INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

Forum for the Implementation of Reliability Standards for Transmission (i2X FIRST) | 07/22/25

An initiative spearheaded by the Solar Energy Technologies Office and the Wind Energy Technologies Office

BERKELEY LAB

ESIG

EPRI

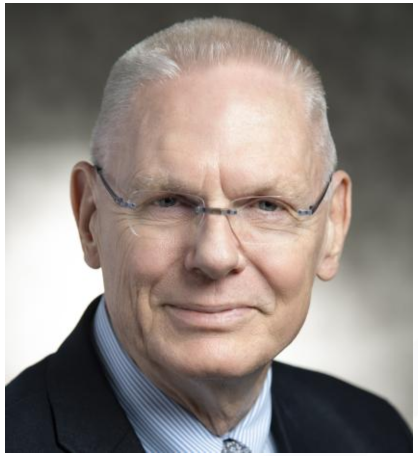
The first half of this meeting call is being recorded and may be posted on ESIG's website. If you do not wish to have your voice recorded, please do not speak during the call. If you do not wish to have your image recorded, please turn off your camera or participate by phone. If you speak during the call or use a video connection, you are presumed consent to recording and use of your voice or image.

Key Goals and Outcomes from i2X FIRST

- To facilitate understanding and adoption of new and recently updated standards relevant for existing and newly interconnecting wind, solar and battery storage plants
- The Forum will convene the industry stakeholders to enable practical and more harmonized implementation of these interconnection standards.
- The presentation portion of the meeting will be recorded and posted, and presentation slides will be shared.
- Additionally, the leadership team will produce **a summary of each meeting** capturing:
  - Recommended best practices
  - Challenges
  - Gaps that require future work

Leadership Team

Cynthia Bothwell, Boston Government Services, contractor to DOE's Wind Energy Technologies Office



Robert Reedy, Lindahl Reed, contractor to DOE's Solar Energy Technologies Office

Will Gorman, Lawrence Berkley National Laboratory

Jens Boemer, Electric Power Research Institute

Julia Matevosyan, Energy Systems Integration Group

Ryan Quint, Elevate Energy Consulting

Summary of the last meeting: NERC Milestone 3 Standards

- **NERC Progress Update on Milestone 3 Projects** – Sandhya Madan, NERC
- **Current State of IBR Modeling in North America** – Miguel Cova Acosta, Vestas
- **Legacy IBR Plant Modeling** – Andrew Isaacs, Electranix
- **Q&A and Structured Discussion**, led by Julia Matevosyan, ESIG
  - What are the biggest impediments to accurate IBR plant modeling?
  - Do you see need for more workforce development related to IBR modeling?

Meeting summary, recording & presentations are posted here

Key Themes from the Last Meeting

- **NERC Milestone 3 Standards Development and Balloting Challenges:** Addressing data sharing, model verification, and system model validation including IBRs. Initial ballots for the three projects did not pass. The challenges underscore ongoing industry tension between compliance needs and implementation feasibility.
- **Upcoming Milestone 4 Work and Expanding IBR Reliability Focus:** will examine broader reliability standards including TOP, IRO, PRC, and TPL, and revise key definitions. 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 in EMT presents unique challenges. Without high-fidelity models, studies may yield unreliable or misleading decisions. This underscores the need for upfront modeling requirements for OEM-specific, validated models. Model maintenance, including change management and source code compatibility, is critical over a plant's lifecycle.
- **UDMs and Standard Library Models:** Standard models may be easier to understand but may not be appropriately configured for, or fully represent actual equipment, risking non-compliance. OEM-validated UDMs may provide more accurate representations and are preferred during interconnection. Using models that have been validated for the specific type and scope of study is essential. Prioritizing simplicity over accuracy inappropriately can compromise reliability as grid complexity grows. OEM validation, support and documentation improve IBR model quality and accuracy.

Key Themes from the Last Meeting (cont.)

- **Commissioning Gaps and Model Fidelity Concerns:** Commissioned IBR plants often lack alignment with the models used during interconnection studies. This can result in mismatches that degrade reliability.

  Commissioning tests help validate models through small-signal disturbances, they may miss crucial large disturbance behavior. Need for post-commissioning model validation and ongoing model support from OEMs.
- **Model Quality and Use in Planning vs. Operational Studies:** SMIB-type model quality tests 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.

Upcoming i2X FIRST Meetings – Season 2

1. May 27, 2025, 11 a.m. - 1 p.m. ET – **Season 2 Kick-Off**
2. June 24, 2025, 11 a.m.- 1 p.m. ET – **NERC Milestone 3 Standards**
3. **July 22, 2025, 11 a.m.- 1 p.m. ET – IBR Plant Design Evaluation with Applicable Requirements I**
4. August 26, 2025, 11 a.m.- 1 p.m. ET – IBR Plant Design Evaluation with Applicable Requirements II
5. September 23, 2025, 11 a.m.- 1 p.m. ET – IBR Plant Modeling Requirements and Best Practices
6. October 21, 2025, 11 a.m.- 1 p.m. ET – Challenges with IEEE2800-2022, Planned Revisions
7. November 25, 2025, 11 a.m.- 1 p.m. ET – Change of Management during IBR Plant Interconnection Process and Commissioning, How to Maintain Conformity
8. December 16, 2025, 11 a.m.- 1 p.m. ET – IBR Plant Commissioning Best Practices I
9. January 27, 2026, 11 a.m.- 1 p.m. ET – IBR Plant Commissioning Best Practices II
10. February 24, 2026, 11 a.m. - 1 p.m. ET – Grid Forming IBR Specifications and Testing Requirements I
11. March 16, 2026 hybrid event during ESIG Spring Workshop: Grid Forming IBR Specifications, Testing Requirements, Lessons Learned

Sign up for all future i2X FIRST Season 2 Meetings here

Follow ESIG i2X FIRST website https://www.esig.energy/i2x-first-forum/ for meeting materials & recordings and for future meeting details & agendas

IBR Plant Design Evaluation – Agenda

- **Meeting Introduction:** Julia Matevosyan, ESIG
- **IEEE P2800.2, IBR Plant Design Evaluation – Overview:** Jens Boemer, EPRI
- **IBR Plant Design Evaluation – Developer Perspective:** Rishi Maharaj, Engie
- **IBR Plant Design Evaluation – EPC Perspective:** Patrick Hart, Mortenson
- **Q&A and Structured Discussion**, led by Julia Matevosyan, ESIG
  - Is IBR plant design evaluation being carried out today? Is it sufficient?
  - How can IBR plant design evaluation be improved to ensure future grid reliability?

