Advancing Certification Testing
From Conformity to Interoperability to End-to-End

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Abstract

This paper covers the multiple layers of testing needed to ensure reliable and interoperable solutions are delivered to the Smart Grid industry. An essential piece of this is the development of End-to-End interoperability testing. The focus of this framework is testing the integration among systems and/or applications based on emerging Smart Grid standards to enable Smart Grid business processes at the inter-systems level within the NIST Conceptual Model domains and sub-domains. The test requirements will be driven by business processes and the technical requirements will be driven by SGIP Smart Grid architectural standards. The end-state of this effort will contribute to the development of testing efforts required to support interoperable, cross-domain Smart Grid solutions as business functions, standards and technologies evolve.

1. INTRODUCTION

By working with key stakeholders of the industry and standards organizations, the National Institute of Standards and Technology (NIST) effort to develop a Smart Grid interoperability framework is yielding results [1]. NIST developed a Smart Grid conceptual model, which includes seven domains and eight high-priority focus areas, as part of the framework. The Smart Grid as a whole includes a very complex set of social, technical, and economical systems that must work together. Interoperability for Smart Grid, therefore, must be defined for all aspects of such a system. NIST recognizes that the initial standards list requires further development and that many additional standards and specifications are needed to achieve interoperability of Smart Grid devices and systems.

Now that NIST has identified an initial list of standards for interoperability, there is a bigger challenge ahead: Developing a comprehensive interoperability testing approach that covers the identified standards, as these standards evolve and new standards that emerge. Existing standards were developed without over-arching Smart Grid vision and use cases, so overlaps, inconsistencies, and incompleteness exist across all standards. Going forward, some key challenges remain in each of the following testing areas:

Conformance: New as well as existing adopted standards need to have clearly defined minimum functional and conformance criteria established and documented, including test plans which define test cases from which executable test scripts are implemented.

Interoperability: New standards are emerging rapidly that require them to work together. Without a clear framework for moving beyond conformance testing, efforts to implement these standards will increase significantly. Interoperability at this level must be viewed as insuring that any two systems claiming conformance to a standard are able to exchange meaningful information between them.

End-to-End: The SGIP End-to-End Work group[1] is focused on the next level of interoperability between products/systems conforming to a given interface specification (OpenADR, SEP, MultiSpeak, CIM, etc.), as well as across domains and system components that use a supposedly complementary set of standards.

The SGIP End-to-End Working Group has identified that a number of organizations have been independently addressing the End-to-End challenge and that the industry would benefit from a common approach to this particular

[1] A sub-committee of the Smart Grid Interoperability Panel Test and Certification Committee.

interoperability standards issue. If a common approach is not developed, the challenges in integrating system components based on different standards will continue to drive up the cost of Smart Grid implementations and hinder the progress toward Smart Grid interoperability.

2. CURRENT STATE OF SMART GRID INTEROPERABILITY

There has and continues to be a great deal of standards development related activity occurring in many areas of the Smart Grid. While there are multiple motivating factors for using standards based products/solutions, the promise of easy to achieve interoperability is by far the greatest. The development of standards results in specifications which define one or more of protocols, interfaces, functionality, and minimum performance criteria.

Well defined specifications set the baseline for interoperability by declaring statements of conformity to both mandatory and optional functionality and even minimum performance criteria where applicable. These PICS (Protocol Implementation Conformance Statements) or equivalent conformity mechanisms set the stage in defining both conformity and interoperability.

2.1. Conformance Testing

Conformance Testing is the foundational cornerstone of interoperability and is the basis for which all other testing relies upon.

2.1.1. Definition

Conformance Testing checks that both the mandatory and optional functional behavior/features work as described in a standard/specification. Conformance Testing typically uses a test harness to emulate the environment in which a device will be operating. Figure 1. shows the relationship between the test harness and an implementation under test, in this case an Electrical Services Interface, ESI.

In Figure 1. the Test Harness emulates both the AMI Network and one or more HAN devices. Each interface is shown as a Point of Control and Observation (PCO), where the test harness can interact with the Implementation Under Test. An additional interface, described as the Upper Tester Interface is also shown. This may be an HMI or another form of communications interface.

