DOE Laboratory Support for DER and Inverter-Based Resource Integration Standards (ACCEL II) Final Report

David Narang,[1] Sig Gonzalez,[2] Jay Johnson,[2] Ross Guttromson,[2] Barry Mather,[1] Jens Boemer,[3] and Andy Hoke[1]

1 National Renewable Energy Laboratory
2 Sandia National Laboratories
3 Electric Power Research Institute

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National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
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Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

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The authors are also grateful to DOE EERE SETO technical monitors Robert Reedy, Kemal Celik, and Jeremiah Miller and to the Systems Integration Program Manager Guohui Yuan for their guidance and support.

List of Acronyms

ACCEL	Accelerating Systems Integration Standards
DER	distributed energy resource
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EPRI	Electric Power Research Institute
GFM	grid forming
GUI	graphical user interface
HIL	hardware-in-the-loop
IBR	inverter-based resource
IEEE	Institute of Electrical and Electronics Engineers
IRPTF	Inverter-Based Resource Performance Task Force
IRPWG	Inverter-Based Resource Performance Working Group
NERC	North American Electric Reliability Corporation
NREL	National Renewable Energy Laboratory
PAR	project authorization request
PV	photovoltaic
SB	Supplement SB
SETO	Solar Energy Technologies Office
SPIDERWG	System Planning Impacts of Distributed Energy Resources Working Group
STP	Standards Technical Panel
SVP	System Validation Platform

Executive Summary

New grid-interactive devices are being introduced and deployed at a rapid pace, and the dramatic increases in photovoltaic and other renewable energy adoption in many parts of the United States have led to a heightened sense of urgency for the standards development process.

This report documents efforts under a project that followed work completed under the Accelerating Systems Integration Standards (ACCEL) project. In this continuation, the project team provided support for updates to critical standards for the interconnection and interoperability of distributed energy resources (DERs) at the distribution level. In addition, the project contributed to the development of guidance for operational best practices of the bulk power system with high levels of DERs. Additional goals of the project were to inform and develop improved recommended practices and certification standards for the end-to-end interoperability of DERs, using Sandia National Laboratories assets when needed.

Throughout this project, the ACCEL team was instrumental in the following key outcomes:

1. The Institute of Electrical and Electronics Engineers (IEEE) Std 1547.1-2020 was published in 2020. This is a major revision to DER test and verification procedures representing the consensus of hundreds of individuals, and it will have significant impacts around the United States and beyond by ensuring that DERs can fully participate in the rapidly modernizing electric grid.
2. UL 1741 Supplement SB (SB) was published in 2020 and revised in 2021. This has triggered the entire U.S. DER industry to update their products to incorporate the new grid support functionality required in IEEE 1547-2018 (which was led under the previous iteration of the ACCEL project).
3. DER test procedures for power and communications functionality were validated at Sandia, and lessons were incorporated into IEEE Std 1547.1 and UL 1741 SB.
4. The first-ever U.S. performance requirements for inverter-based resources connected to the transmission and subtransmission systems were drafted in IEEE P2800 and are nearing publication (expected in 2022). This new standard will be fundamental to the reliability of the future bulk power system.

Table of Contents

List of Figures

1 Project Objectives and Approach

Dramatic increases in photovoltaic (PV) adoption in many parts of the United States have led to a heightened sense of urgency for the interconnection standards development. The scope of work undertaken by the Accelerating Systems Integration Standards (ACCEL) project team was developed to address this urgency by providing leadership and direction in critical areas, including:

- Conformance test requirements for distributed energy resource (DER) interconnection and interoperability
- Support for emerging system integration challenges, such as the application of grid-supportive inverters and the deployment of PV-plus-storage
- Standards and operational best practices to address the impacts of DERs and inverter-based resources (IBRs) on the bulk power system
- Standardization of practices for laboratory procedures related to the hardware-in-the loop (HIL) evaluation of DERs
- Improved certification standards for the end-to-end interoperability of DERs
- Education and knowledge transfer of newly revised standards and the application of standards to ensure effective execution in the deployment and regulatory arenas.

The objectives by year were:

- **Year 1** (October 2018–September 2019):
    - Institute of Electrical and Electronics Engineers (IEEE) P1547.1 passes the public ballot, approval ≥75%, as shown from the ballot count.
    - UL 1741 revision is started.
    - First consolidated draft of entire P2004 Recommended Practice is complete.
    - Completed the IEEE 1547.1 certification test procedure experiments via the SunSpec Modbus communications protocol.
- **Year 2** (October 2019–September 2020):
    - IEEE Std 1547.1 is published.
    - UL 1741 revision passes the UL Standards Technical Panel ballot.
    - Completed the IEEE 1547.1 certification test procedure experiments via the IEEE 2030.5 (SEP 2.0) communications protocol
    - IEEE Std 1547a-2020 amendment is published.
- **Year 3** (October 2020–September 2021):
    - IEEE P2800 completes two rounds of public balloting, with approval ≥75%, as shown from the ballot count.
    - Completed the IEEE Std 1547.1 certification test procedure experiments via the IEEE 1815 (Distributed Network Protocol 3) communications protocol. Demonstrated the three communications protocols in the IEEE Std 1547.1 certification test procedure.

Discussion of the project results follows.

The project's period of performance was from October 2018 to September 2021. The discussions are organized by task, so not all work appears chronologically.

The project used expertise at the national laboratories and engaged with consultants with relevant subject matter experience and expertise.

