IBR Interconnection Requirements

STATUS AND NEEDS

Brief for Decisionmakers

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October 2024

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Interconnection of IBRs Is Surging in Power Systems Historically Designed Around Synchronous Resources

There were nearly 2,600 GW of generation and storage capacity in U.S. interconnection queues at the end of 2023 (Figure 1, p. 2). Astonishingly, this is twice as much capacity as is currently installed in the United States. More than 95% of the new generation in the queue is inverter-based resources (IBRs) such as wind, solar, and battery storage. While only about 20% to 30% of these resources will materialize, they are an excellent source of cost-effective, clean electricity. However, the challenges and opportunities they bring in terms of grid reliability are very different from those of synchronous generators traditionally used in conventional fossil-fueled and hydro generation.

The performance of synchronous generators—large rotating machines directly connected to the grid—is primarily based on their physical characteristics. These conventional power plants are equipped with relatively standardized controls, such as automatic voltage and frequency control and power system stabilizers, with well-established and well-documented principles and models. In contrast, solar, wind, and battery resources use power electronics in their interface with the grid, and their performance is primarily control/software-based. IBR behavior and functionality is much more flexible, and also more complex.[1] Many of these IBR controls are proprietary and, in some cases, protected by patents. Thus, the additional flexibility in controls and provision of essential reliability services is accompanied by increased performance diversity and modeling complexity.

Synchronous generators and power systems evolved hand in hand over the past 100 years, and power systems developed around synchronous generators' capabilities. In contrast, IBRs have been around for about 30 years—with rapid uptake only in the past 10 to 15 years—and they bring capabilities and characteristics that must adapt to the already well-established power systems.

Changing Systemic Grid Reliability Risks Indicate a Need for Comprehensive Interconnection Standards for IBRs

In the United States, a number of widespread, IBR-related large disturbance events have been reported by the North American Electric Reliability Corporation (NERC) since 2016 (Figure 2, p. 3). These reports highlight potential grid reliability risks. Several factors are challenging transmission providers' ability to identify and correct potential risks that may remain latent until a large-scale event occurs, factors including expedited generation interconnection timelines, a lack of detailed interconnection requirements, minimal plant-level

1 IBR manufacturers use a variety of control philosophies, plant-level control topologies, synchronization control loop implementations, freeze and unfreeze logic states, built-in protective functions, etc.

