ELECTRIC POWER RESEARCH INSTITUTE

Electric Power System Connectivity

CHALLENGES AND OPPORTUNITIES

POWER SYSTEM TRANSFORMATION

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INTRODUCTION

For the electric power system, "Connectivity" describes the completed, widespread deployment of communicating equipment that integrates data streams and functions related to decisions and actions along the energy value chain – from power plants to consumers and, potentially, their equipment and devices. Through connectivity, the power system can better integrate advanced digital functionality to become more flexible and resilient. This paper describes challenges and opportunities related to the power system's connectivity and its effective use of technological innovations.

Cisco estimates 21 billion devices will connect to the Internet by 2018 (three times the world population, up from 14 billion in 2013) [1]. Many of these are sensors, energy-consuming devices, energy resources, and other devices that function in the supply and use of electricity. Connectivity becomes paramount as the power system transforms from its traditional, one-way power flow network to a smart network characterized by an interactive, two-way flow of power and information. Customer interest in connected products and services will increase, along with the rapid growth of the Internet of Things (IoT). Investment to address aging infrastructure, changing supply and demand profiles, growing renewables portfolios, energy efficiency gains, and technology innovations will introduce even more devices and technologies requiring increased connectivity.

There are some challenges to the concept of connectivity, however. They include the sheer volume of data; proprietary legacy systems; the need for enhanced security; inconsistent lifecycle timescales of utility assets and connectivity technologies; rapid technological change; and effective integration of technologies into the power system including support for communications at the edge of the grid for intelligent devices, sensors, advanced metering and even customer technologies. Fortunately, these challenges bring opportunities spanning the energy value chain. While no single application may justify a telecommunication system investment, when a single telecommunications infrastructure is a strategic investment that can be utilized across many applications and systems, the value is significantly increased. As Metcalfe's law states, the value of a telecommunications network is proportional to the square of the number of connected users of the system (N^2). This paper outlines what EPRI believes to be the challenges and opportunities associated with connectivity and highlights examples of emerging research in these areas such as the recently launched Telecommunications Initiative.

Electric Power System Connectivity

Connectivity of the electric power system refers to the increasingly widespread deployment of communicating equipment that provides access to data streams and functionality to help inform decisions and behaviors all along the value chain, from the power plant to the end consumer.

Definition of Connectivity

For the purposes of this paper, "Connectivity" describes the widespread deployment of communicating equipment that integrates data streams and functions related to decisions and actions along the energy value chain – from power plants to consumers and, potentially, their equipment and devices.

Through connectivity, the power system can better integrate advanced digital functionality to become more flexible and resilient.

Connectivity becomes paramount as the power system transforms from its traditional, one-way power flow network to a smart network characterized by an interactive, two-way flow of power and information. The transition to a two-way grid implies a directional change within a historically hierarchical grid. According to the GridWise Architecture Council, tomorrow's grid needs to support "transactive energy," which enables "techniques for managing generation, consumption or flow of electric power within an electric power system through the use of economic- or market-based constructs while considering grid reliability constraints." It is essentially a two-way bidding system. The term transactive implies that decisions or transactions are based on value. Transactive energy can include prices-to-devices implementations, auction markets, transactive control, and more [2]. In EPRI's suggested architecture for the Integrated Grid, secure communications will be needed to connect distributed energy resources with system operators, enabling reliable, economic, and efficient use of both central and distributed resources [3].

Continued investments in modernization are addressing aging infrastructure concerns and responding to changing supply and demand profiles. These investments will introduce new technologies that depend on and build upon greater connectivity.

The value of connectivity is only realized when the data/information is put to use by personnel and applications to improve operational efficiency, reliability, and resiliency. Connectivity enables new and innovative applications and increased awareness that can be applied to all aspects of energy supply and demand.

Vertical and Horizontal Connectivity

Vertical connectivity along the value chain applies to sensors, control systems, and active devices. Horizontal connectivity refers to communication between devices on the grid to enable smarter energy usage and storage (as envisioned by transactive energy advocates). Horizontal connectivity also merges information from previously siloed data sources such as end-to-end communications from the utility enterprise down to the end device.

OSI Layer Definition and Models

Connectivity also can be considered in terms of layers of the Open Systems Interconnection (OSI) model (see Figure 1). Important aspects include the physical and data link layers at the bottom of the OSI model (e.g., evolving wireless systems)—up through network and transport layers (e.g., compatibility with IPv6 networking), and applications such as the Open Automated Demand Response and IEEE 2030.5 (SEP2) standards. The OSI model also includes use of semantic models to connect data sources, such as the Common Information Model [CIM]) [4].[1]

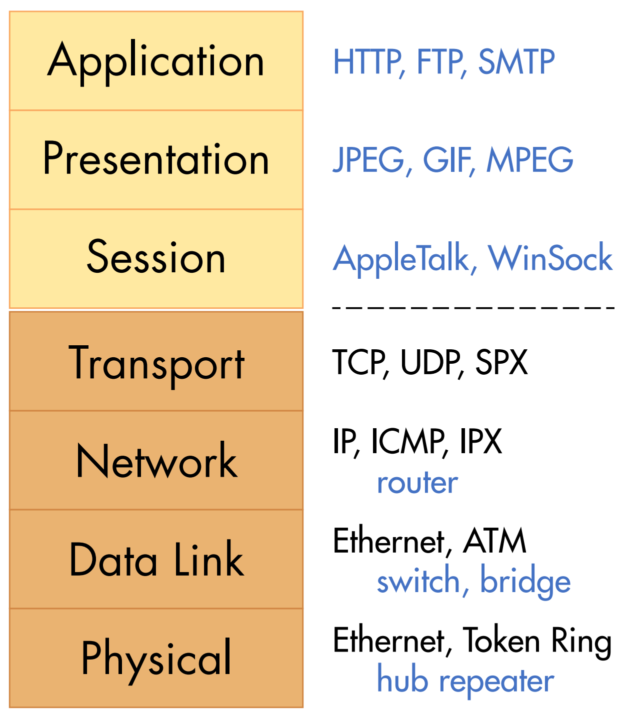

Figure 1. OSI Model—or "Stack"—and Example Protocols [5]

[1] *Although Figure 1 shows example protocols next to each layer, the OSI stack is a model, so actual implementations vary.*

INTRODUCTION

Projected Growth in Connectivity

Cisco's Visual Network Index and its forecast of global IP traffic estimates 21 billion devices will connect with the Internet by 2018, up from 14 billion in 2013) [1]. According to Google, in the past five years global IP traffic has increased by a factor of five, and in the next five years it is expected to increase by an additional factor of three [6]. In that same period traffic from wireless and mobile devices will exceed traffic from wired devices [1]. Many of these are sensors, electricity-consuming devices, resources and other devices that function in the supply and demand of electricity.

IT/OT Convergence

Central to power industry connectivity is the convergence of information technology (IT) and operation technology (OT)—and their collective knowledge among system operators. Until recently, IT functions were not considered integral to electric grid operations. Now, IT functions are increasingly applied to grid operations—an observation confirmed by EPRI's 2012 survey of utility chief information officers (CIOs) [7]. While differing in pace and approach, utilities' efforts to align IT and OT appear to fit into one or more of three themes:

- Utilities are re-engaging in IT/OT convergence discussions;
- Utilities are undergoing a partial reorganization;
- Utilities are orchestrating a complete reorganization.

Regardless of the approach, utilities benefit from advances in information and communication technology (ICT) by aligning technology and organizational structures [7, 8].

CONNECTIVITY DRIVERS

Grid connectivity is being driven by several trends, including:

- Greater diversity and widespread deployment of connected and intelligent end-use devices including plug-in electric vehicles[9]
- Enhanced use of sensors, communication, and computational capacity
- New opportunities for consumers to improve reliability
- Rapid growth of distributed energy resources, particularly solar photovoltaic (PV) installations
- The need for both distribution system operators and bulk power system operators to monitor these devices and their impacts in real time for improving system coordination

Customer Interest in Connected Products and Services

Electric energy customers are increasingly interested in products and services made possible by connectivity. Accenture reports that "Interest in connected home products and services, such as energy management and other monitoring and control solutions, is projected to rise from 7 percent to 57 percent in the next five years (2014 to 2019) due to the expectation that they will help reduce energy bills, increase comfort and convenience, and enable remote control of home devices." [10] Marcu Wohlsen in *Wired* magazine explains that "The paramount value of the connected-home devices, in a sense, lies not in the hardware itself but the interconnectedness of that hardware. As the devices talk to each other, by building an aggregate picture of human behavior, they anticipate what we want before even we know." [11]

EPRI research on plug-in electric vehicle customers indicates that they trust their local electricity provider to be a superior provider of information and services about charging infrastructure. [55] Accenture also observes that energy providers are well-positioned in this market. "While specialized providers are consumers' default choice for solar panels and connected-home solutions, energy providers are currently a very close second. Despite moving into the home energy market, big-box retailers, phone and cable companies and online retailers rank much lower." [10] EPRI research has identified at least eight channels for connected devices, of which utilities are but one.

The growth of connected devices in the customer space has been exponential in the last few years. Customers are driven by the four C's: control, comfort, convenience, and cost. The market will adopt technologies that meet these needs and improve their convenience factor without burdening them with the intricacies. Connectivity architectures that emphasize convenience for the non-technologically oriented customer have a leg up in the marketplace.

The range of connected products extends into multiple segments that impact energy including thermostats, HVAC systems, lighting controls, plug load controls, and wireless variable air volume (VAV) boxes. But, drivers for customer interest also converge from other industries including security and entertainment. Large players in these segments are bundling energy services with their core products through the convergence of connected devices.

The Smart Grid and the Internet of Things (IoT)

Overview

Related to grid connectivity, the need arises to address cyber security, common architecture, business aspects, and energy consumption, and potentially leverage the IoT. The IoT is a broad concept characterized by connectivity among devices, machines, and other technologies referred to as "things" that use public or private infrastructure and can be addressed, identified, and in some cases, located. Gartner forecasts that almost 5 billion connected "things" will be used in 2015, growing to 25 billion in 2020 – more than half of which will be in the consumer sector. The International Data Corporation (IDC) predicts that the IoT will generate almost $9 trillion in annual sales by 2020 [12]. Gartner also predicts that utilities will be the largest industry using connected "things" by 2020 [13].

Integrating many of these devices into grid operations in ways that benefit device owners, third party providers, and grid operators will be a critical challenge. Utilities have been implementing machine-to-machine (M2M) communication for years, but the IoT includes multiple market segments. Some companies use the term Internet of Everything (IoE) to express the difference. One significant distinction is the potential for anything to talk to anything in the IoT, deriving from the improved abilities for devices to interconnect and communicate.

The IoT vision is similar to the smart grid vision—the idea that utility meters, sensors, control devices, and software applications will be able to exchange information securely, at speeds and volumes sufficient to enable a wide range of applications. The IoT creates opportunities to integrate data across operational silos, but there are still emerging and competing standards across multiple OSI layers. Opportunities for the IoT to contribute further to utilities include monitoring and tracking asset life, asset integrity, and energy efficiency, integrating central and distributed resources, among others [14].

Another new arena for utilities is in the area of how devices procured and owned by customers can be leveraged for utility needs. An example is the growth of bring your own device (BYOD) demand response programs, where utilities can work closely with product providers to engage customers with existing devices to participate in programs. This substantially reduces utility program costs, while also providing engagement with customers who otherwise might not relate to the utility except as a commodity provider.

Cyber Security, the Smart Grid, and the IoT

Cyber security is among the most important aspects of smart grid applications and the IoT. Even though every device has the potential to be addressed and communicate with any other device, it does not mean it should be allowed to do so. An essential prerequisite for IoT applications in the utility industry is a comprehensive architecture that is based on appropriate management of communications policies and risk. Electric utility IoT applications will inherently communicate with consumer-owned devices, requiring appropriate security practices.

Business Aspects of the IoT

The utility industry has a stake in various business systems forming around the IoT, including cloud service companies for demand response aggregation, smart charging networks for electric vehicles, and outsourced energy services. Utilities are identifying various ways to take advantage of newly available data from their advanced metering infrastructure (AMI) systems and power system sensors[15]. This trend will continue as the IoT becomes more prevalent. More data from more sources can become the source of even greater value. While taking care to manage the privacy of customer-specific information, utilities are identifying opportunities to gain additional value from data [14].

CONNECTIVITY DRIVERS

Energy Consumption of the IoT

According to a recent International Energy Agency (IEA) report, by 2025, energy consumption of network-enabled devices could increase to more than 1000 terawatt-hours per year, if unchecked. This equals more than the current combined annual electricity consumption of Germany and Canada. The IEA points out that most of this energy will be consumed when devices are in a wait state, rather than functioning, providing tremendous opportunities to reduce energy consumption. The IEA report "lays the foundation for optimizing the benefits of a digitalized society while substantially reducing the associated energy footprint." [16]

THE CHALLENGES OF CONNECTIVITY

Overview

Continued improvement of connectivity in the electric power industry presents a number of important challenges.

- **The Telecom Infrastructure Challenge.** The technology landscape for utility telecommunication is rapidly changing. Carriers and service providers are discontinuing the copper and TDM circuits that utilities have relied on for SCADA and other critical applications. As utilities look at options for replacement circuits or connectivity for new applications, there is no silver bullet solution. It is possible that the long term solution involves building applications on fiber infrastructure that is likely to become ubiquitous but many of the applications that are possible cannot wait for this deployment and may even work better with wireless solutions. When considering wireless technologies, utilities are confronted with a critical shortage of affordable licensed spectrum, and increasing congestion and unpredictable performance in unlicensed spectrum. Commercial cellular operators have yet to establish a track record for reliability and fast service restoration. Fiber is a "gold standard" for performance and reliability, but installation costs for fiber remain high, especially for applications that have endpoints distributed across a wide area.
- **The Data Challenge.** Improving the reliability and operational efficiency of the power system increasingly depends on integrating large volumes of data from heterogeneous sources across the power system, at low cost in a short period. This issue will only become more acute as the number of connected sensors and devices increases exponentially with the supporting communications infrastructure.
- **Proprietary Legacy Systems.** For power supply and demand operations, the ability to take full advantage of emerging connected devices and systems is hampered by a combination of proprietary systems and legacy equipment on the utility side, as well as closed systems on the customer side of the meter.
- **Need for Enhanced Security.** In the changing utility landscape, more communicating devices operate outside the electricity providers' physical control. With respect to cyber security, this presents a growing "attack surface area." The same concern exists for customers and product providers who may have security vulnerabilities if standard internet security protocols are not embedded in the smart devices.
- **Inconsistent Lifecycle Timescales Between Communication Technologies and the Power System.** Generation, transmission, distribution, and retail electric companies need to be sufficiently nimble to integrate emerging and rapidly changing technologies, while providing for the operation of legacy systems and assets that may have a decades-long life cycle.

