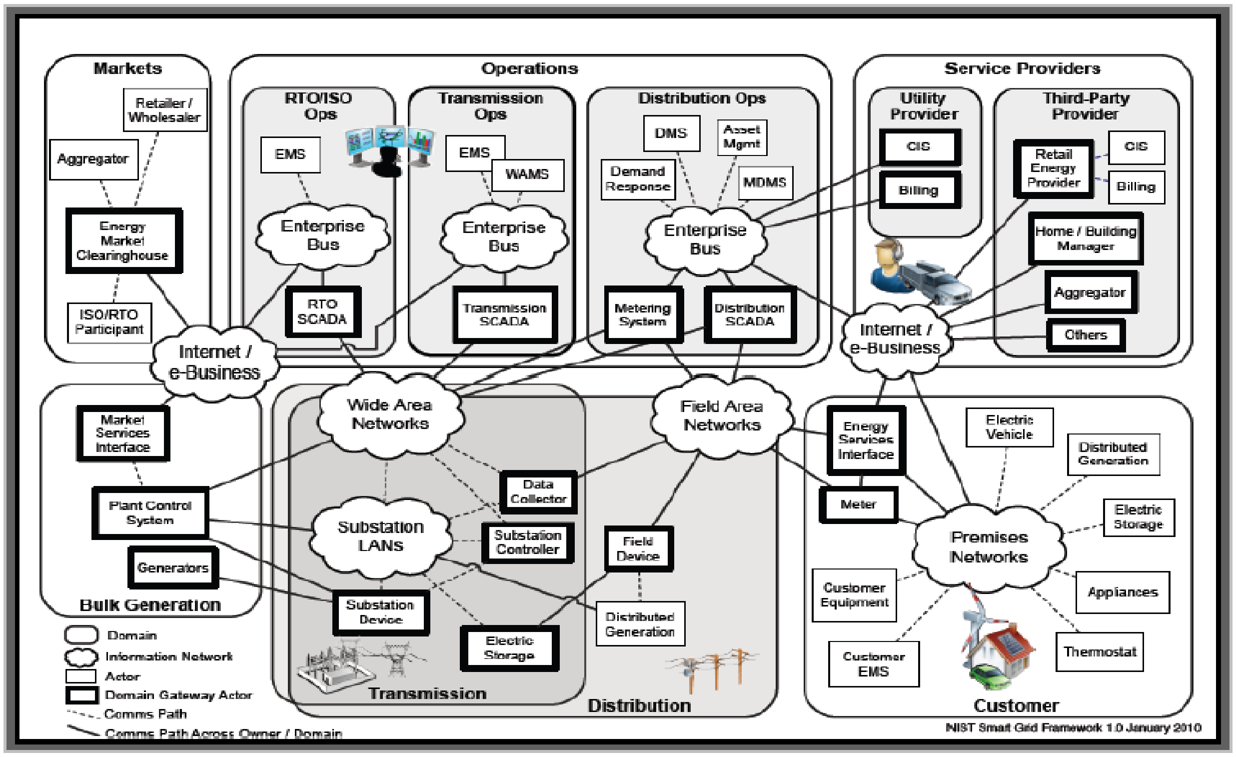

Figure 3 - Conceptual Reference Diagram for Smart Grid Networks (Source: NIST Framework, V2)

5. QUALITY CHARACTERISTICS

Application quality characteristics include security, reliability, scalability, performance and maintainability. These directly impact system architecture and design.

Security and Reliability

Cyber security is critical due to the potential for adverse impact on both the customer and bulk power system. Signals sent to large numbers of customer ESIs represent an attack surface that has the potential to disrupt the bulk power system. Invalid signals sent to customers' ESIs can interrupt and compromise commercial and industrial operations and can result in harm to equipment and personnel. Invalid signals sent from customers to service providers can cause misinformation and result in potentially harmful actions.

Security enables protected interaction and is fundamentally concerned with managing risk. The level of security depends upon the application. For example, published rates for electricity do not need to be encrypted (unless subject to non-disclosure by contractual arrangement) but do need to be authenticated as coming from the service provider and signed to prevent unauthorized alteration. Thus, security must be commensurate with application vulnerabilities and exposures, as evaluated by domain experts at the time application requirements are developed. Security in the marketplace requires transactional transparency to ensure auditable and traceable transactions.

The six areas of security that need to be addressed by ESI-enabled applications are: authentication, authorization, confidentiality, integrity, non-repudiation and auditing. Authentication refers to validating the identity of a user or code. Authorization refers to validating the authority of a user or application to perform actions. Confidentiality is the ability to encrypt data in order to prevent its access and integrity is the ability to detect data tampering. Non-repudiation is the ability to ensure that messages are sent and received by those that claim to have sent and received.

Flexibility is required of an ESI to allow the consumer to make available as much or as little information to the grid and other service providers as needed in order to address the growing concern from the consumers for greater privacy and security.

In addition there is the need to maintain system-wide security and integrity. This means that the above security principles and techniques must be applied in such a way that if the security of a single ESI interaction is compromised, it does not affect the security of other ESI interactions.

NISTIR 7628 provides more guidance on cyber security[9].

Scalability and Performance

The ESI needs to be designed to scale in three dimensions. It must scale across different types of customers. For example, a residential ESI should not be forced to have the same complexity as an industrial ESI. It also needs to scale across a single customer. A facility may have one or more ESIs and a customer may have one or more facilities. Finally, the ESI must scale across multiple customers. A single ESP may interface to hundreds of thousands of separate ESIs.

An ESI is a component in a large-scale, fast-responding energy system with wide geographical distribution. Business and economic requirements that emanate from business cases are often tied to the ability of service providers to reach large numbers of customers within rigid time constraints.

Scalability can be characterized in terms of the quantity of actors involved and the performance required in terms of data throughput (i.e., messages per second) and data delays or latency (i.e., milliseconds).
As a frame of reference, energy service provider systems can interact with upwards to 1,000,000 homes, 100,000 small C&I customers, 10,000 medium C&I customers and 1,000 large C&I customers. Customer systems in large industrial manufacturing plants often involve 100,000 data points from 1000s of embedded systems.
DR programs compiled from the FERC Demand Response Action Plan[10] (See Appendix 10.2) can be clustered according to relative load response time (inclusive of processing/communication overhead and equipment response):

- 2 Hour Programs
- 1 Hour Programs
- 30 Min Programs
- 10 Min Programs
- 5 Min Programs
- Real-time Programs (seconds)

These are general guidelines only. Specific program response requirements will vary based upon the needs of a specific balancing authority.

In order for an ESI to meet the needs of these diverse programs, it is important that the technology implemented can satisfy a broad range of application performance requirements. Technology that meets performance requirements in the context of relatively small numbers of actors may not meet performance requirements when a large number of actors are involved. It should also be noted that performance is asymmetrical: lower performance applications can be addressed using higher performance technology but higher performance programs cannot be addressed using lower performance technology.

Maintainability

To ensure the continuing evolution of the customer centric applications on the Smart Grid, the ESI needs to ensure maintainability. It should be understood that the ESI will evolve over time and methods should be included in the ESI to ensure deprecation and backwards compatibility.

6. ARCHITECTURAL CONSIDERATIONS

An ESI is a bi-directional, logical, abstract interface that can be integrated or realized in physical devices such as gateways, energy management systems and electric meters. It consists of two sides or faces, the grid face and the facility face. The grid face is exposed to energy service providers and the facility face is exposed to customer systems. (See Figure 2)

A customer ESI represents a logical demarcation point at a facility asset ownership or operations support boundary. An ESI may be owned and operated by either an energy services provider or customer. A clear demarcation encourages market development of competitive devices, equipment and appliances that facilitate demand response, energy efficiency and energy management.

The physical location of an ESI is of minimal importance. It can be on the customer network, on the Energy Service Provider (ESP) network, in the meter or may be located remotely from the facility. The number and structure of ESIs will vary as determined by services providers and consumers.

A typical ESI architecture (Figure 4) provides the interface between the customer domain and the markets and grid operations via a service provider node.