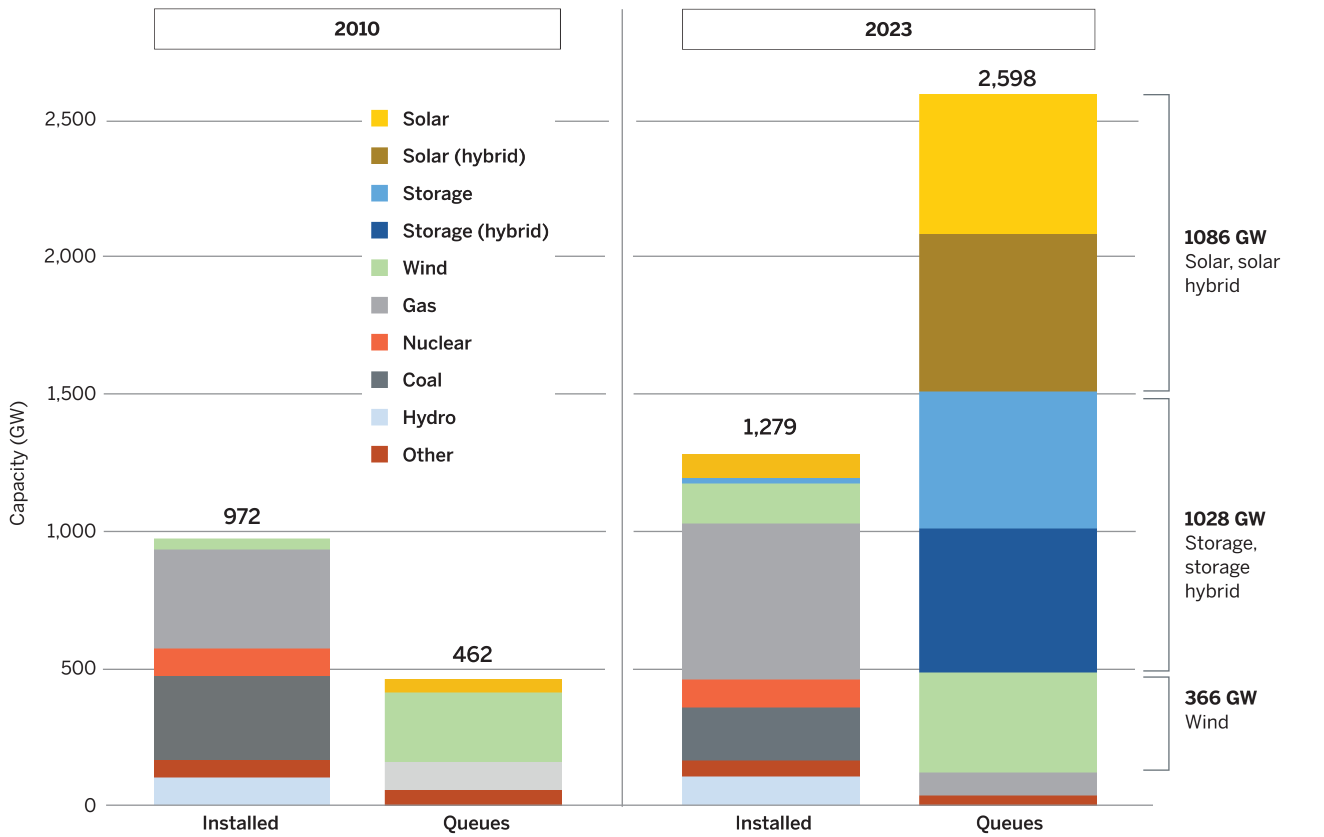
conformity assessments against the applicable requirements, inaccurate modeling, and inadequate reliability studies.

To support the reliable and secure operation of clean energy resources connected to the bulk power system, comprehensive interconnection and reliability standards for IBRs are needed. The standards should address such issues as IBR capabilities, expected performance, and cybersecurity requirements. In addition, the harmonization of such standards across the U.S., and even globally, could help to ensure efficiency and lower costs for equipment manufacturing and IBR integration.

Comprehensive interconnection and reliability standards for IBRs should address IBR capabilities, expected performance, and cybersecurity requirements. The harmonization of such standards across the U.S., and even globally, could help to ensure efficiency and lower costs for equipment manufacturing and IBR integration.

FIGURE 1

U.S. Installed Generation Capacity vs. Generation Interconnection Queue, 2010 and 2023