Virtual Meetings Code of Conduct

1. *Assume good faith and respect differences*
2. *Listen actively and respectfully*
3. *Use "Yes and" to build on others' ideas*
4. *Please self-edit and encourage others to speak up*
5. *Seek to learn from others*

Mutual Respect . Collaboration . Openness

Stakeholder Presentations

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Mutual Respect . Collaboration . Openness

Q & A Session

Interactive Group Discussion Topics

Topic #1: Is IBR plant design evaluation being carried out today?

- Please go to slido to make comments and add questions of your own: **slido.com** and enter event code **FIRST3**
- For verbal commentary, please use the raise hand feature and we will call on you
- Additional related / associated questions:
  - Is IBR plant design evaluation being carried out currently?
  - When in the interconnection process is IBR plant design evaluation done today?
  - Is it based on actual IBR plant design (representative of what will be built in the field) or using default parameters?
  - Does it asses the specified performance for an IBR plant for a specified grid conditions (e.g., a specific short-circuit ratio), or does it assess the full range of IBR plant capability?
  - How are any design changes throughout the interconnection process accounted for?
  - Are current IBR plant design evaluation practices sufficient to ensure reliable IBR plant operation?

Topic #2: How can IBR plant design evaluation be improved?

- Please go to slido to make comments and add questions of your own: **slido.com** and enter event code **FIRST3**
- For verbal commentary, please use the raise hand feature and we will call on you
- Additional related / associated questions:
  - How can IBR plant design evaluation be improved?
  - Should IBR plant design evaluation also assess capability to operate under various grid conditions? If so, how could that be tested?
  - How can IBR plant design evaluation be streamlined or sped up without giving up on reliability or accuracy?
  - What are best practices to capture IBR plant design changes during the interconnection process in the IBR plant design evaluation?

IBR Plant Design Evaluation – Overview

i2X FIRST—Season 2

Jens C. Boemer
Technical Executive

Tuesday, July 22nd, 2025

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Background and Motivation:
Large IBR Plant Interconnection Reliability Roadmap

Increasing scrutiny in Large IBR plant-level conformity assessment

No or insufficient performance specifications

- "everyone is in the dark"
- Large IBR plants trip frequently

Sufficient Performance specifications

- international references
- collaborative learning
- standards

Conformity Assessment by unit certification and plant checklist

- education on, and adoption of performance, testing, and verification standards
- international references
- collaborative learning
- product attestations

Conformity Assessment by unit certification & characterization and plant modeling

- education in modeling for conformity assessment
- model quality and validation/ verification requirements and improvements
- automation via tools

Past — Today — Future — **Time**

Increasing % of instantaneous Large IBR penetration

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Background and Motivation

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IEEE 2800-2022

IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems

No plans for IBR equipment certification to date

Conformity Assessment by <u>unit certification</u> and plant checklist

- education on, and adoption of performance, testing, and verification standards
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- product attestations

?

Conformity Assessment by unit ~~certification &~~ characterization and <u>plant modeling</u>

- education in modeling for conformity assessment
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P2800.2

Recommended Practice for Test and Verification Procedures for Inverter-based Resources (IBRs) Interconnecting with Bulk Power Systems

Active PAR

Past — Today — Future — **Time**

Increasing % of instantaneous Large IBR penetration

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Background and Motivation

Increasing scrutiny in Large IBR plant-level conformity assessment

Scope of this presentation

No plans for IBR equipment certification to date

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✓

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P2800.2

Recommended Practice for Test and Verification Procedures for Inverter-based Resources (IBRs) Interconnecting with Bulk Power Systems

Active PAR

Past | Today | Future | **Time**

Specifications without Verifications are Useless!

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Background and Motivation:
Industry Terms for Safety, Quality, and Efficiency

Compatibility

- Design equipment to support conformity or compliance of a complex system (e.g., IBR plant)
  - ➢ **Equipment level**

Conformity[1]

- Adherence to certain voluntary industry standards or procedures (e.g., IEEE 2800.2)
  - ➢ **Plant level**

Compliance

- Meeting mandatory legal and regulatory obligations (e.g., NERC Reliability Standards)

[1] The term "conformance" is depreciated and should not be used any longer.

STANDARDS EDUCATION

INTRODUCTION TO CONFORMITY ASSESSMENT AND COMPLIANCE: AN OVERVIEW OF PRODUCT CONFORMITY ASSESSMENT AND REGULATORY COMPLIANCE

BY DONALD HEIRMAN, MEMBER OF STANDARDS EDUCATION COMMITTEE

https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8082574

November 2023 | Knowledge Center

Conformance vs. Compliance: Their Key Differences

https://www.inboundlogistics.com/articles/conformance-vs-compliance

Conformity Vs. Conformance Vs. Compliance

Carlos Cisneros
Airline and Airport Safety Management Systems Leader
Published Dec 26, 2016
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https://www.linkedin.com/pulse/conformity-vs-conformance-compliance-carlos-cisneros-cqa/

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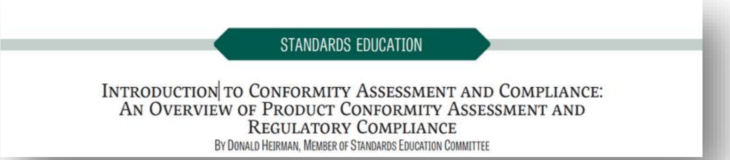
Compliance
- Meeting <u>mandatory</u> legal and regulatory obligations (e.g., NERC Reliability Standards)

