i2X Forum for the Implementation of Reliability Standards for Transmission (FIRST) Summary Notes

Interconnection Innovation e-Xchange (i2X)

DRAFT DOCUMENT – NOT FOR CITATION

Working Draft

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Disclaimers

Table of Contents

Executive Summary

The DOE i2X Forum for the Implementation of Reliability Standards for Transmission (FIRST) established an open industry forum to facilitate discussion, brainstorming, and information sharing regarding the supports the adoption of new standards and test procedures for inverter-based resources (IBRs)[1] connecting to the transmission and subtransmission electric system. Building on the 2024 *Transmission Interconnection Roadmap*, i2X FIRST convenes industry stakeholders to share practices on standard implementation of IEEE 2800-2022 and the upcoming IEEE P2800.2 recommended practices through webinars and workshops. Topics include IBR ride-through, modeling, monitoring, frequency and voltage support, and evolving technologies like grid forming inverters. Discussions also align with FERC directive and ongoing NERC standards revisions.

Season 1 of the i2X FIRST initiative provided a foundational exploration of IEEE 2800-2022, its core requirements, and early industry experiences with implementation. Meeting recordings, presentations and full synopsis and the brief recap summary from Season 1 are available here. Season 2 is continuing these efforts, with a focus on IBR plant design evaluations, change management during the interconnection process, IBR plant commissioning best practices, and emerging standards developments and technology adoption. Sign up for Season 2 i2X FIRST meetings here.

[1] Such as solar photovoltaic (PV), wind, and battery energy storage systems (BESS), and hybrid plants comprised of these technologies.

List of Technical Acronyms

AC	Alternating Current
ACE	Area Control Error
AGIR	Authority Governing Interconnection Requirements
AVR	Automatic Voltage Regulator
BOP	Balance of Plant
BPS	Bulk Power System
CHIL	Control Hardware in the Loop
COD	Commercial Operation Date
CPR	Duke Capability and Performance Report
DC	Direct Current
DER	Distributed Energy Resource
DFR	Digital Fault Recorder
DFT	Discrete Fourier Transform
DLL	Dynamic Link Library
EMT	Electromagnetic Transient
FFR	Fast Frequency Response
FRT	Frequency Ride-Through
GFL	Grid Following
GFM	Grid Forming
GIA	Generator Interconnection Agreement
GIP	Generator Interconnection Procedure
GO	Generator Owner
GOP	Generator Operator
HIL	Hardware in the Loop
HVDC	High Voltage Direct Current
IBR	Inverter-Based Resource
IFRO	Interconnection Frequency Response Obligation
IPID	IBR Plant Information Database
IRR	Intermittent Renewable Resource
ISO	Independent System Operator
LSL	Low Sustained Limit
OEM	Original Equipment Manufacturer
PC	Planning Coordinator
PDT	Phasor Domain Transient
PFR	Primary Frequency Response
PLL	Phase Lock Loop
PMU	Phasor Measurement Unit
POC	Point of Connection
POI	Point of Interconnection
POM	Point of Measurement

PPC	Power Plant Controller
RFI	Request for Information
ROCOF	Rate of Change of Frequency
RMS	Root Mean Square
ROI	Return on Investment
RPA	Reference Point of Applicability
RTO	Regional Transmission Organization
RVC	Rapid Voltage Change
SCADA	Supervisory Control and Data Acquisition
SSCI	Subsynchronous Control Interactions
SCR	Short Circuit Ratio
SIL	Software in the Loop
SMIB	Single Machine Infinite Bus
SSR	Subsynchronous Resonance
TOV	Transient Overvoltage
TP	Transmission Planner
TS	Transmission System
UDM	User-Defined Model
UFLS	Underfrequency Load Shedding
VRT	Voltage Ride-Through
VSC	Voltage Source Converter
WSCR	Weighted Short Circuit Ratio
WTG	Wind Turbine Generator

* Generally not including names of organizations, institutions, or initiatives.

May 27, 2025 Virtual Meeting

Season 2 Kickoff (~200 attendees)

Presentation recording and slides are available to download here. Figure 1 shows the makeup of meeting attendees by industry sector:

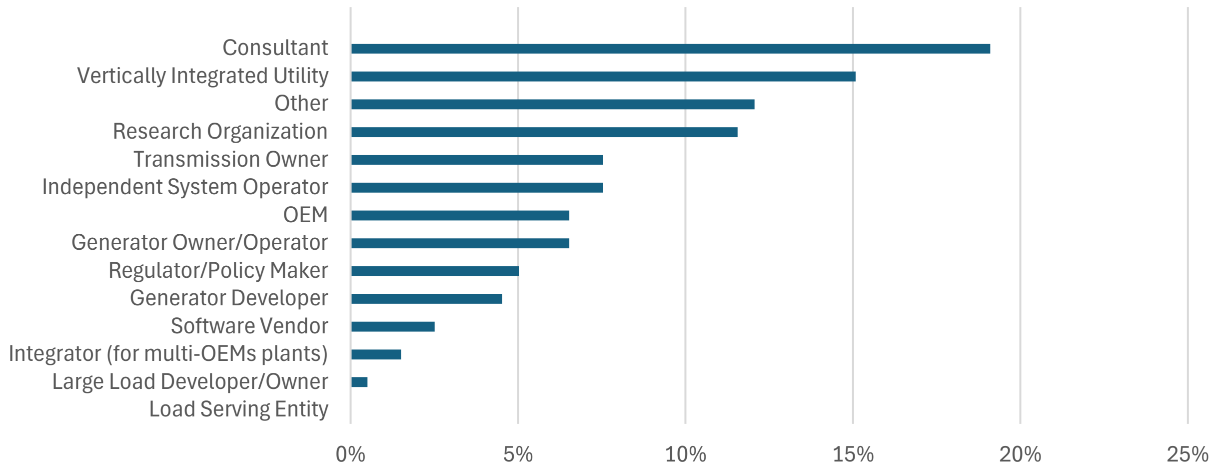


Figure 1: Meeting attendees by industry sector

This first meeting of Season 2 of the DOE i2X FIRST initiative provided a recap of Season 1 highlights and key takeaways, and status updates regarding IEEE 2800-2022 adoption, IEEE P2800.2 progress, and NERC Milestone 2 and 3 standards development efforts. Presentations included the following:

Julia Matevosyan, ESIG

Julia gave an overview of Season 1 topics and shared highlights from the initiate thus far. Season 1 monthly webinars and hybrid workshops were attended by over 1,225 unique participants across a diverse set of stakeholder groups including developers, utilities, system operators, OEMs, and consultants. Consultants comprised the highest percentage of attendees, and this is somewhat to be expected as this group is often supporting generator owner/operators or even independent system operators and utilities through the interconnection process. Season 1 materials can be downloaded on the ESIG i2X FIRST webpage. High-level key takeaways from Season 1 include:

- Harmonizing IBR requirements and enhancing conformity assessments, leveraging IEEE 2800-2022 and IEEE P2800.2, are vital for streamlining the interconnection process while supporting grid reliability.

- NERC or FERC adoption of IEEE 2800-2022 could lead to uniformity and consistency across entities and regions. Coordination with regulatory requirements at the FERC and NERC levels is critical to avoid overlaps, redundancy, and most importantly conflicting requirements. Industry participation in NERC standards development efforts is essential to align with IEEE 2800-2022 and to avoid duplication of effort.
- OEMs are advancing IBR ride-through capabilities and preparing for IEEE 2800-2022 implementation. Guidance is needed from transmission providers on configuration and setting parameters.
- Increased education, engagement, and collaboration is needed between OEMs, transmission providers, IBR plant developers and owners, to enable a streamlined process.
- Accurate IBR unit and IBR plant modeling is a foundational aspect of IEEE 2800-2022 performance conformity assessments. This includes IBR unit model validation based on type testing, IBR plant modeling including in EMT domain, verification of model structures and parameter values, model benchmarking between simulation tools and modeling domains, IBR plant design and as-built/as-left evaluations, commissioning tests, post-commissioning plant-level model validation, and other aspects.
- Retroactively applying advanced requirements to the existing fleet has proven to be difficult, costly, and burdensome on industry overall. Some improvements of IBR plant capability and performance can be achieved with software updates at a minimal cost, these are encouraged.
- Mandatory hardware upgrades have notable risks for existing assets, should be carefully considered.
- Enhancing standards on a regular basis to keep pace with technological advancements, and pro-active requirements for emerging capabilities (prior to their utilization) could minimize the need for retroactivity and ensure continuous improvement of IBR plant performance.

Julia also introduced the agenda for Season 2 which will focus on IBR plant design evaluations, change management during the interconnection process, IBR plant commissioning best practices, and emerging standards developments and technology adoption. Lastly, a brief industry survey conducted at the end of Season 1 also recommended other topics of interest including real-world examples of challenges in overcoming issues to get the most benefit from resources (i.e., tariffs or market limitations), impacts of large loads on transmission grids, oscillations due to changes in load and IBR interactions, and minimum modeling requirements needed for system studies.

Jens Boemer, EPRI

Jens described industry progress towards adoption of IEEE 2800-2022 and the various adoption methods for the standard. He described four generally recognized methods of adoption:

- General reference
- Detailed reference and customization
- Hybrid reference, customization, and specification
- Full specification and customization.

Each method has benefits and challenges yet the hybrid integration approach and the detailed reference approach appear to be widely adopted by industry stakeholders depending on their unique circumstances. Figure 2 shows a recap of an ongoing assessment that EPRI is conducting that shows how industry is adopting the standard. While Clause 7 (ride-through requirements) are widely adopted by most entities, power quality and protection requirements are much less widely adopted. The front matter clauses of IEEE 2800-2022 (Clauses 1-3) are often not referenced, or generally referenced (without customization).

The following are a few adoption methods and approaches used by entities across the country:

- SPP has used a phased adoption strategy with detailed reference to IEEE 2800-2022, and is applying this to the SPP 2025 DISIS queue and beyond. This approach appears to be following the successful adoption strategy used by MISO, with planned additions for grid forming (GFM) inverters.
- ERCOT has also used a phased adoption strategy with NOGRR 245, NOGRR 255, and NOGRR 272 and PGRR 121 nodal operating guide and planning guide revision requests (with additions for GFM batteries). This effort is using a hybrid reference, customization, and specification approach. Phase 1 efforts with NOGRR 245 were delayed three years, mainly due to the fact that ERCOT applied these rules retroactively to existing resources.
- ISO-NE has also adopted IEEE 2800-2022 via planning procedure changes using a detailed reference approach for Clauses 3 to 7, with only 3 succinct pages of material. This applies to new IBRs on or after February 2, 2024.
- NERC has used a full specification approach and is not adopting IEEE 2800-2022 directly or by reference; rather, requirements are individually being aligned with the standard through stakeholder efforts. IEEE 2800-2022 also conflicts with some aspects of the FERC Generator Interconnection Agreement (GIA) such as reactive power capability requirements.

Company	Phase (if applicable)	Adoption Approach (End)	Retroactive Application on Legacy IBRs	Reference Point of Applicability (RPA)	Performance and Capability?	Clause 1: Overview	Clause 2: Normative references	Clause 3: Definitions, acronyms, abbreviatio	Clause 4: General requirements	Clause 5: Reactive power—voltage contro	Clause 6: Active power—frequency respon	Clause 7: Response to TS abnormal condition	Clause 8: Power quality	Clause 9: Protection	Clause 10: Modeling data	Clause 11: Measurement data	Clause 12: Test and verification	Grid-forming Requirements
Ameren IL		Hybrid Reference Customization &	✗	POI	✓	○	○	○	○	◑	○	○	○	○	○	○	○	○
Ameren Transmission Company of Illinois (ATXI)	Interim Phase 1 (ahead of MISO)	Detailed Reference & Customization	✗	POI	✓	○	○	○	○	○	○	◕	○	○	●	○		
	Phase 1 (aligned with MISO)	Hybrid Reference Customization &	✗	POI	✓	○	○	○	●	○	○	◕	○	○	○	○		
Bonneville Power Administration (BPA)		Detailed Reference & Customization	✗	POI	✓	○	○	◑	●	●	●	●	◑	◑	●	◑		
Duke Energy		Hybrid Reference Customization &	✗	POI	✓	○	○	◑	◕	●	●	●	**◕**	●	●	●	**◑**	○
ERCOT	Phase 1	Hybrid Reference Customization &	✓	POI	✓	○	○	○	◔	●	○	●	○	●	**◔**	**◔**	**◔**	
	Phase 2	Hybrid Reference Customization &	✓	POI	✗	○	○	○	○	○	○	○	○	○	○	◑	○	○
HECO	Stage 3 Hawaii RFP	Hybrid Reference Customization &	✗	POI	✓	○	○	○	◔	●	◕	◑	●	●	●	●	○	
ISO-NE		Detailed Reference & Customization	✗	POM	✓	○	○	●	◕	◕	◕	◕	○	○	○	○	○	○
MISO	Phase 1	Detailed Reference & Customization	✗	POM	✓	○	○	○	◑	○	○	◕	○	○	**◔**	○	○	
	Phase 2	Detailed Reference & Customization	✗	POM	✓	○	○	○	◑	**◕**	◕	◕	○	○	**◔**	◕	○	
NYSRC		Detailed Reference & Customization	✗	POI	✓													
North American Electric Reliability Corporation (NERC)	Milestone 2	Full Specification & Customization	✓	POM	✓	○	○	◔	○	○	○	◕ PRC-029	○		○	◕ PRC-028	◔ PRC-030	○
Natural Resources Department of Canada	SREPs Program	General Reference	✗	POI	✓	○	○	○	○	○	◑	○	○	○	○	○	○	○
San Diego Gas & Electric Co.		Hybrid Reference Customization &	✗	POI	✓	○	○	○	○	**◑**	**◑**	◑	◔	**◑**	**◑**	◕	◔	○
SaskPower		Hybrid Reference Customization &	✗	POI	✓	○	○	○	○	**◕**	●	◕	○	○	○	○	○	○
Southern California Edison (SCE)	Phase 1	Detailed Reference & Customization	✗	POI	✓	●	●	●	●	◑	◑	**●**	●	●	○	○		
Southern Company	Phase 1	Detailed Reference & Customization	✗	POI	✓	○	○	○	◑	●	●	●	**◑**	●		◕		○
	Phase 2	Detailed Reference & Customization	✗	POI	✓	○	○	◕	◑	●	●	●	**◑**	●	●	◕	**◔**	○
	Phase 3	Detailed Reference & Customization	✗	POI	✗	○	○	◕	○	○	○	○	○	○	●	○	**◕**	○
SPP	Phase1	Detailed Reference & Customization	✗	POM	✓	○	○	○	◑	○	○	◕	○	○	○	●	○	
SRP	Phase 1	Hybrid Reference Customization &	✗	POI	✓	○	○	●	●	●	●	◕	**◕**	●	●	●	●	○
Tennessee Valley Authority (TVA)	Phase 1	Hybrid Reference Customization &	✗	POM	✓	●	○	●	●	●	◕	●	**◕**	●	●	●	○	○

<u>Legend:</u> ○ – not adopted | ◔ , ◑ , ◕ , ● – various adoption degrees | **◔** , **◑** , **◕** , **●** – various degrees of own specs

Figure 2: Recap of Ongoing Assessment of Industry Adoption of IEEE 2800-2022 [Source: EPRI]

The following lessons learned were emphasized:

- Adoption of IEEE 2800-2022 for new IBRs with specified transition period is relatively easy; adoption for legacy IBR is challenging.
- Reference to IEEE 2800-2022 or its specific clauses increases harmonization and clarity.
- Include a table listing exceptions for clauses or sub-clauses of IEEE 2800-2022.
- Some sub-clauses of IEEE 2800-2022 require specified decisions by the Transmission System (TS) owner/operator or Authority Governing Interconnection Requirements (AGIR).
- Drafting new language may trigger significant stakeholder discussions and debate, as well as inadvertent loss of specific details of IEEE 2800-2022 language (footnotes in IEEE 2800-2022 contain important clarifying details but are often overlooked while drafting new language).
- Some requirements or language in IEEE 2800-2022 likely needs to be revised such as addressing challenging requirements or removing implied barriers for GFM technology.

Lastly, Jens discussed the future plans for IEEE 2800-2022 and what EPRI considers to be the “preferred” approach (see Figure 3). This includes near-term revisions to the standard and IEEE 2800.1/.3 recommended practices for GFM equipment as well as longer term incremental changes to the standard to keep pace with technology.

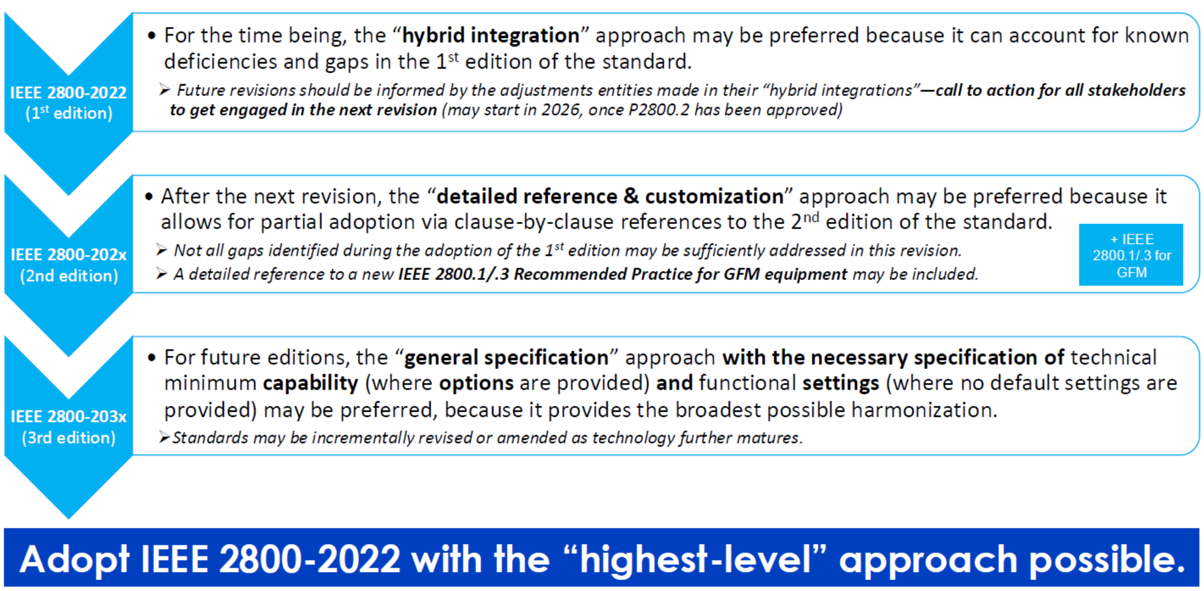


Figure 3: IEEE 2800-2022 Adoption and Revision Roadmap [Source: EPRI]

Andy Hoke, NREL

Andy provided an overview of IEEE P2800.2 content and an update on drafting progress. The requirements of IEEE 2800-2022 each have a Reference Point of Applicability (RPA) – they point where the requirements apply – and almost all requirements have the RPA at the Point of Measurement (POM) of the IBR plant (see Figure 4). Thus, IEEE 2800-2022 requirements are mostly applicable to the entire IBR plant, not to specific devices or components within the plant.

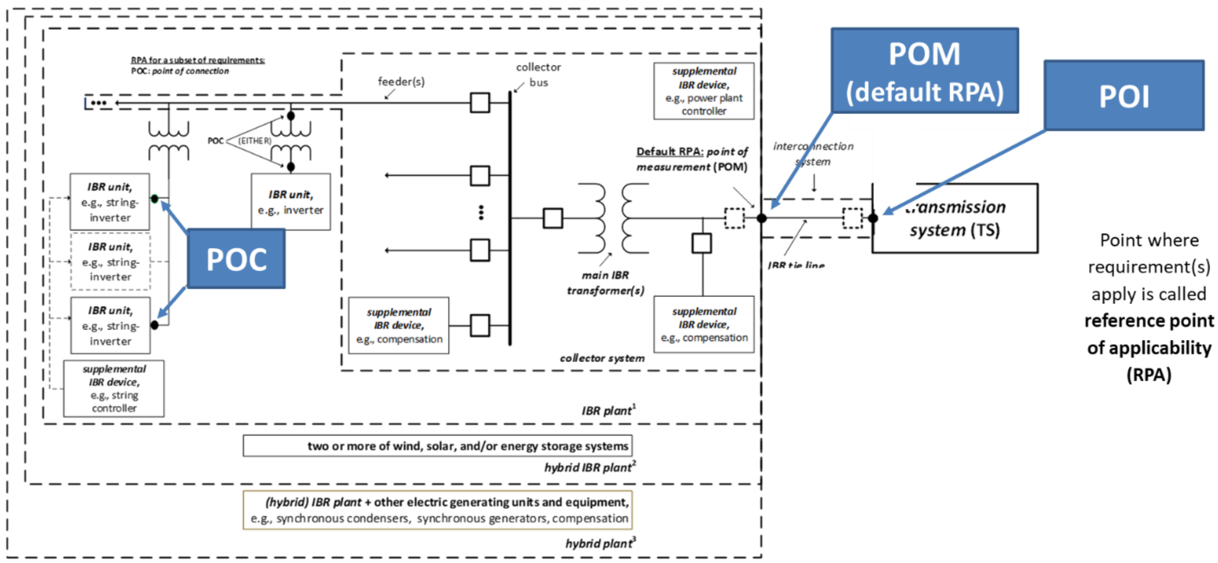


Figure 4: Visualization of IEEE 2800-2022 Reference Points of Applicability [Source: IEEE]

IEEE P2800.2 includes recommended practices regarding the test and verification methods and practices that ensure IBR plant conformity with the standard requirements. The drafting team is compiling and seeking consensus on industry recommended practices and producing them in a consolidated way in IEEE P2800.2. Note that IEEE P2800.2 includes recommended practices; therefore, it primarily uses "should" language rather than "shall" language.

