Table of Contents

6 Testing and Certification

The modernized electric grid is often described as a "system of systems" (SOS) spanning multiple technology domains, involving thousands of organizations, and hundreds of standards (see Section 2.3). Smart grid devices, systems and applications require extensive data exchange and need well-defined interfaces to transfer and translate this data between points across the grid. Interoperability is necessary to provide the seamless functional performance across systems that enables many benefits of the smart grid.

While standards promote interoperability, the breadth and flexibility of implementations each standard means that interoperability is not guaranteed. Test programs are needed to ensure products are developed in a manner where standards are implemented that enhances interoperability.

This chapter provides an overview and benefits of testing and certification for smart grid standards, and describes gaps and required work to address the longer-term implementation needs and challenges in maintaining a robust testing and certification ecosystem for interoperable smart grid systems and devices.

6.1 The Role of Testing and Certification

Testing and Certification (T&C) programs provide common processes that are used to demonstrate conformance with a standard [1]. When accepted and used across industries, these testing and certification processes support interoperability between devices and systems that span equipment vintage and manufacturer. Completing the T&C program allows vendors to offer products certified to a standard and affords customers a level of trust that products will work as intended when deployed.

Standardized interface and performance requirements are necessary for modernizing the grid as new technology integrates with legacy grid systems [2, 3]. Well defined interface requirements enable creation of adaptors and gateways that allow new equipment to interact with existing systems to extend useable service life. Performance requirements are critical to ensure the deployed equipment has the necessary capability or can be upgraded to accommodate future applications.

The value of certification programs increases as the number of devices grows through economies of scale for both manufacturers and test program operators. As the range of technologies and grid operational paradigms continue to evolve—and grid operations become more complex—certification programs become essential to ensure the reliable performance of grid components in this increasingly dynamic environment.

6.1.1 Testing and Certification Value

The T&C value proposition benefits all grid stakeholders.

> **Customers** benefit by ensuring standards and performance requirements are implemented appropriately and consistently across purchased equipment, which eases integration of new products and services with existing infrastructure and operations [4].
>
> **Manufacturers and Vendors** benefit from the establishment of clear performance requirements which reduces implementation costs for new standards [5]. T&C programs ensure product certification occurs in a neutral environment and creates a level playing field for participants, which can facilitate market access and reduce entry barriers for all—including new entrants.
>
> **Regulators** benefit because interoperability T&C maximizes the benefits of new grid technology investments they approve through regulatory proceedings [1, 6].

6.1.2 Current Practice

NIST helped create best practice guidelines for the development of T&C programs for smart grid systems and devices. The foundational products are the Interoperability Process Reference Manual (IPRM) standard [1] and accompanying User's Guide [7]. The IPRM standard defines a process by which industry stakeholders may procure, test, and assert interoperability between disparate vendors of smart grid products built to identified standards. It includes practical guidance on requirements and recommendations for general test policies, test suite specifications, test profiles, interoperability T&C authority technical programs, governance, laboratory qualifications, and process improvements. The IPRM standard defines an entity, the Interoperability Testing and Certification Authority (ITCA), that serves as test program operator. Ideally, there should be an ITCA to support each smart grid standard for which a T&C program is required.

Testing and certification is an important aspect of the technology product development and deployment lifecycle which is often overlooked because of the cost associated with completing a test program, the limited availability of appropriate test programs (see **Catalog** of Test Programs **6.4.2**), and the lack of qualified testing organizations to perform the tests. This is one of the main reasons for the persistent gap in the availability of testing programs for smart grid standards.

6.2 Levels of Interoperability

There are many levels of interoperability, that industry defines in different ways. This is important for T&C because most standards, tests, and certifications have been created by industry to deliver a desired function and interoperability level.

One way to define the interoperability level is through the Open Systems Interconnection (OSI) 7-layer model [6]. This approach provides a method for defining interoperability within and across communications system levels. Another method for defining interoperability is the GridWise Architecture Council (GWAC) interoperability stack concepts [8], which describes interoperability from a functional approach.

A conceptual way to describe interoperability levels is to consider the integration perspective. The range of interoperability levels range from plug-and-play on one end of the spectrum to point-to-point integration on the other, with plug-and-play being the most interoperable.

There are a few examples of plug-and-play integration in the electric grid. One example is the compatibility between electric vehicles and public charging stations. When the station and vehicle support the same plug type and charging protocol, charging begins as soon as the two are connected regardless of the fact that the vehicle and charging systems are owned by different actors.

The middle interoperability level—where devices require integration efforts to work with the rest of the system—is more common. Substations equipment us a useful example of this scenario, as there are two dominant standards in the substation arena. A utility could have substation with equipment that supports the DNP3 communication protocol but wants to buy a new intelligent electronic device (IED) that supports IEC 61850 because that standard has more and different functionalities. This difference in designed-to communications protocols means the new device will not be able to communicate with the rest of the substation without specific integration efforts. However, this integration issue can be addressed with the IEEE 1815.1-2015 standard which provides a mapping between IEC 61850 and DNP3 for a gateway to translate between the two communication protocols [9]. A gateway conforming to that standard would therefore allow the device to interoperate with the rest of the substation.

