GridWise® Architecture Council

Reliability Benefits of Interoperability

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This document was prepared under the sponsorship of the GridWise Architecture Council for the purpose of estimating reliability benefits that might accrue as a result of implementing interoperability in a smart electric grid. The focus of this paper was not on original research, but rather with the goal of identifying similar benefits experienced in other industries through a review of the existing literature. By publishing this document, the GridWise Architecture Council hopes to expand the understanding of potential benefits of interoperability in the electric power industry.

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Section 1: Introduction and Summary

Electric utilities, generators, and grid operators are expected to operate a reliable power system with a high level of delivered service for customers. A reliable electric system is commonly expected to experience few outages and deliver high quality power to customers despite variations in the availability of power plants and lines or external conditions such as storms or load fluctuations. Power system reliability is maintained and enhanced when that system has components that are dependable, substitutable, and easily replaceable if they fail; when the system's performance is flexible and predictable; when information about system conditions flows smoothly and accurately to all who need it; and when much or all of that system can withstand or survive natural or malicious attack without extensive damage or abrupt failure and recover from such damage relatively quickly.

Interoperability is the ability of systems and devices to work together easily and effectively by design. Within the electricity system, interoperability means the seamless, end-to-end connectivity of hardware and software from the customers' appliances all the way through the transmission and distribution system to the power source, enhancing the coordination of energy flows with real-time flows of information and analysis. Interoperability is a necessary foundation for development of a "smart grid." Interoperability has many dimensions, including physical and communications interconnections to informational interoperability (content, semantics, meaning, and format) and organizational interoperability (covering matters such as transactions structures, contracts, regulation, and policy). Interoperability is often achieved and institutionalized with support from formal technical standards and implementation testing.

As this paper explains, interoperability enhances electric system reliability; many of these benefits should be realized as the interoperability-enabled smart grid develops. The principal benefits of interoperability for reliability include:

- Fewer outages, large and small, due to better system monitoring, analysis, and management
- Faster service restoration following an outage, due to the availability of better information about outage locations and causes, the availability of interchangeable parts, and high-speed, automated system operations
- Higher system resistance to attack due to better information flow, greater system redundancy and resilience, and faster sectionalizing of the grid
- Better resource adequacy because interoperability enables better integration of diverse supply and demand-side resources, and substitution of demand-side reductions for supply resources.

The most important ways interoperability improves reliability are through:

- Improving information collection and flows between portions of the grid, which improves situational awareness

- Improving operators' understanding of and reaction to grid conditions
- Improving the ability of power system elements to work together quickly and effectively, spanning interactions between physical parts, resources, software systems, customers and supply sources, and companies.

Background

This paper explains the impacts and benefits of interoperability for electric system reliability. This is one of three interoperability benefits studies commissioned by the GridWise® Architecture Council; while this paper addresses grid reliability, the others address the implications of interoperability for the costs and economics, and for the environmental and resource use entailed by electricity production and use.

The GridWise Architecture Council is an organization created by the U.S. Department of Energy in 2004 to promote and accelerate the development of interoperability to support the GridWise vision of how the latest communications, information, and controls technology can improve operation of the nation's electric system. Interoperability—the capability of systems and devices to share and readily use information securely and effectively—is the foundation for many of the world's critical technologies, including telecommunications, finance, and computing. Interoperability principles need to be applied to enable the effective connection, interaction, and coordination between the many automation systems and devices that make up the electric system.

There has been little formal analysis conducted of the impacts of interoperability within the power system; most of the work done to date looks more broadly at the costs and benefits of a smart grid or at portions of a smart grid, such as the impacts of demand response for electricity production costs and reliability. Absent formal studies, we have to look at the impacts of interoperability on reliability in two other ways – first, by looking at the costs and consequences of insufficient interoperability upon grid operations, to infer that better interoperability could have prevented the adverse consequence; and second, by looking at how interoperability is being pursued and used in other industries to extrapolate those benefits by analogy to the power sector. Some of the most aggressive work on interoperability has been done within the U.S. military and health care sectors, so many examples of the effect of interoperability upon mission reliability are drawn from those two sectors for extrapolation to the power system.

Definition of Interoperability

The GridWise Architecture Council defines interoperability as the capability of systems or units to provide and receive services and information between each other, and to use the services and information exchanged to operate effectively together in predictable ways without significant user intervention. Within the electricity system, interoperability means the seamless, end-to-end connectivity of hardware and software from the customers' appliances all the way through the transmission and distribution system to the power source, enhancing the coordination of energy flows with real-time flows of information and analysis. Interoperability is a necessary foundation for development of a "smart grid."[1]

There are several dimensions of interoperability. Technical interoperability covers the physical and communications connections between and among devices or systems (e.g., power plugs and USB ports). Informational interoperability covers the content, meaning, and format for data and instructions flows (such as the accepted meanings for human and computer languages). Organizational interoperability covers the relationships between organizations and individuals and their parts of the broad system, including business and legal relationships (such as contracts, intellectual property rules, or regulations).[2] Each of these dimensions affects the degree to which interoperability can enhance grid reliability – or, in the absence of interoperability, compromise grid reliability and security.

Interoperability exists when two items work together effectively – when every smart meter on a system has the needed connectors and behaviors, regardless of which vendor manufactured them and what year they were purchased and installed. Interoperability makes it possible to build large-scale systems without extensive customization and piece-by-piece tailoring to force each to work with the whole. Openly available interface specifications allow the purchaser to buy from multiple vendors, and for those vendors to compete against each other through product technology, feature innovation, and performance testing, while improving efficiency and costs for their products.

