2023 White Paper

DER Interconnection Standards and Certifications in North America

Overview and Status Update

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INTRODUCTION

There are a number of existing requirements – enforced by a range of standards, regulations, laws, certifications, and utility protocols – that govern the grid interconnection and operation of distributed energy resources (DER) in North America. These requirements are in a relative state of flux, and ultimately aim to incorporate grid-supportive DER into mainstream use. Table 1 provides an overview of DER requirement types, as well as representative examples with associated scope. Meanwhile, Figure 1 depicts the quilt of local, state, and federal level interconnection rules and guidelines that are intended to enable the safe, reliable, consistent, and cost-effective integration of DER into the distribution and bulk power systems.

Individual utility generator connection agreements, state interconnection rules, national mandates, and certification tests for distribution-connected DER are all intended to be coordinated, and to ultimately reference IEEE 1547 standards (where adopted) as well as equipment performance and safety certification standards, such as UL 1741. Specific to DER, UL 1741 is meant to align with test protocols stipulated in IEEE 1547.1, while IEEE 1547 requirements aim to provide balance between distribution voltage regulation/protection and bulk system reliability needs.

Table 1. *DER requirement types and examples*

TYPE	EXAMPLE	SCOPE (SPECIFIC TO DER)
Broad Standards	IEEE Std. 1547	Interconnection of DG and storage of any technology (inverter-based resources, synchronous machines, etc.)
Equipment Certifications	UL 1741	DER equipment design and operation (tied to standards and/or state requirements)
State/PUC Rules	CA Rule 21, HI Rule 14H, NY SIR	Distribution-connected generation with smart inverters
Federal/State Code	NFPA 70, National Electric Code	Premises wiring
Individual Utility	Interconnection requirements	Specific customer connection

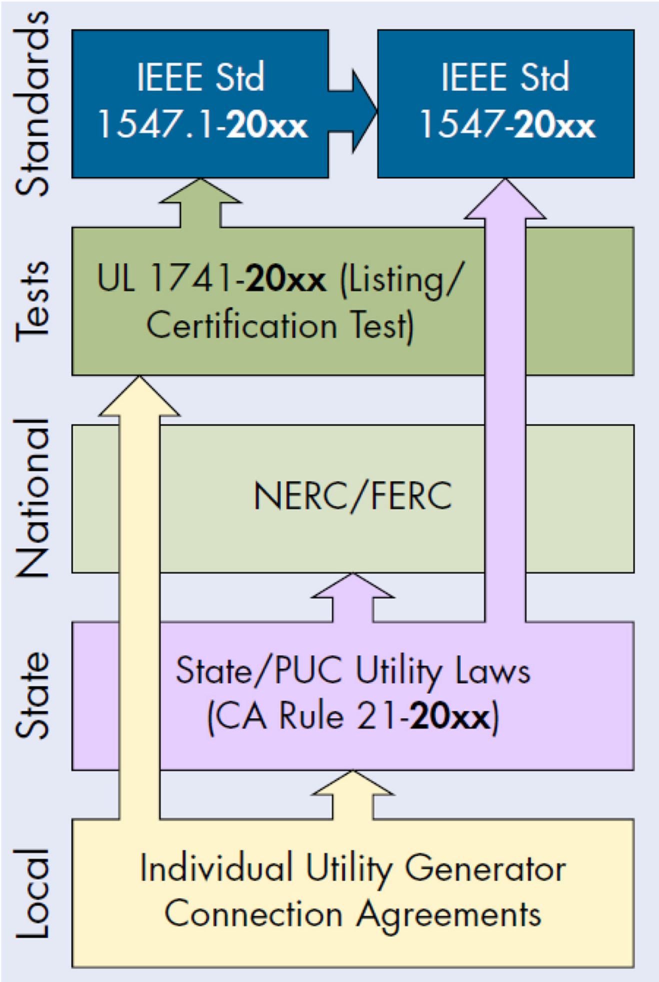

Figure 1. *Illustration of the standards and certification landscape*

In some cases, the advancement and harmonization of interconnection requirements is also being driven at the state level, in part due to the slow pace of standards development activities. For instance, the formulation and phased implementation of smart inverter functions and capabilities in California's Electric Rule 21, the state's tariff governing DER interconnection, operation, and metering requirements, is credited for driving manufacturing equipment changes. Rule 21 has also helped induce the creation of new functional specifications and validating test protocols by Nationally Recognized Testing Laboratories (NRTLs)[1] such as Underwriter Laboratories (UL) that have since been codified in IEEE 1547.1.[2]

1 NRTLs are organizations that are recognized by the U.S. Occupational Safety and Health Administration (OSHA) as having the qualifications to perform safety testing and equipment certification. Example NRTLs include UL, Canadian Standards Association Group Testing and Certification Inc. (CSA), TÜV, and others.

2 As described below, 1547.1 stipulates the testing criteria to meet the requirements expressed in IEEE Std. 1547-2018.

The increasingly complex standards and certifications landscape is prompting questions from electric utilities about how to move forward in supporting the greater grid integration of DER. Key questions, for example, surround optimal approaches for enforcing DER grid support requirements and managing smart inverter settings, strategies for selecting standardized communication protocols at the DER interface, and methods for enabling vehicle-to-grid (V2G) arrangements.

This report provides an abbreviated primer on the standards and certifications that are relevant to DER interconnection in an effort to help inform utility thinking on DER interconnection compliance pathways and considerations. It initially describes the family of IEEE 1547 standards, guides, and recommended practices, which collectively dictate the requirements and considerations for DER interconnection in North America. Certification standards and their relationship with IEEE 1547 are also explored, as are additional issues such as those germane to V2G. Ultimately, through definition and clarification, content aims to help improve utility interconnection process efficiencies and support manufacturer efforts to develop compliant products.

DER INTERCONNECTION STANDARDS

The backbone of DER grid interconnection and interoperability in North America is the IEEE 1547 family of standards, guides, and recommended practices (see Table 2). Collectively, these documents, developed through ongoing multistakeholder working group activities, lay the foundation for integrating solar PV, energy storage, and other distributed generation onto the distribution system.

Importantly, the *standards* within the IEEE 1547 corpus (1547-2018 and 1547.1) are voluntary. As a result, the distribution operating company or regulatory authority (designated in IEEE as Authority Governing Interconnection Requirements [AGIR][3]) may, for example, adopt the 1547-2018 standard in whole as general reference, per clause with exceptions, or forego adoption and fully specify alternative DER interconnection requirements. Formal incorporation into state rules and utility practices in any of these forms may be imposed through regulation or voluntarily by the system operator through disclosure and enforcement.