Point-to-point integration is often referred to as a custom one-off solution. This type of integration is needed when integrating new equipment to existing systems that implement proprietary or obsolete communication protocols. In the electric grid this is a common problem because grid equipment often as long service life [10] and will need to communicate with newer systems to enable new functionalities as part of grid modernization. This scenario will lead to a custom integration solution where the communication mapping between the existing and new systems will need to start from scratch and cannot rely on a published standard. This type of integration is time consuming and costly.

6.3 Types of Testing Processes

Developing testing and certification programs involves many processes, the steps for which are shown in **Figure 1**. Because the designed interoperability level for each product is a function of technical and business considerations, not every product or standard will complete all of the steps.

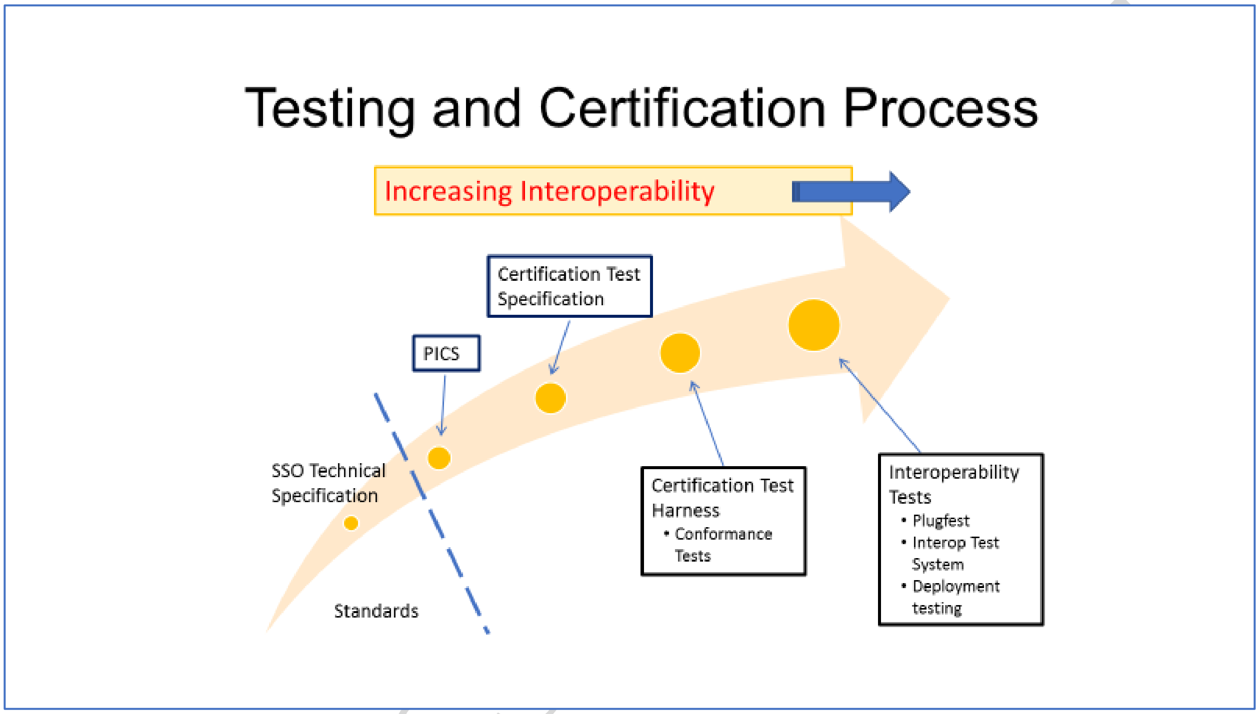

Figure 1- Testing and Certification Development Process

6.3.1 Conformance and Interoperability Testing

Conformance testing ensures products conform to requirements detailed in a standard or other specification. Interoperability testing ensures that products from different vendors can communicate and exchange actionable information in the same system. Conformance testing does not guarantee interoperability because standards often include multiple options manufacturers can choose from to meet a requirement. Standards contain these implementation options to be flexible and allow for innovative approaches to product development and deployment, but this optionality introduces significant product variability that can inhibit interoperability.

One example of standards optionality that may inhibit interoperability is found in the new IEEE 1547-2018 standard for solar inverter and DER grid interfaces [11], which provides three options for communications protocols[1] that could lead to products which conform to the standard but do not interoperate. It is therefore possible for two DERs which conform to this standard to be unable to communicate with each other because they support different communication protocols.

Interoperability testing is more complex than conformance testing since manufacturers will have to agree to a common list of requirements to enable the products to work together. This is generally referred to as an implementation agreement and is an essential element of an interoperability test program. From these agreed upon requirements, the industry stakeholders group develops the protocol implementation conformance statement (PICS) for the test plan.

> **Implementing Agreements** define a common interpretation of a standard which includes a specific subset of requirements from the original standard [7].
>
> **Protocol Implementation Conformance Statement (PICS)** enables the development of a test plan from the requirements identified in the implementing agreement.

This process often leads to an implementation profile for a standard which serves as the basis for interoperability testing requirements. As discussed later in this chapter, the development of interoperability profiles may offer a way to identify a subset of requirements common to a specific implementation of a standard, thereby minimizing the differences between implementations of a standard for a common application.