The down-side of interoperability is that it enables an increase in system size, and thereby can increase system complexity. When interoperability works properly, new devices and assets can be added to the system and work effectively (after sufficient interoperability specification and testing). As a system of systems becomes larger, more geographically dispersed, and more complex, there are more things that can go wrong and more ways that system components can interact in unexpected ways. The direct benefit of interoperability is that it enables large systems to become larger and more complex; the indirect consequence of interoperability may be that larger, complex systems can fail in complex and unpredictable ways.[3]

The Scope of Reliability

This study looks at the impact of interoperability upon the reliability of the electric system. There are several aspects to grid reliability:

- **Reliability** is the degree to which the power system—from generation through transmission and distribution down to the customer and their energy-using devices—delivers sufficient electricity, within accepted performance standards (such as a minimal number of outages or voltage fluctuations). The North American Electric Reliability Corporation defines operating reliability as, “the ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system components.”[4]

- **System adequacy** is the ability of the electric system to supply the aggregate electrical demand and energy requirements of customers at all times, despite scheduled and reasonably expected unscheduled outages of system assets.[5]
- Within a broader societal context, **national security** means the integrity of the nation’s citizens, infrastructure, economy, and environment from physical, medical, or economic harm. To the degree that the electricity system is vital to the economic health and physical safety of the United States, anything that protects and improves wide-scale electric reliability protects our national security.

This study looks primarily at reliability and system adequacy. A reliable electric system has several characteristics or goals:

- It meets end-use customer demands consistently and effectively.
- It fails rarely.
- When one portion of the system fails (whether one specific asset, such as a power plant or transmission line or a geographic region), redundant controls and assets enable the system to keep operating despite the loss of that asset.
- It has sufficient resilience that one asset or region can lose service without causing other portions of the system to fail.
- When it fails, it fails gracefully in the sense that the failure is slow enough for affected pieces to protect themselves from damage (whether those pieces are power plants shutting down or traffic lights and hospitals switching to back-up power quickly enough to protect public safety).
- Once the system has failed, it can be restored to service quickly, so that critical services and societal transactions are not harmed for long.

This paper makes the case that greater use of interoperability within and across the electricity value chain, from the power plant to the customer’s end-use devices, will enhance electricity reliability. Interoperability can affect every one of the reliability characteristics listed above.

Tools for Enhancing Interoperability

Interoperability is achieved using multiple tools and approaches. These include:

- **Standardization** – generically, creating items that are physically and functionally interchangeable (e.g., the standard size base for incandescent lamps and light bulbs, or the standard plug and socket for electric appliances and wall outlets). However, not all standardized items are fully substitutable – even though many light bulbs have the same standardized screw-in base, not every light bulb is a satisfactory substitute for every other bulb.

- **Interchangeability** – closely related to standardization, the ability to exchange parts or assemblies between like equipment without having to alter the item to make the new combination work, because each interchangeable part has been designed to have functional and physical characteristics that are equivalent in performance and durability without alteration (e.g., in a given electric system many distribution transformers at a given voltage level are interchangeable, but most transmission substation transformers are not).
- **Standards adoption** – explicit, formal standards set by industry bodies that specify how devices or languages shall be structured and interact. Standards can include articulating engineering, principles, practices, functionality, and performance (e.g., the standards that are applied to all U.S. residential electric systems use 120-volt, 60-Hz single-phase electric systems for most plug loads, with three-wire, single-phase 240-V systems to supply large appliances).
- **Open systems architecture** – This is an integrated business strategy using a modular design that defines key interfaces within a system using widely supported, consensus-based standards that are available for use by all developers and users without any proprietary constraints (e.g., the internet and much of e-commerce are built upon open architectures).
- **Modeling and simulation** – A model is a simplified representation of a system at some point in time to help understand the real system; a simulation manipulates the model to help the analyst understand the interactions between system elements that would not otherwise be apparent. There are two kinds of models for the grid (and other systems): 1) mathematical models of the power system are used to conduct basic reliability operations processes such as state estimation and contingency analysis and to forecast long-term system behavior and needs, and 2) information models, such as the Common Information Model (CIM), define a common vocabulary for elements of the electric transmission and distribution system and include relevant attributes and relationships with other elements. Power system operations and planning software uses the CIM to exchange information about a power system configuration and the status of this configuration and its components).
- **Reducing unique specifications and proprietary devices** – unique or utility-specific applications and vendor-proprietary applications and devices can be counter-productive to interoperability, but may be necessary to provide needed functionality.[6]

All of these tools are being used as part of the effort to increase interoperability across the electricity value chain.

Section 2: Interoperability Improves Information Exchange to Enhance Reliability

One of the key benefits of interoperability is to improve the flow of information and understanding between devices, institutions, and actors across the electric system. "People have to see the same things – and see the network and the operational picture to fully understand what's going on" – in order to make the best decisions.[7]

In the military, "Interoperability refers to the structured effort by two or more countries in an alliance to ensure that their forces can operate together seamlessly. In practical terms, this means things such as operating procedures, common communications links, common doctrine and standards, and compatible equipment."[8] The U.S. Department of Defense's (DoD's) objectives in pursuing interoperability include: sustaining the "superior war-fighting effectiveness of the nations weapons systems, allow for quick insertion of new technology, lower costs for weapon system hardware and software, facilitate more effective joint operations, and promote capabilities not achievable with any individual system."[9]

In aggregate, the challenges and goals of the electric service providers are similar to those of the military – system operations seek superior electric system performance for effective energy delivery, the ability to insert new technologies (such as demand response, smart meters, or new generators), lower costs for electric system hardware and software, more effective and affordable joint power production and delivery, and better joint outcomes (as from market operations, maintaining real-time reliability and long-term adequacy, and mutual assistance for emergency recovery). Interoperability can help electric service providers achieve these goals in much the same way that it advances the military's efforts.