3 The AGIR is the entity responsible for defining, codifying, communicating, administrating, and enforcing the policies and procedures for allowing electrical interconnection of DER to the Area EPS.

What follows are brief descriptions of some of the individual components of the IEEE 1547 document series, including a snapshot of several key industry working group efforts, as of end-2023. The interrelationship between IEEE 1547 and its bulk system analog for inverter-based resources (IBRs), IEEE Std. 2800-2022, is also illustrated.

IEEE STD. 1547-2018 DEFINITION OF DER

A source of electric power that is not directly connected to a bulk power system. It includes both generators and energy storage technologies capable of exporting active power to an electric power system (EPS), as well as an interconnection system or a supplemental DER device that is necessary for compliance with the standard.

IEEE Std. 1547-2018/IEEE Std. 1547a-2020

DER Interconnection and Interoperability Standard

IEEE Std. 1547-2018 focuses on the technical criteria and requirements for interconnection and interoperability between the power system and DER. It is broadly applicable to all DER connected to the distribution grid, irrespective of technology type (e.g., synchronous machines, induction machines, or static power inverters/converters), size, and interconnection voltage level. Established requirements encompass performance, operation, testing, and safety considerations relevant to DER interconnection. The standard's multiple clauses specifically cover issues spanning reactive power capability and voltage/power control requirements, response to area EPS abnormal conditions, power quality, islanding, DER on distribution secondary and spot networks, information models and protocols, among others.

When originally conceived in 2003, the standard espoused a "do no harm" position assuming a low penetration of DER. However, given the unforeseen growth of DER, successive amendments and full-blown revision have removed restrictions against DER from actively providing grid support, such as voltage regulation. Consequently, in its current form, the standard provides guidance to system operators for utilizing DER grid supportive functions, stipulating performance requirements, their default settings, level of interoperability, and range of adjustability.

It, for example, establishes a framework for assigning appropriate DER disturbance ride-through performance requirements,[4] and formulates standardized operating performance categories that specify the required technical capabilities and settings for a DER under normal and abnormal operating conditions. Normal operating performance categories encompassing reactive power capability and associated control functions are designated by alphabetical characters, Category A and B, and abnormal grid voltage and frequency condition operating performance categories are designated by Roman numerals, Category I, II, and III. This approach is intended to give the AGIR latitude to assign performance categories to specific groups of DER based on technical conditions such as DER technology, application, location, or (expected) penetration levels.[5] (To simplify the adoption of IEEE Std. 1547-2018, an amendment to the standard, 1547a-2020 widens the ranges of allowable abnormal voltage trip clearing time settings for DER in abnormal operating performance Category III.)

For more information about IEEE Std. 1547-2018, its contents, and current scope, please see [1] and [2]. Of note, however, is that a revision of IEEE Std. 1547-2018 is underway that intends to incorporate updates from previous errata, and address other issues (ambiguities and gaps) identified by the industry. Eight working groups and two task forces are engaged in this effort, which is expected to be completed in 2025.

IEEE Std. 1547.1-2020

Conformance Test Procedures

IEEE Std. 1547.1-2020 specifies the type, production, commissioning, and periodic tests and evaluations that must be performed to verify that DER connected to the EPS conform to IEEE Std. 1547-2018.[6] Used by reference in product certification, 1547.1 describes testing criteria and procedures to meet the requirements described in 1547-2018. Nationally Recognized Test Laboratories and other stakeholders lever-

4 Functions for meeting bulk system disturbance ride-through requirements may be needed to prevent widespread voltage or frequency tripping of DER that can negatively impact bulk system reliability when interconnection-wide DER penetration levels reach a significant level.

5 The performance categories framework is flexible enough so that non-technical issues such as societal benefits of certain DER and broader impacts of DER on the environment, emissions, and sustainability may also be considered by an AGIR.

6 Conformance may be established through a combination of type, production, design evaluation (desk-study and on-site), commissioning, and periodic tests, as well as DER design and installation evaluations. IEEE Std. 1547.1-2020 includes a description of normative test signals and ramp functions that can be used in conducting some tests.

age IEEE 1547.1 to create test standards for certifying equipment. (This is typically done via contributions to a consensus body, known as a Standards Technology Panel, or STP, that develops new standards.) Test standards, which include procedures that can provide repeatable results and a degree of flexibility to accommodate a variety of DER technologies and functions, include stipulations for complying with IEEE 1547-2018 requirements along with other safety requirements. [3]

IEEE 1547 Guides and Recommended Practices

An evolving collection of supporting guides and recommended practices are being continuously developed, maintained, and elaborated upon by IEEE standards working groups and committees to help facilitate the adoption and utilization of IEEE Std. 1547-2018 and address other interconnection and integration challenges. While IEEE 1547 standards specify mandatory requirements (if adopted), the associated recommended practices and guides, labeled 1547.x, offer comment for optional consideration (see callout). These documents address (or are in the process of addressing) a range of topics relevant to cybersecurity, microgrids, interconnection in secondary networks, the administration of system impact studies, energy storage interconnection, and DER gateway platforms. They have been newly created, reviewed and updated, sometimes withdrawn, over the past two decades as the DER industry has matured.

***Standards* (“shall”): Mandatory requirements.**

***Recommended Practices* (“should”): Procedures and positions preferred by IEEE.**

***Guides* (“may”): Alternative approaches to good practices are suggested, but no clear-cut recommendations are made. [4]**

Table 2 reports the status and designation of the various 1547 standards, guides, and practices. Note that the “P” in some of the titles indicates that development is in process. Table 3 summarizes active efforts to revise or create several of the draft guides. Revisions to P1547.2 Draft Guide for Application of IEEE Std. 1547-2018 and P1547.3 *Draft Guide for Cybersecurity of DER Interconnected with EPS* are nearly complete. Meanwhile, work recently kicked off to develop a new guide describing grid gateway platforms, P1547.10.

COMMUNICATION PROTOCOLS

Compliance with IEEE 1547-2018 requires communication standardization at the local DER interface. The idea is that once communication networks are deployed, utilities or aggregators can communicate through this interface to monitor, control, and exchange information with DER. This standardization also avoids potential communication challenges if a vendor opts to stop supporting the DER interface or goes out of business. To this end, certified DER must support at least one of three named communication protocols: IEEE 2030.5, IEEE 1815-DNP3 using Application Note 2018-001, and/or SunSpec Modbus (see sidebar) [3].