The following topic areas comprise what were considered important core power systems standards areas that could benefit from U.S. Department of Energy (DOE) support of national laboratory staff leadership and technical contributions.

2 Conformance Testing and Certification Standards

The ACCEL II team supported the completion of the full revision of IEEE P1547.1 and contributed to related revisions to UL 1741. There were two subtasks, as described in the following sections.

2.1 Full Revision of IEEE Standard 1547.1

The ACCEL II team provided leadership, technical contributions, and subject matter expertise to support the completion of the full revision of IEEE Std 1547.1, chaired by an ACCEL team member from National Renewable Energy Laboratory (NREL). The ACCEL team, in coordination with the rest of the IEEE P1547.1 Working Group leadership, led the standard through four rounds of balloting, during which roughly 1,750 comments were addressed. The ACCEL team directly led 4 of the 11 subgroups. The approval rate increased from 79% to 96% during the balloting, as shown in Figure 1.

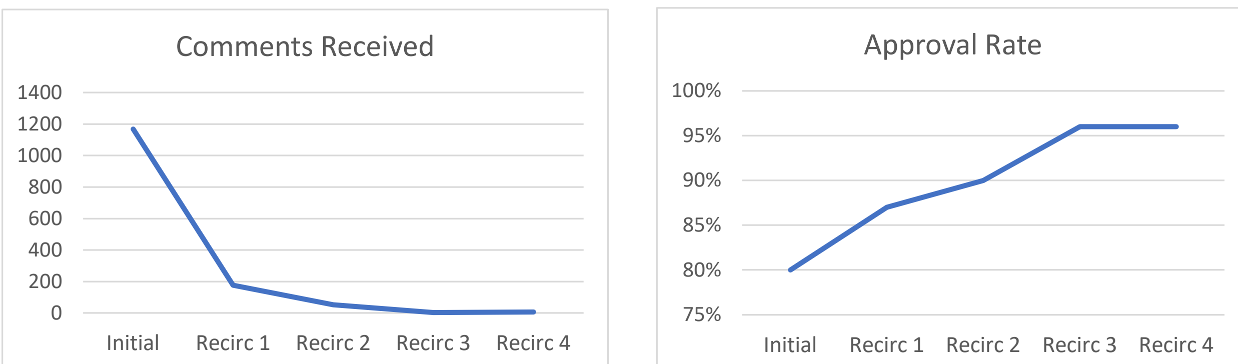

Figure 1. IEEE P1547.1 ballot comments received and approval rate for the initial ballot and four recirculations

IEEE P1547.1 Draft 9.9 received 96% approval in the fourth and final round of IEEE public balloting in December 2019 and was approved by IEEE shortly afterward. IEEE Std 1547.1-2020 was published on May 21, 2020, triggering DER manufacturers to begin updating their products to comply with the revised standard.

2.2 Laboratory Validation of IEEE Std 1547.1 Test Procedures

During and after the development of IEEE Std 1547.1-2020, Sandia National Laboratory engineers provided laboratory validation to many of the IEEE Std 1547.1 tests and supported the development of the UL 1741 Supplement SB (SB) Certification Requirements Decision CRD on Power Control Systems, which developed a test procedure to certify DER systems' ability to limit power flowing on a given path, for example, as used in non-exporting PV-battery systems. These laboratory testing efforts provided valuable feedback to the test procedures. Sandia has been working with industry partners to evaluate inverters that are near IEEE Std 1547-2018 compliance and to assess the test procedure for process and testability, including assessing how DC supply, AC source, and load equipment work during the testing process. The Sandia team ran and evaluated test procedures for DER capabilities, including limiting active power, voltage and frequency ride-through, and voltage and frequency disturbance responses. Grid support procedures, such as voltage and frequency regulation functions, were also evaluated. Sandia has also been engaged with the UL Standards Technical Panel (STP) to work through the comments received during the balloting process and uses this information for Supplement SB.

Looking forward toward potential future standards, Sandia has also been evaluating a grid-forming (GFM) inverter and assessing how the ride-through procedures will work with these types of inverters. Some GFM inverters might choose to open an isolation device and operate as part of a microgrid during events that would normally cause the DER to invoke a momentary cessation and possible trip. Much work is needed in this area and will potentially be investigated in the next revision of IEEE Std 1547.

Sandia obtained from an industry partner a new inverter platform that was designed to meet all the IEEE Std 1547 requirements, including SunSpec interoperability compatibility. For this evaluation, Sandia implemented a SunSpec-based script designed to automate the testing of the functions and features as described in the base standard, discussed further in Section 2.4.

In an initial evaluation of the inverter, which is not yet UL 1741 listed, the inverter was connected to a sufficient DC source and an AC source and operated. It has hot-spot Wifi capability and with the proper Internet Protocol (IP) address and has access to a home page (a graphical user interface [GUI]) where all the parameters of the inverter are available. From this GUI, the device was powered up and commanded to export power to the grid, and the voltage and frequency regulation functions were enabled and adjusted. This initial testing identified the issue that rated power could not be achieved over the available DC voltage ranges. Also, issuing adjustments on active and reactive power resulted in the inverter shutting down and restarting. A software revision partially addressed the issues, and the manufacturer is working to find solutions before we progress to the interoperability testing.