2.1.2. Need

Conformance Testing is needed to ensure that the functional behavior of all products implementing a standard/specification is the same.

2.1.3. Benefits

The mandatory and optional behavior and any minimum performance criteria as defined by the statements of conformity is used in conjunction with the detailed functional behavior from the standard/specification to develop specific test cases. The test plan comprises a compilation of these test cases and defines the level of conformance acceptable for a particular standard/specification. The use of a test harness enables a wide variety of tests to be performed including positive and negative test cases and testing at (and beyond) boundary conditions.

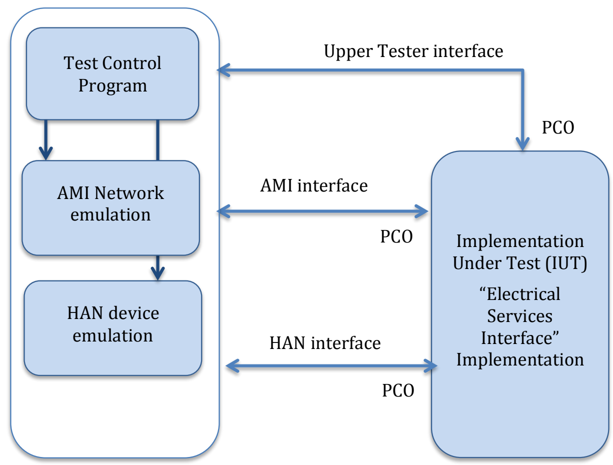

Figure 1. Conformance Test Logical Setup

2.1.4. Issues/Challenges

There are a number of challenges when considering Conformance Testing. First, it is important to establish a balance between adequate test coverage, needed to prove that an implementation is conformant to a standard, and complexity. Testing must be considered economic by both the suppliers and consumers of equipment as test time costs money. Ensuring a structured approach to testing helps achieve this balance. For example, when testing an implementation which includes multiple protocol layers, it is beneficial to perform "bottom up" testing, ensuring conformance of the lowest protocol layer first and working up the protocol stack. Even so, it is difficult to create a test harness which can fully emulate the operating environment for the implementation under test. This is increasingly difficult for devices which operate within a complex network topology.

Additionally, while Conformance Testing is focused on the mechanics of both the mandatory and optional functional behavior/features of a standard/specification, the incorporation of the baseline business and exception processes may not be well defined at the time of the conformance test. As a result, the overall behavior of a product in an End-to-End solution may meet the technical requirements but not support the expected business goals.

2.1.5. Lessons Lost/Learned

While the industry as a whole is making improvements it is still learning. Examples of some areas in which improve on include:

- The development of business process use cases need to be well-defined. The use cases should incorporate both positive and negative conditions.
- The business process use cases need to differentiate between baseline or mandatory business functions and optional business functions.
- Conformance Testing of a product needs to be completed and validated against the baseline set of business process use cases prior to performing Interoperability Testing to assure adherence to a standard/specification, and identify areas within the standard/specification that needs to be further defined in accordance with the business process function.
- Product vendors need to be provided with a common set of business process use cases to completely understand the business functional requirements.

2.2. Interoperability Testing

2.2.1. Definition

Interoperability is the ability of a system or a product to work with other systems or products. Interoperability Testing is the process of assessing whether 2 or more system or product implementations will work together as expected with an "acceptable" level of operator intervention. The diagram in Figure 2. shows the relationship between implementations for an ESI and HAN device.

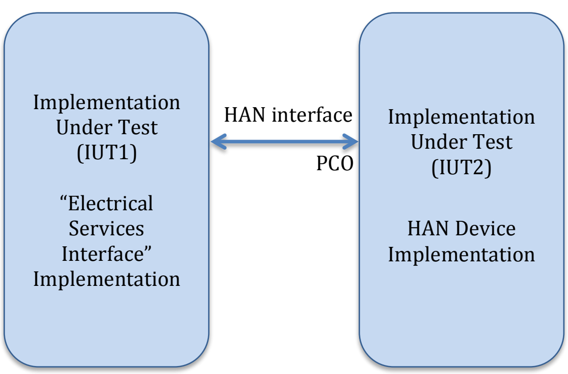

Figure 2. Interoperability Test Logical Setup

2.2.2. Need

Interoperability Testing is essential to ensure that an implementation functions correctly when interacting with other implementations that might be found in any of the product's deployment scenarios.

