Interoperability Strategic Vision: Enabling an Interactive Grid

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PNNL-26338
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April 2017

An Interim Deliverable for Review

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Executive Summary

VALUE OF INTEROPERABILITY

- Reduces the cost and effort for system integration
- Improves grid performance and efficiency
- Facilitates more comprehensive grid security and cybersecurity practices
- Increases customer choice and participation
- Establishes industry-wide best practices
- Is a catalyst of innovation

The purpose of this Interoperability Strategic Vision document is to promote a common understanding of the meaning and characteristics of interoperability and to promote a strategy to advance the state of interoperability as applied to integration challenges facing grid modernization. This includes addressing the quality of integrating devices and systems and the discipline to improve the process of successfully integrating these components as business models and information technology improve over time. Stated succinctly, interoperability is “the ability of two or more systems or components to exchange information and to use the information that has been exchanged.”[1] Reasons to invest effort in addressing interoperability issues are reflected in the sidebar.[2]

Interoperability has important economic consequences. Systems that integrate simply and predictably have lower equipment costs and lower transactions costs, higher productivity through automation, more conversion of data and information into insight, higher competition between technology suppliers, and increased technology and application innovation. Those systems grow faster, use resources more efficiently, and create more value for their users. Such systems consistently prove that interoperability standards and supporting integration mechanisms enhance users' choices, because these agreements create a framework within which vendors and their competitors can innovate to provide new products that deliver new functions that were previously unattainable or even unimaginable.

The electric power system continues the trend of embracing advancements in information and communication technology along with the rest of industry and our society. The vision of a modern energy grid is of a complex, system of physical systems overlaid with a hyper-connected system of cyber systems. It integrates grid operations with end-use business processes and social objectives to achieve ever greater scales of performance efficiency under conditions that must adapt to short-term disturbances and long-term trends.

The strategic vision for interoperability described in this document applies throughout the electric energy supply, delivery, and end-use chain. Its scope includes interactive technologies and business processes from the bulk energy levels to the lower voltage level equipment and the millions of appliances that are becoming equipped with processing power and communications interfaces. A transformational aspect of this vision of the future electric system is the coordinated operation of intelligent devices and systems at the edges of grid infrastructure. These distributed energy resources (DER), which include generation, storage, and responsive load, hold great promise in their ability to interact with the electric delivery system infrastructure for greater efficiency, reliability, and resiliency. Besides technical connectivity issues, the integration of DER for coordinated operations needs to address business and regulatory issues. Services for DER coordination need to be defined and legally sanctioned by government entities, and the electricity system needs to be prepared to accommodate them. In addition, coordination signals need to be

[1] ISO/IEC/IEEE standard 24765

[2] Adapted from *Standards and Interoperability in Electric Distribution Systems*, a report prepared for the U.S. Department of Energy by ICF, 2016. Accessed February 2017 at https://www.energy.gov/sites/prod/files/2017/01/f34/Standards%20and%20Interoperability%20in%20Electric%20Distribution%20Systems.pdf

understood and responses need to be monitored. These signals support business value propositions that are tied to financial transactions. Enabling business-to-business interactions that support the integration of DER adds complexity that must be addressed with a strategic vision.

This image of cooperating intelligent devices and systems is at once fantastic in its scope and annoyingly persistent as it questions our imagination, forcing us to ask “why not?” All that stands in the way of any group of things working together are mutually held agreements. These agreements cover abstract notions (e.g., concepts, structures, boundaries, processes, and responsibilities) captured in conventions, codes, standards, laws, policies, contracts, and cultural norms. Through established agreements, things can connect and interact. This is the substance of interoperability. If achieving interoperability is too difficult, opportunities are lost; however, if achieving interoperability is simple and predictable, new opportunities are imagined and discovered.

The strategic vision for interoperability proposed in this document recognizes that agreements are best established by those responsible for carrying them out—the stakeholders. The strategic elements of this work focus on a process for aligning those people and organizations working in specific grid-integration domains (e.g., electric vehicles, photovoltaic systems, or responsive buildings) toward a shared direction. The destination for that direction should be visionary, such that each stakeholder sees its relevance to their cause. It should elevate notions of simplicity and harmony that can be difficult to imagine under existing regulatory policy, business objectives, legacy technology investments, current agreements, and other immediate constraints.

INTEROPERABILITY ADVANCEMENT

- Vision – The drivers behind need: social change, market change, environmental change, values change
- Methods – The mechanisms and tools to accomplish the goals: programs, regulations, incentives, education…
- Application – The use of methods with engaged technology communities: their systems, solutions, and interactions.

Once a shared vision is established, the steps required to achieve that vision (a roadmap) can be considered. The development of such a roadmap can benefit from a methodical process to engage stakeholders. This work adapts a stakeholder roadmap development process used by the International Energy Agency to focus on improving the integration of intelligent electric-system-related equipment and systems. In particular, the document uses the timely example of DER integration. Besides providing an organizational structure for stakeholder engagement, the roadmap process needs to identify the state of interoperability. It accomplishes this by using a set of tools and relevant concepts for specifying interoperability characteristics that support the measurement and assessment of levels of interoperability from business and regulatory issues to the network protocols that carry the messages and support the business processes. Such an assessment is built upon a clear map to interoperability characteristics that support simplification of the integration experience. Given a way to measure and assess the state of interoperability and a vision for the desired state of interoperability, a set of gaps and challenges can be identified. The resulting gaps and challenges can then be translated into a roadmap for how to improve interoperability using a process of prioritization and consensus building.

Even though hard interoperability agreements need to be instituted by the participants involved in specific technology-integration areas (e.g., bulk generation control, field switch gear coordination, and DER cooperation), the electricity industry profits from commonly held grid architecture concepts and models that identify cyber-physical interface points where multiple types of equipment can be treated similarly. For example, substation equipment deployments can benefit if the agreements for integrating smart circuit breakers, tap changing transformers, and capacitor bank technologies are the same across as many classes of technologies as possible.

This document exercises a set of tools and approaches to systematically pursue interoperability on the specific topic of DER integration. It proposes a set of near-term and long-term activities to bring commonality of approach to encourage convergence on agreements that apply to all the diverse set of DER types. This involves facilitating the creation of a set of generalized grid services and identification of the performance characteristics required to provide each grid service regardless of the type DER. By focusing on the qualifications for providing a service, the integration agreements needed should be simplified. In addition, commonality of approach to addressing interoperability gaps can lead to tools, techniques, best practices, and capabilities that can be leveraged across all types of grid integration scenarios. Working both within and across technology communities (i.e., ecosystems) will be required to achieve the level of alignment prophesized by the vision of a modern energy grid.

The material targets technology advisors of businesses and policymakers whose decisions directly influence the integration of electric-system-related intelligent equipment and systems and their coordinated operation with the rest of the electric power system. This includes those who advise owners and operators of grid and DER assets, technology solutions providers, and industry regulators. It also includes participants in consortia and professional communities that advance interoperability. A basic understanding of ICT is expected by the reader. Some examples of technology or integration challenges may be more fully appreciated with greater in-depth knowledge, however, the gist of the issues being presented is intended to be apparent to all.

While this document exercises the use of a strategic vision for interoperability using DER integration-related examples, the tools and methods are to be improved through this and subsequent exercises for application to the broad array of interoperability challenges that are emerging in the grid, in buildings, and at all touch points across the electricity system.

Acknowledgments

Contributions to this project were achieved through the Grid Modernization Laboratory Consortium (GMLC), a strategic partnership between the Energy Department and the national laboratories to bring together leading experts, technologies, and resources to collaborate on the goal of modernizing the nation's grid. The GMLC was established as part of the U.S. Department of Energy Grid Modernization Initiative to accelerate the development of technology, modeling analysis, tools, and frameworks to help enable grid modernization adoption.

This works rests on a foundation of smart grid interoperability-related work established by the GridWise® Architecture Council over the past dozen years and by work done by the Smart Grid Interoperability Panel under the guidance of the U.S. National Institute of Standards and Technology. The vision for interoperability and plan for a strategic engagement with stakeholders follows from recent efforts funded by the U.S. Department of Energy to advance interoperability for connected buildings.

The authors wish to acknowledge the help and guidance received from their U.S. Department of Energy managers, Marina Sofos and Christopher Irwin, in developing the plans for this document and encouraging outreach to relevant participants. The authors' appreciation extends to their industry partners on this project, including Ron Bernstein, John Caskey, Will White, Joseph Bush, Avi Gopstein, Don von Dollen, Anne Haas, David Forfia, Scott Neumann, Sharon Allen; William Ash, Dave Hardin, Kevin Lariza Powell, Douglas Frazee, Paul Skorochod, Ron Ambrosio, Austin Montgomery, and Margaret Goodrich. In addition, the authors recognize their Grid Modernization Lab Consortium liaisons to related grid modernization projects, including Jeffery Taft, Benjamin Kroposki, Robert Pratt, Liang Min, Ted Bohn, and Tom Rizy.

Lastly, this work's value is determined by the participation of the broad grid modernization community. Without relevant organization input and idea exchange at project review meetings and stakeholder engagement sessions, the ability of this material to influence the transformation of the electric system will vanish.

Acronyms and Abbreviations

AC	alternating current
AMI	advanced metering infrastructure
ANL	Argonne National Laboratory
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Interchange
DER	distributed energy resources
DLC	direct load control
DOE	U.S. Department of Energy
DR	Demand response
EPRI	Electric Power Research Institute
ESI	energy service interface
EV	electric vehicle
EVSE	electric vehicle supply equipment
FAN	Field Area Network
FMS	facility management system
FSGIM	Facility Smart Grid Information Model
GMLC	Grid Modernization Lab Consortium
GWAC	GridWise® Architecture Council
HEMS	home energy-management systems
HVAC	heating, ventilation, and air conditioning
ICT	information and communication technology
IEA	International Energy Agency's
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMM	interoperability maturity model
IoT	Internet of Things
ISO	independent system operator
IT	information technology
JRC	Joint Research Center
MDM	meter data management
NAESB	North American Energy Standards Board
NEMA	National Electrical Manufacturers Association
NIST	National Institute of Standards and Technology
PEV	plug-in electric/hybrid vehicles
PNNL	Pacific Northwest National Laboratory
PV	photovoltaic
SEPA	Smart Electric Power Alliance
SGIP	Smart Grid Interoperability Panel
TOU	time of use
UML	Unified Modeling Language

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1.0 Introduction

Information and communication technology (ICT) is being deployed to ever greater degrees in generation plants, the electric delivery system, and in the end-use systems served by the grid. ICT appears in field and facility equipment used in all areas of the electric system and across the multitude of management systems that coordinate their operations. To enable this technology to work together, cyber-physical devices and management systems are designed with interfaces to support such integration. The integration of these devices and systems and getting them to properly interoperate has not always gone smoothly. Overcoming integration challenges has historically been seen as an art, where knowledgeable experts with creative skills figure out clever ways to solve problems unforeseen at the design stage. However, as the discipline that supports ICT has matured, so have the methods, tools, and business. Further, economic policy communities have matured to specify better interfaces and develop standards and processes that help move integration from an art to a science. The topic of this discipline is referred to as interoperability.

The goal of this document is to identify strategic approaches to interoperability issues that exist throughout the entire electric system and in buildings, transportation systems, and other infrastructures that interface with the grid. The energy infrastructure of the modern electricity grid uses ICT to enhance system efficiency while meeting reliability objectives and making the system more resilient as it faces an evolving set of new challenges. One challenging area for grid operations is the growth of distributed energy resources (DER) at the edges of the delivery system. As opposed to creating challenges for distribution system operations, the pervasiveness of ICT and automation incorporated into these resources offers a level of beneficial coordinated operation that has only recently become practical to consider. A modern grid accommodates the growth and opportunities offered by a changing mix of DER. This document uses the integration of DER as a timely example of a challenging area that requires advancement in the application of interoperability tools and techniques. As the following sections describe the application of a strategic vision for interoperability to the important topic of DER, please keep in mind that the underpinnings of the strategic vision are general and fully applicable to the many other areas throughout the electric system with integration challenges. The trial of the strategy, vision for integration, and supporting methodology and tools presented to address the topic of DER integration are intended to not only improve DER integration, but to improve the tools and processes themselves as they are applied to other challenging areas.

This document uses the term DER to represent all energy consuming and producing resources at the edges of the system that have a responsive component for coordinated operations with the energy system. This includes flexible loads that can offer to change their consumption behavior (e.g., stop operating a motor or lights to shed load), distributed generation that can offer to change its power output or provide voltage support, and storage that can offer to act like either distributed generation or flexible load. The concept of DER also includes buildings and other facilities with systems that may manage a variety of equipment, some responsive (DER equipment) and some non-responsive. Such systems come in many forms (e.g., buildings of various sizes, industrial plants, campuses, electric transportation charging stations, municipal pumping, and street lighting).

To harness the flexibility in operations of DER, their integration with the grid must be cost-effective and reliable. This is the mission of interoperability. A prerequisite to tackle this mission is the involvement and alignment of the multiple participants in the ecosystems that manage, operate, serve, and oversee the various components of this complex system of electricity consumption, generation, and delivery. It is a shared challenge.

This document describes a grid modernization strategic vision for interoperability and relevant concepts for specifying interoperability characteristics that support such a vision. This strategy emphasizes the need to measure and assess levels of interoperability. Such an assessment is proposed to be built upon a clear map to interoperability characteristics that support simplification of the integration experience. Given a way to measure and assess the state of interoperability in an integration area, the resulting gaps and challenges are translated into a roadmap for how to improve interoperability.

Under its Grid Modernization Initiative, the U.S. Department of Energy (DOE), in collaboration with energy industry participants, developed a multi-year plan to modernize the electric grid (DOE 2015a) and established the Grid Modernization Lab Consortium (GMLC) (DOE 2017) to execute projects consistent with this plan. One of the foundational topics for accelerating modernization efforts is interoperability. To address this topic, four national laboratories (Pacific Northwest National Laboratory [PNNL], National Renewable Energy Laboratory [NREL], Lawrence Berkeley National Laboratory [LBNL], and Argonne National Laboratory [ANL]) have begun a three-year project to advance the adoption of interoperable products and services in the energy sector. Key preliminary objectives are to align stakeholders on a strategic vision and to develop measures and tools to assess interoperability challenges and promote action. Accordingly, participants were convened at a meeting on September 27 and 28, 2016 in Chicago, Illinois to review, develop, and refine a shared understanding of interoperability, stories that evoke the desired integration experience, and interoperability characteristics that need to be addressed to improve this experience. The meeting resulted in a Declaration of Interoperability that reflects participant consensus on the objectives of interoperability efforts and their importance for grid modernization. The feedback from that meeting influences the content of this document and, more broadly, DOE's efforts in this area.

The GridWise® Architecture Council's (GWAC) Decision-Makers' Interoperability Checklist has the following to say about interoperability (GWAC 2010):

Historically, progress occurs when many entities communicate, share information, and together create something that no one individual could do alone. Moving beyond people to machines and systems, interoperability is the capability of systems or units to provide and receive services and information between each other, and to use the services and information exchanged to operate effectively together in predictable ways without significant user intervention. When people talk about the "modern" or "smart" grid, interoperability is a necessary foundation of that concept. Within the electricity system, interoperability means the seamless, end-to-end connectivity of hardware and software from the customers' appliances all the way through the T&D [transmission and distribution] system to the power source, enhancing the coordination of energy flows with real-time flows of information and analysis.

Interoperability has important economic consequences. Systems with high interoperability have lower equipment costs and lower transactions costs, higher productivity through automation, more conversion of data and information into insight, higher competition between equipment suppliers, and more innovation of both technology and applications. Those systems grow faster, use resources more efficiently, and create more value for their users. Such systems consistently prove that interoperability and standards enhance users' choices, because those requirements create a framework within which vendors and competitors can innovate – as long as the finished products perform the needed functions and exchange data with other, related products.

1.1 The Purpose of a Strategic Vision for Interoperability

Interoperation is a quality that results from the successful integration of components. While the resulting system of components has value, the impact of new opportunities unleashed by reducing the level of integration effort to achieve interoperation can be difficult to quantify. Henry Ford's automobile assembly line, based on the integration of interoperable components, transformed manufacturing and ushered in the second industrial revolution. The value calculation is straightforward when a single firm controls the component interface definitions and supply lines; however, the assembly line also had broader economic and societal benefits and other ramifications that were difficult to imagine and quantify at the time.

The electric system and its delivery infrastructure is a complex machine so massive and interwoven into our lives and livelihoods that it must accommodate continual evolution in the integration, update, and removal of a great variety of assets while continuing to operate. Each group of stakeholders has a different perspective on the challenges the existing situation poses to achieving their objectives. The concept of a long-term vision provides a vehicle for participants to momentarily set aside their difficulties and battles the present state poses and offers hope toward finding common ground on a desired future state.

A vision for interoperability provides a long-term context for making near-term decisions. The strategic vision for grid modernization interoperability presents a process to work with participants to find common ground on a desired future state and use that desired state as the context for developing a) high-level roadmaps that transcend specific technologies and b) ecosystem-specific roadmaps driven by the value propositions for those on the front lines of technology deployment.

This document is intended for technology advisors of businesses and policymakers whose decisions directly influence the integration of electric-system-related intelligent equipment and systems and their coordinated operation with the rest of the electric power system. In particular, the example of a strategic vision for DER integration should speak to those who advise owners and operators of grid and DER assets, technology solutions providers, and industry regulators. It also includes participants in consortia and professional communities that advance DER integration in one form or another and sponsor or facilitate the development of standards, guides, codes, registries, and other systems that ease integration of DER. A basic understanding of ICT is expected by the reader. While some examples of technology or integration challenges may be more fully appreciated with greater in-depth knowledge, the gist of the issues being presented is intended to be apparent to all.

1.2 Value Propositions and Benefits for Advancing Interoperability

Interoperability efforts that address the integration of a growing number of intelligent devices and systems offers a diverse range of benefits for electric service providers, consumers, and other stakeholders (adapted from [ICF 2016]). These include the following:

- **Reduction of cost and effort for system integration**: Greater interoperability directly decreases costs for deployment and integration of new technologies and/or applications into an existing system, reducing the need for modification of existing systems. This can indirectly reduce design, installation, and upgrade costs as well as reduce repair costs and extend equipment life by utilizing interoperability-enabled monitoring and assessment capabilities.
- **Improvement of grid performance and efficiency**: Interoperability promotes a more efficient, reliable grid in which demand-side and supply-side management work cooperatively and productively. Widely adopted standards help ensure that today’s technology can interface with future technologies.
- **Facilitation of more comprehensive grid security and cybersecurity practices**: Interoperable technologies permit the application of a more comprehensive security framework and enable coordinated and consistent cybersecurity practices. Although common standards could mean that a larger number of systems might be affected by a given vulnerability, it also means that security vulnerabilities and threats can be more rapidly identified and addressed, and that systems can be easier to administer, police, and upgrade against evolving threats. Also, interoperability improvements can reduce the number of types of interfaces required for operators to monitor and manage, enabling more timely and coordinated responses to emergency events.

- **Increase in customer choice and participation**: Interoperability allows customers to choose between features instead of between technologies, prevents companies from “locking in” customers (both utilities and customers) with proprietary systems, and facilitates customer trust of new validated technologies.
- **Establishment of industry-wide best practices**: Interoperability standards can form the foundation of guidance for investors in products and services to be able to confidently use “off-the-shelf” technology.
- **Catalyst of innovation**: Interoperability standards enable a technology-neutral market, which reduces investment uncertainty, incentivizes innovation, and ensures that existing infrastructure can continue to provide value within newer systems.

1.3 The Future of Interoperability

The act of integrating interoperable components should be simple with predictable outcomes. For instance, when a consumer wishes to integrate a Bluetooth-compatible headset for a personal computer, he or she must first ensure the devices are on and available for pairing. After that, the devices find each other and the personal computer asks if the user would like to pair the devices. If the user agrees, the integration is complete. Even after use is finished, the next time the devices are energized, they connect and operate together with no further user action. To keep the integration experience personal, imagine a smart refrigerator or an electric water heater with communications connectivity. When the appliance arrives, the user (or installer) installs it and establishes the communications link to an energy-management system similar to the Bluetooth pairing scenario above. The energy-management system has internet access and automatically checks to see if the user’s present electricity service provider offers programs for which the new appliance qualifies and looks for other local providers that offer such programs. The energy-management system presents the discovered options, including any payments and restrictions, the user selects the desired program, and then is done. The equipment operates to serve the user’s needs and interacts with the energy service provider’s program; it begins with appropriate default settings, which can be changed to reflect the user’s personal preferences. Neither the energy service provider nor the distribution system operator had to invest special effort to enable the integration.

However, there is no free lunch. ICT investments, tools, and interface agreements need to be put in place up front to enable this simple scenario and make the user’s integration experience simple, efficient, and reliable. Section 5.0 of this document provides an in-depth discussion of the desired experience for DER integration with several examples that explore the types of supporting mechanisms that operate in the background. An important visionary aspect to integrating practical and scalable background automation is designing interface conventions, guides, and standards that accommodate all DER types and are not limited to specific DER types. Just as the Bluetooth headset in the earlier scenario worked with a personal computer, it also works with a smart phone or a car audio system using the same technology standards. Similarly, a Bluetooth mouse can connect with a personal computer using the same standards.

Besides technical connectivity issues, the integration of DER for coordinated operations needs to address business and regulatory issues. Services for DER coordination need to be defined and legally sanctioned by government entities, and the electricity system needs to be prepared to accommodate them. In addition, coordination signals need to be understood and responses need to be monitored. These signals support business value propositions that are tied to financial transactions. Enabling business-to-business interactions that support the integration of DER adds complexity that must be addressed with a strategic vision.

Addressing this level of complexity will require a journey of many steps involving many people and organizations to achieve a future vision for interoperability. Before departing on any journey, the destination needs to be clearly understood. A challenge with interoperability is that the relevant ICT technologies change at a rapid pace. What can appear as a firm technology-based destination today needs to be reappraised on a regular basis. Evolutionary and adaptability goals can be as important as operational performance goals.

1.4 Relationship with Other Efforts

Even during early conception of a smart grid, interoperability was recognized as an important quality for grid modernization. Several efforts have been made since to address interoperability. The concept for an interoperability strategic vision has its origins in many, if not all, of these efforts. The following sections summarize ongoing efforts and their relationship to this work.

The GridWise® Architecture Council

GWAC was formed by the DOE in 2004 to promote and enable interoperability among the many entities that interact with the nation's electric power system. The GWAC enlists industry involvement to articulate the goals of interoperability; identify the concepts and architectures needed to make interoperability possible; develop actionable steps to facilitate the interoperation of the systems, devices, and institutions that encompass the nation's electric system; and establish broad industry consensus around the path to interoperability and the value it offers. In 2008, the GWAC published the Interoperability Context-Setting Framework (GWAC 2008) which has received broad support from the industry and internationally, where it has been published as ISO/IEC TR 15067-3-2:2016. This framework was used by the GWAC in 2011 to develop an interoperability maturity model (IMM) (GWAC 2011). Both products contribute foundational concepts to this strategic vision and the GWAC is a partner in this effort. The GWAC is regularly apprised of this work and the advice of its members solicited. Consequently, GWAC member ideas influence this work.