The document will include a framework and procedures for IBR plant standards conformity assessment including the following (see Figure 5) steps that cross multiple stakeholders:

- IBR unit-level type tests (results used for unit-level model validation)
- Design evaluation using verified IBR plant model (including procedures to validate the IBR plant model)
- As-built evaluations
- Commissioning tests
- Post-commissioning model validation, monitoring, periodic tests, and verifications

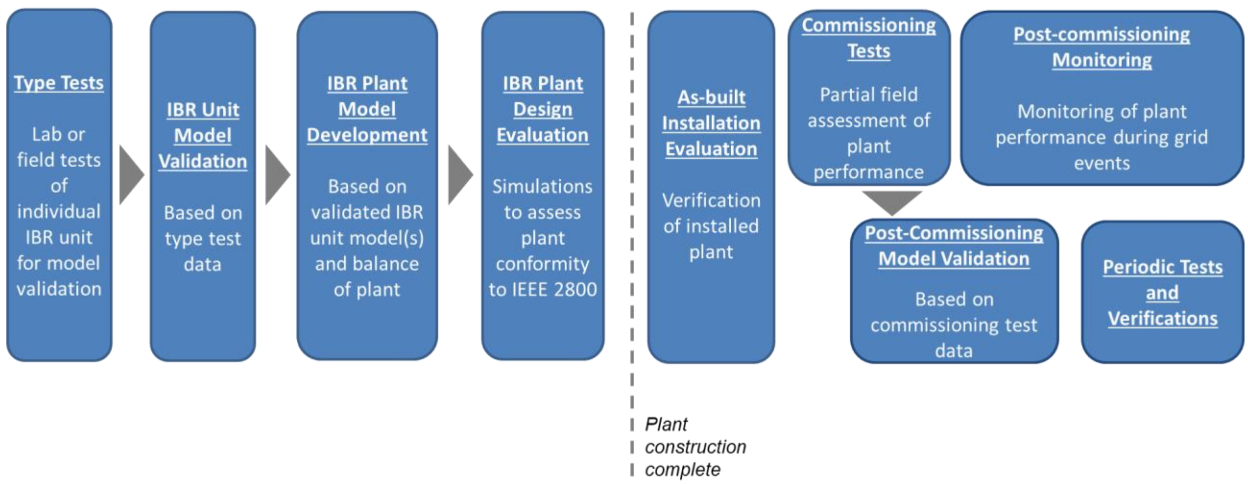


Figure 5: Overview of Conformity Assessment Steps in IEEE P2800.2 [Source: IEEE]

The recommended practices are not intended to define (or redefine) the interconnection process for new generators – this is specifically out of the scope of IEEE P2800.2. The procedures are intended to be used as a part of the interconnection process – particularly around designing, evaluating, verifying, and validating the performance of an IBR plant.

As almost all requirements in IEEE 2800-2022 apply to the IBR plant and not individual inverters/turbines, certification of inverters/turbines is not applicable because conformity is assessed at the plant level. Additionally, the type tests in IEEE P2800.2 do not generally include pass/fail criteria and instead provide data to be used in unit-level model validation. This concept differs from the IEEE 1547/1547.1 and UL 1741 paradigm used on the distribution system.

Andy emphasized that adoption of IEEE 2800 is not necessarily contingent upon publication of IEEE P2800.2. In the absence of IEEE P2800.2, IBR owners, TS owners/operators, original equipment manufacturers (OEMs), etc., can develop their own conformity assessment procedures or use existing procedures. For systems experiencing IBR ride-through events/problems, some requirements may be higher priority than others (e.g., ride-through, transient overvoltage (TOV), rate-of-change-of-frequency (ROCOF), and phase jump).

The IEEE P2800.2 working group continues to develop the recommended practices and test procedures following the proposed schedule shown in Figure 6. The group has been working on IEEE P2800.2 for over three years, and 94% of members agreed to send the draft recommended practice to ballot. The ballot pool has been established and SA initial ballot is open presently; public comments can be submitted through July 7, 2025, here. The group expects to gather useful feedback to move the draft towards completion with a tentative publication time of around Q1/Q2 2026 if everything remains on track.

Figure 6: IEEE P2800.2 Working Group Timeline [Source: IEEE]

After IEEE P2800.2 is approved, revisions to IEEE 2800-2022 will likely start in 2026. Various industry efforts are working towards a standard for GFM IBR equipment or plants (with an initial focus on battery energy storage systems (BESS)) connected to the bulk power system (BPS).

Alex Shattuck, ESIG

Alex provided a refresher on FERC Order 901 directives to NERC to enhance or develop new NERC Reliability Standards to address IBR-related reliability risk in data sharing, model validation, planning and operational studies, and performance requirements. Milestone 2, submitted to FERC in Q4 2024, focused on IBR disturbance monitoring (PRC-028-1), ride-through performance (PRC-029-1), and post-event performance validation (PRC-030-1). PRC-028-1 and PRC-030-1 are approved by FERC and industry is awaiting next steps regarding PRC-029-1.

NERC is presently working on its Milestone 3 efforts with four standards projects underway:

- Project 2020-06 – Verifications of Models and Data for Generators (MOD-026, MOD-027, FAC-002)
- Project 2021-01 – System Model Validation with IBRs (MOD-033)
- Project 2022-02 – Uniform Model Framework for IBR (MOD-032, TOP-003, IRO-010)
- Project 2022-04 - Electromagnetic Transient Modeling (MOD-032, FAC-001, FAC-002)[2]

Alex shared some keys for success for these projects such as learning from Milestone 2 experience; leveraging industry consensus through efforts like IEEE P2800-2022 and P2800.2; using existing best practices such as the NERC dynamic modeling recommendations, NERC

[2] Related but not technically a Milestone 3 project.

alerts, and disturbance reports; gathering input from OEMs; carefully handling retroactivity; and recognizing that FERC directive can have flexibility in interpretation with sufficient technical justification.

Interactive Group Discussion

The MOD-033 drafting team is making minimal revisions to the standard and stating this will meet the FERC Order 901 directives. Any thoughts on how FERC will respond or what actions FERC or NERC may take?

When a drafting team comes to this conclusion, the team needs to have technical justification and rationale for why they believe that this decision meets the FERC directive. The more technical basis possible, the more likely that FERC will accept their perspective. Part of the last drafting team ballot asked these questions to the industry. If NERC or FERC has issues with these perspectives, then FERC will likely respond to NERC's submittal of the standard revisions accordingly later in 2025.

What is the most efficient way to adopt IEEE 2800 as part of enforceable standards?

There are varying ways to adopt IEEE 2800-2022 ranging from general reference to full customization. Most entities are using a detailed reference or hybrid integration approach where the standard (or specific clauses) are adopted, and specific details are provided to help aid in effective implementation. This minimizes rework, enables adoption with minimal additional language in requirements documents while also providing the technical details that interconnection customers need throughout the process. Pros and cons of various adoption methods are covered in ESIG's Brief for Decision-makers: IBR Interconnection Requirements, Status and Needs posted here.

Are there any pertinent updates on IEEE P2800.2 drafting efforts?

The type testing section is nearly complete and in "good shape" according to the team. The plant-level design evaluation materials are likely where most the technical work is still needed. This is one of the last steps in the design process. The team has lots of content and work, but the content needs further refining. Portions of the commissioning and post-commissioning steps are relatively mature. Refer to above link to submit public comments by early July 2025.

Will it be possible for OEMs to state that they tested according to IEEE P2800.2 recommended practices and can prove it has capabilities?

OEMs will be expected to provide type test results and data for IBR unit model validation efforts to demonstrate the model matches reality. IBR developers should be requesting from OEMs documentation and information regarding these reports. This will also tie in with the revisions to NERC MOD-026-2 underway. OEMs may be able to provide information about the "compatibility" of their equipment with IEEE 2800-2022, including a list of equipment capabilities that can support IBR plant conformity with the standard—the draft P2800.2 currently does not include procedures to verify such OEM self-declarations.

Were there any situations where test and verification methods could not be created to demonstrate conformity with IEEE 2800-2022 requirements?

Some requirements have proven challenging to develop test and verification procedures such as transient overvoltage. These can be tested but they are probabilistic in nature and thus make testing very difficult and burdensome. Some of these findings may help inform future revisions to standard but could also—for the time being—be a requirement that is not assessed pre-commissioning yet could be monitored during operations if sufficiently accurate measurement devices were used.

Does it make sense to have hardware-in-the-loop (HIL) testing and certification to a certain "typical" plant setup?

IEEE P2800.2 does not provide options for using a typical or generic plant setup. This concept may be used for some of the inverter-level requirements, but the IBR plant-level requirements should be tested on a site-specific basis.[3]

What are lessons learned from ERCOT NOGRR 245 and IBR ride-through maximization?

ERCOT embarked on NOGRR 245, which adopted portions of IEEE 2800-2022 requirements. Resource Entities are required to "maximize" IBR ride-through capability within equipment limitations (up to hardware-based limits). IBR ride-through maximization has proven an effective way to improve IBR performance and grid reliability; however, the process and methods for doing so should be carefully implemented. Various ride-through issues have been uncovered through this process; however, working with the OEMs to make changes to equipment and to update the models is a long and arduous (and costly) process. See recent presentation on this topic here.

Key Themes

- **Season 1 Recap:** Over 1,225 unique stakeholders participated in Season 1, with consultants making up the largest group. Key takeaways emphasized harmonizing IBR requirements, improving model quality, and the importance of coordination across NERC, FERC, and IEEE efforts.
- **Modeling and Conformity Linkage:** Accurate IBR plant-level modeling and validation—including type testing, commissioning, and post-commissioning verification—are essential for assessing IEEE 2800-2022 conformity.

[3] IEEE 2004-2025 provides a Recommended Practice for Hardware-in-the-Loop (HIL) Simulation Based Testing of Electric Power Apparatus and Controls.

- **Industry Collaboration and Transparency Needs:** Stronger collaboration between OEMs, developers, and transmission providers is needed to improve modeling quality, clarify expectations, and support streamlined interconnection processes.
- **IEEE 2800-2022 Adoption Methods and Lessons Learned:** Four adoption methods (general reference to full specification) are used across ISOs/RTOs; hybrid and detailed reference approaches are most common. Adoption is easier for new IBRs, but legacy retrofits are more complex and costly.
- **Transmission Provider Implementation Examples:** SPP, ERCOT, and ISO-NE are applying IEEE 2800-2022 using phased and customized strategies. ERCOT's experience with NOGRR 245 highlights the benefits of IBR plant ride-through maximization up to hardware limits but also the challenges of retroactive application.
- **Need for Clarification and Flexibility in Standards:** Some IEEE 2800-2022 requirements may need revision or clarification—particularly those that create challenges for grid-forming inverters or that imply barriers to implementation. Flexibility and coordination are key for practical adoption.
- **IEEE P2800.2 Drafting and Scope:** IEEE P2800.2 provides recommended practices for conformity assessment of IBR plants, including type testing, model validation, commissioning, and post-commissioning steps. It uses "should" language and is not intended to redefine interconnection processes.
- **Plant-Level Conformity Emphasis:** IEEE 2800-2022 applies to the full IBR plant, not individual devices, meaning that model validation and testing must occur at the plant level. Inverter-level certification is not sufficient.
- **NERC Standards and FERC Order 901 Response:** PRC-028, -029, and -030 standards address IBR monitoring, ride-through, and post-event validation. NERC Milestone 3 includes ongoing standards updates that build on IEEE 2800-2022 and require industry consensus, best practice integration, and careful retroactivity planning.
- **Future of IEEE 2800 and GFM Capabilities:** Revisions to IEEE 2800 are expected post-2026, along with additional IEEE recommended practices focused on GFM IBRs, with the first edition focused on battery energy storage systems (BESS) connected to the bulk power system.

June 24, 2025 Virtual Meeting

NERC Milestone 3 Update (~230 attendees)

Presentation recording and slides are available to download here. Figure 7 shows the makeup of attendees by industry sector:

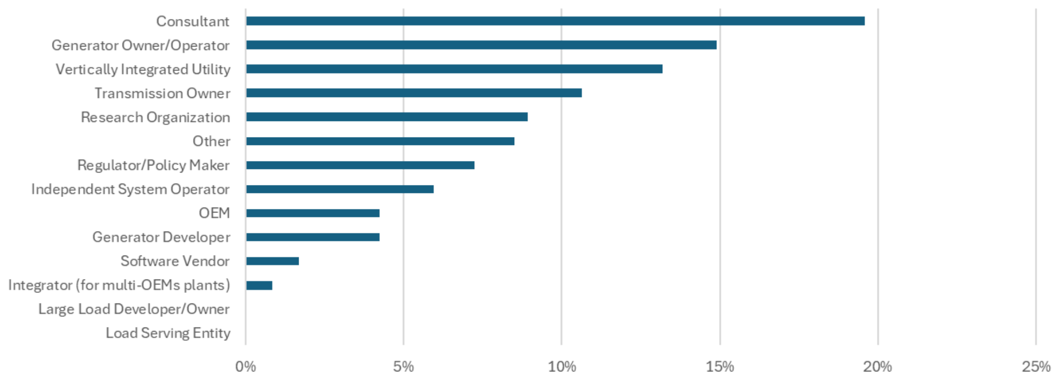


Figure 7: Meeting attendees by industry sector

This second meeting of Season 2 of the DOE i2X FIRST initiative focused on the North American Electric Reliability Corporation (NERC) Milestone 3 standards projects, the current state of IBR modeling in North America, and legacy IBR plant modeling practices. Presentations included the following:

<u>Sandhya Madan, NERC</u>

Sandhya provided an overview of NERC standards revisions underway related to FERC Order 901. NERC has implemented a four-part milestone plan spanning several years (see Figure 8).

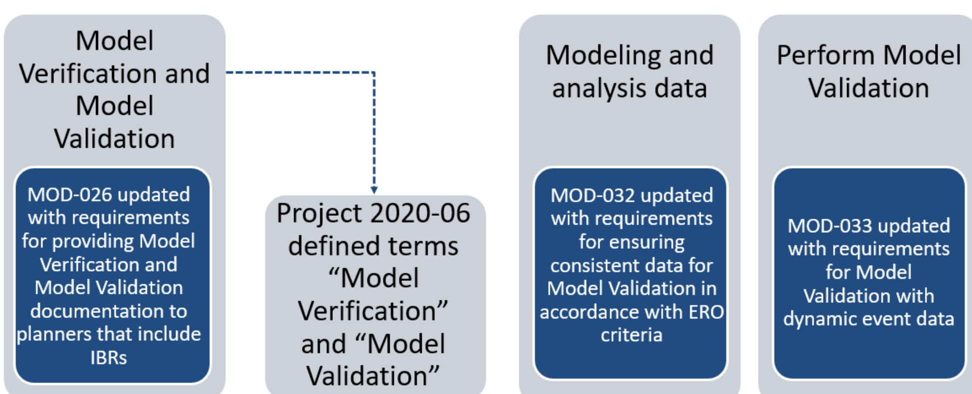
Figure 8: NERC Work Plan Milestones for FERC Order 901 [Source: NERC]

Milestone 1 involved NERC submitting its Order 901 work plan to FERC. Milestone 2 included standards development efforts to address IBR disturbance monitoring (PRC-028), disturbance ride-through and performance requirements (PRC-029), and post-event performance validation (PRC-030). Those standards were submitted by NERC to FERC before the November 2024 deadline. In February 2025, FERC approved the new IBR definition (see below) and proposed Reliability Standards PRC-028-1, PRC-002-5 (for synchronous generators), and PRC-030-1.[4] The implementation plans for each standard were also approved.

> ***NERC Definition of Inverter-Based Resource:*** *A plant/facility consisting of individual devices that are capable of exporting Real Power through a power electronic interface(s) such as an inverter or converter, and that are operated together as a single resource at a common point of interconnection to the electric system. Examples include, but are not limited to, plants/facilities with solar photovoltaic (PV), Type 3 and Type 4 wind, battery energy storage system (BESS), and fuel cell devices.*

Current standards drafting efforts are now focused on Milestone 3 standards revisions, which relate to data sharing and model validation for all applicable IBRs. Figure 9 illustrates the various standards revision efforts underway presently targeting model verification and validation, a uniform modeling framework, and system model validation. The related standards projects include:

- **Project 2020-06 Verifications of Models and Data for Generators:** This project is revising MOD-026 (and consolidating MOD-026 and MOD-027) and has also developed "Model Verification" and "Model Validation" terms for the NERC Glossary of Terms.
- **Project 2021-01 System Model Validation with IBRs:** This project is revising MOD-033 with minor editorial and technical revisions.
- **Project 2022-02 Uniform Modeling Framework for IBR:** This project is revising MOD-032, IRO-010, and TOP-003, as well as developed a definition for "Distributed Energy Resource" for the NERC Glossary of Terms.



[4] At the time of writing, FERC has not made any statement regarding PRC-029-1 approval.

Figure 9: NERC Milestone 3 Summary [Source: NERC]

All three standards projects have now completed their initial ballots. Table 1 provides an overview of the results of those initial ballots. The drafting teams are currently responding to industry comments and feedback provided, making revisions to the standards and implementation plans, and will be re-posting the standards for a next round of balloting in July/August timeframe. The standards must be submitted to FERC by the November 2025 deadline.

Table 1: Initial Ballots for Milestone 3 Standards

Project	Standard	Standard Ballot Results	Implementation Plan Ballot Results
Project 2020-06	MOD-026-2	32.47% (Fail)	40.22% (Fail)
Project 2021-01	MOD-033-2	57.06% (Fail)	59.43% (Fail)
Project 2022-02	MOD-032-2	39.05% (Fail)	39.46% (Fail)
	IRO-010-6	41.62% (Fail)	
	TOP-003-8	34.70% (Fail)	

NERC is also ramping up initial efforts related to Milestone 4 activities. The Milestone 4 SARs will be published around August timeframe for industry comment. NERC is seeking nominations for Milestone 4 drafting team members – specifically looking for individuals from utilities, Regional Entities, and vendors with expertise in planning and operational studies with IBRs. These projects will focus on the NERC TOP, IRO, FAC, PRC, and TPL standards as well as revise the definitions for Real-Time Assessment, Operational Planning Analysis, and Balancing Contingency Event to include IBR performance and sudden IBR output reduction.

Miguel Cova Acosta, Vestas

Miguel presented on the current state of IBR modeling in North America, particularly from Vestas' perspective. Accurate IBR modeling is essential for grid reliability, project stability, and long-term success throughout the lifecycle of the asset. Standard library models are widespread due to their simplicity, ease of use, and ease of review; they are mandated across many regions and used widely in both interconnection studies and planning cases. This can pose a challenge because these models may give the illusion of compliance. The models may appear to provide a smooth and compliant response; however, they may not reflect the dynamic characteristics of the asset under varying system operating conditions, curtailments, etc. This can result in misleading study results that introduce reliability risks. Miguel emphasized the need for IBR developers to raise internal standards in terms of model quality and fidelity, particularly with the use of user-defined models (UDMs).

During the interconnection process, IBR plant design evolves as equipment is selected, plant and protection systems are designed, and site controls are tuned. After the interconnection process, an IBR plant may have further changes due to firmware updates, plant upgrades, and further parameter tuning. Thus, the models must also evolve and refine as the site specifications change. However, current requirements and practices tend to discourage model updates because they may result in interconnection delays and restudies. Up through energization, industry needs a framework that encourages model updates to reflect latest changes rather than punishing entities for making improvements to the models. Additionally, once the resource enters commercial operation, it is imperative that the models reflect the actual installed equipment to support accurate reliability studies.

Use of standard library models, instead of OEM-validated UDMs, may create a false sense of grid code compliance for the IBR developer. Where available, OEM-supplied UDMs with verified site-specific model parameters should be used during interconnection studies and IBR plant performance conformity tests since they are the most accurate representation of the actual controls, protections, and overall representation of the asset. Use of models that do not have all the key controls features of the physical asset may lead to a disconnect between the model and actual performance, introducing reliability risks. Leaning towards model simplicity rather than model accuracy is a prevalent issue across various systems in North America, relying on standard library model representations and not considering UDMs.

Miguel also described the efficacy of different types of supplemental modeling documentation to aid in ensuring model quality. Figure 10 illustrates effective and less effective options. Parameter verification reports, model quality test results and reports, and site-specific verification and validation reports are all effective options; however, OEM attestations, model compliance checklists, and generic requests for information (RFIs) can result in complications or generic information provided if not issued or delivered with clear instructions and understanding of their use.