An example of interoperability testing is a plugfest, the final step in **Figure 1**. An interoperability plugfest is an event where different vendors and stakeholders gather to conduct testing of a standard or specification. The goal of a plugfest is to determine if devices from different manufacturers that claim conformance to a standard are able to communicate and exchange information as specified in the requirements, and to show incompatibilities when interoperability is not achieved. A successful plugfest requires participation from equipment manufacturers, test support personnel, and witnesses.

Reports from recent plugfests, such as the 2017 IEC 61850 plugfest, indicate the value of these activities. The final report for this event identifies communication issues that occurred among devices due to their implementation of certain aspects of the IEC 61850 standard. In one case, a device had its network domain address hardcoded and could not be dynamically changed to different values as required by tests, and the device failed the communication test [12].

Industry recognizes the importance of plugfests in specifying product procurement requirements [13]. A purchaser can potentially require vendors to participate in plugfests to demonstrate the interoperability of their products. Plugfests also provide an avenue for vendors to showcase products and capabilities to potential customers, since utility staff can participate as witnesses at the event.

[1] According to the IEEE 1547-2018 standard, a DER will conform to the standard if it supports any one of three communications protocols, including: IEEE 2030.5 (Smart Energy Profile 2.0), IEEE 1815 (Distributed Network Protocol v3), and SunSpec Modbus.

Interoperability testing is important because it can show compatibility issues for devices from different vendors operating within a closed system. It provides information manufacturers can use to refine their products, and helps implementers avoid integration issues. The key takeaway on conformance and interoperability testing is that they are both necessary for enabling interoperability of smart grid devices and systems.

6.3.2 Certification Regimes

Three certification types described in the IPRM standard are first party, second party, and third party.

> **First-party certification** is when a manufacturer attests that the product meets the standard's requirements. This type of certification, often called self-certification, is common in the industry.[2] In first-party certification, the purchaser relies on the manufacturer developed test plan.
>
> **Second-party certification** is when a user tests and certifies the product to verify that it meets the standard's requirements. This type of certification relies on the user's own test plan which could include specific requirements based on their existing systems, and is not scalable because it is difficult for other users to take advantage of this testing. In the smart grid it is often the utility that serves this role.
>
> **Third-party certification** is done through an independent authority that includes a certification body and associated test lab. Third-party certification has public test plans, which facilitate transparent audit and evaluation of the testing implementations.

Table 1 provides a broad illustration of performance metrics related to the different certification types.

Table 1 - Certification Regime Characteristics (illustrative)

	Speed	Transparency	Independence
First Party	High	Low	Low
Second Party	Medium	Medium	Medium
Third Party	Low	High	High

Third-party certification by fully vetted and independent testing authorities is one of the best means to deliver interoperability. However, the other types of certifications are also useful because some level of testing will still provide some indication of product adherence to the standards.

[2] An example of first party certification is the ANSI C12 family of standards for electric meters. The meters are mostly procured with the manufacturer's certification of conformance to the C12 standard.

6.4 Current Smart Grid Testing Initiatives

This section includes brief discussion of ongoing testing and certification initiatives.

6.4.1 Testing Support

Testing events and test program formations are important catalysts for building a robust testing ecosystem. However, tehse activities are often done by volunteers with limited support from organizers. More support is needed to drive these activities to succeed and further develop the smart grid testing and certification ecosystem beyond the current nascent stage. NIST supports development of test protocols for conformance assessment,[3] and also participates in testing activities such as plugfests.[4]

6.4.2 Catalog of Test Programs

The SEPA Catalog of Standards (COS) provides useful information on standards relevant to smart grid development and deployment [16]. The COS does not, however, include information on associated test programs for these standards—or indicate if any test programs are available. A separate repository is needed to provide industry with information on available test programs. A catalog of test programs will provide guidance to equipment purchases on whether reference test programs are available. A catalog of test programs will also provide visibility for test program operators, and potentially increase their usage.

NIST conducted a landscape analysis on the availability of T&C programs for smart grid standards and determined that T&C programs are available for only a small percentage of interoperability standards (see **Figure 2**). The analysis also revealed there is a significant challenge in finding test programs even for those with expert industry knowledge and awareness.

In response to its findings, NIST plans to work with industry[5] to create a Catalog of Test Programs (CoTP). There are several industry test programs that are beneficial to interoperability of smart grid systems and devices, and a comprehensive directory of available test programs will provide value to the stakeholder community. The CoTP will provide a directory of industry test programs that support assessments against interoperability standards, and will be a one-stop resource to support utilities and vendors as they seek to identify available device testing resources. This initiative could also foster collaboration between test programs and labs, thereby expanding coordination across the T&C ecosystem.

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[3] For example, NIST staff is working on a test suite specification (TSS) for the utility power profile for precision timing protocol (IEEE C37.238 and IEC 61850-9-3), which will serve as the basis for the testing program the IEEE Conformity Assessment Program (ICAP) will operate [14].

[4] NIST staff have developed test harnesses for, and participated in, interoperability plugfests such as the UCAIug hosted 2017 IEC 61850 Interoperability Plugfest [15].

[5] Through the Smart Electric Power Alliance's Testing and Certification Working Group

See **Appendix C** — A List of Reviewed Smart Grid Interoperability Standards for the complete list of interoperability standards evaluated for NIST's T&C landscape analysis [17].