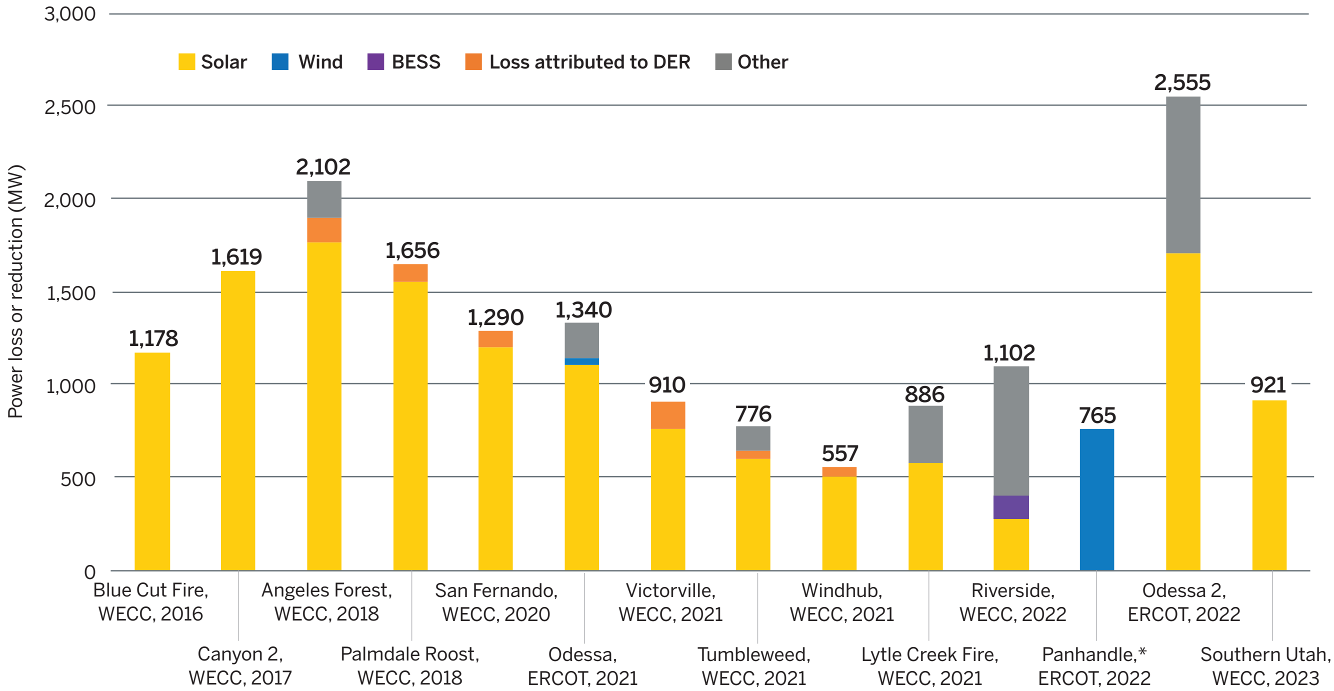


There were nearly 2,600 GW of generation and storage capacity in U.S. interconnection queues at the end of 2023, twice as much capacity as is currently installed in the U.S. Nearly all of the new generation in the queue is inverter-based resources (IBRs) such as wind, solar, and battery storage, which bring both challenges and opportunities for grid reliability.

Source: Adapted from Rand et al. (2024); Lawrence Berkeley National Laboratory.

FIGURE 2

Recent Disturbance Events Between 2016 and 2023 Reported by NERC



Each bar and the number above it show total generation loss in the disturbance event in MW. The colors distinguish the type of generation lost in each event. The labels on the x-axis show the disturbance event title and year.

Notes: BESS = battery energy storage system; DER = distributed energy resources; ERCOT = Electric Reliability Council of Texas; WECC = Western Electricity Coordinating Council.

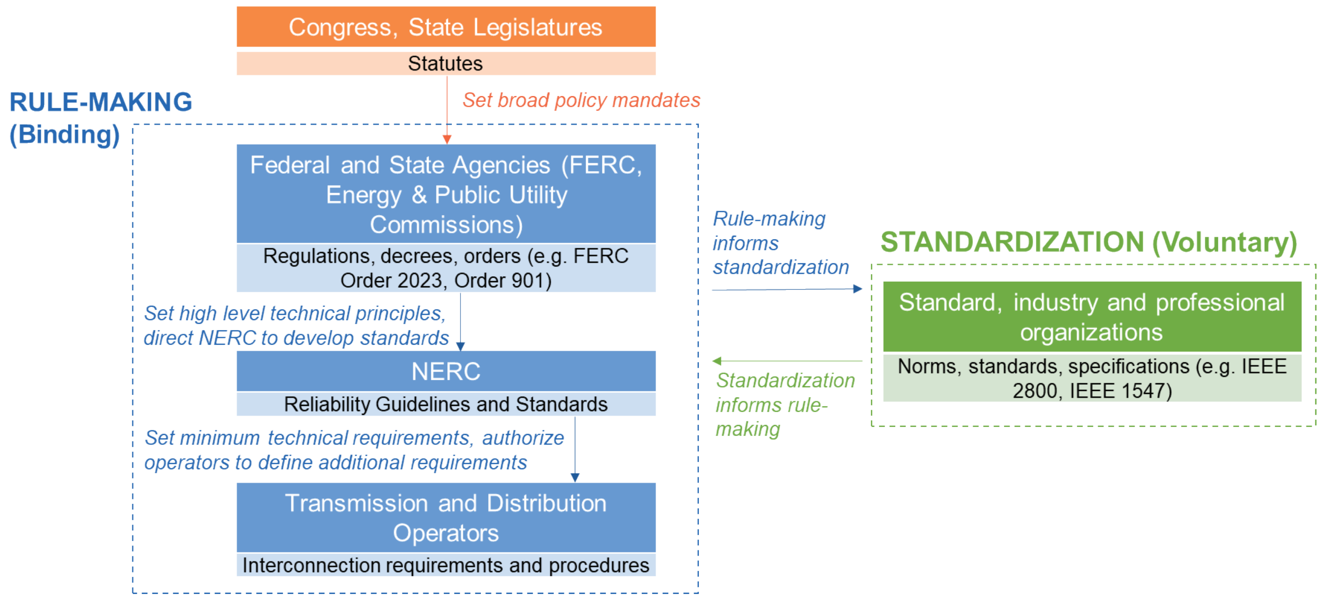
Source: Energy Systems Integration Group; data from North American Electric Reliability Corporation event reports (https://www.nerc.com/pa/rrm/ea/Pages/Major-Event-Reports.aspx).