Connectivity Challenges

Connectivity in the electric power industry poses several challenges, including the large volume of data; proprietary legacy systems and the need for enhanced security; and inconsistent lifecycle timescales of utility assets and rapidly-evolving connectivity technologies.

The Data Challenge

Connectivity inherently presents the challenge of economically and quickly integrating and effectively using large amounts of heterogeneous data across the power system. An essential research question is how to derive information and knowledge from data collected and communicated using new technology? An underlying concern is that massive volumes of data are insufficiently processed to derive the enormous embedded value. Another area of concern is data quality and integrity. Companies often fail to assign personnel roles to address data quality, allowing problems to propagate as systems progress from pilot to production. Utilities may lack accurate accounting for costs incurred from poor data quality because it is difficult to differentiate good data from bad data, making it challenging to know the magnitude of the problem and the associated value at risk [17].

The industry has not yet fully resolved issues related to the integration of disparate data sets and those from operational silos. This is not unexpected, as most data collection has been traditionally funded by departments, which tend to own and protect their data. Many data analytics efforts outside of smart meters are at the pilot stage and not fully deployed.

Much of the value from analytics efforts to date is centered on AMI data. Some utilities are successfully implementing secure cloud solutions for data cost management. These tend to be point solutions and do not yet bridge the enterprise. In nuclear power plants, managing and maintaining diverse collections and streams of information remains a challenge. Implementing an advanced configuration management information system (CMIS), however, could provide significant operational and economic benefits. This opportunity is discussed further beginning on page 29 [18].

Some utilities are making a concerted effort to reconfigure the role and integration of their IT groups with grid operations and analytics. Some have brought in IT management from the banking and data center industries with secure data and streaming analytics experience. Many utilities are grappling with questions concerning ownership of analytics and applications. Corporate buy-in and ownership is an area where best practices for utility analytics must be vetted. Each data set and data analytics project must stand on its own, based on the value it brings to the enterprise. Moving forward, effective coordination between IT and OT will be a key enabler for a flexible power system [19]. Early pioneers like Eversource Energy, Bonneville Power Administration, and Vermont Energy Investment Corporation (VEIC) are beginning programs that will collect massive amounts of data from a variety of devices and will use this data to support energy efficiency (EE) programs and targeted demand response (DR).

In its Transmission Modernization Demonstration and Distribution Modernization Demonstration (TMD & DMD) projects on data analytics, EPRI's two-year update on the general data analytics priorities of 14 utilities found that the volume of data is not the most significant challenge [20]. Although specific data analytics applications are being identified and prioritized, a more significant challenge is associated with what is called "little data" (see Figure 2). "Little data" can be described simply as when the number of data sets is greater than the ability to integrate and analyze or process the associated data [21].

The Telecom Infrastructure Challenge

The telecom infrastructure provides the transport of the data across the power system. This infrastructure is built out of many technologies. The core Wide Area Network (WAN) is generally based on fiber deployed to key locations, with point to point microwave to harder to reach locations. The Field Area Network (FAN) provides connectivity outside the substations and is typically based on wireless technology. Every aspect of the telecom infrastructure is being challenged by the integrated grid. New intelligent devices and sensors require connectivity at locations that have never been served before. As AMI becomes able to provide valuable data in higher volumes and more frequently, the amount of bandwidth needed for AMI backhaul increases. Increased requirements for physical security are driving the deployment of video surveillance, which demands bandwidth orders of magnitude greater than traditional applications.

Modern IP-based technologies make it possible for the telecom network to serve multiple applications over a common infrastructure. The integrated services WAN and FAN are enabling utilities to move away from the approach of deploying an independent communications system for every application. Integrated FAN deployment also requires new economic modeling, since no single application can justify the investment by itself, but the value of the whole network is greater than the sum of the parts.

The primary route for transmission and distribution telecom has been between the control center and the edge of the grid, including substations and intelligent devices further down the feeders. In the integrated grid, connections may include device-to-device paths as distributed intelligence and field message bus standards enable new ways of managing devices and partitioning control applications.

Proprietary Legacy Systems and the Role of Standards

Taking full advantage of emerging connected devices and systems is hampered by a combination of proprietary systems and legacy equipment. As the grid's IT and OT systems converge, a transparent standards development process is important. It must consider the needs of all stakeholders – producers, consumers, and innovators. Industry feedback and contributions will ensure that the industry minimizes use of proprietary interfaces that require customization and prohibit or suppress innovation. Standards provide the flexibility to select products and

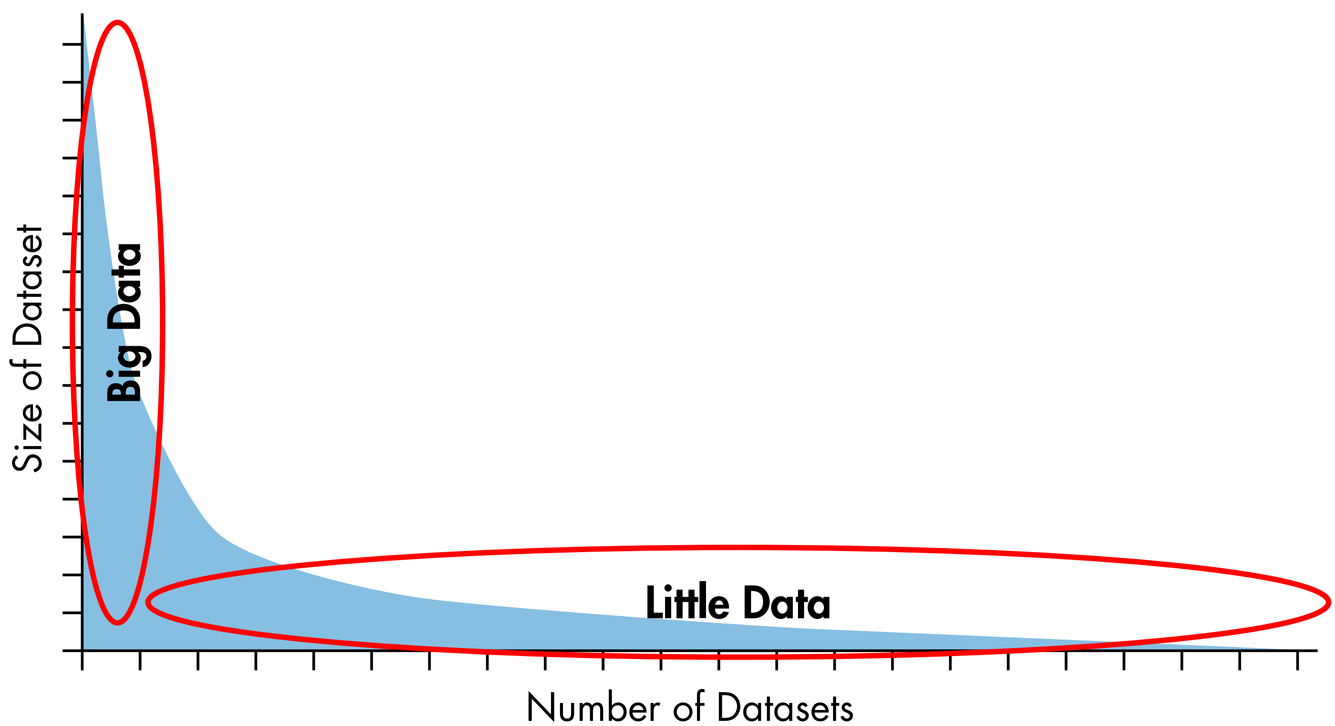

Figure 2. Little Data versus Big Data [21]

tools that affordably address changing business needs. Three important attributes of standards to enable innovation are unlimited use, open and unrestricted access to use the standard, and the ability for anyone to benefit.

Standard: OpenADR 2.0b (Demand Response)

Examining a recently developed standard that addresses connectivity illustrates these attributes. The Open Automated Demand Response (OpenADR 2.0b) standard serves an important function in connecting grid-managed distributed energy resources (DER) on the distribution system. It serves as an example of a standard that was produced with broad stakeholder input.

- **Attribute #1: Unlimited Use.** OpenADR focuses primarily on a resource's electrical characteristics (e.g., load dispatch set point, load control capacity, charge state). Whether the resource is a generator, energy-consuming device, microgrid, building, vehicle, battery, or something not yet envisioned, the standard applies.
- **Attribute #2: Open and Unrestricted Use.** The standard is based on the Organization for the Advancement of Structured Information Standards (OASIS) Energy Interop and is available free to the public on the OpenADR website. Open access enables other stakeholders to develop products that interoperate, are interchangeable, and support cyber security requirements.
- **Attribute #3: Anyone Can Benefit.** As a public standard, anyone can produce products that meet its specification and undergo OpenADR Alliance certification. EPRI has developed OpenADR 2.0b open source software to evaluate the standard in demonstrations and for use by other innovators [22].

Standard: IEEE P2030.5 Smart Energy Profile (SEP) Application Protocol (Demand Response)

SEP 2.0 is an application protocol to enable management of end-user energy environment, including things like demand response, load control, time of day pricing, management of distributed generation, electric vehicles, etc.

Standard: Common Information Model (CIM)

The common information model (CIM) has been adopted by the International Electrotechnical Commission (IEC) and has an active user community, the CIM Users Group. It is supported by vendors such as ABB, IBM, Oracle, Siemens and others, and continually drives toward improvement. The EPRI CIM 2012 Update and 2013 Update provide insights on implementations by several utilities [4, 23]. Response to the 2013 CIM survey nearly doubled from the previous year, indicating growing interest and adoption worldwide. EPRI published a CIM primer that provides an introduction to the core CIM concepts and uses such as semantic models, application integration, and network model management [24].

Significant progress also is being made to enable innovation through web standards such as those led by the World Wide Web Consortium (W3C), and through technical interoperability such as an enterprise service bus (ESB) or service oriented architecture (SOA).

Standard: IEC 61850 (Enhanced Substation Automation)

Developing useful information from the mass of data owned by utilities requires strategies for sharing data among applications and across the enterprise. A model-driven approach is the most valuable long-term strategy.

The IEC Standard 61850 ("Communication for Networks and Systems for Power Utility Automation") and the CIM provide the basis for semantic models in the substation and enterprise levels respectively. IEC 61850 was developed to model various substation devices with a format readable by both humans and machines. Devices based on the IEC 61850 standard are "self-describing" (self describing – to automatically provide all the relevant characteristics, configuration, or qualities of a device upon inclusion into an established system or network), which is critical when many devices must work together to manage the power grid. For more information, refer to EPRI's report on the management of advanced IEC 61850-based systems and its training DVD on IEC 61850 for the smart grid [25, 26].

Standards in Lower OSI Layers

Standards at OSI layers in addition to applications, such as the physical, data link, and network layers, are equally important for interoperable connectivity (see Figure 1). These include standards such as the Institute of Electrical and Electronics Engineers (IEEE) 802 (network standards), 3GPP (3rd Generation Partnership Project, which is a mobile broadband standard), and the Internet Engineering Task Force (IETF) IPv6. Refer to page 29 for more information on IEEE 802, for example.

Need for Enhanced Security

To enable connectivity, cyber security and communication infrastructure need to consider the growing "attack surface area." As more devices on the grid become connected, the cyber-attack surface area becomes larger, requiring "defense in breadth." The defense to this relies on overlapping protective measures so that if one measure fails, another provides adequate protection. As more remote devices are connected to the grid, it is increasingly important that architectures, tools, and procedures provide end-to-end security. Technology needs to be deployed in ways that when compromised, the full risk is known and can be mitigated. Additional complexity and similar risks are posed by remote employees, field crews with mobile devices, and bring your own device initiatives, and these should be considered [8].

Two key topics are relevant in this area and require further work:

- Network and system management
- Centralized threat management

Network and System Management

Network and System Management (NSM) can enhance the security of devices, links, and interfaces. The challenge is that as more IP-based networks and devices are deployed, managing the information infrastructure will become crucial to providing high levels of security and reliability in power system operations. In the transmission domain, NSM addresses this challenge through operational efficiencies, including monitoring, controlling, and securing communication devices, links, and interfaces within systems, with localized and distributed functions.

The electric sector is beginning to recognize the advantages of applying NSM technology to power systems, especially for substation local area networks (LANs), where multiple vendors are developing tools. While moving in the right direction, these tools are still limited in their capabilities and not interoperable. What is needed is a standard, interoperable set of NSM objects that is supported by NSM vendors. Interoperability prevents vendor "lock-in," ensuring that products from various vendors are interoperable and best-in-class components from any supplier can be used.

NSM objects would use and extend existing network control and management protocol standards while creating utility-centric standard object models that are interoperable across equipment supplied by diverse vendors for bulk power system automation and information systems. Applying NSM objects to the transmission system would support several key operational objectives:

- Integrated awareness of network activity, state, and health within electrical utility networks
- Uniform and logically consistent packet prioritization, service segmentation, and processing internally (substation Local Area Network [LAN]) and externally (substation-to-substation area network, substation wide area network [WAN])
- Effective monitoring, maintenance, traffic control, and logging for the electronic security perimeter
- Security monitoring, control, and management of end-use devices

The International Electrotechnical Commission (IEC) 62351-7 Edition 1 standard provides a first draft of abstract object models for performing network and system management functions to enable security architecture guidelines advancing secure access, reliability, and network confidence. Most of the industry is not yet familiar with this standard, and it must be revised to truly support interoperable implementations.

This interoperability will be key to realizing the operational benefits of NSM technology, where the potential is not in the objects themselves, but in the applications that are built to manage these objects. These applications may be deployed in the substation network components, gateway devices, intelligent electronic devices (IEDs), or in the control center [27, 28].

Centralized Threat Management

Another cyber security challenge is the lack of a central threat management capability. Typically, groups and operators within a utility independently gather and analyze information using isolated and siloed systems that monitor security for physical, enterprise, and control system environments. These include data centers, workstation networks, physical security, supervisory control and data acquisition (SCADA) systems, energy management systems, and field equipment. As threats' landscape have grown and changed, utilities need a coordinated view of all aspects of an organization's security posture (situational awareness); a view of potential events (both unintentional and malicious) that may impact an organization's security posture; and planned responses to these events.

