Customer Energy Services Interface White Paper

SmartGrid 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 (ref. NIST Conceptual Model[1]). Within these domains, an ESI performs a variety of functions. The purpose of this paper is to focus on the ESI at the customer boundary and provide a perspective that will aid in developing a common understanding and definition of the ESI through a review of use case scenarios, requirements and functional characteristics.

Note: Appendices available at: http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/B2GEnergyServicesInterface

The goals of this white paper include:

- Providing context and guidance to stakeholders
- Enhancing interoperability between energy service providers and energy customers
- Generating further discussion among residential, commercial, industrial and other stakeholders
- Providing input to the Smart Grid Interoperability Panel (SGIP) working groups, including the standing committees
- Highlighting gaps in standards which should be addressed by the National Institute of Standards and Technology (NIST) and the SGIP
- Understanding the different levels of abstraction for cross-domain interactions
- Examining the standards that exist or are under development that touch the ESI
- Examining the information and use cases for communications across the ESI

1. OVERVIEW

A primary business requirement driving an Energy Services Interface (ESI) 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 abstraction layer between energy services providers (ESP) and energy customers. The foundation frameworks for achieving system-to-system interoperability are the GridWise Interoperability Context-Setting Framework (aka GWAC Stack)[2] and NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0[3] and 2.0 Draft.

An ESI is a bi-directional logical interface that supports the secure communication of information between entities inside and entities outside of a customer boundary to facilitate various energy interactions between electrical loads, storage and generation within customer facilities and external entities. It comprises the devices and applications that provide secure interfaces between ESP and customers for the purpose of facilitating machine-to-machine communications. ESIs must meet the needs of today's grid interaction models (e.g. demand response, feed-in tariffs, renewable energy) as well as those of tomorrow (e.g. retail market transactions).

This is a general definition of an ESI as applied to the customer boundary and does not take into account the complexity that arises due to different customer business and usage models surrounding different types of assets and types of customer facilities. The problem is augmented by differences in complexity of energy management systems in these facilities. This white paper will explore how this diversity affects the definition of an ESI.

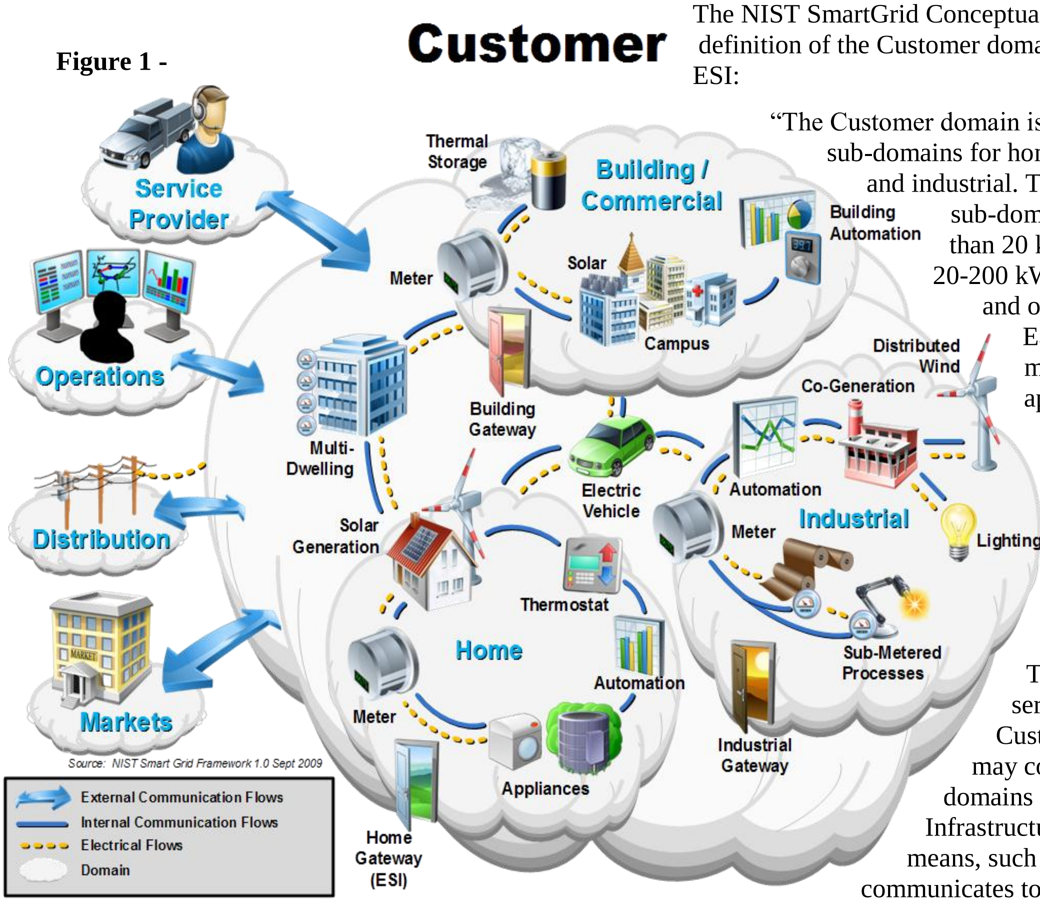
2. THE CUSTOMER

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

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

[3] http://www.nist.gov/public_affairs/releases/upload/smartgrid_interoperability_final.pdf

Figure 1 -



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

The NIST SmartGrid Conceptual Model [4]provides a definition of the Customer domain (see Figure 1) and the ESI:

"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 EMS or in an independent gateway.