[9] http://www.smartgrid.gov/sites/default/files/pdfs/nistir_7628%20.pdf

[10] http://www.ferc.gov/legal/staff-reports/06-17-10-demand-response.pdf

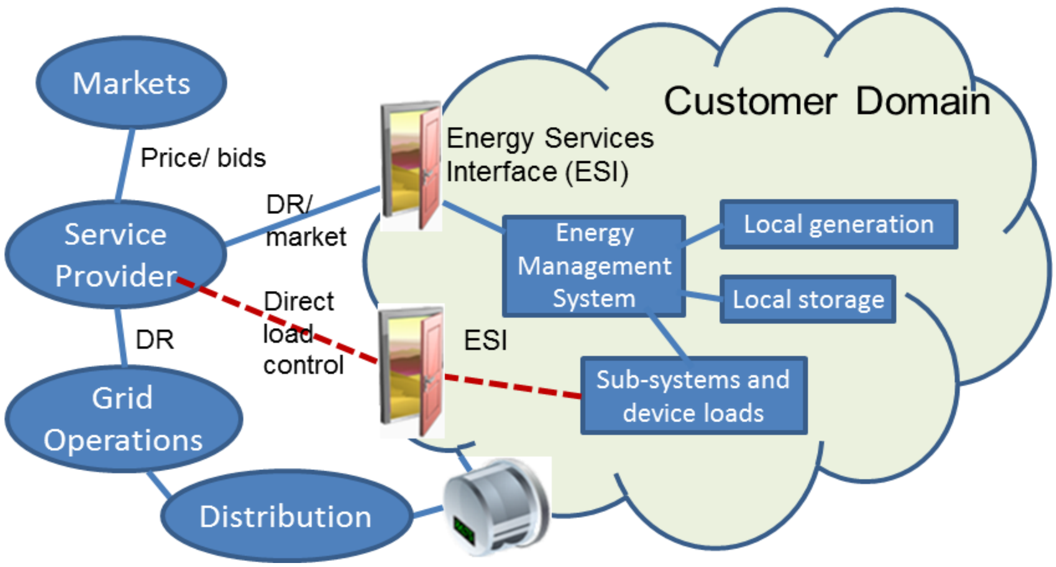

Figure 4 - Typical Energy Services Interface architecture (Source: David Holmberg, NIST)

An ESI should be open, flexible and extensible to allow for innovation and future evolutionary needs. This includes innovation in market structures and services and to adapt to future energy markets as they evolve.

The Abstract Interface

An ESI represents a services interface. It presents details pertaining to the facility side as a limited set of logical services (e.g., available storage resource) to the energy services side as well as presenting grid and market related business processes to the facility.

An interface defines what and how specific information is transferred through the interface but not how that information is processed and what functions and features are provided by systems that implement the interface. 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.

Abstraction refers to a representation with a similar meaning or semantic, while hiding away unnecessary details of implementation. Low-level abstractions expose more details while high-level abstractions expose logical business concepts with fewer details. The level of abstraction provided by an ESI will vary based on the business and application requirements. Abstraction captures important details about an object that are relevant to the current perspective.

As a boundary between the customer domain and external domains, abstraction plays an important role in shielding one side of the interface from changes that occur on the other. It provides a level-of-indirection that significantly improves system robustness and stability by minimizing the propagation of change through the interface.

It should be noted that the interface needs to be well-defined and stable for an ESI to be effective as changes to the interface will impact all dependent systems, on both sides of the interface.

Proper interface design requires that the abstraction level of the interface be as high level as possible but matched to, or balanced with, the required application functionality. If the interface provides insufficient functionality, techniques are 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.

Conformance to this important principle will help achieve the interoperability and reliability goals of the Smart Grid and to enable future innovations.

Direct Load Control

“Direct Load Control” (DLC) involves interrupting a customer load, typically residential air conditioning or hot water heaters, by direct control from the energy service provider system operator. This approach has worked to provide some guarantee of load shedding resource for utilities, but does not provide a good way for customer interaction and resulting customer satisfaction. If a facility energy management system is present, then outside DLC is not recommended, as discussed in Section 2. In all cases, it is beneficial to consider the proper level of abstraction for the particular application.

As an example, the use of a BACnet command to turn a device on or off might be considered direct control but it also represents a level of abstraction. BACnet represents the on/off switch as an abstract Binary Input (BI) object with a defined Write Property interface with priorities. (Note: Using priorities permits a DLC request to be lower in priority than a life-safety request.) A controller uses this interface to command a BI object to turn off, but it is an abstract interface that can serve any device or system on a BACnet network. The BACnet interface thus prevents the exposure of internal device or system details while providing granular information and control functions. The same balanced coupling approach using abstract interfaces is utilized in OPC Foundation's Unified Architecture for industrial automation.

The issue surrounding the appropriateness of direct load control is fundamentally about identifying and operating at the right level of abstraction. For example, a commercial chiller is a complex system. It has a controller that understands all the operational parameters for safety and efficiency. That controller takes requests from a higher level HVAC system controller for more or less cooling, but there is a level of abstraction already implied since the HVAC system controller doesn't control the chiller directly, it assumes the chiller controller will efficiently and safely control the chiller to meet the request. Above this there is an energy management system over the larger commercial facility, and it might request power reduction of the HVAC system, but it does this through yet another level of abstraction, perhaps calling for a setpoint temperature increase. One might describe the chiller as a subsystem within the HVAC system which in turn is a subsystem of the larger facility domain. If we consider a separate ESP requesting load reductions from the facility, we need to add yet another layer of abstraction. This is important for safety and efficiency while satisfying operational needs.

7. STANDARDS

Standards exist (or are under development) to serve different domains of the Smart Grid. Some standards are intended specifically to support communications between Smart Grid conceptual model domains. In this section we will look at the most relevant standards at the information model level or communication protocol level that touch the customer ESI. This includes standards that primarily serve the ESI grid face and those that primarily serve within the facility, touching the ESI facility face.

Standards that are relevant to the ESI are shown in Figure 5. These will be discussed, along with their relationships with each other, followed by some recommendations and observations about where further collaboration might be required to address interoperability.

Standards Touching the Grid Face

- OASIS Energy Interoperations[11] defines information exchanges and services for coordination of energy supply, transport, and use, including demand response and energy market interactions.
- WS-Calendar[12] provides a standard for schedule communications cross-cutting the Smart Grid.
- Energy Market Information Exchange (EMIX)[13] provides a price information standard and common product descriptions for products from wholesale, retail, and other markets.
- OpenADR 2.0 specification, a subset of OASIS Energy Interoperations, includes demand response interactions for commercial and industrial facilities and price communications.
- NAESB Energy Usage Information Model[14] (EUIM) defines the standard for representing energy meter data.
- NAESB Energy Services Provider Interface [15](ESPI) defines the communication protocol used by service providers to access meter data from utilities and other energy service providers. The EUIM and ESPI are the basis for the Green Button and Green Button Connect initiatives.[16]

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[11] http://www.oasis-open.org/committees/tc_home.php?wg_abbrev=energyinterop

[12] http://www.oasis-open.org/committees/tc_home.php?wg_abbrev=ws-calendar

[13] http://www.oasis-open.org/committees/tc_home.php?wg_abbrev=emix

[14] http://www.naesb.org/pdf4/naesb_energy_usage_information_model.pdf

[15] http://www.naesb.org/pdf4/update052511w7.docx

[16] http://www.greenbuttondata.org/

- Weather Information Exchange Model (WXXM), is the standard weather data information model for communicating weather information.
- International Electrotechnical Commission (IEC) Common Information Model (CIM) family of standards (IEC 61968, 61970) defines the information models that are used within energy service provider's enterprise information and data systems. It focuses primarily on information communicated for operation of the traditional grid.
- ISO/IEC 15067-3, Model of a demand response energy management system covering the demand response applications of an ESI for residential applications. This model includes: direct load control, dynamic prices and distributed load control using an energy management agent. The automated or direct load control demand response type is designed to capture the potential from air conditioning cycling programs, direct control programmable thermostat programs, and automated DR (for large C&I only).
- ANSI/CEA 2045 Modular Communications Interface[17] defines a direct local serial communication connection between a communication module and a smart appliance. It supports the pass-through of industry standard application protocols (such as OpenADR 2.0), as well as defining a basic DR application layer.

Standards Touching the Facility Face

- ASHRAE/NEMA 201P Facility Smart Grid Information Model (FSGIM)[18] defines a standard information model for the internal facility within the customer domain. This standard allows for simple mapping of information elements between facility domain information protocols.
- Facility domain protocols such as BACnet[19], SEP 1.0/2.0[20], LONtalk[21], ISA-100[22], Modbus, OPC Classic and Unified Architecture[23] and others. (See appendix 10.8, 10.9, 10.10) These are building and industrial industry-standard protocols that are used within data acquisition and control systems to sense, gather, store, analyze, display and control internal facility processes.
- ISO/IEC 15045-1, 15045-2 Home Energy System gateway architecture impacting the facility specifies the ESI for residential applications. This standard accommodates multiple interconnected gateways in the house.
- ISO/IEC 18012-1, 18012-2, Guidelines for product interoperability related to home energy systems that impact the facility.
- The Society of Automotive Engineers (SAE) International is developing numerous standards for DC charging (J2836/2™ & J2847/2 – harmonizing with ISO/IEC 15118 & IEC 61851-24), wireless charging (J2836/6, J2847/6, J2931/6) as well as customer systems to PEV communications (J2836/5, J2847/5).

Relationships among Standards

As a system-of-systems, information flows between domains and within domains as shown in Figure 5. Each domain typically has a set of standards that are used for interoperability within that domain.

As domains interact with each other, new standards for information transfer are often needed to satisfy new use cases and requirements at the inter-domain touch points.

An important consideration concerning inter-domain communication is the ability to semantically align the information so that the meaning and context of the information is understandable and mappable between systems that reside in different domains. This mapping should be as efficient as possible, relying on minimal external information in order to maximize data integrity. The most resource and cost efficient mapping is one that is algorithmic and does not require external information.