The National Institute of Standards and Technology

The National Institute of Standards and Technology (NIST) was directed by Congressional legislation[1], to advance interoperability for the smart grid. NIST convened industry experts to develop a conceptual reference model to facilitate this shared view and then created the Smart Grid Interoperability Panel (SGIP – now SEPA) to engage industry to advance interoperability on an ongoing basis. The NIST Framework and Roadmap for Smart Grid Interoperability Standards (NIST 2014) proposes a plan for transforming the electric system into an interoperable smart grid. This effort uses NIST to support a discussion framework for the state of interoperability and a path forward. NIST is a partner in this GMLC effort.

The Smart Grid Interoperability Panel (now the Smart Electric Power Alliance)

NIST initiated the Smart Grid Interoperability Panel (SGIP), which has since been merged with the Smart Electric Power Alliance (SEPA), to support NIST in fulfilling its responsibility, under the Energy Independence and Security Act of 2007 (Title XIII, Section 1305)[2] to coordinate standards development for the smart grid. SGIP, a public-private partnership, has been a vehicle for NIST and other branches of government to solicit input and cooperation from private and public sector stakeholders in developing the

[1] https://www.gpo.gov/fdsys/pkg/PLAW-110publ140/pdf/PLAW-110publ140.pdf
[2] ibid

smart grid standards framework. SGIP has provided a discussion forum and work products (e.g., the ESI [Hardin 2011]) that contribute to this work. SGIP is a partner in this effort, which is coordinated with strategic technical activities of SGIP. The recent SGIP merger with SEPA means that its mission and operations will continue these partnership activities under the SEPA banner.

Institute of Electrical and Electronics Engineers

Several societies within the Institute of Electrical and Electronics Engineers (IEEE) contribute to grid modernization through computers, controls, communication, power engineering, and the standards that accompany all of these areas. In 2011, IEEE published IEEE 2030, which provides guidelines for smart grid interoperability. IEEE is a partner to this effort and the new Smart Buildings, Loads, and Customer Systems Committee in the Power and Energy Society has ties to the IEEE Standards Association for advancing interoperability of DER integration. The establishment of this committee provides opportunities for collaboration with this work.

The Electric Power Research Institute

The Electric Power Research Institute (EPRI) has been involved in advancing interoperability in the electric power industry for decades. Its projects were instrumental in the development of a series of standards under the International Electrotechnical Commission (IEC) (i.e., IEC 61970, IEC 61968, and IEC 62325) which establish a common information model and information exchange profiles to support electric power systems application integration. EPRI and its sponsors remain interested in advancing the benefits of interoperability. EPRI is a partner in this effort and coordinates with SGIP and other partners in this area.

Others

Other organizations are advancing interoperability in the electric power field (e.g., the IEC and for European effort on Standardization of the Smart Grid, CEN, CENELEC, and European Telecommunications Standards Institute (ETSI). In addition, other industries have been advancing interoperability to address their own integration challenges. An important example with many of the same issues is the healthcare industry (Health Information Technology 2016). Another example relates to the initiatives associated with the Internet of Things (IoT), including the many organizations (e.g., the Open Connectivity Foundation) that are working on new standards to advance interoperability. This GMLC effort monitors their progress and looks for opportunities for connections with representatives.

1.5 Structure of this Document

This document describes an interoperability strategic vision for grid modernization beginning with background material on the meaning of interoperability and a presentation of relevant terminology and concepts (Section 2.0). Next, a discussion framework is proposed to organize and provide structure around architectural concepts using the operational coordination of DER as an application example. This includes the identification of the technologies, grid services, interacting parties (actors), and ecosystems that encourage and support DER deployment (Section 3.0). Next, this discussion framework is used to present a high-level description of the state of DER integration across the electric system, as well as the integration landscape in DER technology domains (Section 4.0).

Given a view of the state of interoperability, the document then proposes a vision for interoperability by presenting a story that describes the desired integration experience (Section 5.0 – additional stories are presented in the appendix). This experience is supported by a discussion of interoperability characteristics, which if addressed, improve integration (Section 6.0). The desired integration experience provides the destination, while the interoperability characteristics are used to organize a discussion of a path forward for generally advancing interoperability across the grid from the present state toward the desired vision (Section 7.0). Section 7.0 ends with a description of the need to measure interoperability characteristics with tools to identify challenges and a methodology for developing roadmaps that can be applied to the communities of organizations with the incentives to advance DER integration in specific technology areas (e.g., electric vehicle or photovoltaic (PV) systems integration). The document concludes with a summary in Section 8.0 and a list of references in Section 9.0.

2.0 Interoperability Background

2.1 Interoperability Definitions

As the electricity grid and connected DER evolve and advance, interoperability is of increasing interest. However, the term, interoperability, is often misused or misunderstood. Therefore, it is necessary not only to understand what various people mean when they refer to interoperability, but also to explain what this document means by interoperability in the grid modernization context, because any lack of clarity impedes discussions and progress toward establishing good policy, creating needed technology, and formulating standards.

Dictionary definitions of interoperability are diverse and conflicting, as illustrated by two examples:

> "the degree to which two products, programs, etc. can be used together, or the quality of being able to be used together." (Cambridge Dictionary 2017[1]), and

> "the ability of a system to work with or to use data or parts of another system." (Merriam-Webster 2017[2])

In one case interoperability either exists or not, but in the other it is a matter of degree. One applies to "systems" while the other to more specific entities (i.e., "products, programs, etc."). In both cases, however, interoperability exists between two entities, which is the basic and most common case.

The authors reviewed existing definitions of interoperability specific to, or closely tied to, the electric power industry, analyzing their merits and limitations. These include interoperability definitions found in IEC 61850, ISO/IEC/IEEE 24765, IEEE 2030, and in publications from the GWAC, NIST, CEN-CENELEC/ETSI, and DOE/EERE. References, exact text, and other details can be found in the appendix.

Almost all of the electricity-related definitions include three distinct parts:

- what entities are in scope
- that information is exchanged
- that information is useful

The scope of entities varies among the definitions, but the distinctions are not informative. Almost all of the definitions specify "two or more," though arguably all such interactions can be reduced to a collection of interactions where each individual interaction is between just two entities. That information is exchanged is almost the same in each; the exception, adding "end-to-end connectivity of hardware and software," could be considered as the definition of exchanging information. Many of the definitions address aspects of how the information is used (e.g., correctly, securely, and effectively). Others specify additional requirements (e.g., no user inconvenience).

Some definitions cite goals of electrical system interoperability distinct from what a definition requires. The GWAC 1.0 definition cites "common meaning" as needed, which is certainly true but perhaps not needed in a definition. Another definition specifies that products from different vendors may be involved and another that different organizations may be involved. The definitions from NIST, IEEE 2030, and CEN-CENELEC-ETSI are all very similar having probably received the most widespread review. They also provide the perspective of both U.S.-based and international organizations. Other literature on smart

[1] http://dictionary.cambridge.org/us/dictionary/english/interoperability

[2] https://www.merriam-webster.com/dictionary/interoperability

grid interoperability mentions that even though the term is used in a technical systems engineering sense, it must also account for social, political, and organizational factors that impact system-to-system performance.

The recommended definition is from the ISO/IEC/IEEE 24765 standard, which states that interoperability is:

> "The ability of two or more systems or components to exchange information and to use the information that has been exchanged."

The NIST/IEEE 2030/CEN-CENELEC-ETSI definitions appear to have broad support and derive from our recommended definition. However, they also contain additional aspects that should be kept to discussions rather than be part of the definition. A definition is useful for advancing interoperability only if it is as crisp as possible, describing just its essence.

2.2 Integration

A key goal of interoperability is to reduce costs associated with integration. This necessitates a definition for integration in this context. In this document integration as a *process* that occurs after a decision to acquire DER hardware has been made. Integration covers planning for what changes need to be made to the DER or other systems, making those changes, and all other steps leading up to the initial successful operation of the system. These steps may involve mechanical connections, electrical connections, network (or other communication) connections (including cybersecurity), financial arrangements, and a wide variety of configuration steps. Integration activities may also be needed to determine and ensure that the system is safe, operational, optimized, and delivers services as intended. These steps all take time and money, and can be burdensome if they require a large amount of either, or outside personnel, to accomplish. Thus, integration activities can impact the cost-effectiveness of DER and, in some cases, even prevent DER deployment.

All DER that interact to coordinate their operation with the grid require some communications (local within the site, to one or more external entities, or both). At a minimum, integration involves making a single connection that covers both electricity and communications. USB-powered devices are an example of this minimal integration process, and truly earn the description of "plug and play." Attaining this capability involved considerable standards development work (as well as testing and certification) and having a clearly defined scope for the connection (electrically and otherwise).

Larger systems have a greater process of integration, though the amount of effort required varies widely. Part of this is due to electrical capacity design and hardware issues, potential infrastructure needs, impact on user services, financial considerations, non-standard communications infrastructures, variations across utility regions, and more.

Improved interoperability reduces integration burden, ideally to zero. Integration burden is then determined to a significant degree by the amount of "non-interoperability," in the same way that health is, in many ways, the absence or minimal presence of disease.

2.3 Lessons from Interoperability in Other Domains

There are many examples in other domains where interoperability works well. For example, the track gauges used in most of the world's railways. The Information Technology (IT) industry, in particular, provides a multitude of good examples, and IT is the major problem area for electricity interoperability and the focus of this report. This section highlights cases where interoperability occurred, and important principles that were critical for achieving that success. Individual case studies were explored to assess the characteristics of success and which elements factored into creating good outcomes.

Character encoding: The American Standard Code for Information Interchange (ASCII) was released in 1963 to define a common mechanism for representing individual characters among information technology devices (e.g., computers, data storage, and teletypes). Without ASCII, IT systems would need burdensome and potentially error-prone translations or might fail to operate at all.

E-mail addresses: The current system of e-mail addresses (user@domain) was created in 1982 through RFC 822 and the standardized format enables seamless e-mail exchange. Prior to its implementation, many incompatible systems existed that required a multitude of gateways to exchange messages.

Web browsing: Along with e-mail, web browsing is a major use of the internet for most people, who simply expect any web page to show up on any web browser. While pages may be presented differently, these differences generally do not interfere with human understanding of the page. This rampant interoperability relies on two key standards: HTTP and HTML.

General internet technology: The core intent of the technology underlying the internet is to create an interoperable system based on non-interoperable parts (networks), so long as those parts implement several basic functionalities.

These examples show some general principles or common preconditions for attaining interoperability that are highly effective and useful. Among these are the following:

- Use a layered[3] architecture; modularity is good; and keep things separate, if possible.
- When in doubt during design, choose the simplest solution. If there are several ways of doing the same thing, choose one.
- All specifications should use the same terminology and notation.
- Create and use high-quality technology standards and architectures that are extensible and flexible.
- Focus on enhancing existing standards or protocols instead of creating new ones.
- Prefer open (readily accessible) unpatented technology.
- Embrace "Universal Interoperability[4]" as a goal. Designs should be fully international.

Supporting Ecosystems: None of the technical examples above would flourish if it were not for the business communities (composed of commercial, government, and research entities) that latched on to the technology and promoted it. Interoperability achievements in a technical area require agreement in social and organizational areas to advance. Groups such as the Internet Engineering Task Force (IETF), WiFi Alliance, and a host of profession standards organizations are needed to provide governance, supporting policies, and an economic environment that encourages businesses to adopt, develop, and integrate

[3] A layered architecture and modularity refers to the recognition and organization of interoperability characteristics into conceptually separated layers, where specification agreement on the bottom layers support agreements specified in upper layers. The entire "stack" of layers specifies a profile of agreements to enable interoperability. By focusing on concerns within a layer, the specification process can be modular and accommodate a degree of decoupling. Ideally, a layer can choose to have different specification, but still support the layers above and below it. Such structures help support interoperability issues associated with technology evolution and scalability. Sections 3 and 5 reference layered architectures to provide context for further discussion on the state and direction for interoperability.

[4] Universal interoperability is the principle that devices should be interoperable across facility types, end uses, countries, time, and people.

technology. All the trappings that allow an ICT-fueled ecosystem to flourish, including business opportunities, regulation, and finance, need to be aligned to drive down the cost of integration.

Work toward developing a vision of interoperability and driving it into electric power systems should take advantage of these lessons with the aim of working toward the best outcome for DER and grid infrastructure systems.

2.4 Challenges for Advancing Interoperability

Large-scale adoption and deployment of energy management and automation systems throughout the United States requires standards that can successfully address the many advanced facets of interoperability. However, existing standards are not sufficiently comprehensive, which hinders the push for higher interoperability in the electric grid. The following challenges were identified and classified by the GWAC Interoperability Context-Setting Framework (paraphrased from GWAC [2008]):

- **Organizational challenges**: Standards development is time-consuming and expensive, and reduces company-specific market advantages. Companies and other stakeholders need to recognize that the benefits of interoperability outweigh the burdens.
- **Informational challenges:** Current information models are numerous and application-specific. A universally understood and utilized information model, specific to DER interoperability, is needed.
- **Technical challenges:** A wide variety of communication standards are used in DER facilities controls and devices, making data access and other integration expensive and time-consuming. Progress requires greatly reducing the set of control and device standards in wide use, which will enable efficient auto-discovery and consistent semantic information exchange.
- **Security-, privacy-, and safety-related challenges:** Building and other DER owners and operators do not want to surrender asset information and control to outside parties due to perceived risk, mission-critical operations, data sensitivity, and protection of intellectual property. These concerns need to be addressed for interoperability to be promoted effectively.

In addition, these challenges create problems for integration during the initial configuration of communicating devices and systems, evolution of their characteristics or role in the system, and in enabling systems that operate and perform effectively.

Two major barriers to interoperability are legacy and proprietary protocols. Both limit asset owners to a narrow range of products and services centered on the purveyor of the protocol and limit the ability of other companies to innovate (e.g., provide new features). Further, these relatively old technologies lack the design and capabilities of more modern ones. More recently, additional standard technologies have become widely available for individual devices in smaller facilities; however, the large number of these protocols greatly impedes uptake and interoperability.

A core architectural principle of internet technology is a layered architecture that separates physical and application layer protocols. Many times, in technology application domains (e.g., buildings automation), information layer models are directly tied to particular technical layer protocols. This inhibits separation of choice and evolution between layers for interoperability and limits a protocol's long-term success.

2.5 Declaration of Interoperability

As a foundation for this work, the following Declaration of Interoperability is the result of debates and revisions by all the participating DOE national laboratories and partners to galvanize the community to advance interoperability for grid modernization.

We, the participants in the GMLC Interoperability Program, based upon our collective resolve and industry experience, set forth these principles, enumerated below, aligned with the U.S. Department of Energy's congressionally mandated charter to convene, adopt, and deploy tools and techniques to enable interoperability to create a more reliable, secure, affordable, flexible, sustainable, and resilient electric power system. We believe this industry-led approach can, by following these principles, develop the needed solutions to achieve these goals.

We recognize that a lack of cost-effective interoperability creates onerous and ongoing problems for system integration and operation.

- *It wastes energy.*
- *It wastes money.*
- *It wastes time.*
- *It impedes goals of renewable generation and grid performance.*

Our future electric power system must easily integrate great numbers of an evolving mix of intelligent, interacting systems and components. Achieving this state requires the advancement of interoperability and the principles that support it; this is a shared challenge requiring alignment across all electric system stakeholders. It is therefore necessary to articulate interoperability goals and requirements and establish a strategic vision for interoperability.

Interoperability is "The ability of two or more systems or components to exchange information and to use the information that has been exchanged" (ISO/IEC/IEEE 24765). Interoperability also refers to the steps required to achieve this state, which directly relates to the level of effort to successfully integrate systems or components. With this understanding, we recognize the following principles:

- *Systems or components need to interact according to agreements at their interface boundaries.*
- *A system architecture description needs to clearly identify the interface points where systems or components may interact.*
- *Interoperability concerns need to pervade across a heterogeneous mix of technologies, business practices, and deployment approaches.*
- *Stakeholders need to participate in the process to develop, use, and maintain interoperability standards, conventions, and supporting capabilities such as certification programs, registries, and security policies.*

The principles above require changes in today's technologies, business practices, and deployment approaches, to promote interoperability and simplify the integration experiences.

We hereby recognize that improving stakeholder agreement on clear interface definitions and mechanisms to simply and cost-effectively integrate systems and components will catalyze the realization of a more efficient and secure electric system sensitive to our operational, economic, and ecologic needs. And in response, we join in the efforts to advance interoperability of the future electric system and commit to changing technologies and business processes to accomplish this mission.

3.0 DER Interoperability Discussion Framework

Focusing on the area of DER integration as an example of a significant interoperability challenge, the discussion of the state of and future directions for advancing interoperability for DER integration with the electric system can benefit from identifying the following:

1. the relationship with grid architecture and where DER connect and interface with electric system infrastructure
2. the types of DER technologies being integrated
3. the objectives or grid services that drive the reasons for coordinated interactions of DER with the grid
4. the stakeholders and actors that influence these interactions.

While there are many specialized situations for DER and grid interaction, investments toward interoperability concerns are best leveraged in participant communities or ecosystems where standards and conventions serve a vast number of synergistic business interests and deployments.

The following sections provide conceptual views of these various aspects that contribute to communicating the complex dimensions associated with DER interoperability. The section ends with a summary of the framework used to discuss DER integration in the remaining sections of the document.

3.1 Relationship of Interoperability with Grid Architecture

Grid architecture helps identify and provide principles for better design of ICT interfaces between connected entities' devices and systems, and thereby directly affects the ease of achieving interoperability. Grid architecture also helps inform the extent of system vulnerabilities to cybersecurity risks. Grid architecture determines what entities need to interact at all, and about what content.

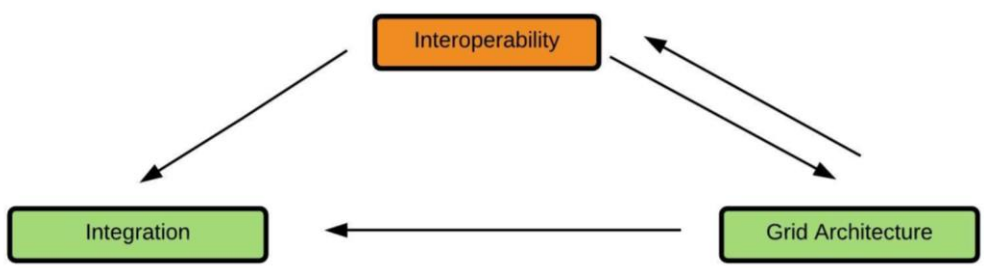

Figure 3.1. Relationships among Interoperability, Integration, and Grid Architecture

Figure 3.1 illustrates the relationships among the concepts of grid architecture, interoperability and integration. Arrows indicate the direction of information flow. Clearly, each topic area informs and improves the development of the others such that, if one of the areas is to be improved it is necessary to take a broader perspective and draw on the considerations placed on that area by the other areas.

3.1.1 Layered Decomposition in the Electric System Architecture

Figure 3.2, taken from Taft (2016a), is a view of the electric power system that embraces an architectural pattern of layered decomposition as a structure for a coordination framework. This model has been used to show commonality across a range of existing and proposed control/coordination architectures, indicating a degree of generality (Taft 2016b). The basic approach of layered decomposition is to decompose the system coordination objectives into a master problem and several sub-problems. These problems are solved iteratively until they collectively reach convergence. Each sub-problem may also be decomposed recursively into set of additional sub-problems. Each level of these nested sub-problems can be considered a coordination domain. The figure starts at the regional, transmission coordination domain, which interacts with the distribution systems operations coordination domain, which in turn interacts with the primary distribution substation domain, which can interact with further decomposition domains until eventually the DER coordination domain is reached.

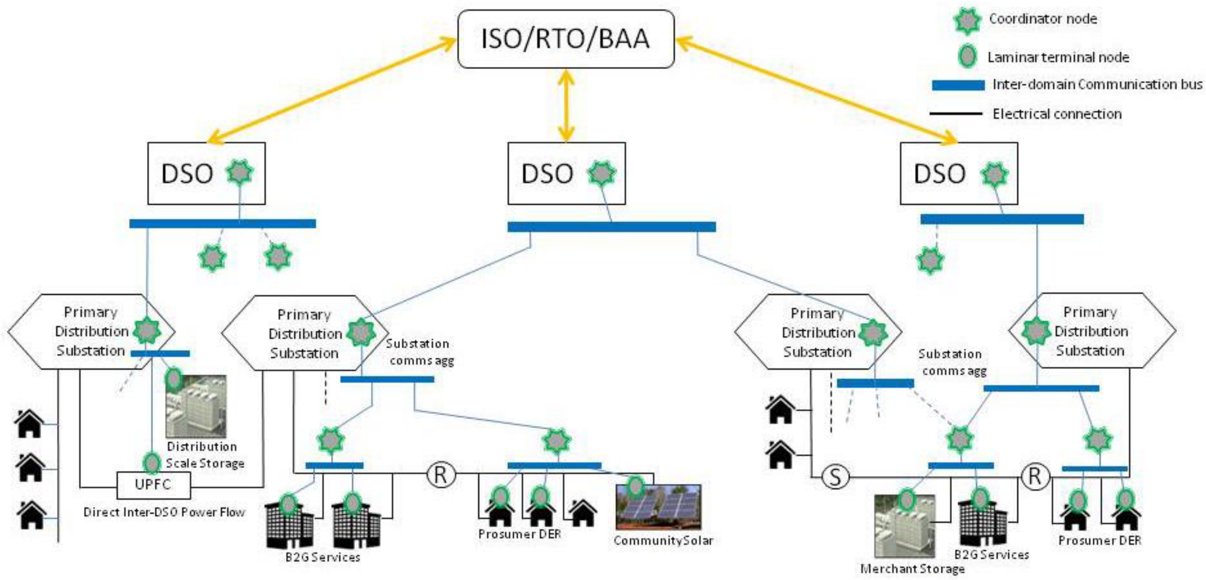

Figure 3.2. Utility Architecture View with Layered Decomposition Coordination[1]

An important aspect of layered decomposition is that the interaction signals are resolved adhering to the master problem and sub-problem hierarchy. Coordination interactions that skip layers of the coordination framework structure can lead to less optimal or unstable behavior. For example, a DER market provider that aggregates responsive equipment for interactions with independent system operator (ISO) energy markets cannot reliably coordinate with sub-problems at the DER facilities level if the coordination frameworks of the affected distribution system operators (DSOs) are not also part of the coordination. How else would such a solution process know if a distribution system delivery constraint was violated? Figure 3.3 (Taft 2016a) indicates how a coordination approach can effectively respect the coordination domains.

There are two figures to show that distribution operations may use different communications configurations that support the coordination framework, such as either having or not having a Utility Field Area Network (FAN). Also, that the figure indicates that DER may be connected and managed by the distribution system infrastructure (inside Grid Edge), or managed directly by the distribution utility (between Grid Edge and Utility Edge), or managed by a third-party grid services aggregator all acting within a common coordination framework. While architecturally, all of these options need to be supported, this document is most concerned with last situation as standards and guides become critical for

[1] Note that the circled S and R refer to switch and recloser, respectively and UPFC stands for Universal Power Flow Controller. ISO is Independent System Operator, RTO is Regional Transmission Organization, and BAA is Balancing Area Authority.

the non-utility DER facility managers to integrate with the power system. Note that DEV in Figure 3.3 corresponds to field devices within the delivery infrastructure (e.g., reclosers, capacitor banks, and tap changing transformers) with actions also subject to the coordination framework.