Historically, most smaller scale commercial DER products have been certified to the SunSpec Modbus protocol, while a minority have been produced with IEEE 1815-DNP3 using Application Note 2018-001 and 2030.5 capabilities [3] [5]. However, there is growth in the other domains. Recent updates to California Rule 21 have adopted IEEE 2030.5 as the default application-level protocol for connection between utilities and aggregators,[7] thereby causing an uptick in 2030.5-compliant vendor products. Note, though, that California Rule 21 focuses on the aggregator-to-utility interface and therefore does not include a standardized interface (local, physical port) like IEEE 1547-2018. Instead Rule 21 focuses on the remote enterprise server’s interface, allowing communication at the device level to be proprietary.

It remains to be seen how industry standard activities will evolve with respect to communication protocols. EPRI will continue to track these trends through [7]. Interoperability is expected to remain highly relevant as utilities ramp up their activities to integrate DER, as well as deploy DER management systems (DERMS) and microgrids. Modern interoperability and integration standards are robust, however even the most thoroughly defined standards are limited by scope [3]. IEEE Std. 1547-2018 requires standardized protocol for the DER interface, but DER management (an optional capability) presents challenges including protocol translation, data management, and secure back-haul; it may also include supplemental hardware and changes to distribution operations. The recently kicked-off IEEE P1547.10 working group aspires to address many of these challenges.

7 IEEE 2030.5 compliance is required in California for all inverter-based resources. However, communications may be provided via a gateway (or enterprise/server), and not necessarily required to be an integral function of the inverter.

Table 2. IEEE 1547 family of standards, guides, and recommended practices

PUBLICATION AND YEAR (TARGET YEAR)	TITLE	CATEGORY	STATUS
IEEE 1547-2018 IEEE 1547a-2020	IEEE Standard for Interconnection and Interoperability of DER with Associated EPS Interfaces	Standard	Active[1]
IEEE 1547.1-2020	IEEE Standard Conformance Test Procedures for Equipment Interconnecting DER with EPS and Associated Interfaces	Standard	Active[2]
IEEE P1547.2-2023	Draft Guide for Application of IEEE Std. 1547-2018TM	Guide	Finalization in progress
IEEE P1547.3-2023	Draft Guide for Cybersecurity of DER Interconnected with EPS	Guide	Finalization in progress
IEEE 1547.4-2011	Guide for Design, Operation, and Integration of DER Island Systems with EPS	Guide	Expired[3, 4]
IEEE P1547.5	Considerations for DER > 10 MVA	NA	Withdrawn
IEEE 1547.6-2011	Recommended Practice for Interconnecting DER in Secondary Networks	Recommended Practice	Expired[3, 5]
IEEE 1547.7-2013	Guide for Conducting Distribution Impact Studies for DER Interconnection	Guide	Expiring 2023[3, 5]
IEEE P1547.8	Expanded Use of IEEE 1547	NA	Withdrawn
IEEE 1547.9-2022	Guide for using IEEE 1547 for Interconnecting Energy Storage DER with EPS	Guide	Active
IEEE P1547.10-202x	Recommended Practice for DER Gateway Platforms	Recommended Practice	New Standard; WG Active

Notes:

1. Revision underway; target completion date: 2025.
2. Amendment started; target completion date: 2026.
3. All approved IEEE standards, guides, and recommended practices must undergo a revision process within 10 years from their approval year to retain active status.
4. Revision kickoff October 2023; target completion date: 2025.
5. Candidate for revision.

Table 3. Descriptions of upcoming IEEE 1547 guides and recommended practices

DRAFT GUIDE / RECOMMENDED PRACTICE	SUMMARY DESCRIPTION
IEEE P1547.2	P1547.2 is an application guide which closely follows the topics and clauses covered in 1547-2018, emphasizing their context, background, and potential cause(s) for concern (i.e., from DER grid impact) to help system operators practically address DER integration the tasks.
IEEE P1547.3	DER constitute a unique asset class that presents potential cybersecurity vulnerabilities and threats. Although cybersecurity requirements have been defined by standard development organizations, they are not specific to DER. Requirements, meanwhile, are not explicitly spelled out in IEEE Std. 1547-2018. P1547.3 seeks to address these issues by providing cybersecurity guidelines that can be harmonized with the IEEE standard.
IEEE P1547.10	IEEE Std. 1547-2018 requires an open data interface to be present at the DER device but goes no further on how to integrate and manage DER devices. P1547.10 is intended to address the two-way flow of data between DER and external management entities. It aims to specify DER interface options (local or distributed platform, for legacy or intelligent DER), functions and communications, operational procedures, and data collection options.

CHARACTERIZING 1547-COMPLIANT COMMUNICATION PROTOCOLS [3]

IEEE 2030.5 is an application layer specification formerly referred to as ***SEP 2.0*** (Smart Energy Profile 2.0). It was developed as a communication protocol to securely integrate customer smart devices – including smart loads, electric vehicles, and DER – into the smart grid. The protocol reduces architectural challenges by using the widely used Internet Protocol (IP) at the internet layer and supporting a variety of protocols at the physical layer (e.g., Ethernet, Wi-Fi, powerline communications, and different low-power radio technologies). IEEE 2030.5 has a dedicated function set for management of DER, including solar and energy storage systems. Its information model is derived from IEC 61850-7-420 and the Common Functions for Smart Inverter.

SunSpec Modbus uses the Modbus protocol but specifies a standardized point map for interoperability.[8] SunSpec has different point maps – also called models – for inverters, meters, energy storage, panels, and more. The functionality defined in the inverter models is inspired by IEC 61850 and the Common Functions for Smart Inverters [6]. The information models are designed to include detailed DER internal information (battery information, cell voltage, etc.) as well as higher-level grid controls to allow a site management system, owner, or utility to manage the system as a single DER. This simplifies the integration of different components of large, multi-component DER, but also allows the grid to control the DER.

IEEE 1815, also known as ***DNP3***, was created to standardize communications between substation equipment, RTUs, IECs, and control systems. The protocol is largely used in utility and energy industries including water, wastewater, transportation, and oil/gas. It was created in 1993. When deployed in DER applications, a complimentary application note – DNP Application Note AN2018-001 – can be used to provide standardization to the DNP point maps. This application note is largely based on work in IEC-61850. DNP3 is considered somewhat of a step forward from Modbus because it supports security features for communication to devices over long distances. It preserves chains of events, event storage, delivery confirmation, and event timestamping—none of which are inherent to the Modbus protocol (but can be accomplished via Modbus). It also supports event reporting and storing information collected for later transmission. Generally, Modbus is viewed as preferrable for administering communications within a plant, while DNP3 is preferable for managing communications remotely to a plant. This is largely because of the security layer that is built into DNP3 (though Modbus can be encrypted).