The ESI is the primary service interface to the Customer subdomains. The ESI may communicate with other domains via the Advanced Metering Infrastructure (AMI) or via another means, such as the Internet. The ESI communicates to devices, applications and systems within the customer premises across a Home Area Network or other Local Area Network." Typical applications within the Customer domain are listed in Table 1.

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.
Micro-generation	Includes all types of distributed generation including; Solar, Wind, and Hydro generators. Generation harnesses energy for electricity at a customer location. May be monitored, dispatched, or controlled via communications.

The customer sub-domains range from small homes and commercial buildings up to large industrial facilities. Energy assets (i.e. loads, storage and generation) within these different subdomains can be classified by:

- **Electrical Capacity**
  Homes and small commercial and industrial (C&I) facilities are typically 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. However, C&I customers contain significantly more diverse loads than multi-tenant residences. Large C&I facilities typically have greater than 200KW of demand and contain a large number of specialized loads.

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

- **Operational Characteristics**
  Most homes and commercial facilities currently have appliances and other loads but few have generation capabilities. Most facilities have HVAC and 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 change 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 primary 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 is often 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, capacity, number and types of energy assets (loads, generation, 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 primarily driven by convenience due to limited economic drivers. This will evolve 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 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 affected by the capability of a customer's energy management systems and their ability to dynamically schedule and optimize the operation of 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 externally cycled (e.g., air conditioning), load shifted (refrigerator defrost) or used for thermal storage (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 (heating and cooling, lighting, thermal storage). At the high end of complexity are large commercial and industrial complexes.

  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 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 (ESP) have and will continue to implement demand response programs based on these scenarios. Protocols, such as ZigBee 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 point of view of the consumer and utility based on convenience to the customer and cost to the utility.

Many large commercial, institutional and industrial customers have integrated energy management systems. Large facilities are composed of complex interacting systems that must meet a wide range of business and safety priorities (sub-system performance, business objectives for process management, occupant comfort, energy cost management, demand response, etc.). They have sophisticated distributed control systems to manage this complexity and, in general, electrical loads cannot simply be turned off and on by an external entity that does not understand the facility complexity. Energy management involves not only electricity, but also gas, oil, chilled water, steam, air quality, and tradeoffs among these.

- **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 upon consuming 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 ESP.

- **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 dependence upon traditional ESPs, 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, ZE 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" we should build a system. It defines the system's estimated costs, tangible and intangible benefits along with the scope required to achieve the benefits.[5] Regardless of the actual business processes used to develop a business case, the closer estimated values are to actual values, the more successful the system. This can rarely be achieved without a clear scope definition of "what must be done."

How does the business case impact the architecture, security, performance and functional characteristics of an ESI? Defining a system's scope requires that a clear understanding of the business requirements, functional requirements, and quality requirements. These requirements form the basis for a system architecture. Business requirements are the "highest level goals and objectives of the system" (PMBOK 5th Edition).

Functional requirements derive from the 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 is 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.

Over time, new business cases will be developed as enabling policy and regulations are enacted, standards and innovative technologies are developed and existing technology becomes more cost effective. Examples of this include increased aggregated, microgrid and direct customer participation in retail and wholesale energy transactions.

[5] Project Management Institute, A Guide to the Project Management Body of Knowledge (PMBOK® Guide) - Fourth Edition