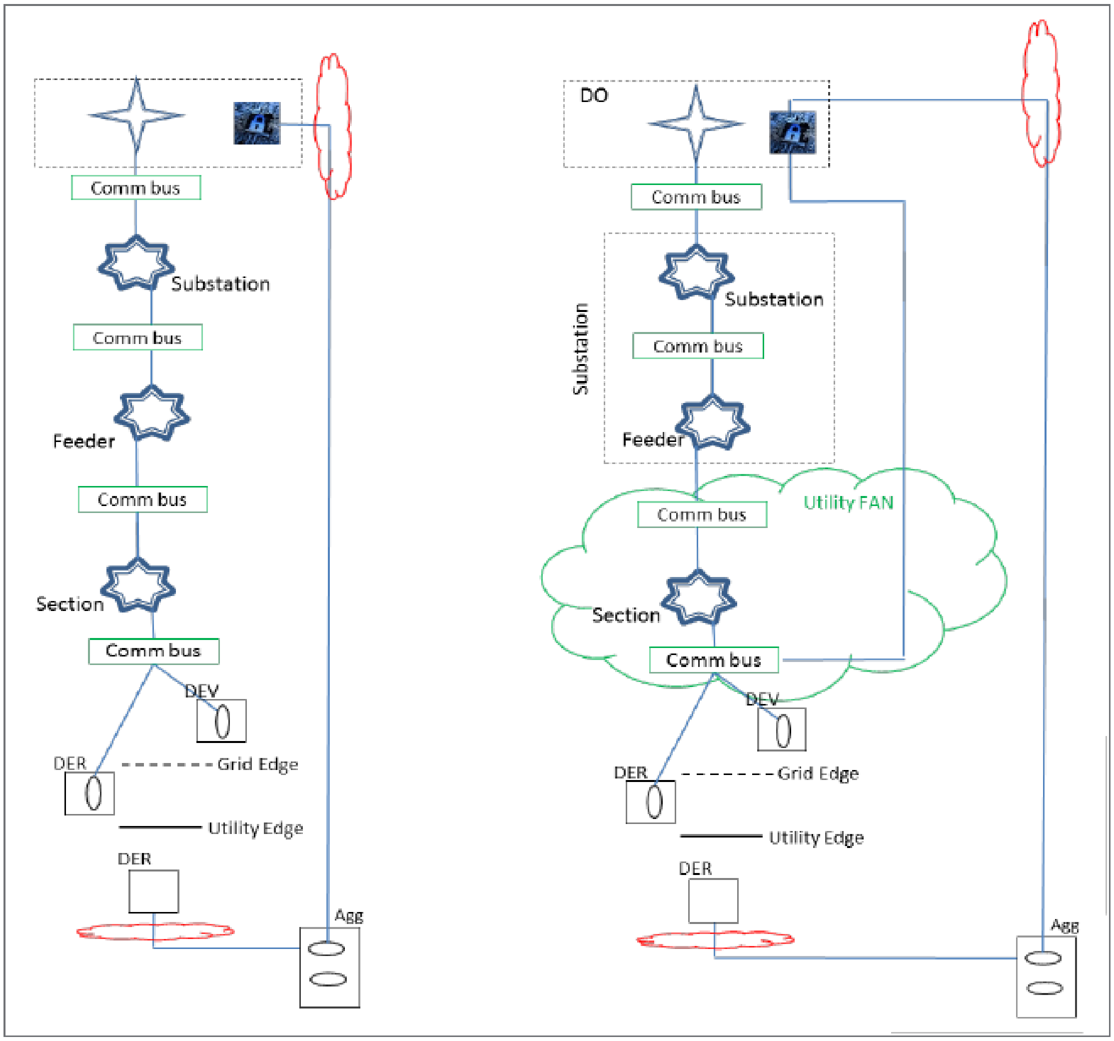

Figure 3.3. Improved Granular Layered Decomposition Networks

DER are devices and systems that, in order to be responsive, need some intelligence to manage or control their operation and interact through a communications interface to other interacting parties in the electric system (see Figure 3.4). The DER equipment in Figure 3.4 are resources responsive to coordination signals. Whether that equipment communicates and coordinates its operation as a unit or is directly controlled by a separate management system is a matter of design choice. The term DER facility generalizes the idea that DER equipment has some intelligent management aspect as indicated by DER facility-management system [FMS]. On the right side, the FMS interacts with DER equipment within a facility, and on the left side interacts with other external parties, such as a distribution system operator or an aggregator. An FMS could be as simple as a communicating controller for a community storage device or a complex management system for a commercial building, manufacturing facility, campus, or an electric vehicle charging parking lot with PV arrays. To interact with DER equipment, the FMS coordinates with internal ICT interfaces with the DER equipment. To coordinate with external parties, the FMS uses an energy service interface (ESI). The ESI is specifies the form of the interactions between the

DER facility and the external parties. The ESI is implemented in the FMS or what could be considered an adapter to the external parties. The double-sided arrow on the left represents the communication connection and interactions with external parties so that the DER facility adheres to the architectural principal of layered decomposition. It also provides a focus for conventions, guides, and standards for simplifying the integration of DER facilities so that their interactions with interacting parties' are similar no matter what type of DER facility is being integrated. It also acknowledges that the integration issues associated with communicating with devices internally to the DER facility may be different than the integration issues with external parties.

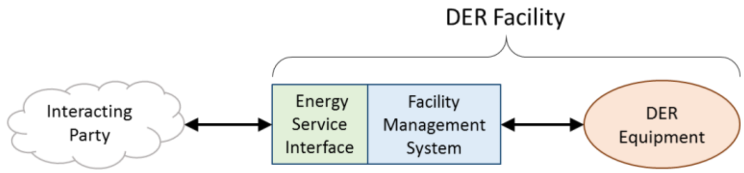

Figure 3.4. Components of DER and Grid Integration

Figure 3.5 comes from a conceptual model presented in Hardin et al. (2015), which was inspired by the ESI from the Buildings-to-Grid Working Group of the SGIP and the NIST Framework Conceptual Model. This figure expands the basic concept of a DER facility to indicate that it may be composed of one or more types of DER managed by an FMS and this system is able to interact with external parties through an ESI. The classes of interacting parties are indicated by the clouds connected by communication path arrows on the left to the ESI and the types of DER equipment are indicated by the ovals connected by different communication path arrows on the right to the FMS. Another important concept included in Figure 3.5 is that of the meter. To reconcile the resulting actions of a DER facility with the coordinating agreements, sensing and measurement systems need to be in place. The electric meter monitors the flow of energy between the DER facility and the electric system. A dotted line indicates the communication path that connects it to distribution system operations, which is the authority responsible for the reliable operation of the distribution system. The sets of arrows and dotted lines of communication represent areas of focus for discussing interoperability issues.

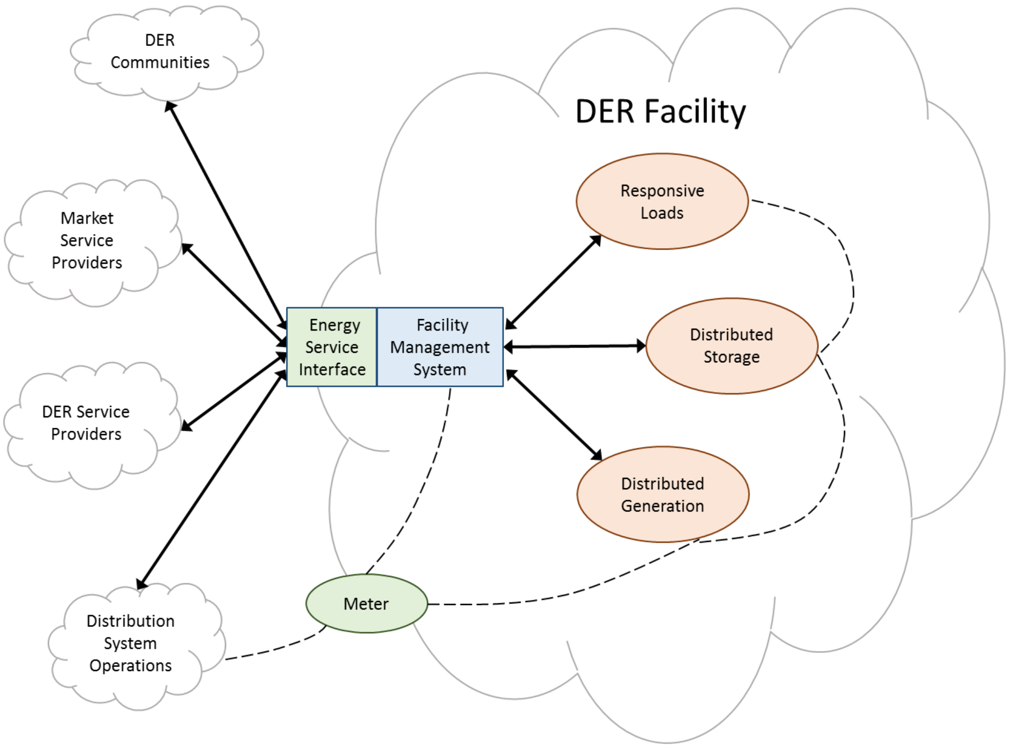

Figure 3.5. DER Facility Conceptual Model

3.1.2 DER Integration Interface Areas

Figure 3.4 makes a distinction between the integration of the DER facility with external entities (the grid) and between the FMS and equipment internal to the facility. A DER facility can be of any type such as a campus, third-party energy storage, or one of a wide variety of building types (e.g., residential, commercial, institutional, and industrial). An external party is a system or an organization with coordination ties to the electric grid, and may be part of a utility operating company, or a third-party organization. Interoperability between external interacting parties, such as between Market Service Providers and Distribution System Operations, is an important topic, but not a focus of this report.

3.2 Technologies

Using the concepts depicted in Figure 3.5, the following types of DER facility technologies are relevant for exploring integration and interoperability concerns. They are listed by the type of responsive equipment, the type of management systems that coordinate their operation, the sensing and measurement types of technology, and the types of customer facilities that integrate these technologies and have interactions with external parties.

- Equipment types
  - Responsive loads
    - Devices: such as appliances, lights, pumps…
    - Systems: such as lighting systems; heating, ventilation, and air conditioning (HVAC) systems; traffic signal systems; water/sewage pumping systems; electric transportation systems; thermal storage systems…
  - Distributed storage

    - Electric batteries
        - Stationary
        - Mobile: such as electric vehicles
    - Flywheels
    - Compressed air systems
  - Distributed generation
    - PV
    - Wind
    - Hydro
    - Combined heat and power capable
        - Combustion engine
        - Fuel cell
- Management systems
  - Smart inverters
    - Fixed power factor
    - Four quadrant control
  - Facility-management systems – energy-management systems (EMSs) for various facility types
    - Industrial sites
    - Commercial buildings
    - Residential buildings
    - Government infrastructure
- Sensing and measurement
  - Electricity service meter
  - Sub-meters and sensing with in the facility

3.3 Grid Services

The purpose of coordinating DER operation with the electric grid is to achieve one or more grid operational objectives. These objectives include efficiency, reliability, stability, quality, and resilience to abnormal situations. To effectively engage DER, these objectives become translated into a set of operational compacts or contracts called grid services. While each jurisdiction may have somewhat different definitions and contractual terms for grid services, the types of services fall into generally recognized categories. The GMLC 1.2.1 Grid Architecture project is organizing a list of grid services for consistent application in the other GMLC projects. While this list is being developed as of this writing, a preliminary list used by the GMLC 1.4.2 Grid Services Equipment Characterization project is presented below.

Today, there are few grid services available for DER coordination. Most DER facility interactions are directly controlled by utilities or third-party aggregators. The service contracts may or may not stipulate the purpose for control so the grid service or system objective is not always apparent to the DER facility.

- **Peak capacity management** – reduce net load as needed so that it never exceeds the capacity of the grid infrastructure to deliver power to a region. Typically, this occurs over a span of several hours on 10 to 15 of the hottest summer days of the year (or, for some regions, coldest winter days).

  Objective – reduce the need for capital expenditure for generation, transmission, and distribution capacity expansion or upgrades.

- **Energy market price response** – reduce net load when prices are high or increase net load taking place when prices are low. This tends to occur in predictable, seasonal daily patterns over periods of a few hours when power plants with expensive fuel and/or low efficiency are required to supply power. Random disruptions to daily patterns may be due to weather conditions, plant outages, shortages in output from renewable generation, or unusual wholesale market conditions.

  Objective – reduce wholesale energy production or purchase costs and ensure that non-dispatchable generation is not wasted.

- **Meet obligation to supply capacity in a wholesale energy market** – reduce net load when called upon by an independent (transmission) system operator to meet a contractual obligation to do so, for which they have received a capacity payment (often through a market intermediary known as an aggregator). When provided by DERs, it is typically utilized as reserve capacity for extreme events lasting a few hours, and may be called upon at any time as a performance test.

  Objective – ensure sufficient regional generation capacity exists and obtain it from the lowest cost resources using a wholesale capacity market.

- **Frequency regulation** – increase or decrease net load to restore balance between supply and demand in response to a ~4-second interval signal from the grid operator. Traditionally supplied by power plants that take many seconds up to a few minutes to respond.

  Objectives –

  Fast regulation – maintain grid frequency within acceptable range in the face of continual, momentary imbalances between supply and demand; varies from up to down within seconds.

  Slow regulation – maintain contractual balance of imports and exports for a regional balancing authority's balancing area; varies within 10 to 15 minutes (may or may not be combined with fast regulation into a single service).

- **Spinning reserve** – remain on standby, ready and able to rapidly reduce net load and sustain the reduction until replaced by generators that are available but offline (typically 15 to 30 minutes).

  Objective – rapidly restore balance between supply and demand when a large grid asset (power plant or transmission line) suddenly and unexpectedly trips offline. This is required to prevent blackouts.

- **Ramping –** remain on standby, ready and able to rapidly increase or decrease net load when the available generation cannot change its output rapidly enough to follow changes in total net demand (regional load net of total renewable output). This is a new type of service being driven by rapid penetration of renewables. Typically, ramping occurs over a couple hours in the morning and late afternoon in regions with high levels of solar generation, or when a wind forecast is mistimed (e.g., by ~1 hour) due to a shift in the wind speed in regions with large amounts of wind power.

  Objective – meet the requirement to rapidly change the output of total generation to maintain balance between supply and demand in response to rapid changes in renewable production.

- **Artificial inertia** – remain on standby, ready and able to self-sense when grid frequency drops rapidly, and act to complement the grid's angular momentum and generator governor controls by instantly and autonomously increasing or decreasing net load (~1 second, less is preferred). Traditionally supplied by a combination of the angular momentum of turbines in steam- or hydro-based power plants and autonomous governor controls on large generators, there is emerging need to supplement the inertial response of these resources with a new type of service from other resources as renewable generation displaces steam-based plants.

Objective – slow and arrest the otherwise precipitous change in frequency that begins instantly when a large grid asset (power plant or transmission line) or a similar amount of load suddenly and unexpectedly trips offline and creates a large imbalance between supply and demand.

- **Distribution voltage management** – remain on standby, ready and able to self-sense when the distribution voltage drops rapidly, and act instantly and autonomously by rapidly adjusting net load in the form of its reactive and/or real power components (~1 second, less is preferred). This is a new type of service being driven by rapid penetration of distribution-connected solar generation. Rapid changes in the combined power output from such systems can occur due to crossings of cloud fronts, which can result in unacceptable voltage fluctuations.

  Objectives –

  Fast response – maintain distribution system voltage within the normal range in response to rapid changes in net demand for power.

  Slow response – assist in maintenance of distribution system voltage within the normal range by coordinating reactive power output with distribution voltage management systems (i.e., transformer tap changers, voltage regulators, and capacitor banks), either on command or autonomously based on self-sensed voltage fluctuations.

3.4 Interacting Parties and Integration Stakeholders

Having a consistent and common list of players can help in discussions of interoperability concerns. This section proposes a list of actors that take on the roles of the interacting parties and the people involved in making interoperability a reality.

Figure 3.5 shows a set of interacting parties that interact with the DER facility to conduct various grid services. These parties are actors in interaction use cases with the DER facility.

- DER operations
  - The entity responsible of the operation of a DER facility.
- DER community
  - DER communities are collections of DER that do not share owners or operators but have characteristics that enable them to work together to coordinate and optimize energy use under a variety of conditions. These communities have the potential to manage DER to enable operation of community microgrids.
- DER service provider
  - DER service providers provide a range of services to DER facility owners and operators. Service domain connectivity involves the interconnection between devices and systems that reside within a facility and remotely located third-party service providers. These providers can manage DER operation for financial benefit of the DER owner in reducing utility bills. These services also supplement DER operations by performing equipment and system monitoring, diagnostics, and troubleshooting along with software and information technology support. Service providers are typically third parties that perform services for DER facility owners or operators under contract relationships. IoT technology is rapidly impacting how service providers connect to sensors and actuators.

- Market service provider
  - Market service providers are remotely located third-party retail market operations systems that provide electricity service agreements to DER facilities. Market service providers also interact with other electric power grid service actors at the bulk system level (e.g., wholesale electricity markets and transmission system operations) and with distribution system operations actors to maintain the layered decomposition coordination framework. In this role they act as a middle man so that DER facilities do not need to interact directly with bulk system-level actors. An example of a market service provider is an aggregator of DER who coordinates responsive resources from multiple facilities to be able to contract with wholesale electricity markets with large offerings.
- Distribution system operations
  - This is the entity responsible for the reliable operation of the distribution system.
  - Distribution system operations involves the interconnection between devices and systems that reside within a DER facility and distribution system operations (e.g., utilities). Market service providers may need to interact with distribution system operations to either offer services on behalf of the DER facility to distribution system operations or to ensure that their service to the facility addresses the reliable delivery requirements maintained by distribution system operations.

Other electric power grid service actors exist (e.g., wholesale electricity markets and transmission system operations); however, these actors interact with distribution system operations and market service providers and not directly with the DER communities and DER facility operations actors.

Categories of stakeholders involved in the integration and not necessarily the coordinated operation of DER for grid services include the following (see Hardin et al. (2015)):

- DER managers, owners, and users
- DER equipment suppliers (hardware manufacturers)
- DER energy-management system suppliers (generally automation software suppliers)
- DER service providers
- market service providers
- distribution system operations (role responsible for reliable operation of the distribution system)
- communications infrastructure and service providers
- regulators and government agencies
- trade associations, industry consortia, and standards development organizations
- testing and certification organizations.

3.5 Integration Ecosystems

DER integration ecosystems are created by communities of organizations who share benefits in the advancement of technology integration objectives. Ecosystems are emerging in DER technology areas (e.g., electric vehicle integration, automated buildings integration, and distributed PV systems integration). This subsection describes some important ecosystems where a community has coalesced because of the opportunities presented for business and/or social benefits. In addition, measurement systems that support the integration of DER technology are represented as an ecosystem because of their importance for validating operational performance and settling business agreements.

This is an exemplary list and is not intended to be comprehensive. Not only can the integration ecosystems be expanded, but other areas of integration in the grid and inside end-use facilities could be added for applying the proposed approach to advance interoperability. For example, ecosystems concerning distribution system operations DER management platforms, substation field automation systems, or microgrid interoperability could also be added to this list in the future.

The description for each ecosystem addresses the following questions:

- What are the business or social opportunity drivers that attract a community of organizations to come together to address DER integration concerns? Related to this, what grid services or applications are addressed by integrating DER with the grid?
- Who are the main stakeholders by type of organization who participate in the ecosystem (see list in Section 3.4)? In particular, who owns and operates the DER technology, who supplies the technology, and what is the level of involvement of market service providers and distribution system operators?
- What is the government (including regulatory) situation that encourages or challenges the ecosystem?
- Who are the convening organizations that facilitate the interactions among stakeholders to address interoperability issues through, for example, standards, guides, tests, best practices, and promotional branding?

3.5.1 Electric Vehicles

There are many stakeholders in the interoperability of plug-in electric/hybrid vehicles (PEVs) and the charging infrastructure. Vehicle original equipment manufacturers and suppliers of electric vehicle supply equipment (EVSE or charging equipment) are directly involved in the development of standards and technology for PEV-EVSE connectivity and communication. Charging network providers would like to serve all PEVs and complete business transactions in a standard manner. Energy market service providers (i.e., retail utilities and aggregators) and distribution system operations consider the possibility of grid services provided by PEVs/EVSE. Building and campus energy system operators may foresee benefits from integrating controllable EVSE to help manage loads and demand charges. Last, but certainly not least, are the PEV owners/users for which interoperability means seamless connectivity to any EVSE and the ability to pay in a manner that is at least as convenient as that of conventional refueling.

Policy makers and regulators view widespread PEVs as a major contributor to national and global energy and environmental objectives. In fact, the U.S. and European governments recognized PEVs as a common growth area and welcomed the opportunity to work together to reduce regulatory divergence and promote the interoperability of PEVs and the charging infrastructure. The result was an agreement in late 2011 between DOE and the European Commission’s Joint Research Center (JRC) to cooperate on pre-normative standards (i.e., tools and test procedures to aid industry efforts to harmonize and accelerate new technology introduction). The agreement included establishing electric vehicle (EV)-smart grid interoperability centers at ANL and JRC for the following purposes:

- establish state-of-the-art facilities to develop and test vehicle-grid interface technologies
- play an active role in standardization, including common testing approaches for EVs and smart grid equipment
- enhance the interoperability of EVs and smart grids, including supporting harmonization of connectivity, communication, and component compatibility.

This agreement has led to substantive industry-government collaboration to support harmonization interoperability requirements and verification procedures in the United States and Europe that have advanced, and are still advancing the state of interoperability for PEVs and the charging infrastructure.

3.5.2 Photovoltaics

The interest of consumers for clean energy and energy independence, coupled with encouraging policies for deploying clean energy resources in certain regions of the country, such as rebates and net-metering rules, has increased the rate of new PV system interconnections. The situation brings together communities of organizations to find ways to reduce the cost of interconnecting new PV systems and address emerging issues in distribution system operations for increased PV hosting capacity on distribution feeders. For example, state policies such as California Rule 21, Hawaii 14H, and New York's Reforming the Energy Vision encourage the integration of PV and thus are having the effect of increasing the need to address interoperability issues.

As the amount of PV increases, integration concerns increase because the aggregate amount of PV has greater impact on distribution system planning and operations. These concerns include maintaining safety for linemen and customers, and maintaining reliability with an adequate mix of energy sources to provide continuity of service during variable solar resource times (e.g., during cloudy days or at night). The resulting situation challenges the electric utility business model, impacting the determination of fair and affordable electric rates as planning, operations, and infrastructure are modified to meet increased integration needs. In some states (e.g., Arizona and Texas),[2] electric utilities are allowed to own and operate distributed PV assets, while other states only allow either customer or third-party ownership of distributed PV.

Policy and market conditions are creating pockets of activity throughout the nation. California's strong desire for reduced environmental impact has been a primary driver for increased renewable energy targets in that state. This has resulted in a large amount of PV activity in all facility types including residential, commercial, and industrial. In Hawaii, environmental impact coupled with high fuel costs have led to an increase in activity.