8 Modbus may be serial (RTU) or ethernet (TCP). In addition, Modbus is still frequently used in local plant controls for inverter to controller communications, etc. However, it is not often used for control and communication "beyond the fence," as there is no inherent security layer in the protocol. This makes servicing the equipment on-site easier, but care should be taken to prevent physical access to such data circuits. Modbus can be encrypted and/or transmitted over VPN to enhance security.

IEEE Std. 2800-2022

IBR Interconnection and Interoperability Standard for Transmission

IEEE 2800-2022 contains uniform technical minimum requirements for the interconnection, capability, and performance of inverter-based resources (IBRs) interconnecting with transmission and sub-transmission systems. Performance specifications are provided for voltage and frequency ride-through, active and reactive power control, dynamic active power support and dynamic active voltage support respectively under abnormal frequency and voltage conditions, power quality, negative sequence current injection, system protection, among others.[9] A recommended test and verification practice, P2800.2, is in development to support the certification of inverter-based equipment to IEEE 2800 capabilities.[10]

9 IEEE 2800 also applies to isolated IBRs that are interconnected to an ac transmission system via dedicated voltage source converter high-voltage direct current (VSC-HVDC) transmission facilities; in these cases, the standard applies to the combination of the isolated IBRs and the VSC-HVDC facility, and not to an isolated IBR on its own.

10 For more information or to get involved in the development of P2800.2, see the working group web page: https://sagroups.ieee.org/2800-2/.

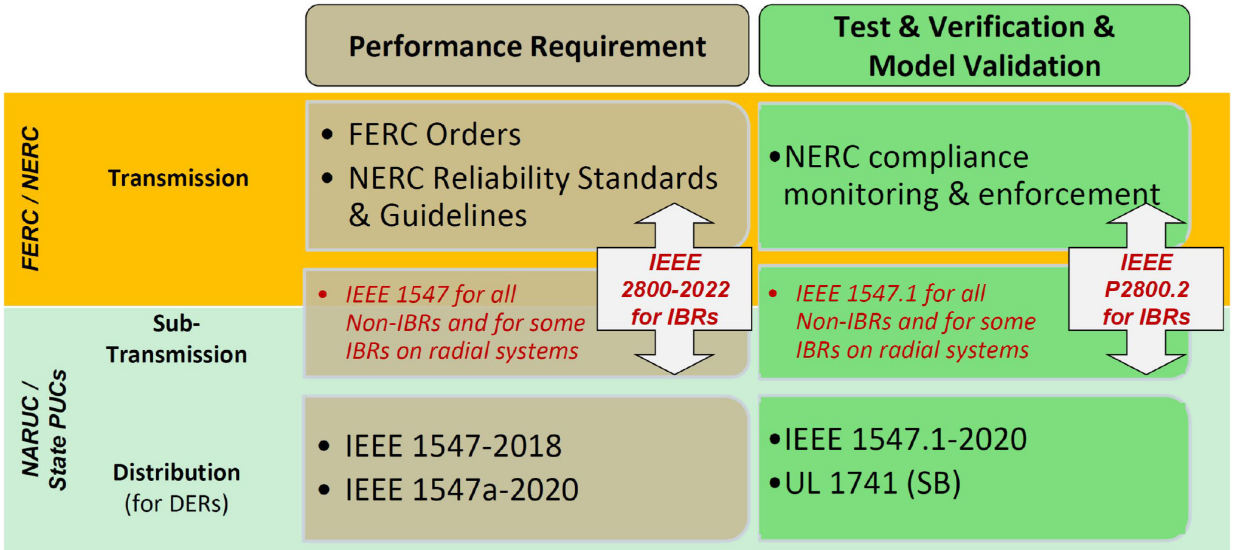

Figure 2. *Standards and certifications for DER by electric system class and jurisdiction*

Figure 2 illustrates how IEEE Std. 2800 applies to bulk system IBRs in a general way that is similar to IEEE Std. 1547-2018's orchestration of DER at distribution voltages. Specifically, it indicates the authority overseeing the different grid domains (transmission, sub-transmission, and distribution) and demarcates where various standards, guidelines, and certifications apply for ensuring and verifying compliance with relevant performance requirements. Additionally, it highlights the technology agnostic nature of IEEE Std. 1547-2018, wherein embedded requirements apply to both inverter-based as well as rotating technologies. Per the figure, inverter-based projects seeking to interconnect to looped sub-transmission are expected to reference requirements outlined in IEEE Std. 2800. However, IBRs seeking to interconnect to *radial sub-transmission networks* (red text in Figure 2) may reference either IEEE Std. 2800 or IEEE 1547-2018, AGIR discretion.

Certification Standards

Underwriters Laboratory (UL) 1741

UL 1741 serves as the certification standard for inverters, converters, controllers, and interconnection system equipment for use with DER. This certification standard defines safety and performance evaluation procedures to be used by NRTLs to test and certify devices. Almost a decade of regulatory action, industry developments, and working group coordination has created a chain of documentation to reliably field and integrate grid support interactive DER.

Figure 3 depicts the history and relationship between IEEE 1547 and UL 1741. It illustrates how interconnection performance requirements, standards which form the basis of grid paralleling DER capabilities, inform Conformance Specifications, which describe test and evaluation procedures and referenced by certifying standards.