[17] http://standards.ce.org/apps/group_public/project/details.php?project_id=61

[18] http://spc201.ashraepcs.org/standards.html

[19] http://www.bacnet.org/

[20] http://www.zigbee.org/Standards/ZigBeeSmartEnergy/Overview.aspx

[21] http://www.echelon.com/products/lonworks_control_networking.htm

[22] http://www.isa.org//MSTemplate.cfm?MicrositeID=1134&CommitteeID=6891

[23] http://www.opcfoundation.org/Default.aspx/01_about/UA.asp?MID=AboutOPC

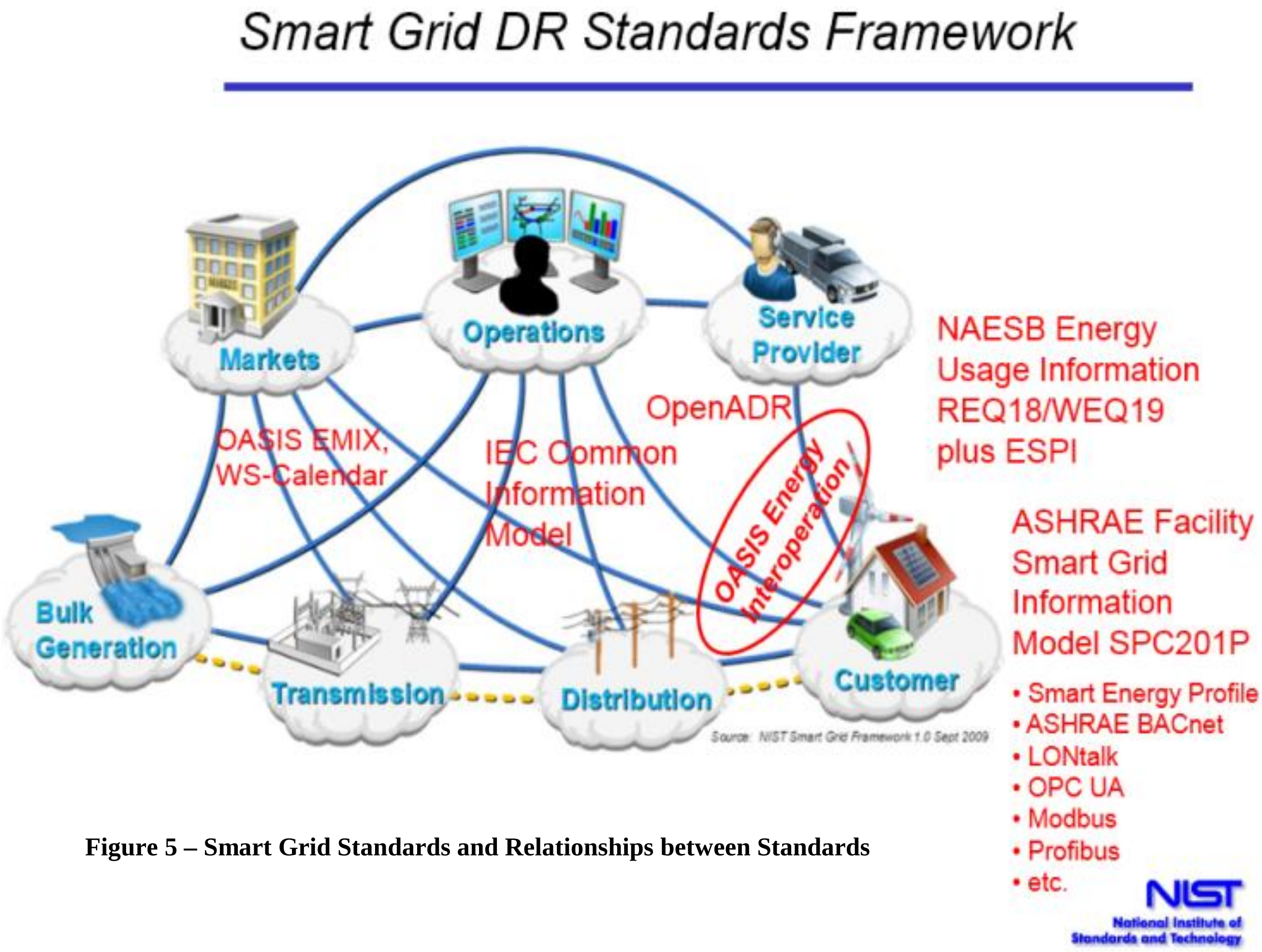

Figure 5 – Smart Grid Standards and Relationships between Standards

Examples

- IEC Common Information Model (CIM) is an important information model that was used, in part, in SEP (Smart Energy Profile) and Energy Interoperation. SEP made the effort to align as much as possible with the CIM. OASIS Energy Interoperations uses the CIM for information links to the grid side for power and energy.
- OASIS Energy Interoperations uses OASIS EMIX and OASIS WS-calendar for market and schedule information models.
- OpenADR 2.0 is a subset or profile of OASIS Energy Interoperation which includes the specification of full, secure, interoperable communications stacks.
- SEP 2.0 and OpenADR2.0 can be used as a suite to provide customers with information related to pricing, energy usage, demand response and other functions. This requires that information exposed by these standards be semantically-aligned and mappable and that systems that reside within a facility be capable of interacting with either or both of these standards. As an example, PEV standards such as SAE J2847/1 (“Communication between Plug-in Vehicles and the Utility Grid”) are designed to interface with SEP.
- SEP 1.0/2.0 within a meter integrates with an AMI network for external backhaul communications. AMI networks are often limited by low-bandwidth communications resulting in constraints being placed on the information available and functions performed by SEP.
- ASHRAE/NEMA 201P incorporates parts of many information models, including the IEC CIM, OASIS Energy Interoperation, EMIX, WS-Calendar, WXXM, and pieces from ASHRAE BACnet and IEC 61850.

8. RECOMMENDATIONS

The following recommendations have been identified and should be considered:

A. Further definition of ESI requirements is needed for the diverse set of complex customer environments.
   - Recommendation: Create a new SGIP SGAC WG to investigate requirements.

B. The IEC is actively working on standards that impact ESI functionally.
   - Recommendation: Coordinate with the IEC on the alignment of information models and communication standards that impact the ESI.

C. The SGIP PAP17 ASHRAE/NEMA 201P Facility Smart Grid Information Model provides a: 1) standard view of loads and load aggregation, 2) standard view of generation and storage and 3) standard representation of schedule intervals, sub-meter data, power quality data, etc. Evaluate the alignment between 201P and internal facility communication protocols such as SEP, BACnet, OPC-UA, etc.
   - Recommendation: Review the ability of a facility standard to expose the 201P data model as part of the SGIP Catalog of Standards review process.

D. The integration of PEV's and charging stations into energy management and demand response programs will require charger connectivity to a diverse set of systems.
   - Recommendation: Coordinate industry stakeholders to ensure that PEVs and charging systems adopt interoperability standards that enable integration with customer and service provider systems.

E. ESI services will need to meet a range of security, performance, latency and scalability requirements. These requirements will dictate the use of transport protocols that cover a range of performance, latency, security and system scalability characteristics. It is required that this transport diversity be incorporated into the ESI design.
   - Recommendation: Create a new SGIP WG to investigate requirements.

F. Tariff rate structures are developed by over 3000 utilities based upon local needs and requirements. Communicating and interpreting a wide variety of tariff rate structures reduces interoperability.
   - Recommendation: Create a new SGIP PAP to investigate requirements and recommend standards development.

9. ACKNOWLEDGEMENTS

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10. APPENDICES

10.1 FERC DEMAND RESPONSE PROGRAMS

FERC (Federal Energy Regulatory Commission) has defined fourteen (14) demand response (DR) program categories in the FERC DR Assessment and Action Plan Summary[24].

- Incentive-based DR Programs
    - Direct Load Control: A demand response activity by which the program sponsor remotely shuts down or cycles a customer's electrical equipment (e.g. air conditioner, water heater) on short notice. Direct load control programs are primarily offered to residential or small commercial customers. Also known as direct control load management.
    - Interruptible Load: Electric consumption subject to curtailment or interruption under tariffs or contracts that provide a rate discount or bill credit for agreeing to reduce load during system contingencies. In some instances, the demand reduction may be effected by action of the System Operator (remote tripping) after notice to the customer in accordance with contractual provisions.
    - Critical Peak Pricing with Load Control: Demand-side management that combines direct load control with a pre-specified high price for use during designated critical peak periods, triggered by system contingencies or high wholesale market prices.
    - Load as a Capacity Resource: Demand-side resources that commit to make pre-specified load reductions when system contingencies arise.
    - Spinning/Responsive Reserves: Demand-side resource that is synchronized and ready to provide solutions for energy supply and demand imbalance within the first few minutes of an Emergency Event.
    - Non-Spinning Reserves: Demand-side resource that may not be immediately available, but may provide solutions for energy supply and demand imbalance after a delay of ten minutes or more.
    - Emergency Demand Response: A demand response program that provides incentive payments to customers for load reductions achieved during an Emergency Demand Response Event. An emergence demand response event is an abnormal system condition (for example, a system constraint or a local capacity constraint) that requires automatic or immediate manual action to prevent or limit the failure of transmission facilities or generation supply that could adversely affect the reliability of the Bulk Electric System.
    - Regulation Service: A type of Demand Response service in which a Demand Resource increases and decreases load in response to real-time signals from the system operator. Demand Resources providing Regulation Service are subject to dispatch continuously during a commitment period. This service is usually responsive to Automatic Generation Control (AGC) to provide normal regulating margin. Also, known as regulation or regulating reserves, up-regulation and down-regulation.
    - Demand Bidding & Buy-Back: A program which allows a demand resource in retail and wholesale markets to offer load reductions at a price, or to identify how much load it is willing to curtail at a specific price.