Situational Awareness and System-Wide Information Flow

The joint U.S.-Canada investigation into the August 14, 2003 blackout in the northeast United States and Ontario found that inadequate situational awareness on the part of utilities and reliability coordinators was a primary cause of the blackout.[10] Situational awareness means, "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future;"[11] more casually, it means to know continually what is going on around you in a dynamic environment, with awareness of potential threats, opportunities, and the range and implications of your potential actions and options.

Interoperability can be equally important for reliable operations and situational awareness. The growing move toward transmission and distribution automation is an effort to remedy two elements contributing to electric system failures – the lack of data collection, and the narrow distribution and use ("silo-ing") of data collected from historically independent field devices.

For instance, many power systems (supervisory control and data acquisition [SCADA]) and Energy Management System [EMS]) today feed data only into the control room, and do not have a way to integrate the operational condition data to field technicians nor to analytical tools that link to customer data systems or third-party energy management aggregators.

Interoperability and Information Availability

Effective information flow between responsible or affected actors and devices, with common understanding of that information, is one of the most important aspects of interoperability for the electricity value chain. The events of the August 14, 2003 blackout illustrate several different ways in which information flows were ineffective, reflecting the severe consequences of the lack of interoperability:

- Utilities give transmission lines ratings to indicate how much amperage each can carry safely; during real-time operations, those ratings are used as limits and thresholds to signify when the line moves from normal to overload conditions. FirstEnergy was using a more aggressive set of line ratings for the Sammis-Star 345-kV line (the last of four 345-kV lines to fail, triggering the wider system collapse) for normal and emergency conditions than its neighbors and reliability coordinators (American Electric Power [AEP], PJM and Midwest Independent Transmission System Operator [MISO]). Thus, FirstEnergy was operating the line at much higher assumed safety levels than other grid operators assumed to be reasonable operating conditions. *Accurate, effective, information exchange between asset owners and grid operators would have prevented this mismatch.*
- On August 14, 2003, FirstEnergy removed several capacitor banks within the Cleveland-Akron area that are used for reactive power production (voltage support) from service; although these resources were critical for voltage support, they were never formally identified as critical and the fact that these resources were unavailable was not known by neighboring control areas and reliability coordinators. *Hourly, automated asset status monitoring and reporting between and among asset owners and grid operators would have prevented this and enabled PJM and MISO to better evaluate conditions and options within FirstEnergy's service territory.*
- Although FirstEnergy's EMS and alarms became inoperable and erratic by 14:19 Eastern Daylight Time (EDT) on the afternoon of the blackout, the utility's control room operators never recognized these failures (and were not told of them by their Information Technology [IT] staff) for almost an hour and a half. They therefore failed to detect changing grid conditions when a series of 345-kV and 138-kV lines began tripping off-line in the next two hours. *Had there been better integration and information flow between the control room and its IT systems, operators could have known to use other methods to monitor system conditions.*

- At 14:32 EDT, AEP operators called FirstEnergy operators to discuss a line trip and reclose of the Star-South Canton 345-kV line spanning the two service areas; because FirstEnergy operators saw no indication of that trip and reclose, they concluded there was no problem on the line. At 15:19 EDT, AEP operators called back to confirm that the trip had occurred, but FirstEnergy operators concluded that the operation was a fluke rather than indication of an operating problem. *If AEP had been able to deliver data on the line trip directly into the FirstEnergy control room, FirstEnergy operators could have recognized the problem rather than dismissing it.*[12]

Interoperability and Information Accuracy

Advances in interoperability have been shown to improve the accuracy, fidelity, and speed of information and data exchanges. This has been a driver behind interoperability research and implementation in the automotive and aerospace manufacturing sectors—National Institute of Standards and Technology's (NIST's) 1999 study found that the auto industry spends over one billion dollars per year needlessly due to the lack of interoperability, and that "up to 50% of these costs are incurred in dealing with data file exchange issues."[13]

Interoperability and the accurate, instantaneous flow of information about packages, senders, routing options, and the like have transformed the shipping and delivery sector. FedEx companies "support more than 100 million electronic transactions and deliver nearly five million shipments every day,"[14] with more than 5,000 global trading partners, using a single gateway to support all e-commerce regardless of the protocol used. To achieve this level of data accuracy and user ease, FedEx uses an interoperability strategy that enables "data exchange between computers of any platform at any time using any communication protocol. It connects trading partners, customers and vendors with near real-time, event-driven and interactive communication capabilities."[15] Information and communications interoperability enables FedEx to flow huge amounts of transaction data seamlessly and accurately between customers and all of the company's corporate subsidiaries and partners, which in turn enables the company to keep its promises for timely, accurate package delivery.