The Relationship of Policy, Regulations, and Standards in the U.S.

Regulations for IBR interconnection exist in a broader context of policy, regulations, and standards in the U.S. Federal and state mandates and policies are ultimately put into practice through rulemaking at FERC, NERC, and public utility commissions. These may result in NERC Reliability Standards or other regulations being put into place. Transmission and distribution operators must comply with NERC's Standards, but they also have significant authority themselves in ensuring reliability of their local grid including the establishment of Facility Interconnection Requirements per NERC FAC-001 Standard. Figure 3 (p. 4) shows an illustration of how these efforts work together.

FIGURE 3

Illustration of the Relationship of Policy, Regulations, and Standards in the U.S.



Regulatory federal and state mandates and policies are ultimately put into practice through rulemaking at FERC, NERC, and public utility commissions. These may result in NERC Reliability Standards or other regulations being put into place. Transmission and distribution operators must comply with NERC's Standards, but they also have significant authority themselves in ensuring the reliability of their local grid. IEEE standards are voluntary, but the rulemaking informs the need for standardization, while approved IEEE standards in turn inform rulemaking and can potentially be adopted by appropriate regulators.

Source: Adapted from EPRI (2016).

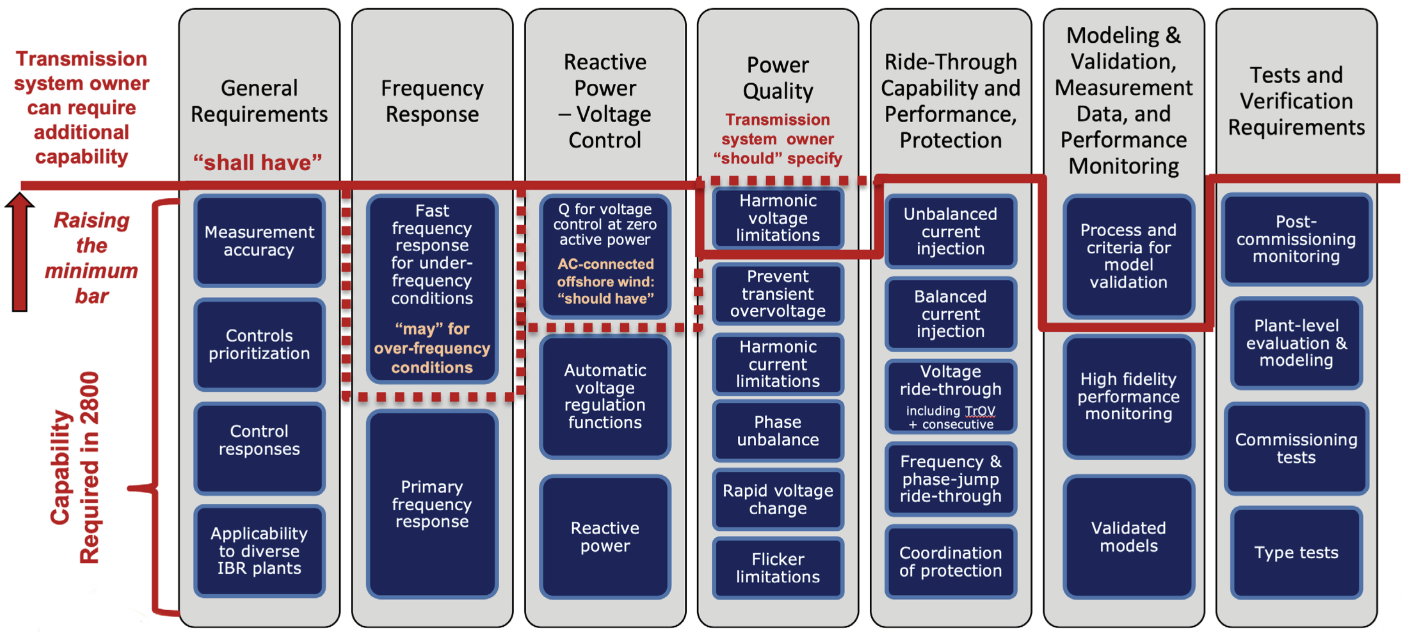
IEEE 2800-2022 Scope and Details

The IEEE 2800-2022 Standard for Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associate Transmission Electric Power Systems was developed in 2022 by a large body of industry experts from utilities, system operators, transmission planners, and manufacturers following an open and consensus-based process (IEEE, 2022). The standard successfully passed the IEEE Standard Association ballot among 466 balloters with more than a 94% approval rate. IEEE 2800-2022 provides a harmonized set of technical minimum interconnection capability and performance requirements that "raise the bar" to make power systems with high shares of IBRs more reliable, yet leaves sufficient space for specific regions or entities to establish requirements beyond those in the standard, if needed. As shown in Figure 4, the standard covers a broad range of IBR requirements.