2.3 Revisions to UL 1741 Certification

The ACCEL team supports revisions to UL 1741, the primary channel for the adoption of the IEEE Std 1547.1 tests. The fast-track revision to UL 1741, including the new Supplement SB pointing to IEEE Std 1547.1, was balloted twice from March 2020 through June 2020, receiving 100% approval on the second ballot. ACCEL team members from Sandia and NREL participate on the UL STP responsible for these efforts. The revised UL 1741 was published on August 3, 2020.

After testing commenced, DER manufacturers and nationally recognized testing laboratories began to raise a steady stream of questions on the application of IEEE Std 1547.1 as testing has accelerated. To address the concerns, UL convened a task group to consolidate industry comments and to develop guidance for managing the issues raised and for cleaning up misunderstandings and errors identified during testing to IEEE Std 1547.1. Many of the concerns raised were readily addressed in the revised certification, but some pointed to issues to be addressed in future revisions or through Nationally Recognized Testing Laboratory (NRTL) processes. The ACCEL team is maintaining a list of topics for future clarification or update in IEEE Std 1547 and IEEE Std 1547.1.

The task force met approximately two times weekly, sometimes more often, from January 2021 to August 2021, with the aim to issue a revision to UL 1741 SB. The UL task group posted the revised UL 1741 SB in early May for UL STP balloting. The final approved UL 1741 clarification document, known as UL 1741 Edition 3, was published in September 2021. DER inverter manufacturers are actively updating and testing their products. Meanwhile, industry has identified a bottleneck in test laboratories available to certify DERs, leading to additional delays that are expected to continue into 2022. Early-adopter states and utilities are pushing back compliance deadlines for IEEE Std 1547-2018 accordingly into later in 2022 to avoid a slowdown in DER deployments.

2.4 Distributed Energy Resource Interoperability Standards and Certification

ACCEL II team members contributed to the development of DER interoperability standards and the test sequences in the IEEE Std 1547.1-2020 certification procedure. Sandia created an IEEE Std 1547.1 interoperability certification script for the System Validation Platform (SVP), which automated the evaluation of the communications capabilities of DER equipment using SunSpec Modbus, IEEE Std 1815, or IEEE Std 2030.5 communications protocols. (See the bibliography section for several publications related to DER testing using standardized communications interfaces.)

3 Distributed Energy Resource and Inverter-Based Resource Integration Impacts at the Bulk Power System Level

As the deployment of IBRs and DERs—in particular, PV—has increased, so, too, has the potential impact of these systems on the bulk power system. Indeed, one of the main drivers for revisions to IEEE Std 1547 was to enable DER capabilities for supporting the bulk power system when needed, including the ability for DERs to ride through a variety of voltage and frequency transients and to perform frequency-watt droop control. There is, however, a realization that standards intended for systems connected at the distribution level cannot and should not be substituted for standards that would apply to systems connected at the bulk power system level, which have different technical requirements. Several working groups have formed to bridge this gap, with an aim to not only define appropriate standards for IBRs interconnected on the bulk power system (i.e., transmission and subtransmission) but also to provide guidance on mitigating the impact of existing distribution-connected systems on the bulk power system.

As originally written in agreement with DOE, Task 3 was a relatively minor task with no subtasks; however, with the emergence of IEEE P2800, the performance and interconnection standard for bulk power system-connected IBRs, Task 3 became a high-priority task in fiscal years 2020 and 2021, with a dedicated subtask for IEEE P2800 and a second minor subtask for related efforts.

3.1 IEEE P2800—Interconnection Requirements for Transmission-Connected Inverter-Based Resources

IEEE P2800 is the first nationwide effort to develop interconnection requirements for IBRs connected to bulk power systems. IEEE P2800 holds the potential to be "the 1547 of the bulk power system," helping to standardize transmission and subtransmission-connected IBR performance and ensure the stability of emerging high-IBR grids. The ACCEL II team re-prioritized resources to better support this potentially highly impactful standard, engaging in three primary ways:

1. NREL executed a subcontract with the Electric Power Research Institute (EPRI) to support the chair of IEEE P2800 and others.
2. A Sandia engineer served as a vice chair and led two subgroups.
3. NREL co-led a subgroup and provided subject matter expertise in areas including fast frequency response (FFR), verification of requirements, and grid-forming technologies.

Summaries of the ACCEL team's work on each of those items follow.

An ACCEL team member from Sandia is a vice chair of the IEEE P2800 Working Group and is also leading two subgroups within IEEE P2800: subgroups 5 (stability) and 6 (power quality). Balloting for IEEE P2800 gained the necessary votes for approval in the first round, with 84% approval, but the IEEE standards process still required due diligence regarding the disposition of comments by balloters, and the working group leadership's goal was to obtain a higher level of consensus and a higher ballot approval rate. Although comments address issues across various subgroups, the resulting votes apply to the IEEE P2800 document as a whole, not to any particular subgroup.

The Subgroup 5 focus is on recommended practices for the preservation of minimum stability as effected by the IBR. Subgroup 5 has about 60 participants. It provides the recommended IBR performance that is desirable to promote system stability. Because the stability of IBR-grid systems is complex and difficult to standardize, most of subgroup 5's content consists of nonnormative guidance rather than requirements.