In the capital facilities design and construction sector, accurate information exchange is critically important yet lacking due to inadequate interoperability:

> "Architects, civil engineers, procurement contractors, equipment and materials suppliers, project managers and building trade general and sub-contractors" all share information and designs in a complex work process. "In most cases … these collaborating parties share this vast quantity of information through the exchange of traditional paper documents. The electronic exchange of design, construction and related documents is in most cases prevented by the absence of a consistent format and syntax for data descriptions used by the firms involved. As a result the same information is often manually interpreted by humans and

> re-entered into one or more different software systems. This practice, which is often repeated over and over again by each participant in the design and construction work process, is very labor and time-intensive, error-prone, and costly."[16]

In the health care field, development of standards for electronic medical records is a national health care priority:

> "In health care, interoperability is the ability of different information technology systems and software applications to communicate, to exchange data accurately, effectively and consistently, and to use the information that has been exchanged…. Without interoperable EMRs [electronic medical records], practicing physicians, pharmacies and hospitals cannot share patient information, which is necessary for timely, patient-centered and portable care."[17]

One example of the adverse consequences of inaccurate medical records delivery is the case of two female patients in a hospital who were scheduled for CT scans; the second patient was given an unnecessary appendectomy because her doctors received the first patient's CT scan results by mistake.[18]

Closely related to medical records is the problem of medication error. Medication systems catch up to 300,000 medication errors *every week*. Such errors could be avoided and many lives saved by leveraging interoperability to link the bar code identifying a patient to the bar codes on medications and electronic medical orders through an information system that verifies that the right medicine is delivered to the right patient at the right time.[19] Similar systems and principles can be used in the electricity value chain to improve customer records and field operations.

Part of the challenge of effective information flow is collecting useful information and delivering it in a meaningful format to actors or applications that can use it effectively – but done well, interoperability can make the difference between success and failure for mission-critical efforts. The U.S. Department of Homeland Security is using interoperability to link multiple information sources and analytical tools in real time to help prevent terrorists and criminals from entering the United States:

> "We have pulled together and unified our counter-terror databases…. We have implemented biometric capabilities, fingerprint-reading capabilities at all of our international ports of entry. With these new fingerprint reading capabilities … deployed all over the ports of entry at land and in the air and at sea, we can now, within seconds, positively confirm a person's identity against their passport and against our databases by checking two-digit finger scans against watch lists and immigration records."[20]

Electric companies are tackling equally ambitious data management challenges with the growth of smart metering and meter data management. For instance, the Italian utility Enel has installed smart meters for over 30 million electricity customers, using the meters to improve customer reliability as well as for demand management and customer service. Enel claims that thanks to the smart meters, it responds to 98% of requests of complaints from customers within 24 hours and can detect and repair outages more quickly.[21]

Interoperability will be essential to the effectiveness of utilities' smart meter projects. Smart meters are expected to directly facilitate a broad variety of functions – measure customer energy consumption during time intervals, report that energy use to the utility billing system, enable customer demand response, execute remote service connects and disconnects – and to provide data that rolls up into a suite of broader utility business processes, including outage management, circuit monitoring, distribution circuit planning, and more. All elements of interoperability must be planned and executed into meter specifications and meter data management systems to perform all these functions effectively – all of the meters will need common physical and communications interfaces, all of the data will have to be in predefined formats and meanings that are used consistently through all of the connected business processes and software applications, and there must be enough communications modes and capacity to retrieve and route the data and its meanings effectively from customer to utility and between the utility's various business applications.

Section 3: Interoperability, Monitoring, Automation, and Diagnostic Systems

Interoperability contributes most to protecting reliability when it facilitates extensive information collection that in turn allows analysis and action based on what that information reveals.

A lack of interoperability hampers safe, effective military operations when data cannot flow smoothly and swiftly in real time: "The convergence of military video, voice and data that led to the successful June 2006 air strike that killed al-Qaeda terrorist Abu Musab al-Zarqawi in Iraq epitomizes the progress and the shortcomings the military faces in making its information systems interoperable," said Air Force Lt. Gen. Michael Peterson…. Peterson said the average time it takes to respond to "time-sensitive targets," measured in minutes, is in the "low teens." Yet, "67 percent of that time involves manual communication because we're not fully interoperable." On the positive side, Peterson cited the ability to identify and redirect two F-16s in the closing minutes of the decision to attack – but in ensuring those aircraft were replaced in action, "We still had to have people entering data from yellow sticky notes" instead of having drag-and-click notification.[22]

An example from the health care field suggests the degree to which ongoing monitoring enables the regular evaluation of key assets and effective response if such assets experience problems – in other words, to protect human safety. Health care leaders are planning to use interoperability to improve individual and societal health care delivery and management:

> "In a system well-designed for improving health, people with heart disease or diabetes can transmit their vital signs – blood pressure, heart rate, glucose levels, temperature, weight, respiration – seamlessly from their home to their health professional, and get real-time feedback on their condition…. To become a central component of the way we manage health, personal health and medical devices must be fully interoperable with each other and with other information sources."[23]

Eventually, they envision the steady flow of real-time health data between interconnected devices from the personal fitness equipment and the home scale to electronic health records and health professionals to assure that patients' medical conditions are fully understood, proactively managed, and receive prompt and effective response in the event of an adverse event; this vision of proactive, distributed intelligence improving human health outcomes parallels many visions for the electricity smart grid and its effect on energy reliability.