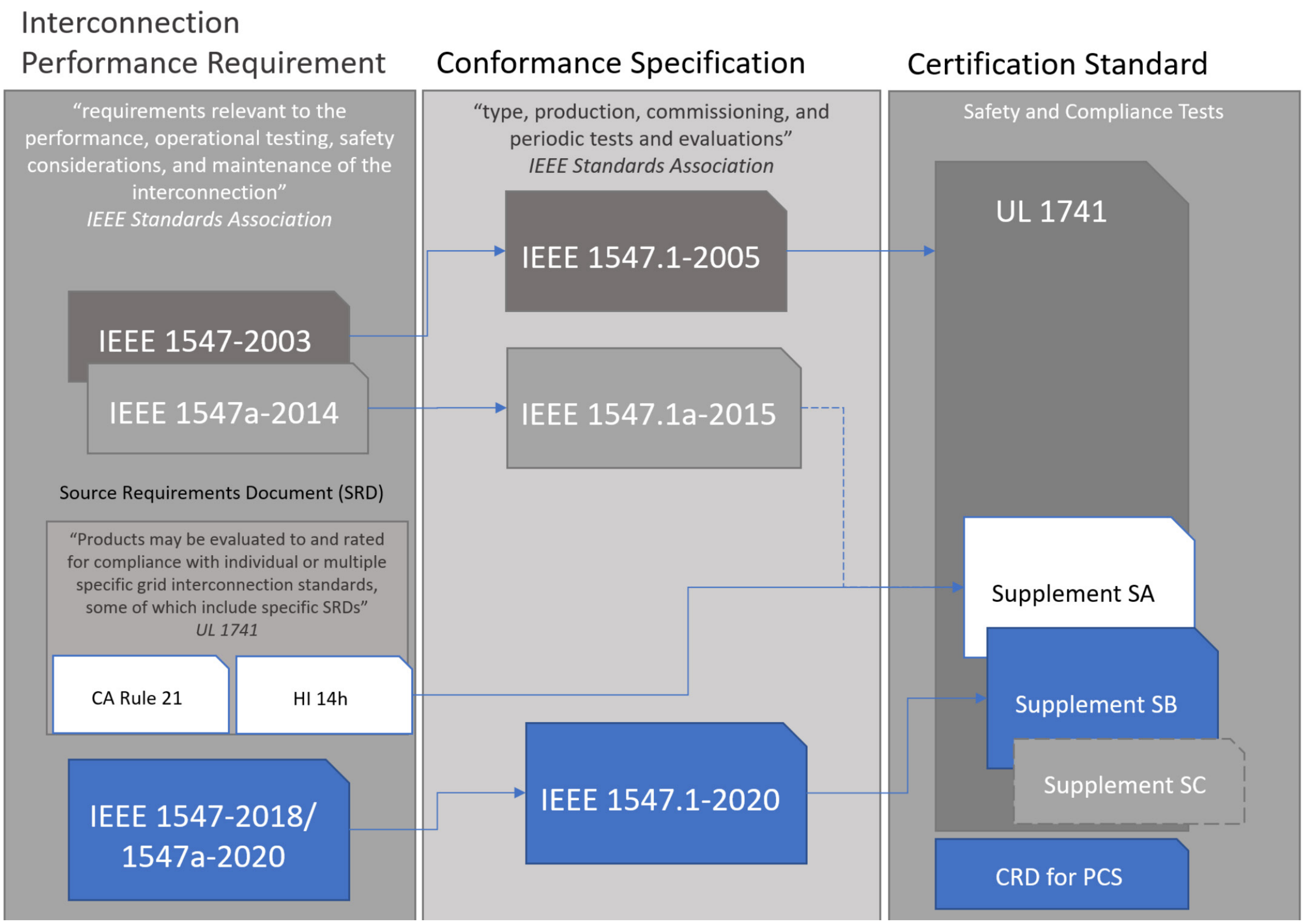

Figure 3. *The relationship between performance standards and certification for IEEE 1547.*

A certification mechanism for advanced grid support capabilities, such as *voltage ride through* and *Volt/VAR control mode*, were not available until UL 1741 Supplement SA was introduced. This supplement, an add-on to UL 1741, outlines tests for validating compliance for grid support utility interactive inverters and relies on Source Requirements Documents (SRDs).[11] The implication is that 1741 SA-compliant devices may be more narrowly certified to non-uniform performance requirements that are specified by the SRDs used for the certification. Supplement SB, released after Supplement SA, references IEEE Std. 1547.1-2020 to standardize certification and ensure testing covers the full range of the allowable settings required by IEEE Std. 1547-2018. In addition, Supplement SB includes a number of additional type tests for bringing DER into full compliance, signaling greater desire for defined grid interactive capabilities. Table 4 itemizes the tests included in Supplement SB compared with Supplement SA. Note: nuances associated with power control systems, such as charge/discharge management and PCC power flow limitations, are not covered.

Figure 3 indicates additional attachments to the UL 1741 certification standard, each of which is further described below. Supplement SC, under development, is intended to bring a focus to certifying grid interactive Bi-directional Electric Vehicle Supply Equipment (BEVSE). Meanwhile, the Conformance Requirement Decision for Power Control Systems (CRD for PCS) has recently been developed to certify systems that can sense and control the output of both generation sources and energy storage systems.

11 An SRD is a reference document used alongside UL 1741 SA certification that specifies certain performance requirements. California Rule 21 and Hawaii Rule 14h developed SRDs to support certification specific to their grid architectures and designs. Other unique SRDs may be similarly developed to stipulate UL 1741 SA certification.

Table 4. UL 1741 SA vs SB test descriptions.

UL 1741 SA SPECIFIC REQUIREMENTS AND TESTS FOR GRID SUPPORT UTILITY INTERACTIVE INVERTERS	
SA8	Anti-Islanding Protection
SA9	Low/High Voltage Ride Through
SA10	Low/High Frequency Ride Through
SA11	Ramp Rate / Soft Start
SA12	Specified Power Factor
SA13	Volt/VAR Mode
SA14	Frequency-Watt (Optional)
SA15	Volt-Watt (Optional)
SA16	Ratings for GSUI Inverters/Controllers
SA17	Disable Permit Service (Optional)
SA18	Limit Active Power (Optional)

UL 1741 SB TYPE TESTS	
Temperature Stability	
Voltage Disturbances	Overvoltage Trip
	Undervoltage Trip
	Low/High Voltage Ride Through
Frequency Disturbances	Low/High Frequency Ride Through
	Voltage Phase-Angle Change RT
	Protection from Radiated EMI
	Surge Withstand Performance Test
Unintentional Islanding	Balanced Generation to Load Test
	Powerline conducted permissive signal Test
	Reverse or min import active-power flow
Voltage Regulation	Constant Power Factor Test
	Volt-VAR Test
	Volt-VAR with autonomously adjust Vref Test
	Volt VAR imbalanced grid Test
	Watt VAR Mode Test
	Constant Reactive VAR Mode Test
	Volt-Watt Test
Frequency Support	Frequency-Watt
Test for prioritization of DER responses	
Limitation of overvoltage contribution	GFOV Test (Optional)
	LROV test
Interoperability Tests	Configuration
	Monitoring
	Management
	Specific Protocol Mappings
	SunSpec Modbus
	IEEE 2030.5
	DNP3

Note: *The core certification standard UL 1741 includes many additional electrical and mechanical safety requirements.*

UL 1741 CRD for PCS

Several years ago, Underwriters Laboratories (UL) formed a task group to develop definitions, as well as test and certification criteria for a Power Control System (PCS) as an extension of the UL 1741 standard. The UL process for making such additions is called a Certification Requirements Decision (CRD). UL 1741 CRD for PCS defines a PCS as a control function that manages the output from generation sources or energy storage devices based on one or more current sensors situated at locations that may be remote from the generation or energy storage devices (see Figure 4). It is, in other words, a controller that resides at DER sites, and can support a number of use cases related to the integration of behind-the-meter DER.