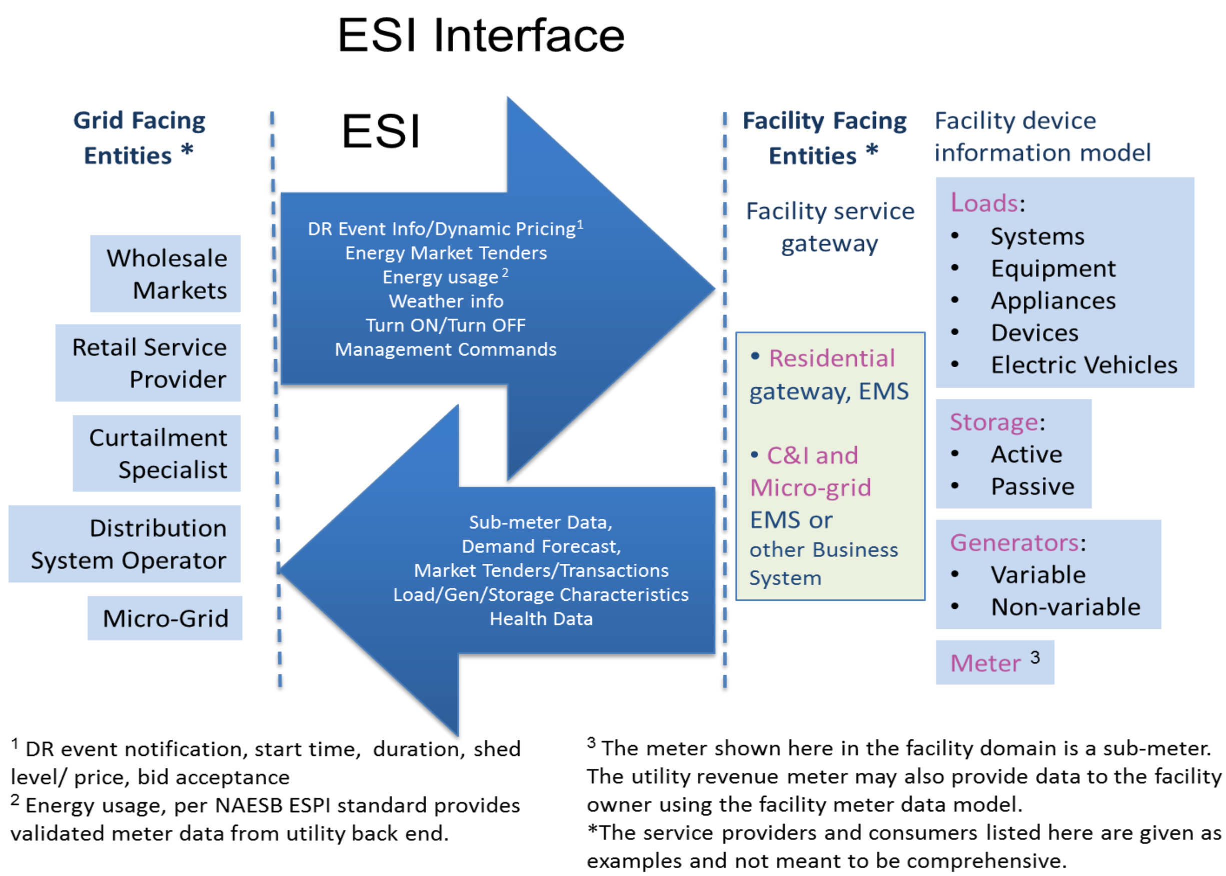


Figure 2 – Information Exchange between the Grid and Customers

As a baseline, the Federal Energy Regulatory Commission (FERC) has defined the following fourteen (14) demand response (DR) program categories in the FERC DR Assessment and Action Plan Summary[6]: 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. 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[7] provide a baseline 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 in Table 2.

Table 2 Energy Information Standards (EIS) Alliance Use Case Categories

• Demand response: shed and shift, to minimize cost and to meet contractual obligations.
• Energy management of complex facility with storage and generation: This expands the demand

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

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

response and transactive energy (dynamic pricing) use cases to include more detailed monitoring and planning energy use and production and storage to meet operational/production energy needs balanced against energy costs.
• Demand forecasts provided to the energy service provider so they know 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. And the energy manager can choose to buy external power or 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, monitoring of power quality, and validation against energy supplier energy usage data.
• Exchange of grid and distributed generation (DG) status--so the facility knows of coming grid outages for planning purposes, and so the utility knows status of DG
• Direct load control
• Monitoring of system health data by service providers. Allows for business models such as leasing of DG, Storage or load appliances and active management (i.e. proactive service) by the equipment/service provider

These use cases together may require certain supporting information to be communicated across the ESI. Information elements include: weather, power quality, pricing information, energy emissions, present demand of site, present demand of sub-loads, available shed-able load, critical loads, state change interval, existing demand thresholds, onsite generation capabilities and availability, onsite energy storage and availability, historical interval 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 serve as an important contribution to the development of the ASHRAE SPC201P[8] facility information modeling specification. 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, 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 demand response (DR) program may utilize a different interface than an event-based DR program.

Some example ESI use cases scenarios are provided below to give some insight into the information that would be communicated across an ESI. 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. Expanded scenario descriptions are included in the Appendices[9].

Renewable Balancing:

Balancing operations have traditionally relied upon the addition 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. To mitigate the intermittency of renewable generation on the electricity grid, demand side resource management is being considered. 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:

- Where does a resource originate within the facility?
- What are its capabilities and limitations?

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

[9] Appendices are online: http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/B2GEnergyServicesInterface

- What are its interactions with other resources on the demand side?
- 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:

In addition to traditional day-ahead DR, residential facilities can provide fast-acting appliances that are capable of participating in ancillary services. This scenario informs specific characteristics of the residential customer interface including:

- What are its capabilities and limitations?
- What are its interactions with other assets in the home? How much, how often, and how long could it be made available?

Large commercial building with multiple tenants participating in demand response:

Large office buildings (with and without multiple tenants) participating in aggregated DR programs. This use case illustrates multiple tenants using a multi-ESI hierarchical approach. 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 right, and shedding load (adjusting process scheduling) based on a real-time market contract. (Note: Large industrial facilities may represent energy sources that can impact both the reliability 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 utility who installs solar, wind, other distributed generation (DG) resources, storage equipment, a PEV (Plugin Electric Vehicles) or other appliances that act as a load. The resource is located behind the meter but the utility takes responsibility for the monitoring and operation and/or maintenance of the resource.

5. EXISTING ENERGY SERVICES INTERFACE DEFINITIONS

Definitions for an Energy Services Interface can be found in the following references (see Appendix: ESI Definitions):

- The NIST Roadmap and Framework 2.0 (Draft)[10]
- UCA-International's user group (UCAIug) Home Area Network (HAN) System Requirements Specification[11]
- Electric Power Research Institute (EPRI) Report to NIST (2009)[12]

The NIST Roadmap and Framework 2.0 provides the foundational definition of an Energy Services Interface. Some key points in this definition include:

- An ESI serves as an information management gateway through which the Customer domain interacts with a variety of energy service providers (ESPs).
- Basic functions of the ESI include demand response signaling as well as provisioning of customer energy usage information to residential energy management systems or in-home displays.
- The standards associated with an ESI need to be flexible and extensible to allow for innovation in market structures and services.
- An ESI is separate from the metering function.

The UCAIug HAN (Home Area Network) System Requirements Specification summarizes an ESI as:

- A special class of device that is network-centric and can be thought of as a gateway.
- The major function of the ESI is to enable secure interactions between home area network (HAN) devices and an energy services provider. In residential facilities, this concept is envisioned to permit applications such as direct load control, monitoring and control of distributed generation, providing energy information system functions and integrating with the building systems.