Interoperability Leverages Distributed Devices

Because interoperability (combined with extensive communications networks and physical connectivity) enables different devices to work together effectively, it improves monitoring and diagnostic capabilities. Those capabilities, leveraged through automation (which itself requires a high level of interoperability) improves grid management in a variety of ways:

> "Automated switches can use information from protective relays at adjacent substations to isolate faulted sections of the supply line to restore service to the substation. Adaptive relaying can activate protective relays during storm conditions and trip substation breakers for faults to protect fuses in the zone. High-speed transfer switches will instantly remove disturbed sources and replace them with clean, back-up power supplies. Automated balancing, shedding and transferring will not only improve performance, but also reduce capital costs, crew dispatching costs and restoration efforts. Automated feeder ties, distributed resources and advanced decisions support systems work together to reduce and move load. Fault detection and restoration applications allow automated detection and isolation of phase-to-phase and phase-to-ground feeder faults, which then restores primary and secondary feeder sections to minimize outage duration…. [And,] real time condition-based monitoring of core equipment has emerged as a way to preserve the existing health and viability of the grid. Equipment monitoring allows continuous analysis of conditions (temperature, pressure, etc.) and operating parameters, which can reduce repair costs, extend equipment life, and prevent major failures."[24]

Interoperability is enabling the growing use of synchrophasor systems, a powerful situational awareness tool. Synchrophasor measurement units and similar data collection devices sample grid conditions up to 30 times per second and feed that time-synchronized data to local and regional data concentrators. This real-time data can be used to better assess wide-area grid conditions and anticipate and act to prevent potential problems and possible grid failures. But synchrophasor data is only accessible because of the extensive investments made in interoperability between the underlying electronic data collection devices, satellite time synchronization, communications systems, and numerous data collection formats and data-using software applications. Phasor data systems are now being used for real-time grid monitoring in all three U.S. interconnections. Southern California Edison is using the high-speed data from its phasor measurement units to identify triggering conditions or events that could require mitigation through a centralized remote access service (RAS), and send those mitigation orders directly to distributed grid devices for immediate implementation.

Another form of monitoring uses wireless sensors – with their underlying connectivity and interoperability – to track critical applications. There is growing deployment of wireless building monitoring and control devices that feed condition and energy use information to the building controls and energy management system; demand response aggregators and automated demand response mechanisms use these distributed sensors and controls as a way to execute widespread, situation-specific demand response events. Such applications would not be possible without a broad suite of interoperability protocols and standards – in the energy space, these include building controls standards and protocols, communications standards within the building for its energy use devices, for the communications systems that connect the building energy manager to the upstream energy manager, and from the grid operator to energy managers and demand response aggregators.

Smart grid visions that rely upon extensive use of coordinated fleets of plug-in electric vehicles, distributed generation and distributed storage devices will require extensive interoperability and implementing standards.

Communications Interoperability and Reliability

Information cannot flow effectively if communications are not fully interoperable. Several examples from the public safety sector – law enforcement, fire and rescue, and emergency management personnel – show the painful consequences of wide-area radio and data communications that are not fully interoperable:

> "During the terrorist attacks of September 11, 2001, the issue of public safety communications interoperability came to a head. As police and fire and rescue personnel swarmed the Twin Towers, communications were either nonexistent, or fragile interoperable systems quickly broke down. While police received the command to evacuate as signs of collapse became apparent, fire and rescue personnel did not. Sixty police officers died in the subsequent collapses, but more than 340 fire and rescue personnel lost their lives. According to a University of New Hampshire … study, non-interoperable communications were at least partially to blame…."[25]

Similar communications problems occurred after Hurricane Katrina. The hurricane devastated much of the Gulf Coast, causing a comprehensive critical infrastructure collapse across multiple states and sectors – energy, information, communications, finance, health, and transportation. Much of the local communications systems infrastructure in Louisiana and Mississippi – landline and mobile phones, commercial radio and television, emergency 911, and fuel to power the facilities that survived flooding and high winds – was destroyed. This failure was exacerbated by the lack of interoperability affecting the hurricane's emergency responders:

> "Law enforcement units who rushed in from other jurisdictions often had two-way radios that used different frequencies than local police. [Department of Defense] military responders found it difficult or impossible to communicate with FEMA or other civilian authorities, some of the key data was locked away on classified systems, and situational awareness – knowing what was going on, who was where, who needed what, and who was going where and when – was significantly degraded."[26]

When the electric system was assumed to extend from the central station power plant only down to the customer meter, most electricity-related communications flows were one-way, bearing information in to the utility and its transmission or generation control rooms, often on utility-owned telecommunications facilities. As utilities began automating their transmission systems, they began building and acquiring redundant communications capabilities, using a mix of private lines, rented satellite space, and the public switched network (landline and wireless) for both voice and data communications. Today, utilities need to exchange huge amounts of in-bound and out-bound data with a wide range of partners – customers, energy users, wholesale market operators, generators and transmission users, vendors and consultants, and many more. All of these data can only flow rapidly and error-free if all parties agree on the points of interface where integration can take place reliably and rely upon the extensive interoperability and standards established (and still evolving) in the communications and information technology fields.

Section 4: Interoperability, Technology Diversity, and Risk Reduction

Diversity is one of the strongest contributors to a reliable energy system because it reduces the vulnerability of the system to specific risks or modes of failure:

- Diversity of technology and fuel type means that the electric system is not wholly dependent upon a single fuel type (e.g., coal or natural gas) or provider (e.g., a single vendor, railroad, or foreign nation).
- Multiple generator locations and transmission options mean that the system is less vulnerable to a location-specific attack, natural disaster, or equipment failure.
- Having demand and storage resources to balance load and supply, as with the ability to use demand response and energy efficiency to manage load, makes the system less dependent on supply-side resources to assure system adequacy, and allows location-specific adjustments to protect local reliability.
- Having a diversity of resource sizes, from a fleet of distributed generators to complement a fleet of mid- and large-sized central station power plants, improves the supply system's overall availability factor (because statistically, the system can bear more losses of small generators without compromising reliability and security than it can the loss of a few large generators).
- Having a diversity of owners means that the system is less vulnerable to the financial harm that can occur from cost overruns, credit availability, and regulatory delays or adverse decisions.