- Time-Based Programs
    - Time-of-Use: A rate where usage unit prices vary by time period, and where the time periods are typically longer than one hour within a 24-hour day. Time-of-use rates reflect the average cost of generating and delivering power during those time periods.
    - Critical Peak Pricing: Rate and/or price structure designed to encourage reduced consumption during periods of high wholesale market prices or system contingencies by imposing a pre-specified high rate or price for a limited number of days or hours.
    - Real Time Pricing: Rate and price structure in which the retail price for electricity typically fluctuates hourly or more often, to reflect changes in the wholesale price of electricity on either a dayahead or hour-ahead basis.
    - Peak Time Rebate: Peak time rebates allow customers to earn a rebate by reducing energy use from a baseline during a specified number of hours on critical peak days. Like Critical Peak Pricing, the number of critical peak days is usually capped for a calendar year and is linked to conditions such as system reliability concerns or very high supply prices.
    - System Peak Response Transmission Tariff: The terms, conditions, and rates and/or prices for customers with interval meters who reduce load

[24] http://www.ferc.gov/legal/staff-reports/06-17-10-demand-response.pdf

during peaks as a way of reducing transmission charges.

10.2 WHOLESALE/RETAIL DEMAND RESPONSE PROGRAMS BY TIME DOMAIN

The following listing contains the DR programs compiled from the FERC Action Plan and clustered according to time domain.

Notes:

FCM: forward capacity market
LMP: locational marginal price
MWh: megawatt-hour
RTDRP: real-time demand response program
RTPR: real-time price response

- **2 Hour Programs**
  - Emergency Demand Response Program Energy Reliability 2 hours
  - Installed Capacity Special Case Resources (Energy Component) Energy Reliability 2 hours
  - Installed Capacity Special Case Resources (Capacity Component) Capacity Reliability 2 hours
  - Emergency Demand Response Program Energy Reliability 2 hours
  - Installed Capacity Special Case Resources (Energy Component) Energy Reliability 2 hours
  - Installed Capacity Special Case Resources (Capacity Component) Capacity Reliability 2 hours

- **1 Hour Programs**
  - Participating Load Program Energy Market bid (energy price > offer price) 1 hour
  - Emergency Load Response — Energy Only Energy Reliability 1 hour or 2 hours (participant-selected)
  - Full Emergency Load Response (Capacity Component) Capacity Reliability 1 hour or 2 hours (participant-selected)
  - Full Emergency Load Response (Energy Component) Energy Reliability 1 hour or 2 hours (participant-selected)
  - Emergency Load Response — Energy Only Energy Reliability 1 hour or 2 hours (participant-selected)
  - Full Emergency Load Response (Capacity Component) Capacity Reliability 1 hour or 2 hours (participant-selected)
  - Full Emergency Load Response (Energy Component) Energy Reliability 1 hour or 2 hours (participant-selected)

- **30 Min Programs**
  - Loads Acting as a Resource Providing Non-Spinning Reserve Service Reserve Reliability 30 Minutes
  - Demand Response Reserves Pilot Reserve Reliability 30 minutes
  - Real Time Demand Response Resource Capacity Reliability 30 minutes
  - Economic Load Response Reserve Reliability (day-ahead notice) 30 minutes
  - Economic Load Response Reserve Reliability (day-ahead notice) 30 minutes

- **10 Min Programs**
  - Participating Load Program Reserve Market bid (capacity bid and separate energy bid > offerprice) 10 minutes
  - Emergency Interruptible Load Service Capacity Reliability 10 minutes
  - Real Time Demand Response Program (Capacity Component) Capacity Reliability 10 minutes/30 minutes
  - Real Time Demand Response Program (Energy Component)Energy Reliability 10 minutes/30 minutes
  - Demand Response Resource Type I Reserve Market bid (energy price > offer price) 10 minutes
  - Demand Response Resource Type II Reserve Market bid (energy price > offer price) 10 minutes
  - Demand Side Ancillary Services Program Reserve Market bid (energy price > offer price) (security-constrained economic dispatch) (10 minute ramp) 10 minutes
  - Demand Side Ancillary Services Program Reserve Market bid (energy price > offer price) (security-constrained economic dispatch) (10 minute/30 minute ramp) 10 minutes/30 minutes
  - Economic Load Response Reserve Reliability (one hour notice) 10 minutes
  - Economic Load Response Reserve Reliability (one hour notice) 10 minutes

- **5 Min Programs**
  - Demand Response Resource Type I Energy Market bid (energy price > offer price) 5 minutes
  - Demand Response Resource Type II Energy Market bid (energy price > offer price) 5 minutes
  - Variable Dispatch Demand Response Energy Market bid (energy price > offer price) (security-constrained economic dispatch) 5 minutes
  - Variable Dispatch Demand Response Energy Market bid (energy price > offer price) (security-constrained economic dispatch) 5 minutes

- **Realtime Programs**
  - Controllable Load Resources - Providing Regulation Service Regulation Reliability Effectively Instantaneous
  - Loads Acting as a Resource - Providing Responsive Reserve Service — Under Frequency Relay Type Reserve Reliability (automatic relay) 0.5 seconds (automatic relay) or 10 minutes (phone)
  - Loads Acting as a Resource - Providing Responsive Reserve Service — Controllable Load Resource Type Reserve Reliability Continuous, similar to governor action by a generator; and 10-minute response for remaining obligation to electronic instruction
  - Day-Ahead Load Response Program for RTDRP Energy Market bid (dayahead LMP = or > offer price) Effectively instantaneous
  - Day-Ahead Load Response Program for RTPR Energy Market bid (dayahead LMP = or > offer price) Effectively Instantaneous
  - Real Time Price Response Program Energy Market bid (dayahead or forecast real-time LMP = or > $100/MWh) Effectively instantaneous
  - FCM: On-Peak, Seasonal Peak Resources Capacity Reliability Effectively instantaneous
  - Real Time Emergency Generation Resource Capacity Reliability Effectively instantaneous
  - Demand Response Resource Type II Regulation Market bid (energy price > offer price) Effectively Instantaneous
  - Demand Side Ancillary Services Program Regulation Market bid (energy price > offer price) (security-constrained economic dispatch) Effectively instantaneous
  - Economic Load Response Regulation Reliability Effectively instantaneous
  - Demand Side Ancillary Services Program Regulation Market bid (energy price > offer price) (security-constrained economic dispatch) Effectively instantaneous
  - Economic Load Response Regulation Reliability Effectively instantaneous

- **Not Classified**
  - Emergency Demand Response Energy Reliability Resource-specific (biddable parameter)
  - Load Modifying Resource Capacity Reliability
  - Day-Ahead Demand Response Program Energy Market bid (energy price > offer price) (security-constrained unit commitment)
  - Economic Load Response Energy Market bid (self-scheduled, cleared day-ahead bid, or real-time dispatch) Resource-specific
  - Economic Load Response Energy Market bid (self-scheduled, cleared day-ahead bid, or real-time dispatch) Resource-specific

10.3 INDUSTRIAL NETWORKS

Industrial networks are typically organized in a layered hierarchy as shown in Appendix Figure 1.

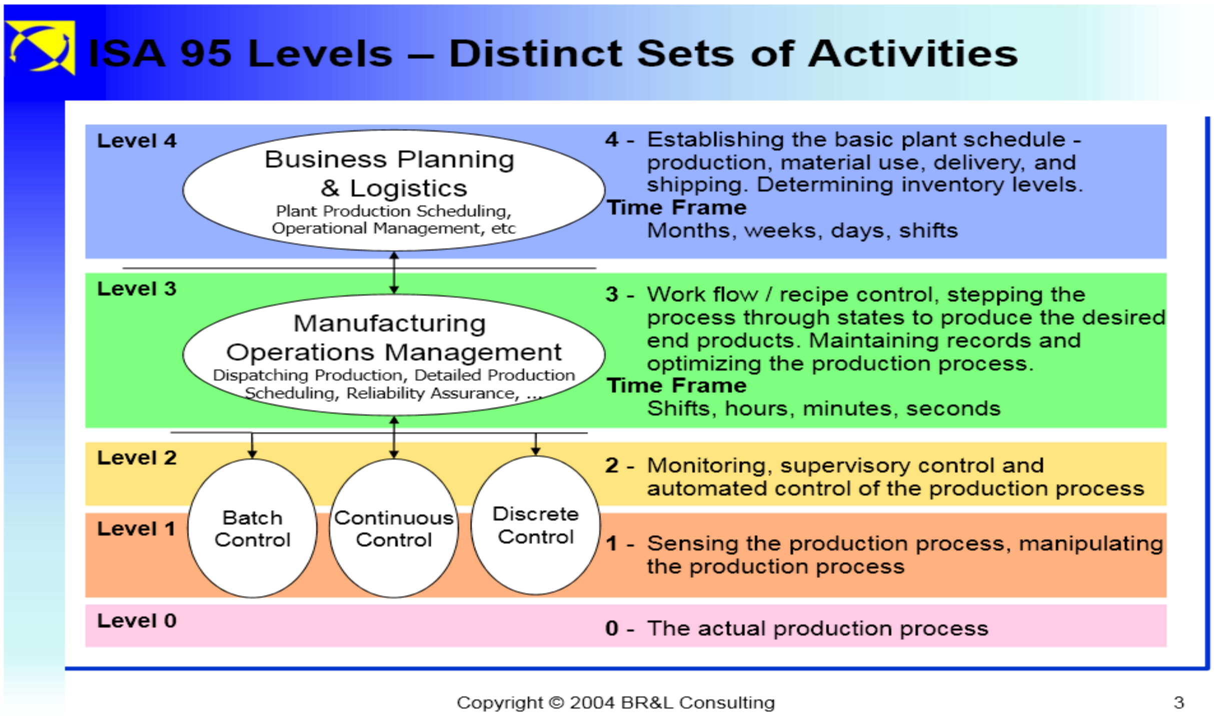
Dynamic pricing negotiations can best be processed at the Business Planning (BP) or Operations Management (OM) levels so that production can be scheduled based on the best tradeoff between electricity rates and delivery schedules. The block pricing information would be received via an ESI and incorporated into the production plans that are subsequently send to the industrial processes.