In the past two years, several utilities addressed this by developing and implementing an integrated security operations center (ISOC) [29]. An ISOC is designed to collect, integrate, and analyze events and logs from these traditionally siloed organizations, providing much greater situational awareness to a utility's security team. Additionally, an ISOC enables utilities to move to an intelligence-driven approach to incident management, which is more effective for handling advanced threats. Given these advantages, an ISOC's value to utilities can include:

- Central (corporate/OT) security incident management
- Optimized security resources and spend
- Improved threat analysis across utility domains
- Unified configuration/patch management
- Efficient forensics gathering and execution of root cause analyses

However, building an ISOC requires significant technical resources, staff, and time. Additionally, companies may need to overcome considerable organizational barriers for the deployment to succeed. EPRI completed a guideline for utilities to plan and implement an ISOC. The process can be accomplished in multiple phases, beginning with control centers and followed by substations [29, 30].

A point of intersection between centralized threat management and network management is the identification of cyber or physical threats through network performance metrics and correlative analysis. This research area is being explored in the Telecom Initiative to identify threats through changes in network traffic patterns and volumes reported through network management and metrics.

Inconsistent Lifecycle Timescales Between Communication Technologies and the Power System

Utilities are challenged to address the disparity in lifespan of their assets juxtaposed with rapidly advancing connectivity challenges. Connectivity-related innovations such as smart thermostats, advanced system sensors, analytical tools, and smart inverters are becoming more prevalent and affordable, and all are characterized by rapid innovation.

Utility assets such as transformers, meters, power plants, and capacitor banks, along with customers' HVAC systems, water heaters, and electric vehicle chargers, may have a lifespan extending to decades. Emerging communication technologies and hardware may have a lifespan of 18 to 36 months before they could be replaced by products with new or more advanced capabilities and features [8, 31]. Given the resulting uncertainty about investment, developing a modular communication architecture becomes more important for preserving the useful life of legacy equipment, while enabling deployment of new communication technologies. Other methods for utilities to avoid near-term obsolescence are cloud-based OpenADR implementations through vendors that provide them with targeted load reductions without having to reach the end-devices. This isolates changes at the end-devices within the vendors' space and provides utilities with required load management, but also may induce risk for the owner of the end-devices if, in the future, that vendor stops providing associated services for the proprietary end-devices.

A related challenge is that most utility information and communication technology (ICT) infrastructure was not designed to integrate or interface with these emerging devices or disparate systems without significant engineering or customization.

OPPORTUNITIES FOR THE ELECTRICITY SECTOR

This section covers opportunities that connectivity enables in the electric power industry. The following areas are addressed:

- Workforce and automation
- Customer end-use devices and distributed resources
- Transmission
- Distribution
- Power system monitoring and control
- Power generation
- Environment

Workforce and Automation

Connectivity can enhance worker productivity using so-called "workforce multipliers." These multipliers support cost-effective performance, without reducing safety, reliability, availability, or capabilities, and reduce the likelihood of human errors. Workforce multipliers include:

- Support systems, including automation
- Better information access (including remote information) and presentation
- Remote access to experts, including audio and video communication
- Automated work packages in the field that can include capabilities such as ensuring that correct equipment is being worked on before the procedure steps can be completed
- Smart sensors that can analyze data and present information to workers in a meaningful and helpful form—groups of smart sensors could share and analyze data to present a more complete picture to the worker
- Shared real-time information among field workers, engineering, maintenance, outage centers and control centers
- Real-time monitoring, diagnostics, and (potentially) prognostics on equipment and systems

Connectivity creates an opportunity for improved data analytics but can create challenges if there is inadequate data governance. If conducted properly however, such analytics can improve productivity. Utilities typically devote significant engineering to data entry, data maintenance, data transfer, and error identification and correction. Enabling integration (connectivity) of existing utility data (to say nothing of the growing volume of new data) could significantly reduce labor, increase insight, and improve decision-making. An EPRI project in this area combined three leading data management frameworks that built on the strengths of each, and now serves as a foundation for utilities attempting to address issues related to big data [32].

Other multipliers are illustrated in the following areas:

- Nuclear plant long-term operations
- Geographic information systems
- Social media

Customer End-Use Devices and Distributed Resources

Connectivity can enable the connection of intelligent customer end-use devices and integrate distributed energy resources into the grid.

Connected and Intelligent End-Use Devices and Resources

Connectivity enables the integration of intelligent customer end-use devices and distributed energy resources. Many utility projects and pilots involve demand-responsive appliances, which requires "smart" communication with heat pumps, water heaters, thermostats, electric vehicle service equipment, and others. These pilots are transitioning into programs for energy efficiency and demand response within utilities such as Eversource Energy (Northeast Utilities), San Diego Gas and Electric, and Commonwealth Edison. As the retail adoption of these devices grows, programs that leverage the customer-owned resources also grow in tandem as the target customer base grows. It is important that we pay heed to consumer needs, as programs that are in tune with customer requirements will find greater adoption in the marketplace.

Ideally, available products would use open information and communication standards, but absent such standards, business decisions must consider the associated risks of deploying proprietary solutions against cost benefits and customer recruitment considerations. Risks include stranded assets, lack of competing products slowing innovation, vendor lock-in, and solutions not aligned with utility requirements.

Consumer Electronics Association (CEA) CEA-2045 is a new standard for a modular communication interface for demand response[2]. It was developed to address issues associated with rapidly evolving communication technologies for appliances with a lifespan of decades, with particular focus on products with demand-response capabilities. It defines a port/plug for off-the-shelf consumer products compatible with multiple utility demand response systems, for a customer-installable plug-in communication module (see Figure 3). Reference 33 is an introduction to American National Standards Institute (ANSI)/CEA-2045, and reference 34 assesses its application to the U.S. Environmental Protection Agency's EnergyStar "Connected" appliance criteria.

This standard enables manufacturers to make retail products demand-response ready. A physical connector (CEA-2045 compliant) that is compatible with utility demand response communication systems can be available through normal retail supply channels – independent of the communication technology or architecture. With this architecture, an appliance with a life of 20–30 years may function in demand response programs without risk of obsolescence due to evolving communication systems.

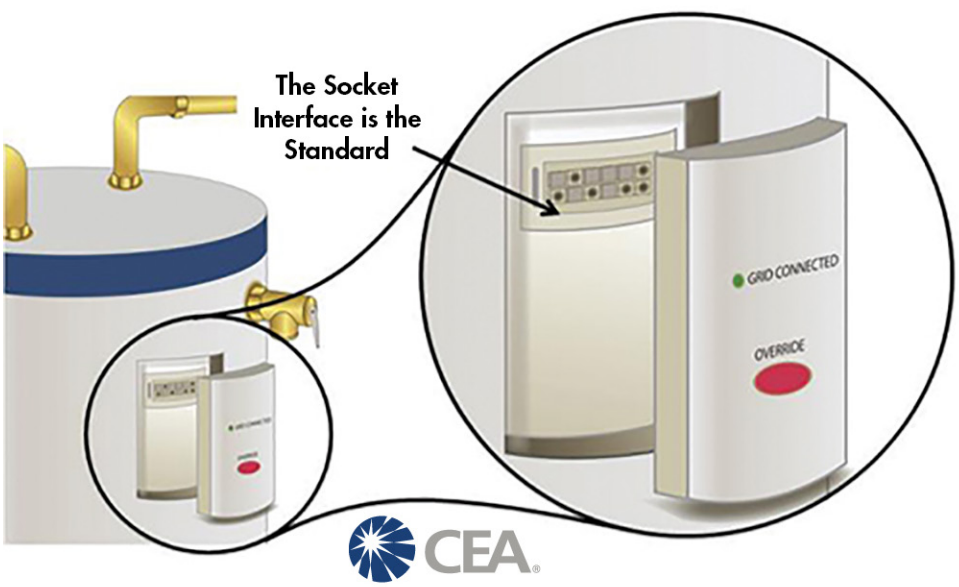

Figure 3. CEA-2045 Modular Communication Interface [8]

The intent of CEA-2045 is to make it practical for end-device manufacturers to mass produce retail-viable demand response (DR)-ready end-use devices, at minimal upfront cost, that could be compatible with DR programs everywhere. It also is intended to avoid the need for utility "truck-rolls" and plumbers or electricians by being simple enough that consumers could plug in communication modules without assistance.

[2] *CEA is an American National Standards Institute (ANSI) standards-development organization.*

EPRI is demonstrating the standard with utilities and exploring other applications of a modular architecture supporting transmission and distribution equipment [8]. The EPRI CEA-2045 Field Demonstration is a comprehensive assessment of this new standard, in which participating utilities install and connect to DR programs water heaters, pool pumps, air conditioners, electric vehicle chargers, and solar inverters. The performance and compatibility of the standard are then evaluated relative to a range of program requirements. Consensus functional requirements for end-use devices are being developed and shared with manufacturers for producing CEA-2045-based products for field installation and testing [35].

In addition to CEA-2045, EPRI is working with multiple approaches to integrate connected devices. In the smart thermostats arena, EPRI is working with multiple DR aggregation partners including Honeywell, EnergyHub, EcoFactor, ecobee, and Cooper systems to conduct demand response field pilots of over 5000 devices. These aggregation platforms enable the bring your own device models by aggregating multiple hardware products using their APIs (for example, EnergyHub aggregates 15 different connected thermostats). Using this approach enables the hardware product provider to deliver a tailored customer experience for comfort and convenience. These aggregation platforms can also be embedded with open standards such as OpenADR to provide an open standards based load management program.

The aggregation of connected devices using APIs can be extended to aggregation of other loads such as water heaters, plug loads, and appliances, as well as balance the loads with PV and storage. In one of the EPRI initiatives studying grid impacts of zero net energy homes in Southern California, a control platform is being built to measure PV output and its impact at the distribution transformers and drive a combination of end-use loads and energy storage to reduce grid impact. The device architecture being implemented in this project is shown in Figure 4, and two key requirements for this architecture are that the device should be capable of operating independent of the aggregation architecture, and the customer should be able to experience their smart home without seeing an impact of grid management actions (such as demand response).

In summary, various approaches that use currently available open standards can be utilized to manage connected devices on the customer side of the meter.

Integration of Smart Distributed Resources into the Grid

Connectivity enables integration of smart distributed resources into the grid. Since 2009, EPRI has facilitated the Smart Inverter Communication Initiative, working to define common functions and communication protocols for integrating smart distributed resources with the grid. The goal is to enable scenarios in which diverse inverter-based

The Integrated Grid

The successful integration of DER depends on a grid that, particularly in its distribution systems, was not designed to accommodate a high penetration of DER while sustaining power quality and reliability. The technical characteristics of certain DER, such as variability and intermittency, differ significantly from central power stations. To realize fully the value of distributed resources and to serve all consumers at established standards of quality and reliability, the need has arisen to integrate DER in grid planning and operation and to expand its scope to include DER operation—what EPRI is calling the *Integrated Grid* [3].

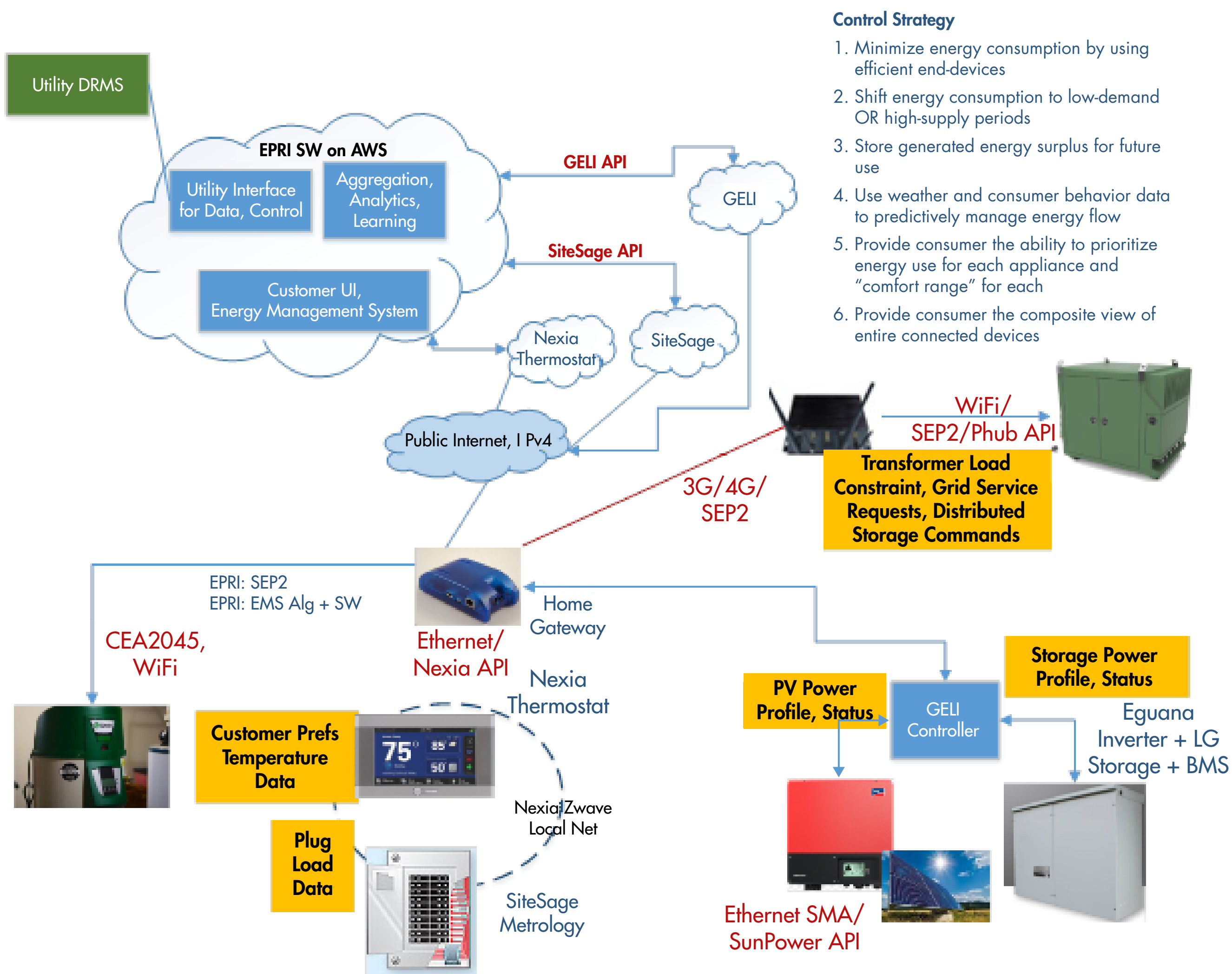

Figure 4. Zero Net Energy (ZNE) Grid Integration Platform

systems, such as photovoltaic and battery storage of various sizes and from various manufacturers, can be integrated extensively into distribution circuits in a manageable and beneficial way. This requires consistency in the devices' services and functions, along with uniform, standards-based communication protocols for their integration with utility distribution management and SCADA systems. Utilities and device manufacturers are encouraged to utilize these functional descriptions to aid in the development of requirements for smart distributed resources [36]. EPRI has also published a state-of-the-industry overview of smart inverter field experiences [37]. In addition, standards for required data from connected devices could enable utility programs for energy efficiency and demand response, as well as provide better targeted customer services.