But diversity only enhances reliability if all of the diverse elements can work together cleanly and effectively, as enabled by interoperability at the points of interface between the diverse elements.

Additionally, these various types of diversity are possible because of institutional interoperability – deliberate policy decisions, laws, and regulations have created an institutional and contractual framework that enables the power system to accommodate and integrate this diverse of owners and resources.

Section 5: Interchangeable Parts and System Recovery

Interchangeability is a principal way to achieve physical interoperability. Examples of interchangeability include standardized physical interconnections and interfaces (such as the electric outlet and plug, light bulb sockets, and USB ports and connectors) or devices that perform the same function with no physical adjustment (such as USB memory sticks, computer printers, or incandescent and most compact fluorescent light bulbs). Interchangeability usually entails development of physical standards and rigorous implementation testing to assure that every vendor's device that meets the language of the technical standard in fact performs perfectly in a wide variety of uses.

The United States contains almost 3,000 electric utilities. These utilities were, for the most part, not designed with the intention that their physical or communications systems would work together and integrate effectively; rather, each was built to serve a specific geographic area and meet the needs of its customers with limited attention to how it interfaced and interacted with its neighbors. Therefore, most utilities are characterized by insular design characteristics and location-specific assets that do not match their neighbors' systems and infrastructure – for example, not all of Entergy's distribution pole-top equipment matches its neighbors', so when the neighbor utility sends distribution crews in for mutual assistance after a hurricane or ice storm, not all of the neighbors' equipment will work on Entergy's distribution system because their bolts and crossbars are sometimes the wrong size to replace the host utility's damaged equipment. This lack of equipment standardization and interchangeability extends the time required to repair and recover from system damage or failure.

Much high-voltage transmission equipment exemplifies the lack of standardization and interchangeability within the electric industry. Items such as high-voltage transformers, circuit breaker parts, and transformer bushings are relatively unique or customized, and would be hard to replace quickly with either identical or new, substitute technology. If one of these transformers or related equipment is damaged, it can make an entire substation inoperable and compromise reliability for a group of transmission assets or an entire service area. Lacking the availability of easy substitutes for such equipment, the electric industry has taken several steps to address the problem. Nationally, the industry has secured federal regulatory approval for an industry-wide program to acquire and maintain excess, spare transformers in each of nine different transmission voltage classes (with each transformer costing from $500,000 to $11 million, with six months to two years of lead time per transformer), to ensure that a spare transformer can be made available to replace an existing transformer if it fails in an emergency.[27] If high-voltage transformers were more interoperable and interchangeable, it would be faster and easier to maintain transmission reliability by improving the speed of system repair and recovery.

PJM is taking a different tack to address its critical transformers. With half of its 500/230-kV transformers (including spares) over 30 years old, PJM's utilities have experienced both transformer failures and degradation that required reducing ratings on at least four transformers, causing costly congestion and reliability mitigation. In addition to creating an aggressive spare equipment acquisition and storage program, PJM is developing "a common 500/230-kV transformer design specification to be used for ordering new transformer banks. This will improve spare transformer sharing capabilities, reducing lead time and reducing the total number of spares needed to be retained across PJM." The first of these new, standardized transformers were ordered in 2006.[28]

Another example of the importance of physical interoperability comes from the military. The military has recognized that if multi-national forces use guns that use the same size of ammunition, those forces can be more effective in joint operations with smoother logistics. Similarly, "developing Air Force and Navy aircraft to use the same fueling nozzles and receptacles and their engines to use compatible fuel allows aircraft from either service to be refueled at any Air Force or Navy facility (or in flight)."[29]

As the above examples illustrate, a higher degree of interoperability and interchangeability for critical assets – whether transformers or gas nozzles – makes a system more reliable because it is less vulnerable to the failure of critical spares; if a critical part fails it can be fixed faster.

Section 6: Interoperability, Reliability and Smart Grid

Interoperability will be essential to the success of electricity stakeholders' smart grid visions. A smart or modern grid will be a digital energy system that will:

- Detect and address emerging problems on the system before they affect service
- Respond to local and system-wide inputs and have much more information about broader system problems
- Incorporate extensive measurements, rapid communications, centralized advanced diagnostics, and feedback control that quickly return the system to a stable state after interruptions or disturbances, automatically adapt protective systems to accommodate changing system conditions
- Re-route power flows, change load patterns, improve voltage profiles, and take other corrective steps within seconds of detecting a problem
- Enable loads and distributed resources to participate in operations
- Be inherently designed with reliability and security as key factors
- Provide system operators with advanced visualization tools to enhance their ability to oversee the system.[30]

Many of the above functions will rely upon both distributed supply and demand resources and distributed computing and intelligence located across the electricity value chain, in supply and demand, and various grid sites. Increasingly, those resources will be acquired and operated by entities that are not associated with the utility or the grid operator, and they will feature a wide range of technologies and capabilities provided by a variety of vendors. These resources and assets will be connected only at their physical and communications interfaces, but they will have to interact and interrelate as smoothly and easily as a new computer connects to the internet or a new appliance plugs into a wall outlet.[31] This can only be achieved if the service provider (and its neighbors and reliability coordinators) share and act upon a commitment to interoperability and open architectures – to ensure that the physical, informational, and communications interfaces between all of the hardware and software and functions are designed, acquired, and put together in ways that work effectively and predictably with minimal user intervention.