Figure 10: Effective and Less Effective Supplemental Documentation to Ensure IBR Model Quality [Source: Vestas]

Miguel recommended that the model development process should always follow a source code integration concept, which should mirror parameterization and performance of the IBR plant as built in the field. Industry standards should focus on interfacing source code-integrated models rather than standardizing control structures for IBR plant models generically.

Andrew Isaacs, Electranix

Andrew presented on legacy (i.e., existing) IBR plant modeling practices and challenges, primarily focused on EMT modeling. When an IBR plant model is needed for a legacy asset for the purposes of conducting a study, there is often no satisfactory solution. Hence, this is why it is very important to ask for high-quality models prior to interconnection whether or not those models will be used immediately in a study. Sufficiently detailed and specific modeling requirements are important, if not necessary to ensure that the right questions are asked, appropriate tests/model reviews are conducted, and that accurate models are supplied. These concepts apply to both IBR plants and power electronic loads such as data centers, and should be a major priority for all regions across North America.

If an EMT model is needed for an existing asset, there are a few guiding questions that can be asked:

- Is the model needed for posterity/requirements, or is there a study being conducted?
- If a study is being conducted, how impactful is the plant to the study area?
- Is it the main device being studied?
- Is it electrically very close or impactful under key contingencies?

- What phenomena are the key areas of focus (e.g., subsynchronous control interactions (SSCI), fault ride-through (FRT), voltage impacts, other transients, etc.)?
- Is the plant large or small relative to the other plants and study area?

These questions help determine the level of effort needed to ensure accuracy of the missing model. If an EMT model is not available and cannot be acquired through requirements, regulations, or other mandatory and enforceable ways, there are a few options that can be considered (from best to worst):

- Best approaches:
- Collect a model from the interconnection customer/GO that meets the requirements established.
- Find engineers involved from the original OEM and ask (or pay) them to create a model using their best information.
- Proxy model approach:
- Learn as much as possible about the equipment, and configure a proxy model using a similar vintage and type of model from the *same* OEM.
- If possible, test the hardware in a lab and configure an appropriately parameterized generic model to match the performance.
- Learn as much as possible about the equipment, and configure a proxy model using a similar vintage and type of model from a *different* OEM.
- Generic model approach (not recommended):
- Learn as much as possible about the equipment and configure a generic model to match key settings to the extent possible.
- Use a completely generic model.

Deviations from accurate implementation of phase lock loop (PLL), protection circuits, and inner controls will cause misrepresentations of SSCI damping, ride-through performance, and voltage control response. Deviations from accurate implementation of delays, power plant controllers (PPCs), outer loop controls, etc., can cause important errors depending on the study being performed. If a device is important to the study, proxy modeling is not recommended and it may be best not to conduct a study at all.

Anything other than a fully-tested, verified, and validated EMT model will degrade the benefit obtained from the EMT study in terms of accuracy and the ability to make business decisions using the results obtained (i.e., accuracy requirements exist for a reason). If the model quality is degraded too far, and the plant is critical in the study being performed, it may not be possible to drive useful results from the EMT study.

Additionally, all models will require maintenance and updating throughout the lifecycle of a plant. Effective data organization procedures, documentation, and change management practices help ensure the model remains accurate as compared with the actual equipment. Furthermore, as requirements change, older models may become noncompliant and require updates; thus, it is important to have robust requirements to start with and also for IBR developers to have strong contract language for ongoing support from OEMs.

Dynamic link library (DLL) wrapper real code model writing processes are helpful to maintain compatibility across tool and compiler revisions. Models should be written to support these techniques.[5]

Q&A and Interactive Group Discussion

What are the initial ballot results for MOD-026-2 and what is the current status for Project 2020-06?

The initial ballot for MOD-026-2 recently closed as of late June 2025. The standard and implementation plan received a 32.5% and 40.2% weighted ballot score, respectively. The drafting team is currently reviewing comments received and working on addressing those comments in a revised version that is planned for another ballot in late July or August.

With the next ballots for the Milestone 3 projects scheduled for late July (and subsequent review in August/September), how is NERC expecting to meet the November 4 FERC deadline particularly given that the NERC Board meeting is scheduled for October? Will NERC expect to leverage its Rules of Procedure Section 321 process again for these standards?

NERC and the drafting teams are working towards revised standards that meet the concerns raised by industry commenters as part of the ballot process. NERC is conducting informational webinars to share updates along the way. However, the deadlines are fast-approaching, and NERC may need to take alternate paths (e.g., NERC Section 321 process) to expedite meeting the November deadlines set by FERC if the standards do not pass the next ballot.

[5] Cigre B4.82 "Guidelines for Use of Real-Code in EMT Models for HVDC, FACTS and Inverter based generators in Power Systems Analysis" Available here.

What are the pertinent updates regarding approval and effective dates for NERC Milestone 2 projects including PRC-028-1, PRC-029-1, and PRC-030-1?

FERC approved both NERC PRC-028-1 and NERC PRC-030-1. FERC also issued a Notice of Proposed Rulemaking (NOPR) to gather additional information and industry feedback on NERC PRC-029-1 and has not yet ruled on this standard as of June 2025. With the NOPR, FERC sought comments on all aspects of the proposed PRC-029-1, but was particularly interested in comments and supporting materials on concerns regarding: "(1) the IBR performance requirement set forth in Requirement R1; (2) the absolute RoCoF in Requirement R3; and (3) the adequacy of NERC's proposed exemption provision in Requirement R4 as it pertains to both projects in service and those under contract, but not yet in-service as of the effective date of Reliability Standard PRC-029-1."[6]

Regarding effective dates, NERC PRC-028 became effective on April 1, 2025. FERC did not establish an effective date for PRC-030-1 since it relies on NERC PRC-029-1. Thus, industry expects that once FERC rules on PRC-029-1, it will also include an effective date for PRC-030-1 in that ruling.

The proposed NERC MOD-026-2 leaves establishing a model verification and validation procedure up to each Transmission Planner (TP) and Planning Coordinator (PC). This may lead to widely disparate requirements and lack of harmonization across North America, creating additional obstacles and barriers for IBR asset owners. What is NERC doing to address this concern, which has been raised in industry stakeholders numerous times?

Sandhya stated that NERC Reliability Standards explicitly do not define how a standard must be implemented and only focus on what must be implemented. Thus, to handle the need for regional or transmission entity-specific differences, the NERC Project 2020-06 drafting team has left these considerations up to the TP and PC to determine. It was acknowledged that this could lead to disparity across TPs and PCs, which could create complications for GOs.

How can entities effectively commission an IBR plant when the OEM does not have a mapping between PSCAD and their actual equipment settings, parameters, and controls?

IBR commissioning has been identified by the NERC Inverter-Based Resource Performance Subcommittee and other organizations as an area for improvement for IBR integration. IBR plants may be commissioning in a way that does not match the modeling and studies conducted during the interconnection process. This is further exacerbated when the IBR plant model parameters are obfuscated by the OEM and thus the Generator Owner is unable to discern whether what is being commissioned matches expectations. Improvements in IBR model

[6] https://www.ferc.gov/media/e-10-rm25-3-000

transparency, regardless of model type, are needed to map actual equipment to models and their respective parameters.

ISOs may emphasize overlaying simulation plots and lack attention to how controls, protections, etc., are implemented in the IBR plant. Any recommendations for this can change?

Much of the interaction between the interconnection customer and the TP/PC is related to ensuring that the models are verified to match the actual equipment, meet certain model quality test requirements, and are suitable for transmission system impact studies. Transmission entities should adopt modeling requirements that ensure model verification – the model matches the proposed and actual equipment – as well as model quality and performance tests that ensure the IBR plant meets a certain performance, and the models are adequate for use in studies.

The concepts of 1) "the IBR plant passes the model quality tests" and 2) "the IBR plant operates reliably under all credible contingencies" are almost entirely orthogonal to each other; yet, almost all simulation time and effort between the IBR developer/owner and TP/PC is devoted to the former. How can this be overcome?

These different types of tests are intended to analyze the IBR plant models in different ways. Model quality tests are intended to check that the model is suitable for studies and is a reasonable reflection of the actual equipment planned or installed at the facility. These test may consider varying system conditions such as voltage and frequency fault ride-through or system strength. Once the models pass the necessary single machine infinite bus (SMIB) type modeling tests, then they are integrated into the system model for system-level performance evaluations. Significant time between the IBR developer/owner and the TP/PC needs to be devoted to ensuring models are accurate and of high quality to help aid in preparations for effective systems studies, which are the responsibility of the TP/PC.

For the current state of IBR modeling, why was the option for OEMs to more actively participate in the standard library model building process not included?

OEMs should still engage in standard library model building processes, particularly since the use of these models is mandated by FERC for use in interconnection-wide base cases. Industry cannot simply forego these efforts as they are mandated by federal law presently. Thus, as observed by the NERC modeling recommendations and other guidelines, both types of models are needed and OEMs need to actively be engaged in creating high-quality UDMs as well as sufficiently reflective standard library models for their equipment.

If models across simulation domains are to only be real code models, does industry thus have to trust the OEMs if a model cannot accurately represent a feature in the actual equipment? This may introduce significant reliance on OEMs on intellectual property concerns regarding information sharing.

Focus needs to turn toward effective collaboration between the interconnection customer/GO and the OEM to ensure that the currently-used models are reflective of the actual product (make, model, version, etc.), rather than artificially tuning standard library models which are not reflective of the actual equipment. OEMs will need to be transparent about what is and is not modeled, and should provide IBR unit (single inverter or wind turbine) model validation reports to demonstrate that the model adequately reflects actual product across a range of operating conditions. Note that "real code" models remain black boxed models (i.e., the real code is not accessible to the end user of the model).[7,8]

What is the difference between UDMs and standard library models regarding IBR plant commissioning? Intuition is that UDMs would also be subject to "manual tuning, patchwork fixes, and late-stage overrides" to reflect as-built conditions but the slides implied otherwise.

Regardless of model type, it is important to ensure that the commissioned IBR matches the models used during study, and that any discrepancies are identified, updated in the models, and shared with the transmission provider for evaluation. Commissioning tests may subject the site to small disturbance events that can then be used to conduct post-commissioning model validation. It should be noted that these tests likely will not subject the site to large disturbance events that initiate ride-through modes of operation. Hence, post-conditioning event monitoring and model validation is important to also ensure accuracy of the models upon commissioning.

It was mentioned that EMT modeling concerns raised regarding IBRs may also apply to data center load modeling efforts – can you elaborate on those issues and give some examples?

Many of the issues pertaining to IBR modeling today – model transparency, model verification versus actual equipment, model quality testing, and post-event model validates – all translate to large power electronic load (e.g., data center) modeling. Ensuring that the models used to represent data centers are adequate representations of the actual facility, particularly for rather large load sites, is imperative to ensure reliability of the bulk power system.

[7] https://www.e-cigre.org/publications/detail/gb-16-power-system-dynamic-modelling-and-analysis-in-evolving-networks.html
[8] https://www.e-cigre.org/publications/detail/881-electromagnetic-transient-simulation-models-for-large-scale-system-impact-studies-in-power-systems-having-a-high-penetration-of-inverter-connected-generation.html

Why do so many organizations push for creating and running generic models in studies? Seems like a lot of research effort is going into creating generic models for use in real world studies and this may not be the recommended approach. Thoughts?

Generic model may have a place for exploratory studies or research and development activities; however, these models are not adequate for making utility decisions such as determining reliability impacts of a specific IBR plant seeking interconnection, establishing operating limits, or determining the need for transmission network upgrades. This is particularly relevant for those conditions that invoke instability risks. Further, the generic models may inappropriately show stable operating conditions whereas the more detailed UDMs in phasor domain or EMT studies may uncover reliability risks. Thus, general industry consensus, as recommended by NERC and required in FERC Order 2023, is to gather both UDMs for local reliability studies and appropriately parameterized standard library models for interconnection-wide base case development.

Key Themes

- **NERC Milestone 3 Standards Development and Balloting Challenges:** The current NERC Milestone 3 efforts are addressing data sharing, model verification, and system model validation including IBRs. Initial ballots for the three Milestone 3 projects did not reach passing scores; current drafting team efforts are focused on addressing industry concerns. NERC is aiming for re-ballots by late summer to meet a tight FERC submission deadline in November 2025. If needed, NERC may need to use its Section 321 procedures to meet the FERC timelines. The challenges underscore ongoing industry tension between compliance needs and implementation feasibility.
- **Upcoming Milestone 4 Work and Expanding IBR Reliability Focus:** NERC is preparing to launch Milestone 4 projects, which will examine broader reliability standards including TOP, IRO, PRC, and TPL, and revise key definitions. Draft SARs will be released in August 2025, and NERC is actively seeking drafting team members with experience in planning and operational studies involving IBRs. The goal is to integrate IBR-specific considerations into operational and planning assessments.
- **Legacy Modeling Practices and the Importance of Accurate EMT Models:** Modeling legacy IBR plants presents unique challenges, especially when EMT models are needed post-interconnection and were never initially required. Without high-fidelity models, studies may yield unreliable or misleading decisions. Proxy models and generic models offer limited accuracy and should only be used when absolutely necessary. Upfront modeling requirements and OEM-supplied, validated models are essential, particularly for high-impact assets. Ongoing model maintenance, including change management and source code compatibility, is equally critical over a plant's lifecycle.

- **UDMs vs. Standard Library Models:** Standard library models, though easy to use and review, often present a simplified and misleading picture of IBR performance. Reliance on these models may give a false sense of compliance with applicable interconnection requirements, as they often omit the nuanced dynamics of actual equipment. UDMs provided and validated by OEMs offer a more faithful representation and should be preferred, especially during interconnection studies and plant commissioning. Industry's current tendency toward simplicity over accuracy introduces reliability risks that grow as grid complexity increases. More OEM collaboration, transparency, and use of supplemental documentation can help ensure IBR model quality.
- **Commissioning Gaps and Model Fidelity Concerns:** The commissioning process for IBR plants often lacks alignment with the models used during interconnection studies. Discrepancies between installed equipment and model parameters—especially when OEMs obscure model details—can result in mismatches that degrade reliability. While commissioning tests help validate models through small-signal disturbances, they may miss crucial behaviors activated during grid faults or instability events. This highlights the need for robust model validation post-commissioning, and for utilities to require transparency and ongoing model support from OEMs. Accurate commissioning models are essential to uphold both compliance and operational integrity.
- **Model Quality and Use in Planning vs. Operational Studies:** The industry tends to over-emphasize verifying model quality while under-investing in ensuring reliable system-level performance of IBRs under real-world contingencies. While SMIB-type tests verify models against equipment, they do not guarantee that a plant will behave reliably under stressed grid conditions. Transmission planners must adopt dual objectives: ensuring models are technically valid and conforming with applicable interconnection requirements, while also verifying actual plant performance through contingency simulations as part of system impact studies.
- **Modeling Challenges Shared by IBRs and Data Centers:** The challenges with IBR modeling—model transparency, verification, lifecycle accuracy, and event-driven validation—are now also surfacing in modeling large data center loads. As with IBRs, inaccurate or generic data center models can misrepresent impacts on the grid. Industry must recognize that reliability risks are not limited to generation but also apply to increasingly complex, inverter-dominated loads. Robust model requirements and validation protocols for both generation and load are essential for ensuring bulk power system reliability.
- **Limitations of Generic Models in Decision-Making:** Generic models may be useful for early-stage research or exploratory studies, but they are generally not sufficient for decision-making such as setting operating limits or approving transmission upgrades. These models often miss critical OEM-specific control behaviors, potentially masking

underlying reliability risks. As such, NERC, FERC, and OEMs all stress the need for UDMs in phasor domain and EMT for reliability-critical studies. Interconnection-wide base cases may still require standard library models, but local reliability studies should rely on detailed, OEM-supplied, site-specific models to ensure accuracy. The industry must evolve from a generic-first mindset toward a precision-first approach to grid modeling.

July 22, 2025 Virtual Meeting

IBR Plant Design Evaluation with Applicable Requirements I (~200 attendees)

Presentation recording and slides are available to download here. Figure 11 shows the makeup of meeting attendees by industry sector:

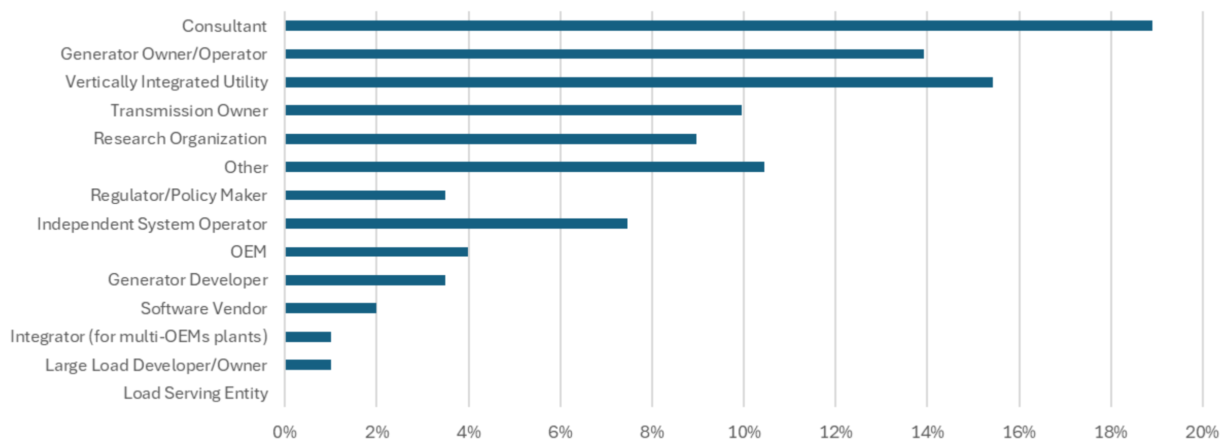


Figure 11: Meeting attendees by industry sector

This third meeting of Season 2 of the DOE i2X FIRST initiative focused on IBR plant design evaluation with applicable IEEE 2800-2022 requirements, providing an overview of IEEE P2800.2 IBR plant design evaluation clauses and sharing perspectives from both an IBR plant developer and owner/operator as well as engineering, procurement, and construction (EPC) provider. Presentations included the following:

Jens Boemer, EPRI

Jens provided an overview of IBR plant design evaluation and related topics. These IBR plant design evaluations are a continuum of IBR scrutiny in terms of conformance against established requirements (see Figure 12). In the past, little to no performance specifications were established and this may have resulted in abnormal performance (e.g., tripping). More recently, transmission providers have established performance specifications (including adoption of IEEE 2800-2022 requirements and other regional requirements). In some instances, such as on the distribution system with IEEE 1547-2018, unit-level certifications are used; however, this approach is not being used by IEEE 2800-2022. Rather, IBR plant-level conformity is assessed using power system models, model quality and verification tests, and performance conformity simulations.

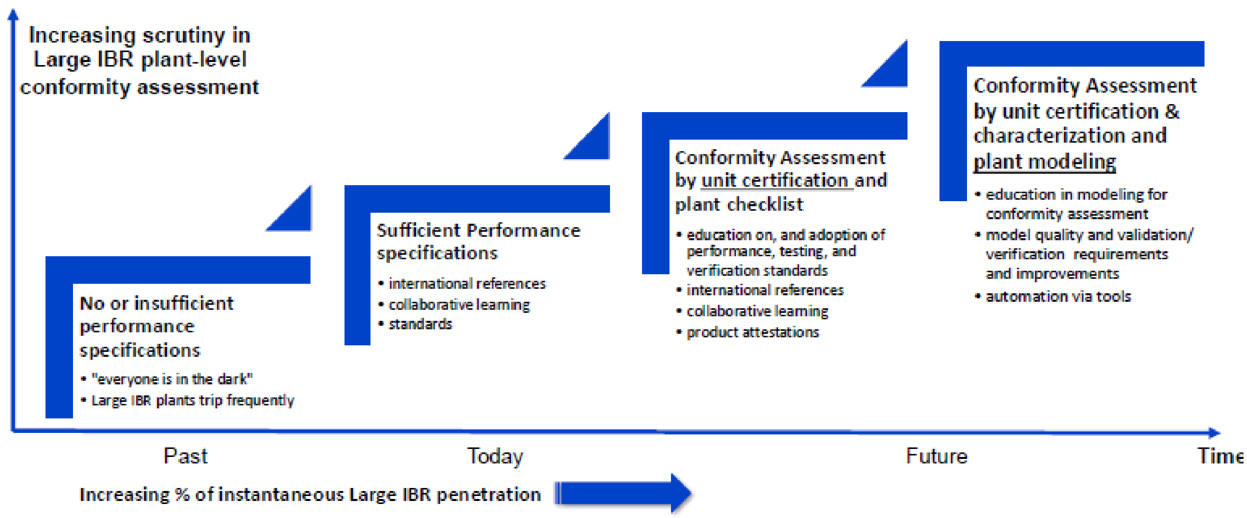


Figure 12: Large IBR Plant Interconnection Reliability Roadmap [Source: EPRI]

It is important to acknowledge and recognize the meaning of different terms used in this space, including:

- **Compatibility:** Design equipment to support conformity or compliance of a complex system (e.g., IBR plant) – equipment level.
- **Conformity:** Adherence to certain voluntary industry standards or procedures (e.g., IEEE P2800.2) – plant level.
- **Compliance:** Meeting mandatory and enforceable legal and regulatory obligations (e.g., NERC standards or interconnection requirements) – plant level.