Transmission

Connectivity can provide benefits in the following areas related to transmission:

- Improved insight into transmission (and distribution) asset health
- Improved management of transmission network modeling

Transmission and Distribution Asset Health Insight

Connectivity enables improved insight into transmission and distribution asset health. Asset health is fundamental to the need for solid, model-based information sharing on both transmission and distribution systems. Many analytics applications are available to aid in determining asset condition and performing asset-related risk assessments. However, nearly all require data that originates from diverse sources in differing formats and in different time horizons. Similarly, outputs of typical asset health analytics are provided in siloed, proprietary form, impeding their use by other applications. The CIM has the potential to form the basis of a robust semantic model supporting the organization of asset health-related information for analytic applications, though it has not been widely deployed for that purpose. Details on how the CIM can be employed in creating a framework for effective asset health information sharing can be found in an EPRI report on this subject and an *Electricity Today* article [38, 39].

Improved Transmission Network Model Management

Connectivity enables improved management of transmission network modeling. Multiple applications within a utility make use of electrical system network models. These include those used for real-time operation of the grid, expansion and generator interconnect planning, outage studies, electricity market operation, protection system design, and training. These models typically are maintained independently for each application, with variations of the same data manually entered into each application's database. Engineers often spend significant time entering, synchronizing, validating, and correcting duplicate information instead of actually doing system engineering. Because CIM is mature and field-tested for network equipment, connectivity, topology, and power flow solution exchange, it provides a basis for a coordinated network model maintenance strategy. A recent EPRI report outlines steps that a utility could follow to understand and document its transmission network model management processes, to envision how centralized model management might work, and to understand where this might provide the greatest benefit [40].

Distribution

Connectivity can provide benefits in the following areas related to the electric distribution system:

- Enhanced storm damage assessment, outage management, and restoration
- Enhanced worker productivity using geographic information systems
- Enhanced worker productivity using social media
- Enhanced customer communication regarding outages, duration and restoration
- Enhanced communications with field devices and crews using field area networks
- Enhanced interoperability in advanced metering infrastructure
- Leveraging retail broadband networks

Enhanced Storm Damage Assessment, Outage Management, and Restoration

Connectivity enables enhanced storm damage assessment, outage management, and restoration. On distribution systems, data analytics can predict outages or equipment failures, and communication networks can automatically indicate when and where an outage has occurred. For storm recovery, assessing the damage and improving tools to communicate field crew activities may reduce recovery time significantly. For major events, any efforts or technology that can accelerate damage assessment could reduce restoration times by hours or even days.

One tactic is providing field crews tablets with global positioning system (GPS) sensors and cameras, equipping crews to document damage and create work orders on site (see Figure 5). Developing standards for doing this could allow mutual assistance crews to use their own companies' devices, needing only to familiarize themselves with the interfaces and process, thus minimizing the required training [8].

Figure 5. Augmented Reality Applications on Tablets for Field Crews [8]

Enhanced Worker Productivity Using Geographic Information Systems

Connectivity enhances worker productivity using GIS. Another workforce multiplier enabled by connectivity (described earlier) is using geospatial data via geographic information systems (GIS), which is poised to increase dramatically in the next few years. A Navigant study reports that about 60 percent of utility employees work on field assets with spatial attributes [41]. Mobile GIS tools can provide better information access and presentation, automate work packages in the field, and communicate information among field workers, outage centers and control centers in real time.

Benefits of Using Social Media

Connectivity using social media enhances storm damage assessment, communication with the public, and restoration. Utilities are exploring the use of social media in outage management to make the public an integral part, including setting expectations for restoration time. Utilities are using social media in damage assessment, recognizing the need to expand options for two-way communications with customers, particularly for large outages. Social media also may help reduce outage duration through better communication with the public, but it also poses risks, including unauthorized information disclosure and the spread of false information. EPRI conducted three U.S. workshops in 2013 to examine opportunities and challenges for using customer information generated through social media and other applications to improve outage management capabilities [42, 43].

Enhanced Communications with Field Devices and Crews Using Field Area Networks

Connectivity via field area networks (FANs) enhances communications with field devices and work crews. EPRI research assessing utility FANs is paralleling global trends. EPRI sees growing interest in pursuing unified IP-based networks in various scenarios (e.g., public, private, licensed, unlicensed) for communications to field devices and work crews. The business case for combining multiple, disparate communication systems into a single system becomes stronger as costs continue to drop, products become more available, and network performance improves [8].

EPRI's three-year FAN demonstration program explores best practices in their architecture, design, deployment, and operation. The FAN concept is a ubiquitous, high-performance, secure, reliable network serving a range of smart grid applications that historically have been performed by separate communication infrastructures. This in turn may reduce utility and customer cost, increase reliability, improve power quality, and reduce environmental impacts. Although a FAN does not produce these benefits, it can enable them. A network such as this with no applications presents only a cost, but one supporting multiple applications can be very valuable [44].

A FAN evaluation project at the Salt River Project (SRP) illustrates this type of network. SRP is assessing the technical and business options for deploying a FAN with an objective to determine the approach that best unifies existing wireless systems, and enables additional IEDs to support SRP's electrical distribution network and water business.

For SRP, the FAN is a strategic capability that benefits existing systems and planned upgrades by unifying various single-purpose communications systems. It also enables applications that would be otherwise impractical due to technical limitations or cost. Among the applications that SRP evaluated were distribution feeder automation, capacitor control, electronic systems monitoring, water SCADA, water delivery gate keeper, video, and field force data. Advanced metering backhaul is being considered for future evaluation (see Figure 6). The project developed the data and analysis to answer the questions: "Should SRP implement a FAN?" and "What type of FAN architecture and technology should be deployed?" [45]

Enhanced Interoperability in Advanced Metering Infrastructure

Connectivity facilitates interoperability. Interoperability is the ability of two devices or systems to exchange information and use that information to perform their functions. The vision of the smart grid is that millions of devices in different domains and with different owners will be able to exchange information securely, with minimal integration cost and difficulty. Therefore, interoperability is critical.

Connectivity enables interoperability in advanced metering infrastructure projects. EPRI is developing a roadmap for an open, operable AMI. In recent years, AMI systems have been among the largest smart grid-related utility investments. However, most (if not all) systems available are proprietary, limiting utilities to a single vendor, limiting flexibility, and raising costs. Even when some elements of a given system are based on standards, proprietary elements could restrict a utility to an AMI vendor. As with other aspects of grid modernization, open standards for AMI have the potential to improve interoperability, increase choices, and provide greater flexibility in system implementation.

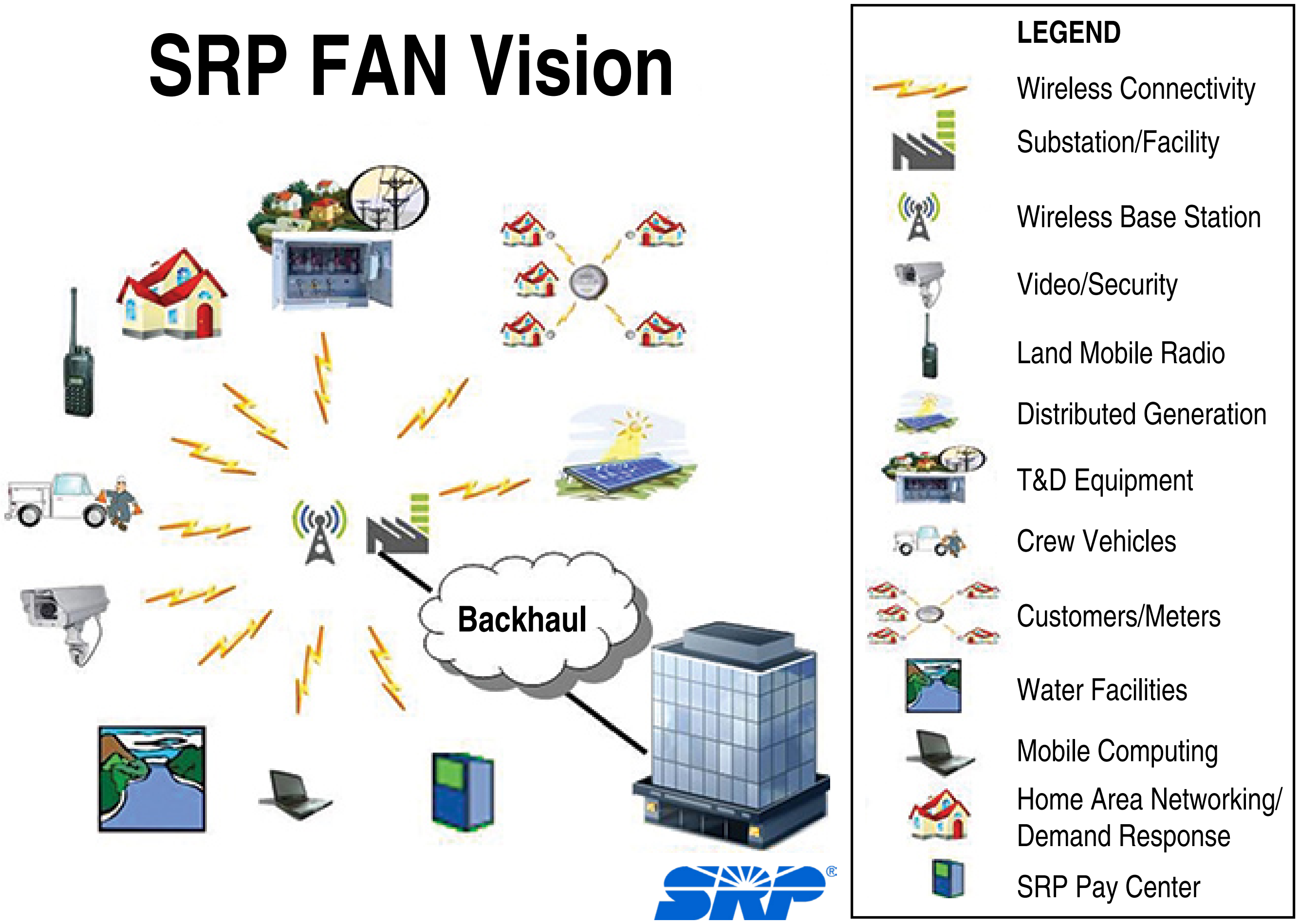

Figure 6. Vision of a Field Area Network at the Salt River Project [45]

EPRI developed a roadmap for open interoperable AMI, as the first step in developing a strategic plan to achieve open, interoperable AMI systems. Initially, participation in plan development has been limited to utilities. What differentiates this from prior industry activities is its focus on specific points of interoperability that add value to the utility.

Initial development was conducted in conjunction with a focus group of utility representatives identifying the values to be realized from interoperable AMI. A generic AMI architecture was developed to represent all types of AMI systems and put the values in context. Using the architecture, participants and interfaces could be identified, along with the existing standards and gaps at those interfaces. A workshop evaluated the values and ranked them in terms of perceived value and the time frame for completion. Based on this input, the different aspects of interoperability were consolidated into four "themes," which are elements of the roadmap (see Figure 7).

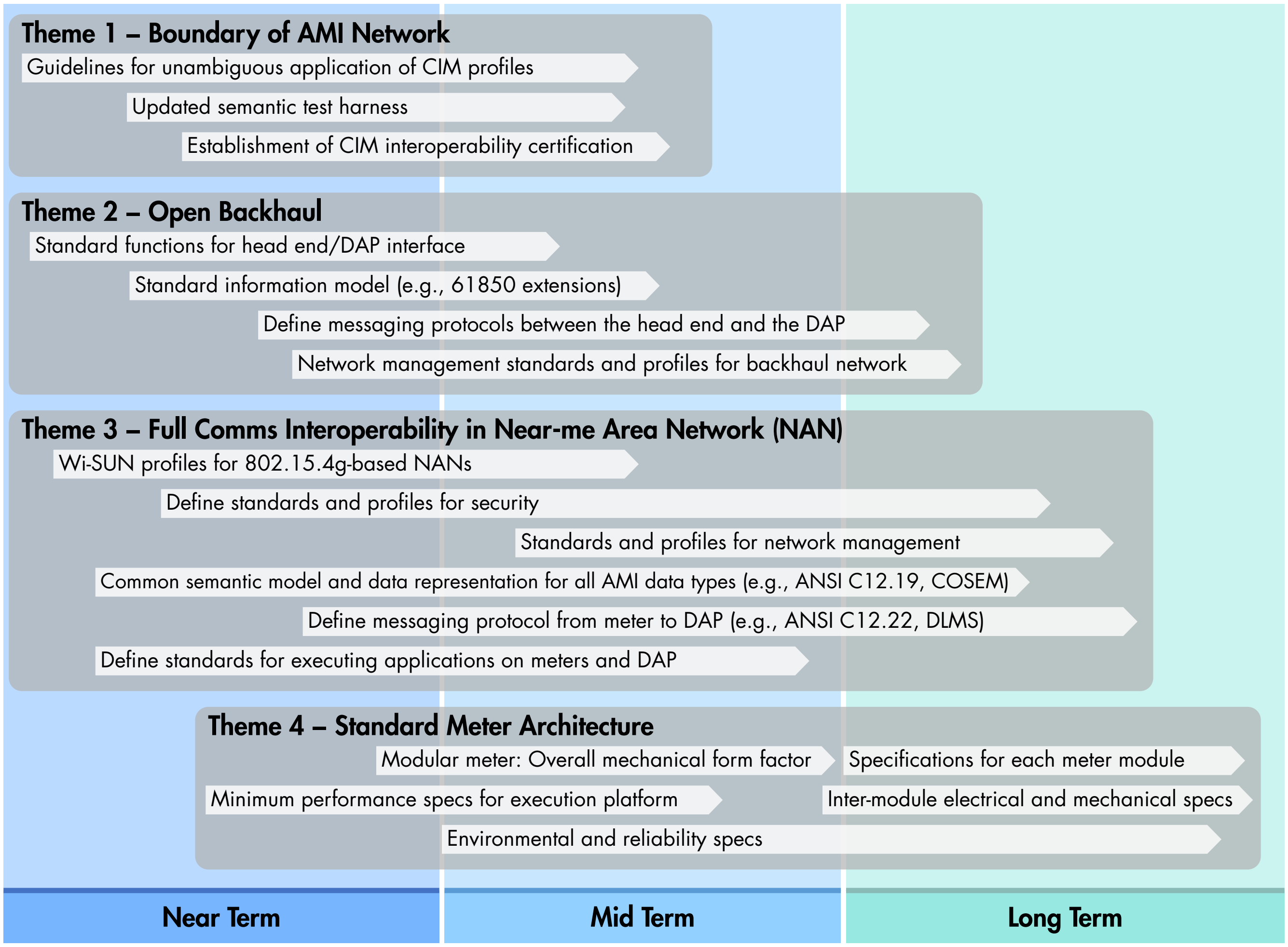

Figure 7. EPRI Roadmap: Open, Interoperable Advanced Metering Infrastructure (AMI) [46]

Connectivity Can Leverage Retail Broadband Networks

Connectivity enables utilities to use ubiquitous retail broadband networks. Another way to address communications infrastructure challenges is to examine the possibility of using existing communications infrastructure for power industry needs – specifically, retail broadband networks. These networks, such as cable, digital subscriber line (DSL), and high-speed wireless networks are available at nearly all customer premises in the U.S. and many other countries. The portion of the population subscribing to these networks for Internet service is rising. EPRI issued a report examining the use of retail broadband networks for smart grid applications, particularly those related to residential customer integration. It provides insights into the architecture required for future AMI systems, specifically exploring the potential of customer broadband systems and methods for determining the need to deploy private utility networks.