PV technology developers, integrators, and installers face integration issues at differing levels. Some developers and integrators own, install, and maintain large fleets of distributed PV in multiple states. They may be interested in providing not just local electric generation to customers, but may also be interested in providing ancillary services (e.g., voltage control) to distribution or transmission operators. Evolving integration challenges include additional complexity for adding energy storage to existing or new installations to augment these ancillary services. Examples of projects include Xcel Energy's battery storage at Stapleton,[3] Arizona Public Service Distributed Solar Study,[4] and SMUD's Anatolia project.[5] These projects and others like them are exploring the varieties of technical capabilities that various deployments and technologies can provide and are also exploring the monitoring, control and data exchange requirements between utility and PV facility. These types of demonstrations provide not only results from technical trials but also provide valuable information regarding the maturity of business practices required to support the necessary interoperability.

There are several industry organizations that support collaboration, sharing of best practices, and research on improved methods for PV integration. These include EPRI,[6] the Smart Electric Power Alliance,[7] the

[2] http://solaroutreach.org/wp-content/uploads/2015/11/Final_UtilityOwnedRooftopSolar.pdf
[3] https://www.xcelenergy.com/energy_portfolio/innovation/stapleton
[4] https://www.greentechmedia.com/articles/read/aps-deploys-4mw-of-aes-batteries-in-comprehensive-solar-study
[5] http://www.cesa.org/projects/energy-storage-technology-advancement-partnership/energy-storage-news/newsitem/smud-partners-kick-off-energy-storage-project
[6] http://www.epri.com/Pages/Default.aspx
[7] https://sepapower.org/

Solar Energy Industries Association,[8] the SunSpec Alliance,[9] and the Utility Variable-Generation Integration Group.[10] All of these organizations are actively involved in integration efforts; however, the SunSpec Alliance is most heavily involved directly in communications standards and certifications for integration and interoperability. Members from these organizations support formal standards development organizations such as IEEE.[11]

DOE has supported and facilitated numerous interactions among stakeholders to address interoperability issues through direct funding of research and development as well as demonstration projects and continues support through initiatives such demonstrations under the High Penetration Solar Deployment,[12] GMLC,[13] and ENERGISE.[14]

3.5.3 Commercial Building Responsive Load

Multiple stakeholders participate toward the proliferation and effective performance of responsive loads in commercial buildings, and each participant has its specific reasons and goals. Utility energy traders want to reduce costs when there is a mismatch between wholesale electricity costs and retail rates. Third parties (e.g., aggregators and other market service providers) have identified a business opportunity to be intermediaries between traditional utilities and end users and offer services that the utilities cannot offer easily or cannot offer at all. Building owners are always exploring ways to save money at the meter or get payments for additional services either from the grid or a third party. Most of these solutions today are largely focused on efficiency and on demand response for peak load reduction. Finally, manufacturers of end-use devices increase sales by adding the capability to be grid-responsive to their products. In addition, for those who want to provide or utilize microgrid capability for reliability, having some loads that are responsive increases efficiency when islanded from the grid and reduces capital costs due to better battery sizing while also ensuring continuous operations. People may also want to make loads responsive for environmental considerations because difficulty in dealing with supply variability is a stated barrier for greatly increasing the amount of renewables on the grid, whether central or distributed.

There are three main methods within commercial buildings for the integration of DER with the grid. The first is direct load control of the DER by either the distribution system operator or a market service provider. The second is a price-reactive DER, whereby dynamic price signals are used to encourage changes in end-use consumption. The third is the use of responsive loads by building operators to reduce demand charges.

The responsibility of operation of commercial buildings can be complicated. Some building owners own and operate their own facilities, while others own the facility and outsource its operation. Traditional market service providers operate DER owned by others through control signals, while other market service providers both install and operate the DER. In some markets, non-utility electricity retailers exist and may be responsible for DER operation.

Rate making is the main policy tool available to regulators for promoting or limiting the growth of DER. The flat rates common today do not encourage DER interaction with the grid. Rather, they encourage

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8 http://www.seia.org/
9 http://sunspec.org/
10 https://www.uvig.org/
11 https://www.ieee.org/index.html
12 https://energy.gov/eere/sunshot/high-penetration-solar-deployment-funding-opportunity
13 https://energy.gov/eere/articles/energy-department-announces-30-million-projects-integrate-solar-nation-s-electric-grid
14 https://energy.gov/eere/sunshot/enabling-extreme-real-time-grid-integration-solar-energy-energise

direct load control (DLC) demand response whereby utility or third-party market service providers are incentivized to implement the DER equipment control within the building, and in return, provide payment to the owner-operators. In contrast, time-varying rates offer a way to encourage DER facility managers to adjust demand, which can reduce or eliminate the need for utilities to engage third parties. (Note that third parties may still be contracted by DER owners to reduce utility bills.)

A number of consortia are involved in facilitating interaction among stakeholders to improve the state of interoperability. The Zigbee Alliance convenes participants on standards for wirelessly controlling assets within a building. Similarly, the OpenADR Alliance convenes organizations for external commercial building interactions with the grid through standards. Both support DLC as well as dynamic price signals.

3.5.4 Residential Responsive Load

Historically residential responsive load has been directly controlled by utility (combined Market Service Provider and Distributions Systems Operations) roles (i.e., DLC) under a critical peak program or similar agreement with the customer. Typical loads for such a program are air conditioners, electric water heaters, and pool pumps. Indirect load response has also been attempted with in home indicators with the hope that the customer will observe the indicator and defer an action such as drying clothes or running the dishwasher. Time of use (TOU) tariffs are also used by some utilities to try and achieve a similar, customer action-based result.

There is a developing ecosystem in home automation that includes energy-related capabilities such as smart thermostats and lighting controls. Vendors including Apple, Google, Amazon, home security companies, and many others are competing to provide integration platforms and devices. These suppliers are providing a broad set of capabilities primarily focused on comfort, convenience, entertainment, information and security. Some specific devices such as Nest and Ecobee thermostats have capabilities used by utilities in either utility-supplied or “bring your own device” energy-efficiency programs. Well-developed home energy-management systems that can enable participation in markets or other responsive load programs are not yet mature or widely available. Currently, standards including Zigbee, Z-Wave, and Wi-Fi compete to integrate multiple devices in the home. The most common point of integration is the smart phone with apps that allow remote viewing of data and interaction with the individual devices.

There is an emerging opportunity for residential responsive loads to participate in markets either directly or through aggregators. A key impediment is a regulatory reluctance to offer dynamic rates to residential customers. States such as California, New York, and Hawaii are working on enabling consumer choice of energy supply and facilitating DER integration; these states may be the first to allow distribution system operations that include markets or other mechanisms for residential loads to dynamically respond to operational signals. In addition, the opportunity exists for the government to facilitate standards (e.g., appliance standards) that will benefit multiple manufacturers by lowering the cost to integrate their products with home energy-management systems (HEMS).

There is a lack of a focused interest community to address integration and interoperability within the home to facilitate cost and ease of deployment and use for customers. This problem also exists for the interface between the home and external parties.

3.5.5 Metering

Metering is an intrinsic part of supporting the measurement and verification of activities performed by DER systems and is an interesting ecosystem from an interoperability perspective. The business drivers are embedded in the need for measurement of electricity transferred between the grid and the DER facility. Advanced metering infrastructure (AMI) meters can provide two-way communication not only directly to the distribution system operations and business operations via metering networks, but also with other meters and with DER facilities to interact with DER equipment. The primary drivers for installation have been utilities updating older meters to establish a basis for TOU metering, gaining visibility into system operation, and reducing meter-reading costs. In addition, sophisticated users want information about their electricity usage and, thus, desire access to the data.

Meters are needed for reconciling DER facility participation in grid services. This includes distinguishing the direction of flow and usage periods (e.g., TOU, critical peak pricing, and other dynamic tariffs). Further, meters provide load information for phase balancing and voltage information for Volt-VAR coordination.

A metering ecosystem involves at least three types of stakeholders: one on each side of the meter and regulation. The meter measures electricity transferred as part of a contract so both parties are stakeholders. This may include DER operators, owners, and users as well as DER service providers, market service providers, distribution system operations, regulators, and government agencies. Others who may use the information, provide third-party services, or are involved in specifying requirements are also stakeholders. Because meters are being used to validate financial transactions quality levels must be specified. This means technology providers, standards bodies, and testing and certification organizations are also stakeholders.

In terms of dealing with the changing technology and data requirements, the American National Standards Institute (ANSI) C12 standard was a huge step forward in establishing a standard communication protocol for electricity meters. However, soon after compliant meters were deployed, users wanted to be able to send and receive ANSI tables remotely. This presents a problem to meter vendors who want to comply with standards to make their products more attractive to utilities yet fear the consequences of a commodity meter market which drives down prices.

The abundance of information with multiple organizations who are interested in metering information means that benefits can be gained from advancing interoperability. To address this, in the fall of 2011 DOE launched Green Button, based on the Energy Services Provider Interface data standard released by the North American Energy Standards Board (NAESB). With their own data in hand, consumers can take advantage of a growing array of online services to help them manage energy use and save on their bills. Voluntary adoption of a consensus industry standard by utilities and companies across the country both enables and incentivizes software developers and other entrepreneurs to build innovative applications, products, and services.

3.6 Framework for Discussing DER Interoperability

The previous sections organize concepts for discussing interoperability issues surrounding the special case of DER integration. They represent some of the important dimensions to explore when assessing the state of interoperability for grid modernization in general and in specific technology domains where ecosystems of stakeholders come together to support different types of DER deployment. This strategic vision integrates these concepts into a framework to facilitate a discussion about the state of DER interoperability.

The framework in **Error! Reference source not found.** is adapted from Hardin et al. (2015). The GWAC's Interoperability Context-Setting Framework (GWAC 2008) falls on the vertical axis to represent the layers of interoperability categories that support ease of integration. The horizontal axis depicts the interacting parties with DER operations (DER actors) as inspired from the NIST Smart Grid Conceptual Model (NIST 2014) and described in Section 3.4. The third dimension provides the automation zones used to describe the layered coordination framework for a DER facility as derived from the ASHRAE model (ASHRAE 2014). The perspective provided by this figure can be helpful in understanding the internal and external interactions between actors, DER facilities and DER equipment. For example, interoperability issues within a DER facility are contained in the space occupied by the DER operations sections. The DER automation zones describe the nature of internal interactions from local device coordination to management level interactions that go beyond the DER facility. The interactions via communications with other actors along the DER Actor Domain axis represent interoperability issues between DER operations and each of the external actors identified in Section 3.4. These generally occur at the management or supervisory levels of the DER Automation Zones axis. Note that higher, system-level (bulk transmission) interactions beyond Distribution System Operations and DER Market Services are not modeled here; however, these specific actors are expected to have interactions with the bulk energy levels of the power system based on the layered decomposition coordination framework principles discussed in Section 3.1.

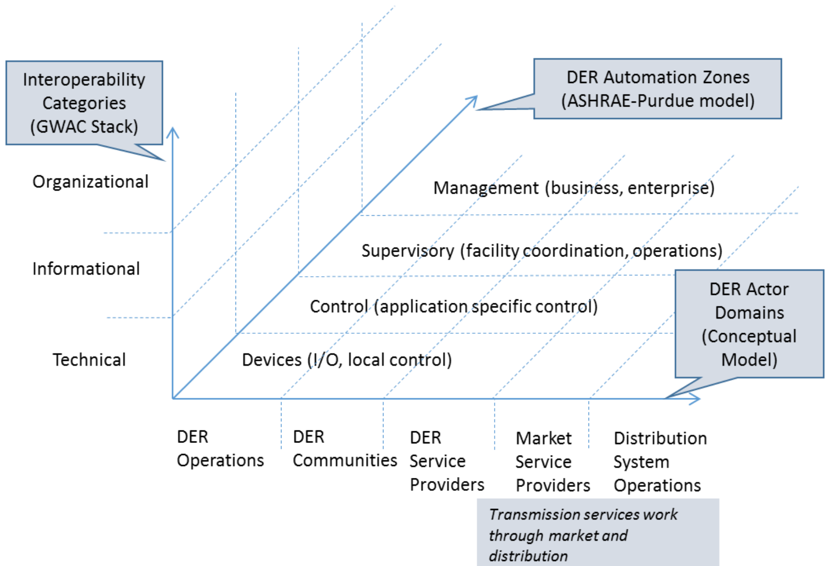

Figure 3.6. DER Interoperability Discussion Framework

4.0 The State of Electric System and DER Interoperability

The following subsections describe the general state of interoperability of DER integration with the electric system. The first subsection provides general observations on current status followed by views of the interoperability landscape within specific DER technology areas.

4.1 General Observations

The electrical interconnection of DER with the electric system advanced significantly since the IEEE 1547 interconnection standard was introduced. However, from an interoperability perspective, the ICT interfaces for coordinating interaction of DER with the electric system generally use specialized ICT approaches. While several ICT standards are involved in these interfaces, they tend to be adopted based on the DER type of technology being integrated. The concepts and terminology described in Section 3.0, are used below to provide a high-level view of the current state of interoperability for DER integration.

4.1.1 Organizational State – Business Drivers

The primary business driver for the grid for coordinating the operation of DER with the electric system is to obtain grid services in a cost-effective manner. Programs that engage DER to meet system operations needs are offered by regulated utilities, and in some regions with ISOs, there are markets for engaging DERs.

4.1.1.1 Distribution System Operations Programs

Many different types of programs are offered by utilities to engage DER. For example, large, commercial loads (e.g., pumps, cold storage warehouses, and some manufacturing plants) participate in emergency load-shedding programs for peak capacity management and spinning reserve grid services. System operators engage some buildings loads (particularly in commercial buildings) to address these service needs.

Many of these programs operate a direct control signal that turn DER equipment on or off or adjust set points. The negotiation for allowing this control is done manually up front with an incentive provided for the ability to control the resource. While distribution system operations understands why the resource is being controlled, the DER facility may not know what grid service is being addressed. These programs may also overlook the potential function of a DER facility-management system and connect directly to the DER equipment.

Some programs are designed to encourage consumer behavior changes in ways that help system operations without using direct control methods. Examples of these programs include tariff schemes such as demand capacity charges that provide an incentive to stay below a power or energy limit, or TOU programs that change the price of energy depending upon the time of day it is consumed. These programs rely on meter data to reconcile DER operations with program agreements. The program agreements vary from utility to utility and require meters with the capability to capture usage information in the required granular detail. Adoption of program standards beyond the technical level of metering is limited. Systems in which prices are dynamic beyond fixed schedules are rare today, but gaining attention. These include price-reactive response approaches and price/quantity negotiation mechanisms.

4.1.1.2 DER in Electricity Markets

In some regions, ISOs market operators provide demand response (DR) programs. These programs are primarily used for peak capacity management and spinning reserve grid services. If a DER is large enough in size (determined by each ISO) it may be able to participate in such a market directly. Market service providers (aggregators) of DER are able to qualify for participation in these markets by coordinating the operation of many DER facilities to reach the minimum size needed. Observations about the interoperability organizational characteristics for these aggregators of DER include the following:

- They tend to use proprietary communications and control systems to directly control DER and either work with a customer's facility-management system to control the local equipment or control the DER equipment directly with the aggregator's own control technology.
- The DR market interfaces are market-provider-dependent and not standardized across ISO market systems, making it necessary for DER aggregators to customize their technology to support different DR power markets.
- The interfaces between aggregators and the DER facilities are usually aggregator dependent and also not standardized. This hinders the ability of DER facility managers to easily change aggregators, though in some jurisdictions, standards such as OpenADR and SEP2 have been used to attain greater interoperability.
- From an architectural coordination framework perspective, there is little recognition of a layered decomposition requirement to include coordination between aggregators working with the DR markets from those responsible for the reliable operations of the distribution system. This could lead to potential operations problems when DR programs scale to high penetration levels within a distribution feeder.

4.1.1.3 Regulatory and Legislative Policy Environment for DER Integration

Some regulated utility service providers have seen DLC as an affordable option to obtain DER capability to address grid operational needs. However, the regulated utility compact with a fixed rate of return on capital investments usually discourages DER integration. Instead, legislative and regulatory policies are enacted to encourage DER integration. This includes net metering programs for PV systems. While such policies encourage PV interconnection, they do not require ICT-related coordination of its operation except for fixed interconnection agreement configuration requirements, such as low-voltage ride-through support. This mitigates the need for interoperability ICT-related standards to ease integration, but strains grid operations by requiring more responsive resources to address greater levels of uncertainty in power flows because of the resource variability, particularly at the distribution system level.

Grid modernization initiatives recognize the value of coordinating the flexible use of electricity from DER. Grid service markets with dynamic pricing have been proposed for coordinating DER operations. These include grid services for peak capacity management, energy market price response, and spinning reserves; however, they remain largely demonstrations rather than commercial deployments. This has encouraged the development of interoperability standards related to DER coordination, but there are no broad standards that address the organizational (business process) categories of interoperability and the coupled measurement requirements from meters to support financial settlement. In addition, technology-oriented ecosystems for integration of DER (e.g., PV, EV, or automated buildings) are emerging, but they are each developing their own standards and there is no general acceptance or clear distinction of layered decomposition coordination framework concepts such as coordination with distribution system operations and coordination through a DER facility's ESI instead of the direct control of equipment within a facility.

The Standards and Interoperability in Electric Distribution Systems report from ICF (ICF 2016) notes that looking across state regulatory commissions, "There is a deficit of quantitative analyses on the costs and benefits of promoting interoperability, or adopting associated open interoperable standards at the distribution system level." While benefits are recognized in general statements, the lack of substantive approaches to estimate the financial benefits of interoperability make policy decisions that systematically encourage processes or investments that promote interoperability difficult to institute.

4.1.1.4 Cybersecurity Policies for DER Integration

DERs generally fall below the criteria that trigger NERC CIP compliance requirements. Consequently, most DERs operate without any cybersecurity requirements. Even in California, where the California ISO has set ICT security requirements for Distributed Energy Resource Providers, these requirements stop at the level of the DER aggregator--the DERs themselves operate without security requirements.

The lack of security requirements potentially leaves DERs vulnerable to attack, but it does lower the barrier to entry for those interested in deploying. Security requires time, equipment, and expertise to implement, adding to the cost of deployment. Governments interested in encouraging DER deployment may see security requirements as counterproductive.

However, the cost of securing DERs is made more expensive due to the lack of standards listed in the sections above, including the lack of standards between DERs, aggregators, and system operators. Having to secure the myriad combinations of connection types at each level greatly enlarges the level-of-effort. In addition, the emergence of technology-oriented ecosystems discussed in the previous section means that the approach for securing PV is different from securing EV or automated buildings. A unified ICT interface for DERs would help enable a unified (thus less costly) and more comprehensive approach to DER security. It would provide an opportunity to improve the tools and policies to address cybersecurity threats and vulnerabilities from the ICT perspective, while accommodating the diverse nature of the size and type and evolution of DER facilities moving forward.

4.1.2 Informational State

Given that there is no general agreement on the concept of an ESI for a DER facility or the definition of grid services, the information modeling standards that are emerging are specific to each DER technology ecosystem (e.g., EVs, PVs, and automated buildings). The format and information science-based methods and tools, such the use of Unified Modeling Language (UML) and the knowledge representation, for defining information models is not consistent between ecosystems. Some information models are extensions of existing standards that use specialized modeling language formats, making harmonization of standards across different ecosystems difficult.

The existing information models also tend to support direct control types of interactions with DER equipment for reading and writing information rather than service-oriented message exchanges; however, information models in standards that support service-oriented message definitions with an ESI of a DER facility are starting to be adopted for specific ecosystems, particularly in demonstrations.

4.1.3 Technical State

The technical aspects for integrating DER are addressed by a great variety of standards. These are mature standards that support all forms of wired and wireless communications. At the protocol level, everything from DER equipment to DER facility-management integration is using a wide variety of standards, some open and some proprietary. Each DER technology ecosystem has its own, often competing, set of protocols for talking to DER equipment. Electric utility-oriented projects tend to use technical-level standards derived from electric power field equipment automation standards, while DER equipment suppliers tend to use standards developed in their professional areas.

While most technical-level standards tend to address integrating DER equipment, some standards are DER facility-oriented, particularly in industrial plants or large, commercial buildings area, where FMSs coordinate various types of equipment.

On the measurement front, electric metering technology uses various communications protocols for use by electric utilities. Protocols also exist for a DER facility to access metering information. Standards based on IoT technology are becoming important for integrating sensing networks that support DER facility and electric system infrastructure management applications.

For cybersecurity, standards exist that could be useful in securing DERs. IEC 62351 is a standard designed to address cybersecurity in the electric utility infrastructure field and is applicable for a number of other power systems field communication standards, including IEC 61850 (substation automation). IEC 62351 includes transport layer security encryption, X.509-formatted digital certificates, Role-based access control, and SNMP-based system management. However, IEC 62351 is not specific to DERs, nor are the standards it was designed to support. A full revision of the IEEE P1547 standard is underway and is focused specifically on DER. This work is expected to address cybersecurity. In addition, non-utility cybersecurity standards may be useful in securing DERs. These include standards applicable to IoT such as IEEE P1363 (public-key cryptography), IEEE P1619 (encryption of stored data), and IEEE 802.1AE (connectionless data security for media access). Emerging security standards for building automation may also prove helpful.

The application of standards like IEC 62351 is voluntary, and thus data is lacking on the degree to which it is used. Note that in order to put it into use, the standard must be properly implemented by the vendor (sometimes an issue); the utility must set implementation as a goal; and the utility must have the technical expertise to implement correctly.

4.2 Specific Technology Observations

The actual effort to deploy DER technologies and integrate them with grid are done through their respective integration ecosystems. This subsection presents a summary view of the state of interoperability for each DER integration ecosystem introduced in Section 3.5. The state is summarized by addressing the following questions as organized by the organizational, informational, and technical accomplishments and challenges.

- Organizational: What is the government (local, state, and federal) and associated regulatory environment doing to encourage interoperability? Are there common business processes and practices accepted in the ecosystem to support grid services and support investment decisions? Are these processes and practices captured in agreements that address business, safety, cybersecurity, and privacy terms and conditions? If there are different pockets of activity throughout the nation, what are they? Is the ICT interface between the grid and the DER facility or between the DER FMS and the equipment it manages defined? Related to this, does the concept of an ESI exist? Are the standards that support the ecosystem openly accessible for reasonable fees?
- Informational: Do one or more standard information models describe the information message content for any part of an interaction between the grid and a DER facility or between a DER FMS and the equipment it manages? Is it represented in UML or another commonly recognized modeling language that can be translated to work with different messaging protocols?

- Technical: Does the messaging protocol standard separate from the descriptive information content so that information content in the message can evolve independent of messaging protocol? Can multiple network communication protocols be supported? Are communication technologies available that the meet the performance needs for the applications being supported?

4.2.1 Electric Vehicles

The primary motivation for interoperability with electric vehicles is business, i.e., minimizing the risk of investing in PEV/EVSE technology and the charging infrastructure. The need for standardized interfaces and interactions between vehicles and the charging infrastructure has led to establishing numerous standards committees in the United States, Europe, and Asia to define the interfaces and communication between users, PEVs, and the charging infrastructure.