2.2.3. Benefits

Ideally products / implementations will work "out of the box"; interoperability testing can highlight product inconsistencies as well as problems with product configuration.

Interoperability Testing can also highlight inadequacies in Conformance Testing as well as the Standard.

2.2.4. Issues/Challenges

Testing for Interoperability has a number of associated challenges:

- Testing becomes increasingly challenging as more devices participate in an interoperability test, particularly for peer-to-peer communications protocols as is shown in Figure 3.

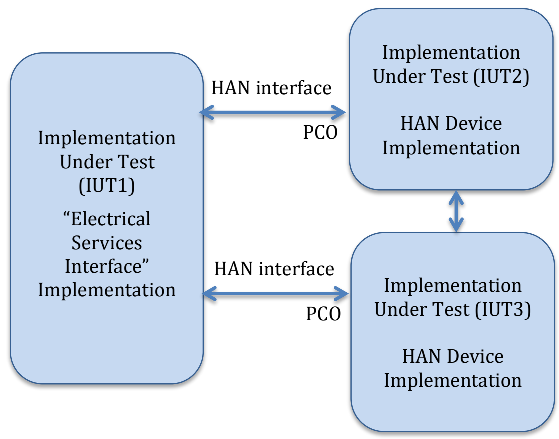

Figure 3. Peer to Peer Communication Example

- For each additional device added, the number of logical interfaces increases exponentially.
- The logistics of Interoperability Testing becomes increasingly challenging as the number of products implementing the standard increases.
- Test scenarios for complex standards or those that support complex topologies – e.g. mesh routing - pose a significant challenge when defining interoperability test scenarios.
- Interpretation of the test results can also present its own problems. For example, communications protocols which include error recovery require a

skilled and knowledgeable test engineer to understand the results.

- Backward compatibility (or lack thereof) with older versions of a Standard creates additional interoperability test challenges New releases of standards often require backward compatibility to ensure existing deployed devices can interoperate with new devices.

- When products first appear based on a new standard, there is often a settling period when product versioning complicates conformant product behavior. Manufacturers are enhancing product capabilities and releasing new versions faster than the interoperability test process can validate interoperability. This poses a challenge as the number of possible products increases rapidly.

2.2.5. Lessons Lost/Learned

Areas in which Interoperability Testing can be improved include:

- It is desirable to minimize the number of configurable options in the mandatory set of functions that any may support. The more optional functionality, the greater number of permutations are necessary for assessing product interoperability.

- Regular Interoperability Testing events should be organized from an early stage, ideally before completion of the Conformance Test Plan development as Interoperability Testing can highlight deficiencies in a Conformance Test Plan.

- If it is deemed desirable to have "Golden Units", then they should be readily available. "Golden Units" should not be special implementations, but should be implementations which have undergone Conformance Testing and extensive Interoperability Testing and are considered mature implementations. It is probable these will be devices that are extensively deployed. The availability of Golden Units gives producers of new implementations a benchmark against which to test.

- To effectively support an Interoperability Testing program for competing solutions, the business use cases should establish and utilize a baseline set of business functions that is common to the industry.

3. SGIP EFFORTS

The Test and Certification Committee of the Smart Grid Interoperability Panel (SGTCC) released Version 1 of the Interoperability Process Reference Manual (IPRM) in 2010 [2] and has Version 2 in draft. The goal of the IPRM is to specify a set of guidelines and requirements for an organization that is responsible for certifying conformance and interoperability of products claiming conformance to a single technology standard.