Quantifying the Reliability Benefits of Interoperability and Smart Grid

Many of the expected benefits of building a smart grid are reliability- and security-related. The San Diego Smart Grid Study identified and quantified a number of specific reliability benefits that would result from implementation of a smart grid, which in turn would require a foundation of interoperability – estimated annual benefits for the area studied included:

Reduction in congestion cost	$13.1M
Reduced blackout probability	$1.5M
Reduction in forced outages/interruptions	$38.6M
Reduction in restoration time and reduced operations and management due to predictive analytics and self-healing attribute of the grid	$11.3M
Reduction in peak demand	$25.6M
Other benefits due to self-diagnosing and self-healing attribute of the grid	$0.2M
Increased integration of distributed generation resources and higher capacity utilization	$14.7M
Increased security and tolerance to attacks/natural disasters	$1.2M
Power quality, reliability, and system availability and capacity improvement due to improved power flow	$1.3M

Source – SDG&E, SAIC Smart Grid Team, “San Diego Smart Grid Study,” Final Report (October 2006), Table 18, “Summary of Annual Benefits.”

Many electric service providers are investing aggressively in Advance Metering Infrastructure (AMI) as a foundation for their smart grid efforts. AMI investments will only deliver operational benefits for utilities if they use interoperability techniques aggressively to ensure that appropriate, timely information flows seamlessly from the customer’s energy uses through the meter to the distribution company’s many operations and business applications. Many of the operational savings utilities expect to result from AMI investments are explicitly reliability benefits enabled by interoperability, among them:

- Identification of outage locations
- Supports more rapid customer restoration time
- Eliminates need for customer outage reporting
- Allows more accurate dispatching of repair crews
- Improved capacity utilization
- Grid voltage and phase monitoring.[32]

Another study reports that the business case for a smart grid offers multiple reliability benefits, including, "significant SAIFI [System Average Interruption Frequency Index] and SAIDI [System Average Interruption Duration Index] improvement through AMI, fault detection, isolation and restoration, integrated outage management system and field force automation; improved power quality for an increasingly digital economy; ongoing M&D will further improve reliability; improved customer service through billing accuracy and reduced outages."[33]

Effective, extensive information flow between utility applications that were once completely separate, illustrates how interoperability shortens customer outages by allowing information residing in one system to be accessed and leverage by other systems:

> "Outage management systems [OMS] use customer outage reports, knowledge of distribution system infrastructure, and predictive algorithms to determine where a failure has occurred in the network. An OMS process has outage detection/analysis and outage restoration states…. AMI systems can help significantly in both stages to reduce a utility's SAIDI [System Average Interruption Duration Index]. Using the power of near-real time information has improved electric utilities' SAIDI by an average of 4 to 6 minutes through faster and more accurate outage response.
>
> Another element of the outage detection and analysis process is avoiding trouble calls. As many as 75% of calls are single-service outages. With AMI, an operator can perform an on-demand read to verify if the premise is energized. … Exelon was able to cancel more than 1,200 trouble calls during a single thunderstorm event near Philadelphia in 2006 by using its AMI system.
>
> A sophisticated utility can use its distribution map to verify power around sectionalizers and other fault isolators to give the OMS stronger confidence in pinpointing a failed device or line. Most utilities already integrate their OMS with geographic information systems, mobile workforce management, CIS, SCADA, and others."[34]

Such technology and system integration should drive significant reductions in the Customer Average Interruption Duration Index (CAIDI), which measures the average length of customer outages. DOE estimates that smart grid technologies could improve CAIDI by "an order of magnitude," and that "the vast majority of affected consumers should have power restored within five minutes of the service interruption."[35] For this, as with other reliability benefits, it is difficult or impossible to tease out how much of these reliability impacts are due to interoperability as distinct from the collected smart grid technologies that are facilitated by interoperability.

Smart Grid, Interoperability, and Security

Many characteristics of the interoperability-enabled smart grid will enhance the security of the electricity system by reducing vulnerability to physical and cyber attack, increasing the system's ability to resist and recover from an attack, and speed service restoration.[36]

Section 7: Conclusion

As outlined above, interoperability and a smart grid offer numerous, significant benefits for improved electricity reliability. Those reliability benefits include greater situational awareness, fewer outages, faster service restoration after a disturbance, higher system resistance to attack, greater system diversity and redundancy, and greater resource adequacy. As greater interoperability and smart grid elements are built into the domestic electricity system, we will be able to formally quantify the value of these reliability benefits.