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[10] http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/IKBFramework

[11] http://osgug.ucaiug.org/sgsystems/openhan/default.aspx

[12] http://www.nist.gov/smartgrid/upload/Report_to_NIST_August10_2.pdf

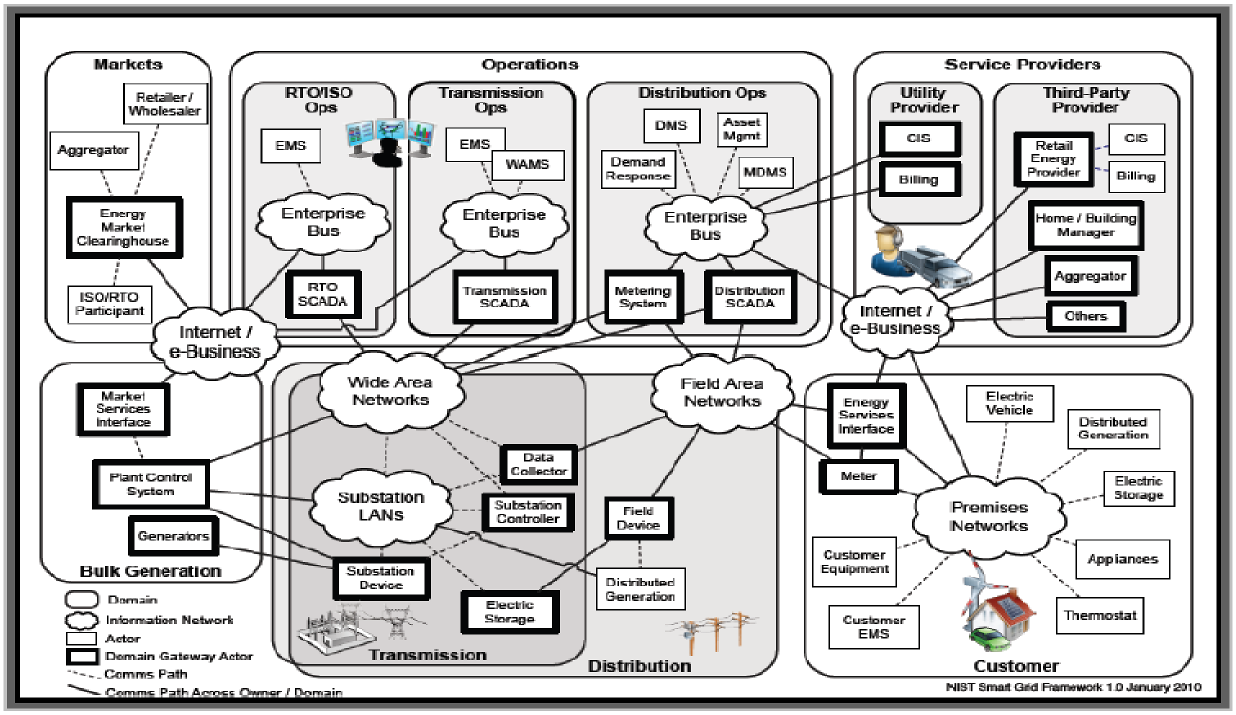

Figure 3 - Conceptual Reference Diagram for Smart Grid Networks (Source: NIST Framework, V2)

- A secure interface to a premises communications network (i.e. HAN) which facilitates relevant energy applications (e.g. remote load control, demand response, monitoring and control of DER (Distributed Energy Resources) , in-premises display of energy usage, reading of energy and non-energy meters, PEV (Plugin Electric Vehicles) charging and roaming coordination, and integration with energy management systems, etc.), provides auditing / logging functions that record transactions to and from HAN Devices, and, often coordination functions that enable secure transactions between the HAN Devices Commissioned and Registered on its network and Enrolled in a Service Provider program.

The EPRI Report to NIST summarizes an ESI as:

- A boundary of the Customer domain.
- Providing a secure interface for Utility-to-Consumer interactions.
- Acting as a bridge to facility-based systems such as a building automation system (BAS) or a customer’s energy management system (EMS).
- May reside in the meter or on the EMS or in an independent gateway.
- The primary service interface to the Customer domains.
- The ESI may communicate with other domains via the AMI infrastructure or via another means, such as the Internet.
- The ESI communicates to devices and systems within the customer premises across a Home Area Network or other Local Area Network.
- There may be more than one ESI—and therefore more than one communications path—per customer. The ESI is the entry point for such applications as remote load control, monitoring and control of distributed generation, in-home display of customer usage, reading of non-energy meters, and integration with building management systems and the enterprise.
- The ESI may provide auditing/logging for cyber security purposes.
- The ESI can receive pricing and other signals to influence and manage the operation of customer systems and devices, including appliances, DER, electric storage, and PEVs.
- Provides cyber security and, often, coordination functions that enable secure interactions between relevant Home Area Network Devices and the Utility.
- Permits applications such as remote load control, monitoring and control of distributed generation, in-home display of customer usage, reading of non-energy meters, and integration with building management systems.

- Can also act as a gateway.

These definitions share many common elements but they also bring to light differences based on customer sub-domain and a particular view or level-of-abstraction.

6. FUNCTIONAL CHARACTERISTICS

An application is an assembly of technologies that together meet a particular business need using an architectural approach that meets business, functional and quality requirements for that application. This infers that ESIs will need to satisfy a range of application requirements and therefore will have general characteristics as well as specific characteristics for applications such as event and economic demand response, energy efficiency, remote energy management and market-related business processes.

General

An ESI is a logical interface and can be integrated or realized in physical devices such as gateways, energy management systems and electric meters.

One or more ESIs are responsible for energy information exchange between the customer facility and one or more energy services providers.

An ESI represents a demarcation point between customer facility operations and energy services provider operations. For residential applications, a clear demarcation may encourage market development of competitive residential devices and appliances that facilitate demand response, energy efficiency and energy management programs.

An ESI 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.

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

An ESI interacts with a variety of energy service providers outside the customer facility domain. Therefore an ESI may process information that may be common and useful to one or many entities.