Subgroup 6 has about 40 participants. It defines the minimum performance requirements for the purpose of maintaining minimum power quality. Significantly, consensus has been reached on some core philosophies with the power quality subgroup. There had been a long-standing difference by two separate sets of experienced engineers within the subgroup: one with greater focus on establishing voltage harmonic limits only and the other with greater focus on current harmonic limits only. This was one of the most contentious topics in IEEE P2800. The solution focused on the implementation of revised (relaxed) current harmonic limits found in IEEE Std 519 and the development of a new voltage harmonic informative annex. Finally, agreement was made to recommend a project authorization request (PAR) to implement voltage harmonic requirements in the first full IEEE P2800 revision (as opposed to a guideline). The voltage harmonic informative annex draft has been approved. In addition to harmonics, the subgroup has also developed transient overvoltage contribution limits and root-mean-square overvoltage contribution limits.

NREL led the development of a mathematically defined requirement for FFR. FFR broadly means the ability of a PV/wind/battery energy storage system to quickly inject power during the arresting phase of a frequency event, as a replacement/supplement to inertia, and therefore is expected be fundamental to the stability of future high-IBR power systems. The mathematical definition of FFR has been debated heavily, and it remains in Draft 6.2, though only for underfrequency conditions.

NREL also co-led the IEEE P2800 subgroup on the testing and verification of the IEEE P2800 requirements. This subgroup has made an effort to ensure that testing and verification methods are feasible for all IBR technologies. The outcome of this subgroup's work was a framework for conformance verification rather than detailed procedures, which would be in the scope of future standards IEEE P2800.1 or IEEE P2800.2.

The ACCEL team also engaged a senior member of the EPRI technical staff, chair of the IEEE P2800 Working Group, to support EPRI's IEEE P2800 efforts. Beginning in 2020 and continuing through the end of September 2021, ACCEL partially funded EPRI's leadership of IEEE P2800 through an NREL subcontract. The funding provided EPRI with significant resources that helped accelerate the drafting of IEEE P2800.

EPRI's efforts related to IEEE P2800, which are partially funded by ACCEL, are summarized as follows: the senior member of the EPRI technical staff led the overall IEEE P2800 Working Group as well as the general requirements subgroup and the overall document subgroup. After approximately two years of work, this resulted in a draft of IEEE P2800 that achieved 99% approval from the working group to initial the public ballot. The team initiated the ballot in spring 2021. During the working drafting and the IEEE Standards Association ballot, the team organized biweekly teleconferences of the IEEE P2800 leadership team (officers) for strategic and tactical decision making. The initial ballot resulted in an 84% approval rate, exceeding the 75% required by IEEE-SA. The ballot also generated 1,407 comments, of which 659 were classified as "must be satisfied." The breakdown of comments by subgroup is shown in Figure 2.

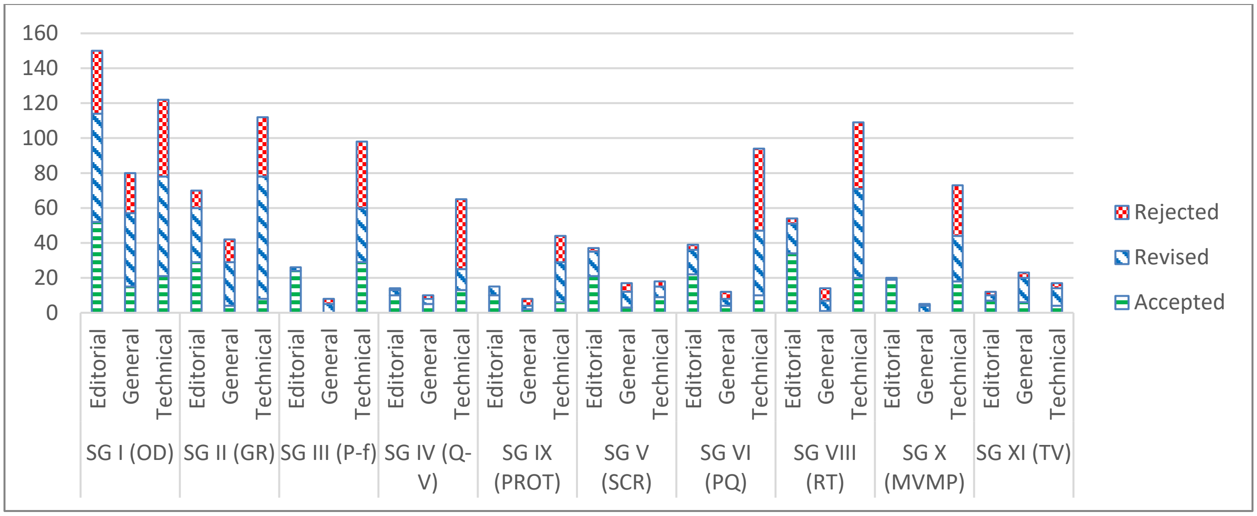

Figure 2. IEEE P2800 comments from initial ballot by subgroup, with near-final resolutions indicated. ACCEL team members led subgroups I, II, V, VI, and XI and made substantial contributions to other subgroups.

The ACCEL team and the other members of the IEEE P2800 leadership led weekly meetings of the comment resolution group to address all comments, particularly those deemed especially difficult or controversial. Examples included:

- Applicability of IEEE P2800 to synchronous machines, especially synchronous condensers, when used as supplementary IBR devices (i.e., devices that are used to help an IBR plant meet the requirements of P2800)
- Applicability of IEEE P2800 to grid-forming inverters, particularly the desire not to inadvertently create barriers to this emerging technology
- Voltage and current harmonic limits for IBR plants
- IEEE P2800 requirements as applied to voltage source converter-high-voltage DC and offshore wind power plants
- Applicability of IEEE P2800 requirements in weak grid conditions
- Specificity and testability of requirements for current injection during fault ride-through (including negative-sequence current injection)
- Cybersecurity requirements, if any, of IEEE P2800
- Capability requirements for reactive power at night and FFR.