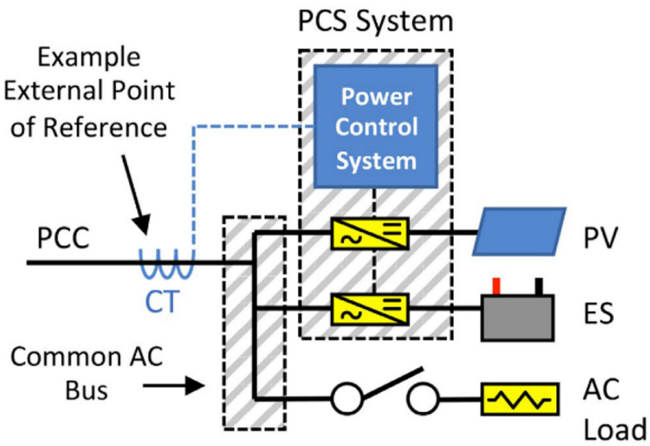

Figure 4. *Example arrangement with AC-coupled PV plus storage system with PCS*

The CRD for PCS introduces optional tests, summarized in Figure 5, that can be used to assess a set of PCS functionalities not previously addressed in the UL 1741 standard. Overall, the new test specification addresses specific grid- and National Electric Code-related conditions that exist when distributed generation, storage, and/or load are deployed together. These conditions include export limiting and assurance of net energy metering (NEM) integrity as well as thermal limitations of secondary conductors and busbars.

For utilities reviewing energy storage and hybrid DER applications, PCS capabilities can be cited to help address interconnection issues [9]. The California Energy Commission (CEC) Approved Equipment List, a widely used reference in the U.S., includes a growing list of certified PCS products.

Typically, CRDs are temporary measures that are enforced while working groups establish how to integrate them (i.e., their testing requirements) into certification standards.

As of this writing, the CRD for PCS has not been formally incorporated into UL 1741 – it was not included in the recent release of the certification standard's 3rd edition (which added Supplement SB) – and the timeline for doing so is unclear. In the meantime, It is likely that the CRD for PCS will continue to serve as the means for certifying power control systems.[12]

For more details regarding PCS for DER and the role of CRD testing, please see [9] and [10].

DOWNSTREAM: INVERTER CERTIFICATION AND ITS IMPACT ON DER INTEGRATION

As introduced above, the CEC certified equipment list is heavily leveraged by interconnection programs across the U.S. The actively managed list represents photovoltaic, inverter, and PCS equipment that is certified to be integrated into electric networks in California. But given the California's large DER market, the CEC list is representative of the equipment that system operators in other jurisdictions are likely to see in project designs and system commissioning. As of November 2023, 40% of the "Grid Support Solar Inverter" included on the CEC list consisted of UL 1741 SB devices, while 60% was composed of SA certified devices.

12 **Note:** Generally, UL 1741 is a test "to" the IEEE 1547 standard, and it is expected that IEEE 1547 will eventually document PCS requirements. In some cases where there is stakeholder demand, UL 1741 requirements are developed ahead of the IEEE 1547 standard. The CRD for PCS is one such example; it was developed in response to concerns raised by stakeholders in California and Hawaii over high DER penetrations and the need to export-limit new interconnections. In general, EPRI's preference is for IEEE to act first, and for UL tests to follow the IEEE standard. This chronology take advantage of the broader sets of people and perspectives involved in 1547 development.