Scope of this presentation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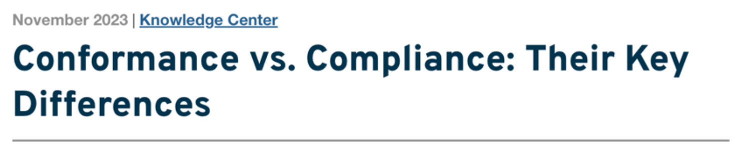
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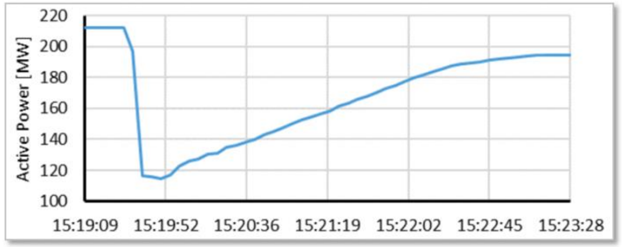
The Challenge: Example for Non-Conformity with IEEE 2800

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Plant Controller Interactions Persist



Fault Occurs
⇩
Voltage Drops
⇩
Inverters Enter Momentary Cessation
⇩
Plant Controller Pauses Control
⇩
Fault Clears
⇩
Voltage Recovers
⇩
Plant Controller Regains Control
⇩
Plant Controller Limits Inverter Recovery

Example: Plant with Legacy Inverters

- Momentary cessation settings:
  - Voltage threshold: 0.875 pu
  - Delay to recover: 1.020 sec
  - Recovery ramp rate: 8.2%/sec
- Expect recovery to pre-disturbance in about 13-14 seconds
- Plant requires about 4 minutes to restore output

- Systemic issue seen across many facilities – big and small, old and new

19 **RELIABILITY | RESILIENCE | SECURITY**

- Momentary cessation occurs above 0.1 pu voltage
- Plant controller slows restore output after fault beyond 1 s

Function Set	Advanced Functions Capability	IEEE 2800-2022	Conformity Assessment
Bulk System Reliability & Frequency Support	Frequency Ride-Through (FRT)	‡	
	Rate-of-Change-of-Frequency (ROCOF) Ride-Through	‡	
	Voltage Ride-Through (VRT)	‡	Pass
	Transient Overvoltage Ride-Through	‡	
	Consecutive Voltage Dip Ride-Through	‡	
	Restore Output After Voltage Ride-Through	‡	Fail
	Voltage Phase Angle Jump Ride-Through	‡	
	Frequency Droop / Frequency-Watt	‡	
	Fast Frequency Response / Inertial Response – Underfrequency FFR	‡	
	Fast Frequency Response / Inertial Response – Overfrequency FFR	√	
	Return to Service (Enter Service)	‡	
	Black Start	√	
Dynamic Voltage Support	**Dynamic Voltage Support / Current Injection during VRT – Balanced**	‡	Fail
	Dynamic Voltage Support / Current Injection during VRT – Unbalanced	‡	Fail
Protection Functions and Coordination	Abnormal Frequency Trip	√	
	Rate of Change of Frequency (ROCOF) Protection	√	
	Abnormal Voltage Trip	√	
	AC Overcurrent Protection	√	
	Unintentional Islanding Detection and Trip	√	
	Interconnection System Protection	√	

IEEE 2800-2022 requirements apply to the IBR plant*

- IBR units and IBR plant controller (= “supplemental IBR device”)

* with exception of ‘current injection during VRT’ which applies to IBR unit

How can conformity with IEEE 2800-2022 be assessed?

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The Challenge: Emerging IBR Model-Based Verifications

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—voltag e contro	Clause 6: Active power—freque ncy 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	✓	○	○	◑	◕	●	●	●	◕ (red)	●	●	●	◑ (red)	○
ERCOT	Phase 1	Hybrid Reference Customization &	✓	POI	✓	○	○	○	◔	●	○	●	○	●	◔ (red)	◔ (red)	◔ (red)	
	Phase 2	Hybrid Reference Customization &	✓	POI	✗	○	○	○	○	○	○	○	○	○	○	◑	○	○
Georgia Transmission Corporation	Phase 1	Hybrid Reference Customization &	✗	POI	✓	○	○	◕	◑	●	●	●	◑	●	◑ (red)	●	◔ (red)	○
	Phase 2	Hybrid Reference Customization &	✗	POI	✓	○	○	◕	◑	●	●	●	◑	●	◑ (red)	●	◔ (red)	○
HECO	Stage 3 Hawaii RFP	Hybrid Reference Customization &	✗	POI	✓	○	○	○	◔	●	◕	◑	●	●	●	●	○	
ISO-NE		Detailed Reference & Customization	✗	POM	✓	○	○	●	◕	◕	◕	◕	○	○	○	○	○	○
MISO	Phase 1	Detailed Reference & Customization	✗	POM	✓	○	○	○	◑	○	○	◕	○	○	◔ (red)	○	○	
	Phase 2	Hybrid Reference	✗	POM	✓	○	○	○	◑	◕ (red)	◕	◕	○	○	◔ (red)	◕	○	
NYSRC		Hybrid 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	✓	○	○	○	○	◑ (red)	◑ (red)	◑	◔	◑ (red)	◑ (red)	◕	◔	○
SaskPower		Hybrid Reference Customization &	✗	POI	✓	○	○	○	○	◕ (red)	●	◕	○	○	○	○	○	○
Southern California Edison (SCE)	Phase 1	Detailed Reference & Customization	✗	POI	✓	●	●	●	●	◑	◑	● (red)	●	●	○	○		
Southern Company	Phase 1	Detailed Reference & Customization	✗	POI	✓	○	○	○	◑	●	●	●	◑ (red)	●		◕		○
	Phase 2	Detailed Reference & Customization	✗	POI	✓	○	○	◕	◑	●	●	●	◑ (red)	●	●	◕	◔ (red)	○
	Phase 3	Detailed Reference & Customization	✗	POI	✗	○	○	◕	○	○	○	○	○	○	●	○	◕ (red)	○
SPP	Phase1	Detailed Reference & Customization	✗	POM	✓	○	○	○	◑	○	○	◕	○	○	○	●	○	
SRP	Phase 1	Hybrid Reference Customization &	✗	POI	✓	○	○	●	●	●	●	◕	◕ (red)	●	●	●	●	○
	Phase 2	Hybrid Reference Customization &	✗	POI	✓	○	○	●	●	●	●	◕	◕ (red)	●	●	●	●	◑ (red)
Tennessee Valley Authority (TVA)	Phase 1	Hybrid Reference Customization &	✗	POM	✓	●	○	●	●	●	◕	●	◕ (red)	●	●	●	○	○

Legend: ○ – not adopted | ◔ , ◑ , ◕ , ● – various adoption degrees | ◔ , ◑ , ◕ , ● – various degrees of own specs

Sources:

- OATI Open Access Same-Time Information System (OASIS)
- Own research based on EPRI member information

Last Update: May 27, 2025

Please send feedback to jboemer@epri.com

Jens Boemer, EPRI (2025)

Heterogenic requirements for IBR performance test and verification.