The ACCEL team and others drafted text, provided critical review, and fostered consensus among balloters and comment resolution group members related to these comments and others. After the comment resolution group had addressed all 1,407 comments, EPRI then initiated the first recirculation of the ballot in June 2021. The recirculation resulted in an 89% approval (up from 84% previously), with a solid 86% response rate.

The requirements of IEEE P2800 at the time of this writing are summarized in Figure 3.

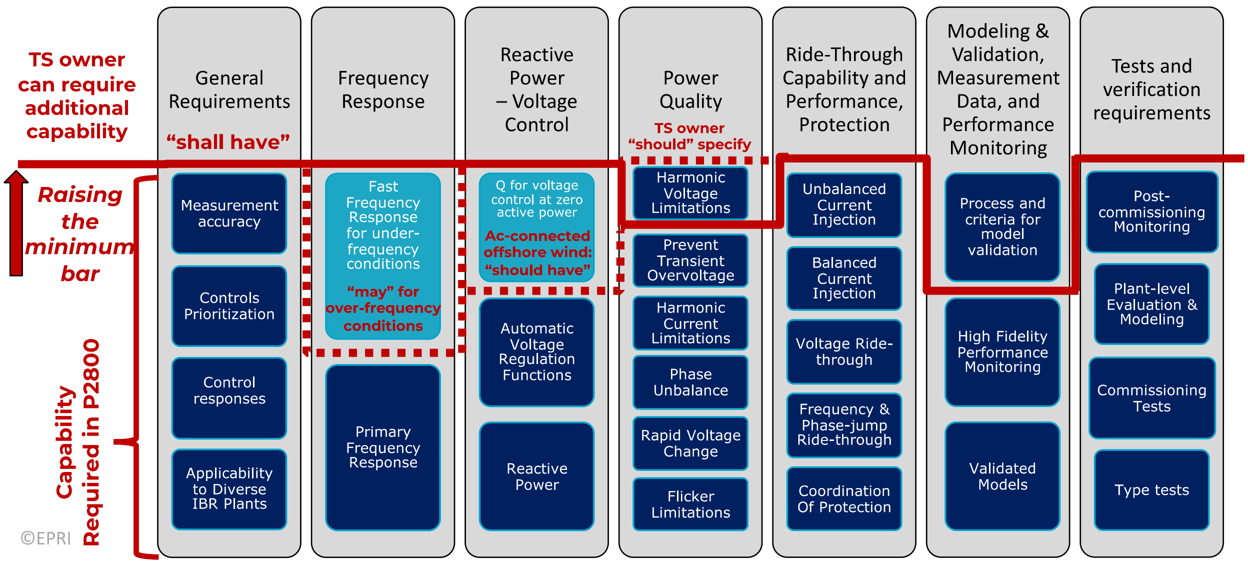

Figure 3. Technical minimum requirements specified in the near-final IEEE P2800 Draft 6.3

Due to the extensive efforts needed to address comments and prepare drafts for revision, the timeline for publication of IEEE P2800 was pushed back three months from the initial goal to near the end of the first quarter of 2022.

3.2 IEEE P2800.2—Verification of IEEE P2800 Requirements on Bulk Power System-Connected Inverter-Based Resources

The IEEE P2800.1 Working Group, which will develop a guide for the testing and performance verification of transmission-connected IBRs, held its first meeting co-located with the IEEE P2800 kickoff but has been waiting to undertake significant efforts until the IEEE P2800 content was relatively stable. The ACCEL team has some concerns about IEEE P2800.1, including:

1. As an IEEE guide (not a standard), the effort might not be as impactful as desired.
2. IEEE P2800.1 follows the IEEE entity standards development process, which many IEEE P2800 stakeholders expressed a preference not to use; thus, it appears that IEEE P2800.1 is not receiving the strong industry backing it would need to be impactful.

Given these concerns around IEEE P2800.1, the ACCEL team engaged with the IEEE P2800 and IEEE P2800.1 leadership on this topic as well as with DOE, the North American Electric Reliability Corporation (NERC), IEEE, and EPRI. The group was reluctant to create another standard similar to the already proposed IEEE P2800.1, so several routes to full IEEE P2800 compliance verification were considered, but none were found likely to produce the desired result: verification procedures for IEEE P2800 requirements developed through industry consensus. In early 2021, the group reached a consensus that a separate, new IEEE standard using the IEEE individual standards development process was needed to allow full participation of IEEE P2800 stakeholders and technical experts in the development of IEEE P2800 test and verification procedures, which, in turn, will help lead to the broad adoption of the standard. Based on this consensus, NREL led the development of a new IEEE PAR for IEEE P2800.2. The

ACCEL team obtained sponsorship of five IEEE committees and submitted the PAR to IEEE's new standards committee (NesCom) in the first quarter of 2021. The PAR was approved, and the ACCEL team will initiate the working group starting in 2022. The timeline proposed for IEEE P2800.2 is shown in Figure 4.