Two broad conclusions emerge. First, customer integration applications beyond meter reading are likely to have gaps in performance, especially throughput and latency, if attempted over private AMI networks. Second, operationally critical applications may have gaps in reliability, security, and coverage when operated over customer broadband networks without special provisioning from the operator. This would be of particular concern in applications involving distributed energy resources and outage management. Improvements in security, availability, and reliability should be achievable with cooperation and partnership between the utility and broadband service provider, but the details will vary based on the relationship and the specific provider network [47].

New models for leveraging retail broadband are emerging with the rapid deployment of Fiber to the Home (FTTH). Google Fiber is frequently mentioned in the news, but the FTTH deployment by the Electric Power Board (EPB) of Chattanooga, Tennessee, is a leading example of utility application of FTTH. EPB deployed a fiber network to reach every customer in their service territory. In addition to offering television, telephone, and gigabit Internet access to their customers, EPB uses the fiber as a field area network for operations, including distribution automation on 171 distribution circuits, and for AMI backhaul on 170,000 smart meters. The distribution switching automation enabled by a fiber connection to every recloser has resulted in 42% improvement in the System Average Interruption Duration Index (SAIDI) and a 51% improvement in the System Average Interruption Frequency Index (SAIFI) between 2012 and 2014. [54]

The Telecom Initiative is continuing research into the strategic application of fiber for utilities, including evaluation of potential new business models, economic analysis of fiber deployment, and fiber technology evaluation and roadmapping.

Power System Monitoring and Control

Connectivity can provide benefits in the following areas related to power system monitoring and control:

- Next generation control systems
- Smart grid devices as open application platforms for monitoring and control
- Wide area situational awareness

Next Generation Power System Control Systems

Connectivity enables next generation power system control systems. An effort by PJM Interconnection as part of its Advanced Control Center (AC^2) program demonstrates next generation power system control [48]. Commissioned on November 8, 2011, AC^2 features two fully functional control centers and remote data centers. Both sites are staffed 24/7 and simultaneously share responsibilities for operating the transmission system and PJM-administered wholesale electricity markets. Either site can run the regional transmission organization's (RTO) entire system independently should the other become inoperable.

This breakthrough proves that innovative technology, such as an SOA- and a CIM-based messaging architecture, can be adapted to real-time, high-performance, mission-critical environments leading to next-generation control systems. PJM sought an integrated architecture with embedded security controls, scalability, and flexibility, leading PJM to an SOA to interoperate with a new shared architecture platform. This was co-developed with Siemens to enable new members to integrate with the RTO, to support the adaptation of new technologies, and to invite innovation.

This open architecture, built on an ESB, as shown in Figure 8, enables the rapid integration of traditional utility applications and emerging smart grid applications. It provides flexibility and choices previously unavailable due to legacy control center applications. The shared architecture enabled PJM to deploy new energy management and market management applications while using legacy applications that can be replaced consistent with planned technology life cycles, avoiding unnecessary investment and risk [49].

Smart Grid Devices as Open Application Platforms for Monitoring and Control

Connectivity through smart grid devices can facilitate advanced monitoring and control. On the power delivery system, using utility smart grid devices as open application "platforms" rather than simply as "products" can facilitate interoperable advanced monitoring and control, among other benefits. While a product's function may be limited for its service life, or limited to functions that only the manufacturer can update, a platform can be open to the owner, and available to perform new functions enabled by applications that the owner selects. Advancements in microprocessor and software technology have made this practical. The range of utility devices to which it may apply is broad, including advanced meters, communication gateways or access points, SCADA networking equipment, and distribution controls such as capacitor banks, regulators, and switches. Beginning in 2013, EPRI launched an initiative to define and demonstrate an open application platform for advanced meters, working with utilities, meter

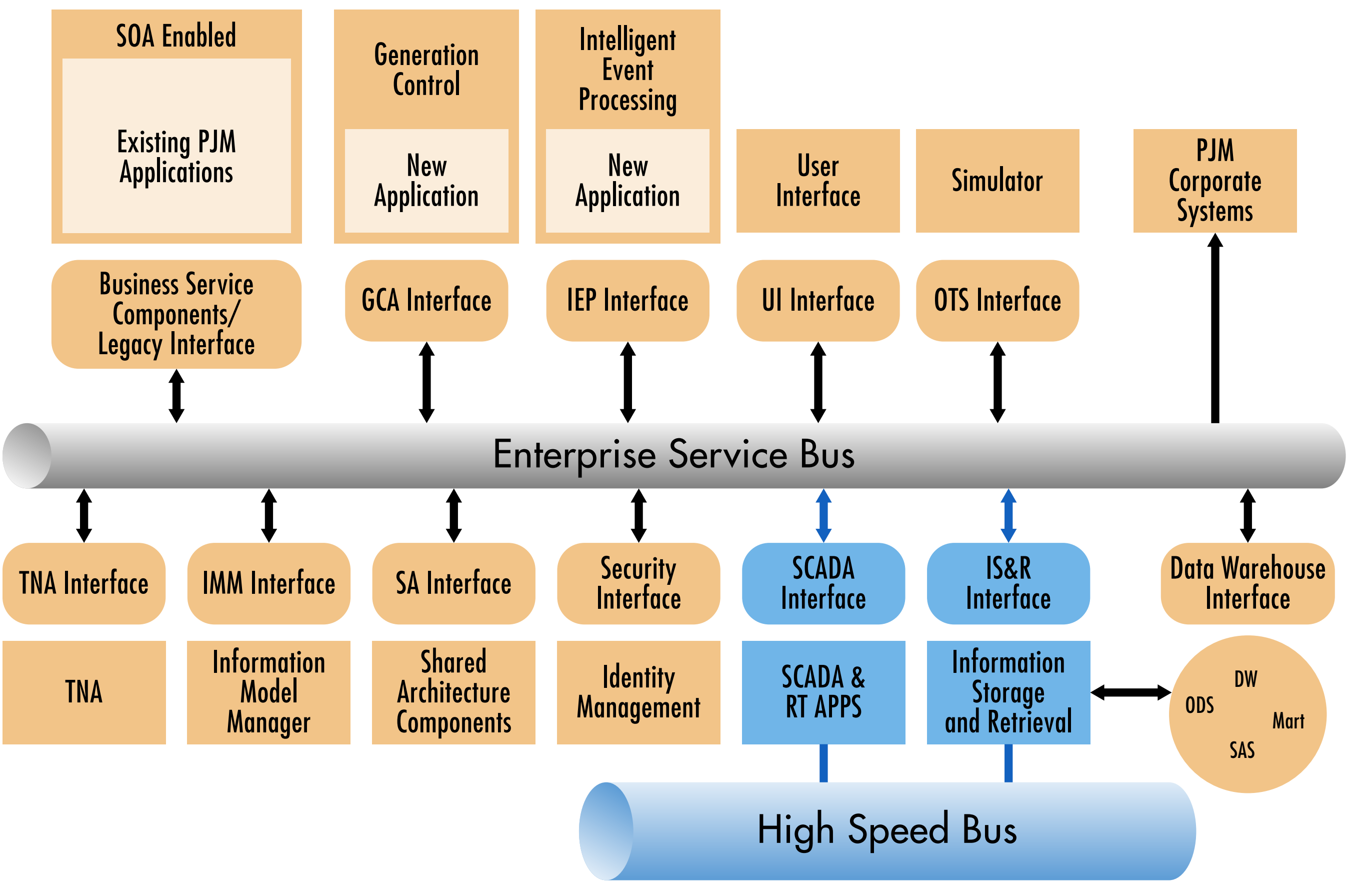

Figure 8. PJM Enterprise Service Bus [49]

Note: TNA = Transmission network analysis; OTS = operator training simulator manufacturers, and embedded platform providers. It resulted in a concept application programming interface (API) design, and meter platforms that were independently developed by project participants. Next steps include plans to conduct demonstrations, broaden participation, contribute the work to a formal standardization process, and to continue with other smart grid devices [50].

Wide Area Situational Awareness

Connectivity can facilitate improved wide area situational awareness. The operation of smart grid technologies is generating tremendous volumes of data. Utilities are taking on the daunting task of managing and turning this data into actionable information for monitoring, control, and other applications. For example, geographic information systems (GIS) are fundamental to integrating and using data across a utility for wide area situational awareness (WASA), and they require interoperable data exchanges from multiple data sources. The Federal Energy Regulatory Commission (FERC) defines WASA as the "visual display of interconnection-wide system conditions in near real time at the reliability coordinator level and above" [51].

Power Generation

Related to power generation, connectivity can provide benefits in these areas:

- Enable remote monitoring and analysis of generator performance, enhancing predictive maintenance and heat rate.
- Enhance worker productivity.
- Enable various capabilities.
- Allow for configuration management for nuclear plant information systems.

Worker Productivity in Generating Stations

Connectivity enables remote monitoring and analysis of generator performance, enhancing predictive maintenance. Remote monitoring of power plant operation has been used successfully to identify reliability-related problems in advance, permitting timely maintenance and preventing in-service failures. Remote monitoring requires a reliable communications network between the power plant and a central data facility. A *Power Magazine* article describes four case studies of the benefits of remote power plant monitoring [52]. An EPRI report describes the use of remote monitoring for heat rate improvement [53].

Connectivity enhances worker productivity in generation stations. In nuclear power work is ongoing under the joint U.S. Department of Energy (DOE) Light Water Reactor Sustainability Program and EPRI Long-Term Operation Program—as well as in the EPRI Nuclear Instrumentation and Control (I&C) Program that will include the information, interface, and connectivity aspects necessary to implement workforce multiplier capabilities. Much of this also will apply to fossil fueled plants and large renewable generation installations such as wind farms. Sample enabling topics may include:

- Architectures that integrate systems, work processes, and information
- Guidance for implementing effective human support systems
- Guidance for automation and human and automation function and task allocation and teamwork
- Guidance for procedures that are manual, partially automated, and fully automated
- Information models to support information exchange and consistent databases

- Augmented and virtual reality for consistent and better understanding of the situation for a person and among a group of people – including those in different locations, adding to the challenge of having a common understanding of the situation, context and needs
- Configuration management of information
- Guidance for segmentation of networks and systems and other defensive design measures.

Enhanced Connectivity in Generating Stations

Connectivity enables various capabilities in generating stations. Connectivity opportunities in generating stations can be identified by analyzing specific use cases on how communications can enable uses of available data from communicating devices and sensors. This can begin by inventorying available data and analyzing how it can be used, followed by establishing an accepted, recognized connectivity expectation. Logical connectivity between process data and business data would facilitate the process (e.g., automatically generate work orders based on process data).

A fresh wireless connectivity initiative for industrial applications that operates out of the box would potentially payoff by considering frequencies (including multi frequency and spread spectrum), modulation, power levels, and directional beaming that are tailored to the environment and application. New wireless standards for the 60 GHz band such as 802.11ad are now available and could be researched along with other mm wave frequencies for high power/short range applications. Other emerging standards such as 802.11ah operate at much lower frequencies with better propagation and penetration. This would also include hardened electronics for harsh environments.

However, wired technology can be considered in many applications. Wireless communication is susceptible to natural and man-made (accidental and malicious) interference because its perimeter cannot be reliably established. Uncontrolled use of wireless in unlicensed bands compounds the problem of electromagnetic interference/radio frequency interference and is causing congestion. While wireless is designed for mobile devices, most of the devices in the power industry are fixed.

Opportunities for mitigating negative aspects of hardwiring include reduced cable size; innovative conductor or channel methods; a "third way" for wires other than electromagnetic and optical; reduced structural requirements; and innovative electrical transmission methods that reduce power requirements of loop powered sensors. Lower-power sensors and wiring not requiring conduit and cable trays could make wired sensors affordable and draw attention to their use. Combined with "power scavenging" methods being researched for wireless equipment, wires could become very small and light with digital protocols. Wired technology also may address cyber security. Additional opportunities follow:

- Wired work-order tablet docking stations at every plant could be lower-cost to install and maintain, easier to use, and more reliable and secure than wireless tablets. They could use thin network technology other than baseband Ethernet, and high frequency electronics (HFE) could be used for validation.
- For installing e-net in industrial facilities, significant cost is associated with providing reliable power and HVAC in numerous places, due to the 100-m length limitation on unshielding twisted pair cabling. Standardized low-power, long-distance (1000 m) links could address this.

Industrial versions that comply with IEEE 1901 (the standard for broadband over power line networks) could open up advanced wired communications using the same wire for power and communications. In addition to power line communication (PLC) technologies, the IEEE 802.3 working group is developing standards for Ethernet over a single pair of wires (802.3bp) as well as Power over Ethernet (POE) for single pair (802.3bu). These have the potential to reduce cable cost and size and simplify installation while providing higher performance than PLC.

Configuration Management Information Systems in Nuclear Plants

Connectivity enables data-centric configuration management information systems in nuclear plants. In nuclear power plants, challenges arise for managing and maintaining diverse information relating to the plant's physical configuration. An advanced CMIS, however, could provide significant operational and economic benefits. A recent EPRI study estimated opportunity savings for implementing data-centric CMIS at $8 billion for the approximately 100 operating U.S. nuclear power plants over 20 years, and more than $1 billion for four U.S. plants under construction over their projected 80-year life. Through savings associated with more efficient data retrieval, reduced data errors, and increased workflow efficiencies, EPRI calculated a probable economic payback of 3.3 years for new plants and 5 years for operating plants.