Many interoperability characteristics are being addressed in various standards/regulatory committees. The organizational layers are addressed to some degree in the General Technical Regulations committees that attempt to balance economic/regulatory policy with business objectives and procedures. Informational layers are addressed in standards committees or consortia with a common business context; for example, industry groups such as CHAdeMO (primarily Asia) and Charin (United States and Europe) promote the use of competing charge connector standards (including semantics). Technical layers are being addressed in the SAE, IEEE, and ISO standards committees by industry representatives that are cognizant of their business interests in the informational and organizational layers.

Because of the different standardization efforts in multiple industry groups, PEVs and EVSE are not globally compatible at this time. However, considering basic connectivity, the differences between the United States and Europe are primarily due to the 3-phase electric power supplied to most of Europe versus single-phase in the United States. PEV-EVSE communication interactions (e.g., vehicle identification, battery status, and charge control) have been harmonized for alternating current (AC) charging. Technical, informational, and organizational interoperability (i.e., messaging and protocols between EVSE and the grid) have not been standardized due to competing charging networks and technical preferences. In addition, different charging technologies are in development, including inductive AC (i.e., wireless charging) and 'Xtreme' high-power charging. These technologies have different interface requirements that are yet to be addressed.

PEVs and Stationary Batteries – Batteries, whether in PEVs or not, can provide the same functionality from a grid perspective. Stationary batteries are known quantities to utilities and grid operators, but PEV batteries have unique advantages and disadvantages. One advantage is that they are mobile and could function as a DER to support a local grid or be aggregated to provide higher-level power. However, mobility is also the source of their disadvantages (i.e., uncertainty in location and availability). This has been pointed out in GMLC Task 1.4.2, which focuses on characterization of devices for grid services. PEVs and stationary batteries have the potential to provide the same services; however, the uncertainty makes it difficult to define a unique 'drive cycle' to represent their availability. The variable locations with potentially different grid interfaces (V2G or not), times, and battery conditions make this a difficult DER to take advantage of from the grid perspective. Of course, the perspective could be quite different at a workplace, where the vehicle is parked at least some portion of the day.

The interoperability centers at ANL and JRC were asked to join the Global InterOP team (i.e., with representatives from Audi, BMW, Daimler, Fiat Chrysler Automobiles, Ford, General Motors, Opel, Porsche, and Volkswagen) to aid in the development of specific use cases, requirements, test procedures, and verification tools for AC and direct current (DC) charging. This collaboration is reflected in the design and implementation of the first 'transatlantic' interoperability verification tool for AC and DC charging. The scope of collaboration is expanding to address high-power DC and wireless AC charging as well as communication and control requirements for vehicle integration with building systems, DERs, and energy storage.

4.2.2 Photovoltaics

The primary motivation for grid interactions with inverter-based DER (e.g., PV) is to coordinate operation with the distribution system to alleviate system operating issues such as local electricity delivery capacity and voltage limits. The need for improved coordination becomes apparent as the amount of inverter-based DER increases to a level that has an impact to the operation of the local electric grid.

In today's deployments, the inverters operate autonomously according to pre-programmed instructions based on response to the electric quantities measured on the electric line at the point they are connected. Electric meters are the most common method used to provide this monitoring (see metering section below for more information on meters). Inverters also have built-in capability for communications that is used by many installers to monitor the operation of these installations for maintenance purposes.

When the amount of inverter-based systems increases even further (for example, to the levels in Hawaii and parts of California), it becomes advantageous to coordinate the inverters so they can participate in power operations similarly to other distributed generation to provide energy and other grid services under normal and abnormal conditions. This type of operation requires communications-based interactions, which give rise to interoperability challenges. A great deal of these grid services can be performed through more sophisticated control algorithms within the inverters themselves; however, communication is necessary to coordinate operation for providing various grid services at the required time.

To date, there is no common business process for interoperability of PV systems. Traditionally, elements such as communications have been led by manufacturers and have tended to remain proprietary. This has been sufficient in most markets where the amount of PV is still low to moderate. In high deployment areas (e.g., California and Hawaii), standard business processes and practices have become more critical and these markets have adopted statewide standard policies for interconnection of DER including PV. These standard interconnection policies provide a common framework for safety, privacy, monitoring and controls, and procedural requirements. Additional requirements are provided by individual utilities without general agreement across interested parties.

The main standards to date have been interconnection standards such as IEEE 1547, *Standard for Interconnecting Distributed Resources with Electric Power Systems*. The current interconnection standards do not specify any specific communication protocols, physical medium, etc., to provide flexibility to the PV manufacturers and users. Recommendations and guides related to ICT interoperability have been developed within a few organizations. For example, SunSpec Alliance has developed an interoperability standard for inverters and offers certification to that standard. SunSpec Alliance PV models have been ratified through a consensus process with members of the SunSpec Alliance and are openly accessible but are not universally adopted.

The interoperability standards for PV inverter-based DER are still evolving, with a view toward harmonization of the requirements.

An attempt was made in 2007 at standardizing interoperability with IEEE 1547.3, *Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems*. IEEE 1547.3 covers monitoring, information exchange, and control aspects of DER connected to the grid. The guide discusses the desire for interoperability, configuration management, a sample information model, communication protocols, and security guidelines, but these have not been used in deployments.

More recent efforts are working to unify IEC 61850 information models (referred to as object models) associated with DER power converters with an information model for DER devices to provide grid support services (e.g., volt/VAR and frequency-watt). This technical report is being updated and converted to a standard within IEC 61850-7-420.

The SunSpec Alliance provides a number of information, monitoring, and advanced DER function models for direct control functions (e.g., volt/VAR, frequency-watt, and watt-power factor). Ongoing efforts by SunSpec Alliance are focused on translating object models from IEC 61850-90-7 to various other protocols to provide utilities, aggregators, and users direct control of these PV inverters.

More modern ICT system-level interoperability standards such as OpenFMB and IEEE 2030.5 (Smart Energy Profile [SEP] 2.0) contain information models that may be pertinent to the interoperability of PV inverters in the future, but they are not being used in deployments yet. IEEE 2030.5 has an information model that originated from SEP. IEEE 2030.5 is currently undergoing a revision to include DER advanced inverter models included in IEC 61850 (information models), California Rule 21 (grid code), Hawaii Rule 14H (grid code), and UL 1741 (certification protocol).

4.2.3 Commercial Building Responsive Load

Individual end-use devices in buildings not associated with generation or storage become DER if they can modulate their energy-use pattern in response to commands or preferences from the grid. Any type of device can participate (e.g., appliances, lights, HVAC systems, and pumps); however, some device types have characteristics more suited to particular grid services. This report only focuses on DER that interact with the grid using ICT, and not those that change energy use through simple timers.

There is a significant gap in regulatory policy and other incentives for improving interoperability for better integration of DER with the utility grid. Similarly, buildings interoperability standards also struggle with a lack of standard interaction processes, common business objectives for interactions, and supportive business with which to align technology decisions. This problem is further compounded by the existence of many competing standards addressing interoperability, which leads to increased market uncertainty. Also, interoperability is often perceived as a threat to existing business models, thereby further complicating the alignment of business targets with interoperability goals. In addition, coherent policies are needed to address the privacy and security of interactions between the grid and the building. Those interactions are one of the key perceived risks that prevent building owners and operators from providing access to building asset data and control.

Most commercial buildings have fixed TOU rates or demand charges that can be reduced by using DER. These do not require any communication with the grid and, therefore, do not require a standard ICT interface between the grid and DER. OpenADR, which is based on the OASIS Energy Interoperation Standard, does establish an ICT interface between the DER facility and the grid. OpenADR can also potentially be used as an interface between the FMS and the equipment it manages; however, in its current form it is overly complex for that application. Alternative standards used for interfacing responsive equipment with commercial buildings management systems include BACnet and LonMark; however, these standards do not include business process models or rich information models that enforce consistency in naming equipment types and attributes. None of the standards or protocols mentioned above contain a standard specification of an ESI that could be implemented as part of an FMS.

OpenADR information exchange is specified using a collection of overlapping standards from OASIS. These include the Energy Management Information Exchange (EMIX), which defines standards for energy system availability and schedules, Energy Interoperation schema which works together with EMIX to communicate energy prices and schedules and WS-Calendar schema that focus on aligning scheduling and performance metrics within and across domains. The ASHRAE 201-2016 Facility Smart Grid Information Model (FSGIM) also includes the modeling of multiple types of pricing information and corresponding DR signals. Both FSGIM and OpenADR information models are represented in UML, making it easy for them to be translated into a variety of technical-level messaging protocols. For supporting the coordination of DER equipment operation within the building, no UML-based information model standards exist. Project Haystack[1] represents an industry ecosystem effort that takes a step in the direction to provide an information modeling context with common names (known as tags) for building equipment types.

Existing information models within OpenADR support applications between the grid and a DER facility. Similarly, the intent behind the FSGIM standard is to support the needs of applications within a DER facility to be able to characterize a building's flexibility for providing grid services.

4.2.4 Residential Responsive Load

A key point of demarcation for interaction and integration of residential responsive loads is some form of ESI "gateway" presumably supported by a HEMS or within an appliance. The HEMS may be embedded in, and communicate through, the energy service provider's revenue meter or it may have an independent parallel communications path via the internet. The key interfaces are from HEMS to grid and within the residence between the various responsive loads and the HEMS.

At the technical layer, standards exist for the physical connection of appliances and similar equipment. Australia and New Zealand have codified work on basic appliance DR standards in AS/NZS 4755. In the United States, EPRI has led a collaboration that resulted in the USNAP Alliance for a basic appliance connector codified in CTA-2045. In Europe there have been similar efforts. For communications connectivity, competing wireless connectivity include Zigbee, Wi-Fi, and various proprietary standards including Z-Wave. A growing number of home automation products implement one or more of these standards. These products are designed with some structure; for example, some are designed to operate with or without a hub device, some are designed with dependence on a hub device, and some are designed to allow remote access via the internet without a hub device. Ecosystems are emerging around hub device vendors such as Wink, Samsung SmartThings™, and Piper NV that consist of the hub device and families of compatible devices. Another set of ecosystems have formed around operating system platform vendors such as Apple (HomeKit), Amazon (Alexa), and Google (Home). Finally, companies providing residential physical security system, such as ADT, are beginning to offer energy-related products bundled with their services. These commercial ecosystems leverage existing products and services. At this point it appears that while the commercial platforms may integrate some devices using existing standards (e.g., those mentioned above), they also use proprietary standards. Note that some of these commercial platforms have published APIs. One existing standard that could be applied for these platforms is ISO/IEC 18012, Home Electronic System Gateway, which defines a distributed object oriented system with messaging. Several reference implementations are used on product platforms including the IBM Internet Scale Computing System (iCS). A similar open source platform is VOLTTRON™ maintained by PNNL and Open Thread, which was initiated by NEST. Another open platform with home automation API standards, openHAB, may provide a foundation for the needed interoperability.

[1] http://project-haystack.org/

For the informational layer, the published APIs enable application of standards that include information models. Application messaging platforms provide the mechanism for exchanging well-defined sets of information and for acting on that information. Within a residence there are some existing standards such as FSGIM, and the FAN standard being created in Europe that covers both the home to grid interface and the interfaces within the home. The ASHRAE standard was recently adopted and has not yet been widely applied. The FAN standard is being applied in various field demonstrations and comes from a network of vendors and utilities.

For the residence to grid, OASIS and NAESB have done some early work on the Energy Interop and Green Button standards respectively, but these are starting points. SGIP may be able to facilitate further action to adapt existing standards or develop new ones as the range of desired interaction between homes and the electric power system is better understood.

A key to progress in the informational layer is to advance work on the organizational layer that clearly defines policy, regulations, and business process models regarding the interaction between residences and the grid. Currently, a regulatory ecosystem is emerging among several states (i.e., New York, California, Minnesota, and Hawaii) and the District of Columbia. They are working with DOE on definition of common requirements for distribution system operator platforms including distribution level markets. The information needed to further define the details at the informational layer may come from such activities.

4.2.5 Metering

Grid sensors support specific systems or applications and have been deployed as adjuncts to those systems or applications. Consequently, they have not generally been treated as network structures with architecture and relevant standards (Taft and De Martini 2016). Grid sensor architecture must consider the underlying physical system structure, the relationship to communications network structure, and the relationship or relationships to applications that make use of sensor data. This section focuses on the relationships of sensor data for DER, specifically focusing on metering.

To understand the state of interoperability relating to DER metering data it is necessary to understand the types of metering that exist and how the data are used. This means understanding what is being measured, who wants the data, what they intend to do with the data, how they get the data, and any intermediaries that exist.

Organizational

The uses of DER metered data typically fall into two broad categories: business and operational. Both of these categories reflect requirements for technical interoperability and for compliance with standards and regulatory requirements. The business focus is on energy metering for bill settlement whether for generation or consumption. The operational use can potentially include the use of remote disconnect functionality but can provide valuable insight into distribution system or building situational awareness (for sub-meters) by collecting reactive quantities (distribution system), power quality, and voltage information. This places different sets of requirements on data collection frequency, latency, and measurement quantities and opens the discussion as to whether metering is considered information technology or operational technology.

As mentioned in Section 3.5, Green Button is an industry-led initiative that responds to a White House call-to-action to provide electricity customers with easy and secure access to their energy usage information in a consumer- and computer-friendly format. This has advanced interoperability on access to stored “back office” metered data. For field integration of smart meters, NIST facilitated industry work to a National Electrical Manufacturers Association (NEMA) smart meter standard, NEMA SG-AMI-1, Requirements for Smart Meter Upgradeability to help address the ability of deployed technology to evolve over time.

Although state governments are not driving metering standards, state regulators have approved rate increases to provide advanced metering to customers. These regulations typically have minimum requirements, which in turn translate into metering requirements that incorporate metering standards. The standards that support the metering ecosystem are openly accessible for reasonable fees from standards development organizations (e.g., ANSI, ISO, IEC, and NEMA).

In general, metering consists of installing the meter, testing the meter, reading the meter, and disposing of the meter. The business processes for each of these are largely very similar from utility to utility, but the specific processes are unique and influenced by many organizational, historical, or geographic factors.

The fact that the overall processes are very similar has allowed AMI and meter data management (MDM) vendors to create configurable solutions that meet these requirements. It has also led to detailed requirements specifications for these types of systems that not only address business requirements but also include safety, cybersecurity, and privacy terms and conditions. This places an increased emphasis on interoperability and standards in these areas. Other areas of common processes involve the areas of validation, estimation and editing. This is an interoperability topic because it relies on common understanding of how to handle missing data.

The key areas of interoperability for metering are between the meter and the utility (for AMI) and between the meter and a FMS, mostly in the case of more sophisticated (large) customers. Large customers may make decisions based directly on the data, but other customers may take action based on price signals from the utility of from an aggregator. The utility uses the data for business (i.e., billing and cash flow) and operational uses.

Informational

Most meters communicate to a system known as a head end. The head end is a system typically provided by the meter manufacturer and which is designed to collect and process meter from its meters. In a typical installation the head end sends the data to a MDM system. The MDM may also share data with other systems and is typically the system of record for meter data. The MDM has an interface for external data transfers.

There are standard information models that describe the information message content for interactions between the grid and a metering system. These are covered under the IEC power systems common information model set of standards where IEC 61968-9 for metering is a part of a family of IEC 61968 standards that cover information exchanges between electrical distribution systems. Meter data is increasingly used by many applications that reside in various systems, both operational and in the back office (billing). This means that depending on the use of the data, several standards could potentially apply and that, for the operational systems, access and latency issues become significant as distribution dynamics increase in speed.

For IEC 61968-9, Interface Standard for Meter Reading & Control, the standard is defined in UML that can be translated to work with different messaging protocols; however, in practice the collection of data is using a head end system that should be designed around IEC 61968-9.

Technical

Metering for DER can be divided into the following types:

- **Utility meters**
  Utility meters communicate back to the utility. They mark the point at which a customer interacts with the electricity delivery system and the primary use (and cost justification) is typically for energy metering and customer billing. These meters are “revenue grade” that meet the requirements outlined in the ANSI C-12.1-2008. In this standard, the minimum accuracy of the meter is required to be +/-2 percent.

- **Customer sub-meters**
  Sub-meters are used for the metering of individual loads within a building. Typically, these are for billing or load control purposes. For billing purposes the building is typically metered by a utility meter (see previous bullet) and the property owner can use sub-meters to meter and charge individual tenants for their portion of the electricity consumed or to use that information for building optimization purposes.

A smart meter can communicate information about metered data. Interoperability challenges depend on who needs to use the data, who is collecting the data, and how the data are being collected. Smart meters may use mesh networks, point-to-point networks, cellular communications, or even fiber for substation meters. The introduction of multiple parties creates syntax, latency, sequencing, and semantic issues, all of which need to be addressed.

5.0 The Desired Integration Experience

Interoperability is a quality or characteristic of the relationship between two or more systems. It is related to the problem of integrating two or more systems across an interface. The degree of difficulty in accomplishing the integration is the subject of this section of the document.

Section 3.6 describes a framework for discussing DER interoperability issues and uses the GWAC Stack as a construct to consider categories of alignment that need to be clearly defined and interpreted between interacting parties for interoperability to occur. As shown in Figure 5.1, the detailed version of the GWAC Stack [GWAC 2008] has eight layers grouped into three categories: technical, informational, and organizational.

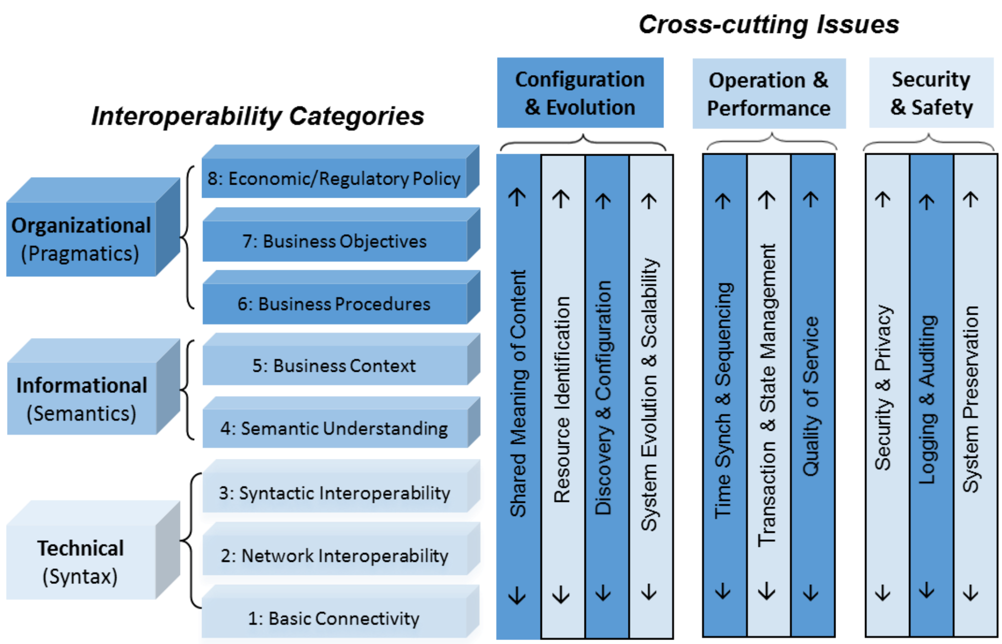

Figure 5.1. The GWAC Stack Layered Model of Interoperability

Interoperability is achieved through the process of integrating two or more systems such that they can achieve the desired exchange of information. This section explores the desired characteristics of the integration experience with respect to meeting interoperability requirements.

Consider an ideal case of interoperability in which a system integrator wishes to establish the basic physical connection between two systems and then have the combined, or "integrated" systems "just work." Consumers today are very conscious of this expectation whenever purchasing a new printer, disk drive, thumb drive, digital camera, or other technology-based products. For example, consumers wish to plug in a new wireless router and instantly have all their Wi-Fi devices connected to the internet.

This expectation reflects detailed layers 1 and 2 of the GWAC Stack. In practice, some configuration is necessary; however, vendors' products work to simplify configuration by offering "push-to-connect" functionality, which allows the consumer to easily configure the connection between devices.

This basic connectivity only enables the devices to exchange data. The next two layers – syntax and semantics – have to do with being able to understand and apply the data, in other words to not just exchange data but to have information. This requires an agreement between the connected systems as to structure (syntax) and meaning (semantics). Syntax allows for decoding a given blob[1] of data into a structured form (e.g., letters, integers, and floating point numbers) based on the agreed structure of the information.

Semantic agreement allows for associating the structured information with a model, for example, to recognize text as the name of a piece of equipment and the numerical data as information about that piece of equipment (e.g., a voltage, current, or another parameter).

So, for connections to "just work," there must be an agreement on the syntax and semantics of the exchanged data. But how do the connected systems know what to do with the information? The GWAC Stack recognizes that semantics is associated with a specific use of information or a "business context" to accomplish the purpose of the interaction. In turn, that business context is informed by the organizational layers (e.g., business procedures, objectives, and possibly policy and regulation). Thus, for connected systems to "just work" we need agreement on the specifics in these categories.

In addition to the layers summarized above, there are other considerations that cross-cut the layers. Cybersecurity, for example, must be considered at each layer along with other considerations including resource identification, shared meaning of context, scalability to name a few (GWAC 2008).

The desired integration experience can be subdivided into expectations about the existence of agreements at each layer of the GWAC Stack. These agreements may take the form of technical standards at the lower layers and codification of business practices or policy and regulation at the upper layers. These upper layers could be construed as business process agreements, contracts, or laws.

5.1 The Impact of Scale

With large numbers of devices or systems, as with DER integration, the expected ease of integration experience is critical. The cost, for example, to enable millions of customers to usefully engage with the electric power system through use of a smart thermostat, home energy-management system, or similar product greatly benefits from extremely simple integration. In the limit, this means "plug and play," where the consumer or service person attaches the device and turns it on. The device then connects and establishes itself in a role appropriate for the other devices and systems it interacts with while maintaining appropriate security and privacy.

5.2 Interoperability Scenario: Distribution Voltage Management

Consider a scenario in which a distribution system operator realizes the need for distribution voltage management to mitigate fluctuations caused by PV variability during a clear spring day on a specific radial feeder. (Note that this is one of the grid services described in GMLC 1.4.2.) Figure 5.2 illustrates the systems and devices that may be a part of this scenario and their basic electrical and information interactions.

[1] The term "blob" is used here to denote that there are many technologies available to exchange data some of which may group the data, for example into packets, while other are simply writing data into memory.

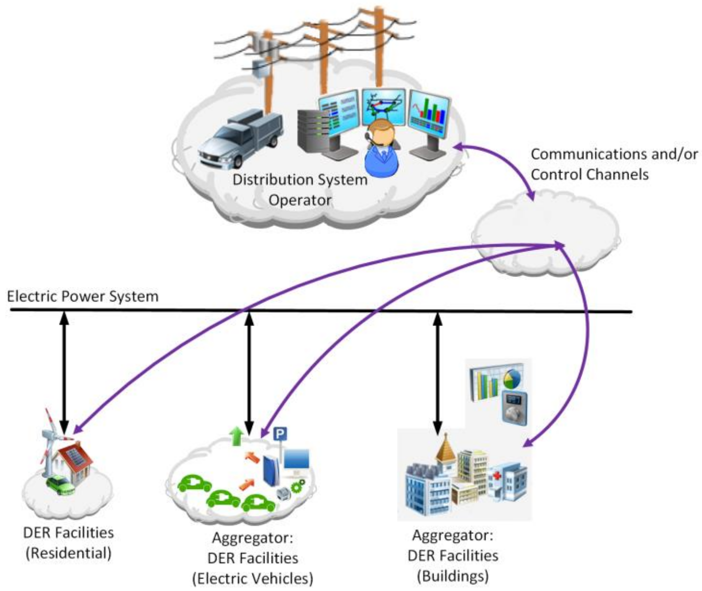

Figure 5.2. Interoperability Scenario: Distribution Voltage Management

In such a scenario, the existing voltage regulation equipment on the feeder must work together with any DER on the feeder to modulate the voltage all along the feeder within the acceptable ANSI range. Consider that the circuit configuration is such that the voltage regulating equipment, by itself, cannot perform the required regulation (i.e., grid services from DER are expected).