HMI (Human Machine Interface) systems would allow operators to monitor and approve direct load control requests. This makes it possible for factory owners to participate in load control schemes when they are not willing to let the utility control their equipment directly. This also provides flexibility since an operator or software may be able to choose which equipment to shutdown depending on the current state of their operations.

Metering systems are often installed by the utility for revenue metering and are capable of communicating directly to the energy service provider. Industrial users also need this information to optimize their processes and to monitor and track their energy usage. As a result, there is a benefit to letting the information flow through the industrial user's network.

The HVAC systems are usually on their own network, however, an industrial user will want to integrate control of these systems into their industrial networks since their ability to turn off air conditioning or ventilation may depend on the current state of their operations.

Industrial processes are complex and will have sub-components that can run at reduced or no power depending on the state of the system. These components can be adjusted as part of a demand response event, dynamic pricing-based production schedule or via a direct load control event.



Appendix Figure 1 - Typical Industrial Network

10.4 INFORMATION EXCHANGE PATTERNS

The following message exchange concepts are important when evaluating different exchange patterns:

1. Cardinality
   - One to One: Messages are sent from one application to one other application.
   - One to Many: Messages are sent from one application to many applications. This is also referred to multicasting.
   - Many to One: Messages are sent from many applications to one application.
   - Many to Many: Messages are sent from many applications to many other applications.
2. Networking Structure
   - Server-to-Server: Messages sent horizontally between shared servers.
   - Peer-to-Server: Messages sent vertically between dedicated devices and shared servers.
   - Peer-to-Peer: Messages sent horizontally between dedicated devices.
3. State Management
   - Stateful Message Exchange: Client state is maintained on the server.
   - Stateless Message Exchange: Client state is not maintained in the server but is transferred with the message during an exchange.
4. PUSH/PULL
   - PUSH: An application sends data to another application (or vice versa) based on a pre-arranged agreement. This is a very time and resource-efficient and scalable pattern.
   - PULL: An application sends data to another application (or vice versa) based on a specific request. This pattern is also called polling and is not recommended for time and resource- efficient communications.
5. Session Management
   - Session: Messages are related to each other within a session. Related to state management.
   - Session-less: Messages are independent of each other.
6. Streaming
   - Buffered: Entire message is sent as a unit before processing.
   - Stream: Message is a stream of data which is processed as it is delivered. Improves scalability, especially when large messages are exchanged frequently.

7. Quality of Service
   - Guaranteed delivery
   - Delivery Notification/Acknowledgement
   - Failure and fault detection

8. Synchronous Communication Patterns

Synchronous patterns imply that messages are sent based on a shared understanding of time.

- Half-duplex Request-Response: (PULL) The client application sends a request to a server. The client then waits for and receives a response message. If the response message does not arrive, the client times out. In short, a message is sent, and a reply is received. The pattern consists of request-response pairs. Examples of request-response calls are remote procedure calls (RPC), transactions and browser GET requests. This pattern is also known as half-duplex. Not recommended for high-speed continuous data exchange.
- Full duplex Request-Response: (PUSH/PULL) The client sends an arbitrary number of messages to a server that is received in any order. This is like a phone conversation, where each word being spoken is a message. Both sides can send and receive. Responses may be optional. This pattern has both synchronous and asynchronous characteristics.

9. Asynchronous Communication Patterns

Asynchronous patterns imply that messages are sent at arbitrary times. These patterns are recommended where efficient data exchange is required as they minimize the transfer of redundant information. The actual performance of these patterns is directly related to the underlying messaging protocols used to transfer the data. These patterns are used for data distribution and event messaging.

- Publish Subscribe: (PUSH) The client dynamically subscribes to specific data (called a topic) from a server and receives the latest data available. The client then receives new data when it changes.
  - Queuing: (PUSH) A form of publish-subscribe where the client subscribes to a first-in first-out (FIFO) queue and then receives updates as they become available.
- Point-to-Point: (PUSH) The client is pre-configured to receive data from a server based on endpoint. Can be unidirectional or bidirectional.
- Multicast: (PUSH) A set of clients is pre-configured to receive unidirectional data from a server based on endpoint.

10.5 RESIDENTIAL SCENARIOS

Background

In order to match supply and demand at all times, and over different time scales, power system operators provide what are referred to as “ancillary services” by maintaining so called “balancing reserves” . These reserves are necessary, but wasteful and expensive components of the current electrical grid needed to maintain real-time matching of supply and demand. It is well-known that the need for balancing reserves increases as the penetration of renewable sources of power, solar & wind, increases given their intermittent nature.

There are different kinds of balancing reserves differentiated based on the events and associated time scales for which they are required to be invoked. Contingency reserves are typically maintained to balance supply and demand in response to catastrophic events. System operators bring contingency reserves on-line to manage sudden, unexpected failures of generators and/or transmission lines. Generally, contingency reserves include: spinning reserves, non-synchronized reserves, and replacement reserves. Spinning reserves are typically provided by generators supplying base-load power. The generators are operated below their rated capacity, and then ramped up when called upon to deliver spinning reserves. The larger the spinning reserve requirement, the greater capital and operational investment and the greater the emissions these facilities produce. When called on, generators must supply spinning reserves within 10 minutes, and historically, it has been observed across various markets that spinning reserves need be deployed for up to 10 minutes or so.

Dynamic load management enabled by smart appliances may impact this spinning reserve requirement. Smart appliances capable of interacting with the grid are particularly well suited as sources of 10-minute spinning reserves when their operation can be interrupted for short periods (up to 10 minutes) without causing any diminution of the quality of service for consumers. Furthermore, smart appliance operation can often be curtailed almost instantaneously as opposed to generators that must ramp up and down subject to operating constraints in order to avoid equipment damage. Finally, given the potentially large number of grid enabled smart appliances, their aggregate response could be extremely reliable when called upon to provide spinning reserves.

Thus, smart appliances could obviate the need for maintaining some fossil-fuel based generation for providing spinning reserves thereby reducing operating costs and also lowering emissions. But in order to enable smart appliance to respond when called upon, appropriate, standardized control signals must be communicated across the ESI.

Definition of Smart Appliances

As per AHAM[25], residential smart appliances (that include clothes washers/dryers, refrigerators/freezers, dish washers), are defined[26] as follows:

> **The term "smart appliance"** means a product that uses electricity for its main power source which has the capability to receive, interpret and act on a signal received from a utility, third party energy service provider or home energy management device, and automatically adjust its operation depending on both the signal's contents and settings from the consumer.
>
> These signals must include (but are not limited to) appliance delay load, time-based pricing and notifications for load-shedding to meet spinning reserve requirements. Any appliance operation settings or modes shall be easy for an average, non-technical consumer to activate or implement.
>
> **The term "delay load capability"** refers to the capability of an appliance to respond to a signal that demands a response intended to meet peak load deferral requirements, but which also could be used to respond to a sudden maintenance issue at another time of day.
>
> **The term "spinning reserve capability"** means the capability of an appliance to respond to a signal that demands a response intended to temporarily reduce load by a short-term, specified amount, usually 10 minutes.

AHAM further goes on to list appliance-specific responses that characterize **"delay load capability"** and **"spinning reserve capability".**

Residential Scenarios

Peak-Load Shifting & Spinning Reserves

When an electric utility company or third-party energy service provider needs to curtail demand, an appropriate control signal need to be sent across the ESI to smart appliances at a customer's home, and the appliances, automated based on customer's preferences, then react based on the signals contents as follows

1. Override the signal and continue operation
2. Load shifting: Halt operation and resume at a later time (say when another appropriate signal is received)
3. Spinning reserves:
    a. Temporarily (up to 10 minutes) halt operation completely

Continue operation but temporarily 'shed load' (for example, a dryer operating with 2 heating elements ON might continue operation with only one heating element ON).