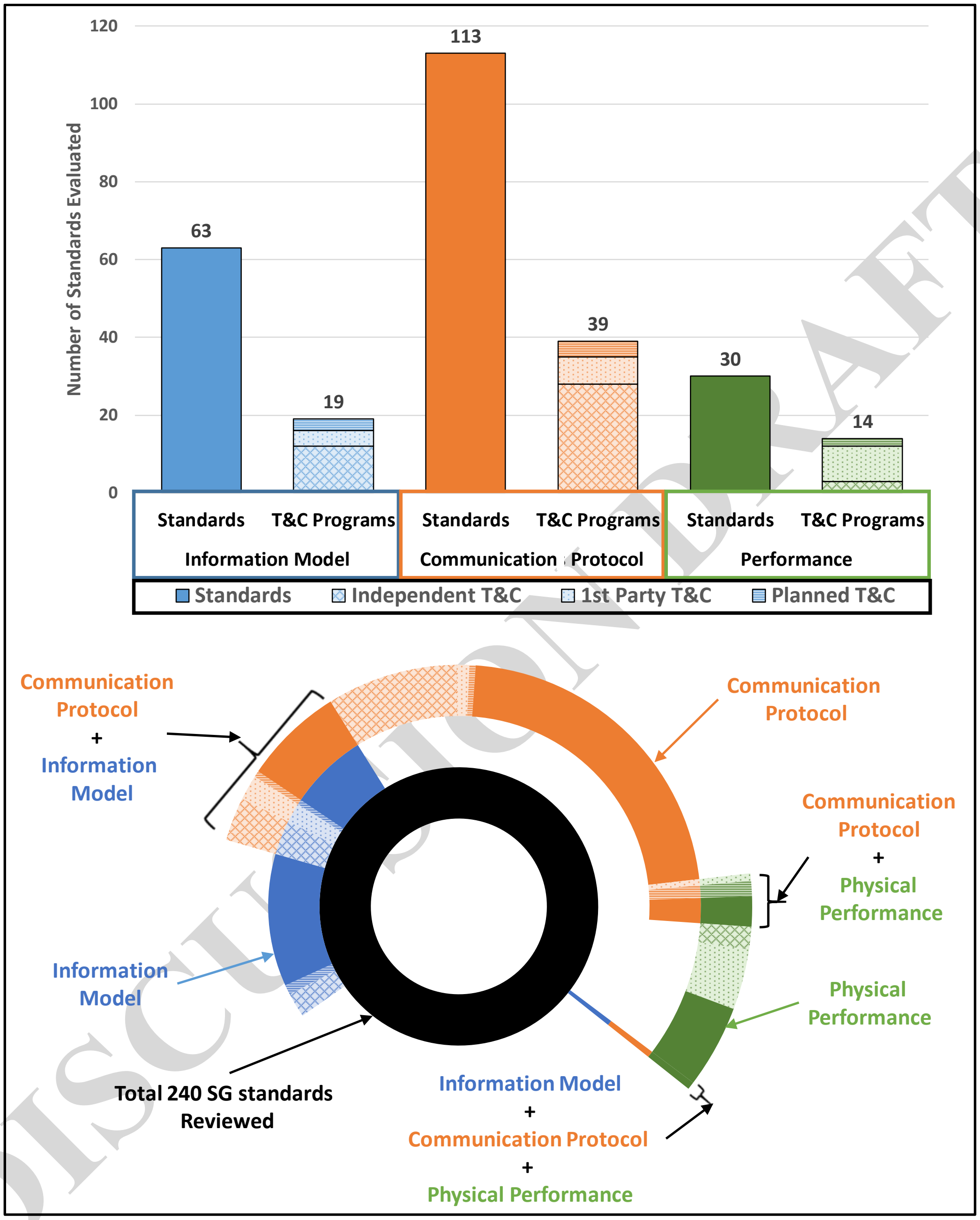

Figure 2 - Interoperability Standards and Associated Testing and Certification [17]

6.4.3 Reference Interoperability Procurement Language

Procurement language is crucial to specifying product interoperability requirements so that integration issues can be addressed and mitigated before deployment. It is more efficient for customers to develop interoperability requirements at the purchasing stage than it is to deal with integration issues after products are delivered. Failure to reference specific interoperability requirements in the procurement language increases the chances that the resulting product will not be interoperable with other equipment or systems.

A challenge in this space is that technical requirements for acquisitions by utilities and other customers are often focused on the functional specifications of the systems to be purchased and do not include appropriate descriptions for the interoperability requirements. One solution is to develop reference language so that it is readily available to specify interoperability requirements during procurement.

NIST is partnering with SEPA and the Department of Energy's (DOE's) Grid Modernization Laboratory Consortium (GMLC) to develop interoperability procurement language. This effort will develop a list of interoperability criteria and associated metrics that can be applied to procurement language.

6.5 Future Directions for Testing & Certification

Developing and implementing T&C programs for smart grid interoperability standards is a long-term process. As described in **Catalog** of Test Programs **6.4.2**, the latest landscape assessment reveals a limited availability of T&C programs for smart grid standards. NIST will continue working with industry stakeholders to accelerate the launch and availability of new T&C programs.

The development of interoperability profiles, wherein application-derived interoperability requirements are specified, is one opportunity to accelerate T&C program development. Another is through the development of open source test tools.