3.1. Overview

The IPRM is a ground-breaking guide to developing and managing a world-class test and certification program. Until the issuance of Version 1.0, nothing like it existed for the Smart Grid (or any other industry) that we are aware of. Every trade alliance has had to create its own certification program which has resulted in a great deal of variation in how such programs have evolved. Having a roadmap such as the IPRM can greatly accelerate achieving the goals of product interoperability based on a specific standard.

The IPRM defines the standard against which the SGIP assesses the quality and maturity of certification programs for Smart Grid standards. Although NIST[2] is not directly bound to accept the conclusions and recommendations of the SGIP (in terms of which standards to adopt), it is clear that the SGIP process is closely watched by NIST managers and SGIP assessments of certification program maturity are expected to influence the market adoption of specific standards.

The IPRM identifies some 86 formal requirements in 5 distinct areas that serve as a specification for what a good test and certification program for a Smart Grid technology standard should look like. In addition, a number of guidelines are discussed that further clarify how such a program can achieve its goals of interoperable and conformant products based on the specification.

3.2. Need

The SGTCC believes that implementation of the IPRM will lead to reduced deployment costs of Smart Grid systems and devices and enhanced product quality with respect to interoperability and conformance, ultimately providing confidence to the buyer through meaningful certification programs.

While there is a great deal of interest in writing new standards or improving existing electrical system standards, the real challenges emerge when vendors attempt to bring standards-based products to market, and customers attempt to integrate them into new or existing applications. Invariably, the creation and use of certification test programs and other methods to ensure achievement of the

[2] NIST is the National Institute of Standards and Technology, US Department of Commerce. NIST established the Smart Grid Interoperability Panel specifically to engage a broad range of stakeholders in assisting with their mission to identify Smart Grid technology standards.

standardization goal are addressed inadequately, if they are addressed by the industry at all.

The IPRM grew out of a clear need to find ways to encourage and support various industry alliances with a roadmap for improving their certification programs.

3.3. Application to End-to-End Test Challenges

Conceptually, the implementation of the IPRM by an organization that certifies products for a standard is the first building block of an End-to-End testing activity that includes the specific standard. Indeed, the End-to-End Work Group views both an IPRM compliant certification program and certification by the program as pre-requisites for including a product in End-to-End testing.

Figure 4. illustrates the relationship between the IPRM, a standards-based certification program and End-to-End testing. Vendor products are first certified in the appropriate IPRM based certification program and then are configured into an End-to-End Test Configuration.

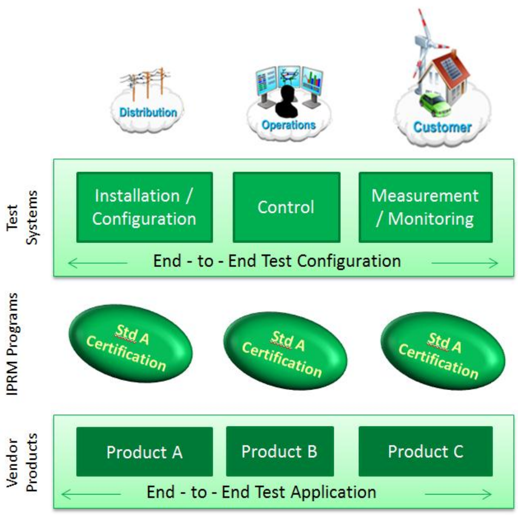

Figure 4. The IPRM and End-to-End Test System

The structure and focus of the IPRM can provide some guidance in designing the End-to-End test methodology. For instance, the guidance for best practices, General Test Policies, Test Suite Specification, Cyber security and ITCA[3] role and requirements can be borrowed from to construct aspects of the End-to-End Test Process.

An example of leveraging IPRM concepts can be found in the End-to-End concept of an Interoperability Function Statement (IFS). The starting point in the development of an IFS can be the PICS, which should identify the options and conditions which apply to the protocol to be tested. The IFS has comparable attributes such as:

- Format is typically a questionnaire
- Each function/feature of the specification(s) should be clearly described with reference to the specific clause(s) in the specification(s)
- All features / functions should be clearly described as mandatory or optional, with dependencies described

While the IPRM itself does not address the specifics of a standardized End-to-End test methodology, its use as a pre-cursor and model for the End-to-End process is clear.