The information passed to a smart appliance across the ESI in order to trigger either a load shift or spinning reserves dispatch, could be either purely pricing information or could involve specific grid-control signals (SGIP PAPs 3, 4, 9). This needs to be studies further.

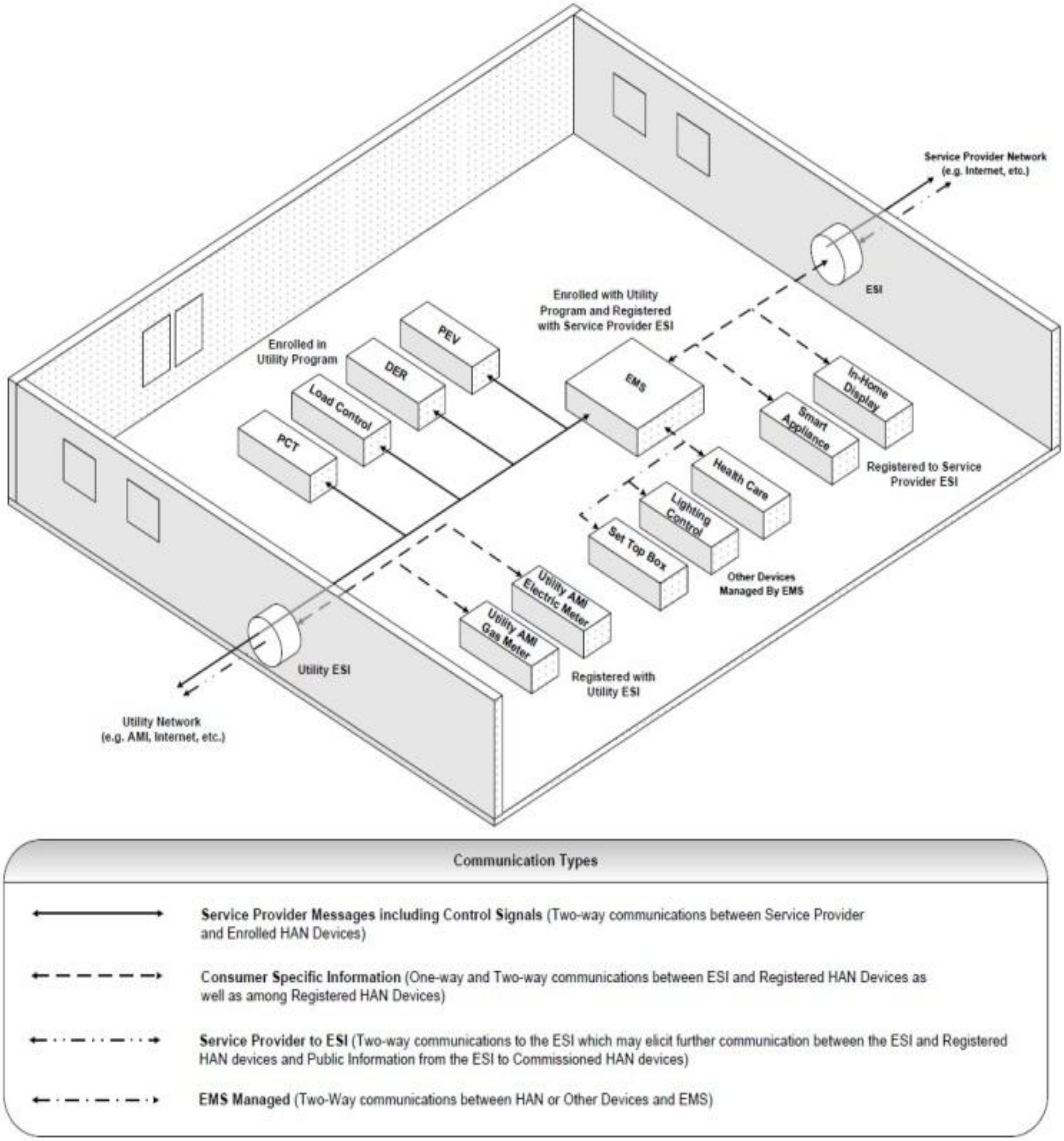
Smart Appliances Optimize Energy Use Based on Broadcast of Real Time Wholesale Prices[27]

In this use case, a regional transmission organization (RTO) (or alternatively an Electric Distribution Utility (EDU)) would broadcast price signals reflecting its current real-time energy market interval price, plus components reflecting relevant prices in the RTO's, other markets, and an indicator of likely future prices. These signals would be broadcast for each pricing interval using a ubiquitous broadcast medium. Smart appliances and devices would receive the signals through the ESI and treat them as a proxy for control signals. Each smart appliance or device would then optimize its energy usage over the current and forward pricing intervals consistent with any preset consumer preferences and device specific constraints. Additionally, the RTO (or alternatively the utility) would have the option to incorporate the anticipated price response in its demand forecasts and system operations.

[25] Association of Home Appliance Manufacturers

[26] http://www.aham.org/ht/a/GetDocumentAction/i/51594

[27] From Ohio PUC Paul Centollela and SGIP BnP Appliance Integration Workgroup Discussion



Appendix Figure 2 – Distributed Load Control Using an ESI
OpenHAN SRS v2.0 Facilities Physical Architecture

Appliances and other responding devices will have a capability to recognize and authenticate appropriate price signals.

Given that this use case does not involve an RTO (or utility) payment for the performance of the responding appliance or device, this use case does not require the development of a usage baseline or tracking of device participation. The impact of responses by smart devices will be reflected in changes in feeder and system load profiles and reductions in overall system costs and prices.

Frequency Regulation

Residential smart appliances that have a certain amount of thermal inertia such as water heaters can be equipped with smart controls that would be capable of quickly changing their charge rate and charge level, factoring in renewable generation and other critical needs of the grid; thereby significantly reducing carbon emissions and bringing a new dimension of conservation and efficiency to the electric grid[28]. What this means is that water heater controls can be programmed to respond to what are referred to as automatic generation control (AGC) signals received across the ESI from a system operator to provide up/down frequency regulation to correct for short-term imbalances in power grid frequency due to mismatch between supply and demand. Water heater charge rate is reduced (up regulation) or increased (down regulation) for a certain length of time depending on the contents of the AGC signal. But the charge rate and charge levels are varied only to the extent that hot water temperatures are maintained at a certain set point set by consumers. Given the aggregate load shape of water heaters, it has been shown that indeed it is possible to make available water heaters in aggregate to alleviate short-term frequency imbalances in the power grid, and at the same time compensate customers.

Architecture

In either case, the overall system effect of the load curtailment may be seen to offset the need for a portion of the spinning reserve requirements of the system operator. The ESI, in either direct communication with the system operator, or in coordination with a third party energy services provider, provides the interface through which the appropriate load curtailment information is communicated. Appendix Figure 2 shows a demand response implementation for distributed load control based on ISO/IEC 15067-3. This architecture accommodates distributed energy resources (DER). A local controller called the Energy Management Agent uses price and event data combined with appliance capabilities, user budget limitations, and use preferences to allocate power and to manage appliance functionality, subject to override by the user. Appendix Figure 2, as referenced from the UCIAug OpenHAN SRS v2.0, presents a depiction of a physical architecture through which such control may be achieved.

10.6 COMMERCIAL SCENARIOS

Background

Commercial buildings vary in function (office, retail, institutional, hospital, etc.) as well as size of peak load and shape of load. The loads are mainly driven by heating, ventilation, air conditioning (HVAC) and lighting systems. Majority of large buildings, over 50,000 ft^2 or over 200 kW of peak load, are equipped with energy management control systems (EMCS) and some with lighting controls. These systems are used to automate operations and typically have data logging capabilities for all the sensors that are used in the operation sequences. A small portion of these buildings have energy information systems (EIS) capabilities. Sometimes EIS are separate systems and most of the times EMCSs deliver energy information functionality by adding data analysis and visualization capabilities in their control platforms[29].

Small commercial buildings, less than 200 kW, usually do not have sophisticated EMCSs. Lighting controls are usually manual and HVAC operations are typically controlled through thermostats in zones[30].
The information required for the ESI can be captured from EMCSs or EISs in large buildings and individual devices or gateways in small commercial buildings. This requires enhancements, such as additional analytics and communication capabilities, to the current capabilities of these systems.
Commercial buildings can shift, limit or shed loads (and also increase loads) depending on the requirements of their DR participation[31]. They can participate in day-ahead, day-of and fast (ancillary services) DR. In this section, scenarios describing DR participation for each timescale are presented. The scenarios are based on reliability programs or ancillary services which are programs where being able

[28] Grid-Interactive Renewable Water Heating, Steffes Corporation: http://www.steffes.com/LiteratureRetrieve.aspx?ID=72241

[29] http://eis.lbl.gov/pubs/lbnl-2224e.pdf

[30] http://drrc.lbl.gov/sites/drrc.lbl.gov/files/lbnl-2195e.pdf

[31] http://drrc.lbl.gov/sites/drrc.lbl.gov/files/59975_0.pdf

to predict demand response is a key requirement. Also, all of the scenarios assume that there is a combination of load, generation and storage available behind the meter.