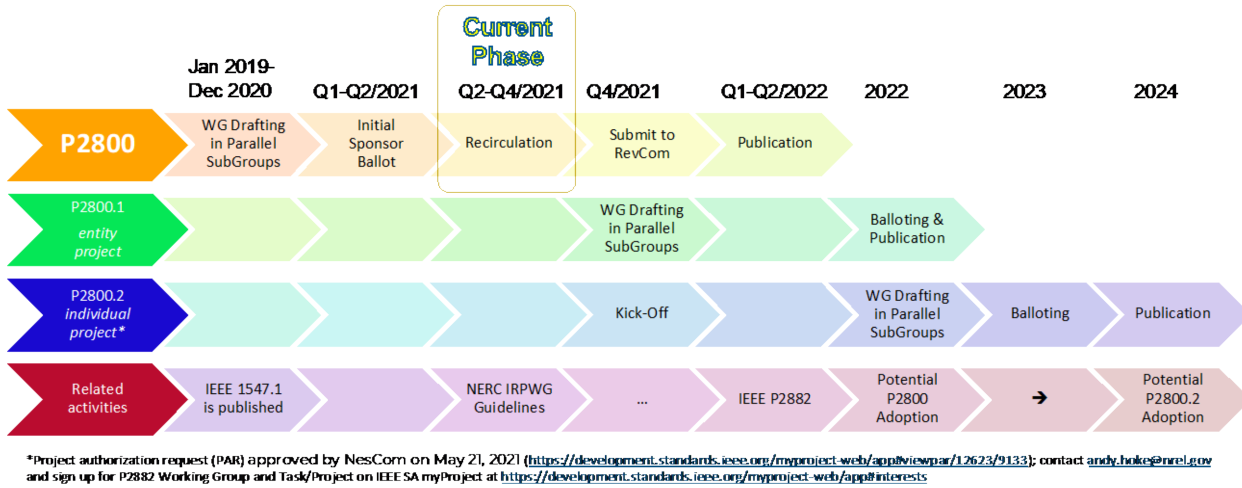

Figure 4. Timeline for the development of IEEE P2800 and related standards

3.3 North American Electric Reliability Corporation Working Group on System Planning Impacts from Distributed Energy Resources

The NERC System Planning Impacts of Distributed Energy Resources Working Group (SPIDERWG) focuses on addressing the impacts of DERs on the bulk power system. The ACCEL team engages when possible with select issues and work products of the SPIDERWG to coordinate and contribute a technical perspective that is unique and unbiased. This effort was led by a senior researcher from NREL, with coordination with other ACCEL team members as was needed.

The overall scope of the SPIDERWG is very broad, and the group has a large number of participants and supporters. Given the limited funding available, active participation in only the most critical SPIDERWG activities from a standards perspective was taken on. Four subgroups were formed under the SPIDERWG: modeling, verification, studies, and coordination. NREL actively participated in the studies and coordination groups but also engaged in a few work products, such as NERC-recommended practices that were developed by the modeling subgroup.

Notable outputs of the studies subgroup during the ACCEL II effort include the following:

- NERC white paper on an "Assessment of DER Impacts on NERC Reliability Standard TPL-001—System Planning Impacts of Distributed Energy Resources (SPIDERWG).[1] This white paper focused on addressing questions about whether DERs need to be

[1] See https://www.nerc.com/comm/PC/System%20Planning%20Impacts%20from%20Distributed%20Energy%20Re/SPI DERWG_White_Paper_TPL-001_Assessment_and_DER.pdf.

included in NERC's annual planning assessment and set the stage for the consideration of changes to other NERC standards as necessary.

- NERC reliability guideline on underfrequency load-shedding and undervoltage load-shedding on systems with considerable DERs, not yet publicly released. This guideline defines the new operational challenges present for system operators in implementing underfrequency load-shedding and undervoltage load-shedding functionality when there is a significant amount of generation on the distribution system.

Notable outputs of the coordination (i.e., standards coordination) subgroup include:

- *NERC Reliability Guideline: Bulk Power System Reliability Perspective on the Adoption of IEEE 1547-2018.*[2] This important guideline provided a detailed review of IEEE Std 1547-2018 requirements, clause by clause, and highlighted any bulk power system concerns and implications. This document provides a perspective on IEEE Std 1547 that is not often presented given that IEEE Std 1547 has historically been relevant primarily to distribution system operators.
- NERC white paper on a review of NERC standards requiring revision to include DER-related impacts, not yet published. This major effort included the review of more than 40 NERC standards by a large cross section of the SPIDERWG and the development of recommendations for which NERC standards needed to be prioritized for revision in the short term, those that needed revision but not urgently, and those that needed no revision at this time. Under this project, NREL led the review of emergency operating procedure standards and provided input on many others.

Notable outputs of the modeling subgroup in which NREL participated include:

- *NERC Reliability Guideline: Parameterization of the DER_A Model*.[3] This guideline provides guidance on the many settings/parameters of the DER_A model, the current, most advanced, positive-sequence model for DERs used in transmission planning studies.
- The review of a survey developed by the modeling subgroup to collect information on currently used DER modeling practices from utilities and system operators.

The work of the NERC SPIDERWG has been successful during the past three-plus years engaging the broader industry and laying the foundation for power systems to operate reliably even with high levels of DERs.[4] This success is due to the strong commitment and regular participation of electric power industry members, including experts from the DOE national labs.

3.4 North American Electric Reliability Corporation Working Group on Inverter-Based Resource Performance

The NERC/Western Electricity Coordinating Council Inverter-Based Resource Performance Working Group (IRPWG, formerly a task force, IRPTF) was set up to provide guidance on the performance of transmission-connected IBRs to minimize negative impacts and to maximize

[2] See https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Guideline_IEEE_1547-2018_BPS_Perspectives.pdf.