With a few exceptions, there are no notable concerns from IBR manufacturers around future resources' ability to meet the majority of the new requirements; however, some degree of flexibility in terms of timing may likely be needed for conformance testing. Additionally, existing resources do have limitations that would require some exemptions if these requirements were imposed retroactively, although most transmission providers currently implementing IEEE 2800-2022 are not seeking retroactive applicability to existing resources for this reason. While there are a few requirements specified in the first (2022) edition of IEEE 2800 that future resources may not be able to meet in the short term, future revisions and continued improvement of this standard will be informed by what we learn from different stakeholders' interpretations of its language and the industry's experience with the standard's adoption by governing entities.

FIGURE 4

IEEE 2800-2022 Technical Minimum Capability Requirements



The technical minimum capabilities specified in IEEE 2800-2022 comprise general requirements and requirements for frequency response, reactive power/voltage control, power quality, and ride-through and protection. The standard also specifies requirements for modeling and model validation, measurement data, and performance monitoring, as well as test and verification requirements for conformity assessment that are currently being developed in IEEE P2800.2. The transmission system owner can add additional categories and detailed requirements beyond those specified in IEEE 2800 if desired. Everything below the red line has "shall" language and is strictly a requirement. The two boxes that include additional pink text have "may" or "should" language in the respective specifications. Regarding the "harmonic voltage limitations" category, there is no specific requirement as such in the standard but rather language that says that the transmission operators should specify the requirement.

Source: EPRI (2021).

However, IEEE 2800-2022 is not enforceable until it is adopted and implemented by an Authority Governing Interconnection Requirements (AGIR), an entity responsible for administering the interconnection process and requirements. This could be a regulatory body, an independent system operator or regional transmission organization (ISO/RTO), or a transmission provider. Recognizing the comprehensiveness of this standard and its ability to address systemic issues observed in NERC disturbance events, some ISO/RTOs and transmission providers in the U.S. have already started on the path of using IEEE 2800-2022. There are a number of adoption strategies currently being undertaken by different ISOs and utilities, each with certain advantages and disadvantages.

IEEE 2800-2022 Adoption Strategies

Generally, four different adoption strategies are seen (see Figure 5, p. 6).