Commercial Scenarios

Day Ahead Demand Response
Scenario Description: Commercial building is notified one day ahead that the next day at certain hours there will be a DR event. Facility EMCS evaluates the next day's weather forecast and next day's schedule by accessing the facility's event calendar, DR strategies appropriate for the given timescale and duration, and develops a DR estimate (or pseudo generation) (based on past participation) about each system in the building (on-site generation, storage or load) and delivers 5 min. to 1 hr. forecasts of load (defined by the DR contract) and DR for the next day during preset DR event hours.

Information Exchange Mapping: From the grid, the building receives DR event information (including but not limited to start time, end time, DR program info, etc.). To the grid, the building provides load, generation and storage forecasts, as well as forecast of DR (or pseudo generation). Real-time meter data is required to provide operational feedback for event monitoring and control. For settlement purposes, the grid can take revenue meter data any time after the period ends.

Day of Demand Response
Scenario Description: Commercial building is notified anywhere between 2 hours to 30 minutes ahead of a DR event. The notification includes the start and end times and/or the duration of the event. Facility EMCS evaluates the next several hours' weather forecast and schedule by accessing the facility's event calendar, DR strategies appropriate for the given timescale and duration, and develops a DR estimate (or pseudo generation) (based on past participation) about each system in the building (on-site generation, storage or load) and delivers 5 min. to 1 hr. forecasts of load (defined by the DR contract) and DR for the same day during DR Event hours.

Information Exchange Mapping: From the grid, the building receives DR event information (including but not limited to start time, end time, DR program info, etc.). To the grid, the building provides load, generation and storage forecasts, as well as forecast of DR (or pseudo generation). Real-time meter data is required to provide operational feedback for event monitoring and control. For settlement purposes, the grid can take revenue meter data any time after the period ends.

Ancillary Services (Non-Spinning Reserves)
Scenario Description: Commercial building develops forecast of loads, DR (pseudo generation) and ramp time during the period of time the building plans to participate in the wholesale market and bids it into the market two days ahead. A day before the trading day, wholesale market accepts or rejects the bid. If rejected, a rejection notification is sent to the building. If accepted, an acceptance notification is sent to the building. An award notification is sent to the building when this resource is required and the building starts to participate at that point in time. The building knows the bid and the conditions with all the systems behind the meter and regulates its DR to match its bid. A real-time meter data collection capability to maintain the bid level is required. During the award period, building maintains the forecasted bid levels until the award period ends.

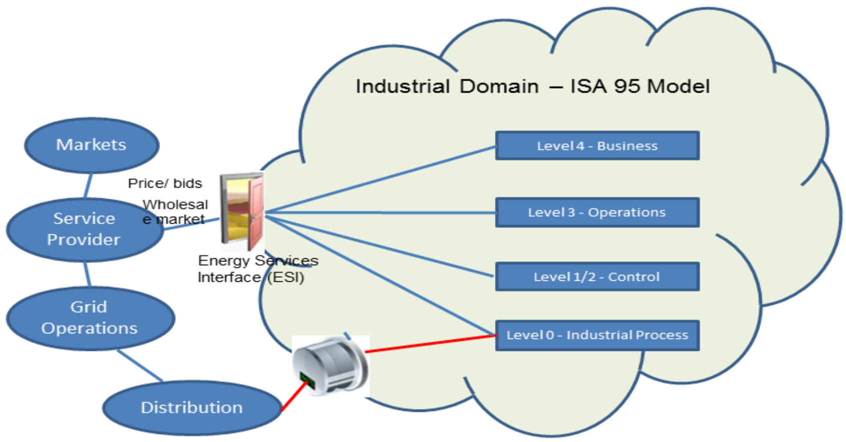
Information Exchange Mapping: From the grid, the building receives acceptance or rejection of the bids (daily). If accepted, it receives award information that triggers the DR implementation. To the grid, the building provides a bid which is forecast of DR (or pseudo generation) and actual load data. Real-time meter data is required to provide operational feedback for event monitoring and control. For settlement purposes, the grid can take revenue meter data any time after the period ends.

Ancillary Services (Regulation)
Scenario Description: Commercial building develops high operating limit (HOL), low operating limit (LOL) and ramp time during the period of time the building plans to participate in the wholesale market. This can be dynamically calculated and delivered to the wholesale market. During the time of the day when the DR resource makes itself available, the AGC system modulates the DR resource between HOL and LOL.

Information Exchange Mapping: From the Grid, the building receives instructions between HOL and LOL. To the Grid, the building provides HOL, LOL and ramp rate as well as forecast of DR (or pseudo generation), source of the pseudo generation (load, storage, generation) and actual load data. Real-time meter data is required for the facility to maintain instruction levels or flag if the instruction level cannot be met. For settlement purposes, the grid can take revenue meter data any time after the award period ends.

10.7 INDUSTRIAL SCENARIOS

Background
Industrial facilities range in diversity from small manufacturing shops to large, geographically distributed industrial complexes that contain many integrated and



Appendix Figure 3 – ESI and ISA 95

coordinated industrial operations. These facilities manufacture products or produce services that rely upon the availability of quality electrical power to generate revenue. Operational costs associated with electrical energy are combined with other resource costs to determine operating profit margins.

Industrial facilities are driven by profitability. Production metrics and meeting production schedules are of highest priority. Demand response strategies which involve shedding load, shifting load, rescheduling batch processes, shutting down continuous processes, pausing in-process operations or stopping production lines are all viewed as potentially interrupting revenue generation. Clear economic justification using an operational impact analysis is required as these perturbations can be potentially very costly and have unintended side-affects.

The internal structure of industrial facilities has been modeled by the ISA (International Society of Automation) in the ISA 95 standards based on the Purdue Enterprise Reference Architecture[32]. This model identifies 4 distinct levels within which industrial activities occur.[33] It is important to note that these activities cover industrial activities from high-level business processes down to low-level field instrumentation. Some business processes may be automated while others may be manual. This model provides a framework within which to describe and understand industrial ESI interactions.

Some important characteristics of industrials and their impact on an ESI include:

1. Most include buildings such as warehouses, offices, etc. These buildings would typically use commercial building automation technology for lighting and HVAC control. These processes are typically separate from industrial operations but need to be integrated into the facility DR strategies. This implies that several ESIs may be required and that some may be dedicated to building automation while others may be focused on industrial operations. (Note: The OASIS information model supports this hierarchical approach.)
   - Facility Protocols of Importance: BACnet, SEP, LONtalk, ISA-100, Modbus, Ethernet/IP
2. Some industrial processes are flexible and can be safely and economically interrupted on short notice. These processes could be incorporated into real-time DR strategies that respond to operational or emergency conditions on the grid. The ESI would normally interface at the automation level 1 or 2.
   - Facility Protocols of Importance: ISA-100, Modbus, Classic OPC, Ethernet/IP, OPC Unified Architecture
3. Some industrial processes can be safely and economically interrupted during certain operational phases. These resources could respond to economic or operational demand response but probably not to emergency demand response. This implies that the

[32] Williams, "Purdue Enterprise Reference Architecture", 1992, ISBN 1-55617-265-6

[33] Used with permission from Dennis Brandl, BR&L Consulting

ESI needs to interact with level 3 operations management systems.
   - Customer Protocols of Importance: Classic OPC, OPC Unified Architecture
4. Some processes cannot be safely or economically interrupted during certain operational phases, but they could be rescheduled if the financial gain was high enough and sufficient notice was provided so that operations could be re-planned and re-scheduled. This implies that the ESI needs to interact with high-level operations and business systems for integrated decision making at level 3 or 4. This includes the case where management decides to move some production to off-peak times well in advance based on day ahead or week ahead price forecasts.
   - Customer Protocols of Importance: Classic OPC, OPC Unified Architecture, IBM MSMQ, SAP Connectors
5. Some processes must run continuously and cannot be disturbed. These processes will normally run during a grid demand response event. They will not participate in economic DR unless the electrical energy consumption is very high or if the price forecast becomes unfavorable for more than a relatively short period of time. Under these conditions, managers may decide to shut down even critical processes. This could be termed extra-slow economic DR.
6. Due to the importance of electrical power and its impact on operations, many industrials have implemented industrial micro-grids that provide on-site power generation in the form of co-generation or combined heat and power (CHP). Co-gen refers to the production and use of both heat and power. This increases energy efficiency and decouples on-site operations from grid events. As a result of on-site co-generation, many facilities have the capability to sell power back to grid under favorable economic conditions. The use of on-site distributed generation and the development of self-contained microgrids are expected to increase. The ESI needs to accommodate customers as net power exporters to the grid.

7. Many industrial facilities will participate in energy efficiency programs that help identify areas where energy can be better utilized or optimized. These programs may be provided remotely by the same service providers that interface through the ESI. The ESI design should take this into account either directly, indirectly through the use of appropriate extensions or through the exposure of additional external interfaces.