An ESI provides an information representation for energy that is being consumed, generated, and stored. (Ref. Section 5 above). This information is similar across residential, commercial and industrial customers and distinguished mainly by level of complexity.

An ESI provides energy pricing information for energy that is being consumed, generated, and stored.

An ESI provides customer billing information for energy that is being consumed, generated, and stored.

An ESI translates information originating from an energy service provider into the communication protocol or protocols used within the customer's facility. Facilities represent diverse environments consisting of many different protocols, applications and architectures. This requires mapping the syntax and semantics of the information across domain boundaries (Figure 3).

Facilities interact with energy service providers and market operations through one or more ESIs.

An ESI needs to be open, flexible and extensible to allow for innovation and future evolutionary needs.

An ESI may be owned by either an energy services provider or customer.

Operational, Emergency and Economic Demand Response

An ESI needs to meet the functional and quality requirements of securely interacting with grid operations as a component of a time-constrained, large-scale system of systems.

An ESI needs to enable Direct Load Control Demand Response.

Energy Efficiency and Remote Energy Management

An ESI needs to provide the information interactions and data flow that enables service providers to remotely analyze and manage energy assets within a customer's facility. This includes the capability to interface to building/home energy management systems for the purpose of detecting operational efficiencies.

Market-related Business Processes

An ESI needs to enable interactions with existing wholesale and retail energy markets.

An ESI needs to allow for innovation in market structures and services and to adapt to future energy markets as they evolve.

Safety Processes

An ESI needs to enable the monitoring of facility energy producing equipment that may affect the safety of grid maintenance personnel.

Energy Benchmarking
An ESI needs to enable the monitoring of facility energy characteristics to allow for energy benchmarking.

Environmental Monitoring
An ESI needs to enable the monitoring of facility emissions for benchmarking, market trading, or reporting purposes.

An ESI needs to enable the monitoring of grid emissions for facility reporting purposes.

7. QUALITY CHARACTERISTICS

Application quality characteristics include security, reliability, scalability and performance. 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 on 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 five areas of security that need to be addressed by ESI-enabled applications are: authentication, authorization, confidentiality, integrity and non-repudiation. 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. The digital techniques used to mitigate these security issues are:

- authentication: digital certificates (X.509), username/password pairs
- authorization: digital certificates(X.509), username/password pairs, usually handled internally by the application.
- confidentiality: message encryption using Transport Level Security (TLS) with digital certificates
- integrity: message signing using TLS with digital certificates
- non-repudiation: uses a combination of the above including message signing using digital signatures, time-stamps, and encryption
- minimizing attack surface area: by limiting the number of connections and minimizing or eliminating inbound connections to customer facilities

The use of X.509 digital certificates requires that the certificates themselves be managed securely and efficiently. As such, an application needs to enable the secure and efficient management of digital certificates.

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 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.
The NIST NISTIR 7628 provides more guidance on cyber security[13].

Scalability and Performance
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 and performance characterized in terms of throughput (such as messages per second) and delays/latency (such as seconds).

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

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/or 1000 large C&I customers. Customer systems in large C&I facilities often involve 100,000 data points from 1000s of systems.

DR programs compiled from the FERC Demand Response Action Plan[14] can be clustered according to relative time domain:

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

In support of these time-domains, Lawrence Berkeley National Laboratory has identified the following program categories ranging from slow to fast time response:

- Daily Energy Efficiency
- Daily Time of Use Energy
- Dynamic Peak Load Management
- Scheduled Demand Response
- Realtime Demand Response (Ancillary Services)
- Regulation (Ancillary Services)

In order for multi-program service provider applications 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 applications that consist of a relatively small number of actors may not meet performance requirements when a large number of actors are involved.

8. ARCHITECTURAL CONSIDERATIONS

The ESI serves primarily as an interface for cross-domain communications. Each domain of the smart grid has its own collection of data models that serve that domain along with a set of communication protocols implementing those data models to serve intra-domain applications. Whenever one domain intersects another, a larger domain is created and the disparate data models and communication protocols must be bridged or harmonized. Fundamentally, the information that must be communicated across different domains for a given application must be identified and an information mapping created from one domain to another.

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

A customer ESI is an interface that exchanges information between one or more devices within a customer premises and one or more devices that reside in external systems. It is not a physical device itself. An ESI can be implemented within one or more physical devices or systems such as a home or facility gateway, building automation system, energy management system or industrial automation system. The distinction between an interface and a device is important in order to reduce semantic confusion.

A customer ESI is a logical demarcation point at the facility boundary that may also represent an energy information or control ownership boundary. The physical location of an ESI is of minimal importance. It can be behind the meter in the customer premises, outside the meter on the Energy Service Provider (ESP) side or may be located remotely from the facility. There may be more than one ESI within a premises or facility, possibility connected in a hierarchical or mesh network. 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. Note that the ESI is not a meter, but an interface specification for communicating information between the facility and the outside world.

The smart grid is bringing together multiple domains and forcing them to talk to each other. There is nothing unique about bringing together different domains. Many logical and technical approaches exist for connecting different domains with different inherent information models and technical solutions. These approaches are based on different requirements and constraints. They range from simple firmware-driven gateways to enterprise SOA (Service Oriented Architecture) systems. Experience with these solutions has produced some guiding principles and best practices for addressing these types of interactions.

9. PRINCIPLES OF THE ABSTRACT INTERFACE

Abstraction refers to a representation with a similar meaning or semantic, while hiding away 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 details about an object that are relevant to the current perspective. Some ESIs will provide a high-level of abstraction while others will provide lower levels of abstraction.