6.5.1 Interoperability Profiles

Reducing the complexity of implementing a standard and the associated testing requirement is one approach to addressing the T&C challenges described in this chapter. This could be accomplished through the development and use of Interoperability Profiles, which would describe a well-defined subset of the standard for implementation that has been agreed upon by a user community, testing authority, or standards body. By defining this implementation subset—which could describe a subset of supported data types, logical nodes and elements, or services—an Interoperability Profile would narrow interoperability gaps by reducing the degrees of freedom for implementing standards by the device supplier, implementer, and system owner.

Interoperability Profiles would not replace or be considered standards, but would instead serve to clarify standards-based implementation requirements for all stakeholders. Interoperability Profiles could therefore take many different forms based on the technology and underlying standards. For example, an Interoperability Profile based on an application would define the standard elements to be utilized in that specific application environment, thereby giving all stakeholders greater confidence in asset functionality.

The basic set of elements for an Interoperability Profile include the asset description and associated physical performance specifications, communication protocol, and information model.

The growing complexity of information models means that only a subset is likely to be necessary for any single application of piece of equipment. This can lead to interoperability failures when devices compliant to the same standard attempt to communicate different parts of the same data model. This communications failure could be mitigated through the application of Interoperability Profiles that define implementations using a specific subset of the broader standard.

An Interoperability Profile with a narrow set of implementation requirements could be more easily tested for certification, and eventually could be listed by vendors that support it or be used in procurement specifications by end users. This could facilitate the development and utilization of T&C programs, and advance interoperability for smart grid equipment and systems.

6.5.2 Example of an Interoperability Profile

The core elements of the Interoperability Profile approach have already been successfully demonstrated for smart inverters. California Rule 21 and IEEE 1547-2018 both define the specifications for interconnection and interoperability of distributed energy resources with associated electric power systems interfaces. The standards include physical performance specifications, communication protocols, and required data elements. While the physical performance specifications are similarly prescriptive, Rule 21 and IEEE 1547 employ different approaches to communication protocol and data element requirements.

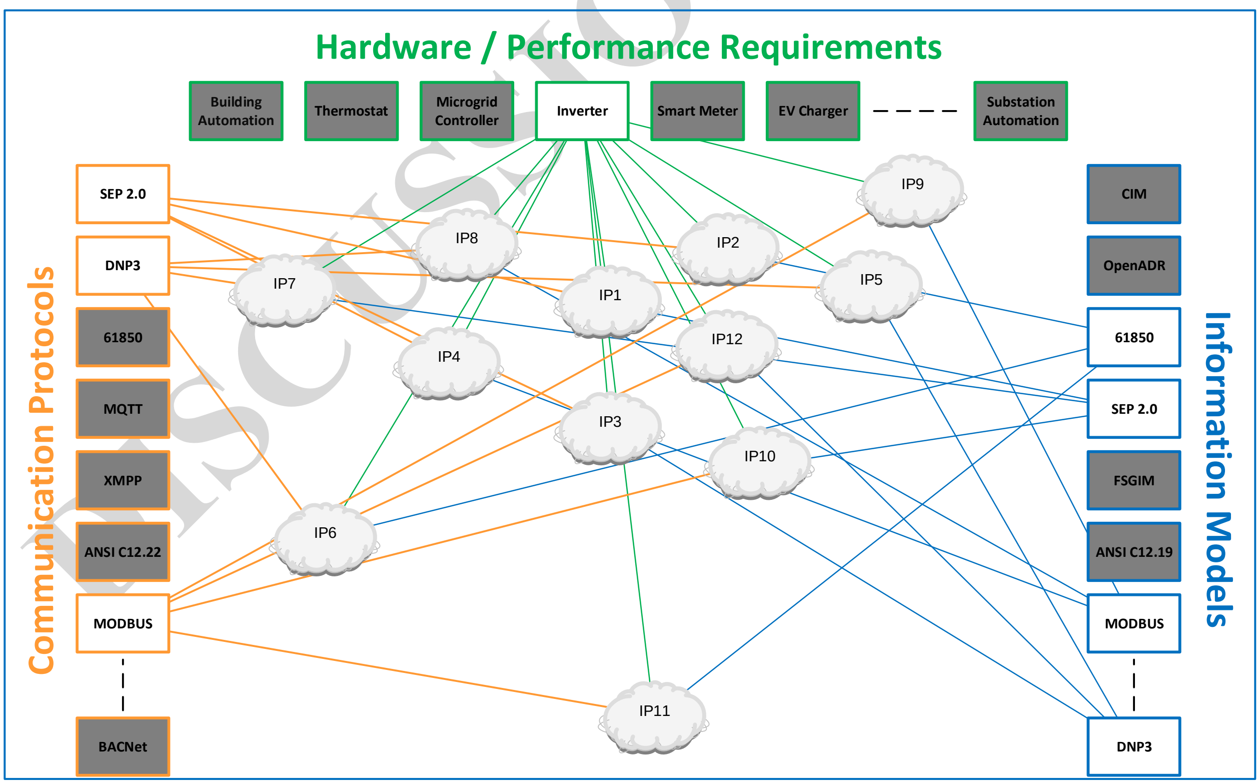

Figure 3 - Potential Implementation Combinations for IEEE 1547-2018

As discussed in **Conformance** and Interoperability Testing**6.3.1**, an inverter can be compliant to IEEE 1547 as long as it implements one of three defined communications protocols (IEEE P2030.5, IEEE 1815, or SunSpec Modbus). The standard also defines required data elements but does not specify a particular information model. Additionally, section 10 of the IEEE 1547 standard describes additional communications protocols and data models (including IEC 61850) that could also be used; the universe of implementation is therefore significantly larger. Since there are multiple allowable communication protocols and no specific required information model, there are numerous permutations of possible interoperability implementations as shown in **Figure 3**. While the inverter physical performance requirements are clear, the relatively large number of potential communication protocols and data model implementations could limit the ability to test for and certify device interoperability under the IEEE 1547 standard.