[3] See https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_DER_A_Parameterization.pdf.

[4] See additional information/resources on the NERC landing page: https://www.nerc.com/comm/PC/Pages/System-Planning-Impacts-from-Distributed-Energy-Resources-Subcommittee-(SPIDERWG).aspx.

positive impacts on bulk system reliability. The IRPWG initially focused on protection functionality implementation (disturbance ride-through) but quickly expanded into related areas, including frequency and voltage regulation, fault response, and other topics. ACCEL team members occasionally contribute to IRPWG and its subgroups.

A key recent IRPWG product is a white paper on GFM inverters. ACCEL team members were requested by the NERC project leader to redline the entire document. Their input included:

- Focusing the definition of GFM inverters on the core GFM characteristics and excluding extraneous information. This also included aligning the GFM definition with the recently published SETO white paper on GFM.
- Tempering language that emphasized only the potential benefits of GFM inverters without summarizing the state of the art, including challenges
- Clarifying which behaviors are unique characteristics of GFM inverters and which are also available from advanced grid-following inverters
- Clarifying that GFM inverter technology has existed for decades (e.g., for off-grid applications) and that the key emerging technology of interest (and the topic of the white paper) is GFM inverters connected *in parallel with large power systems*
- Clarifying the use of the term "inertia" in the context of GFM IBRs
- Various other technical edits.

ACCEL team members also provided periodic updates to IRPWG on the status and key technical issues in IEEE P2800, which grew from IRPWG initiatives.[5,6]

[5] See additional information/resources on NERC landing page: https://www.nerc.com/comm/RSTC/Pages/IRPWG.aspx.
[6] See the NERC report on *Grid Forming Technology: Bulk Power System Reliability Considerations*: https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_Grid_Forming_Technology.pdf.

4 Standards Adoption and Application

ACCEL team members work toward ensuring that important DER interconnection and interoperability standards are maintained going forward, including planning for the future of IEEE Std 1547. They also contribute to the development of appropriate guidance for the use and applications of the relevant standards.

4.1 IEEE Std 1547.9—Application Guide for Interconnection of Energy Storage

Select ACCEL team members contribute to the IEEE P1547.9 Working Group. This application guide will set the basis for the future development of energy storage devices and the implementation of best practices for energy storage DER interconnection requirements. IEEE P1547.9 is currently (February 2022) in balloting.

An ACCEL team member is chairing the IEEE P1547.9 Working Group, and his initial work on this standard was funded by ACCEL. The IEEE P1547.9 Working Group held its final meeting in June 2021. IEEE P1547.9 is now in balloting.

4.2 IEEE P2004—Recommended Practice for Hardware-in-the-Loop Evaluation of DERs

An ACCEL team member provided leadership and technical contribution to IEEE P2004, a working group started by Florida State University, Austria Institute of Technology, and NREL in 2017 to develop a "Recommended Practice for Hardware-in-the-Loop (HIL) Simulation Based Testing of Electric Power Apparatus and Controls."

As the use of HIL moves from the research space to industry use, IEEE P2004 will provide a consensus-based recommended practice that will be valuable to industry, DOE, system operators, and research institutions to encourage consistent and rigorous application of HIL simulations. For example, IEEE Std 1547.1 Draft 9.5 permits power-HIL methods for use in unintentional islanding tests, but the industry test labs that will run these tests in practice have little or no experience with HIL testing. In addition, it is possible that IEEE P2800 may permit (or possibly even require) HIL testing for the verification of certain requirements that are not feasible to test using full-scale hardware. In both examples, HIL testing can streamline the verification of new requirements that are necessary for reliable grid operation, but HIL testing also introduces new complexities and sources of error. IEEE P2004 can provide uniform guidance to increase HIL test repeatability and reduce error, increasing industry's ability to integrate DERs and IBRs while ensuring that they perform reliably under normal and abnormal conditions.

An ACCEL team member is the secretary for the working group and has a key role in helping to structure and write the recommended practice, running meetings, and providing technical expertise as a subject matter expert and pioneer in the use of HIL for power systems applications. IEEE P2004 leadership continues to work closely with existing IEEE groups when appropriate, especially the Power System Relaying and Control Committee Task Force CTF-33 and the IEEE Task Force on Real-time Simulation of Power and Energy Systems, to solicit input and participation from their members.

This task received a low level of ACCEL support.

4.3 Harmonization of Communications and Power Systems Standards

Several ACCEL team members provided recommendations to the IEEE Std 1547.1-2020 interoperability requirements and contributed to communications standards updates. IEEE Std 1547-2018 requires DER devices to include an IEEE Std 2030.5, IEEE Std 1815 (Distributed Network Protocol 3), or a SunSpec Modbus interface that uses a standardized information model. The team worked with the standards development community and the SunSpec Alliance to update protocol implementations to align with the requirements in IEEE Std 1547 and IEEE Std 1547.1.