Nonconformity with IEEE 2800-2022 requirements can be assessed, and there are historical examples such as the large NERC disturbance reports that illustrate failures to meet specific requirements.

Additionally, conformity with requirements can be assessed and tested as part of the interconnection process. For example, MISO is currently proposing to implement IBR modeling requirements that also include performance tests that can be used to test the IBR plant conformity against established requirements, to some extent. While the tests may not mirror IEEE 2800-2022, MISO is starting with a set of test procedures that can be effectively implemented by interconnection customers.

The IBR plant design evaluation uses the complete IBR plant model once it is fully developed. This model includes the validated IBR unit model(s), the verified IBR plant model components, and verified balance of plant protection elements as well. With this model, simulations are conducted to assess plant conformity with IEEE 2800-2022 requirements (see Figure 13). In these tests, it is important to remember that the requirements regarding current injection during abnormal voltage conditions apply at the POC whereas the other requirements apply at the POM.

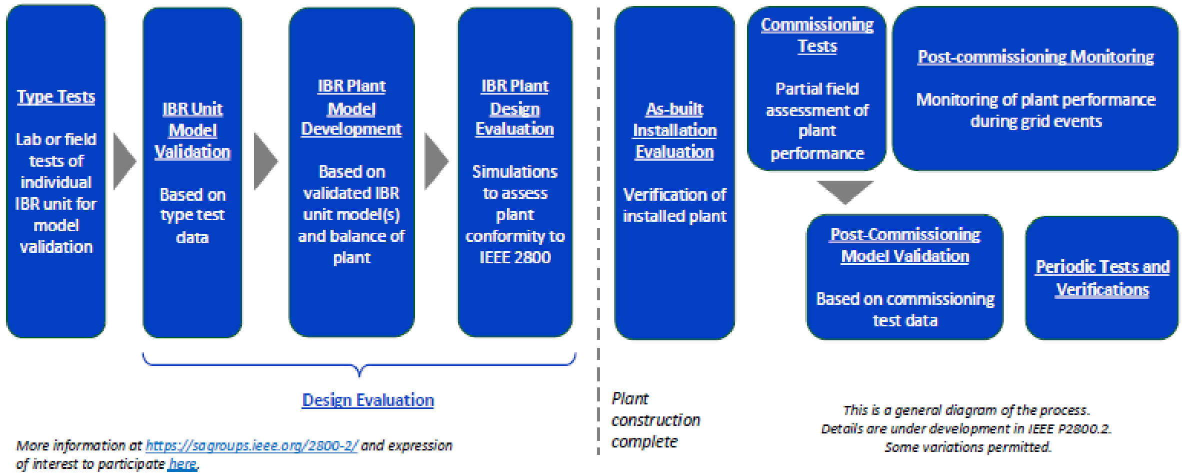


Figure 13: IEEE P2800.2 IBR Plant Conformity Assessment Framework [Source: IEEE]

An IBR plant design evaluation and performance conformity assessment is notably different from a system impact or reliability study. The IBR plant design evaluation ensures that the IBR plant meets the minimum requirements established whereas the system impact study ensures that the IBR plant reliably operates when connected to the grid. The IBR plant design evaluation includes both documentation checks (verification) and modeling and simulations. The documentation checks focus on reviewing capabilities, settings, and equipment model validation reports; modeling and simulations focus on model quality checks, plant model development and verification, and simulations of capability and performance.

The simulation tests can be set up with a controllable AC source connected to the POM through an impedance (see Figure 14). The controllable source induces POM grid conditions which are used to invoke a response from the IBR plant model, which can be assessed. The adjustable impedance is used to simulate different grid strength conditions.

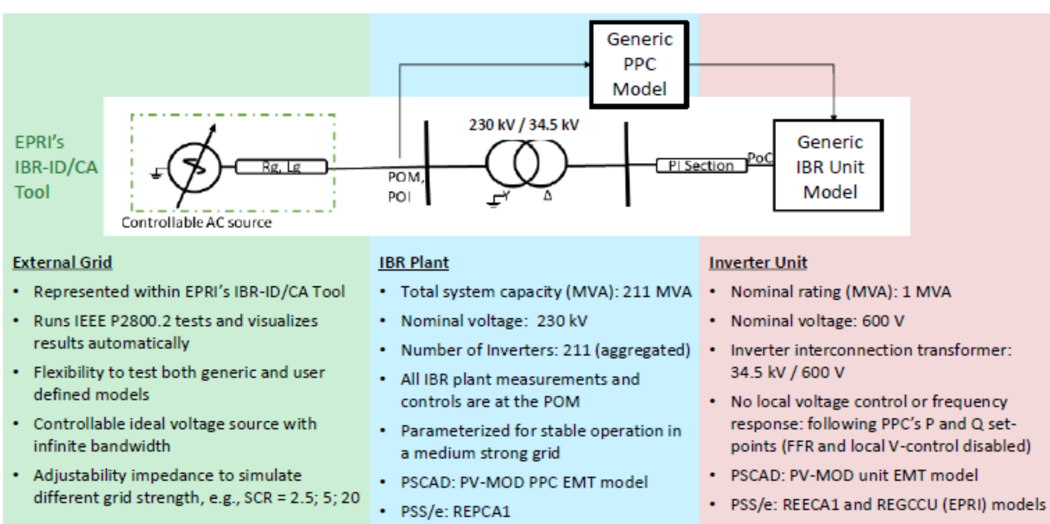


Figure 14: Example of IBR Plant Design Evaluation Simulation Setup [Source: EPRI]

Rishi Maharaj, Engie

Rishi shared practical experience from an IBR plant developer and generator owner/operator pertaining to IBR plant conformity assessment gaps and opportunities. Development and operation of a new IBR plant is often perceived as involving two primary categories of entities: the developer or generator owner/operator (before and after commercial operation date (COD), respectively) and the transmission entities such as Transmission owner/operators, transmission planners, RTO, etc. While the IBR plant developer/owner has obligation to comply with applicable interconnection requirements, in some organizations nearly all work upon which the performance and conformity of the plant depends will be performed by the following third parties (see Figure 15):

- OEMs
- Engineering consultants
- EPC contractors who may subcontract either of the above

Therefore, achieving conformity with technical requirements (NERC, ISO, Transmission Planner, etc.) requires coordination and communication between many parties through the project phases from interconnection application to commercial operation. The primary tool for a developer to obtain any technical deliverable is to write it into the contractual scope of work of a consultant, EPC, or OEM. Gaps in these scopes of work, and limited coordination between parties, are often where problems and eventual non-conformity originate.

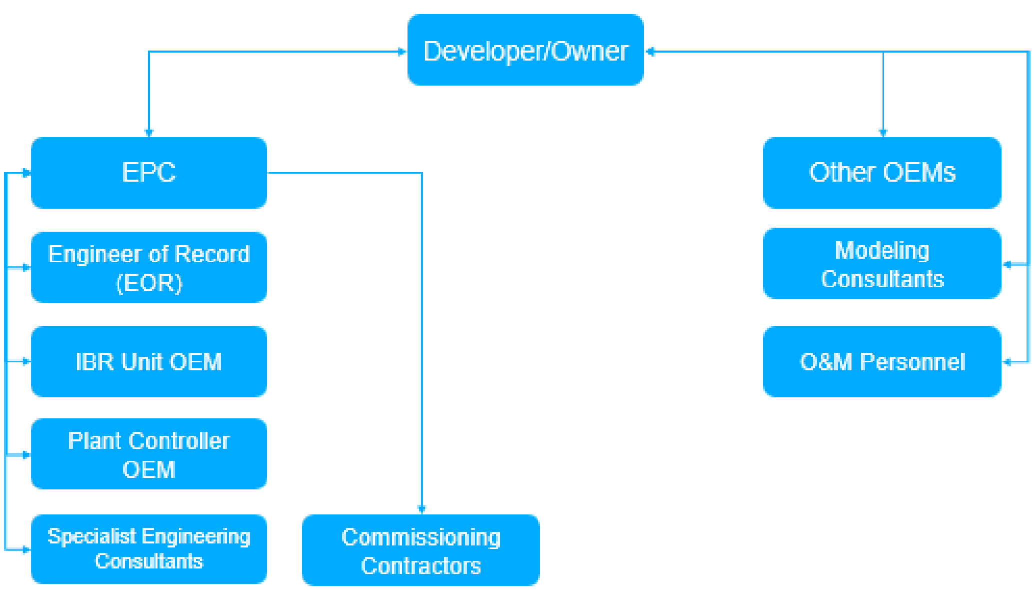


Figure 15: Simplified IBR Plant Project Hierarchy of Organizations [Source: Engie]

With this structure, an IBR plant developer/owner is therefore responsible for a tremendous number of activities that lead to eventual conformity, such as:

- Map out required scopes of work from each project participant to achieve the new requirement; and
- Negotiate with each party to include that scope in their respective contracts; and
- Monitor each party's delivery of their component from their respective subcontractors at the correct time; and
- Perform an overall plant conformity assessment to the new requirement considering the entire project holistically (perhaps by assigning it to yet another consultant); and
- If possible, verify performance with commissioning tests.

This is a lot for a non-expert IBR plant developer who may have very limited or no internal power systems expertise. Achieving and assessing conformity with a requirement that is relatively simple from a technical point of view can still be quite complex from a project execution perspective, requiring a consistent effort from the IBR plant developer/owner to coordinate all parties.

Rishi also explained that there is a basic conflict between the desire of IBR plant developers/owners to contract out technical work and the fact that only the owner has visibility of the entire project and the ability to deliver the required technical coordination.

The definition of conformity assessment is "demonstration that specified requirements are fulfilled."[9] However, to an IBR plant developer, it is unclear which requirements. Interconnection requirements applicable to a particular transmission-connected IBR plant in North America can originate from multiple sources:

- NERC Standards – uniform, but largely do not address IBR performance (especially prior to Order 901 standards)
- ISO Rules that apply uniformly to all facilities meeting certain thresholds (e.g., ERCOT Nodal Protocols and Operating Guides)
- ISO, RTO, or TO requirements that are specific to a particular GIA

A non-trivial amount of work is required simply to identify all applicable requirements. Writing "comply with all interconnection requirements" into a contract is largely useless. Without both parties being aware of the specific requirements in sufficient detail to enumerate them, it is very difficult to deliver and validate conformity. Since most requirements apply at the IBR plant level and require coordination between multiple parties, trying to write IBR plant-level conformity obligations into any one party's contract is not practically workable. Thus, in many projects, a comprehensive understanding of "all applicable interconnection requirements" does not exist.

[9] IEEE P2800.2 referencing ISO/IEC 17000:2020.

Comprehensive, proactive "grid code compliance" studies addressing all applicable requirements are not typically done by IBR plant developers. The extent to which engineering studies (i.e., IBR plant design evaluations) are done to assess conformity with applicable interconnection requirements is almost entirely driven by processes formally mandated by the transmission provider or other authority governing interconnection requirements (AGIR). Reactive power studies, stability studies, subsynchronous oscillation (SSO), etc., are all examples of IBR plant studies that are on a mandatory path to COD. However, mandatory studies only address a relatively small subset of interconnection requirements.

Further, various mandatory studies may be done by different project participants without coordination with each other, resulting in conflicting, inaccurate, or wrong models being used by different entities to study the same plant. The items specifically verified or checked by the AGIR to grant commercial operation are the core focuses of the IBR developer; everything else is, for practical purposes, optional. The net result is passive or inadvertent non-conformity with a significant fraction of the presently enforceable requirements.

Power plant controllers (PPCs) are also an under-appreciated risk in IBR plant design evaluations. The current trend of procuring PPCs from EPCs, which cannot be accurately simulated until very late in the project (if at all), limits the ability to perform IBR plant design evaluations for certain requirements earlier in the interconnection process. Design evaluation is only one aspect of conformity assessment. Even when design evaluation is done, gaps exist in feeding required changes back into the IBR plant design and implementing them in the field. Most AGIRs in North America have no enforced requirement for verification of IBR plant parameters and settings. Consultants may tune model parameters without OEM involvement, resulting in a plant model that "passes" assessments but cannot be implemented in the field. OEMs may be willing to update EMT models to provide favorable results in ways that do not accurately reflect their actual product as deployed in the field. The lack of a standardized format for exchanging IBR unit and plant controller parameters causes inadvertent errors. Again, Rishi emphasized that what is mandatory is what gets done.

Fortunately, many of the pain points and pitfalls mentioned above are directly addressed in IEEE P2800.2, which comprehensively maps how conformity assessments should take place. It does not (and cannot) define exactly how IBR plant owners/developers, TS owners, operators and planners execute that process in actual projects. The 2024 NERC Alert on IBR Model Quality Deficiencies results show that many IBR plant owners do not have basic facility information available to them. Layering new, more comprehensive and more complex requirements with current and future adoption of IEEE 2800-2022 by AGIRs requires process improvement to successfully attain conformity. IBR plant developers/owners will need to devote significant resources to building internal expertise to successfully build plants that conform with IEEE 2800-2022.

Patrick Hart, Mortenson

Patric shared EPC perspectives on IBR plant design and commissioning. EPCs may span different portions of the IBR plant design and commissioning processes (see Figure 16).

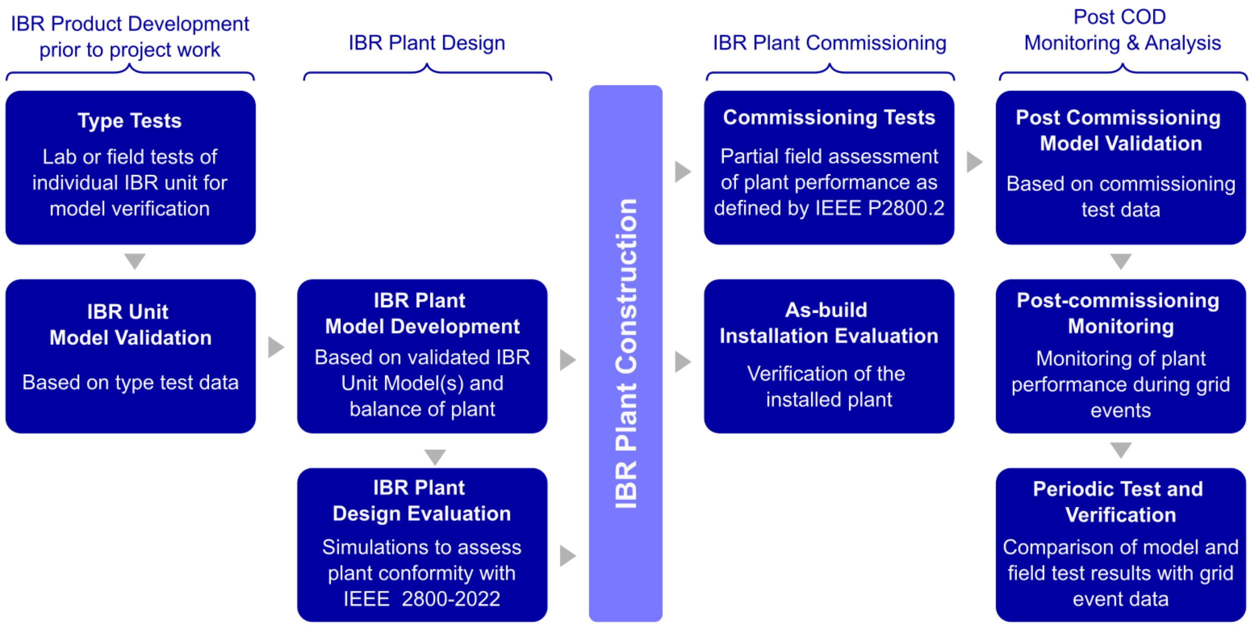


Figure 16: EPC Scope Focused Around Construction [Source: Mortenson]

Standard work is critical for effective deployment of IBR projects. Missing the COD can lead to significant losses for IBR developers, owners, and operators. Product design is centered around test requirements; project design and commissioning are also centered around test requirements. In both cases, if the product or plant are not tested, they likely will not operate as expected. OEM equipment may be capable but must be configured correctly. OEMs serve many markets, and IBR equipment must be inherently designed for that variability. More market variability means more configuration settings, which means more opportunity for errors and failures.

Some of the pain points faced today with IEEE 2800-2022 requirements P2800.2 conformity assessments include:

- IBR plant reaction time less than 200 ms – more difficult to meet with multiple vendors (power conversion system OEM plus PPC OEM(s) plus inverter OEM(s) and challenging for hybrid power plants; leveraging Modbus protocol is a challenge in meeting this requirement, which is common industry practice.
- Data recording requirements – OEMs yet to implement functionality required to log data (e.g., IBR fault codes and oscillography); perceived as “not my problem” by the OEMs.

- Time synchronization – very difficult and expensive to meet at the IBR unit level; IRIG-B, PTP, and NTP protocols[10] all have challenges and costs; can equate to added cost of $200k+ per project just to meet stringent time synchronization costs.
- As-left control settings – control settings often controlled by the OEM engineers; limited visibility into these parameters and settings; hundreds or thousands of parameters, most associated with enabling/disabling features to shape response.

IBR plant developers and owner/operators are including compliance with IEEE 2800-2022 as a contractual requirement. OEMs are working towards compatibility at the unit level; however, plant-wide coordination is still a major hurdle. Industry players continue to get more knowledgeable about specific requirements and how to verify, test, or assess conformity.

Q&A and Interactive Group Discussion

Is IEEE P2800.2 proposing too many tests and is that level of testing necessary?
Some stakeholders believe the volume of proposed tests—spanning various operating conditions, SCR levels, and modeling tools—is impractical for implementation. However, rigorous testing is critical for ensuring grid reliability. Reliability is a shared responsibility among IBR developers, OEMs, and transmission entities to ensure models are accurate and reliable, even if that means conducting a significant number of tests. The key challenge is finding a feasible, coordinated, and efficient approach—some suggest that frameworks like MISO's may offer a manageable path forward. The true challenge lies in coordinating across multiple stakeholders—developers, OEMs, EPCs—to produce a unified and verified model.

Can we automate these tests to reduce the burden?

Standardized test procedures enable automation and incentivize OEMs to build testing features into their equipment. Without standardization, fragmentation reduces the return on investment (ROI) on automation investments. Many of the plant-level tests can be automated (with a human engineer in the loop), especially during IBR plant design evaluation and commissioning. Automation helps reduce effort and improves consistency, particularly with the level of tests required.

What is the distinction between commissioning tests and simulation tests?

Commissioning tests verify performance post-installation, while simulation tests earlier in the project are used to ensure expected behavior. Both are critical but serve different purposes.

[10] These are various protocols used to synchronize time across different systems and devices.

How do we make testing more efficient to avoid project delays?

The goal is not to overload projects with tests but to focus on tests that evaluate the behavior ahead of time—through type testing, design evaluation, and smart scheduling—to avoid surprises later in the process.

Doesn't the cost of testing pale in comparison to the total project cost?

Yes, testing costs are relatively minor in the context of a $100M+ project. The bigger issue is doing it efficiently to avoid delays and errors, which can be far more costly.

When in the project lifecycle should these studies and tests occur?

They should happen "all along the way"—design, iteration, and adjustment should be embedded throughout the project lifecycle to avoid late-stage surprises.

How should contract language address changing regional requirements and evolving standards?

Don't just meet the minimum. Adopt a forward-looking, high-bar standard that integrates upcoming or likely requirements into the EPC contract. This avoids costly retrofits later.

How can developers handle evolving technical deliverables in long project timelines?

Since standards may change mid-development (e.g., NERC PRC-024 to PRC-029), contracts should include flexible language that anticipates new requirements and ensures compliance by COD.

How are HIL/CHIL simulations being used in IBR projects, and what is their value—particularly for PPCs?

While HIL use on the EPC side is limited due to equipment variation and complexity, it's increasingly recognized as essential for large or hybrid plants. CHIL is especially valuable for PPC validation, allowing testing with actual hardware and firmware to reduce reliance on potentially inaccurate models. This is critical, as PPCs are often under-validated and pose significant modeling risks.

How can industry improve PPC validation and reduce project-by-project inefficiencies?

One solution is to shift PPC procurement outside of EPC scope and rely on high-quality OEMs that offer pre-validated, certified products. Certification is most effective at the product level, with version-controlled, configurable designs. However, integration risks remain, especially between PPCs and inverters, highlighting the importance of system-level testing such as HIL to catch issues like firmware mismatches and configuration errors.

What are key focus areas for improving IBR design evaluation over the next six months to a year?

- **Jens:** Finalize and resolve comments on P2800.2, engage industry to promote adoption.
- **Rishi:** Standardize information exchange formats (e.g., IBR Plant Information Database (IPID) or .IBR file).
- **Patrick:** Focus on areas not covered in typical studies, especially documentation quality and completeness.