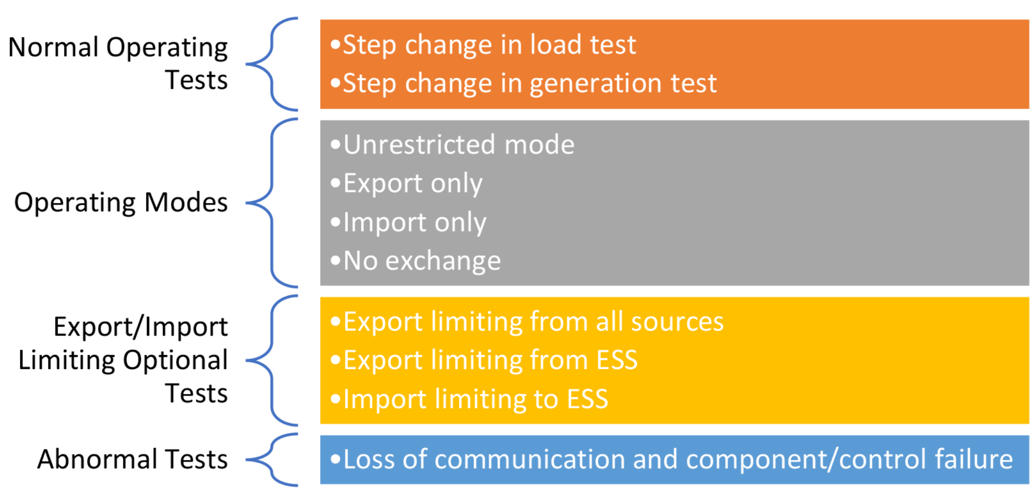

Figure 5. *CRD for PCS tests [8].*

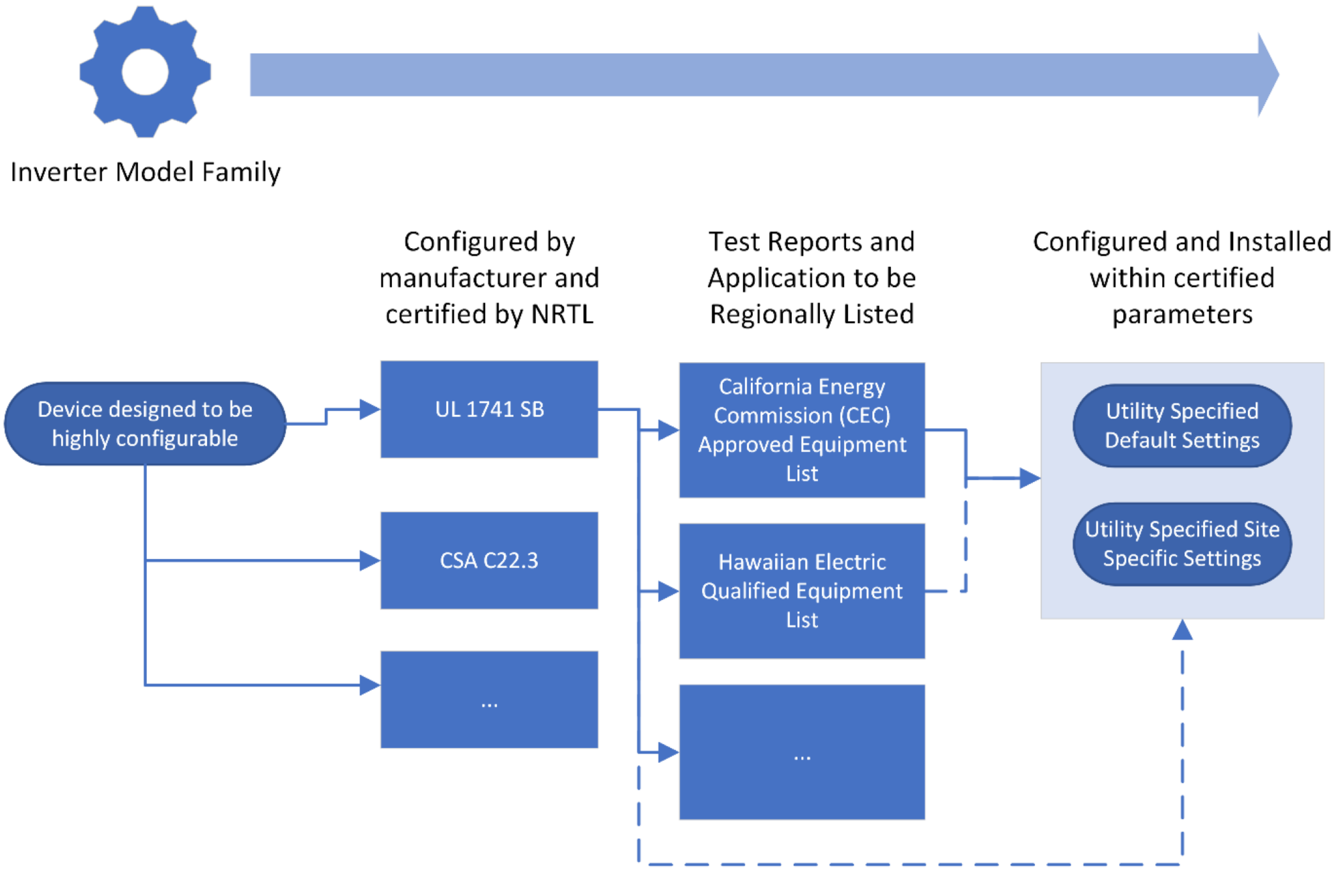

Figure 6. *An example of the factory to field pipeline for a smart inverter device*
Notes: *Equipment listings, such as those in HI and CA, often overlap but are not mandatory for use in other regions (dashed line).*

A study conducted by the Interstate Renewable Energy Council, with input from inverter manufacturers and NRTLs, projects that 85% of battery and solar inverters on the market will be certified to UL 1741 SB by January 2024 [11].

Generally, smart inverters are highly configurable and often designed to be sold into global markets for various applications. A series of configurations can occur from factory floor to field deployment. For instance, companies integrating UL 1741 SB may tailor interconnecting projects to general or site-specific utility-specified smart inverter settings (see sidebar), which remain within the adjustable ranges of settings required by IEEE 1547-2018. Figure 6 walks through an example of this development pathway, where a given device carries a UL 1741 SB certification, has been approved and listed for use in California, and is further configurable by a company's specified DER settings. (Note: A device approval and listing by CEC does not require its use exclusively within California.) All this is to illustrate that the overlapping layers of credentials awarded to a commercial device are coordinated yet flexible. Utilities integrating UL 1741 SB equipment will be able to assess the capabilities dictated by IEEE 1547-2018, plan for and optimize DER configuration, and field equipment that can perform to the standard. The certification itself primarily ensures that devices can be compatible. A utility interconnection program must establish a reliable means of dictating the device configuration.

CSA is a Canadian certification standard, depicted here as an example of varying certification paths.

California and Hawaii maintain approved equipment lists:

- Solar Equipment Lists Program | California Energy Commission
- Customer Energy Resource (CER) Equipment | Hawaiian Electric

THE COMMON FILE FORMAT FOR THE EXCHANGE AND STORAGE OF DER CONFIGURATION SETTINGS

When a system operator has established specific smart inverter settings (e.g., default, by DER class, or site-specific settings) there is an additional challenge of ensuring that devices are programmed, commissioned, and operated accordingly. To address this challenge, the DER common file format has been developed to help facilitate how utilities express required DER default settings to developers, how DER developers provide evidence of as-programmed settings back to the utility, and how utilities store and track the settings of DER throughout their systems.

To the extent possible, the common file definition utilizes the parameter attributes from the IEEE 1547.1-2020 standard, including the unique parameter labels, data types, units, and possible value options. The publicly available report, Common File Format for DER Settings Exchange and Storage: Version 2.0 dictates how these parameters and their values are expressed and formatted within the common file format so that its contents can be handled electronically or otherwise interpreted and applied without ambiguity [12]. The file format was developed through an open/public working group facilitated by EPRI.

INTEROPERABILITY STANDARDS FOR VEHICLE TO X (V2X)

As electric vehicle (EV) penetration increases, the industry is making strides toward a future state that includes new approaches for leveraging energy from EVs. These "Vehicle to X," or vehicle to everything, arrangements involve the transfer of electricity stored in EV batteries to (and from) the grid, commercial buildings and parking lots, residential dwellings, and other places.

Per Figure 7, the standards and certifications governing the interoperability requirements and capabilities for V2X correspond with the location of the inverter. If the inverter is fixed at electric vehicle supply equipment (EVSE), then UL 1741 SB is used to certify grid interoperability capabilities for power export (Figure 6, top). Meanwhile, the DER interoperability standard (IEEE Std. 1547-2018/2020a) applies to generation sources which are intended to parallel with the electric system. Therefore, EVSE with an inverter and capabilities to facilitate discharge to the electric system (referred to as Bi-Directional EVSE [BEVSE] or Electric Vehicle Power Export Equipment [EVPE]) are evaluated for compliance with IEEE Std. 1547-2018. The fixed point of common coupling (PCC) must reliably operate in coordination with the area EPS.