The distribution system operator broadcasts a signal alerting all DER that voltage management is needed. DER facilities on the feeder receive the message and autonomously decide which of them are design-capable of providing the required service and which of them are currently operationally capable of providing the required service. The relevant DER then begin to actively monitor the voltage at each connection point and to regulate the voltage if it goes outside the acceptable range.

Once the mitigation period has passed, the distribution system operator sends the "all clear" indication and the DER revert to "normal" operation.

Numerous interactions occur in this scenario, each of which requires integration facilitated after interoperability between the parties to the interaction is achieved. This can be appreciated by considering the "actors" in this example: the system operator, the conventional voltage regulators, and the DER assets. For this example, actors will be treated at a high level of abstraction. The scenario concentrates on the ICT aspects of integrating the DER facilities, while other areas of integration will be ignored (e.g., basic electrical interconnections that also benefit from integration standards).

The desired integration experience is to minimize the cost to integrate the DER facilities with the distribution system operator's voltage management system. To illustrate this desired integration experience, consider the interface between the system operator and the DER facilities. In the absence of interface standards, the system integrator must determine the interface between the system operator's voltage management platform and the potentially unique ESI of each DER facility. In each DER facility, the DER equipment controls must be configured to implement the desired electrical behavior so that the facility can respond appropriately to the commands from the system operator. To fully elaborate what the integrator would do is too much for this example – that is how complicated integrating even one interface might be.

On the other hand, if the ESI for the DER facilities are standardized and each DER facility implementation has been tested to comply with the defined ESI and equipment performance standards, then the integrator can make the communications connection knowing that the software system used by the distribution system operator to interact with the ESI is able to begin or end autonomous voltage regulation. In addition, the communications system supplier only needs to implement a compliant communications technology for supporting that interaction to coordinate the voltage regulation. The interconnection of the DER facilities may be further simplified if cross-cutting capabilities (e.g., resource identification and discovery) are supported. The capabilities make available details about the DER facilities that automate the integration process. For example, as a first step in integrating a DER facility for a distribution voltage management service, the DER facility integrator may query the distribution system operator's grid services website to see the equipment models that qualify for the program. The FMS may show the list of DER equipment models available to participate and provide an easy to use display to see if the equipment qualifies for participating in the service. Once that is done, a registration step may be initiated that automatically registers the DER facility and verifies its qualifications for the program based on the models of equipment under its control. This requires unique resource identification of the DER facility and a discovery interface for the DER equipment. Once that step is completed, the integrator may be given permission to run some software that configures the DER facility to talk to the distribution voltage management service platform. During this step, the integrator may be presented options and fields to enter to complete the integration process. As much of this business process is standardized and interoperability criteria are addressed up front, the more this step becomes automated, speeding the integration experience and reducing errors.

The appendix to this document, "Integration Vision Stories," provides additional discussion of the desired interoperability experience through more scenarios or "vision stories" that anecdotally illustrate a desired future. These stories cover several different domains, such as building energy management and cross domain interoperability (e.g., EV charging at different locations). These vision stories are intended to provoke thought as to the nature of the agreements needed at interfaces and how the use of standards, or other codification of such agreements, can reduce the cost of integration.

6.0 Interoperability Benefits and Measurement Criteria

Interoperability, though it requires upfront costs, makes interactions cheaper, more reliable, and more effective.

6.1 Benefits

With any initiative, a cost-benefit balance must be evaluated. However, because interoperability advancements make the integration of DER simpler, the payback will be seen in many areas and accumulate ever greater benefits over time. However, upfront investments are needed to improve the ease with which technology is integrated for coordinated interaction with electric system operations.

Difficult to integrate devices and systems cause errors (some detected, and some not detected); lead to manual intervention where fully automated solutions would be quicker, cheaper, and more effective; and result in custom integration efforts that take time and money and inevitably introduce additional problems.

Interoperability in the electric distribution system offers a diverse range of benefits for utilities, consumers, and other interested parties (ICF 2016). The benefits of improving interoperability will vary from technical domain to technical domain and from organization to organization. In one sense, the benefits can be seen as the goals of interoperability. Building upon the work cited in ICF (2016) and using the categories of interoperability goals in GWAC (2011), a summary of interoperability benefits is presented below.

- **Reduces integration cost**: Decreases costs to deploy and integrate new standards compliant technologies.
- **Reduces cost to operate**: Monitor equipment and operating conditions to reduce repair costs and extend equipment life.
- **Reduces capital IT cost**: Reduces investment uncertainty, extends the useful life of legacy infrastructure.
- **Reduces installation cost**: Reduces the need to modify existing systems to interoperate with new technology.
- **Reduces upgrade cost**: Ensures that today's technology can be interface with future technologies.
- **Better security management**: Reduces the number of different interfaces and permits the application of a single security framework.
- **More choice in products**: Select features not technologies, avoid technology "lock in," buy technology "off the shelf."
- **More price points and features**: Incentivizes innovation and facilitates customer trust of new technologies.

Because interoperability is a quality of each ecosystem and reflects different values to different stakeholders it is difficult to provide general quantitative summaries of the benefits of interoperable systems and components. However, the following set of qualitative benefits underscores the value of interoperability, and quantifiable benefits of interoperability advancements will fall within one or more of these areas to different degrees for those who follow this path.

6.2 Criteria for Measuring Interoperability

Although the benefits of interoperability are widely acknowledged by experts, their value is difficult to quantify (ICF 2016). Finding ways to measure the state of the complex dimensions of interoperability can help organizations and communities clarify gaps and challenges.

The GWAC (2011) views interoperability advancement as a continuous improvement process and proposed an IMM as an appropriate mechanism to facility progress. Maturity models help provide a measurement structure for assessing how a set of characteristics has evolved. Most maturity models conform to some structural basics. This structure is important because it provides a linkage between objectives, assessments, and best practices and facilitates relationships between current capabilities and improvement roadmaps by linking them to business goals, standards, and so forth. The basic elements of a maturity model include the following:

- **Levels**: These represent transitional states in a maturity model. Each level may be a progressive step or plateau, or may represent an expression of a capability or other attribute that can be measured by the model.
- **Categories** (often referred to as domains): These are a means for grouping like attributes into an area of importance for the subject matter and intent of the model. Depending on the model, users may be able to focus on improving a single domain or a group of domains.
- **Criteria**: These represent the core content of the model grouped together by domain and level. They are typically based on observed practice, standards, or other expert knowledge, and can be expressed as characteristics, indicators, practices, or processes.
- **Appraisal and Scoring Methods**: These are developed to facilitate assessment using the model as the basis. They can be formal or informal, expert-led, or self-applied. Scoring methods ensure consistency of appraisals and a common standard for measurement.
- **Improvement Roadmaps**: These can be used to guide improvement efforts. Many models have prescribed methods for identifying an improvement scope, diagnosing current state, and then planning and implementing improvement and verifying that it has occurred.

The state of interoperability maturity can be measured by focusing on specific areas based on the objectives of the groups initiating the desired interoperability advancement. It is important to ensure measured criteria are those that help to determine if the community is on track to achieve their objectives. By successfully articulating interoperability criteria the statements can be used not only to discuss the state of interoperability, but they can also be used for forming performance requirement statements in procurements of specifications, and they can be used to explore the maturity of the processes in place to improve the qualities of interoperability that simplify integration.

To be a “good” basis for measuring interoperability, a criterion needs to exhibit several specific characteristics. Characteristics of good criteria include the following:

- **Traceable**: Criteria must be traceable back to a goal and be attributable to an authoritative source. This is most important for functional requirements but the interoperability requirements specified in this document can, in many cases, be linked to a specific standard, report, paper, or other source.
- **Unambiguous**: The wording of each criterion should be considered from different stakeholder perspectives to see if it can be interpreted in multiple ways. Vague, general statements are to be avoided.

- **Measurable**: The implementation of criteria can be assessed quantitatively or qualitatively. Where the measurement is qualitative guidelines should be provided to create consistency between assessments.
- **Testable**: Functional criteria must be testable to demonstrate that the end product satisfies the requirements.
- **Consistent**: Criteria must be consistent with each other and avoid conflicts.
- **Uniquely Identified**: Uniquely identifying each criterion is essential if criteria are to be traceable and able to be tested. Uniqueness also helps in referring to requirements in a clear and consistent fashion.
- **Design-Free**: A criterion reflects "what" shall be accomplished, while the design reflects "how" it is accomplished. Given the broad applicability of interoperability criteria to multiple technology domains, criteria should not be domain-specific.
- **Independent**: Criteria should be independent of each other so they can be assessed without impact from other criteria.
- **Negotiable**: Understanding the business drivers and context mandates flexibility. For instance, it may be possible for a criterion to be met using different standards in different domains.

A set of categories conceived in GWAC (2011) are briefly explained next. They will be used as a means to organize interoperability criteria statements in a subsequent list.

- **Configuration & Evolution**: These criteria address topics relating to vocabularies, concepts, and definitions across multiple communities and companies. This is important over time as new automation components enter and leave the system and provides the ability to upgrade (evolve) over time and to scale without impacting interoperability.
- **Security & Safety**: These criteria are concerned with aligning security policies and maintaining a balance of the tension between minimizing exposure to threats while supporting performance and usability.
- **Operation & Performance**: These criteria focus on synchronicity, quality of service, and synchronization as well as operational concerns (e.g., maintaining integrity and consistency during fault conditions that disrupt normal operations).
- **Organizational**: These criteria represent the pragmatic aspects of interoperability. They represent the policy, business drivers, and business processes for interactions.
- **Informational**: These criteria emphasize the semantic aspects of interoperability. They focus on what information is being exchanged and its meaning and focus on human recognizable information.
- **Technical**: These criteria emphasize the syntax or format of the information. They focus on how information is represented within a message exchange and on the communications medium. They focus on the digital exchange of data between systems, encoding, protocols, and ensuring that each interacting party is aligned.
- **Community**: These criteria focus less on the interoperability of systems and devices but more on the culture changes and collaboration activities required to help drive interoperability improvements that reflect organizational maturity with respect to interoperability. They reflect the participation of organizations in efforts to improve interoperability in general, not just specific interfaces or processes.

Although the interoperability criteria have been organized into six categories to facilitate participant focus on specific, related criteria for measurement, the category dedicated to safety, cybersecurity, and privacy issues has also been the focus of its own maturity model (DOE-DHS 2014) in the past and is an area of increasing focus for the industry, not just from an interoperability perspective. These requirements are concerned with aligning security policies and maintaining a balance of the tension between minimizing exposure to threats while supporting performance and usability. This includes the capability to troubleshoot and debug problems that span disparate system boundaries while placing the integrity and safe operation of the electric power system above the health of any single automation component.

Criteria for measuring interoperability characteristics are presented in Table 6.1. With good measures for interoperability characteristics, communities can better articulate the state of interoperability, organizations can better stipulate the desired level of interoperability performance from technology suppliers, and roadmaps can be developed to help ecosystems prioritize and focus their efforts to improve technology integration.

Table 6.1. Criteria for Measuring Interoperability

Configuration & Evolution
The accommodation and migration path for integration between legacy and new components and systems shall be described.
The capability to revise and extend capabilities over time (versioning), while accommodating connections to previous versions of the interface shall be supported.
How regional and organizational differences are supported shall be described.
Configuration methods to negotiate options or modes of operation, including the support for user overrides, shall be described.
The capability to scale the integration of many components or systems over time without disrupting overall system operation shall be supported.
The ability of overall system operation and quality of service to continue without disruption as parties enter or leave the system shall be supported.
Unambiguous resource identification and its management shall be described.
Resource discovery methods for supporting configuration shall be described.
Safety & Security
The requirements and mechanisms for auditing and for logging exchanges of information shall be described.
Privacy policies shall be defined, maintained, and aligned among the parties of interoperating systems.
Security policies shall be defined, maintained, and aligned among the parties of interoperating systems.
Failure mode policies shall be defined, maintained, and aligned among the parties of the interoperating systems to support the safety and health of individuals and the overall system.
Operations & Performance
Performance and reliability requirements shall be defined.
The way errors in exchanged data are handled shall be specified. Note that specific interfaces may need to specify their error handling expectations.
Time order dependency and sequencing for interactions shall be specified.
Time synchronization requirements for interactions shall be specified.
Transactions and state management capability for interactions shall be specified.

Table 6.1. (contd)

Organizational
Compatible business processes and procedures shall exist across interface boundaries.
Business conducted across the interface shall be aligned with jurisdictional economic and regulatory interoperability policies defined for the community.
Where an interface is used to conduct business within a jurisdiction or across different jurisdictions, it shall comply with all necessary economic and regulatory policies.
Informational
Information models relevant for the interface shall be formally defined using standard information modeling languages.
Information exchange relevant to the business context that is derived from information models (i.e., ontologies) shall be specified.
Where the information exchanged derives from multiple information models, the capability to link data from different ontologies shall be supported.
Technical
The structure and format, and management of the communication transport for all information exchanged shall be specified.
The informational and organizational categories in an interface definition specification shall be independent from the technical categories.
Community
Stakeholders shall reference openly available standards, specifications, or agreed upon conventions in interface definitions.
Stakeholders shall participate in development of interoperability standards efforts consistent with their business.
Stakeholders shall support interoperability test and certification efforts and have clear incentives for participation.
Stakeholders shall actively identify and share lessons learned and best practices as a result of interoperability improvements.
Stakeholders shall periodically review refinements and extensions to interface definitions.
Stakeholders shall not compromise security or privacy requirements through efforts to improve interoperability
Stakeholders shall manage the balance between information exchange transparency and privacy agreements across the interface.
Stakeholders shall manage the balance between usability and security in interface definitions.
Purchasers of connected technology shall specify interoperability performance language in relevant procurement contracts.
In order to sustain interoperability improvement, the creation of an interoperability culture is required using education and marketing, such as material expressing the return on investment of interoperability.
Stakeholders shall work to specify existing, mainstream, modern information exchange technologies that fit their business objectives and maximize the longevity of interface definitions.
Stakeholders shall not create a new standard where a suitable standard already exists.

7.0 DER Interoperability Roadmap

The previous section proposed a set of interoperability characteristics that support ease of integration of an application ecosystem of conforming products and services. To advance interoperability of all types of DER, high-level coordination can be used to encourage consistency, convergence of approaches, and consolidation of standards and conventions. Such cross-technology actions need to be undertaken; however, real progress for adoption requires action in business ecosystems where value propositions are directly tied to the process of aligning stakeholders; establishing standards, guides, testing, certification; and promoting the ecosystem.

The approach for either high-level coordination or alignment within ecosystem objectives must be methodical, requiring steps that involve the relevant parties in planning and decision-making activities where they retain ownership. This section first discusses a high-level path forward to advance interoperability for DER integration with the electric system by aligning participants on important principles for a vision, followed by near-term and long-term steps toward that vision. Using that context and acknowledging the requirement for those in the ecosystems driving DER deployments to participate in developing standards and supporting material relevant to each ecosystems needs, the last portion describes the importance of roadmap development methods and tools that can facilitate stakeholder action within these DER integration ecosystems. Such methods and tools aim to identify the state of interoperability, a vision for the future, and a path forward that is ecosystem-specific.

7.1 A Path Forward

To coordinate the operation of a changing mix of DER over time, the integration of each resource must be simple and reliable. While each DER technology will have specific reasons for grid connectivity and may support different grid services, general integration mechanisms that span DER technologies are needed to keep costs down. Because technology and business demands are continually changing, the path forward to advance interoperability requires continual improvement. This means developing alignment on a vision for the future, understanding the current state, identifying gaps, prioritizing needs, planning the steps to meet the objectives of the vision, and repeating the process to refresh plans over time.

This section proposes a path forward with near-term (3 to 5 years) and long-term (greater than 5 years) areas of activity that need attention to effectively advance interoperability for grid modernization. It draws upon the interoperability characteristics presented in Section 6.0 to explore a broad set of concerns. This section acknowledges that stakeholder involvement is required for any plan to be adopted and that clear incentives must be understood by organizations to encourage their participation in the process. One area for encouragement of participation is in the demonstration of advanced capabilities that hold promise to address today's interoperability shortcomings. In some cases, the activities proposed below will have short-term payoffs, while others will contribute to achievements that may only be realized over the long term.

To encourage the development of a path forward, federal and state governments can, and arguably have the responsibility to, play a role. The *National Opportunity for Interoperability and its Benefits for a Reliable, Robust, and Future Grid Realized through Buildings* (DOE EERE 2016) describes how governmental entities can play a key role in driving interoperability. Besides being an inspiration for this work, the document outlines several steps where government efforts can make a difference.

7.1.1 Alignment on Vision – The First Step

Section 1.0 described the importance of a vision for interoperability efforts as a way to establish agreement with a community of stakeholders on a desired future. Sharing such a vision aligns the community directionally. The path forward for improving integration starts with establishing a vision of the concepts, structures, and characteristics that grid modernization participants accept are desirable. This document proposes alignment on the following:

- The benefits and criteria of interoperability (see Section 6.0).
- The desired integration experience as exemplified in the vision stories (see Section 5.0 and the appendix).
- The architectural coordination framework concepts of layered decomposition and a reference model for grid services (see Section 3.0 as derived from the GMLC 1.2.1 Grid Architecture effort).
- The concept of an ESI as a commonly defined interface point for all DER facilities interacting with the grid (see Section 3.0).
- The concept of a reference model for describing the performance characteristics needed to qualify to participate in a grid service program. These characteristics would be measureable independent from DER type (see GMLC 1.4.2 Grid Services Equipment Characteristics).
- The concept of an interface contractual model that allows an ESI and interacting parties to define, change, or choose different contracts (terms and conditions) without the need to replace the DER facility as long as performance qualifications are met.
- The recognition that the goals, benefits, and vision stories may need to be tailored for the business concerns of each technology ecosystem; however, to create convergence, government must work with industry to bring commonality and consistency across all DER technology types.

Section 7.1.2 uses the organizing structure of interoperability criteria to discuss near-term and long-term developments.

7.1.2 Near-Term and Long-Term Activities

The stakeholder communities related to DER integration will continue to evolve and coalesce around topics with articulated value propositions. Addressing the steps in Table 7.1 through Table 7.8 will require continual engagement with a cross-section of participants across DER communities as well as working directly with each community. Unless otherwise stated, each statement below is expected to be addressed with broad stakeholder engagement.

Table 7.1. Community Activities

Near Term	Long Term
Interoperability Vision	
Socialize the definitions, concepts, architectural structures to support the integration vision (e.g., layered decomposition coordination framework and ESI concepts for DER facility external interface interactions).	Refresh the strategic vision based on practice and change of landscape (e.g., grid integration, DER technology, information technology, transaction-based coordination models).
Communities & Ecosystems	
Identify the communities or ecosystems, and plan to engage these communities using the roadmap methodology and tools (See Section 7.2) to define state, identify gaps, and prioritize steps forward.	Review the evolvement of DER ecosystems given changes in value propositions, regulatory policy, and technology. Apply roadmap lessons learned to bring commonality of DER and grid services interaction across all DER technology ecosystems.
Encourage Interoperability Culture	
Develop initial pro-forma procurement language to encourage interoperable investments with those who make technology investments. Make this readily available to the greater DER community. Sponsor reference implementations in challenges, prizes, or projects that advance the state of the art for interoperability.	Refine pro-forma procurement language to include more advanced levels of interoperability as the solutions marketplace matures. Develop ratings systems and certification programs similar to or coordinated with ENERGY STAR or LEEDS for products and services that support interoperability. Recognize champions for interoperability in professional societies and trade groups.
Marketing, Communications, and Education	
Develop introductory material and flyers for tutorial material on interoperability and its benefits. Develop and support partners' websites on interoperability for grid integration. Plan and support public presentations at conferences, webinars, and in publications (e.g., technical journals and industry trade magazines).	Develop training material and course curriculum for an appreciation of interoperability, how to measure its qualities, and the use of applicable tools and best practices to advance grid integration.

Table 7.2. Configuration & Evolution Activities

Near Term	Long Term
Resource Identification	
Develop a plan to recognize and announce all DER facility unique identification schemes for interactions with external parties. Develop a plan to recognize and announce all DER equipment unique identification schemes within DER facilities.	Support unique identification management for all DER facilities to external parties and all DER equipment within DER facilities. The support should include a path for legacy devices and systems to be supported.
Registration and Discovery	
Develop a plan to provide registration and discovery mechanisms for DER facilities, external parties (including grid service programs), internal DER equipment, and interface specifications. Develop a registry for equipment suppliers to post grid services performance characteristics based on model identification.	Support registration and discovery mechanisms for all DER facilities to external parties and all DER equipment within DER facilities. The support should include a path for legacy devices and systems to be supported. The mechanisms may initially be ecosystem dependent, with steps to encourage a consolidation of approaches.
Scalability	
Document requirements for scalability and identify specific gaps not addressed by other activities.	Demonstrate scalable approaches for DER integration and coordinated operation.

Table 7.3. Security & Safety Activities

Near Term	Long Term
Security Policies	
Work across ecosystems to develop best practices for security policies in interface specifications for both external and internal interactions associated with DER facilities. This includes methods to quantify risk associated with the compromise of individual DER and the aggregate risk arising from the compromise of large numbers of DER.	Continually review security policy best practices and provide reference language for ecosystem-related deployments understanding that threat and risk assessments vary over regions, applications, and time. Identify the elements for affordable, standardized cybersecurity apparatus or treatments that could be applied to DER integration in uniform way.
Privacy Policies	
Work across ecosystems to develop best practices for privacy policies in interface specifications external and internal to DER facilities (e.g., see DOE 2015b)	Continually review privacy policy best practices and provide reference language for ecosystem-related deployments.
Failure Mode Policies	
Support electric system industry initiatives for high penetration of DER on grid codes or best practices for safe-mode operation during failures in communications or the DER facility and DER equipment to honor grid service agreement. Move from DER-type dependencies to generalized DER performance dependencies.	Establish tests and certify products for adherence to grid codes on failure mode operations.

Table 7.4. Operation & Performance Activities

Near Term	Long Term
Operations & Performance Characteristics	
The operations and performance characteristics are captured in the "organizational" activities regarding an interface specification. This includes performance and reliability, error handling, time-ordered dependency, time synchronization, and transaction and state management requirements. For DER equipment, the "informational" activities to develop an information model for of the performance characteristics required to qualify for specific grid services will be instrumental in defining expectations and establishing ratings and certifications for DER equipment to help determine qualifications for supporting the performance and reliability needs of grid services programs.	Develop ratings and certification programs to common operation and performance specifications on an ecosystem basis initially with facilitated programs for general requirements across DER integration ecosystems.