California Rule 21 also establishes rules for interconnection of inverter-based DER to the grid. While the physical specifications mirror those of IEEE 1547, Rule 21 specified IEEE P2030.5 as the required communication protocol and IEC 61850 as the required information model. The resulting combination is shown in **Figure 4**. This example demonstrates the application of an interoperability profile on existing standards by narrowing the degrees of freedom and complexity for implementing the required communications.

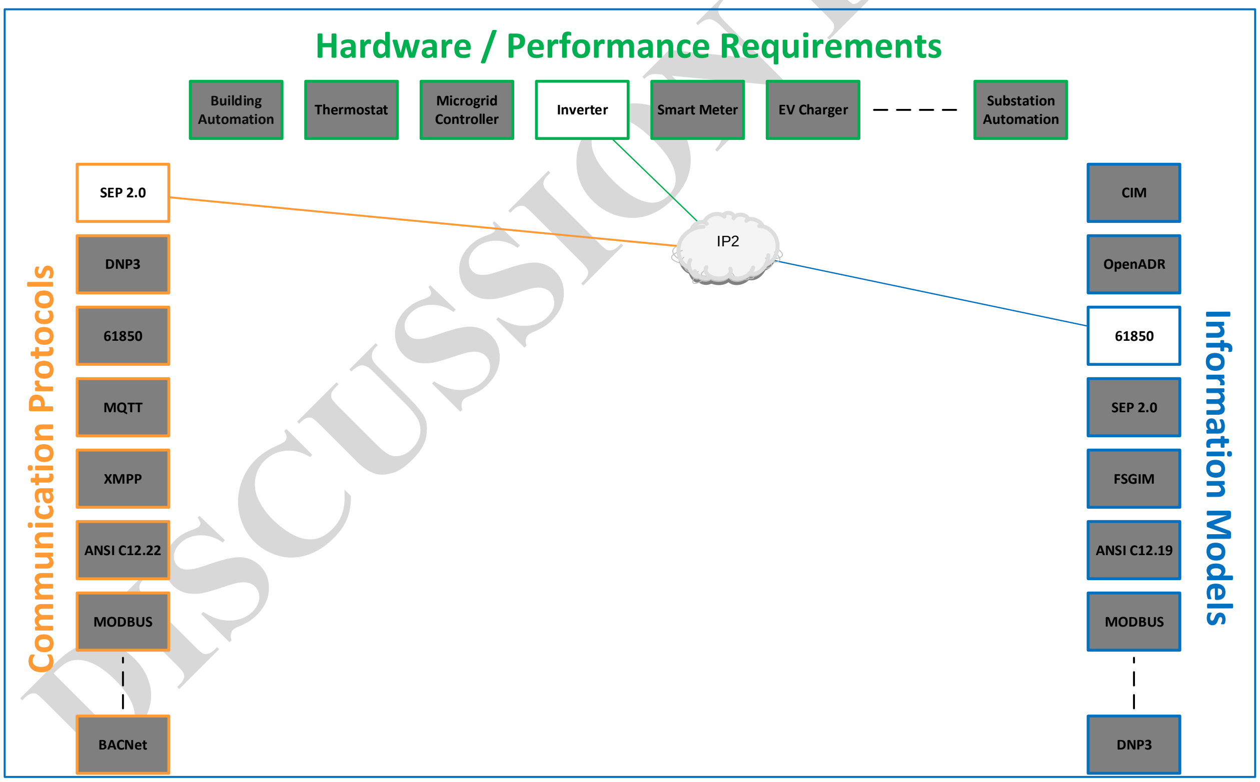

Figure 4 - California Rule 21 Implementation

Rule 21 clarified inverter interoperability requirements, and an independent testing and certification program has been formed [18] that has since been adopted as requirement by utilities and system operators in other regions of the country [19].

6.5.3 Interoperability Profiles Work Plan

One important aspect of the first *NIST Framework and Roadmap for Smart Grid Interoperability Standards* [20] was that it included a set of priority gaps that NIST worked with industry to address through collaborative activities. Interoperability Profiles are will be developed using similar industry collaborations.

The first step in the work plan is to create a list of smart grid interfaces that could potentially be developed into complete interoperability profiles. The functional requirements of candidate interfaces will be evaluated, and then will be mapped to a subset of the appropriate communications and information model standards.

Once a profile is completed, the necessary test tools will have to be developed.

6.5.4 Open Source Test Tool Development

One of the key components of the T&C process is the test harness, which is created by translating test cases into automated scripts that can be executed to evaluate interoperability function. It is usually the costly part of the test program, and requires a different skillset than traditional standards development. The test harness provides automation for the testing process which creates efficiency. Test harness developers, however, often charge high fees to use their harnesses, which creates a barrier to entry for T&C programs.