4. ADVANCING CERTIFICATION TESTING FOR TOMORROW'S NEED FOR INTEROPERABILITY

End-to-End Testing is a comprehensive Interoperability Testing approach that places emphasis on the integration among systems and/or applications to enable Smart Grid business processes at the inter-systems level within the NIST Conceptual Model domains and sub-domains. Figure 5. high-lights several key business functions that rely on Smart Grid Interoperability.

4.1. Definition

End-to-End Testing validates the entire solution to ensure that it satisfies previously established acceptance criteria and performs as an integrated system. It should be used to simulate a scenario as seen by the actual business users.

4.2. Need

The growth of Smart Grid devices and smart meter pilots, which are quickly turning into large-scale deployment is advancing Standard Setting Organizations (SSOs), user groups, vendors and end users to develop Smart Grid-related standards to support this growth. Some of these standards include:

- IEC 61968/61970/61850
- MultiSpeak
- Smart Energy Profile (SEP) 2.0
- ANSI C12.19
- IEEE 1547
- NERC CIP 002-009
- NIST SP 800-82
- OpenADR V2
- OpenADE/ESPI

[3] Interoperability Test and Certification Authority. Defined in the IPRM.

Each standard focuses on a different aspect of the Smart Grid domain. For example, IEC 61968/61970 integrates energy management systems while SEP 2.0 communicates data between devices within a home area network (HAN). Due to timing and different focus, overlap and duplication exist across these standards. For example, both MultiSpeak and IEC 61968 address very similar use cases within utility enterprise integration. As a result, the interoperability among the standards is a concern, as a single concept could be presented in different terms in different standards. To address this and many other interoperability issues, the Department of Energy (DOE) funded NIST under the Energy Independence and Security Act (EISA) to "coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of Smart Grid devices and systems". [4]

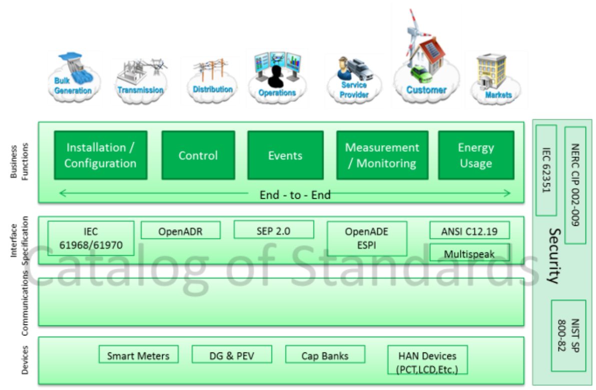

Figure 5. Typical End-to-End Interoperability Problem

While the IPRM defines a frame-work for Interoperability of Smart Grid standards, there is an industry need for a set of comprehensive End-to-End Testing guidelines needed to ensure that the implemented standards for the Smart Grid system of systems deliver the intended business functions and benefits. The term "interoperability" is often misunderstood. The term is often used for "Plug Fest" between a single standard and multi-vendor test or is a planned event that is used to show the progress of relevant industry standards beginning to come together. Unfortunately, these types of tests tend to be less structured and not repeatable, which is a critical step in Interoperability Testing for End-to-End scenarios. It is necessary that End-to-End interoperability testing is repeatable and looks across the Smart Grid systems as a collection of business services and provides an approach for testing as these standards and technologies evolve.

4.3. Benefit

End-to-End interoperability is a key benefit of a comprehensive test approach for Smart Grid Standards. It will be common for Interoperability Testing to focus on a specific category like testing events from field devices, validating messages can be sent to devices, validating command and controls , however if these types of test groups are tested as a whole then this will provide a comprehensive End-to-End interoperability test. Interoperability at this level will pave the road for insuring the Smart Grid vision and growth.