What are best practices for contractual language with OEMs and EPCs, particularly when the inverter or turbine OEM is different from the PPC OEM and not all equipment is procured under the EPC contract?

It is important to ensure that contractual language addresses configuring the equipment in alignment with the model accepted by the transmission provider, at least as reasonably close as possible, and providing proof upon commissioning or upon request that the as-left settings accurately reflect the model that has been provided by the OEM. This is particularly important for IBR unit and PPC models in EMT and positive sequence UDMs. The contractual language should also address troubleshooting of modeling issues by the OEM to support IBR plant-level modeling and studies by the IBR developer or third-party consultant. OEMs should also be obligated to provide field parameter mapping/parameter verification reports of as-left settings any time a change is made to the facility to ensure the model remains accurate.

Key Themes

- Achieving conformity with IEEE 2800-2022 requires coordination across IBR plant developers, OEMs, EPCs, and consultants. Misaligned scopes of work and fragmented responsibilities often lead to non-conformity, even when the technical requirements are achievable.
- Relying solely on the minimum path to commercial operation often results in missed or misunderstood requirements. A proactive, high-bar approach—baked into contracts and internal processes—is needed to future-proof projects and avoid compliance failures down the line.
- Without consistent data formats, simulation procedures, or model verification practices, IBR projects face recurring issues like poor model fidelity, redundant work, and errors in implementation. Standardization is essential to enable automation and reduce risk.
- PPCs are often delivered late, poorly modeled, and disconnected from overall plant validation efforts. They pose high modeling risk and are rarely validated early, making them a weak link unless product-level certification and integration practices improve.

- Design evaluations and testing should occur continuously—from early design through commissioning. Simulation-based assessments and field commissioning tests serve different purposes but are both essential to verifying plant behavior and performance.
- Conformity assessments will not be widely adopted unless AGIRs enforce them—requiring IBR plant design evaluations prior to energization and as-built verification before final commissioning is essential for meaningful implementation.
- IBR developers and owner/operators need to build internal capabilities to execute on IBR plant design evaluations effectively. As interconnection standards become more performance-driven, in-house expertise will be critical and can still be supplemented by external support.

August 26, 2025 Virtual Meeting

IBR Plant Design Evaluation with Applicable Requirements II (~225 attendees)

Presentation recording and slides are available to download here. Figure 17 shows the makeup of meeting attendees by industry sector:

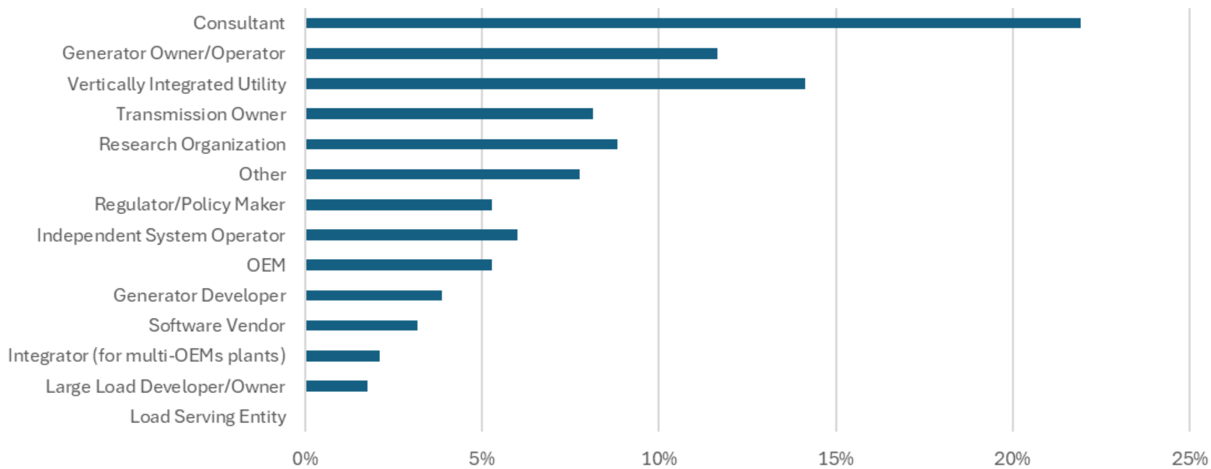


Figure 17: Meeting attendees by industry sector

This fourth meeting of Season 2 of the DOE i2X FIRST initiative focused on IBR plant design evaluation with applicable IEEE 2800-2022 requirements, providing an overview of IEEE P2800.2 IBR plant design evaluation clauses and sharing system operator and utility perspectives on IBR design evaluation requirements. IBR plant design evaluations based on model testing and on review of equipment type tests and other available documentation were discussed. A full picture of how these requirements fit together to ensure grid reliability was presented as well as potential pathways to process automation were discussed. Presentations included the following:

Alan Urban, MISO

Alan shared MISO's proposed IBR modeling requirements currently under development and finalization. MISO proposed updates that will be used in the interconnection process as part of a new BPM-015 appendix. The requirements focus on evaluations that would be performed during the interconnection process and are generally aligned with the high priority performance capabilities MISO is seeking from its adoption of relevant clauses from IEEE 2800-2022.

MISO is requiring the submission of four types of models to align with FERC Order 2023 directives and to meet simulation platform compatibility needs. These include:

- PSS/E standard library model
- PSCAD model

- TSAT user-defined model (UDM)
- PSS/E UDM

PSS/E UDM is required only at the time of signing the GIA; the other models are required at the initial interconnection application. The requirements also include 17 model quality performance tests, and all models must be benchmarked against that test. Results must be submitted in a report that documents acceptable performance.

Alan recognized that MISO's intended goal was to strike a balance in their enhancements to modeling requirements. On one hand, no IBR modeling requirements would lead to inadequate quality checks and performance conformity testing and higher reliability risk. On the other hand, exhaustive modeling requirements fully aligned with IEEE 2800-2022 would require significant work from interconnection customers and MISO and result is slowdown of the interconnection process. Hence, MISO selected a subset of simulation tests that closely align with IEEE 2800-2022 clauses and the IBR plant design evaluation proposed in the draft IEEE P2800.2 (see Figure 18).

Test	MISO Test #	IEEE 2800 Clause	Model Applicability
Initialization Tests	5.1.1	5.1 Reactive Power Capability	Generic, UDM, EMT
Balanced Fault Ride-Through Tests	5.1.2	7.2.2.5 Dynamic voltage support 7.2.2.6 Resetore output after voltage ride-through	Generic, UDM, EMT
Small Voltage Disturbance (SVD) Tests	5.1.3	7.2.2.2 Voltage disturbances within continuous operation	Generic, UDM, EMT
Small Frequency Distrubance (SFD) Tests	5.1.4	6.1 Primary Frequency Response	Generic, UDM, EMT
High-Voltage Ride-Through (HVRT) Tests	5.1.5	5.2 Voltage and Reactive Power Modes 7.2.2.1 Voltage distrubance ride-through: General 7.2.2.3 Low- and high-voltage ride-through 7.2.2.5 Dynamic voltage support	Generic, UDM, EMT
Low-Voltage Ride-Through (LVRT) Tests	5.1.6	5.2 Voltage and Reactive Power Modes 7.2.2.1 Voltage distrubance ride-through: General 7.2.2.3 Low- and high-voltage ride-through 7.2.2.5 Dynamic voltage support	Generic, UDM, EMT
High-Frequency Ride-Through (HFRT) Tests	5.1.7	7.3.2 Frequency disturbance ride-through	Generic, UDM, EMT
Low-Frequency Ride-Through (LFRT) Tests	5.1.8	7.3.2 Frequency disturbance ride-through	Generic, UDM, EMT
Protection Verification Tests	5.1.9	7.2.2.1 Voltage distrubance ride-through: General 7.2.2.3 Low- and high-voltage ride-through 7.3.2 Frequency distrubance ride-through	Generic, UDM, EMT
Short Circuit Ratio SCR Tests	5.1.10	Common industry test	Generic, UDM, EMT
Phase Angle Change Tests	5.2.1	7.3.2.4 Votlage phase angle changes ride-through	EMT

Figure 18: Mapping MISO Tests to IEEE 2800-2022 Clauses [Source: MISO]

For all the tests, active power, reactive power, and voltage values must reasonably match between the models when measured at the POM. Acceptable damping ratios are considered 0.3 or greater. All tests are performed on a single-machine-infinite-bus (SMIB) system with a controllable voltage source. SCR is specified as 3 for initial tests, with SCR being updated to reflect actual interconnection conditions later in the process as needed.

Test	Model	IEEE Clause(s)	MISO Test No	Disturbance	IBR Plant Initial Conditions			Grid Initial Condition	
					Active Power at POM	Reactive power at POM	Voltage at POM	Infinite Bus Voltage	SCR
Small Voltage Disturbance (SVD) Tests	Generic, UDM, EMT	7.2.2.2 Voltage disturbances within continu	5.1.3-1	Small voltage disturbance	Pmax	0	Figure 3	N/A	3

Pass/Fail Criteria

The models pass these tests if all the following conditions are met:

1. The plant shall not trip.
2. The plant shall have a stable and well-damped response. An acceptable damping ratio is 0.3 or greater [5].
3. The plant shall not enter momentary cessation (current blocking) mode.
4. Appropriate reactive power response shall be observed based on control settings.
5. Active, reactive, and voltage values shall reasonably match between standard library, PSS®E/TSAT™ UDM, and PSCAD™ models at the POM.

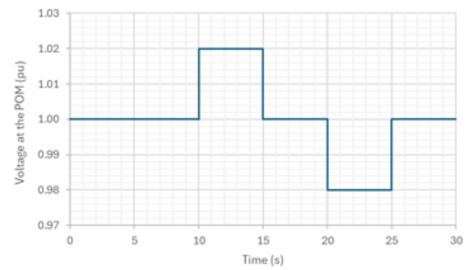


Figure 19: Example of Small Voltage Disturbance (SVD) Tests [Source: MISO]

In terms of next steps, MISO is bringing draft requirements to their Planning Advisory Committee stakeholder meeting and intends to publish the requirements in Q4 2025. The requirements would go into effect in 2026. MISO is also exploring tooling options to automate tests, benchmarking, and reports.

Jens Boemer, EPRI

Jens presented IBR design evaluation steps that focus mostly on documentation review such as type tests, IBR unit model validation, IBR plant model development, and IBR plant design evaluation steps of the IEEE P2800.2 conformity framework. Clause 7.3.3 of IEEE P2800.2 describes design evaluation practices based on review of OEM and IBR plant documentation. Some IEEE 2800-2022 specifications are not suited for simulation test evaluations such as consecutive voltage deviation ride-through capability and transient AC overvoltage ride-through capability. Similarly, conformity with other types of requirements is best verified by reviewing IBR plant documentation such as prioritization of IBR response, control capability requirements, measurement accuracy, enter service performance, protection settings, etc.

Jens described that IBR documentation-based verification can be conducted at various stages of the interconnection process (see Figure 20). Early verification may focus on OEM documentation of anticipated IBR equipment, IBR plant design considerations, overall conformity approach with the requirements, etc. Later-stage verifications can focus on changes made to equipment, IBR plant design, settings, and other features that may adversely affect conformity with the requirements.

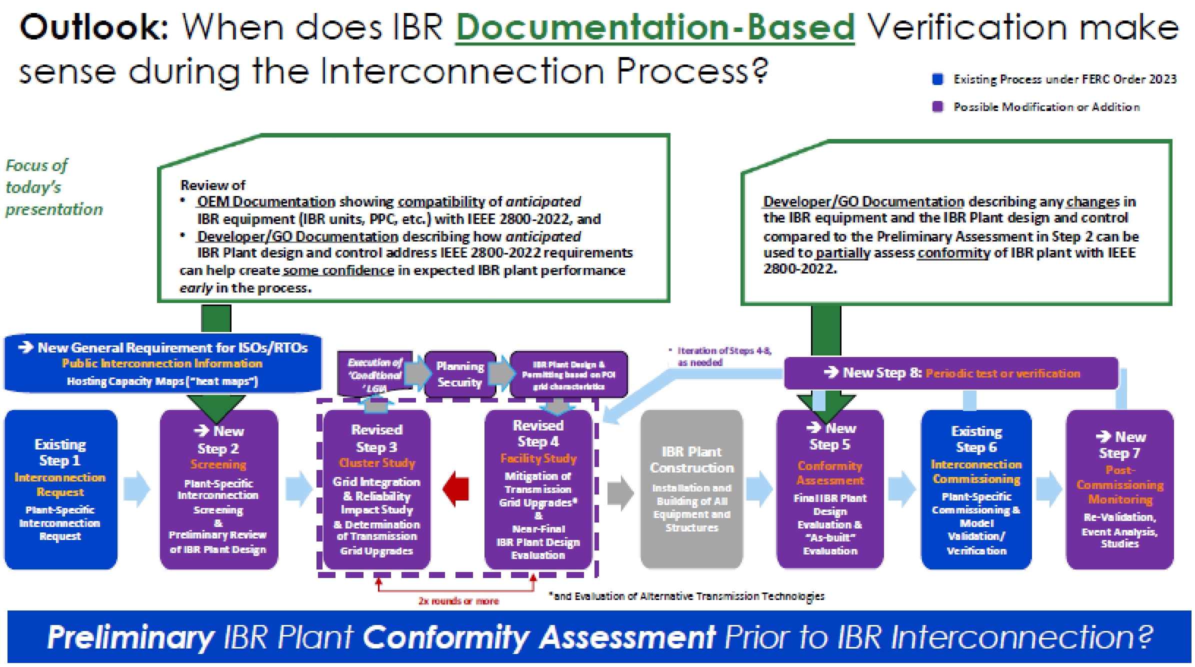


Figure 20: Documentation Verification during Interconnection Process [Source: EPRI]

Jens also mentioned a concept regarding an EPRI IBR Performance Identification and Conformity Assessment (ID/CA) Tool which may be funded at a later time.

Anthony Williams, Duke Energy

Anthony shared Duke Energy's IBR design evaluation process and ongoing efforts in this area. Duke pilot project regarding IBR design evaluation and commissioning align with past presentations in the i2X FIRST discussions regarding number of partners and players during IBR plant design, coordination issues among parties, difficulty of developers identifying and conveying technical information, aligning roles and responsibilities, and ineffective requirements/practices to ensure adequate work is completed. Industry collectively knows there are IBR configuration and performance issues and most understand the benefits of IBR plant design reviews, yet implementing a formal (or informal) design review is a difficult and complicated process.

Duke has established a Capability and Performance Review (CPR) process between the Interconnection Agreement and Commissioning stages of the interconnection process for IBR plants. This process includes 4 distinct stages – CPR.1 (initial design), CPR.2 (intermediate design), CPR.3 (final design/integration), and CPR.4 (pre-commissioning and pre-verification). Duke is changing processes to be more involved throughout this process, and developers are subsequently changing processes to include reviews as part of interconnection. Some key goals for the Duke CPR include:

- Identify and discuss design requirements early so there is opportunity to make changes with minimal impact to project cost and schedule
- Provide supplemental guidance on information that helps the IBR developer know how to comply with the interconnection requirements
- Allow for multiple reviews rather than one lumped review at the end
- Allow reviews to align with the Developer's / EPC's normal design process
- Have reviews prior to critical tasks to minimize the possibility of equipment specification or IBR plant design that does not meet requirements

The core goal is to ensure the IBR plant is designed to meet the established requirements, to verify the design ahead of commissioning, and to have the actual design accurately represented in the IBR plant models.

Duke has evolved their transmission-connected IBR requirements and documentation (see Figure 21). Today there are three core documents:

- **IBR Technical Interconnection Requirements (TIR):** establishes the defined interconnection requirements that the interconnection customer must comply with.
- **Coordination Document:** describes what is required to be submitted (e.g., plant documents, OEM documents, inverter and PPC narratives, plant studies, models), with fields for interconnection customer responses and Duke review responses; transparent and consistent for both parties involved.
- **Design Evaluation Checklist:** describes what the design should include and how to demonstrate compliance with the requirements; includes a checklist of items to submit as well as expected time of submittal (event-based, not date-based).

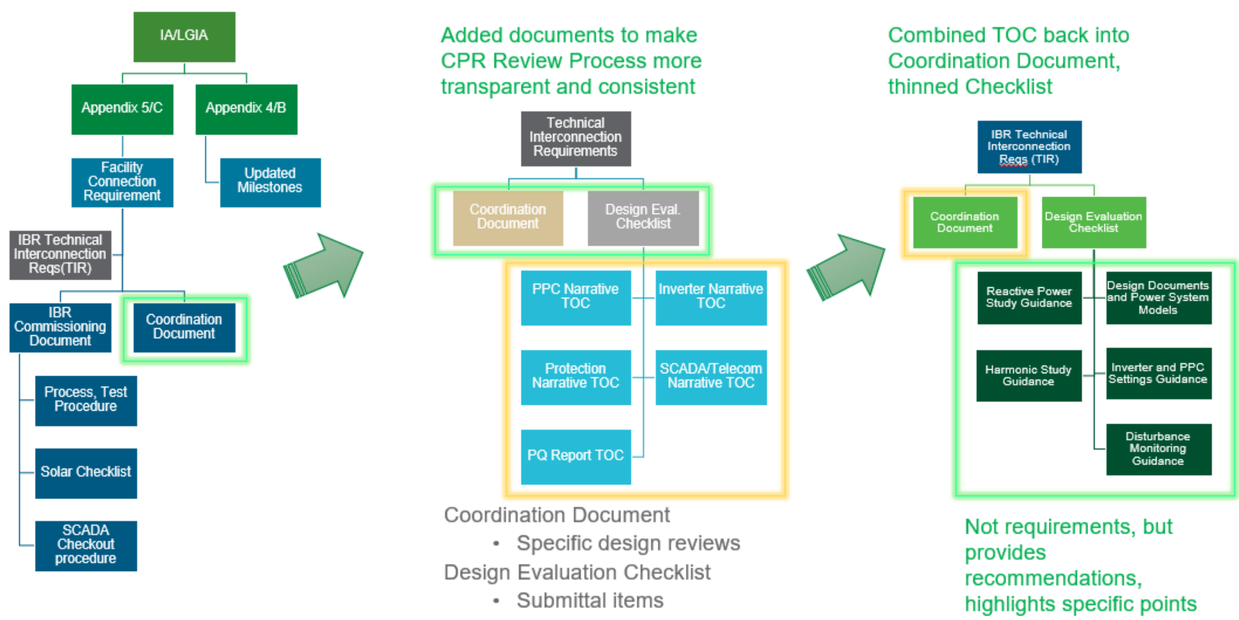


Figure 21: Evolution of Transmission-Connected IBR Documents [Source: Duke Energy]

Anthony highlighted that there are dependencies between work products, and the order of IBR developer work may cause repeat work needed, which Duke is seeking to avoid. A dependency diagram was developed based on a thorough review of work products and dependencies (see Figure 22).

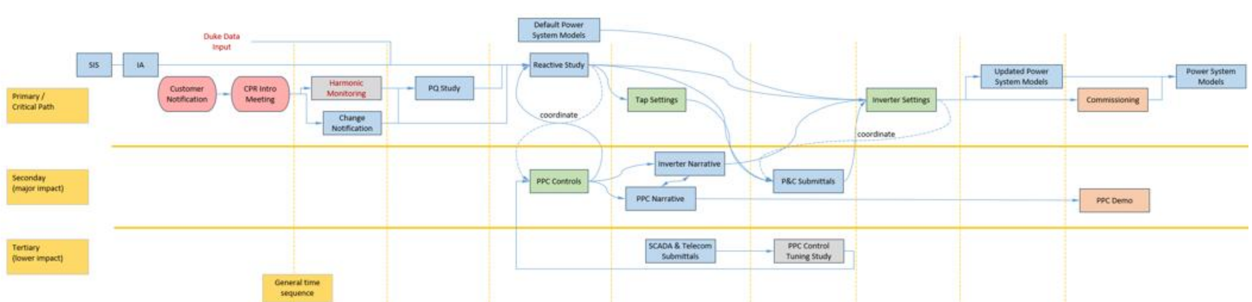


Figure 22: Work Products and Dependencies during Duke CPR Process [Source: Duke Energy]

Duke expects several iterations of this CPR process to improve review documents and is exploring ways to subdivide information between proper contractors, consultants, and OEMs. Balancing the right level of specificity – clear versus overly detailed – is a challenge. They expect that the review process will help ensure proper IBR plant configuration, providing the required performance and updated IBR plant models.

Ryan Quint, Elevate Energy Consulting

Ryan presented practical considerations and approaches for putting IEEE P2800.2 concepts into action following adoption of IEEE 2800-2022 requirements. The presentation highlighted moving away from focusing only on IEEE 2800-2022 requirements and focusing more holistically on IBR plant design, performance requirements, modeling requirements, and verification methods in a coordinated manner. While industry has made progress defining expectations, actual implementation across transmission providers, developers, and OEMs remains uneven and may be insufficient moving forward. Ryan emphasized that several efforts at NERC, including standards development work and recent Alerts, are making some aspects of IEEE 2800-2022 and IEEE P2800.2 mandatory in terms of modeling requirements, model verification, possibly commissioning, and post-commissioning.