Once a complete Interoperability Profile is available, NIST will engage the smart grid community to determine the viability of developing the relevant test harness in an open source environment. Similar to open source software development, the community would be expected to develop and manage the tool. The benefit of this approach is that it would allow for broad participation and reduce barriers to entry for T&C activities. This reduced barrier to entry is, in turn, expected to enable innovation based upon Interoperability Profile specifications.

Once development of the open source test tools is complete, equipment manufacturers, customers, or independent test program operators could all have access to and benefit from the capability.

7 Appendix C — A List of Reviewed Smart Grid Interoperability Standards

The NIST Review of Smart Grid Standards for Testing and Certification Landscape Analysis [17] evaluated 240 standards drawn from multiple sources that are relevant to the smart grid. Of those 240 standards, NIST's functional categorization approach indicated 169 were relevant to interoperability. Each of the 169 standards deemed relevant to interoperability were assessed for the existence—or plan for—a testing and certification (T&C) program.

The 169 standards interoperability relevant standards are listed in **Table 2**. Included within this table are the functional categories used to identify standards as interoperability-relevant. Also included is the NIST assessment of T&C availability for each standard.

T&C programs in **Table 2** are categorized as follows:

x – an independent T&C authority (ITCA) exists for this standard
y – the ITCA program for this standard derives from requirements established in a different standard
z – 1st or 2nd party T&C programs exist for this standard
p – a T&C program is planned for this standard

This table is graphically depicted in **Figure 2**.

The full paper and methodology for this analysis, with detailed descriptions of each of the 240 standards reviewed, can be downloaded via this link: https://doi.org/10.6028/NIST.TN.2042

Table 2 – A List of Interoperability Standards Reviewed for Testing & Certification

Standard No.	Information Model	Communication	Physical Performance	Communication Mapping	Model Mapping	T&C
ANSI C12.1-2008			x			z
ANSI C12.1-2014			x			z
ANSI C12.18-2006	x	x	x			
ANSI C12.19-2008	x					
ANSI C12.19-2012	x					
ANSI C12.20-2015			x			z
ANSI C12.21-2006	x	x				
ANSI C12.22-2012	x	x				

Standard No.	Information Model	Communication	Physical Performance	Communication Mapping	Model Mapping	T&C
ANSI/ASHRAE 135-2016 (ISO 16484-5:2017)	x	x				y
ANSI/ASHRAE/NEMA 201-2016 (ISO 17800:2017)	x					
ANSI/CEA 709.1-D-2014 (ISO/IEC 14908-1:2012)		x				
ANSI/CEA 709.2-A-2006 (ISO/IEC 14908-2:2012)		x				
ANSI/CEA 709.3-R2004 (ISO/IEC 14908-3:2012)		x				
ANSI/CEA 709.4-2013		x	x			
ANSI/CEA 852-C-2014		x				
ANSI/CEA 852.1-A-2014		x				
CTA 2045		x				
IEC 60255			x			
IEC 60255-1:2009			x			
IEC 60255-24:2013		x				x
IEC 60255-26:2013			x			
IEC 60870-5-101:2003		x				x
IEC 60870-5-102:1996		x				
IEC 60870-5-103:1997		x				
IEC 60870-5-104 Ed. 2.1 b:2016		x				x
IEC 60870-6-503:2014		x				x
IEC 60870-6-702:2014		x				x
IEC 60870-6-802:2014	x					x
IEC 61000-2-2:2002+AMD1:2017+AMD2:2018			x			
IEC 61000-3-2:2018			x			
IEC 61000-4-30:2015			x			
IEC 61334-4-32:1996		x				
IEC 61334-4-41:1996		x				

Standard No.	Information Model	Communication	Physical Performance	Communication Mapping	Model Mapping	T&C
IEC 61334-4-511:2000		x				
IEC 61334-4-512:2001		x				
IEC 61334-5-1:2001		x				
IEC 61850-5:2013		x	x			
IEC 61850-6:2009+AMD1:2018		x				y
IEC 61850-7-1:2011	x	x				y
IEC 61850-7-2:2010	x	x				y
IEC 61850-7-3:2010	x					y
IEC 61850-7-4:2010(E)	x					y
IEC 61850-7-410:2012+AMD1:2015	x					
IEC 61850-7-420:2009	x					
IEC 61850-7-500:2017	x					
IEC 61850-7-510:2012	x					
IEC 61850-8-1:2011		x		x		y
IEC 61850-8-2:2018		x		x		
IEC 61850-90-1: 2010		x				
IEC 61850-90-10:2017	x					
IEC 61850-90-8:2016					x	
IEC 61850-9-2:2004		x		x		y
IEC 61850-9-2:2004 LE		x		x		y
IEC 61850-9-2:2011		x				y
IEC 61850-9-3:2016		x	x			p
IEC 61850-80-1:2016	x				x	
IEC 61850-80-3:2015		x		x		
IEC 61850-80-4:2016	x				x	
IEC 61850-90-2:2016		x		x		
IEC 61850-90-3:2016		x				
IEC 61850-90-5:2012	x	x		x	x	