Table 7.5. Organizational Activities

Near Term	Long Term
Interface Specification	
Establish a model framework for defining the specifications needed for interactions between DER facilities and external parties as well as internal equipment. The model should cover the specification of how interoperability characteristics are addressed for each DER facility interaction with external parties and with internal DER equipment. This includes the following: • discovery/registration/qualification process – unique identification – protocols supported – grid services characteristics • negotiation process for a grid service • operations process • measurement and verification • settlement and reconciliation	Support the ability to register and discover interface specifications in machine and human readable forms. Develop templates for defining interface specifications that can be applied to the integration of any DER facility with the electric grid and with DER equipment. Templates will likely be ecosystem- or technology-dependent.
Business Drivers for Interoperability	
Establish a grid services reference model for DER participation with stakeholders. Prioritize the initial grid services for DER participation in order of likely adoption.	Refine early grid services requirements and develop templates. Engage work on next priority grid services given ecosystem value proposition. Institute tests, provider (i.e., device and system) certification for grid service qualification.

Table 7.6. Informational Activities

Near Term	Long Term
DER Performance Characteristics	
Define an information model of the performance characteristics required to qualify for specific grid services. Coordinate with GMLC 1.4.2 Grid Services Equipment Characteristics work, which is specifying the general characteristics independent of the type of technology. This step would provide a semantic model for this information for use by all DER integration ecosystems.	Simplify the qualifying process for a DER facility to provide specific grid services, such as establishing a test and certification program with supporting IT infrastructure (e.g., a registry) to verify DER equipment qualifying characteristics.
Information Modeling	
Work with ecosystems to clarify the information models that support the DER integration interfaces for near-term grid services.	Establish or adopt an information model for all DER facilities that supports the interface specification framework described under "organizational" activities and supports a growing number of grid services.

Table 7.7. Technical Activities

Near Term	Long Term
Consolidate Protocols	
For each ecosystem develop plans to consolidate the number of protocols used in new deployments. Ensure technical communication network layers are defined independent from informational and organizational characteristics.	Develop plans to consolidate the number of protocols used integrating all new DER deployments, including the potential to leverage the popularity of internet protocol standards.
Transition Path	
Develop transition paths for legacy protocol deployments within ecosystems.	Develop transition path for legacy protocol deployments across DER facilities.

Table 7.8. Government Role Activities

Near Term	Long Term
Interoperability Path Forward	
Bring stakeholders together to obtain alignment on vision, the state of interoperability in general, and a general path forward with industry and government roles identified.	Review progress on electric industry alignment to determine challenges and plans to address them.
Ecosystem Roadmaps	
Identify and engage early adopter DER technology integration ecosystems to apply a roadmap development methodology with tools to measure the state of interoperability in each specific ecosystem and identify challenges and opportunities.	Expand and facilitate the roadmap development process to remaining DER technologies, learning from near-term efforts and encouraging convergence on interoperability standards and approaches.
Advance Interoperability Capabilities	
Support (with industry involvement) the demonstration of advanced interoperability capabilities (e.g., challenge/prize event to solicit proposals leading to projects that demonstrate advanced integration capabilities).	Assess success of near-term demonstrations to determine areas for improvement and encourage industry-led efforts to specify and perform demonstrations of next-generation advancements.
Lead by Example	
Work with one or more government agencies to adopt interoperability performance criteria in procurement specifications where DER facilities are being integrated with the grid.	Improve interoperability procurement specifications and institutionalize interoperability requirements in all government procurements related to DER facilities being integrated with the grid.
National Registries	
Work with industry to establish and support a global DER facility unique identification approach to support registration and authentication capabilities.	Consider an appropriate government role for facilitating other registries (e.g., equipment characteristic or grid services interface specification registries.)

7.2 Gap Identification and Roadmap Methodology

Real progress to address interoperability is done by those working to achieve business and policy objectives within ecosystems generally formed around promoting technology deployments. The development of standards and related testing material is often done with a requirements analysis based upon the present market needs for technology deployment. The process can be opportunistic, relatively narrow, and somewhat ad hoc. A roadmap methodology (the process of developing a high-level plan forward) geared to stakeholder engagement can provide perspective and direction to improve interoperability. A roadmap process involves understanding the state of situation and identifying interoperability gaps (both capability and implementation related). This can be facilitated by application of an interoperability maturity assessment tool to specific technology domains. Once these gaps have been identified, strategic plans can be developed to address the gaps.

Relevant and useful work on measuring interoperability for smart grid technology integration has already been drafted by the GWAC. GWAC (2011) provides a convenient framework on which to further develop and refine an interoperability maturity assessment tool that can be applied to DER integration ecosystems. An improved version of the IMM beta – based upon characteristics described in Section 6.0 of this document – is proposed as a tool to measure interoperability.

The IMM consists of a set of broad questions plus descriptions to identify the level of maturity for each criterion. The output of the IMM indicates a baseline interoperability maturity level. This baseline can be used to compare against the target maturity levels for each criterion. The insights from this exercise can be used to develop a set of prioritized actions to meet the desired target levels. The process of applying the IMM and then developing prioritized actions and roadmaps for improving interoperability capability fits into a broader strategy for engaging the appropriate parties to ensure the process is adequately understood and executed. The framework for this stakeholder engagement has been heavily informed by the International Energy Agency's (IEA's) *Energy Technology Roadmaps: A Guide to Development and Implementation* (IEA 2014).

The IEA roadmap development process (Phases 1 through 6) is shown below in Figure 7.1. Note that these phases have been augmented by adding "Phase 1" and "Phase 6" for reasons that will be discussed below.

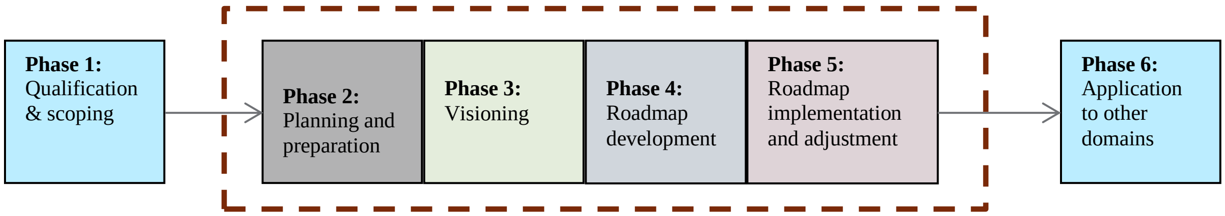

Figure 7.1. IEA Roadmap Development Process

The IEA process has been designed to emphasize stakeholder engagement in creating a roadmap with guiding principle being that once consensus is built among the participants toward shared goals and results, these relationships can help support the roadmap implementation and will also increase the likelihood that the participants will implement the roadmap successfully.

The roadmap will help the team to develop a clear vision of the target interoperability maturity as well as the specific steps for reaching it. Key elements include the following:

- **Interoperability maturity goals**: These targets should be clear and concise. They should be designed such that, if achieved, the result will be the desired maturity level. Interoperability criteria are inherently designed to be quantifiable, which enables progress to be measured and provides clear, specific guidance (see Section 6.0 for a listing of desired interoperability characteristics).
- **Milestones**: These are interim targets for achieving the goals and should be keyed to specific dates.
- **Gaps and barriers**: As identified above, one step in the analysis of IMM baseline results is a comparison against target maturity. This step builds on that step to create an understanding of gaps between current interoperability and barriers or obstacles to achieving the milestones and target maturity.
- **Priorities and timelines**: These identify the priority actions required to achieve the target interoperability maturity within the project timeframes and accounting for any dependencies between actions.
- **The roadmap**: This is the plan of executing the specific prioritized actions that will be taken to achieve target maturity.

The overall roadmap process is presented in Figure 7.2. The IMM toolkit is required throughout the roadmap development process to inform the roadmap development partners. In Phase 1, the interoperability champion requires an executive overview of the IMM and the roadmap process itself to successfully gain buy-in from the rest of executive leadership and to kick off the roadmap process by selecting key steering committee members. The steering committee itself will require details to determine the composition of the experts needed and to determine workflow during the workshops in Phase 4.

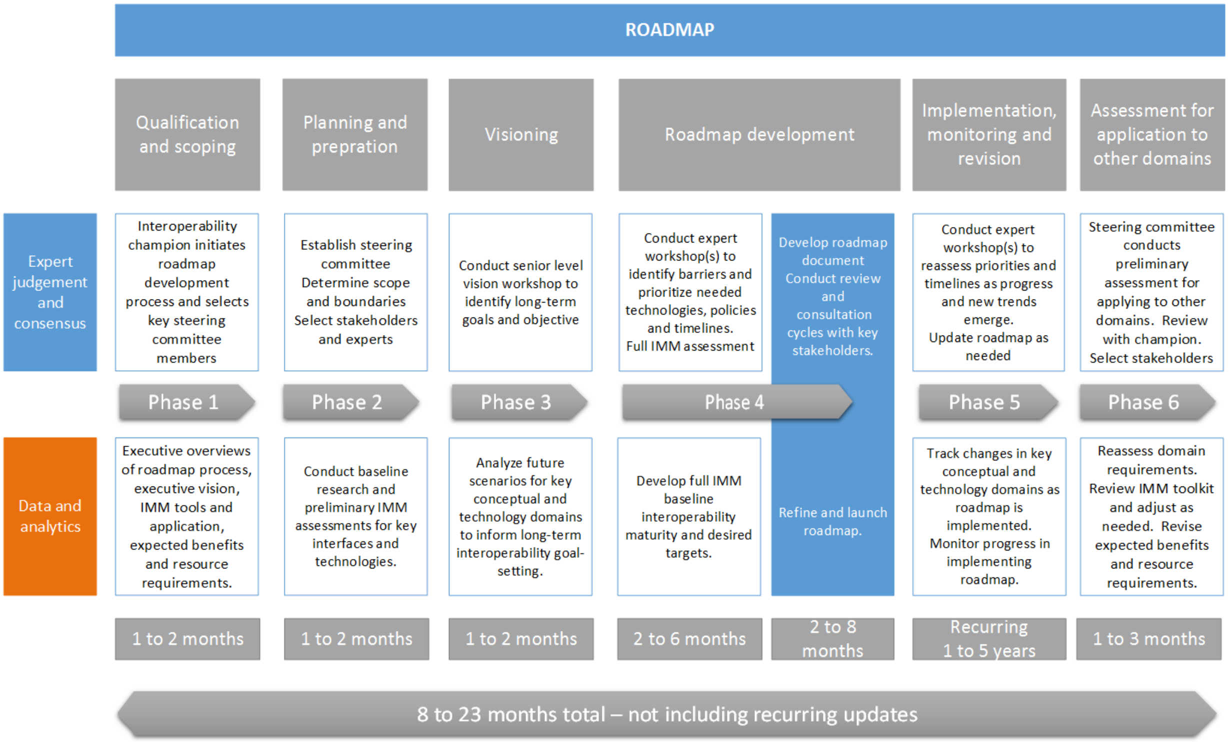

Figure 7.2. Roadmap Methodology

During the roadmap development phase, The IMM is expected to be leveraged to provide a baseline maturity level for interoperability. During the workshops and analysis, a target level will be established and specific action plans will be created to address any gaps to meeting the target interoperability level.

8.0 Summary

Historically, social progress occurs when many entities communicate, share information, and together create something that no individual entity could do alone. As machines and automated systems are integrated into our society, interoperability is the necessary capability of systems and devices to provide and receive services and information between each other, and to use the services and information exchanged to operate effectively together in predictable ways without significant user intervention. When people talk about the "modern" or "smart" grid, interoperability is a necessary foundation of that concept.

Interoperability has important economic consequences. Systems that integrate simply and predictably have lower equipment costs and lower transactions costs, higher productivity through automation, more conversion of data and information into insight, higher competition between technology suppliers, and more innovation of both technology and applications. Those systems grow faster, use resources more efficiently, and create more value for their users. Such systems consistently prove that interoperability standards and supporting integration mechanisms enhance users' choices, because these agreements create a framework within which vendors and their competitors can innovate to provide new products that deliver new functions that were previously unattainable or even unimaginable.

But interoperability does not just happen; it takes foresight and upfront work on complicated issues to clarify the interface points and address scalability requirements. The supporting standards and guides need to consider approaches that allow the power system as a complex system-of-systems to evolve. The integration mechanisms need to understand that system objectives and technology solutions will change over time. Underlying every interoperable system is hard work by many people usually clustered on specific portions of the system with business opportunities and technology expertise (ecosystems). Providing a vision of the general interoperability characteristics for devices and systems integration in the future can raise awareness across ecosystems toward a common direction. With tools to measure the state of interoperability and a methodology for assessing and prioritizing gaps and challenges, roadmaps can be created by stakeholders in an ecosystem to take steps that converge toward more generally applied approaches that transcend individual ecosystems, and leverage more common approaches to support successful deployments.

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Appendix

Integration Vision Stories

Appendix

Integration Vision Stories

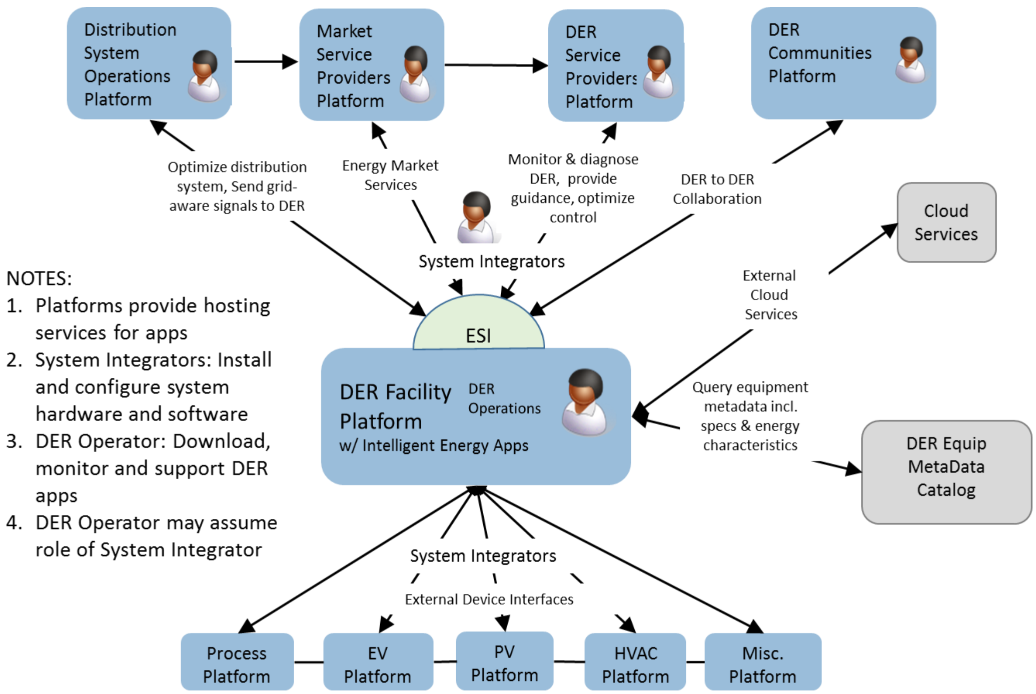


Figure A.1. DER Facilities Interactions

A.1 Integration Vision Story Context

The following interaction stories depict first person scenarios, or stories, inspired from existing buildings integration use cases contained within the Transaction-Based Building Controls Framework, Volume 1: Reference Guide (Somasundaram 2014). Settings for the stories are derived from the Buildings Interoperability Vision section of the Buildings Interoperability Landscape document (Hardin 2015) and adapted to include other facilities for integration. This vision portrays key actors, such as DER facility operators, interacting with intelligent software applications running on an ecosystem-supported hardware-software system platform. Figure A.1 provides a pictorial view of these entities. Intelligent applications, also referred to as intelligent agents, execute logic on behalf of the facility operator. The stories represent hypothetical but realizable scenarios that could enable key visionary interoperability objectives such as ease-of-interaction, cost-effective integration, and deployment at scale.

Each situation has multiple paths of interaction (i.e., threads). The stories that follow choose a specific thread, which is summarized in each story. The threads selected are not intended to be rigorous scenarios for product development. Their purpose is to provide a visionary context for extracting interoperability requirements that enable a variety of methods for enabling a range of services like the ones depicted. Details relating to specific interactions such as service messaging payload contents, message syntax and transport are important to the extent that the interoperability requirements extracted do not limit specific future interactions.

Each story describes an ideal future where integration has been facilitated using interoperability standards and practices. As such, the stories do not illustrate the complexities of integration that have been simplified. To provide a glimpse of what is behind the ideal experience, each story is accompanied by a table derived from the GWAC stack found in the GridWise® Interoperability Context Setting Framework (GWAC 2008). The table includes consideration of the eight layers of the GWAC Stack and the cross-cutting elements as shown in Figure 5.1 in the main body of this document and organized into categories for the interoperability criteria listed in Section 6.

The table constructed for each vision story is organized into rows for each of the categories of criteria with a column for the tools, systems, and key actors and a column with an example of interoperation of integration across system boundaries where agreements must be reached. For any given story, some rows will be blank.

Certain philosophical assumptions were applied in developing the stories below. The next section introduces the importance of these assumptions to support interoperability goals.

A.1.1 System Integration Philosophy

Interoperability makes the integration of equipment and systems simpler and predictable. To manage the complexity of a large number of connected equipment and systems over a long period, the philosophy of system integration must consider enduring qualities such as the ability to evolve the system and its equipment over time and the ability to scale up to integrate greater numbers of components. These considerations have led to focus on the interface where things connect and the boundary within which qualities such as authority, responsibility, security, and privacy can be clarified. The following philosophical considerations are borrowed from the GridWise® Interoperability Context-Setting Framework (GWAC 2008).

Agreement at the Interface: The interface agreement captures the interaction between parties, including any assumed actions. It is about the goods and services exchanged, price, scope, schedule, quality, and consequences for failure to perform. It is about what is delivered and the process to get it, not how the deliverable is generated.

Boundary of Authority: The agreement is situated in the transactive stream at the place where responsibilities are clearly defined. This forms a boundary of authority for addressing rights of privacy and security, and separates the way business is conducted on either side of the interface. Requirements between transacting parties for the way business, privacy, and security are dealt with need to be reflected in the interface agreement along with appropriate mechanisms for auditing.

Decision Making in Very Large Networks: For networks of things to scale, they need to delegate responsibility to the end points. One can draw a bubble around an end-point (equipment, subsystem, building), but the hyper-network of end-points relies on these areas of automation acting in their own best interests while conforming to policies (rules) that support the health of the overall system. Hierarchical approaches have their place in complex systems as well and are helpful for defining lines of responsibility that are important to the above 2 considerations.

Role of Standards: Open standards have obvious interoperability benefits and should be encouraged, but they are not the full story. The use of standards should be a technical/design/business choice and not a hard policy. This is because technology and standards change over time and this evolution needs to be accommodated rather than stifled. Policy is best when it sticks to results-oriented performance requirements and ecosystem necessary conveniences (e.g., VIN numbers on vehicles).

A.2 DER Internal Interaction Story

Use Case: Automated Building Energy Efficiency

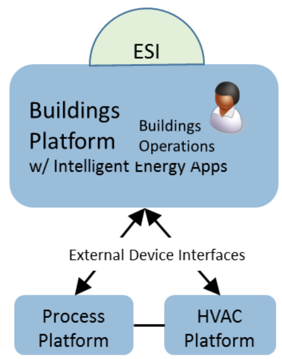
Actors: Buildings Operator (BO)

Description: A first-person view of applying automation to a small building through the eyes of its operator. It focuses on technology integration but draws from familiar interaction patterns.

Value Proposition: The use of standards based software and devices allows the BO to install, deploy, and operate an integrated system in a reduced time, at lower cost, and with other benefits including increased energy optimization and efficiency.

Story Sequence:

- BO purchases a "Building Platform" based on ability to integrate with existing equipment
- BO downloads an app that discovers the building and begins monitoring devices
- BO adds a heating, ventilation and air conditioning (HVAC) system and kitchen appliances using "Black Boxes"
- BO downloads an app that monitors building energy and provides guidance and control
- BO interacts with the "Cyber Intrusion Agent" and has privacy concerns.



I own and operate a decent-sized food restaurant. Some other building owners in the area have "Buildings Platforms" and I'm thinking about buying one. They rave about how easy they are to install and use, and the comfort, security, and savings they allow.

There are two that seem very popular. One, the "iBuilding," has the reputation of being very easy to use and has a bunch of cool features. Most new kitchen appliances, security systems, and heating and lighting systems are compatible with iBuilding. The other, the "LightSaver," is like iBuilding and seems to have the same features and functions. The one thing I did notice is that the LightSaver supports a bunch of older appliances and HVAC systems. This is important to me because my building is 20 years old and has older kitchen appliances and HVAC system. I can buy these little boxes called "Black Boxes" that plug into the freezer, fridge, and HVAC that let them work with the LightSaver. I decided that this feature was a "must-have."

I ordered the LightSaver and all I had to do was plug it in and download an app called "The Agent" into my phone. The Agent quickly walked me through the process of discovering my buildings system after I got past the security and privacy screens. It found the electric and gas meters and the security and fire alarm system. Everything communicates by wireless so that makes installation easy. I can see my energy usage and my security cameras from anywhere, at any time from my phone, tablet, or PC!

I ordered and plugged in Black Boxes for my HVAC and appliances. Bingo! The Agent found them and now I can see and change the temperature as well as check out how the appliances are operating. I can even change the temperature setting on my freezer and fridge if I want to.

I go to the online Agent store and download an app called "The Breeze" that monitors my energy usage then shows me where I'm spending my money and how much I could save if I made some changes. It's important that my kitchen is fully functional during breakfast, lunch, and dinner but I have flexibility between these times. I also don't mind if my lighting dims but it needs to be above a certain level during dinner. After walking through some screens where I tell it what my needs are, it responds by letting me know what information and resources it needs access to. It doesn't ask for everything, but for each capability, it lets me know what's needed to perform the job and asks for and obtains my permission beforehand. The access policies are established under pro forma language agreed to by the Smart Buildings Better Business Society, which works with state and federal legal groups on consumer rights and privacy issues.

Once the initial set up is complete, it begins monitoring the energy usage of my building and my appliances. If anything goes wrong, I get text and e-mail messages with links to a website that provides more information on the problem and summarizes my building's operation.

I like the way the LightSaver is sensitive to the privacy aspects of my business, but I've been reading about major banks and businesses getting hacked. I started looking into this more deeply and found that the system is equipped with a cyber intrusion detection agent that allows me to configure my potential risk exposure while letting me know the trade-offs in performance and functionality of the apps I've deployed. I regularly get notices for security upgrades and occasionally an event occurs when an immediate patch is recommended. It also has the capability to move into degraded modes of operation changing its behavior if it detects an abnormal situation. Part of the operating agreement with each app is that they supply the fail-safe aspects of each buildings component so that devices can go to a default safe place while not necessarily shutting off.