General Reference

This adoption strategy references IEEE 2800-2022 in its entirety in the entity's existing binding documents or codes. This approach is simple to adopt but hard to put into action. One entity taking this path is Florida Power and Light. The main challenge with this approach is that the standard explicitly requires the adopting entity to make a number of important decisions and specify, for example, the reference point of applicability, chose specific settings from provided ranges, and chose certain performance metrics. Without such specifications, the adoption is incomplete and uncertain.

A number of adoption strategies are currently being undertaken by different independent system operators and utilities—each with certain advantages and disadvantages.

Detailed Reference With or Without Customization

This adoption strategy cites specific clauses of IEEE 2800-2022, allowing for a targeted or phased approach, and may or may not specify minimum capability requirements and functional settings (where options exist in the standard). While this approach could, and ideally should, include specifications of functional settings that customize IBR performance, to account for ambiguities in the standard or the local system needs, this is not always the case. The absence of customization for functional settings may in turn lead to a lack of clarity in case of conflicts between IEEE 2800-2022 and existing interconnection requirements. Duke Energy and the Independent System Operator of New England are among the regions that have taken this adoption approach.

Hybrid Integration with Reference, Customization, and Additional Specifications

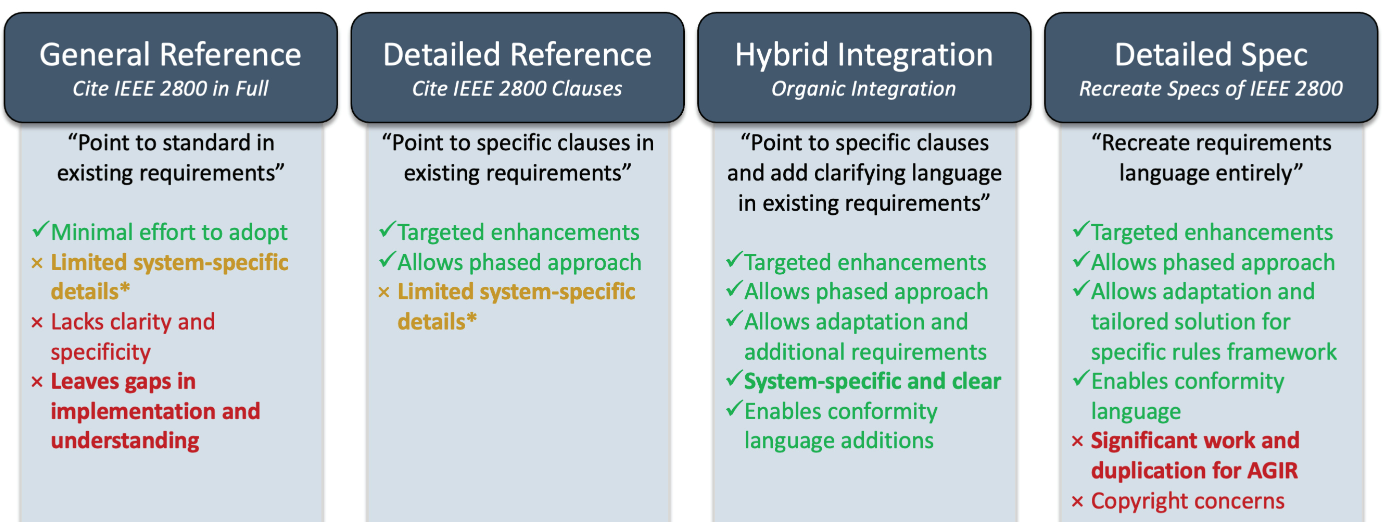
This strategy builds on the detailed reference with customization approach and adds clarifying language, modifications, and even additional requirements as needed for local system needs. This approach strikes a balance between effectiveness and ease of adoption. The additional clarity and specifications of subclauses of IEEE 2800-2022 add necessary details for applicable entities to effectively implement the standard. Note that adding additional performance requirements beyond IEEE 2800-2022 could make unified conformity assessment more challenging. Examples of entities that have taken this approach are the New York State Reliability Council (NYSRC), Midcontinent Independent System Operator (MISO), Southern Company, and the Electric Reliability Council of Texas (ERCOT).