The first step in these endeavors is to adopt IEEE 2800-2022 in interconnection requirements, and there are multiple industry references that emphasize this recommended practice. Once the transmission provider codifies the specific capability and performance requirements for newly connecting IBRs, then IBR developers can build processes around the overall steps of the conformity framework in IEEE P2800.2. However, in many cases, those steps also need to be codified in the requirements themselves; otherwise, IBR developers are unlikely to adopt them voluntarily. Examples include, but are not limited to, the following:

- Type test documentation and IBR unit model validation reports should be required with interconnection applications and after any updates.
- IBR plant model development and model verification documentation should be provided with the IBR plant models.
- IBR plant design evaluations using either documentation or simulation tests need to be defined to demonstrate the IBR plants conformity with the requirements.
- IBR plant commissioning checks and documentation should be provided that verify the site is configured as expected.
- IBR plant commissioning test data can be used for subsequent dynamic model validation and submittals.

The next step in the process is for the IBR developer to build processes that comply with the requirements set forth. IBR plant documentation management and version control are critical at this stage. IBR plant information repositories are key to handling the large volume of data from many entities involved in the IBR plant design, construction, and commissioning steps. Examples of documentation that need to be retained include the following:

- Contractual language in OEM equipment procurements
- Coordination with EPCs and third parties

- IBR plant design considerations
- Documentation collection and vetting
- Model(s) development, version control, and verification
- Model performance testing
- Interconnection application completeness and process alignment
- As-planned/as-left settings verification
- Increased visibility across departments and collaborators

The development of IBR modeling requirements by the transmission provider should be combined with the concepts of the IBR plant design evaluation (see Figure 23). Interconnection customers can automate much of the simulation model testing that checks whether the IBR plant model meets quality checks and whether the as-designed IBR plant complies with the requirements established. There are various categories of tests being developed such as those presented by MISO (see presentation from Alan Urban above) as well as Southern Company, ISO-NE, ERCOT, and others. At a high level, the categories of tests may include:

- Initialization and model functionality
- Balanced and unbalanced fault ride-through
- Small voltage and frequency disturbances
- Voltage control and reactive power capability
- High and low voltage and frequency ride-through
- Short circuit strength performance
- Protection verification

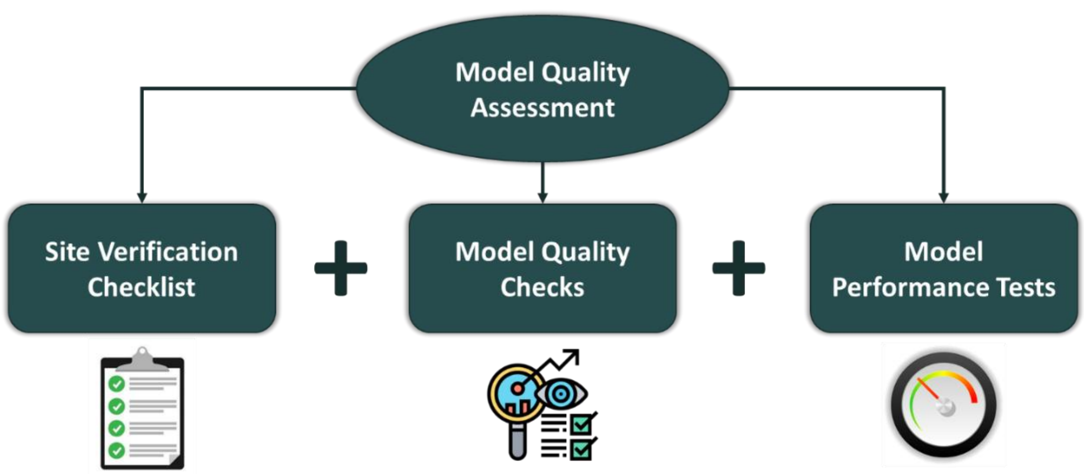


Figure 23: Work Products and Dependencies during Duke CPR Process [Source: Duke Energy]

Ryan also noted that there is an apparent gap in industry practices in terms of coordination between the transmission provider and the interconnection customer post-GIA up to COD. At this stage, the project design has been solidified, and the project will eventually be constructed and operated. Transmission providers need to develop processes, tools, and resources to support oversight and verification that the IBR plant is commissioned to match the IBR plant design used in studies, address any discrepancies, and ensure the as-left settings are documented and verified. This requires dedicated and educated staff on these topics.

IBR requirements must cover not only performance and capability but also robust modeling, documentation, and process-oriented elements, with compliance verification being just as important as the requirements themselves. By embedding IEEE P2800.2 conformity assessments, using documentation repositories, and automating model performance checks, transmission providers can adopt a "trust but verify" approach that streamlines interconnection while ensuring reliability.

Q&A and Interactive Group Discussion

Would it be more efficient to shift the requirement for UDM benchmarking from the application phase to the pre-sync validation phase for the new MISO process? Benchmarking a standard library model to PSCAD should allow MISO to run a comprehensive interconnection study, while still aligning with Order 2023.

MISO did not believe this aligned with its interpretation of the Order 2023 directives and does not recommend deferring all UDM delivery and benchmarking to a later phase. MISO must collect UDMs during the study phase, and the tests/report validation are materially easier and more efficient to perform at application. While benchmarking a standard library model to PSCAD can enable base-case creation, it may not satisfy the detailed studies needs for local interconnection applications and thus the UDM is needed. This also aligns with NERC's recommendations and guidance on this topic. This preserves study fidelity and schedule discipline without pushing critical work into the already time-compressed interconnection periods.

How are developers meant to navigate the unavailability of OEM models across platforms? For example, if TSAT UDMs are unavailable at interconnection request phase, will a project be kicked from the queue?

MISO flagged platform readiness in June 2025 with an expectation that OEMs be "up to speed" by June 2026. TSAT is a major platform, and projects should plan to have TSAT UDMs by that effective date. Under some case-by-case instances, if a TSAT UDM is missing at interconnection application, the interconnection customer may consider submitting a standard library model benchmarked to PSCAD and provide a dated OEM letter of commitment with a delivery plan for TSAT UDMs ahead of the June 2026 applicability. This reduces queue risk while acknowledging current supply-chain/model-release realities. However, developers should assume MISO will not accept prolonged gaps and may tie study progress or milestones to delivery of the missing UDM.

In MISO LVRT/HVRT tests, what is the requirement for reactive power injection? The term 'appropriate reactive current injection' is very general.

The term is intentionally non-prescriptive to accommodate OEM design diversity and system conditions. MISO may clarify without over-constraining OEMs by specifying expectations. Ranges of acceptability could be considered for additional guidance to interconnection customers; however, this is a difficult and contentious topic of IEEE P2800.2 efforts and thus was not intended to limit or preclude technologies seeking interconnection. The requirements for "appropriate" response are intended to flag gross errors or discrepancies, where needed.

Is there a reason why the balanced phase jump test is only in the EMT domain?

The requirement is tied to sub-cycle response (IEEE P2800.2 Clause 7.3). Certain control and protection behaviors (e.g., phase-locked loop and fast protection latching) are not captured accurately in phasor-domain models, so EMT is preferred to ensure fidelity.

Has MISO considered developing a change management process detailing when model re-testing is required after commercial operation due to model updates or plant changes? Particularly IBR unit or PPC software/firmware updates.

MISO already uses material modification reviews; many firmware/setting changes will fall under facility modifications that still require model updates. A clear, written change-control matrix helps. Changes that affect the electrical behavior of the IBR facility require model updates and resubmittal of the model performance tests and benchmarking.

For some documentation-based design evaluation steps, is PPC verification included?

The PPC should not be overlooked in verification steps, as it is often a source of error and late-stage tuning is rather common. Requiring a function map showing prioritization (voltage control, VRT/FRT, P/Hz, Q/V, ride-through logic), timing artifacts (delays, ramps, latches, fault-mode transitions), plant-level Q/P dispatch coordination across units, and as-planned/as-left settings with traceability are all key. IEEE P2800.2 explicitly calls out PPC prioritization and model-based tests—leverage that to make PPC evidence mandatory in the submission and to anchor IBR plant-level performance in both positive-sequence and EMT domains.

Does MISO perform consecutive voltage ride-through testing?

Not today. This did not rank as a high-priority requirement in MISO's internal prioritization. If adopted later, a risk-based approach makes sense: require it where short-circuit strength is low, where back-to-back contingencies are plausible, or where historical oscillography indicates multi-dip exposure.

As MISO collects UDMs at the generator interconnection level, do those same UDMs enter the Eastern Interconnection base case?

For EI-wide case creation, PSS®E standard library models are typically preferred for portability and model useability. PSS®E UDMs may be used where supported, but broad guidance tends toward standard library models for base cases.

For MISO, if relay voltage/protection settings change in operation, are all benchmarking tests required?

Not necessarily. The scope depends on what was changed and any downstream impacts on IBR plant performance. For example, a VRT threshold change warrants at least the VRT/HVRT suite, protection coordination checks, and any coupled PPC behaviors (e.g., current-limit transitions). Provide old vs. new comparisons and rerun the affected test groups, and this likely will suffice.

Please touch on a global perspective. Are all regions aligned in following and using IEEE P2800.2 as the preferred process? Or are there differences?

Broadly yes, there is general high-level alignment with the concepts outlined in IEE P2800.2. The concept set—unit-model validation, plant model build/verification, and a conformity assessment at point of interconnection—aligns with practices in Australia, the EU, and parts of South America. Regional differences in implementation exist, particularly for more detailed and sensitive requirements such as transient overvoltage or consecutive VRT requirements. Overall, the direction of requirements + evidence + testing matches international norms. Various recommended practices in IEEE P2800.2 can be adopted or integrated into existing practices, where needed, to improve IBR integration.

How common is IBR plant design evaluation and conformity framework internationally?

In parts of Europe (e.g., Germany), this has existed for more than a decade; although, historically, with less emphasis on grid reliability studies given their more meshed grids. As IBR plants scale, penetration levels rise, and other characteristics of different grids evolve, regions are extending from "design-meets-code" to "design + validated performance + selective impact studies," which mirrors the P2800.2 philosophy.

Staffing gaps have been an issue on both the transmission and generation side. Now, even OEMs are overloaded and understaffed with modeling queries. How do you envision this staffing issue being resolved?

Pair people with process and tools. Having clear and concise requirements that are easily understood creates streamlined processes and submissions. Deploying automation tools for asset management, model management, documentation management, and simulations can also expedite delivery of information and results. Standardized artifacts such as settings databases, test documentation, model benchmarking reports, etc., can help as well. Training and resourcing to bridge interconnection support, modeling/studies, protection and control, commissioning, etc., can also help minimize rework.

When will final version of IEEE 2800.2 be published?

The working timeline targets the first half of 2026 for publication.

Key Themes

- MISO is moving to a balanced, risk-informed modeling framework that requires four model types (PSS®E Standard Library, PSCAD, TSAT UDM, and PSS®E UDM) and a subset of tests mapped to IEEE 2800-2022/P2800.2. Draft requirements are slated for Q4 2025 publication with 2026 effectiveness, and MISO is exploring automation to run tests, benchmarking, and reporting efficiently. The MISO model performance tests and benchmarking center on 17 model quality performance tests with cross-model consistency at the point of interconnection (active/reactive power and voltage).

- Conformity assessment is both simulation- and documentation-driven: some IEEE 2800-2022 specifications (e.g., consecutive VRT, TOV) are best verified via documentation, not studies. Verification needs to cover the entire plant (inverter, PPC, balance of plant, etc.) must be sufficiently evidenced for traceability.

- Shifting models submittals later in the interconnection process can cause complications for transmission providers conducting studies. Model benchmarking is critical to ensure accuracy of models across platforms. Collecting UDMs and validating reports at application preserves study fidelity, enables early error detection, and avoids compressing critical work into late project windows.

- Platform readiness and tooling may be a near-term execution risk. Various tools, practices, processes, etc., are all being developed to support IEEE P2800.2 conformity assessments and verifications throughout the IBR interconnection process. However, industry may need to staff up to handle increased workloads.

- Post-COD change management should distinguish material modifications from facility modifications yet still require targeted re-tests when electrical behavior changes. A change-control matrix, delta reports (old vs. new settings), and scoped re-execution of only the affected benchmarks reduce burden while maintaining confidence.

- Utilities are operationalizing design evaluation through staged processes (e.g., Duke's CPR.1–.4) and clearer artifacts (TIR, Coordination Document, Design Evaluation Checklist), but staffing remains a constraint across TSOs, developers, and OEMs. Standardized repositories, version control, and automated test/report pipelines enable a "trust-but-verify" approach that aligns with emerging international practice and positions stakeholders for IEEE P2800.2's anticipated 2026 publication.

September 23, 2025 Virtual Meeting

IBR Plant Modeling Requirements and Best Practices (~225 attendees)

Presentation recording and slides are available to download here. Figure 24 shows the makeup of meeting attendees by industry sector:

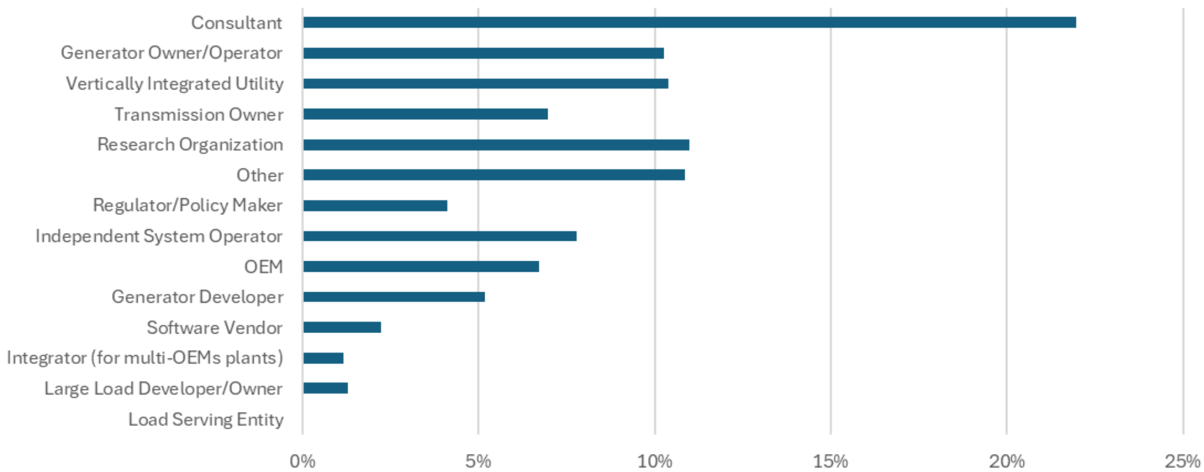


Figure 24: Meeting attendees by industry sector

This fifth meeting of Season 2 of the DOE i2X FIRST initiative focused on IBR plant modeling requirements and best practices, sharing experience from an ISO/RTO, developer/consultant, and perspectives looking forward in this area. Presentations included the following:

Bruno Leonardi, New York Independent System Operator (NYISO)

Bruno shared recent updates, initiatives, and perspectives from the NYISO. FERC Order 901 and New York State Reliability Council (NYSRC) Reliability Rule B5 (effective since February 9, 2024) have been some of the key drivers for NYISO to enhance their modeling requirements, and NYISO believes its IBR modeling requirements are in alignment with NERC's vision in this area (see Figure 25). While enhanced modeling and performance validation requirements can improve reliability and increase the accuracy and trust in models used for studies and decision making, these requirements can also affect timely commercial operation dates which can affect resource adequacy and reduction of security margins. In particular, Bruno mentioned that the NERC recommendations use the following statement (emphasis added):

> *"Performance testing processes should include sufficient tests necessary to show conformity with published performance expectations without adding undue study burden"*

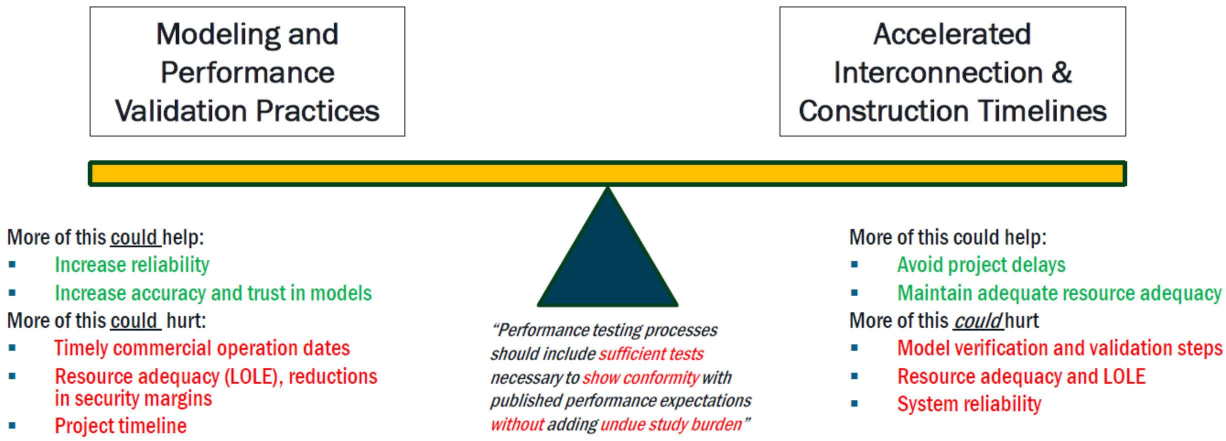


Figure 25: NYISO Perspectives on IBR Modeling Requirements and NERC Vision [Source: NYISO]

NYISO has established some core practices regarding IBR plant modeling, as shown in Figure 26. These include:

- Requiring models to accurately represent the as-planned and as-installed equipment.
- Clear equipment and model performance requirements
- Aggregate plant representation
- Benchmarked and aligned phasor domain transient (PDT) and EMT models
- Preference for standard library models but accepting all types of models
- Performing EMT studies later in the interconnection study process rather than earlier

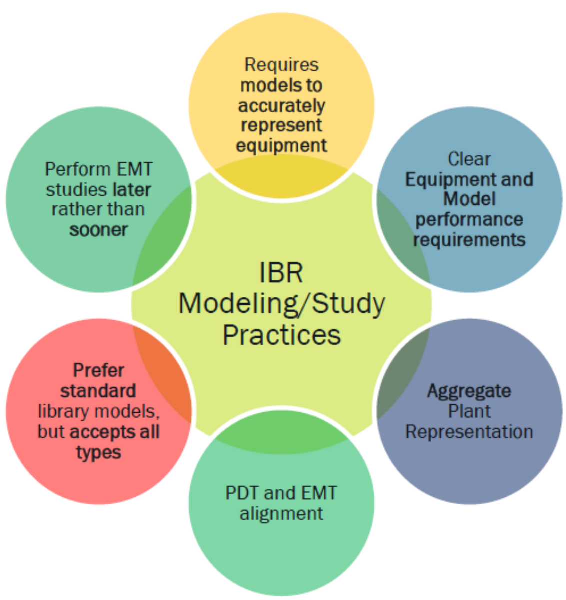


Figure 26: NYISO IBR Plant Modeling Practices [Source: NYISO]

Regarding EMT modeling and studies, Bruno shared some ongoing efforts and requirements that NYISO has implemented. EMT models are required for all IBR plants in the New York system including existing plants, plants under construction, and future IBR plants. Most EMT studies are only performed on a small area of the network, and NYISO is developing screening methods and processes to determine which IBRs must undergo more extensive EMT studies. NYISO is also thinking about the EMT study process as more of a “cycle” rather than a snapshot of the interconnection process, where EMT studies may be redone during plant construction or prior to COD once settings are confirmed/verified. The EMT study efforts have been moved later in the study process, once project details are solidified. This includes gathering EMT models *after* the cluster system impact studies prior to/during plant construction and then conducting studies as needed leading up to plant COD.

In terms of IBR modeling requirements, NYISO has established a set of tests that are similar to those specified in IEEE 2800-2022. NYISO opted not to specify quantitative pass/fail criteria; clear deviations off of baseline performance will generate questions during reviews. NYSRC Rule B5 adopted IEEE 2800 requirements (see Figure 27).