IEEE Std 1547.1 interoperability tests require evaluating nameplate, configuration, and monitoring information as well as management information. In the latter, the electrical tests are executed after communicating parameters to the equipment under test; therefore, doing the full IEEE Std 1574.1 interoperability evaluation is time consuming and challenging. For this reason, Sandia and a collection of other research laboratories, known as the Smart Grid International Research Facility Network, have been working to create automated electrical tests, such as:

- Constant power factor, volt-volt ampere reactive, frequency-droop, and volt-watt[7]
- Limit active power, constant reactive power, active power-reactive power (watt-volt ampere reactive), and prioritization of grid-support functions[8]
- Voltage ride-through, frequency ride-through, and rate-of-change-of-frequency ride-through.[9]

There were three primary contributions from the interoperability research. The first was a detailed analysis of the IEEE Std 1547.1 certification procedures using the three standardized communications protocols. The second was a collection of suggested changes to IEEE Std 1547.1 and the communications protocols and information models. The third was the creation of an automated test script and DER equipment drivers for evaluating the interoperability of the DER equipment to IEEE Std 1547 functionality. These contributions were described in an *IEEE Access* paper[10] and are available open sourced in two GitHub repositories[11],designed to be used with the SunSpec System Validation Platform.[12]

4.4 Revision of IEEE Std 1547.2, Application Guide to IEEE Std 1547

Some ACCEL team members contribute to updating IEEE Std 1547.2, the application guide for IEEE Std 1547, which provides much-needed context to ensure that IEEE Std 1547 is interpreted and applied appropriately. The ACCEL team assessed the level of effort that should be directed toward IEEE Std 1547.2 as other priorities emerge, in coordination with DOE. NREL and Sandia have reduced their IEEE Std 1547.2 efforts below the originally low level that was planned,

[7] See Ninad et al. (2019).
[8] See Ninad et al. (2020).
[9] See Ninad et al. (2021).
[10] See Johnson et al. (2021).
[11] See https://github.com/jayatsandia/.
[12] See https://github.com/sunspec/svp.

allowing industry to take the lead on this effort. This allows the ACCEL team to focus on other topics.

4.5 IEEE Std 1547 Standards Family Maintenance and Revision Planning

ACCEL team members maintain leadership roles in standards development efforts: chair of the IEEE Std 1547 Working Group and IEEE Standards Coordinating Committee 21 liaison; chair of the IEEE P1547.1 Working Group and IEEE Standards Coordinating Committee 21 liaison; distribution secondary networks subject matter expert/subgroup lead; and unintentional islanding subject matter expert/subgroup lead. Responsibilities include addressing concerns related to IEEE Std 1547/IEEE Std 1547.1 application and development of plans for future revisions and amendments. Team members are engaged in various leadership roles at the working group and subgroup level. These include the following maintenance tasks of IEEE Std 1547:

- Tracking issues and leading investigation and coordination with IEEE to issue errata as necessary
- Answering questions from industry that arise during the application of IEEE Std 1547 and IEEE Std 1547.1
- Coordination with officers and industry leaders on the use and adoption of the standards as well as emerging issues
- Coordination with other standards working groups
- Monitoring and cataloging items for inclusion in future amendments or updates
- Contribution to development and dissemination of standards-related educational materials
- Planning and coordination with industry regarding the future of IEEE Std 1547 and related standards.

During this project, activities in this area resulted in one amendment to IEEE Std 1547 (Amendment 1, published in March 2020). In addition, preplanning efforts were initiated to inform the next revision cycle for the IEEE Std 1547 base standard.

With the publication of IEEE Std 1547.1-2020, that standard also transitioned to the maintenance activities listed here.

5 Changes/Problems

5.1 IEEE Std 1547-2018 Rollout Delay

An accumulation of issues that have arisen during testing are delaying the completion of the DER certification to IEEE Std 1547. These issues arise from the complexity and time requirements of the tests needed to verify conformance to the many new grid reliability requirements. Although Edition 3 of UL 1741 includes a revised and lengthened Supplement SB that clarifies questions about IEEE Std 1547.1 test procedures, DER inverter manufacturers and the nationally recognized testing laboratories that certify their products are running into a bottleneck in available test laboratories. This resulted in many inverters not being certified by January 1, 2022, as initially planned, so early-adopter utilities are pushing back compliance deadlines. The ACCEL team continues to work with UL and the industry to resolve these issues and avoid slowdowns in DER deployments.

6 Conclusion

As the proportion of generation coming from DERs increases, grid operators and DER industry stakeholders throughout the country are recognizing the need to adopt the new DER grid support functionality encoded in the updated IEEE Std 1547-2018 standard. The publication of IEEE Std 1547.1-2020 triggers this transition to begin on a nationwide scale and in a standardized fashion, creating a strong foundation for continued DER growth that does not sacrifice the reliability and resilience of the electric power system. Other countries are also beginning to look at the updated IEEE Std 1547 and IEEE Std 1547.1 when setting their own interconnection requirements.

Likewise, with the proliferation of IBRs connected directly to the bulk power system, industry has realized the need for robust, forward-looking requirements for large-scale IBRs that fall outside the scope of IEEE Std 1547. IEEE P2800 holds the potential to fill that large gap, allowing continued growth in transmission- and subtransmission-connected IBRs while maintaining or improving bulk power system stability; hence P2800 has the potential to be as impactful as the original IEEE Std 1547-2003, the foundational standard in the interconnection of DERs.

For these reasons, the IEEE Std 1547 series and IEEE P2800 are the core standards whose development and adoption this project seeks to accelerate. The other efforts under this project allow the ACCEL team (and, by extension, DOE) to remain abreast of emerging efforts and fill key technical leadership roles.

Bibliography: Inventions, Patents, Publications, and Other Results

The following publications were developed as part of this project. The standards listed here were authored by industry working groups with participation and leadership from the ACCEL team:

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