4.4. Issues/Challenges

End-to-End Testing is in its infancy and faces many issues including:

- An industry-wide baseline set of business process use cases needs to be defined in order to effectively establish a common End-to-End Testing framework.
- The End-to-End Testing framework needs to support a common testing program which can support varied technologies, standards and specifications that support a similar functional concept.
- With the incorporation of many solutions, technologies and standards for use within an End-to-End environment, the business processes need to recognize the variations in which each component interoperates with another component as well as how they will ultimately be used within the End-to-End environment.
- A well-defined set of business process use cases need to be developed to support both positive and negative testing efforts.
- The negative testing needs to incorporate operational conditions or exceptions that may occur with the failure of one or more End-to-End components.

5. HAN END-TO-END CASE EXAMPLE

The SGTCC End-End Work Group was tasked to look at creating a common method and set of guidelines for how energy vendors and providers can repeatedly test Smart Grid End-to-End business functions in order to achieve interoperability. The SGTCC working group created a list of potential test use-cases that have a different focus, but provide a good context for establishing End-to-End interoperability. The working group then identified gaps within the context of the use cases and developed a template for what and how End-to-End Testing should consider in the process of developing the abstract test cases. One of the areas that had the most interest and included End-to-End business functionality was the Installation and Configuration of Home Area Network (HAN) devices. A HAN installation use-case was selected that became the base test case to complete the set of guidelines identified for End-to-End Testing.

5.1. Approach

The approach developed provides a set of testing guidelines to a set of common Smart Grid use cases and technologies that support the Smart Grid business functions from End-to-End. There are four main categories to support End-to-End Testing and each category contains a set of sub steps and provides an explanation for how it can be used. Figure 6. illustrates the model.

Figure 6. End-to-End Test Model

The four main categories used in the End-to-End Test Model include:

Test Use Case: This section provides a common set of Smart Grid business requirements and processes for customers to adopt and for vendors to help implement.

Test Requirements: This section is primarily aimed at developing the abstract test suites for testing devices and systems that span across multiple business services of the NIST Smart Grid Conceptual Model.

Testing Process: This section provides the principles, arrangement, planning, and execution of End-to-End Testing.

Feed Back: This section provides a common process and format to communicate back to the SSO's ITCA and user groups the observed events for End-to-End Testing.

The End-to-End Test Model builds on a number of concepts already developed in the IPRM.

5.2. Benefits

The End-to-End Testing of the HAN device will be used to determine how each component within an End-to-End environment will support the Installation and Configuration of the HAN device through the use of positive and negative business test cases.

For this specific example, acceptance criteria may include response times associated with installing or configuring a device, management of user data entry errors, trying to pair more than one device to a meter, management of device status throughout the install or configuration process, removing a HAN device in a normal or abnormal state.

5.3. Applicability to other Use Cases

The HAN End-to-End Testing approach provides the relevant guidelines and validation for testing the implementation of interoperability standards among the different systems across boundaries. The same approach was designed to support other key use cases that include Demand Response Direct Load Control, Price Signals and Text Messages. Having a common approach to the HAN test scenario that provides a structured, common and repeatable method for testing system interoperability across the various components of the Smart Grid landscape is a key component to addressing interoperability challenges.

In a nutshell, the approach developed was designed to provide a good context for establishing End-to-End interoperability. As new business services are developed and additional End-to-End requirements are available then additional use-cases can be applied.

6. CONCLUSION

Implementing a multi-layered testing program within the Smart Grid industry provides a foundation in which reliable and interoperable solutions can be developed and implemented based on key standards, testing processes and business use cases. The inclusion of an End-to-End Testing program, coupled with Conformance and Interoperability Testing, provides a comprehensive approach with respect to the overall development of interoperable, cross-domain Smart Grid solutions as business functions, standards and technologies evolve.

Efforts are currently underway within the SGTCC to define the initial framework for End-to-End Testing. This framework has identified a set of key business functions that require comprehensive testing to help enable an interoperable Smart Grid landscape. The working group selected a HAN installation scenario to help validate that the approach will support a common test method that can be leveraged by more than one vendor or utility and will provide consistent results when testing a set of standards that support a specific business function.