Section 8: Notes

1. Gridwise Architecture Council, "Introduction to Interoperability and Decision-Maker's Interoperability Checklist," 2007, p. 1.
2. Ibid, p. 2.
3. Since information technology and software are critical to electric system operation – and even more essential to a smart grid – it is worthwhile to look also at work done on software complexity. Robert N. Charette's article, "Why Software Fails," is a good analogy and caution for the interoperable smart grid: "Studies indicate that large-scale [software] projects fail three to five times more often than small ones. The larger the project, the more complexity there is in both its static elements (the discrete pieces of software, hardware and so on) and its dynamic elements (the couplings and interactions between and among hardware, software, and users' connections to other systems; and so on). Greater complexity increases the possibility of errors, because no one really understands all the interacting parts of the whole or has the ability to test them." *IEEE Spectrum*, September 2005, p. 47.
4. A bulk power system with adequate reliability is controlled to stay within acceptable limits during normal conditions, performs acceptably after credible contingencies, limits the impact and scope of instability and cascading outages, and can be restored promptly if it is lost. From "NERC Definition of Adequate Level of Reliability," in letter from David N. Cook to Kimberly D. Bose, Federal Regulatory Commission, May 5, 2008.
5. Ibid.
6. "Interoperability," Selected Topics in Assurance Related Technologies, Reliability Analysis Center," Volume 10, Number 1, START 2003-1, pp. 3-5.
7. Kash, Wyatt, quoting Cindy Moran, director of Network Services at the Defense Information Services Agency, in "Defense leaders push interoperability agenda," *Government Computer News*, October 30, 2007.
8. Nelson, Brendan, Minister for Defense, The ANZUS Alliance, "Address to the Bradfield Forum," September 8, 2006.
9. "Interoperability," *Selected Topics in Assurance Related Technologies* 10(1):2.
10. U.S.-Canada Power System Outage Task Force, "Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations," U.S. Department of Energy, April 2004.
11. Endsley, M. R., "Toward a Theory of Situation Awareness in Dynamic Systems," *Human Factors* 37(1), 65-84.
12. U.S.-Canada Power System Outage Task Force, "Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations," U.S. Department of Energy, April 2004, Chapters 4 and 5.
13. See, for example, "Interoperability Cost Analysis of the U.S. Automotive Supply Chain," 1999, National Institute of Standards and Technology, available at http:nist.gov/director/prog-ofc/report99-1.pdf, and Steven Ray (NIST), "Manufacturing Interoperability," who writes that technical and business information "must now be passed electronically and error-free to suppliers and customers around the world."
14. "FedEx Speeds Ahead to Transport Industry Success, A GSX Case Study," at http://www.gxs.com/pdfs/caseStudies/CS_FedEx_GXS.pdf, retrieved March 30, 2009.
15. Ibid.

16. “Interoperability Standards for Capital Facilities Equipment and Construction Supply Chains,” research summary dated October 2006, at http://www.mel.nist.gov/msid/sima/07_cfe.htm, and Gallaher, Michael P., Alan C. O’Connor, John L. Dettbarn, Jr., and Linda T. Gilday, “Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry,” National Institute of Standards and Technology, NIST GCR 04-867, August 2004.

17. “Electronic Medical Record,” www.wikipedia.org, retrieved November 30, 2008.

18. Muller, Gerrit, “Increasing Interoperability, What is the Impact on Reliability? Illustrated with Health Care Examples,” September 5, 2008, retrieved March 30, 2009 at http://www.gaudisite.nl/InteroperabilitySlides.pdf

19 Colvin, Geoffrey, “McKesson: Wiring the Medical World,” Fortune at www.Fortune.com, February 7, 2007.

20. Chertoff, Michael, U.S. Secretary of Homeland Security, “Speech on the Fifth Anniversary of 9/11,” International Relations and Security Network, September 8, 2006.

21. “Going metric: Italy’s Enel leads the way in adoption of “smart” electricity meters,” *The Economist*, December 16, 2006, p. 66.

22. Kash, Wyatt, “Defense leaders push interoperability agenda,” *Government Computer News*, October 30, 2007.

23. Continua Health Alliance, “The Personal Telehealth Opportunity,” at http://www.continuaalliance.org/about/.

24. The Shpigler Group, “Understanding the Smart Grid from Definition to Deployment,” prepared for Edison Electric Institute, December 2008.

25. Mountjoy, John, “Broken Connections,” Council of State Governments, “State News,” October 2005, p. 34.

26. Miller, Dr. Robert, National Defense University, “Hurricane Katrina: Communications and Infrastructure Impacts,” *Threats at Our Threshold*, 2007, p. 196.

27. Federal Energy Regulatory Commission, “Order on Application for Blanket Authorization for Transfer of Jurisdictional Facilities and Petition for Declaratory Order,” 116 FERC 61,280, September 22, 2006.

28. “PJM Regional Transmission Expansion Plan,” 2006, pp. 181-184.

29. “Interoperability,” *Selected Topics in Assurance Related Technologies* 10(1):1.

30. Modern Grid Initiative, www.moderngrid.org, and Steven W. Pullins, “San Diego Smart Grid Study Overview, Results and Insights,” January 12, 2007.

31. This easy interaction is commonly termed, “plug and play,” which is the ability to add a new device onto a system and have it work immediately without physical modification or user intervention to resolve device or instruction conflicts. Plug and play is an extreme form of interoperability that requires not only standards and protocols designed for interoperation, but also relentless testing to verify that every device built under that standard effectively interoperates with every other device that is supposed to be able to receive and work with it.

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33. Borlase, Stuart, “Smart Grids – Moving Beyond the Utility Pilots,” *Utility Automation & Engineering T&D*, September 2008.

34. Ketchledge, James, Enspiria Solutions, “Enhancing Outage Management with AMI,” *Utility Automation & Engineering T&D*, February 2008.
35. National Energy Technology Laboratory, Modern Grid Initiative, “A Systems View of the Modern Grid,” January 2007, p. 9.
36. Ibid. p. 10.