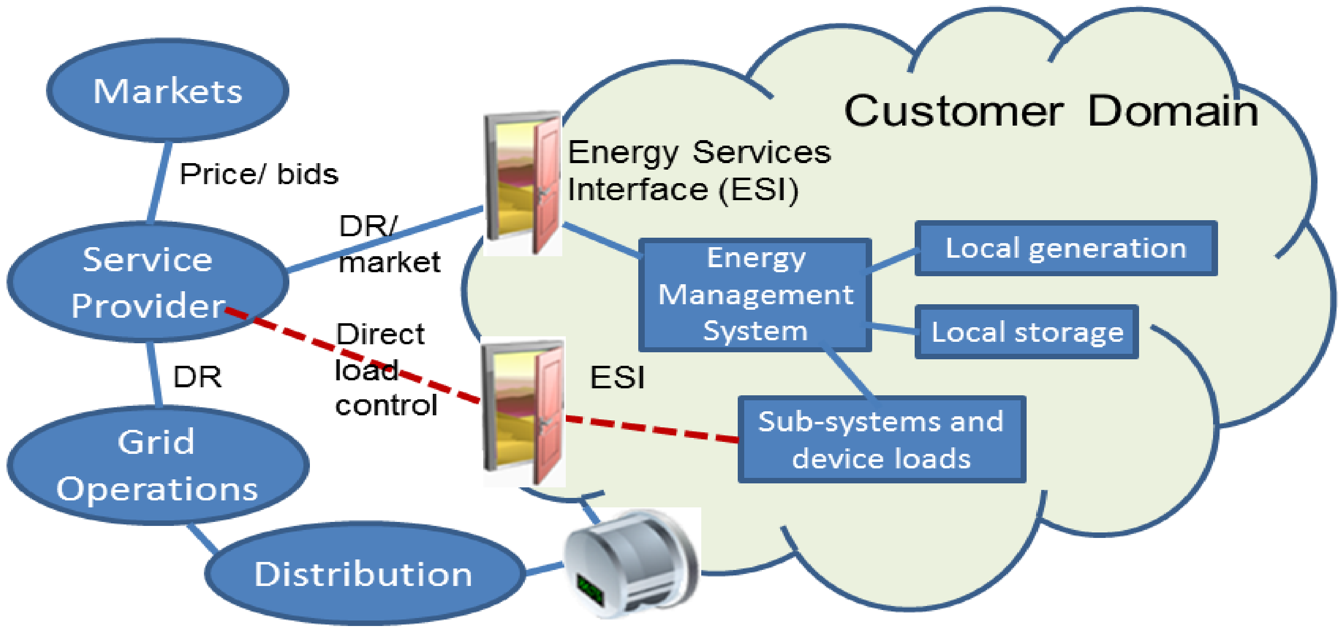

Figure 4 - Typical Energy Services Interface architecture

As a boundary between the customer domain and external domains, an important role of an ESI is to shield one side of the interface from changes that occur on the other. This requires that the interface provide an abstracted and logical view of the internal details on both sides of the interface. It should minimize exposure of internal details. This approach 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. Conformance to the following principles will help achieve the interoperability and reliability goals of the smart grid and to enable future innovations.

Balanced Coupling

Proper interface design requires that the abstraction level of the interface be 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.

Another issue relates to the hierarchical nesting of abstractions. Nesting abstractions can have a negative impact on system performance and must be balanced with application requirements.

Balanced Coupling and Direct Load Control

"Direct Load Control" (DLC) implies that internal customer details are not abstracted but exposed directly. When DLC is required, it is recommended that control operations be performed on a logical representation and not on a physical representation thus providing a layer of abstraction and indirection.

Balanced coupling implies the appropriate de-coupling for the application. Every application has an appropriate level of abstraction. As an example, the use of a BACnet command to turn a device on or off might be regarded as direct control but it also has an appropriate level of abstraction. BACnet represents the on/off switch as an abstract Binary Input (BI) object with a defined Write Property service with priorities. (Note: Using priorities permits a DLC request to be lower in priority than a life-safety request.) A controller uses this service 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 service 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 in its own right. 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, rather than touching knobs on the chiller. 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 smart grid domain requesting load reductions from the facility domain, we need to add yet another layer of abstraction. This is important for safety and efficiency while satisfying operational needs.

Separation of Concerns

Separation of concerns refers to the separation of functions both within an interface and between interfaces resulting in increased resilience and robustness to change. Within an interface, functions are layered with each layer providing services to the layer above and receiving services from the layer below. An example is a communication stack. Individual interfaces should be self-consistent and provide functionality independent of other interfaces. The separation of concerns helps ensure that versioning an interface has minimal impact on other interfaces thus promoting orderly change and evolutionary adaption to new requirements.

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.

Architectural Reuse

While the ESI offers new functionality to the Customer Domain of the smart grid, an interface between two system domains is not new. The ESI can and should learn from the development efforts of other interfaces. To reduce errors and decrease development, effort should be made to reuse industry standards whenever possible and attempt to extend them as needed to accommodate new ESI functionality.

Scalability

The ESI needs to be deigned to scale in three dimensions. The ESI must scale across the different customer segments in the customer domain. 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 thousands of separate ESIs.

Security and Confidentiality

To ensure the security and integrity of the smart grid, the ESI must participate in protecting it. The ESI needs to provide services for physical, network, application, and human security and confidentiality.

Interfaces and Innovation

Standardization, in general, is often viewed as an inhibitor to innovation. This occurs primarily when a "system" is standardized instead of an "interface" to a system. A "system" standard defines how a system is implemented including what functions and features it will support. This minimizes innovation in the market by reducing product differentiation. All systems are essentially the same and therefore commoditized.

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 products, systems and services that implement and use the information transferred to provide enhanced customer value through innovation.