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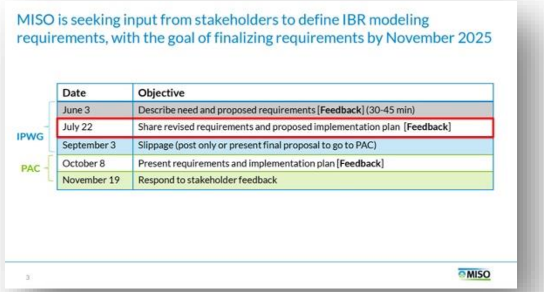
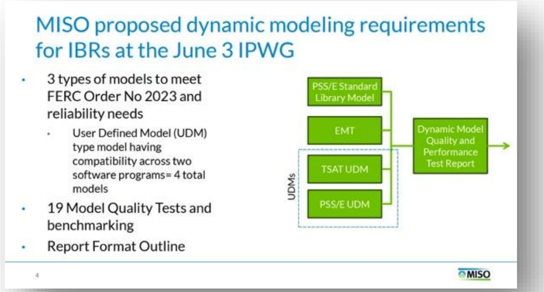
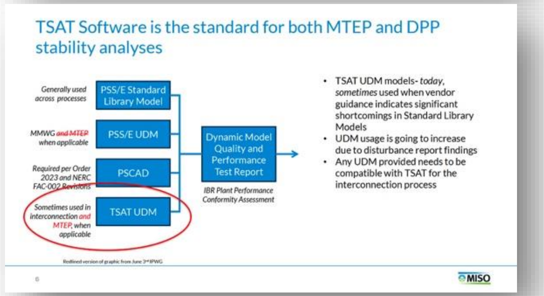
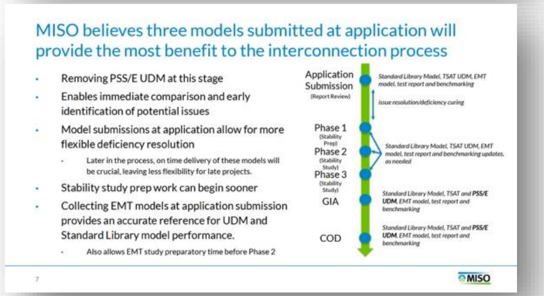
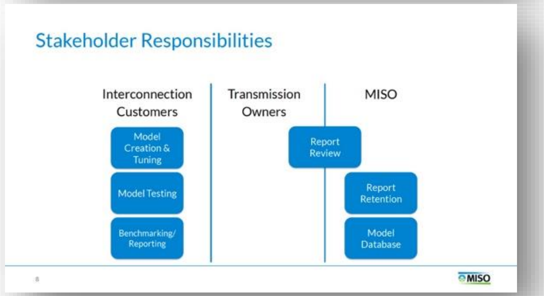
Example: MISO is proposing **IBR modeling requirements for** *IBR Plant Performance* ***Conformity Assessment***

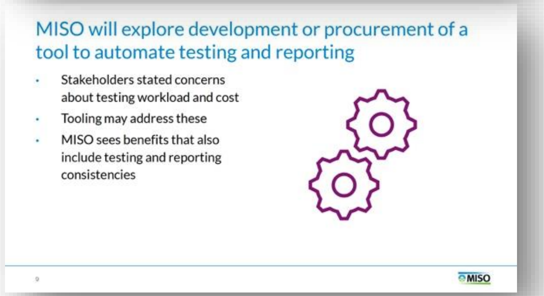


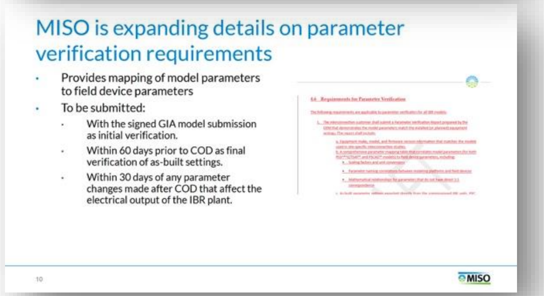


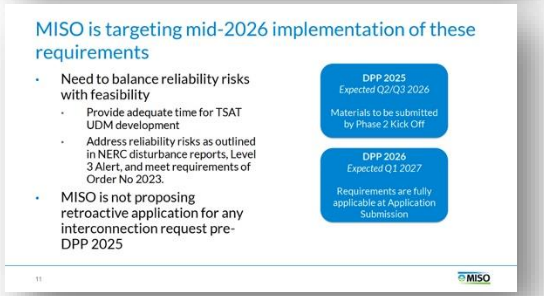












Source: https://www.misoenergy.org/events/2025/interconnection-process-working-group-ipwg---july-22-2025/

- While **both TSAT UDM and EMT [UDM] required at application**, PSS/e UDM not required until GIA.
- IC customer responsible for producing a "**Dynamic Model Quality and Performance Test Report**" that TO and MISO must review.

MISO is requesting feedback on the Proposed IBR Modeling Requirements (PAC-2024-2) by August 5, 2025: https://www.misoenergy.org/engage/stakeholder-feedback/

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One Solution: IEEE 2800 and P2800.2 Conformity Framework

Type Tests

Lab or field tests of individual IBR unit for model validation

IBR Unit Model Validation

Based on type test data

IBR Plant Model Development

Based on validated IBR unit model(s) and balance of plant

IBR Plant Design Evaluation

Simulations to assess plant conformity to IEEE 2800

Design Evaluation

Plant construction complete

As-built Installation Evaluation

Verification of installed plant

Commissioning Tests

Partial field assessment of plant performance

Post-commissioning Monitoring

Monitoring of plant performance during grid events

Post-Commissioning Model Validation

Based on commissioning test data

Periodic Tests and Verifications

More information at https://sagroups.ieee.org/2800-2/ and expression of interest to participate here.