An integrated CMIS encompasses data and information for all phases of the plant life cycle, including licensing, design, procurement, construction, testing, operations, maintenance, and decommissioning. A CMIS that is not data-centric requires plant staff to find the data in a document or siloed database, then verify that it is accurate and updated. Before such data can be used, users frequently must resolve document revisions and naming discrepancies, assure consistency with the design basis, and assure compliance with licensing. EPRI has found that plant staff spend 30–40% of their time searching and validating information in multiple documents, reducing confidence that technical data is available readily for decisions and evaluations relative to a given design or licensing issue.

Definition of Success

Success is defined as an architecture or platform enabling grid communication and control to enhance resiliency and optimize distributed and central energy resources across distribution and bulk power systems.

Data-centric configuration management supports decisions drawn from data, not from documents. Documents are maintained as the record of the source of the data, which under the new approach is centralized, accurate, change-controlled, and easily retrievable. A nuclear plant typically has approximately 300,000 controlled documents and millions of historical plant records. Moving to a modern data-centric, object-relationship database can add another 250,000 equipment records per unit that also must be change-controlled.

The challenge is to identify the data needed to support the testing, inspection, engineering, maintenance, and operating processes that maintain the plant in conformance with the design basis. Software tools have emerged to assist the document-centric plant make an effective transition to more "intelligent" information. Compared with manual searches, these tools reduce the cross-referencing time by searching documents based on established rules and identifying equipment tag numbers and document references that can be related to the document [18].

NEXT STEPS

EPRI has framed Research Imperatives (RI) to help identify gaps and to align and communicate research and development (R&D) that is critical to enabling the transformation of power systems to be more flexible, resilient and connected. Research Imperative 1, *Develop an Integrated Grid Platform*, is related to connectivity, proposing an Integrated Grid architecture or platform to enable a controllable and communicating grid to enhance resiliency and optimize the value of distributed and central energy resources across distribution and bulk power systems.

The RIs were introduced during various EPRI committee and sector council advisory meetings during the winter 2014-2015 EPRI Advisory meetings. Overall research themes were discussed in the context of where existing or future sector R&D, as outlined in EPRI portfolio planning documents and strategic roadmaps, may contribute to these RIs. As a result, joint EPRI research program activities and coordination discussions will continue to be enhanced to maintain a broad technical perspective when planning R&D, and to address the broad level concerns associated with the RIs.

What Will Success Look Like by 2020?

Collaboration among utilities, technology suppliers, DER developers, and policy makers can enable transformation to an open integrated grid. Among the tasks: define architectures and supporting technologies/systems to plan, design, operate, and manage an integrated power system that is more resilient and able to integrate high penetration of DER. This open grid platform will enable utility and others' DER to operate as integral elements in the overall resource mix and system performance management. Utilities will be able to shape and adapt their grids in ways and at a pace that provide value to their customers, using a "no-regrets" investment strategy. This architecture will primarily affect the distribution system. Integrated grid research and development will include:

- Distribution cyber-physical infrastructure reference designs that are more resilient and support large-scale DER integration
- Reference architectures for distribution grid IT and OT and control systems that provide for monitoring, control, communication, and security
- Reference distribution protection schemas that accommodate multi-directional flows and high penetration of intermittent DER
- New standard distribution operating practices, decision support capabilities, and related information requirements and protocols for integrating DER into distribution system operations
- Standard service definitions for distribution systems aligned with engineering and operational standards to meet regulatory requirements in multiple states

What Relevant R&D is Ongoing and What Are the Research Gaps?

Significant work related to an integrated grid platform continues across EPRI base, supplemental, and Technology Innovation programs, along with industry activities globally.

Within the Information, Communications and Cyber Security (ICCS) Research Areas, the **Telecom Initiative** has been designed to address the research gaps and utility "pain points" in the area of connectivity. Advisors from the ICT Council have provided input to identify the multiple, complex challenges that they face with respect to telecommunications. These include:

- Transition from isolated, application-specific networks to unified networks and management
- Retirement of analog and TDM leased line services
- Transition to packet-based systems
- Dynamic bandwidth and capacity requirements for intelligent field devices and advanced grids

NEXT STEPS

- Pending obsolescence of legacy wireless systems
- Needs for dedicated spectrum for critical grid operations
- Reliability concerns from unlicensed spectrum
- Non-negotiable requirements for highly reliable and resilient telecommunications networks
- Increased focus on cyber security and operational impacts from NERC CIP requirements

The Initiative will utilize a combination of workshops, laboratory and field evaluations, and human expertise to conduct prioritized telecommunications research and also evaluate longer-term telecommunications research that will transition to ongoing EPRI research projects in 2018. The six areas of research focus include:

- Approaches for migrating from serial to packet based communication
- Leveraging licensed, unlicensed and shared spectrum for private field area networks
- Public network operations and network sharing
- Strategic deployment of fiber
- DER Connectivity at the edge of the grid: Connectivity beyond-the-meter
- Best practices for network management and reliability metrics

The two-year project launched in the first quarter of 2016 with participation of a wide range of utilities with different communications challenges around the world. The number of participants in this collaboration continues to expand.

Additional examples include:

- Information and Communication Technology (EPRI Program 161)
- Cyber Security and Privacy (EPRI Program 183)
- Integration of Distributed Renewables (EPRI Program 174)
- Bulk Power System Integration of Variable Generation (EPRI Program 173)
- Distribution Systems (EPRI Program 180)
- End-Use programs (EPRI Programs 170, 182, 18, and 94)
- Advanced Nuclear Technology and Instrumentation and Control and Digital Systems (EPRI Program 41)
- Generation – Instrumentation, Controls and Automation (EPRI Program 68)
- Environmental Technology Assessment, Market Analysis and Generation Planning (EPRI Program 178)
- Technology Innovation – End-to-End Interoperability Platform
- Industry:
  - The Smart Grid Interoperability Panel (SGIP)
  - The NIST Framework by the National Institute of Standards and Technology
  - EPA EnergyStar Connected specifications
  - IEEE, IEC, and CIGRÉ
  - Transactive Energy
  - PNNL VOLTTRON™ by the Pacific Northwest National Laboratory
  - The European Union (EU), including Future INtErnet Smart Utility ServiCEs (FINESCE), Energy Regulators Regional Association (ERRA), and Grid4EU
  - Japan, including the Ministry of Economy, Trade, and Industry (METI), the New Energy and Industrial Technology Development Organization (NEDO), and the Central Research Institute of the Electric Power Industry (CRIEPI)
  - Vendors, academia, etc.

NEXT STEPS

Research Gaps for Research Imperative 1: Develop an Integrated Grid Platform

This section outlines research gaps in developing an integrated grid platform. The gaps do not imply that no research is addressing these areas, but that more effort is needed to achieve goals by 2020. This is due especially to the pace at which connected devices and resources are being deployed on the distribution system and to their expected lifespan before replacement by the next generation of technology.

NEXT STEPS

Gap 1: DER management architecture (see Figure 9)

- Lack of a flexible OT architecture that accommodates future changes and implements fundamental IT principles, such as separation of concerns (divide applications into distinct features with no overlap and minimizing interaction points), single responsibility principle (each component is responsible for a specific function), and principle of least knowledge (each component should not be required to know about the internal details of other components).
- For customer-owned equipment, architectural requirements to account for inherent uncertainty with respect to availability, and measurement and verification (M&V). Extend ongoing research looking into data from devices to develop comprehensive data architectures, as well as privacy frameworks to further real time M&V and demand response management platforms.
- Inability to easily integrate mobile workforce applications with both central and local systems and devices.
- Inability to use an "open application platform" at the device level (analogous to smart phone apps) for local decisions.

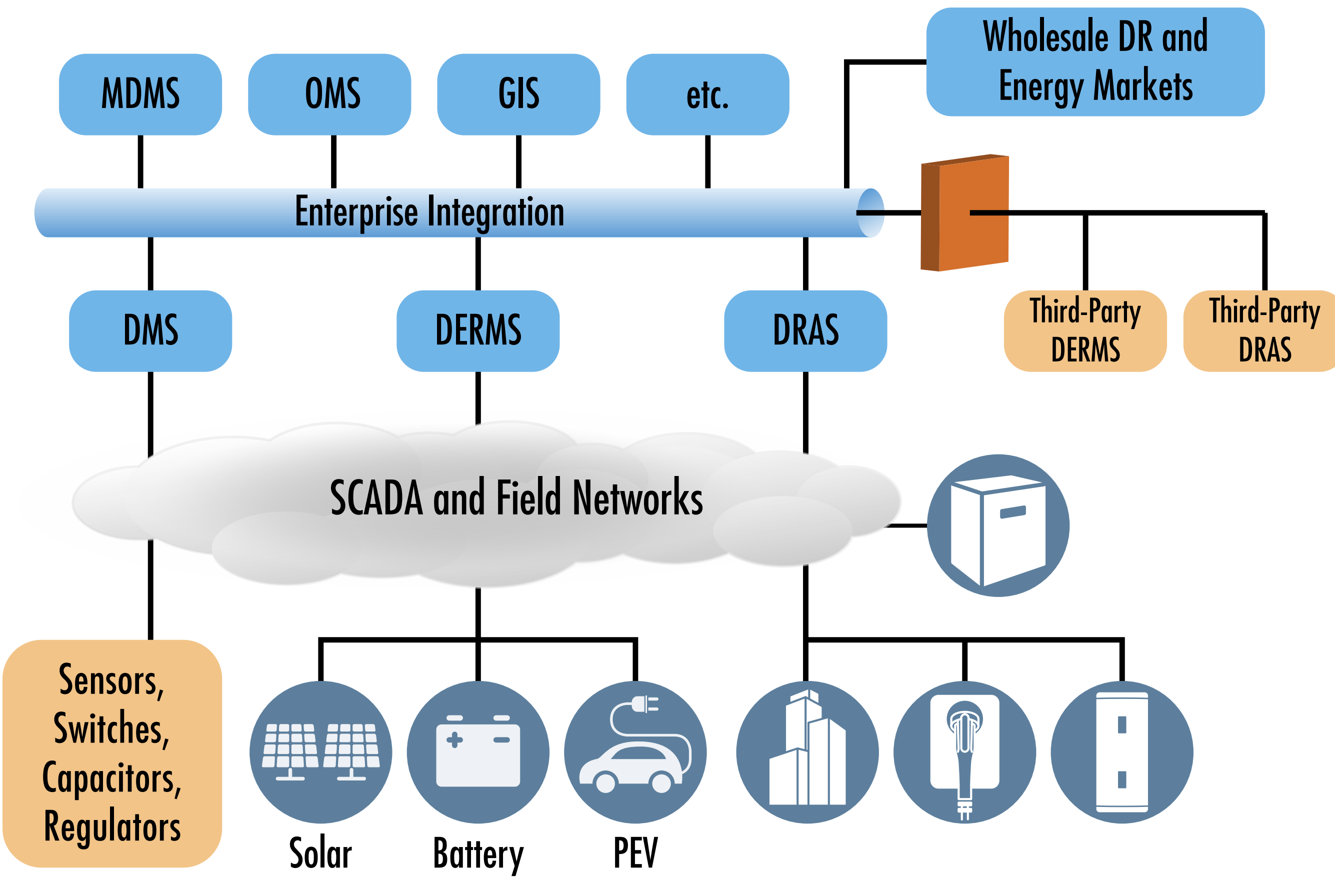

Figure 9. A Flexible DER Management Architecture is Needed

NEXT STEPS

Gap 2: Full connectivity to distribution and DER devices (see Figure 10)

- Non-standard communication technologies (individual or combined) across utility applications.
- Lack of reliability, performance, and metrics for wired, wireless, and power line carrier technologies.
- Lack of resilient, high-bandwidth communication networks that react to disruption, reconfigure, and maintain critical services.
- Lack of quantified value (financial, reliability, operational flexibility, and M&V) made possible by improving the capacity, coverage, and reliability of the communication network(s) serving DER devices.
- Lack of flexibility in configuring DER devices with communications. Devices are typically provided with a single communication option, chosen by the vendor, rather than a standardized (and "swappable") communications module.
- Lack of processing power to support communications and cyber security requirements in basic devices.
- Lack of ability to support mobile workforce connectivity to devices and DER.

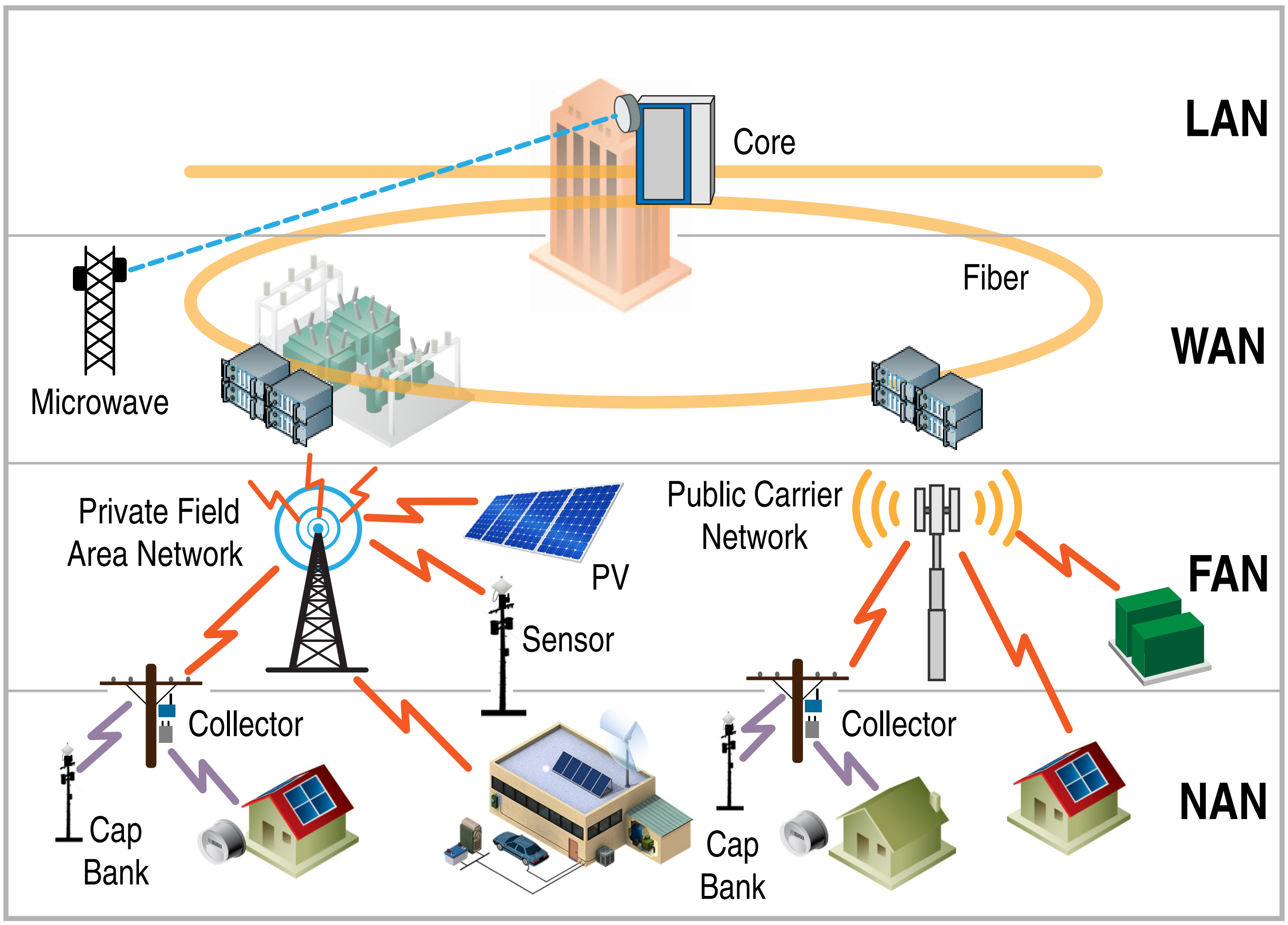

Figure 10. Full Connectivity to Distribution and DER Devices is Needed

NEXT STEPS

Gap 3: Grid-interfaced device standards and protocols for all types of DER (see Figure 11)

- Specifications for defined grid-support services that are common to all energy resources. This IT principle, "separation of concerns" was identified in Gap 1. Grid operators and planners need to know how DER will perform and can be managed with respect to capacity, energy, voltage, VARs, time, duration, etc. Standards should not dictate how the equipment will perform functions, but leave that open to product innovation. Existing protocols need to be assessed, including OpenADR 2.0, Smart Energy Profile 2.0 (SEP 2.0), Open Field Message Bus (OpenFMB), IEC 61850, etc.
- Consumer-connected devices with numerous new IoT protocols are not compatible with grid support services that are emerging and changing rapidly.
- Lack of interoperability testing and certification.
- Utilities do not require solution providers to use standard protocols for grid-interfaced devices.