Standard No.	Information Model	Communication	Physical Performance	Communication Mapping	Model Mapping	T&C
IEC 61850-90-7:2013	x					
IEC 61850-90-17:2017		x				
IEC 61851-1:2017			x			
IEC 61851-23:2014			x			y
IEC 61851-24:2014	x	x				
IEC 61869-9:2016		x				z
IEC 61968-4:2007		x				z
IEC 61968-8:2015		x				
IEC 61968-9:2013		x				
IEC 61968-11: 2013	x					p
IEC 61968-13:2008		x				p
IEC 61968-100:2013		x				
IEC 61970-301:2016	x					p
IEC 61970-401:2005		x				
IEC 61970-501:2006	x					
IEC 62053-21:2003+AMD1:2016			x			z
IEC 62053-22:2016			x			z
IEC 62053-23			x			z
IEC 62054-21			x			z
IEC 62056-3-1:2013		x				
IEC 62056-4-7:2015		x				x
IEC 62056-5-3:2017		x				x
IEC 62056-6-1:2017	x					x
IEC 62056-6-2:2017	x	x				x
IEC 62056-6-9:2016	x				x	x
IEC 62056-7-3:2017		x				x
IEC 62056-7-5:2016		x				x
IEC 62056-7-6:2013		x				x
IEC 62056-8-20:2016		x				x

Standard No.	Information Model	Communication	Physical Performance	Communication Mapping	Model Mapping	T&C
IEC 62056-8-3:2013		x				x
IEC 62056-8-5:2017		x				x
IEC 62056-8-6:2017		x				x
IEC 62056-9-1:2016		x				x
IEC 62056-9-7:2013		x				
IEC 62056-42:2002		x				
IEC 62056-46:2002		x				
IEC 62282-2:2012			x			
IEC 62325-301:2014	x					
IEC 62325-351:2016	x					
IEC 62325-451:2017	x					
IEC 62325-503:2014		x				
IEC 62357-200:2015	x	x				
IEC 62541-3:2015	x					
IEC 62541-4:2015		x				
IEC 62541-5:2015	x					
IEC 62541-6 :2015					x	
IEC 62541-8:2015	x	x				
IEC 62541-9:2015	x	x				
IEC 62541-10:2015	x					
IEC 62541-13:2015	x					
IEC 62541-100:2015	x	x				
IEC 62689-2:2016			x			
IEC 62689-100:2016	x				x	

Standard No.	Information Model	Communication	Physical Performance	Communication Mapping	Model Mapping	T&C
IEEE 1377-2012 (ANSI C12.19)	x					
IEEE 1451.0-2007	x	x				
IEEE 1451.1-1999		x				
IEEE 1451.4-2004		x				
IEEE 1451.5-2007		x				
IEEE 1547-2018			x			y
IEEE 1547.3-2007	x	x				
IEEE 1588-2008		x	x			z
IEEE 1701-2011 (ANSI C12.18)	x	x				
IEEE 1702-2011 (ANSI C12.21)	x	x				
IEEE 1815-2010	x	x				z
IEEE 1815-2012	x	x				z
IEEE 1815.1-2015/Cor1-2016	x	x		x	x	
IEEE 1901-2010		x				
IEEE 1901.2-2013/IEEE Std 1901.2a-2015 (Amendment to IEEE Std 1901.2-2013)		x				
IEEE 2030-2011		x				
IEEE 2030.5-2013	x	x				z
IEEE 2030.7-2017		x	x			
IEEE C37.118.1-2011			x			
IEEE C37.118.1a-2014			x			x
IEEE C37.118.2-2011		x				
IEEE C37.238-2011		x	x			
IEEE C37.238-2017		x	x			p
IEEE C37.239-2010		x				

Standard No.	Information Model	Communication	Physical Performance	Communication Mapping	Model Mapping	T&C
IETF RFC-6272-2011		x				
ISO 15118-2:2014		x				
ISO 15118-3:2015		x				
ISO 15118-6		x				
ISO 15118-8:2018		x				
ISO/IEC 14908-1:2012		x				
ISO/IEC 14908-2:2012		x				
ISO/IEC 14908-4:2012		x				
ISO/IEC 15067.3:2012	x	x				
ITU T-G.9903		x				
ITU T-G.9960-2011		x				
ITU T-G.9972:2010		x				
MultiSpeak Security-V1.0		x		x		x
MultiSpeak V3.0:2015	x	x				x
NAESB REQ.21	x	x				x
NAESB RMQ.18	x					
NAESB RMQ.26	x	x				p
NAESB WEQ.19:2010	x					
NEMA SG-AMI 1-2009 (R2015)			x			z
NISTIR 7761-2011		x				
NISTIR 7862-2012		x				
NISTIR 7943-2013		x		x		
OASIS EMIX V1.0:2012	x					
OASIS EI-2014 V1.0	x	x				
OASIS WS Calendar V1.0	x					
OPC-UA	x	x		x	x	z
OGC-GML	x	x				

Standard No.	Information Model	Communication	Physical Performance	Communication Mapping	Model Mapping	T&C
OpenADR 2.0 Profile A OpenADR 2.0 Profile B	x	x				x
SAE J1772-2017		x	x			
SAE J2836-Use-Cases-(1-3) SAE J2836/1		x				
SAE J2847/1:2010		x				

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