This is a general diagram of the process. Details are under development in IEEE P2800.2. Some variations permitted.

IEEE P2800.2 SA Initial Ballot was successful—743 comments need to be resolved.

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One Solution: IEEE 2800 and P2800.2 Conformity Framework

Type Tests

Lab or field tests of individual IBR unit for model validation

IBR Unit Model Validation

Based on type test data

IBR Plant Model Development

Based on validated IBR unit model(s) and balance of plant

IBR Plant Design Evaluation

Simulations to assess plant conformity to IEEE 2800

As-built Installation Evaluation

Verification of installed plant

Commissioning Tests

Partial field assessment of plant performance

Post-commissioning Monitoring

Monitoring of plant performance during grid events

Post-Commissioning Model Validation

Based on commissioning test data

Periodic Tests and Verifications

Design Evaluation

Scope of this presentation

Plant construction complete

This is a general diagram of the process.
Details are under development in IEEE P2800.2.
Some variations permitted.

More information at https://sagroups.ieee.org/2800-2/ and expression of interest to participate here.

IEEE P2800.2 SA Initial Ballot was successful—743 comments need to be resolved.

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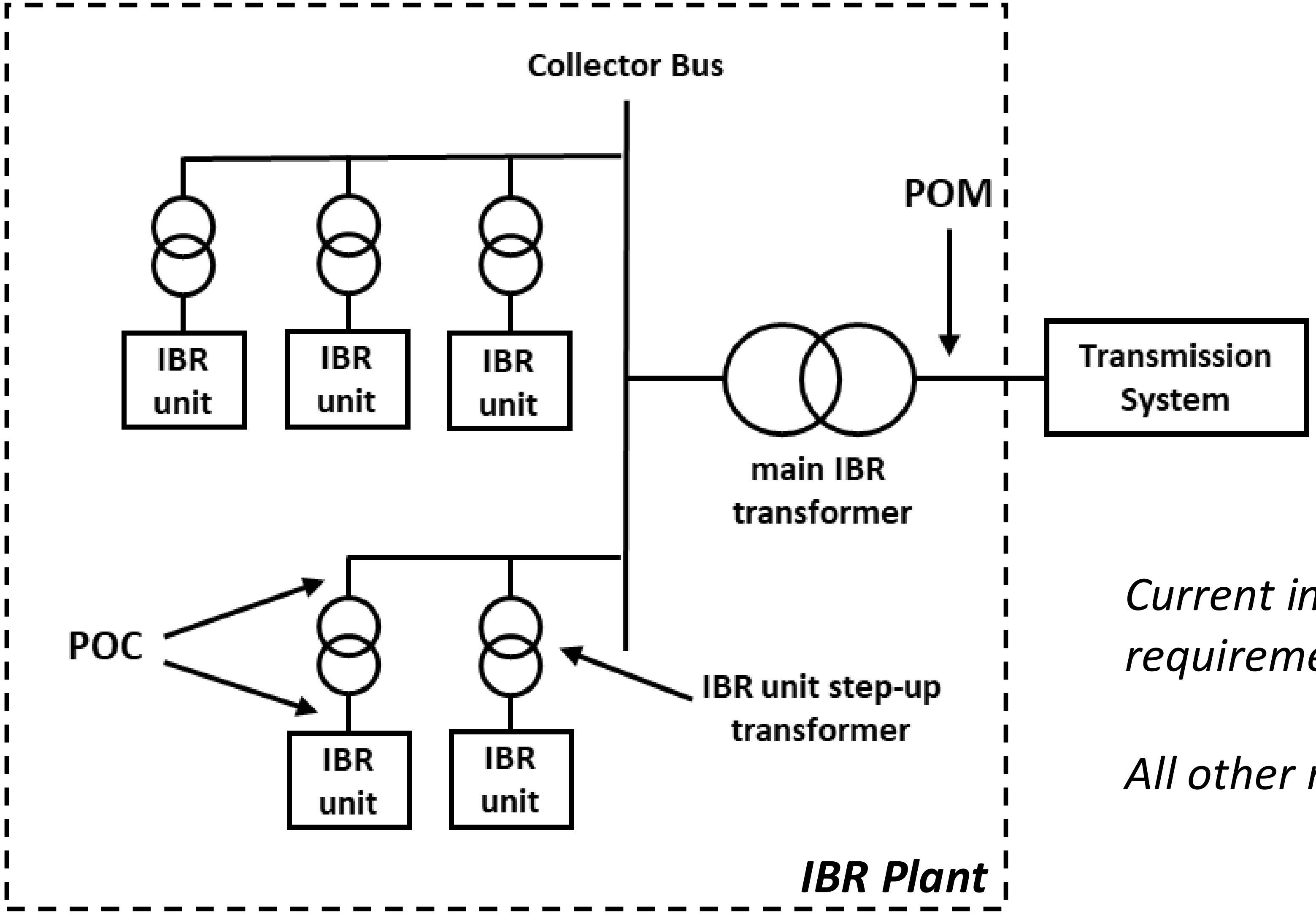
One Solution: IEEE 2800 and P2800.2 Conformity Framework



POM → Point of Measurement
POC → Point of Connection

Current injection during abnormal voltage requirements apply at POC

All other requirements apply at POM

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One Solution: P2800.2 Clause 7 (Design Evaluation)—Scope

Documentation check (verification)

- Review of capabilities specified in IEEE 2800:
  - Clause 4.0 (General requirements), Clause 7.2.2.4 (Consecutive voltage deviation ride-through capability), Clause 7.2.3 (Transient overvoltage ride-through), Clause 9 (Protection)
- Review of settings
  - IBR units, supplemental IBR devices like IBR power plant controller, etc.
- Review of equipment model validation report

Modeling & simulations

- Model quality checks
- Plant model development & verification
- Limited amount of capability tests
- Significant amount of performance tests

IBR Conformity Assessment is NOT a System Impact / Reliability Study

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One Solution: Clause 7.3.4 Tests

- ***For IBR plants with energy storage systems, run certain tests at P = ICR; 0; and ICAR.***

- ***Test for grid conditions specified by TS owner/TS operator*** **for applicability per IEEE 2800-2022, Clause 4.1.1. If no conditions have been specified, use SCR = 2.5 and SCR = 20 with X/R = 10.**