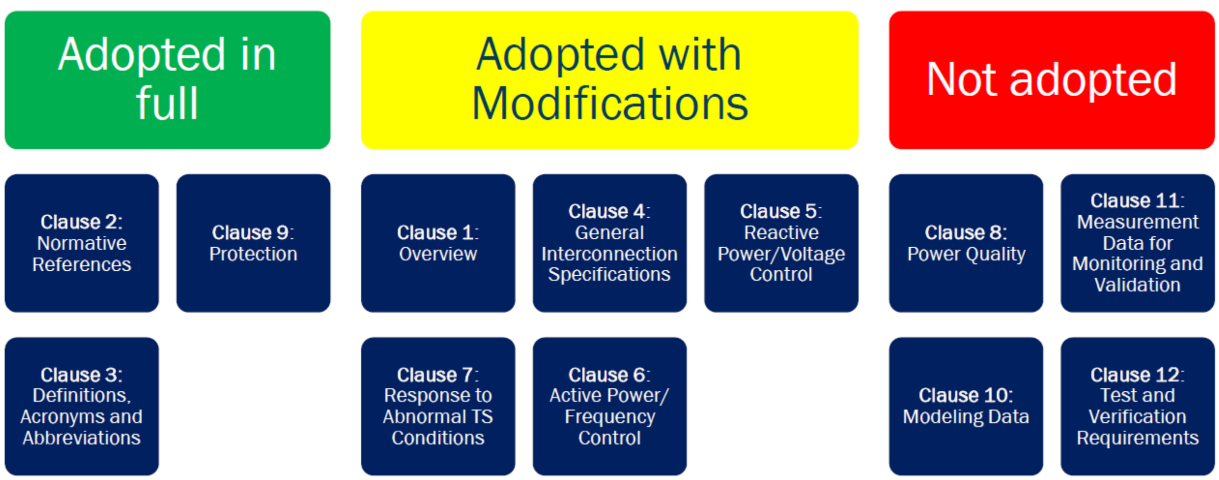


Figure 27: NYSRC Rule B5 Adoption of IEEE 2800-2022 [Source: NYISO]

<u>Kasun Samarasekera, Elevate Energy Consulting</u>

Kasun shared three recent case studies of IBR modeling and related those efforts to many of the IBR modeling and performance issues described in the i2X initiative. The first case involves a recent PSCAD model validation effort that revealed discrepancies between what was assumed to be a verified EMT model and actual behavior of the equipment in the field during an event. Somewhat abnormal response in the field was observed and the team attempted to recreate this performance in the model. To do so, the team needed to extract the inverter as-left settings, review the PSCAD model documentation, and review the actual PSCAD model. Inconsistencies in naming conventions across these three domains resulted in challenges interpreting what is installed in the field versus in the model (see Figure 28). Findings showed that the model performed very well to simulated disturbances and that model was used to pass ISO/RTO modeling tests whereas the actual equipment in the field had abnormal performance issues that needed further analysis. This highlighted the need for model verification (i.e., comparing "as-built" equipment and settings with the submitted model) during commissioning as well as ongoing model validation efforts to ensure the model matches the actual performance.

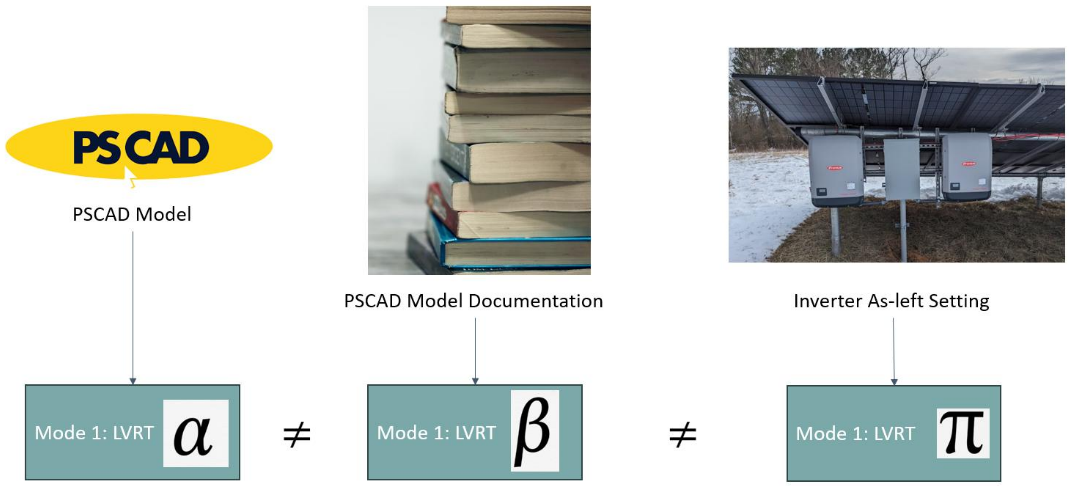


Figure 28: Discrepancies between Model, Documentation, and As-Left Settings [Source: Elevate Energy Consulting]

The next case study focused on a PPC OEM's generic model that may not meet the new ERCOT requirements related to PPC accuracy and validation as well as ongoing challenges interpreting what qualifies as "generic" versus actual control hardware in the loop (CHIL) testing and model validation. Generic PPC models based on, for example, the standard library "REPC" control block diagrams are no longer allowed in ERCOT. CHIL validation has become increasingly common for IBR units (i.e., turbines and inverters) but not necessarily for PPCs. Unrealistic PPC models (i.e., high gains, no communications delay, etc.) are rather common to achieve desired performance required by the system operator and these models are often used as defaults during the interconnection process.

Kasun highlighted the importance of accurate PPC model validation, which can include two options:

- .DLL "real code" wrapper where the actual control code is used and masked by a .DLL in the simulation models[11]
- PSCAD block model with CHIL validation to prove that the model matches actual performance

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[11] CHIL testing is still recommended even when using these types of models to validate that the model matches the actual performance of the equipment.

The last case study described working with an OEM PSCAD model in the HECO region where model updates by the OEM to pass certain tests resulted in failed results for other tests that previously passed, which highlights the need for comprehensive model testing approaches. In this situation, the OEM-specific models were provided with default parameter values and may not meet all grid code requirements under all necessary conditions. Thus, model tuning is necessary. This required close collaboration between the OEM, the project developer, and the consultants supporting the project to ensure inverter compliance with the applicable rules. The OEM made changes to the model based on a new version that enabled the plant to improve its ride-through capability; however, the plant then exhibited unacceptable damping following some disturbances. Conducting all required tests to ensure the model wholly passes all requirements prior to submission can help lead to a successful submission. Ensuring some degree of verification of the model against the field equipment/proposed settings helps ensure accuracy throughout the process.

Lastly, Kasun highlighted a recent concept and framework developed by Elevate to create more consistency and standardization between models and as-left settings across OEMs. Some OEMs have adopted a process where a mapping file can be used to extract as-left settings and port them to the models, and vice versa. However, these mapping files are not standard and require significant time to understand and refer to for project engineers. The exercise of extracting as-left settings and understanding how they map to the models should be a 5-minute exercise that can be quickly checked; however, this is not the case presently on a widespread basis. Thus, the concept of a ".IBR" file could be used to convert OEM mapping of their parameters (models and as-lefts) such that a standardized reporting tool could be used to extract parameters and settings when needed.

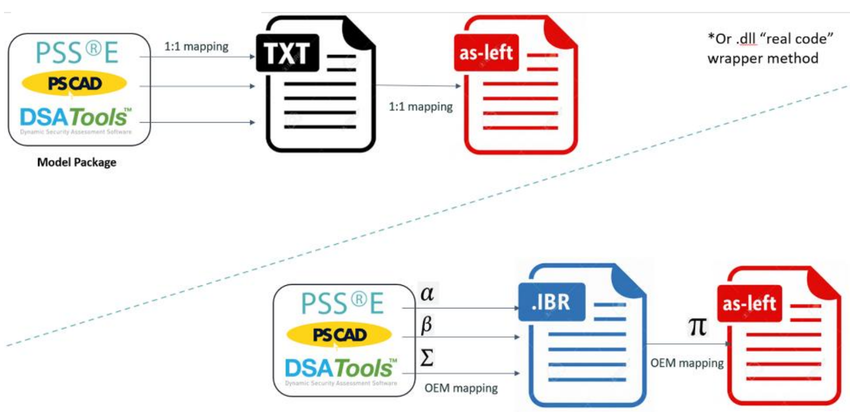

Figure 29: Concept of ".IBR" Standardized Mapping File between Model and As-Lefts [Source: Elevate Energy Consulting]

Andrew Isaacs and Lukas Unruh, Electranix

Andrew and Lukas highlighted that industry has made good progress in the area of IBR performance and modeling including publication of an IEEE standard that raises the performance bar, the prevalence of IBR modeling requirements, development of automations and processes to gather and review models, and understanding of GFM technology. These efforts have hopefully led to meaningful reliability benefits and the reduction of risks to the bulk power system. However, more work is needed moving forward to improve model accuracy such as:

- Requirements and guidance regarding unit-level model validation reporting and inclusion of type testing from IEEE P2800.2
- Improved IBR commissioning, testing, and verifications around COD
- As-built confirmations (i.e., verification) to ensure control firmware, parameters, etc.
- Adoption of .dll standards (i.e., real code models)
- Improved PPC modeling, modeling of plant communications delays, DC-side protections and controllers, etc.

OEMs may be providing a general purpose model that must be parameterized for specific projects and conditions yet the OEMs do not have sufficient resources to create and maintain as-left models that continually reflect the equipment in the field. OEMs are apprehensive to share "proprietary" information with project developers and consultants supporting the modeling efforts throughout the interconnection process. Some equipment protections may be disabled by default, leaving errors or omissions in the models if not carefully reviewed.

Data management is also becoming a challenge as more model iterations are required during the interconnection process as changes occur to the IBR plant design and equipment selection. Documentation and models need to reflect these changes and be reported accordingly. Code management, version control, etc., are all key to enabling this more effectively. Data repositories where models are "fetched" can play a key role here.

Improvements and maturity in screening tools and automations are also key for EMT studies. This includes screening for weak systems, SSO risks, etc., using high-quality, commercial-grade tools rather than one-off scripts. Clean and effective automation tools for building cases and conducting studies is needed so that the everyday study engineer does not need to be an expert in EMT modeling, similar to how PDT tools are used today.

Andrew and Lukas also highlighted that expanding study capabilities will also improve informed decision making, and this is applicable not only to IBRs but also to large load interconnection analysis as well.

<u>Q&A and Interactive Group Discussion</u>

What requirements, checks, verifications, etc., does NYISO have in place to ensure the models match the proposed equipment, particularly early in the interconnection process?

Some requirements exist for PDT models but no requirements around verification exist for EMT models yet. NYISO recently started their EMT implementation strategy and are working through when to request models, the level of detail in the models, and how those models will be used in studies. NYISO has not gotten to the point of requiring verification steps but did highlight that the NERC alert included recommendations regarding verification and validation of models.

Did NYISO send a request to all GOs for EMT model submissions from existing plants? Did it include model quality testing or benchmarking?

All existing IBR plants have been asked to submit an EMT model in accordance with the EMT modeling guidelines NYISO has published and were given six months to prepare and submit the model. There are several tests in the guideline to evaluate model performance and usability, and those tests are not pass/fail but rather are meant to be informational. If significant discrepancies from the "baseline response" are observed, additional discussions to understand why the models deviate may ensue. This should lead to better, usable models. Benchmarking between the PDT and EMT models is only requested for selected tests. NYISO recognizes that this is a fluid topic with IEEE 2800.2 and the recent NERC alert proposing test procedures to help facilitate conformity evaluation, so new processes to address that may emerge in the future.

Is Rule B5 applicable from Calendar Year 2023 onwards? What is the expectation from IBR projects submitted before that time? Does NYISO still expect an EMT model?

Correct, if you read Rule B5, it says it is applicable to projects in the interconnection studies process. Plants already in commercial operation are not asked to comply with it. The expectation for existing IBR plants remains unchanged and guided by the NYISO Tariff and manuals, local TO requirements, and applicable NERC, Northeast Power Coordinating Council (NPCC) and NYSRC rules and standards. The NYISO tariff grants NYISO the ability to request EMT models (or studies) from any market participant. EMT models were not requested until recently but given the significant volume of new IBR plants interconnecting to the system, having accurate EMT models of existing IBR plants is important. Those models are useful not only for system reliability studies, but also when there is a need to study new IBR plants connecting near existing ones.

Please elaborate on how NYISO enforces changes/upgrades to the IBR plant or network when the studies are occurring post-GIA? The developer has a signed GIA, so how do you enforce requiring changes at this late phase?

NYISO has requirements that every time a change occurs at the facility, a new model must be provided and additional studies may be needed. NYISO recognizes that settings changes do occur throughout the interconnection process. Things are likely to change, so it is hard to set a firm date on when changes can no longer occur. The requirements in the NYISO manuals and tariff require developers to report changes and a new study cycle may be initiated.

NYISO has not adopted IEEE 2800-2022, Clause 10 (Modeling Data). Does NYISO intend to adopt this clause in the future along with tests specified in IEEE P2800.2? If not, what

would need to change in IEEE 2800-2022 or IEEE P2800.2 for NYISO to be more inclined to adopt the 2800/.x framework and tests?

NYSRC Rule B5 adopts most of IEEE 2800-2022 and made modifications to clauses that NYSRC thought needed adjustment. Clause 10 has not been adopted as part of Rule B5. NYISO has started collecting EMT models so, to an extent, is already doing part of what Clause 10 asks. Complete adoption of Clause 10 remains a topic of discussion. Adoption of IEEE P2800.2 (or a slightly modified version of it) seems like a natural step for NYISO given that NYISO/NYSRC adopted most of IEEE 2800-2022 requirements through rule B5. Currently NYISO is not asking for model validation steps to be performed, and this is a critical step in ensuring models capture actual equipment behaviors. This remains a fluid topic of discussion. NYISO will issue public statements when more details can be shared.

There appears to be a lot of focus on "validation" but not nearly as much focus on "verification". What do the presenters think about this?

The state of the art IBR modeling is rather good, particularly model validation at the IBR unit level when done correctly (e.g., using DLL real code wrapper standards). It is useful to do validation both at the IBR unit and IBR plant level to identify issues, fix modeling or site errors, etc. However, the much larger gap is verification right now. There are many instances where the models simply do not match the as-left settings, configuration, controls, protections, etc., at the site. This completely invalidates the model and makes validation efforts meaningless and/or much more difficult. The process of verification is not straightforward and standardization in this area is needed. Verification should be a 5-minute exercise, but it presently is a spiderweb across settings, models, and documentation. Industry harmonization and ideally standardization would be very impactful for industry practitioners.

Regarding identifying weak system, what is the main advantage and features of the mentioned commercial software over various SCR-based methods?

Traditional SCR based metrics become unreliable in medium-to-high penetration IBR scenarios. SCR does not consider the impacts of nearby IBRs. Weighted SCR (WSCR) can consider nearby IBRs but 1) assumes they are all interacting in unison (overly conservative), and 2) requires discrete selection of which IBRs to include in the calculation which can arbitrarily skew the metric one way or another. New tools are a highly-scalable implementation of SCR with Injection Factors (SCRIF) (see Cigre WG B4.62 *Connection of wind farms to weak AC networks* (2016)), with the modification of setting device-dependent source impedances to distinguish between short-term voltage control ability of various resources. It accounts for nearby IBRs according to the voltage coupling between POIs, which can also be defined as off-diagonal impedance elements in the equivalent reduced impedance matrix.

Key Themes

- NYISO continues to evolve and enhance its IBR modeling requirements in response to FERC Order 901 and NYSRC Rule B5, emphasizing alignment with NERC's broader vision. The approach seeks to balance improved model fidelity and reliability benefits against potential delays in achieving commercial operation dates, which directly affect resource adequacy and system security margins.
- EMT modeling is becoming a core requirement for all new and existing IBR plants in New York, but NYISO is treating EMT studies as a cyclical process rather than a one-time step. Studies are being conducted later in the interconnection process, with screening tools developed to identify which IBRs require more detailed analysis and ongoing updates through construction and prior to COD.
- Case studies highlight gaps between verified EMT models and actual equipment behavior, underscoring the importance of commissioning-based model verification and ongoing validation. Challenges such as inconsistent naming conventions, unrealistic generic PPC models, and OEM tuning that resolves one test but breaks another all point to the need for more comprehensive and standardized validation frameworks.
- Verification of models against as-left settings remains a significant industry gap compared to validation. Without ensuring that models truly reflect installed equipment, protections, and settings, validation efforts become far less meaningful. Efforts like the conceptualized framework of the standardized ".IBR" mapping file aim to streamline and harmonize this process, making verification efficient and practical across OEMs.
- Industry progress includes adoption of IEEE 2800-2022, growing use of DLL "real code" wrappers, and increased reliance on CHIL validation, but OEMs face resourcing and proprietary-data barriers that limit the availability of accurate, project-specific models. Data management and version control are increasingly critical as models evolve through plant design changes, highlighting the need for structured repositories and automation.
- Looking forward, automation and improved screening tools are viewed as essential to making EMT studies more accessible and less expert-dependent. Enhancing PPC modeling, incorporating plant communication delays, and applying commercial-grade screening methods for weak systems and SSO risks will elevate study quality and help ensure that BPS decision-making reflects the real performance of IBRs under diverse operating conditions.

October 21, 2025 Virtual Meeting

Challenges with IEEE2800-2022, Planned Revisions (~215 attendees)

Presentation recording and slides are available to download here. Figure 30 shows the makeup of meeting attendees by industry sector:

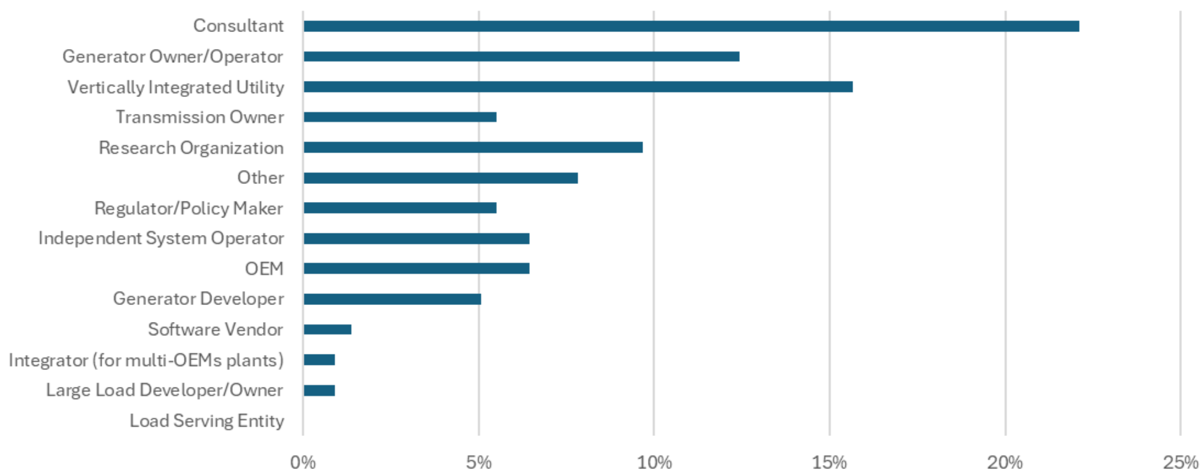

Figure 30: Meeting attendees by industry sector

This sixth meeting of Season 2 of the DOE i2X FIRST initiative focused on challenges with IEEE 2800-2022, ongoing IEEE P2800.2 recommended practice developments, and new efforts starting to revise IEEE 2800-2022 and initiate new projects related to grid forming (GFM) inverter technology as it relates to the standard. Presentations included the following:

Andy Hoke, National Renewable Energy Laboratory (NREL)

Andy provided an overview of the evolution, technical content, and implementation status of IEEE P2800.2, which provides recommended practices for test and verification procedures for **inverter-based resources (IBRs)** connecting to the transmission and sub-transmission system. The draft set of practices are closely tied to the foundational standard **IEEE 2800-2022**, which defines the minimum performance and capability requirements for applicable IBRs.

IEEE P2800.2 is current in the IEEE Standards Association (SA) ballot process and is expected to finish in late 2025 with publication in early 2026. The P2800.2 working group has over 170 voting members and over 50 non-voting members, with all major stakeholder groups represented (see Figure 31). The ballot group represents all key stakeholder groups and is not dominated by any one group. Initial ballot results back in June had an 87% approval rate, which exceeds the 75% threshold to pass. However, the working group continues to refine and improve the standard based on the comments received.