Figure 11. Grid-interfaced Device Standards and Protocols are Needed for All Types of DER

NEXT STEPS

Gap 4: Cyber security – Monitoring and managing communicating devices and resources (see Figure 12)

- Integrated grid "attack surfaces" and potential vulnerabilities are not documented.
- Lack of integrated grid cyber security requirements and standards for distributed energy resources (e.g., storage, distributed generation, electric vehicles, photovoltaics) and associated vendor adoption.
- Device and system cyber security health cannot be monitored.
- Cyber or operational issues/alarms from other domains have not been integrated and correlated.
- Lack of mitigation and response strategies for assessing and prioritizing events.

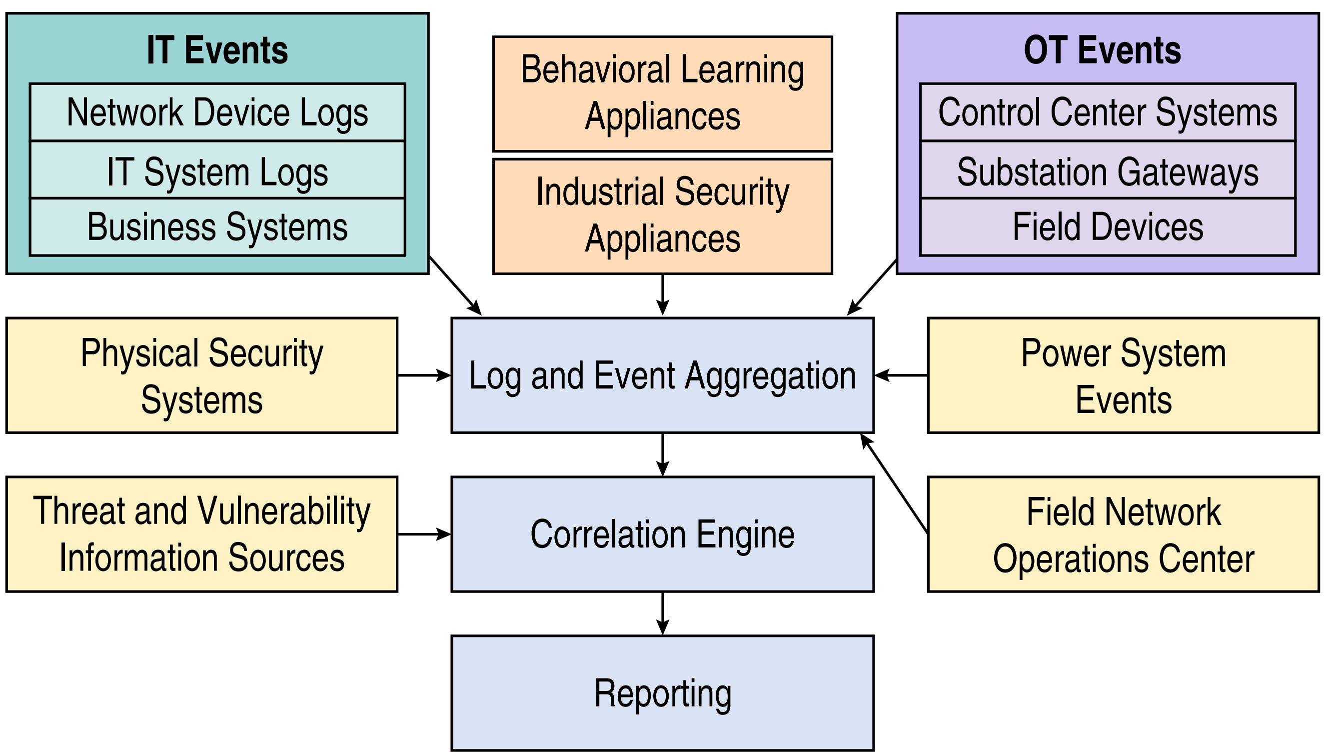

Figure 12. The Need for Cyber Security Includes Visibility and Management of Communicating Devices and Resources

NEXT STEPS

Gap 5: Distribution system information model enabling "continuously accurate" data for grid-connected devices, assets, and resources (see Figure 13)

- Lack of automated processes and technologies for capturing and maintaining data in data repositories
- Inability to use visualization to assess the data
- Redundancies with other systems (i.e., duplicate data)
- Lack of currency with as-built systems
- Inaccuracies in the field
- Uncertainty of data quality (e.g., customer connectivity by phase)
- Vendor resistance to standards
- Cost-benefit case is unclear

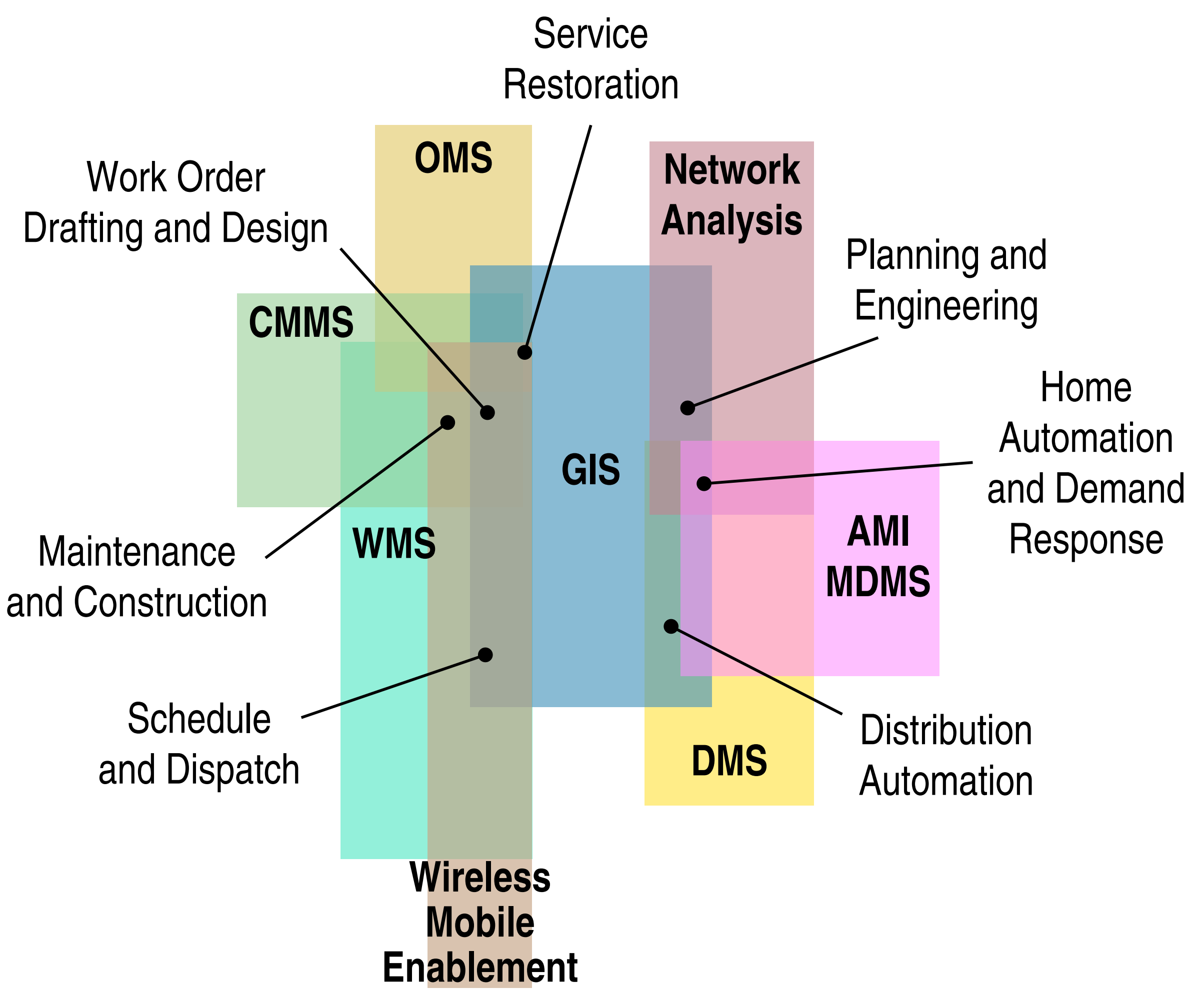

Figure 13. A Distribution System Information Model is Needed

NEXT STEPS

Gap 6: Nuclear – Architecture supporting load-following and demand dispatch with remote connectivity and security (see Figure 14)

- Nuclear plants are isolated from the grid. They are manually dispatched, optimized for baseload operation, and require licensed operators to make mode and power changes.
- Regulatory and cyber security issues require control air-gap.
- Fail-safe and limited power maneuvering protocols are needed.
- Control systems should be optimized for more dynamic plant operation.

Figure 14. For Nuclear Plants, an Architecture is Needed That Supports Load-following and Demand Dispatch with Remote Connectivity and Security

NEXT STEPS

Gap 7: Environment and economic reliability and environmental footprint of water use in an Integrated Grid (see Figure 15)

- Economic and population growth and tightening regulations will drive the industry to reduce water withdrawals and consumption, and increase competition for land.
- Water and land use changes could make it necessary for utility planners and industry stakeholders to use both national and regional information in choosing technology.

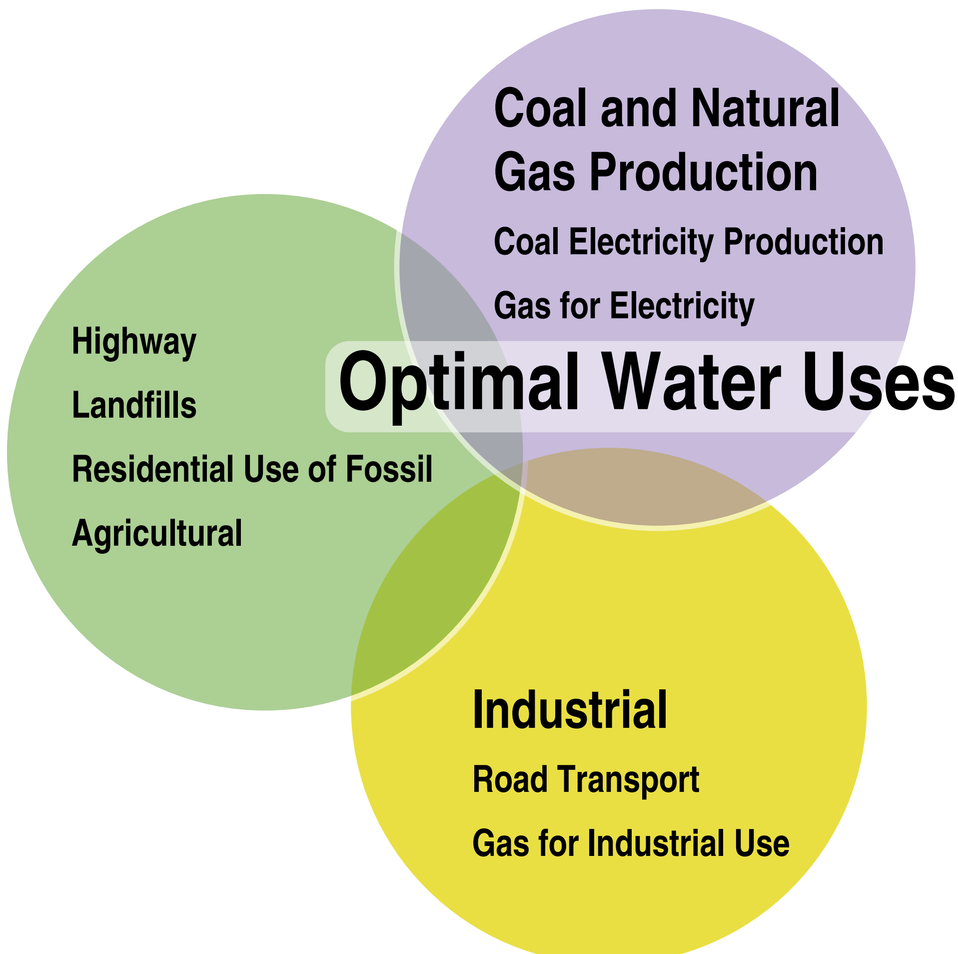

Figure 15. Water and Land Use Footprints May Change

NEXT STEPS

Bridging the Gaps

The following table lists actions being taken or under evaluation to bridge these gaps.