Full Specification and Customization

This strategy is similar to the hybrid approach but instead of referencing, it copy/pastes (sometimes with modifications) the IEEE 2800-2022 requirements into existing requirements documents or recreates the requirements language entirely. This approach is comprehensive but may require duplication of work and a permission from IEEE SA to use or modify their copyright-protected content.[2] For example, Ameren

FIGURE 5

IEEE 2800-2022 Adoption Strategies



*** Industry practice has tended not to provide the necessary AGIR-specific details (i.e., functional settings) needed for complete adoption of IEEE 2800-2022.**

Notes: Green text indicates advantages of the adoption method, yellow text indicates limitations, and red text indicates gaps. More important advantages, limitations, and gaps are in bold. AGIR = Authority Governing Interconnection Requirements.

Source: Elevate Energy Consulting.

2 https://standards.ieee.org/ipr/copyright-permissions-form/

in Illinois has taken this adoption approach. ERCOT also started down this adoption path, but realized that important details from the original IEEE 2800-2022 can be easily "lost in translation" and switched to the hybrid integration approach.

In 2022, work began on IEEE P2800.2, "Recommended Practice for Test and Verification Procedures for Inverter-based Resources Interconnecting with Bulk Power Systems," to develop an accompanying set of uniform recommended practices regarding testing and verification of conformity with IEEE 2800-2022 requirements. IEEE P2800.2 focuses on plant-level conformity, which requires inverter-level tests and verification as well as overall IBR plant design evaluation, modeling, and studies; "as-built" evaluation; plant commissioning practices; and post-commissioning performance monitoring and validation throughout the lifecycle of an IBR plant. The widespread use of these practices could help support a more reliable and resilient IBR fleet in conformity with IEEE 2800-2022 requirements moving forward. IEEE P2800.2 is intended to be balloted and published in 2025.

Looking at the IEEE 2800 adoption efforts listed above, a general adoption pattern can be observed.

- Entities that have not yet developed their own comprehensive interconnection requirements for bulk power system–connected IBRs chose IEEE 2800-2022 adoption by general reference. They include a reference to IEEE 2800-2022 in their relevant documents, decide on the effective date, and wait for IEEE P2800.2 to be developed and approved before starting to assess newly connecting resources for conformity with IEEE 2800-2022.
- Entities that already have their own comprehensive interconnection requirements chose one of the other three adoption methods: detailed reference, hybrid integration, or detailed specification. They conduct a detailed gap analysis between existing interconnection requirements and the respective clauses of IEEE 2800-2022 and decide on priorities for implementation of certain clauses of IEEE 2800-2022. The entities then decide on the effective date and either develop new conformity assessment procedures, leveraging

existing practices or the draft IEEE P2800.2, or wait until IEEE P2800.2 is fully developed and approved before assessing newly connecting resources for conformity with IEEE 2800-2022.

FERC Order 901, NERC Work Plan and Standards Revisions

The adoption of IEEE 2800-2022 is voluntary, and, to date, too few entities have adopted it following one of the four approaches outlined above or are taking steps toward its adoption, effectively falling short of addressing persisting reliability risks. Therefore, regulatory entities are now stepping in more authoritatively to invoke changes to North American reliability standards applicable to IBRs. In October 2023, the Federal Energy Regulatory Commission (FERC) issued Order No. 901 that directed NERC to make sweeping changes to its reliability standards applied to IBRs and address significant gaps related to data sharing, model validation, performance requirements, and planning and operation studies. Additionally, FERC ordered NERC to modify its registration requirements to include smaller IBRs connected to the bulk power system that have a material impact on bulk power system reliability. In response, in January 2024, NERC published a workplan identifying priorities for standard improvement and the development of new standards (NERC, 2024). NERC also regularly publishes progress updates to FERC.[3]

The first batch of new NERC standards is expected to be filed with FERC in November 2024. The standards are being developed by NERC Standard Drafting Teams (SDT) made up of industry stakeholders. SDT meetings are open to the public, and all interested parties can participate in the drafting process.