Table A.1. Automated Building Energy Efficiency

Interoperability Category	Tools, Systems, Key Actors	Examples of interoperation or integration across system boundaries where agreements must be reached
Configuration & Evolution		
Shared Meaning of Content	LightSaver, "The Agent" app, and building systems and devices	This links to "Semantic Understanding" applying it across the platform, app, building systems and devices enabling functional elements to be included. App developers can provide apps for broad use within the problem domain reducing the overall cost for all customers.
Resource Identification	LightSaver and Black Boxes	These systems use an identification system that assigns a unique ID within the building to the communicating assets. There is no confusion which Black Box LightSaver is talking with even allowing equipment names to change.
Discovery & Configuration	Building owner, LightSaver platform, "The Agent" app, and building systems and devices	"The Agent" interoperates with LightSaver and with the legacy systems and devices in the building allowing automation of discovery of the devices and systems. Otherwise, the Building Operator would have to manually enter and configure the details for each system and device.
System Evolution & Scalability	LightSaver and Black Boxes	These applications with discovery and resource identification features allow devices to enter and leave the building configuration over time. LightSaver also supports legacy interfaces in smart appliances that went back 20 years. Being sensitive to length, issues like LightSaver product upgrades and backward compatibility with previous releases are not stated, but would enrich the story

Table A.1. (contd)

Interoperability Category	Tools, Systems, Key Actors	Examples of interoperation or integration across system boundaries where agreements must be reached
Security & Safety		
Security & Privacy	Building operator, vendor	Industry best practices security features are designed into and included in LightSaver, “The Agent,” and “The Breeze” providing more robust results and lower cost than after-the-fact security measures.
Logging & Auditing	LightSaver and The Breeze	LightSaver logs when equipment is connected is connected and removed from the system. It also logs connection with The Breeze application including access rights settings to data to ensure operator preferences are honored and recorded.
System Preservation	LightSaver and Black Boxes	To support the capability to move into degraded modes of operation if it detects an abnormal situation, the Black Boxes can detect when their device needs to go to a default safe operating position appropriate to that device.
Operation & Performance	Note: Operation and performance criteria are not emphasized criteria in this story.	
Time Synchronization & Sequencing	The Breeze, LightSaver	The way that sequencing for interactions is implemented needs to be take building occupants and their habits into consideration.
Transaction & State Management	LightSaver, iBuilding	Transactions and a state management capability need to be included in the LightSaver and iBuilding.
Quality of Service		Changes to the system (e.g., devices entering or leaving) and errors in exchanged data need to be managed without disrupting overall system operation and quality of service.
ORGANIZATIONAL		
Economic/Regulatory Policy Political and economic objectives as embodied in policy and regulation	The Breeze, LightSaver, BO	Common information access policies address security and privacy issues reducing liability for the building owner. Otherwise, the building owner would have to develop such policies incurring legal expenses and without the reduced risk available by using codified industry best practices.
Business Objectives Strategic and tactical objectives shared between businesses	The Breeze, BO	The product vendor aligns the features with the analysis needs and ease of installation needs of the building operator. The product is sensitive to privacy issues and the configuration interaction allows options.
Business Procedures Alignment between operational business processes and procedures	The Breeze, LightSaver, BO	The interaction with the integrator to set up follows a defined business procedure that allows the operational interactions between the product and the buildings platform to work once the configuration is complete.

Table A.1. (contd)

Interoperability Category	Tools, Systems, Key Actors	Examples of interoperation or integration across system boundaries where agreements must be reached
INFORMATIONAL		
Business Context Awareness of the business knowledge related to a specific interaction	The Breeze, LightSaver, BO	Knowledge of building operation and energy management allows The Breeze to perform value-added processing of the data available from the building's devices and systems on the LightSaver platform. Otherwise custom analyses would have to be created, driving up the cost of integration, deployment, and maintenance.
Semantic Understanding Understanding of concepts contained in the message data structures	LightSaver, The Agent, building systems and devices	Because there is common semantic understanding the Building Operator can see meaningful displays of information supplied by the building systems and devices. Otherwise, custom parsers would have to be constructed for each data source along with display screens driving up the cost of deployment and increasing maintenance costs.
TECHNICAL		
Syntactic Interoperability Understanding of data structure of messages exchanged between systems	LightSaver, The Agent, building systems and devices	Agreement on the data transferred between devices and systems enables The Agent and LightSaver to accept data from the building's devices and systems without constructing custom parsers and messaging systems for each.
Network Interoperability Mechanism to exchange messages between multiple systems across a variety of networks	System Suppliers Consultants Standards Organizations	The configuration and operation are supported by wireless networking technologies. It also connects with internet-based systems with little or no configuration steps because of the standards, testing, and certification of the products.
Basic Connectivity Mechanism to establish physical and logical connections between systems	Wireless communications system, building systems, devices, computers, mobile devices	LightSaver and The Agent are hosted on computers and/or handheld devices that communicate wirelessly with the systems and devices in the building. The wireless communications is based on existing standards. Otherwise some form of custom communications would be required that would not be scalable and that would not be easily maintained – driving up the cost of integration and deployment
Community		
Community Stakeholder involvement in development of standards, practices & improvement	End-users, integrators, system & component suppliers, standards organizations	The technologies employed need to include interoperability tests, certification, and ratings supported by consortiums of manufacturers and driven by communities of building owners through industry or trade associations that include standards-making bodies.

A.3 Distribution Systems Operations Story

Use Case: Acquisition of Ancillary Services

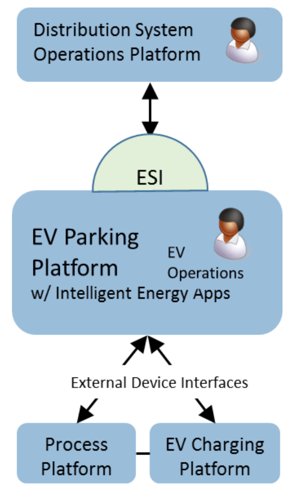
Actors: Electric Vehicle Parking Operator (EVPO), Distribution Systems Operator (DSO)

Description: A view of how an EVPO might supply spinning reserves to a DSO ancillary service market, and how the DSO may interact with the EVPO.

Value Proposition: Increased renewables are resulting in more grid fluctuations. Buildings can be a less expensive near-term alternative than distributed generation. Winning bidders are compensated for their ability to reduce load if called upon.

Story Sequence:

- DSO runs an hourly reserve program for spinning reserves
- EVPO connects to this interface using apps provided by the DSO or third parties
- EVPO configures his app and devices to respond to the DSO program and bid messages
- DSO clears the program's market hourly and the cleared price is broadcast to all EVPOs
- When needed, DSO broadcasts a reserve event and all EVPOs who won the bid curtail demand
- When expired, EVPO and DSO reconcile contract performance.



As the DSO, I monitor the system and run an hourly reserve market for feeder locational real-time pricing for EVPOs to participate in a spinning reserve ancillary services program. I define the prerequisites for a building to qualify for the market. That includes the minimum amount of power and energy to bid, the range and speed of response that is acceptable for performance, and how the payment for the service will be reconciled (including measurement and validation requirements). This is reflected in the interface to this DSO program. The DSO designed this program to work with a regional operations system, which manages the reliable operation of the system at the transmission level. There are many structures and service agreements that could be explored, but they are not the focus for interoperability in this story.

As the EVPO, I can connect to this interface using apps provided by the DSO or third parties who use the same reserve market interface and may offer services to integrate with my EV charging automation platform. I am able to discover the DSO offering from their website, fill out the qualification material, and once qualified obtain a secure sign-in code for interfacing with the DSO interface. I configure my automated equipment to be able to respond to the DSO reserve program. I use a third-party app that the DSO website suggested as compatible with my EV charging platform and the DSO program platform's interface to help do this. I give the app permission to discover my equipment, my system schedules, and preferences for operation. It is smart enough to figure out where I have connected charging equipment that may have some flexibility and offers me options for setting my preferences on ranges of operation (e.g., minimum charging level per EV station and the maximum time available to complete a full charge) that I'm willing to live within. Once set up, the app connects to the DSO program for real-time operation.

Within the vehicle parking system, I use another app that came from the charging equipment supplier to control the charging of electric vehicles. This app recognizes the interfaces to all the standard electric vehicle interfaces supported by the major electric vehicle manufactures. The internal applications in the vehicle allow their owners to set their preferences for energy prices, the time the vehicle will be picked up, and the minimum level of charge desired. The EVPO is able to use the charging station app to manage the vehicle charging to control the overall power demand of the station. This in turn works with the DSO reserve program app to manage the flexibility in charging the vehicles while respecting the vehicle owner needs.

As the DSO, I confirm that the EVPO is signed up and available for the program. Reserve market messages are sent periodically to the EVPO indicating opening and closing of the market and market clearing results.

As the EVPO, my app monitors the EV charging states and forecasted electricity needs within my preferences and sends the DSO a bid curve of price and quantity of demand reduction.

The DSO reserve market clears hourly using the last bid from each EVPO. The cleared price is broadcast to all EVPOs. This indicates whether they are on-call to deliver demand reduction in the next hour.

As the DSO, I broadcast a reserve event and all EVPOs who won the bid automatically notify their charging systems to affect the demand reduction. Appropriate data is collected per the contract agreement to support their response. Once the crisis has finished, I remove the reserve event. EVPOs' systems respond with the appropriate information for reconciling the contract performance. My reserve program notifies the billing system of information, which reconciles the EVPO's bill for the service provided. In the case that no spinning reserve event is called, the bill is reconciled in accordance with the compensation for being on-call.

Table A.2. Distribution System Operations Story

Interoperability Category	Tools, Systems, Key Actors	Examples of interoperation or integration across system boundaries where agreements must be reached
Configuration & Evolution		
Shared Meaning of Content	Third-party application, DSO system, the interface	The third-party application needs to understand the semantics communicated in messages for interactions with the DSO using the energy service interface (ESI) and for EV parking platform interactions with the charging equipment.
Resource Identification	DSO system	The DSO program uses a unique identification approach to ensure individual EVPO communications are not confused. Within the parking lot, the vehicles and charging stations also have their unique identification systems so that coordination and billing can be supported.
Discovery & Configuration	DSO system, EVPO, third-party application	The DSO program is able to discover the EV parking charging system using the ESI supported by the third-party application. The application is able to discover the charging equipment within each system. Also, the EVPO was able to discover the DSO program and find compatible third-party applications through the DSO-supported website. The EV owner's charging preferences would be discovered when the car connects at the EVPO by means of an app-based standard profile.
System Evolution & Scalability	DSO system, third-party application	Both these systems are designed in such a way that, EVPOs can participate in and leave the market at any time without disrupting the system. Also, the third-party application supports changing

		charging equipment, and the individual electric vehicles follow standards that allow them to connect and disconnect as needed. Legacy and upgrade issues are not discussed in this example.
Security & Safety		
Security & Privacy	Third-party application, DSO system	While not stated, the standards and processes used behind the scenes ensure that both these interfaces have steps to see that the transactions are happening in a private and secure environment
Logging & Auditing	Third-party application, DSO system	The third-party application is responsible for monitoring the performance of the charging system and ensuring it is prepared to respond to DSO signals. Similarly, the DSO system is responsible for communicating with the individual EVPOs to ensure there is no shortfall between supply and demand.

Table A.2. (contd)

Interoperability Category	Tools, Systems, Key Actors	Examples of interoperation or integration across system boundaries where agreements must be reached
System Preservation	DSO system, third-party application	The DSO system has the capability to broadcast a crisis message in case of a system emergency thereby notifying the EVPOs of its needs with relevant compensation as needed. The third-party applications also have the ability to manage the system in the case of unexpected events when connected to the DSO system. Behind the scenes, should communications fail, the third-party platform maintains the event as active up to an agreed maximum period.
Operation & Performance		
Time Synchronization & Sequencing	DSO system, third-party application	The DSO system broadcasts messages letting EVPOs know of its needs and, according to the responses it receives from all the EVPO’s, schedules supply or keeps the EVPOs on standby for the next hour. The third-party applications have the capability of reducing demand of the charging equipment within the performance required by the agreement.
Transaction & State Management	DSO system, third-party application	The protocols employed between the DSO system and the ESI confirm that messages are received and will resend as necessary.
Quality of Service	DSO system, third-party application	To qualify for the program, the agreement stipulates the minimum quality of the communications needed. The DSO system and the third-party application are responsible for maintaining quality of service.
ORGANIZATIONAL		
Economic/Regulatory Policy	DSO system	The DSO can offer this program because of an agreement with the local regulation authority who reviews and approves the design and compensation scheme. The DSO system is responsible for implementing the applicable economic/ regulatory policy for facilitating the market. Establishing the program includes working with the bulk system spinning reserve program to ensure the offering qualifies.
Business Objectives	EVPO, DSO, Customers	The EVPO is trying to maximize profit while keeping charging customers happy. Similarly, the DSO is working with the bulk system to obtain spinning reserve capacity at the most affordable rates and this is aligned with the regulatory policy for the area. Also, the third-party application developers need to identify the value proposition for supporting these transactions through fees obtain by

Table A.2. (contd)

Interoperability Category	Tools, Systems, Key Actors	Examples of interoperation or integration across system boundaries where agreements must be reached
		the use of their software. Both the DSO and the EVPO agreed upon procedures for dispute resolution as well as facilitating interactions between both organizations for smooth functioning of this system. Such an interface allows for each part to consider other business decisions. For example, the EVPO could also create a more predictable set of resources to bid into DSO market by incentivizing repeat and reliable EV customers.
Business Procedures	DSO, EVPO	The agreement between the EVPO and the DSO is mediated by a third-party application that automatically monitors the price of the DSO and accordingly decides how much power to make available to the DSO. Based on the service provided, the billing agent compensates the EVPO periodically to ensure a smooth relationship.
INFORMATIONAL		
Business Context	EVPO	A profile of the appropriate portions of the standard information model related to the DSO to ESI interactions and the third-party application to charging equipment is clearly defined. The third-party application also references the standard information model for charging equipment interactions.
Semantic Understanding	Third-party applications, DSO system, EVPO	Behind the scenes is an industry standard information model for DER facilities to external entities that includes all of the semantic definitions and relationships used for this scenario as well as other DER types that can participate in this and similar programs. Similarly, there is a standard information model for charging equipment that the local controllers and third-party application can reference for their interactions.
TECHNICAL		
Syntactic Interoperability Understanding of data structure of messages exchanged between systems	Third-party applications, DSO system, EVPO	Agreement on the messaging protocol that is being used between the DSO system and the third-party applications ensures that the information payload will be able to be sent over different networks (e.g., wireless or cable).
Network Interoperability Mechanism to exchange messages between multiple systems across a variety of networks	System Suppliers Consultants Standards Organizations	To accommodate a great number of configurations with access to different communications media (wired and wireless) multiple types of communications networks are assumed to be supported, while still supporting the message syntax.
Basic Connectivity Mechanism to establish physical and logical connections between systems	Third-party applications, DSO system, EVPO	If all charging stations and vehicles used the same physical adapter it would be a big interoperability aid.
Community		
Community	End-users, integrators,	Behind the scenes, the technologies employed in this story include interoperability tests, certification, and branding supported by one or

Table A.2. (contd)

Interoperability Category	Tools, Systems, Key Actors	Examples of interoperation or integration across system boundaries where agreements must be reached
Stakeholder involvement in development of standards, practices & improvement	system & component suppliers, standards organizations	more consortiums of manufacturers. The DSO organization has its own testing and certification program to see that third-party applications can easily integrate with different EV parking platforms. Similarly, charging equipment suppliers follow certification processes to ensure their equipment can be easily integrated.

A.4 Market Service Provider Story

Use Case: Energy Market Exchange

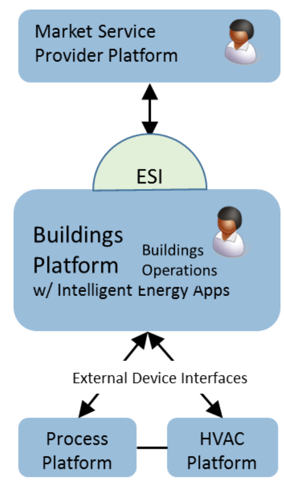
Actors: Buildings Operator (BO), Market Service Provider (MSP)

Description: A view of how a BO might purchase energy from an MSP provided energy market and how a MSP may interact with the BO.

Value Proposition: Forward contracts may result in reduced peak demand and congestion, increased operational efficiency, better capacity planning, and increased integration of renewable resources. Energy consumers will have a broad range of purchasing options to better manage their energy costs with their demand flexibility.

Story Sequence:

- MSP works with wholesale energy providers to create buy/sell forward products
- MSP runs a forward contracts market for energy that exposes an interface
- BO connects to this interface using apps provided by the MSP or third parties
- BO configures his app and devices to select contracts automatically
- As agent for BO, app buys/sells contracts according to anticipated and historical consumption
- In monthly billing period, BO and MSP reconcile contract performance. BO's app uses this information to improve future contract selection.



As a MSP, I work with electricity generation, transmission, and distribution providers to develop products that allow individual BOs to participate in a retail market. The products I develop are electricity contracts that can vary by contract duration and energy quantity. These contracts are bought and sold by electricity producers and consumers alike in an "energy stock market."

As a BO, I would like to shop for electricity like I shop for other commodities. I need a mechanism for buying/selling forward contracts in the market operated by the regional MSP. The buildings platform I've purchased allows me to participate through apps designed to interface with the market.

As a MSP, I want to grow my market, so I expose a standardized market interface to enable a variety of third-party buildings platform apps. I also supply a free app called MyEnergyMarket. This app can integrate historical information from a buildings platform, using a standard software interface, to automatically enable smarter electricity purchasing decisions.

As a BO, I install the MyEnergyMarket app and it walks me through a set of contractual, security, and privacy forms, and registers me as a participant in the forward energy market. The app recognizes my energy assets and appliances through an interface exposed by the buildings platform and can access my historical energy usage. I also have the option to use the MyMarketOptimizer app that is available from MicroFirm, a third party application provider. This app will evaluate the cost of operation under a contract and a) select a different contract duration and/or b) adjust operation to reduce energy cost.

As a MSP, I offer forward contracts with intervals ranging from 5 minutes to 1 year in duration with the various energy suppliers in our network. These contracts help my network of energy providers manage the operation of their assets and address system constraints through the pricing of their contracts. For example, Electricity Provider Inc. may increase the cost of 5-minute contracts to reflect congestion in its distribution system.

As a BO, I am offered recommendations by the app monthly for purchasing energy based upon how I have used energy in the past. The app shows me a list of providers in my area and the types of energy contracts for which the app can bid. Some of these are short-term contracts on the order or minutes and others are longer term on the order of months. The app can dynamically buy and sell these contracts to minimize my energy cost. I review the options MyEnergyMarket app suggests based on my historical usage and configure the app to automatically buy and sell contracts on my behalf based on my energy use.

As a MSP, I maintain a highly secure, automated system that tracks and verifies the transactions between supplier and consumer using advanced metering and the openly available standardized, cybersecure, software service interfaces that the apps use to interact with the market. This system allows me to accurately reconcile contracts with BOs on a monthly basis.

Table A.3. Market Service Provider Story

Interoperability Category	Tools, Systems, Key Actors	Examples of interoperation or integration across system boundaries where agreements must be reached
Configuration & Evolution		
Shared Meaning of Content	BO, MSP, MyEnergyMarket	Market and contract terms must be understood be all parties including MyEnergyMarket and are derived from shared information models.
Resource Identification	MyEnergyMarket	MSP platform uniquely identifies the building associated with new participants once the participants are accepted into the market. The id is shared with the buildings system through the ESI
Discovery & Configuration	MyEnergyMarket MyMarketOptimizer	The MSP exposes its registration platform through a website. Once enrolled, the BO downloads the MyEnergyMarket app, and the BO's platform is able to discover the MSP and begin the negotiated process of configuring the connection and using MyMarketOptimizer.
System Evolution & Scalability	MyEnergyMarket BO MyMarketOptimizer	The BO (and MyEnergyMarket) have the capability to scale the integration of many components or systems over time without disrupting overall system operation. Similarly

		MyMarketOptimizer needs the ability to scale as I add or change equipment in my building. System operations and quality of service are designed to continue without disruption as parties enter or leave the system.
Security & Safety		
Security & Privacy	MyEnergyMarket	MyEnergyMarket supports privacy and security policies that are defined, maintained, and aligned among all parties that exchange data.
Logging & Auditing	MyEnergyMarket	MyEnergyMarket supports requirements and mechanisms for auditing and for logging exchanges of information with the BO platform and contract changes made as a result.
System Preservation	MyEnergyMarket MyMarketOptimizer	Failure mode policies are defined, maintained, and aligned among the devices for the BO. Default preferences are provided by the building platform and coordinated with the MyMarketOptimizer app. These are adjustable by the BO.

Table A.3. (contd)

Interoperability Category	Tools, Systems, Key Actors	Examples of interoperation or integration across system boundaries where agreements must be reached
Operation & Performance		
Time Synchronization & Sequencing	MyEnergyMarket MyMarketOptimizer	The way that time order dependency and sequencing (synchronization) for interactions are specified. The order in which bids are processed and contracts are executed adheres to established market rules.
Transaction & State Management	MyEnergyMarket MyMarketOptimizer	Transactions and state management capability are included in the capabilities of MyEnergyMarket and MyMarketOptimizer.
Quality of Service	MyEnergyMarket MyMarketOptimizer	Changes to the system (e.g., parties entering or leaving) or errors in exchanged data are managed without disrupting overall system operation and quality of service. Failure Modes are systematically identified and fault tolerance built in to capitalize on the interoperability features to gracefully degrade.
ORGANIZATIONAL		
Economic/Regulatory Policy	MyEnergyMarket	Where business is conducted within a jurisdiction or across different jurisdictions, MyEnergyMarket is designed to comply with all required technical, economic, and regulatory policies.
Business Objectives	MyMarketOptimizer, MSP, BO	The MSP designs services (and contracts) that support the objectives of its suppliers and consumers.
Business Procedures	All parties involved in the process(es)	Compatible business processes and procedures are set up across interface boundaries within the building for the BO and between suppliers, the MSP, and consumers.
INFORMATIONAL		
Business Context	BO, MSP	The business context information model is not limited to data elements, it also includes elements that support time, scheduling, time synchronization, time order dependency, and sequencing requirements and mechanisms that are required to support the rules for how the data are to be used. The MSP provides rule-based (smart) contracts that the BO platform can act on autonomously based on local information.

Table A.3. (contd)

Interoperability Category	Tools, Systems, Key Actors	Examples of interoperation or integration across system boundaries where agreements must be reached
Semantic Understanding	MSP principally but also BO	Where the information exchanged derives from multiple information models, the capability to link data from different ontologies is supported.
TECHNICAL		
Syntactic Interoperability data structure of messages	BO, MSP	The collaboration agreements between parties (i.e., BO-MSP, MSP-supplier) describe what formats they expect in the messages being communicated.
Network Interoperability Mechanism to exchange messages	BO, MSP	The information transported on the communication networks (consumer-MSP, MSP-supplier) are independent from the network protocols. The management of the networks between interacting parties is aligned such that communications paths support reliable message exchange.
Basic Connectivity Mechanism to establish physical and logical connections	BO, MSP	The hardware in the communicating devices support access the networks.
Community		
Development of standards, practices & improvement	Technology suppliers, consortia, standards groups	ICT suppliers specified the standards' profiles that fit the community business objectives and maximize the longevity of interface definitions.

GRID
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http://gridmodernization.labworks.org/