Reactive power capability test

Table 33

P_init = ICR; ICAR; Pmin (0)

Q_init = 0; 0.3287 x ICR and ICAR injecting and absorbing

Test number	*IBR plant* power output			Criteria
	Active power	Reactive Power	RPA voltage (per unit)	
RPC#1[a]	ICR ICAR[d]	0.3287 x 0.7 x ICR injecting 0.3287 x 0.7 x ICAR injecting[d]	0.90	*IBR plant* conforms to reactive power capability requirements specified in clause 5.1 of the IEEE Std 2800-2022 at the RPA.
RPC#2	ICR ICAR[d]	0.3287 x ICR injecting 0.3287 x 0.7 x ICAR injecting[d]	0.95	
RPC#3	ICR ICAR[d]	0.3287 x ICR absorbing 0.3287 x 0.7 x ICAR absorbing[d]	V2[b]	
RPC#4	ICR ICAR[d]	0.3287 x ICR injecting 0.3287 x 0.7 x ICAR injecting[d]	V3[b]	
RPC#5	ICR ICAR[d]	0.3287 x ICR absorbing 0.3287 x 0.7 x ICAR absorbing[d]	V5[b]	
RPC#6[a]	P_{min}[c]	0.3287 x 0.7 x ICR injecting 0.3287 x 0.7 x ICAR injecting[d]	0.90	
RPC#7	P_{min}[c]	0.3287 x ICR injecting 0.3287 x 0.7 x ICAR injecting[d]	0.95	
RPC#8	P_{min}[c]	0.3287 x ICR absorbing 0.3287 x 0.7 x ICAR injecting[d]	V2[b]	
RPC#9	P_{min}[c]	0.3287 x ICR injecting 0.3287 x 0.7 x ICAR injecting[d]	V3[b]	
RPC#10	P_{min}[c]	0.3287 x ICR absorbing 0.3287 x 0.7 x ICAR absorbing[d]	V5[b]	

[a] This test may not be applicable for *IBR plants* consisting of type III WTGs.
[b] Refer to IEEE Std 2800-2022, Figure 8 and Table 4.
[c] Refer to IEEE Std 2800-2022, Figure 6 and Figure 7.
[d] Applicable when *IBR plant* consists of battery-energy storage system

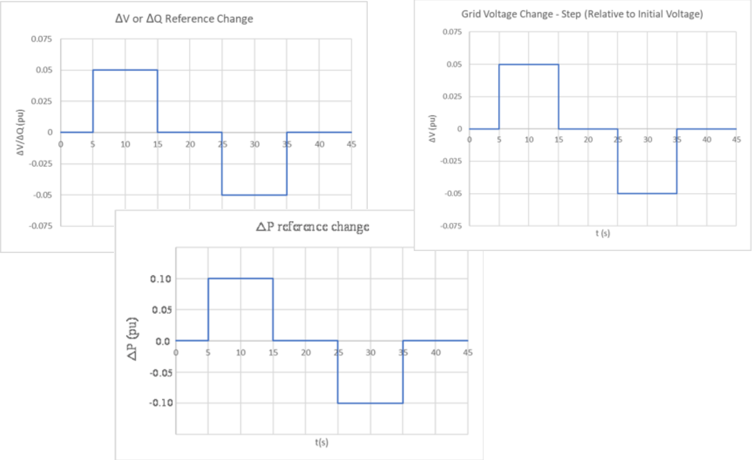
Reactive power control tests signals

Table 34

Figure 42

Figure 43

Figure 44

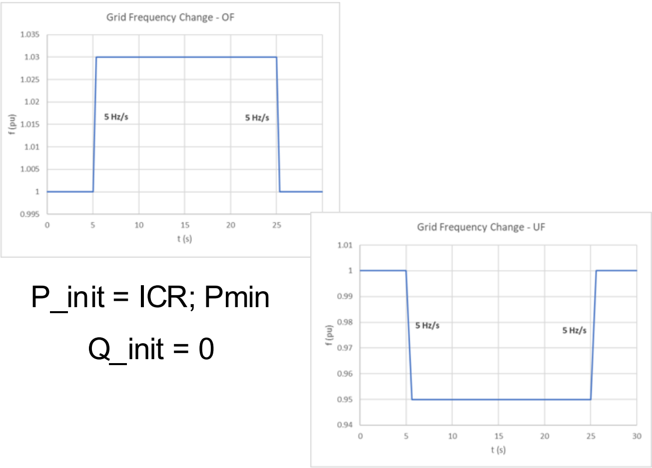


Frequency Response

Table 38

Figure 45

Figure 46



P_init = ICR; Pmin

Q_init = 0

Low Voltage Ride-Through

Table 35 (balanced)

Table 37 (unbalanced)

High Voltage Ride-Through

Table 36 (balanced)

P_init = ICR; ICAR

Q_init = 0; 0.3287 x ICR and ICAR injecting and absorbing

+ Seq. V-phase angle change RT

Table 39

P_init = ICR; ICAR; Pmin (0)

Q_init = 0

Source: IEEE ©2025

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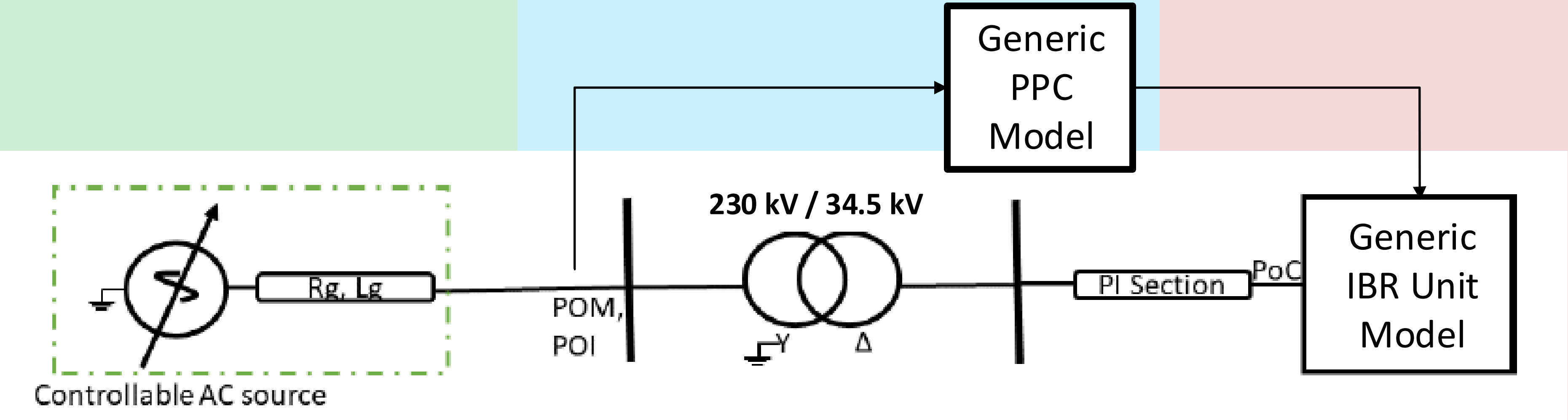
Example: Simulation Test Setup and Specifications