Action to Bridge Gap	Gap #
An EPRI initiative on telecommunications was launched at the beginning of 2016 as an international collaborative project to assess communication challenges and demonstrate solutions that can provide connectivity to the wide variety of system devices and even customer technologies in the future.	2, 4
An EPRI Technology Innovation project on end-to-end interoperability is evaluating use cases related to DER management. Future phases include architecture development, lab evaluation, and commercialization.	1, 2, 3, 4
EPRI sponsored an open industry workshop on end-to-end interoperability in April 2015, hosted by CPS Energy along with Duke Energy and NREL.	1, 2, 3, 4
EPRI was awarded NREL/DOE INTEGRATE projects on an integrated network testbed and connected devices and enhancing EPRI's OpenDERMS software.	1, 2, 3
The Smart Grid Interoperability Panel has prioritized action on OpenFMB and cyber security.	3, 4
EPRI research through government projects (CPUC, SHINES) that is investigating grid impacts from customer owned resources and the OEM Central Server projects.	1, 2, 3, 5
EPRI research on data from devices and customer preferences through smart thermostats and solar preferences.	1, 2
The EPRI supplemental project, Integrated Threat Analysis Framework, is coordinated with Cyber Security (EPRI Program 183) and Grid Operations and Planning (EPRI Programs 39 and 40).	4
The EPRI ICT Innovators Forum is engaging solution providers to evaluate vendor capabilities along with utilities needs and wants related to standards and cyber security for an integrated grid.	1, 2, 3, 4, 5
A pre-demo of Integrated Network Model Management for Distribution Systems is underway.	1, 5
An EPRI supplemental project, Assessing Augmented Reality in the Electricity Industry, has been launched to examine improved efficiency and safety for mobile work crews through improved tools and connectivity, and advance associated standards.	1, 2, 3, 4, 5
Industry coordination includes New York Reforming the Energy Vision, California More than Smart, PNNL VOLTTRON™, and academia.	1, 2, 3, 4, 5
EPRI advanced nuclear technology includes continued assessment of architecture supporting load-following and demand dispatch, remote connectivity, and security.	6
Through one of the Research Imperatives, EPRI is performing an assessment in the area of environment – reliability and environmental footprint including water use with an integrated grid.	7

NEXT STEPS

EPRI advisors and sector councils vetted these research gaps and generally concurred that the three major gaps not fully addressed in EPRI's research portfolio are:

- Gap 5: Distribution system information standardized models to enable "continuously accurate" data
- Gap 2: Full connectivity to distribution and DER devices
- Gap 4: Cyber security – Visibility and management of communicating devices and resources.

Along with new R&D activities, the Information, Communication and Cyber Security (ICCS) program in EPRI's Power Delivery and Utilization (PDU) sector is further assessing these gaps in its October 2015 R&D roadmap update.

ACRONYMS

3GPP	3rd Generation Partnership Project
AC^2	Advanced Control Center
AMI	advanced metering infrastructure
ANSI	American National Standards Institute
API	application programming interface
BYOD	bring your own device
CEA	Consumer Electronics Association
CIM	Common Information Model
CIMug	Common Information Model Users Group
CMIS	configuration management information system
CRIEPI	Central Research Institute of the Electric Power Industry
DAP	data aggregation point
DER	distributed energy resources
DMD	distribution modernization demonstration
DOE	U.S. Department of Energy
DSL	digital subscriber line
EMI	electromagnetic interference
EPRI	Electric Power Research Institute
ERRA	Energy Regulators Regional Association
ESB	enterprise service bus
FAN	field area network
FERC	Federal Energy Regulatory Commission
FTTH	Fiber to the Home
FINESCE	Future INtErnet Smart Utility ServiCEs
GIS	geographic information system
HFE	high frequency electronics
I&C	instrumentation and control
ICCS	Information, Communication and Cyber Security
ICT	information and communication technology
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IED	intelligent electronic device
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IoT	Internet of things
IP	Internet protocol
ISOC	integrated security operations center
IT	information technology
LAN	local area network
M&V	measurement and verification
M2M	machine-to-machine
METI	Ministry of Economy, Trade, and Industry (Japan)
NAN	neighborhood area network
NEDO	New Energy and Industrial Technology Development Organization
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
NSM	network and system management
OASIS	Organization for the Advancement of Structured Information Standards
OMS	outage management system
OpenADR	Open Automated Demand Response standard
OpenFMB	Open Field Message Bus
OSI	Open Systems Interconnection
OT	operation technology
PDU	Power Delivery and Utilization (EPRI Sector)
PLC	power line communication
PNNL	Pacific Northwest National Laboratory
R&D	research and development
RFI	radio frequency interference
RI	research imperative

ACRONYMS

SCADA	supervisory control and data acquisition
SEP	Smart Energy Profile
SGIP	Smart Grid Interoperability Panel
SOA	service oriented architecture
SRP	Salt River Project
T&D	transmission and distribution
TMD	transmission modernization demonstration
TVA	Tennessee Valley Authority
W3C	World Wide Web Consortium
WAN	wide area network
WASA	wide area situational awareness

REFERENCES

1. Cisco Visual Networking Index: Forecast and Methodology, 2013-2018, http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.html.
2. GridWise Architecture Council web site, http://www.gridwiseac.org/about/transactive_energy.aspx.
3. EPRI, "The Integrated Grid: Realizing the Full Value of Central and Distributed Resources," 3002002733, February 2014, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002002733.
4. EPRI, "CIM Update for 2013," 3002003034, April 2014, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002003034.
5. About.com, Bradley Mitchell, "Visual Index of Computer Networking Topics, The OSI Model of Computer Networks," http://compnetworking.about.com/od/basicnetworkingconcepts/ig/Visual-Index-of-Networking/OSI-Model.htm.
6. Cisco Visual Networking Index, "The Zettabyte Era – Trends and Analysis," June 10, 2014, http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/VNI_Hyperconnectivity_WP.html.
7. Utility Chief Information officer (CIO) Outlook – 2012, EPRI, Palo Alto, CA: 2013, product number 3002000085, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002000085.
8. Matt Wakefield, EPRI, "Information and Communication Technology (ICT) – a Key Enabler for the Future Power System," *ElectricEnergy T&D Magazine*, January-February 2014, http://www.electricenergyonline.com/show_article.php?mag=95&article=759.
9. EPRI, "Characterizing Consumers' Interest in and Infrastructure Expectations for Electric Vehicles: Research Design and Survey Results," 1021285, 2010, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001021285.
10. Accenture, "Interest in Connected-Home and Alternative Energy Solutions to Increase Six-Fold, Accenture Research Show," June 23, 2014, http://newsroom.accenture.com/news/interest-in-connected-home-and-alternative-energy-solutions-to-increase-six-fold-accenture-research-shows.htm.
11. *Wired* Magazine, Marcu Wohlsen, "What Google Really Gets Out of Buying Nest for $3.2 Billion," January 14, 2014, http://www.wired.com/2014/01/googles-3-billion-nest-buy-finally-make-internet-things-real-us/.
12. IDC, C. MacGillivray, V. Turner, and D. Lund, "Worldwide Internet of Things (IoT) 2013-2020 Forecast: Billions of Things, Trillions of Dollars," October 2013, http://www.idc.com/getdoc.jsp?containerId=243661.
13. Gartner, "Gartner Says 4.9 Billion Connected 'Things' Will be in Use in 2015," November 11, 2014, http://www.gartner.com/newsroom/id/2905717.
14. EPRI, "Redefining 'Internet of Things' (IoT) for the Utility Industry," *EPRI Communications & Connectivity Technology Newsletter*, May 2014, 3002004089, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004089.
15. EPRI, "Survey of Advanced Metering Infrastructure Applications," December 2013, 3002001077, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002001077.
16. International Energy Agency, "More Data, Less Energy; Making Network Standby More Efficient in Billions of Connected Devices," 2014, http://www.iea.org/publications/freepublications/publication/MoreData_LessEnergy.pdf.
17. EPRI, "Data: The Most Valuable Asset That an Electric Service Provider Owns: The Whys, Whats, and Hows of Managing Data as an Asset," January, 2014, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002002820.
18. EPRI, "Advanced Nuclear Technology: Data-Centric Configuration Management for Efficiency and Cost Reduction: An Economic Basis for Implementation," EPRI report 3002003126, December 2014, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002003126.
19. EPRI, *Information and Communication Technology Newsletter*, "EPRI Data Analytics 'Immersions' with TMD and

DMD Member Utilities," November 2013, http://smartgrid.epri.com/doc/EPRI_ICT_Newsletter%202013_11.pdf.

20. EPRI, "Data Analytics Initiative for Transmission and Distribution: Year One Update," 3002006377, May 2015, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002006377.
21. EPRI, Matt Wakefield, "From Research to Action: Data Analytics and the 'Little Data' Challenge," Electric Energy Online.com, http://electricenergyonline.com/show_article.php?mag=99&article=799.
22. Matt Wakefield, EPRI, and Ron Cunningham, American Electric Power, "Unleashing Innovation on the Electric Grid with Enabling Standards," *ElectricEnergy T&D Magazine*, May-June 2014, http://www.myvirtualpaper.com/doc/Electric-Energy/eemag_may-june2014/2014060201/20.html#20.
23. EPRI, "Common Information Model (CIM) 2012 Update: EPRI Development, Testing Activity, and Plans," 3002000406, March 2013, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002000406.
24. EPRI, "IntelliGrid Common Information Model Primer," 3002001040, October 2013, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002001040.
25. EPRI, "System and Network Management; The Management of Advanced IEC 61850-Based Systems," 1024608, December 2012, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001024608.
26. EPRI, "IEC 61850 for the Smart Grid," 1025677, August 2012, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001025677.
27. Galen Rasche, EPRI, "The reason network management systems are growing in the transmission domain," *Intelligent Utility*, March 10, 2013, http://www.intelligentutility.com/blog/13/03/reason-network-management-systems-are-growing-transmission-domain.
28. EPRI, "Network System Management: End-System-Related International Electrotechnical Commission (IEC) 62351-7 Object Definitions," EPRI 3002000373, December 2013, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002000373.
29. Metering International, "How utilities can fight physical and cyber attacks," February 24, 2014, http://www.metering.com/how-utilities-can-fight-physical-and-cyber-attacks/.
30. EPRI, "Guidelines for Planning an Integrated Security Operations Center," 3002000374, December 2013, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002000374.
31. EPRI, "Advanced Nuclear Technology: Guidance and Methodologies for Managing Digital Instrumentation and Control Obsolescence," EPRI report 3002002852, October 2014, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002002852.
32. EPRI, "Data Governance and Utility Analytics Best Practices," 3002003006, April 2014, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002003006.
33. EPRI, "Introduction to the ANSI/CEA-2045 Standard," 3002004020, May 2014, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004020.
34. EPRI, "Mapping EPA Connected Criteria to CEA-2045," 3002003960, April 2014, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002003960.
35. EPRI, "CEA-2045 Field Demonstration Project Description," 3002004009, June 2014, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?productId=000000003002004009.
36. EPRI, "Common Functions for Smart Inverters, Version 3," 3002002233, February 2014, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002002233.
37. EPRI, "Smart Inverter Field Experiences; A State of the Industry Overview," 3002001247, December 2013, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002001247.
38. EPRI, "Standard Based Integration Specification – A

Reference Architecture and Basic Asset Model in Support of Asset Health Analysis," 3002000607, December 2013, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002000607.

39. Paul Barnett and John Steward (Tennessee Valley Authority), and Pat Brown (EPRI), *Electricity Today* article, "The Truth about Field Data Management," July/August 2014, pp 82-91, http://www.electricity-today.com/overhead-td/the-truth-about-field-data-management.

40. EPRI, "Network Model Manager and Repository: A Guide to Exploring the Potential of Centralized Network Model Management," 300200609, December 2013, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002000609.

41. Navigant, Richard Martin, "The Integration of Geographic Data into Smart Grid Applications Will Drive Rapid Growth in the Utility GIS Market," July 31, 2012, http://www.navigantresearch.com/newsroom/the-integration-of-geographic-data-into-smart-grid-applications-will-drive-rapid-growth-in-the-utility-gis-market.

42. EPRI, "Social Media in Support of Outage Management," workshop summary, 3002002280, January 2014, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002002280.

43. EPRI, John Simmins and Christina Haddad, "Opportunities and challenges: social media as an outage management tool," *Smart Grid News*, June 20, 2013, http://www.smartgridnews.com/artman/publish/Business_Strategy/Opportunities-and-challenges-social-media-as-an-outage-management-tool-5832.html?fpt#.VBXxShYZlLc.

44. EPRI, "Field Area Network Demo: First Year Update," EPRI, Palo Alto, CA: 2014, product number 3002003094, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002003094.

45. Matt Wakefield, EPRI, and Joe Nowaczyk, Salt River Project, and Jason Handley, Duke Energy, "Communication Research and Actions to Enable the Future Electric Power System," *ElectricEnergy T&D Magazine*, March-April 2014, http://www.electricenergyonline.com/show_article.php?mag=97&article=772.

46. EPRI, "Open Interoperable AMI: A Roadmap from the Utility Perspective," EPRI, Palo Alto, CA: 2013, product number 3002001043, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002001043.

47. EPRI, "Open Advanced Metering Infrastructure (AMI) Systems: Leveraging Customer Broadband for Grid Integration," EPRI, Palo Alto, CA: 2012, product number 1024306, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001024306.

48. Siemens.com, "PJM Interconnection; Integrating state-of-the-art, large-scale energy management systems," http://w3.siemens.com/smartgrid/global/SiteCollectionDocuments/Projects/PJM_CaseStudy.pdf.

49. TruEnergy, Terry Boston, "PJM Implements the Advanced Control Center," July 25, 2013, http://truenergy.net/pjm-implements-the-advanced-control-center/.

50. EPRI, "Transforming Smart Grid Devices into Open Application Platforms," 3002002859, July 2014, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002002859.

51. FERC, "Smart Grid Policy," 18 CFR Chapter I, Docket No. PL09-4-000, July 16, 2009, http://www.ferc.gov/whats-new/comm-meet/2009/071609/E-3.pdf.

52. Una Nowling, *Power* Magazine, "Remote Monitoring and Diagnostics Within a Smart Integrated Infrastructure," February 1, 2014, http://www.powermag.com/remote-monitoring-and-diagnostics-within-a-smart-integrated-infrastructure/?pagenum=1.

53. EPRI, "Evaluation of Remote Monitoring for Heat Rate Improvement," EPRI report 1023075, November 2011, https://membercenter.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001023075.

54. US Department of Energy, Electric Power Board of Chattanooga (EPB) - Smart Grid Project – Final Project Description, July 2014, https://www.smartgrid.gov/files/EPB_Final_Project_Description_-_20140422_reformatted_0.pdf

55. EPRI "Electric Vehicles: Characterizing Consumers' Interest and Infrastructure Expectations,"1020504, November 2009, https://membercenter.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001020504

REFERENCES

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