Industrial Scenarios

10-min Ancillary Reserves Market

Scenario Description

The facility interfaces with the markets through its service provider and bids DR load reduction into the 10-min reserves ancillary market of the local independent system operator/regional transmission organization (ISO/RTO). These contingency reserves provide fast ramping of demand resources in the event of a generator or line trip. The facility interfaces directly to the industrial automation system in order to execute fast-ramp down of several large loads that can be interrupted without affecting the production line. The service provider receives the dispatch event and cascades the event to all participating industrial sites. In some cases, there will be fewer participants localized within a constrained region but in other cases, there will be large numbers of participants spread over a large region. The ESI at each site must receive the signal in a timely fashion to maximize its ability to reduce load in the short time window required. The ESI monitors the event and feeds back real-time event performance to the service provider. The service provider in turn summarizes and feeds back to the ISO/RTO concerning overall reserve capacity provided.

Use Cases

Emergency DR
Renewable Load Following

Application Issues

1. What general use case(s) is this expanding?
   - Operational demand response
2. Actors and interactions
   - ISO/RTO – interacts with the service provider
   - Service Provider – interacts with the ISO/RTOs and C&I customers
   - C&I customers – interacts with the service provider and on-site automation systems
3. Security, and other cross-cutting concerns (e.g., latency concerns, QoS, etc) specific to this implementation
   - Security – Due to the importance of the energy involved, all transactions need to have access control, data privacy, tamper-proofing and audit support through adequate logging and tracking.
   - Latency – The delivery of events and monitoring of curtailed energy by the ISO/RTO must be performed at a sufficiently high frequency to ensure compliance with the capacity contract.
   - QoS – Reliable communications is required for all transactions. High

performance exception-based data streaming is required for event performance monitoring and feedback.

4. Standards in use
   - Numerous
5. Discussion of unique elements of this implementation that impacts the architecture or function of the ESI
   - The ESIs are required to interface with a diverse set of customers and service providers yet provide the same information back to the Service Provider.
   - The information flows are relatively straight forward but the quantity of messages and timing requirements present challenges. . The data monitoring during emergency DR events does require low-latency, high-resolution data telemetry.
   - The ESI must reliably and efficiently interact with the service provider and with on-site devices. This implies that it must provide an efficient mapping of information and data between the service provider and the on-site devices with as little reliance upon external data sources and systems as possible. High availability options such as fail-over redundancy need to be incorporated into the design.
   - The service provider needs to interact with a range of participants with potentially several ESIs per participant. The ESI needs to be able to accommodate the worse-case scenario in terms of providing events and feedback to the largest number participants within the shortest amount of time. Timing requirements for events and data will become tighter over time as technology and costs permit.

Industrial Microgrid Management (IMM)

Scenario Description

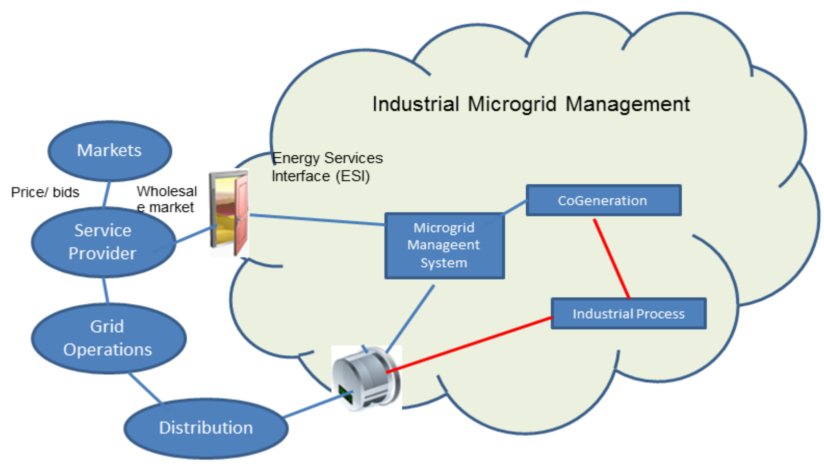
The IMM monitors, balances and optimizes on-site cogeneration (Combined Heat and Power) unit consisting of several mid-sized steam turbines (75mw). Spare capacity was designed in to allow for scheduled outages and unscheduled down-time. When fully operational, excess capacity is available for export to the grid. Under some operating conditions, it is economically viable to import power from the grid. The IMM monitors the wholesale price of electricity and bids its extra capacity into the day-ahead wholesale capacity market. IMM integrates with the business planning and scheduling system to extract operational plans along with power and steam requirements. If sufficient excess power capacity exists and contingency plans are acceptable, then bids are placed. Once accepted, the IMM receives the dispatch event and monitors the generation export. Event notifications and reports are produced and delivered to all involved parties.

Use Cases

Power Export

Application Issues

1. What general use case(s) is this expanding?
   - Large industrial Power Export
2. Actors and interactions
   - ISO/RTO – interacts with service providers
   - Service Providers – interacts with ISO/RTOs, power plant and process operations
   - Power Plant Unit Operations –interacts with service providers, directly responsible for generation export
   - Process Operations – interacts with power plant operations
   - Business Planning and Scheduling – interacts with service providers and operations
3. Cross-cutting concerns (e.g., security, latency concerns, QoS, etc) specific to this implementation
   - Security – Due to the large amount of energy involved, all transactions need to have access control, data privacy, tamper-proofing and remediation support through adequate logging and tracking.
   - Latency – The monitoring of exported energy by the ISO/RTO must be performed at a high frequency to ensure compliance with the capacity contract.
   - QoS – Reliable communications is required for all transactions. High performance exception-based data streaming is required for generation export performance monitoring and feedback.



Appendix Figure 4 – ESI and a MicroGrid

4. Standards in use
   - Numerous
5. Discussion of unique elements of this implementation that impacts the architecture or function of the ESI:
   - The ESIs are required to interface with a diverse set of customers and yet provide the same information back to the service provider.
   - The information flows are relatively complex but the quantity of messages is small and timing requirements for the transactions is loose. Data monitoring during generation export does require low-latency, high-resolution data telemetry. This can most cost-effectively be provided through the ESI rather than through a proprietary and expensive SCADA system.
   - The ESI must reliably and efficiently interact with the service provider and with on-site devices due to the critical nature of this application. This implies that the ESI must provide an efficient mapping of information and data between the service provider and the on-site devices with as little reliance upon external data sources and systems as possible. High availability options such as fail-over redundancy need to be incorporated into the design.

10.8 PARTIAL LIST OF INDUSTRIAL AUTOMATION PROTOCOLS

- OPC Classic – OPC Foundation
- OPC Unified Architecture – OPC Foundation
- DF-1
- FOUNDATION fieldbus
- Profibus - by PROFIBUS International.
- PROFINET IO
- CC-Link Industrial Networks - Supported by the CLPA
- CIP (Common Industrial Protocol) - Can be treated as application layer common to DeviceNet, CompoNet, ControlNet and EtherNet/IP
- Controller Area Network utilised in many network implementations, including CANopen and DeviceNet
- ControlNet - an implementation of CIP, originally by Allen-Bradley
- DeviceNet - an implementation of CIP, originally by Allen-Bradley
- DirectNet - Koyo / Automation Direct proprietary, yet documented PLC interface
- EtherNet/IP - IP stands for "Industrial Protocol". An implementation of CIP, originally created by Rockwell Automation
- Ethernet Powerlink - an open protocol managed by the Ethernet POWERLINK Standardization Group (EPSG).
- EtherCAT

- Interbus, Phoenix Contact's protocol for communication over serial links, now part of PROFINET IO
- HART Protocol
- Modbus RTU or ASCII
- Modbus-NET - Modbus for Networks
- Modbus/TCP
- Modbus Plus
- Modbus PEMEX
- EGD (Ethernet Global Data) - GE Fanuc PLCs (see also SRTP)
- FINS, Omron's protocol for communication over several networks, including ethernet.
- Host Link, Omron's protocol for communication over serial links.
- MECHATROLINK - open protocol originally developed by Yaskawa.
- MelsecNet/10, supported by Mitsubishi Electric.
- Optomux - Serial (RS-422/485) network protocol originally developed by Opto 22 in 1982. The protocol was openly documented and over time used for industrial automation applications.
- SERCOS interface, Open Protocol for hard real-time control of motion and I/O
- SERCOS III, Ethernet-based version of SERCOS real-time interface standard
- GE SRTP - GE Fanuc PLCs
- Sinec H1 - Siemens
- SynqNet - Danaher
- TTEthernet - TTTech
- PieP - An Open Fieldbus Protocol
- BSAP - Bristol Standard Asynchronous Protocol, developed by Bristol Babcock Inc.

10.9 PARTIAL LIST OF BUILDING AUTOMATION PROTOCOLS

- 1-Wire - from Dallas/Maxim
- BACnet - for building automation, designed by committee ASHRAE
- C-Bus
- CC-LINK, supported by Mitsubishi Electric
- DALI
- DSI
- Dynet
- Idranet - from Idratek
- Konnex (KNX) - previously AHB/EIB
- LonTalk - protocol for LonWorks technology by Echelon Corporation
- Modbus RTU or ASCII
- Modbus/TCP
- oBIX
- xAP - Open protocol
- ZigBee - Open protocol

10.10 PARTIAL LIST OF RESIDENTIAL AUTOMATION PROTOCOLS

- X10
- Insteon
- Z-Wave
- Zigbee