Effective interface standardization further helps innovation by aiding market growth and encouraging market competition. An example taken from web technology is the standardization of "HTTP and HTML" for web browsing. They helped ignite market growth, resulting in strong and sustained competition between product implementations.

10. SYSTEM DESIGN CONSIDERATIONS

Network Topologies

The Customer domain is electrically connected to the Distribution domain and communicates with the Distribution, Operations, Market, and Service Provider domains."[15]

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

There may be more than one ESI and therefore more than one communications path, per customer. The ESI is the entry point for applications such as remote load control, monitoring and control of distributed generation, in-home display of customer usage, reading of non-energy meters, and integration with building management systems and enterprise systems. The ESI may provide auditing/logging for cyber security purposes.

Residential, commercial and industrial facilities with diverse behind-the-ESI technologies may use various methods for generating and receiving ESI signals. To enhance coordination and optimization among the systems, an ESI can be provided by one or more integrated systems. For smaller facilities, or more independent subsystems, the ESI functionality may be provided with each independent system or device. For larger facilities, the ESI functionality may be provided by each system separately or from the facility as a whole. As such, an ESI may be hosted by both integrated and isolated (or independent) systems (e.g., HVAC and lighting are good examples of integrated systems whereas an appliance would be an independent system).

Facilities may include multiple ESIs, potentially structured in a hierarchical arrangement, where one ESI acts as an aggregation (gateway) point to the other ESIs. An example of this might be a campus or a set of multi-tenant office buildings where an owner wants to distinguish sub-units and have internal ESIs as demarcation points for accounting purposes, but only one higher level ESI for external communications.

There are other ESI relationships and topologies that may provide equivalent (and possibly greater) functionality. Examples are peer to peer networks of ESIs that allow dynamic, contextually-based, associations of assets to ESPs based upon market processes/policies and lattices of ESIs that also provide support for contextually-driven associations of information within and outside of the facility.

An ESI topology for a facility need not be homogeneous; for example, several ESIs may form a hierarchy (possibly rooted in the facility EMS) whereas other ESIs may allow direct grid interactions for electric vehicles.

A given entity such as a single owner facility may have multiple systems communicating with different outside entities, using several distinct ESIs. For example, in a residential scenario, an ESI may be provided by the cable company, in addition to an ESI associated with the AMI (advanced metering infrastructure) meter.
Industrial networks are further discussed in Appendix: Industrial Networks.

ESI and the Utility-Owned Meter
A meter is a sensing device that has the following characteristics:

- The meter is under the control of the energy service provider.
- The meter's primary function is to provide an accurate measurement of electricity usage to the energy service provider.
- The meter is a device that has a very long life cycle.
- The meter is a cost sensitive device with limited resources that is installed at all customer facilities. This may limit a meter's capability and upgradability.

ESI's physically embedded within a meter share, and are constrained by, these characteristics.

Performance and Scalability
Which techniques lead to scalability, higher quality integration of customer energy assets and to achieving greater response from the customer assets?

Message exchange patterns represent widely used communication methods and structures that provide a range of capabilities for addressing different application requirements. (Ref. Appendix: Information Exchange Patterns)