EPRI's IBR-ID/CA Tool



External Grid

- Represented within EPRI's IBR-ID/CA Tool
- Runs IEEE P2800.2 tests and visualizes results automatically
- Flexibility to test both generic and user defined models
- Controllable ideal voltage source with infinite bandwidth
- Adjustability impedance to simulate different grid strength, e.g., SCR = 2.5; 5; 20

IBR Plant

- Total system capacity (MVA): 211 MVA
- Nominal voltage: 230 kV
- Number of Inverters: 211 (aggregated)
- All IBR plant measurements and controls are at the POM
- Parameterized for stable operation in a medium strong grid
- PSCAD: PV-MOD PPC EMT model
- PSS/e: REPCA1

Inverter Unit

- Nominal rating (MVA): 1 MVA
- Nominal voltage: 600 V
- Inverter interconnection transformer: 34.5 kV / 600 V
- No local voltage control or frequency response: following PPC's P and Q set-points (FFR and local V-control disabled)
- PSCAD: PV-MOD unit EMT model
- PSS/e: REECA1 and REGCCU (EPRI) models

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Example: Test Scenario and Cases

Scenario	IBR Unit's *nameplate rating* [kVA]	Number of IBRs connected to MITS	*apparent power installed capacity* (Sagg) [MVA]	*active power installed capacity* (Pagg) [MW]	*IBR continuous rating* (ICR) [MW]	*minimum active power capability* (pmin) [pu@ICR]	*available active power* (Pavl) [MW] Note: may be at the DC side of the IBR units	Dispatch / Curtailment [pu@Sagg]	*actual active power* (Pact, p) [MW]	Measure-ments [pu@Sagg]
P2800.2 Pact = ICR	1 MVA	211	211 MVA	200 MW	200 MW	0.01 * ICR	1.0 * ICR	0.95 pu (200 MW)	1.0 * ICR (200 MW)	P_IBR = 0.95 pu

Reactive power control tests - Table 34/D3.0

Test number	*Event*	*IBR plant active power*	*IBR plant reactive power*	*EMT & PDT Model Benchmarking*
V/RPC#3	RPA voltage step change as per Figure 44 (D3.0)	ICR	0	✓
V/RPC#4	RPA voltage step change as per Figure 44 (D3.0)	Pmin	0	✓

Balanced low-voltage disturbance ride-through tests (EMT and PDT) - Table 35/D3.0

Test Number	*Fault type*	*Residual voltage (pu)*	*Duration (s)*	*IBR plant active power*	*IBR plant reactive power*	*Comments*
BLVRT#1	3PHG	0.00	0.32	ICR	0	✓
BLVRT#3	3PHG	0.50	3.00	ICR	0	✗

Balanced high-voltage disturbance ride-through tests (EMT and PDT) - Table 36/D3.0

Test Number		*Balanced voltage at RPA (pu)*	*Duration (s)*	*IBR plant active power*	*IBR plant reactive power*	*Comments*
BHVRT#1		1.20	1.00	ICR	0	✗

Frequency ride-through capability and performance tests - Table 38/D3.0

Test Number	*Event*	*IBR plant active power*	*IBR plant reactive power*	*Comments*
FRT#1	Overfrequency Change as per Figure 45 (D3.0)	ICR	0	✓
FRT#3	Underfrequency Change as per Figure 46 (D3.0)	ICR	0	✓

Positive-sequence voltage phase angle change ride-through tests (EMT) - Table 39/D3.0

Test Number	*Event*	*IBR plant active power*	*IBR plant reactive power*	*Comments*
PAJ#1	RPA positive-sequence voltage angle change equal to +25° (i.e., all three phases jump together/)	ICR	0	✓
PAJ#2	RPA positive-sequence voltage angle change equal to -25°	ICR	0	✓

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Example: Test Scenario and Cases

Scenario	IBR Unit's *nameplate rating* [kVA]	Number of IBRs connected to MITS	*apparent power installed capacity* (Sagg) [MVA]	*active power installed capacity* (Pagg) [MW]	*IBR continuous rating* (ICR) [MW]	*minimum active power capability* (pmin) [pu@ICR]	*available active power* (Pavl) [MW] Note: may be at the DC side of the IBR units	Dispatch / Curtailment [pu@Sagg]	*actual active power* (Pact, p) [MW]	Measure-ments [pu@Sagg]
P2800.2 Pact = ICR	1 MVA	211	211 MVA	200 MW	200 MW	0.01 * ICR	1.0 * ICR	0.95 pu (200 MW)	1.0 * ICR (200 MW)	P_IBR = 0.95 pu

Reactive power control tests - Table 34/D3.0

Test number	*Event*	*IBR plant active power*	*IBR plant reactive power*	*EMT & PDT Model Benchmarking*
V/RPC#3	RPA voltage step change as per Figure 44 (D3.0)	ICR	0	✓
V/RPC#4	RPA voltage step change as per Figure 44 (D3.0)	Pmin	0	✓

Balanced low-voltage disturbance ride-through tests (EMT and PDT) - Table 35/D3.0

Test Number	*Fault type*	*Residual voltage (pu)*	*Duration (s)*	*IBR plant active power*	*IBR plant reactive power*	*Comments*
BLVRT#1	3PHG	0.00	0.32	ICR	0	✓
BLVRT#3	3PHG	0.50	3.00	ICR	0	✗