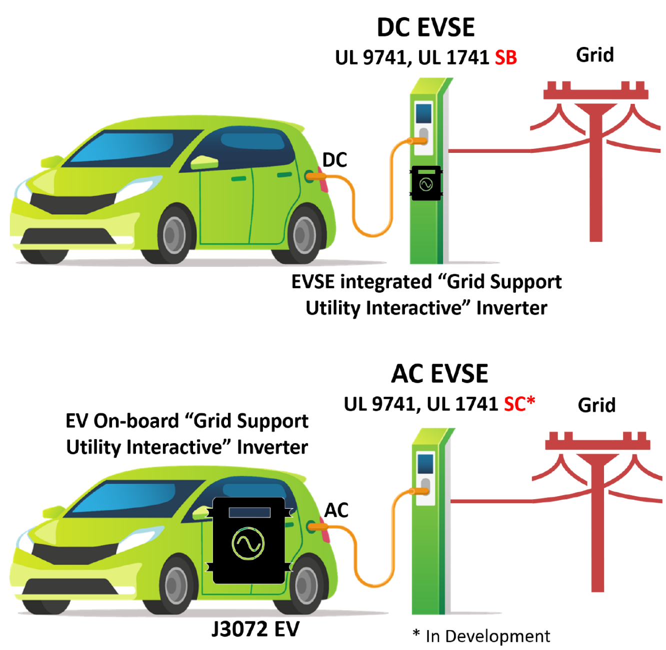

Figure 7. *Certifying standard for grid interactive inverter when part of the EVSE (top) and on-board the EV (bottom)*

In cases where the inverter and logic dictating EV charge/discharge capabilities are mobile and governed within the vehicle on-board smart inverter (Figure 7, bottom), requirements are defined by the automotive industry. Smart inverter capabilities regarding IEEE Std. 1547-2018 are certified to SAE J3072 "Interconnection Requirements for Onboard, Utility-Interactive, Inverter Systems," and are intended to address potential complications from vehicle charge/discharge from multiple points of common coupling across various geographies.

SAE STANDARD J3072

SAE Standard J3072 establishes interconnection requirements for a utility-interactive inverter system that is integrated into an EV and connects in parallel with an electric power system electric vehicle supply equipment. J3072 also defines the communication between the vehicle and the EVSE required for the onboard inverter to be configured and authorized by the EVSE for discharging at a site. J3072 requirements are intended to be used in conjunction with IEEE 1547 and IEEE 1547.1. The standard also supports interactive inverters which conform to the requirements of IEEE 1547-2003 and IEEE 1547.1-2005, recognizing that many utility jurisdictions may not authorize interconnection.

EVSE enabling V2X should be certified to UL 9741, which designates “Electric Vehicle Power Export Equipment (EVPE)”. Published in September 2023, UL 9741 mandates that power export functionality include functions to limit or prevent export to the utility grid for locations that are not permitted to receive back-feed power. This is addressed using requirements established in the CRD for PCS.

To harmonize the coordination between a V2X point (AC EVSE in Figure 7) and the onboard inverter, a third supplement for UL 1741 is in development, known as Supplement SC. The requirements in Supplement SC cover utility grid interconnected Bi-directional Electric Vehicle Supply Equipment and Interconnection Systems Equipment (BEVSE/ISE) that use on-board EV inverters and power converters to facilitate 1) AC charging for EVs from the Area EPS, as well as 2) interactive AC export from the EV to the Area EPS. These requirements are intended to facilitate and control charging/discharging administered by EV inverters and power converters that have been evaluated for compliance with other interconnection requirements within SAE J3072, its supplements, and the utility interconnection standards. Equipment evaluated for export exclusively to a Local EPS will need additional functionality and or equipment such as a PCS to prevent backfeed to the Area EPS. Table 4 lists the various standards and protocols across the V2G interoperability space. EPRI’s Electric Transportation team provides an annual summary of standards in this rapidly developing space (see, for example, 3002026760).

CONCLUSIONS AND TAKEAWAYS

Years of multi-stakeholder collaboration across the industry have resulted in reliable, highly configurable interoperable devices as well as a wealth of supporting information to assist in the integration and leveraging of grid interactive DER support capabilities. The evolving standards and certification landscape is helping to define and, in turn, simplify DER grid integration efforts. In understanding the fundamental capabilities described in the family of IEEE 1547 standards, guides, and recommended practices, electric system operators are positioned to model, anticipate performance, and manage grid-supportive DER. The use and configuration of equipment certified to UL 1741 and other safety standards is ensuring that the grid support capabilities specified in 1547 can be successfully carried out.

Table 4. *V2G-applicable standards by certification topic [13]*

SCOPE	STANDARDS AND PROTOCOLS
Interconnection	IEEE 1547-2018, IEEE 1547.1-2020
EVSE Safety and Functionality	UL 1741, UL 9741
Vehicle Functions	SAE J2836/3, SAE J3072
Communication	IEEE 2030.5-2018 (SAE J2847/3), OCPP, OpenADR, ISO 15118

Following are several notable takeaways and expectations as they relate to DER standards and certifications:

- Correct utilization of interconnection standards and certifications are critical for proper interconnection of DERs.
- The release of IEEE 1547 supporting guides in 1547.2 (Standard Application Guide) and 1547.3 (DER Cybersecurity Guide) is imminent. Meanwhile, a new project, 1547.10, is expected to enhance applications that involve gateway communication and future DERMS.
- The next revision of the base IEEE 1547 standard is expected by end-2025.
- Although UL 1741 SB certification is ongoing, legacy and non-certified inventories will continue to be proposed in inverter equipment designs in 2024 and possibly beyond. Consequently, certificates of certification and managed equipment lists should be used to identify DER equipment class.
- EPRI's Common File Format can help facilitate the exchange and storage of configuration settings for DER [12]. This file format can, for example, be used to convey how utilities express required DER default settings to developers, how DER developers provide evidence of as-programmed settings back to the utility, and how utilities store and track the settings of DER throughout their systems.
- Power control systems are still being certified through a Conformance Requirement Document attachment to UL 1741 (the CRD for PCS). Until further notice, this will continue to serve as the vehicle for achieving PCS certification.
- DER compliant with IEEE 1547-2018 should support one of the three standard communication protocols mandated by the standard, enabling more consistent direct interface and DER management.
- As V2G continues to unfurl, Vehicle to Home (V2H) or behind-the-meter non-export solutions will need additional functionality and/or equipment such as a PCS to prevent backfeed to the Area EPS. If UL 9741 properly incorporates the UL CRD for PCS, this could quickly become the new standard for EVPE.

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