NERC balloting of standards requires 60% approval to pass; however, recent NERC balloting of the draft reliability standards have shown historically low acceptance rates in early ballots, indicating a need for greater industry participation. While the two draft standards, PRC-028 for IBR disturbance monitoring and reporting and PRC-030 for IBR performance analysis and issue mitigation, successfully surpassed two-thirds approval in August 2024, the approval rate for the draft PRC-029

for IBR ride-through capability and performance requirements reached only about 53%. Regarding the latter, some stakeholders submitted comments suggesting that more alignment between NERC Standards and IEEE 2800-2022 requirements could potentially increase industry's acceptance of new NERC standards, for example, because some regions have already adopted the IEEE standard or are in the middle of the adoption process. NERC recently held a technical conference to gather feedback from industry stakeholders, and it subsequently released an updated draft PRC-029 that more closely mirrors the voltage and frequency ride-through curves within IEEE 2800-2022 as well as includes an exemption for frequency ride-through performance for legacy assets. These revisions are an effort to reach the 60% ballot necessary before the FERC submission due date of November 4, 2024. More education and impact assessment of IEEE 2800-2022 requirements, paired with broad and active industry participation in NERC Standard Drafting Teams, could facilitate further alignment while also informing future revisions and improvements of the IEEE standard.

IEEE 2800-2022 is intended to help raise the bar in terms of forward-looking IBR capabilities and configurable performance requirements. Both IEEE 2800 and the NERC standards will evolve in the years

3 For NERC filings to FERC 2024, see https://www.nerc.com/FilingsOrders/us/Pages/NERCFilings2024.aspx.

to come; however, this should not hinder or preclude industry from seeking harmonized and consistent IBR capability and performance requirements for newly connecting IBRs to the extent possible. IEEE 2800-2022 is filling a critical gap for the reliable interconnection of IBRs and the larger bulk power system, although, as is to be expected from new standards in new areas, industry has identified areas for improvement that will be addressed in subsequent amendments or revisions of the standard. At the present time, stakeholders will need to use engineering judgment and reason when applying IEEE 2800-2022 to newly connecting IBRs. Some degree of flexibility and latitude may be needed by the transmission provider and interconnection customer in applying requirements to existing and emerging technologies. As industry stakeholders collaboratively learn from the adoption of IEEE 2800-2022, RTOs/ISOs, transmission providers, IBR developers, and manufacturers should take their insights back into the IEEE 2800 and P2800.2 Working Groups to inform future, incremental improvements of the standard.

U.S. DOE i2X Forum for the Implementation of Reliability Standards (FIRST)

To help industry navigate changing standards and the interconnection requirements landscape, the U.S. Department of Energy (DOE) established a Forum on the Implementation of Reliability Standards (FIRST). The forum is led by the DOE Solar and Wind Energy Technology Offices in partnership with the Lawrence Berkeley National Laboratory, Energy Systems Integration Group, and EPRI, with support from Elevate Energy Consulting. The forum is the continuation of the DOE Interconnection Innovation e-Xchange (i2X) initiative, begun in 2022 to facilitate peer-learning and knowledge exchange and inspiring new interconnection ideas and capabilities. i2X FIRST is focusing on the cohesive implementation of solutions outlined in the i2X Roadmap (developed in 2023) related to standards, leveraging insights from early adopters.

The purpose of this forum is to go beyond the dissemination of standard language and to (1) delve into specific enhancements of interconnection requirements, (2) facilitate the practical implementation of IEEE 2800-2022, and (3) discuss linkages with regulatory activities such as FERC Order No. 901 and relevant NERC Standards that are under revision or in development. Interested parties can sign up for i2X FIRST meetings and access meeting materials, agendas and recordings on the project webpage at *https://www.energy.gov/eere/i2x/doe-transmission-interconnection-roadmap-transforming-bulk-transmission-interconnection*.

Call to Action

ISO/RTOs, transmission providers, and their customers will benefit from adopting large parts of voluntary industry standards such as IEEE 2800-2022 as an effective solution to mitigate reliability risks during this energy transition. The rapid pace of the energy transition calls for proactive steps to mitigate risks. The adoption of voluntary technical standards plays a major role in this process and can help inform policies, regulatory rulemaking, and other business decisions, as well as help streamline and expedite the interconnection process for new IBRs.

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This brief for decisionmakers is available at https://www.esig.energy/reliability-working-group/.

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