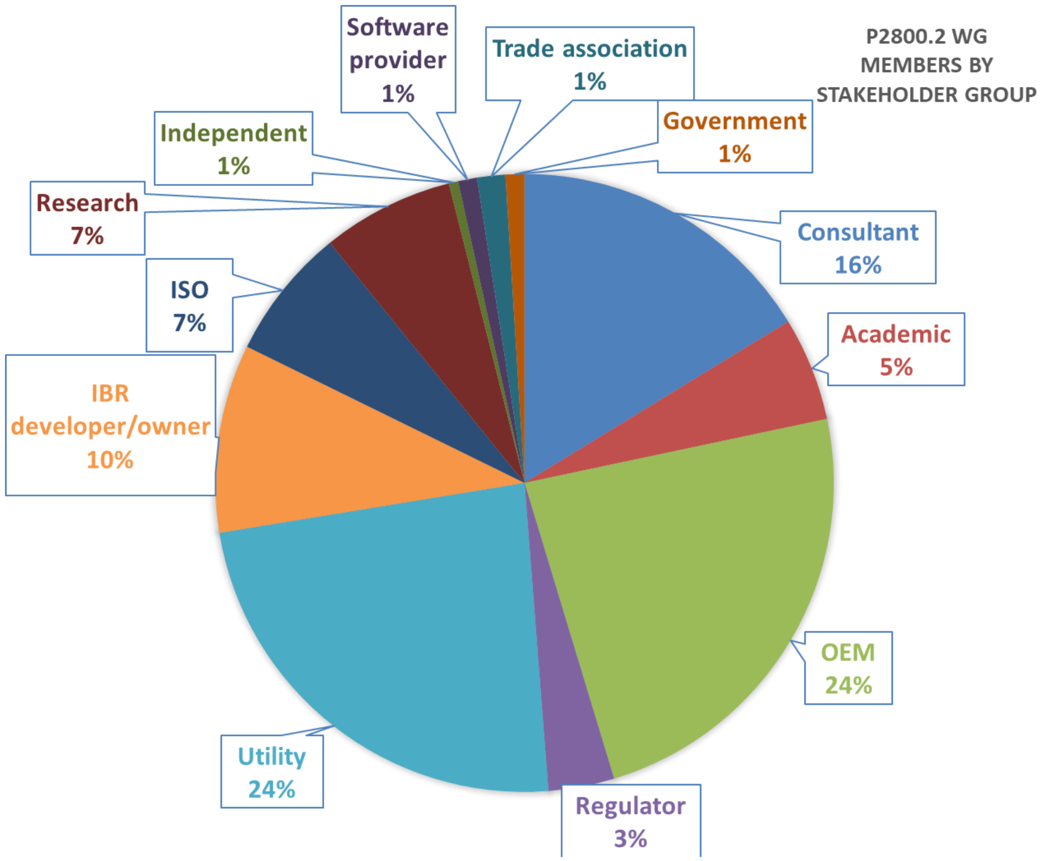

Figure 31: IEEE P2800.2 Working Group Members by Stakeholder Group (Source: IEEE)

The working group received 778 comments during the initial ballot and the Comment Resolution Group (CRG) of the working group – a group of 33 industry experts (the IEEE P2800.2 leadership team plus 13 additional invited subject matter experts) – has completed their review to address those comments. Most comments focused on type testing and IBR plant design evaluations, with a few notable themes:

- **Prescriptiveness vs. Flexibility:** The working group debated whether type tests and IBR plant design evaluation tests should be prescriptive for uniformity and efficiency or flexible for user interpretation; Draft 4.0 of the standard is now somewhat more prescriptive than the prior draft following comment resolution.
- **Type Tests:** Expanded detail and clarity with new tables, figures, and more rigorous frequency and ROCOF ride-through testing, while retaining general flexibility.
- **Design Evaluation:** Slightly lowered model validation rigor, and removed the partial framework for quantitative IBR unit model validation – model validation is only qualitative in Draft 4.0 now. The guidance regarding non-aggregated models was moved to an annex and the draft retained the option to use either a simple test system or detailed real-grid test system.

- **Commissioning Tests:** Broadened scope with added voltage feedback, reactive power control, and power factor control tests, but maintained adaptability and declined alignment with specific regulatory frameworks.

The working group is expecting the timeline to publication as shown in Figure 32.

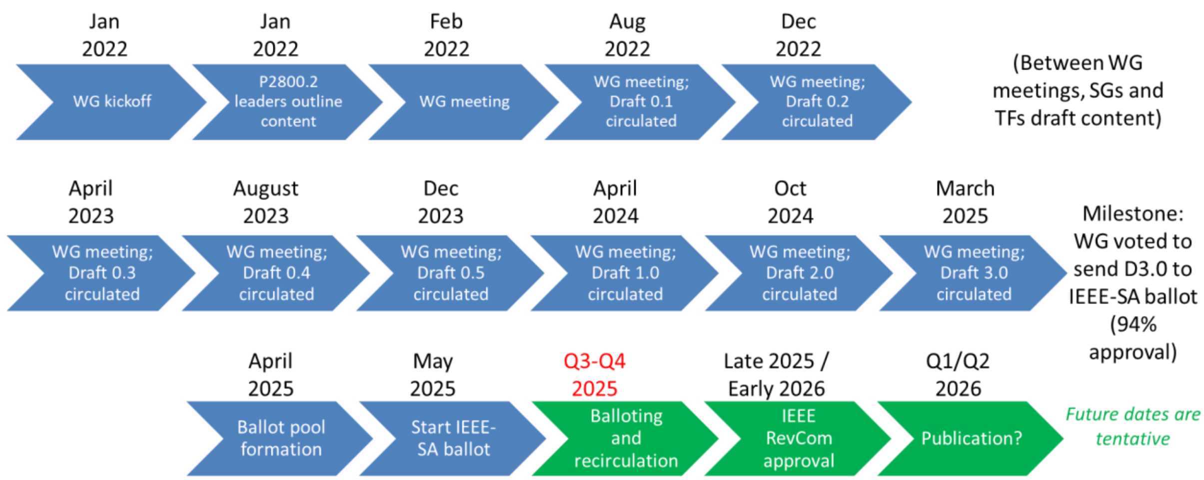

Figure 32: IEEE P2800.2 Working Group Timeline to Publication (Source: IEEE)

Manish Patel, Silicon Ranch

Manish provided a detailed review of potential areas of concern and issues to consider for a future revision of IEEE 2800-2022, including:

- Reactive power capability requirements (Clause 5.1)
- Voltage and reactive power control mode (Clause 5.2)
- Voltage ride-through capability requirements (Clause 7.2.2.1)
- Transient overvoltage ride-through requirements (Clause 7.2.3)
- Consecutive voltage deviation ride-through capability requirements (Clause 7.2.2.4)

Regarding reactive power capability (Clause 5.1), the clause states that the IBR units shall have the capability to provide reactive power support when the primary energy source is available and not available. It is recognized that this should likely be a requirement on the IBR plant, and not the IBR units directly (as the standard language currently seems to suggest). Further, the IBR plant is not required to operate at zero reactive power when voltage is greater than V4; however, the IBR plant is required to operate at zero reactive power when voltage is less than 0.95 pu (see Figure 33). Thus, additional considerations and adjustments may be needed to the capability curve.

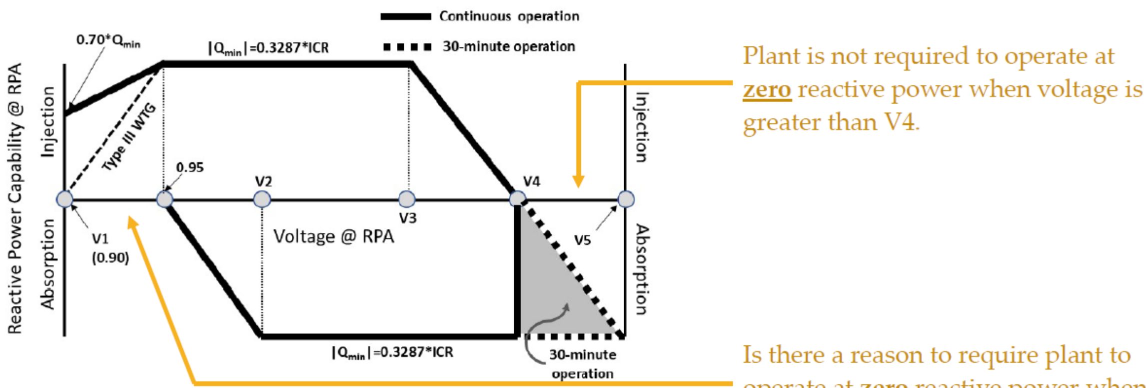

Table 4—RPA voltage range[a]

TS nominal voltage at the RPA	V1 (p.u.)	V2 (p.u.)	V3 (p.u.)	V4 (p.u.)	V5 (p.u.)
< 200 kV	0.90	0.99	1.03	1.05	1.10
≥ 200 kV except 500 kV and 735 kV as below	0.90	1.00	1.04	1.05	1.10
500 kV	0.90	1.02	1.06	1.10	1.10
735 kV[b]	0.90	1.02	1.06	1.088	1.10

Figure 33: Annotated IEEE 2800-2022 Clause 5.1 Reactive Power Capability Curve (Source: IEEE)

Regarding voltage and reactive power control modes, Clause 5.2.2 includes confusing use of “reference value” and “RPA voltage set point” that may lead to the inability to meet the requirements depending on voltage droop and pre-event reactive power output. Additionally, the clause also uses the term “reactive power droop” whereas some Transmission Planners require voltage droop control and the standard may want to consider allowing this. Lastly, Table 5 of IEEE 2800-2022 includes a reaction time requirement and some individuals have argued that this time may need further clarification regarding if the measurement time is included or not in the reaction time requirement.

In Clause 7.2.2.1 regarding voltage disturbance ride-through requirements, the voltage versus cumulative time curve and table may be misunderstood by some and may need additional clarification. It is the intent of the working group that this requirement be interpreted as a voltage versus time curve wherein for a given voltage, the IBR plant shall not trip until the duration at this voltage exceeds the ride-through curve capability. Based on this understanding, one interpretation of the voltage ride-through requirement is that a wind plant, for example, must withstand a single voltage disturbance event where the voltage drops to zero at time t=0 and then gradually recovers following the curve steps. Additionally, there are some differences between IEEE 2800-2022 Clause 7.2.2.1 and NERC PRC-029 Attachment 1 Item #7. For a voltage that remains below 0.7 pu for 2.0 seconds and below 0.9 pu for 3.5 seconds, the IBR plant is allowed to trip per IEEE 2800-2022 but not allowed to trip per NERC PRC-029-1 based on the interpretation of the requirements. This may cause inconsistencies and difficulties meeting both distinct standards in situations where both apply.

Regarding transient AC overvoltage (TOV) requirements in Clause 7.2.3, the requirement applies at the point of measurement (POM); however, TOV protection is not applied at the POM and is usually included in IBR units (at the point of connection (POC)) to protect their power electronics. Hence, it is important to understand how TOV at the POM is reflected down to the POC. It is unclear whether an aggregate model is sufficient to study this or if a detailed non-aggregated model would be needed. Regardless, the IBR plant is allowed to trip if TOV is above the specified threshold for a duration longer than specified even if the fundamental frequency phasor component of the applicable voltage is within the mandatory or continuous operation region. One of the key challenges to this requirement is how to demonstrate conformance with the TOV ride-through requirements.

Some individuals have articulated that the consecutive voltage deviation ride-through capability requirement in Clause 7.2.2.4 is too complicated and impractical to test so many different scenarios. Furthermore, the consideration of energy displacement during faults and post-fault active power recovery is key for certain technologies. There are challenges with voltage source converter (VSC) high voltage DC (HVDC) connected IBRs typically used for offshore wind plants and certain Type 4 wind turbine generators (WTGs). IEEE 2800-2022 includes an exception only for IBRs connected via VSC HVDC due to limitations of the DC chopper to absorb energy, which can affect ride-through behavior, the balance of active/reactive current during the fault, and post-fault active power recovery.

All these issues are being documented in various ways and are planned to be included in the subsequent revision of IEEE 2800-2022.

Jens Boemer, Electric Power Research Institute (EPRI)

Jens shared forthcoming revisions to IEEE 2800-2022 and the development of a new IBR recommended practice for GFM equipment. The IEEE Power and Energy Society (PES) Wind and Solar Power Plant Interconnection and Design Subcommittee (WSPPID-SC), under the Energy Development and Power Generation (EDPG) Committee, is the parent subcommittee of the Inverter-Based Resources Interconnection Working Group (IBRI-WG), which houses the IEEE 2800-2022 standard efforts and IEEE P2800.2 recommended practice developments. As the IBRI-WG begins to embark on revisions to IEEE 2800-2022, they are encouraging anyone interested in participating to sign up if they are not currently part of the IEEE P2800.2 effort (those individuals part of IEEE P2800.2 efforts will automatically be included in the subsequent efforts). A direct link to express interest in the IBRI-WG in IEEE myProject is here.

Stakeholders have asked for a revision cycle in the following areas:

- IEEE P2800a: IEEE 2800-2022 will be modified to reduce potential barriers to GFM technology adoption through an amendment process, and this topic has been identified as the most urgent.

- IEEE P2800.1: Specifications for optional GFM equipment capability and standardized performance will be established in a Recommended Practice document,[12] which will be deemed the IEEE P2800.1.
- IEEE P2800: A full revision effort to IEEE 2800-2022 will commence based on industry learnings during adoption thus far.

The IEEE P2800.1 project on GFM IBR equipment will also need to align with the other IEEE 2800/.x series of documents and thus the main standard will also need to be revised so as not to preclude the technology from being unable to meet the requirements applicable to all IBRs. This effort will need to evaluate the grid services provided by varying types of GFM technology as the future GFM recommended practices are developed. Additionally, a list of various clauses have been identified as a starting point for alignment between the IEEE P2800a, IEEE P2800.1 and IEEE P2800 efforts. There are also some plans to align with the IEC (International Electrotechnical Commission) and its efforts, where possible.

For the time being, adoption of IEEE 2800-2022 is still strongly encouraged as it establishes a solid baseline of IBR plant capability and performance requirements. After the forthcoming revisions are complete, industry may need to update their requirements to reflect the new version(s) of the standard. It is expected that the IEEE 2800 series of standards will undergo continuous learning and improvements, which should not deter any transmission provider or other authority governing interconnection requirements (AGIR) from adopting the latest version of the standard.

Q&A and Interactive Group Discussion

In addition to type testing of IBR units, is type testing of PPCs included in IEEE 2800.2? How do the considerations/type tests differ in that case?

IEEE P2800.2 includes type tests for IBR units (i.e., turbines/inverters) and PPCs. The same general concepts apply to validate these models.

ERCOT now requires type test results (control hardware in the loop (CHIL)) of PPCs or real code models of PPCs. What does IEEE P2800.2 say about this? And how should industry think about this for legacy and new projects?

CHIL testing and/or real code models are recommended. IEEE 2800-2022 is designed as a forward-looking standard and not intended to be applied retroactively to existing facilities. Industry may be adopting portions of the standard differently, which may result in challenges and obstacles.

[12] IEEE Standards are documents that specify mandatory requirements (i.e., “shall) whereas Recommended Practices are documents in which procedures and position preferred by the IEEE are presented (i.e., “should”).

How many individuals submitted comments to the IEEE P2800.2 initial ballot?

About 40 people submitted comments (most people voted without commenting). As the working group moves into recirculation ballot, the group will look for ways to wrap up the work and try to avoid making major changes.

The original IEEE P2800.1 was the entity-based test and verification effort. Did that effort get replaced with this new effort? What are the processes/procedures?

Yes, the original IEEE P2800.1 entity-based project expired and no progress was made. Thus the.1 came available again, and the working group decided to use the opportunity to apply the .1 for the forthcoming GFM recommended practice effort.

ERCOT, MISO, and others already published GFM requirements. How does the working group envision the new IEEE requirements aligning with existing ones?

The idea is that the GFM task force under the IBRI-WG will review all requirements in North America and some internationally and to the extent that the group agrees on equipment-level requirements or recommended practices, they can be published as such. However, note that what will be published are recommended practices and entities can adopt as they see fit.

Please explain the benefits of harmonization between IEEE and IEC standards.

This is an aspirational goal by the IBRI-WG to coordinate with IEC. One of main drivers is that IBRs are a global market and OEMs design products for all markets and build in capabilities to design for regional configurations. These IBR often use the same hardware platform with different software versions. So, to the extent possible, such interconnection requirements should be globally coordinated and enable a more streamlined set of product offerings across markets.

Other regions around the world have already developed significant experience with GFM and how the technology can be utilized. Breaking down requirements for capability and performance and sorting out what are capability versus utilization requirements is essential.

When will the recirculation ballot for IEEE P2800.2 start and for how long will it be open?

The recirculation is expected to start the last week of October 2025 and will last 21 days.

How is the IBRI-WG deciding to make changes to IEEE 2800-2022?

The group has an informal list of potential items to change or fix in IEEE 2800-2022 based on feedback from industry thus far, including feedback from the i2X FIRST forum. Ultimately, what gets changed will be decided by the working group.

What is the rationale for different reactive power requirements for Type 3 and Type 4 wind turbines? There are type 4 wind turbines without any reactive power capability below cut-in wind speed.

The presenters noted that the justification was that Type 4 wind can easily be designed to provide reactive power at zero active power, just like a solar PV or BESS. In contrast, it is more difficult to design a Type 3 WTG to provide reactive power at very low active power. However, this is one of the requirements that some want to change in the revision to IEEE 2800-2022. Some of the currently available Type 4 wind turbines do not offer any reactive capability at zero wind.

Describe the term "utilization requirement" (in the context of GFM).

IEEE 2800-2022 front matter has informative notes describing differences between capability requirement, performance requirement, and utilization. Utilization is outside the scope of IEEE 2800-2022. However, it can relate to GFM performance and capabilities; for example, a GFM-capable inverter that provides response to voltage phase angle jump may require the inverter to adjust active power instantaneously. Inverter may be capable of this design, but it may not be able to deliver this active power if it is already operating at its maximum active power level. So, it is hard to differentiate what is about design of equipment and what is about utilization of equipment to deliver specific services. Utilization is outside scope of the IEEE 2800 series but may need further clarification in the context of GFM.

How can we better educate Utility Regulators on evolving IBR technology capabilities, requirements developments, and how changes are being made to address these?

The presenters talked about alignment, education, information sharing, etc. ESIG serves as a forum to provide such education, and there may be opportunities to coordinate with the National Association of Regulatory Utility Commissioners (NARUC).

<u>Key Themes</u>

- **IEEE P2800.2 Toward Publication:** The IEEE P2800.2 Working Group is nearing completion of recommended practice for testing and verification of applicable IBRs. The initial draft received 87% ballot approval and nearly 800 comments—most centered on type testing and design evaluation. The group continues refining the document, targeting publication in early 2026 following recirculation.
- **Balancing Prescriptiveness and Flexibility in Testing and Design:** A central theme throughout the P2800.2 development is the balance between standardized, prescriptive testing for uniformity and flexible approaches that accommodate diverse technologies. The latest draft (D4.0) modestly increases prescriptiveness for type testing while keeping space for user interpretation in design and commissioning evaluations.

- **Emerging Lessons and Gaps in IEEE 2800-2022 Implementation:** Experience with IEEE 2800-2022 has surfaced areas needing clarification—particularly in reactive power capability, voltage and reactive control modes, and ride-through requirement definitions. Misinterpretations of key clauses, complexity of other clauses, and alignment issues with NERC PRC-029 have revealed inconsistencies that can complicate compliance. These insights are shaping the next revision cycle to make the standard more practical and consistent with system operator expectations.
- **Upcoming Revisions and New Efforts on GFM Technology:** Parallel to the P2800.2 ballot, IEEE is launching three new efforts that will continue to refine and reshape the IEEE 2800 series of standards: P2800a to reduce barriers for GFM adoption, P2800.1 to define equipment-level requirements for GFM equipment, and a full revision of IEEE 2800-2022 to align all related standards.
- **Importance of Global Harmonization and Regulatory Education:** IEEE and IEC are attempting to coordinate efforts, although noted as "aspirational." IBR technology and manufacturing are global efforts. Thus, aligning international standards reduces cost, complexity, and regional divergence in product design. Participants also emphasized the need to better educate regulators and policymakers about evolving technical standards.
- **Industry Participation and Continuous Improvement:** The IEEE IBRI-WG is encouraging broad participation in ongoing and future projects. Stakeholders were reminded that adoption of IEEE 2800-2022 should continue even as revisions are underway, since each iteration builds on lessons learned. The evolving IEEE 2800 series is intended to be a "living framework," continuously refined to reflect advancements in technology, modeling, and system reliability practices.

November 25, 2025 Virtual Meeting

Change of Management during IBR Plant Interconnection Process and Commissioning, How to Maintain Conformity (~___ attendees)

Presentation recording and slides are available to download here. Figure 34 shows the makeup of meeting attendees by industry sector:

[FIGURE]

Figure 34: Meeting attendees by industry sector

Q&A and Interactive Group Discussion

Key Themes

December 16, 2025 Virtual Meeting

IBR Plant Commissioning Best Practices II (~___ attendees)

Presentation recording and slides are available to download here. Figure 35 shows the makeup of meeting attendees by industry sector:

[FIGURE]

Figure 35: Meeting attendees by industry sector

Q&A and Interactive Group Discussion

Key Themes

January 27, 2026 Virtual Meeting

IBR Plant Commissioning Best Practices II (~___ attendees)

Presentation recording and slides are available to download here. Figure 36 shows the makeup of meeting attendees by industry sector:

[FIGURE]

Figure 36: Meeting attendees by industry sector

Q&A and Interactive Group Discussion

Key Themes

February 24, 2026 Virtual Meeting

Grid Forming IBR Specifications and Testing Requirements I (~___ attendees)

Presentation recording and slides are available to download here. Figure 37 shows the makeup of meeting attendees by industry sector:

[FIGURE]

Figure 37: Meeting attendees by industry sector

Q&A and Interactive Group Discussion

Key Themes

March 16, 2026 (Hybrid event at ESIG Spring Workshop)

Grid Forming IBR Specifications, Testing Requirements, and Lessons Learned (~___ attendees)

Presentation recording and slides are available to download here. Figure 38 shows the makeup of meeting attendees by industry sector:

[FIGURE]

Figure 38: Meeting attendees by industry sector

Q&A and Interactive Group Discussion

Key Themes

For more information, visit: energy.gov/i2X