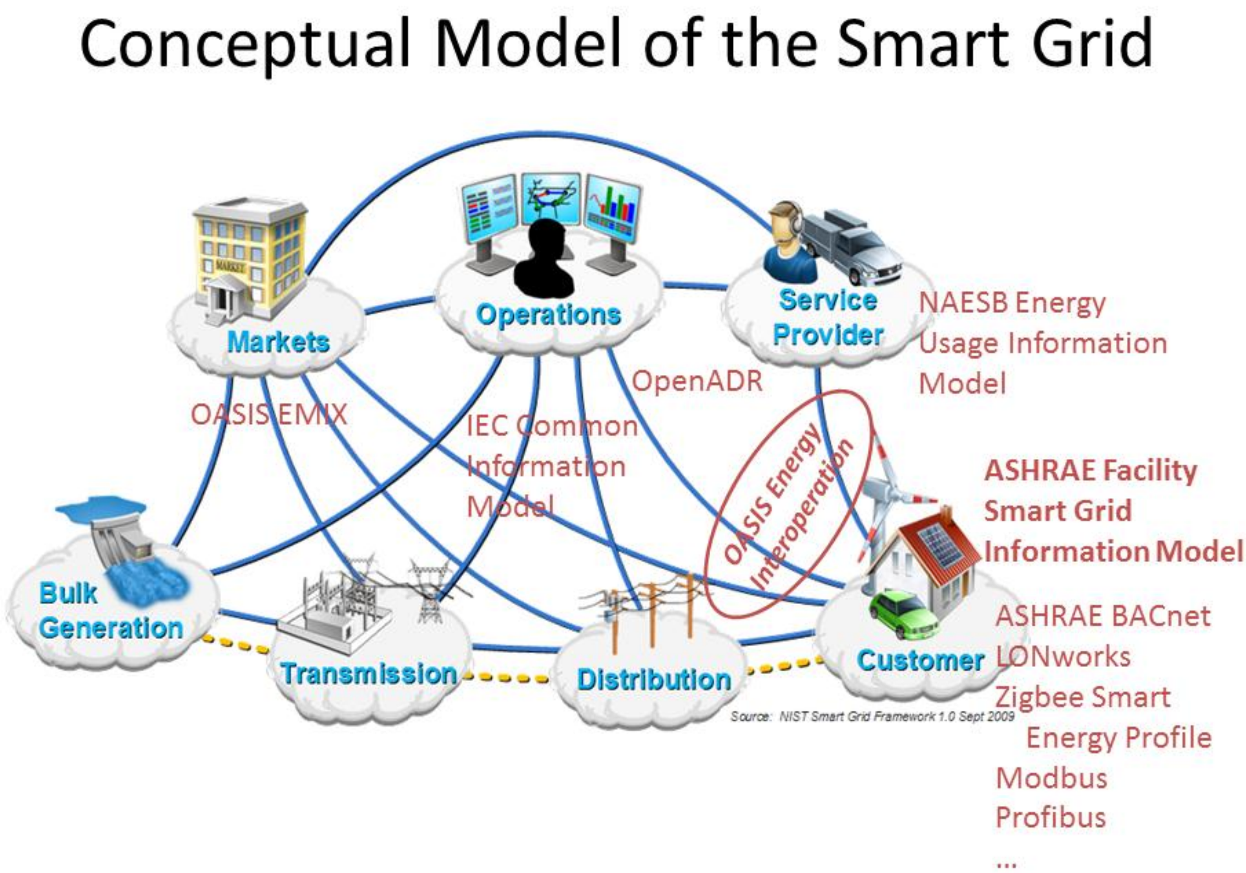

Figure 5 – Smart Grid Standards and Relationships between Standards

System performance and scalability are dependent upon many subsystems working together efficiently. These factors include system and communication bandwidth and latency along with the use of efficient message exchange patterns. Improving performance requires identifying and removing constraints to efficient communications. In general, the use of asynchronous, streaming, PUSH patterns will yield higher performance at scale.

11. STANDARDS

Standards exist (or are under development) to serve different domains of the smart grid. Some standards are intended specifically to support cross-domain communications. 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 on the grid side, interacting with 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 observations about where standards gaps exist or further collaboration might be required to address interoperability.

Standards Touching the Grid Face

- OASIS Energy Interoperations[16], WS-Calendar[17] and EMIX[18] are defining the interactions between the

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

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

distributed energy resources and the grid, schedules and price representations and market interactions, respectively.

- OpenADR 2.0 specification includes demand response interactions for commercial and industrial facilities.
- NAESB Energy Usage Information Model[19] is defining the standard for representing energy meter data
- NAESB Energy Services Provider Interface [20](ESPI) is defining the communication protocol used by service providers to access meter data from utilities and other energy service providers.
- WXXM is the standard weather data communication protocol for communicating weather information.
- International Electrotechnical Commission (IEC) Common Information Model (CIM) family of standards (IEC 61968, …) defines the information models that are used within energy service provider's enterprise information and data systems.
  - Focuses primarily on information communicated for operation of the traditional utility grid in the utility domain
- ISO/IEC 15067-3, Model of a demand response energy management system
  - Model of a residential energy management system including the demand response applications of an ESI for residential applications. This model includes: direct load control, prices-to-devices 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 AutoDR (for large C&I only).

Standards Touching the Facility Face

- ASHRAE/NEMA SPC 201 Facility Smart Grid Information Model (FSGIM)[21]
  - FSGIM 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[22], SEP 1.0/2.0[23], LONworks[24], ISA-100[25], Modbus, OPC Classic and Unified Architecture[26] and others (see Appendix 5, 6, 7) 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 face.
  - The gateway architecture of an ESI for residential applications is specified in ISO/IEC 15045-1 and ISO/IEC 15045-2, the international standard residential gateway. 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 ESI facility face.

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 any external information.

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

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

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

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

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

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

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

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

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

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, interoperable communications stacks.
- SEP 2.0 and OpenADR2.0 will often 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 theUtility Grid) is designed to interface with SEP, not OpenADR 2.0)
- SEP 1.0/2.0 within a meter integrates with an AMI (Advanced Metering Infrastructure) 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.

12. CONCLUSIONS AND RECOMMENDATIONS

Recommendations

- Information standards should provide a mechanism for implementing vendor/consortium extensions within the standard. This promotes interoperability by minimizing the need to circumvent the standard and helps to inform future versions of the standard.

Identified Gaps in Standards

The following gaps in standards and technology have been identified and need to be addressed within the SGIP process:

- Evaluate the alignment between existing internal facility communication protocols (SEP, BACnet, OPC-UA, etc.) and the PAP17 ASHRAE/NEMA 201P Facility Smart Grid Information Model, which provides: 1) Standard view of loads and load aggregation, 2) Standard view of generation and storage, 3) Standard representation of schedule intervals, sub-meter data, power quality data, etc.
    - Recommendation: Develop analysis work plan.
- Evaluate the alignment between OASIS Energy Interoperation and 1) the PAP17 ASHRAE/NEMA 201P Facility Smart Grid Information Model and 2) SEP2.
    - Recommendation: Develop analysis work plan.
- 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.
- SAE J2847/1 (Communication between Plug-in Vehicles and the Utility Grid) is designed to interface with SEP. In order for PEVs to participate in service provider demand response programs, this standard should incorporate connectivity to both SEP and OpenADR 2.0. It is recommended that PEVs interface to facility systems use an abstract interface rather than a direct link to SEP.
    - Recommendation: Bring industry stakeholders together to standardize the initial core set of services, extension and versioning strategy and a set of requirements and specifications for the ESI which address diversity requirements and enable the standards to be adopted and products delivered to the national and international markets.
- The ESI core services and service payloads, as defined in Energy Interoperations and other specifications, will need to meet a range of performance and latency requirements from day-ahead capacity to economic, operational and emergency demand response including balancing services for renewables. These requirements will dictate the use of transport protocols, in addition to SOAP/RESTful Web Services, that cover a range of performance, latency and system scalability characteristics. It is required that this transport diversity be incorporated into the ESI design.
    - Recommendation: Create a new SGIP PAP to investigate and create requirements.
- 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 and create requirements.

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