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BIOGRAPHIES

Phil Beecher is the owner of BCC, a consulting company specializing in Smart Grid communications, Testing and Certification. He is Chair of IEEE 802.15 TG4g and OpenSG Edge Conformity Task Group, Vice Chair of 802.15 TG4m and an Elected member of the SGTCC. Phil has previously held positions in the WiFi Alliance and Bluetooth SIG. He has been an active contributor in the development of communications standards and the specification of test plans for a number of Smart Grid standards, including ZigBee SEP2 and NAESB ESPI. Prior to forming BCC, Phil worked as Software Engineering Manager for Integration Associates, a semiconductor manufacturer specializing in low power wireless products.

Donny Helm is the Director of Technology Strategy and Architecture at Oncor Electric Delivery. He has over twenty years of experience in the electric utility industry including the areas of Distribution Engineering, Customer Service and Marketing, Transmission Operations, Transmission Performance Analysis and Technology. Of this time, sixteen years was associated with the management of Transmission-related activities. Mr. Helm's primary field of experience has been in Transmission Operations, Transmission system event monitoring and coordination, Transmission system performance / statistics, Transmission work management processes and systems, Transmission outage management processes and systems, Transmission network communications standards, Transmission equipment condition monitoring systems and processes. In his current position, Mr. Helm provides and manages technology strategy for all organizations within Oncor Electric Delivery with respect to systems, system integration technologies, network communication technologies and security. Mr. Helm is also an active participant in the Smart Grid Testing and Certification Committee as part of the National Institute of Standards and Technology (NIST) initiative under the Energy Independence and Security Act (EISA) of 2007.

James Mater founded and has held several executive positions at QualityLogic, Inc. from June 1994 to present. He is currently Co-Founder and Director working on QualityLogic's Smart Grid strategy including work with GWAC, the Pacific NorthWest Smart Grid Demonstration Project and giving papers and presentations on interoperability. From 2001 to October, 2008, James oversaw the company as President and CEO. From 1994 to 2001 he founded and built Revision Labs which was merged with Genoa Technologies in 2000 to become QualityLogic. Prior to QualityLogic, James held Product Management roles at Tektronix, Floating Point Systems, Sidereal and Solar Division of International Harvester. He is a graduate of Reed College and Wharton School, University of Pennsylvania.

Mark Ortiz is an Associate Principal Consultant at Xtensible Solutions, which provides enterprise information management and integration solution and services to the energy and utility industry. Mark is involved in a wide range of research and development projects, providing technical leadership and standards setting for the Smart Grid. Mark is an active Member and chair of multiple key industry standards groups influencing Smart Grid development including IEC TC57 WG14 (CIM for Distribution Applications), NIST Smart Grid Interoperability Panel (SGIP) and UCAIug OpenSG. Mark has extensive enterprise architecture experience with integrating the Utility's Back-Office systems with Advance Metering Systems, Outage Management, Geographical Information Systems, and many other utility enterprise systems.

Clint Powell is the owner of PWC, LLC and is currently consulting to Southern California Edison on Wireless Communications Standards, Systems, and Testing for the Smart Grid. In this role he is helping to drive and establish standards, define next generation architectures, and establish communications testing capabilities. Clint has also consulted to equipment vendors and device manufacturers. He is a Vice-Chair of IEEE 802.15 TG4g, Technical Editor for IEEE 802.15 TG4m, Chair of the ZigBee Qualification Group, Elected Member of the SGTCC and Member of the OpenSG Edge Conformity Task Group. He previously played roles in IEEE 802.15 TG4c, IEEE 802.15.4-2006, ZigBee Qualification Group, and the ZigBee Application Framework Group. Prior to forming PWC, LLC Clint was the Chief Architect & Global Platform Systems & Architecture Mgr. for the Wireless Connectivity Operations at Freescale. During his 20 years at Motorola/Freescale he held a number of Systems & Architecture management positions where he defined next generation communications architectures for 802.15.4/ZigBee, 3G, 2.5G, 2G, Multimedia-wireless, BT, DECT, CT-2, 2-Way and 1-Way Paging and proprietary wireless systems. He was an elected member of both companies Scientific and Technical Advisory Boards. Clint has 32 issued US patents and has published a number of papers.