Balanced high-voltage disturbance ride-through tests (EMT and PDT) - Table 36/D3.0

Test Number		*Balanced voltage at RPA (pu)*	*Duration (s)*	*IBR plant active power*	*IBR plant reactive power*	*Comments*
BHVRT#1		1.20	1.00	ICR	0	✗

Frequency ride-through capability and performance tests - Table 38/D3.0

Test Number	*Event*	*IBR plant active power*	*IBR plant reactive power*	*Comments*
FRT#1	Overfrequency Change as per Figure 45 (D3.0)	ICR	0	✓
FRT#3	Underfrequency Change as per Figure 46 (D3.0)	ICR	0	✓

Positive-sequence voltage phase angle change ride-through tests (EMT) - Table 39/D3.0

Test Number	*Event*	*IBR plant active power*	*IBR plant reactive power*	*Comments*
PAJ#1	RPA positive-sequence voltage angle change equal to +25° (i.e., all three phases jump together/)	ICR	0	✓
PAJ#2	RPA positive-sequence voltage angle change equal to -25°	ICR	0	✓

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Example: Test Results for a RPA Voltage Step Change

Reactive power control tests - Table 34/D3.0					
Test number	*Event*	*IBR plant active power*	*IBR plant reactive power*	*EMT & PDT Model Benchmarking*
V/RPC#3	RPA voltage step change as per Figure 44 (D3.0)	ICR	0	✓
V/RPC#4	RPA voltage step change as per Figure 44 (D3.0)	Pmin	0	✓

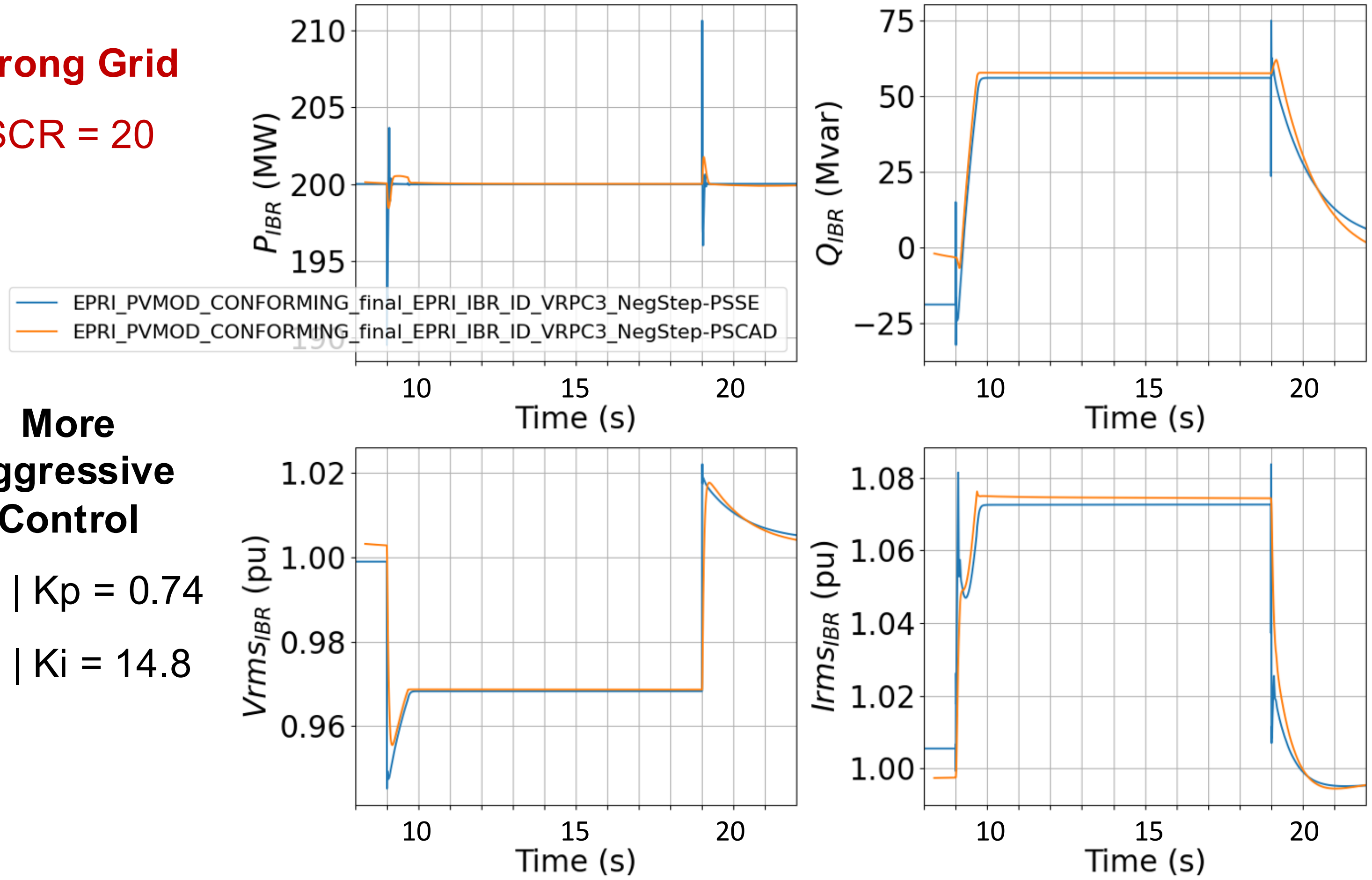
Strong Grid

SCR = 20

More Aggressive Control

Kpv | Kp = 0.74

Kiv | Ki = 14.8



- **Good match** between EMT and PDT models
- Both models adjust their reactive power within ~1 s of RPA voltage step change

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Example: Test Results for a RPA Voltage Step Change

Reactive power control tests - Table 34/D3.0					
Test number	*Event*	*IBR plant active power*	*IBR plant reactive power*	*EMT & PDT Model Benchmarking*
V/RPC#3	RPA voltage step change as per Figure 44 (D3.0)	ICR	0	✓
V/RPC#4	RPA voltage step change as per Figure 44 (D3.0)	Pmin	0	✓

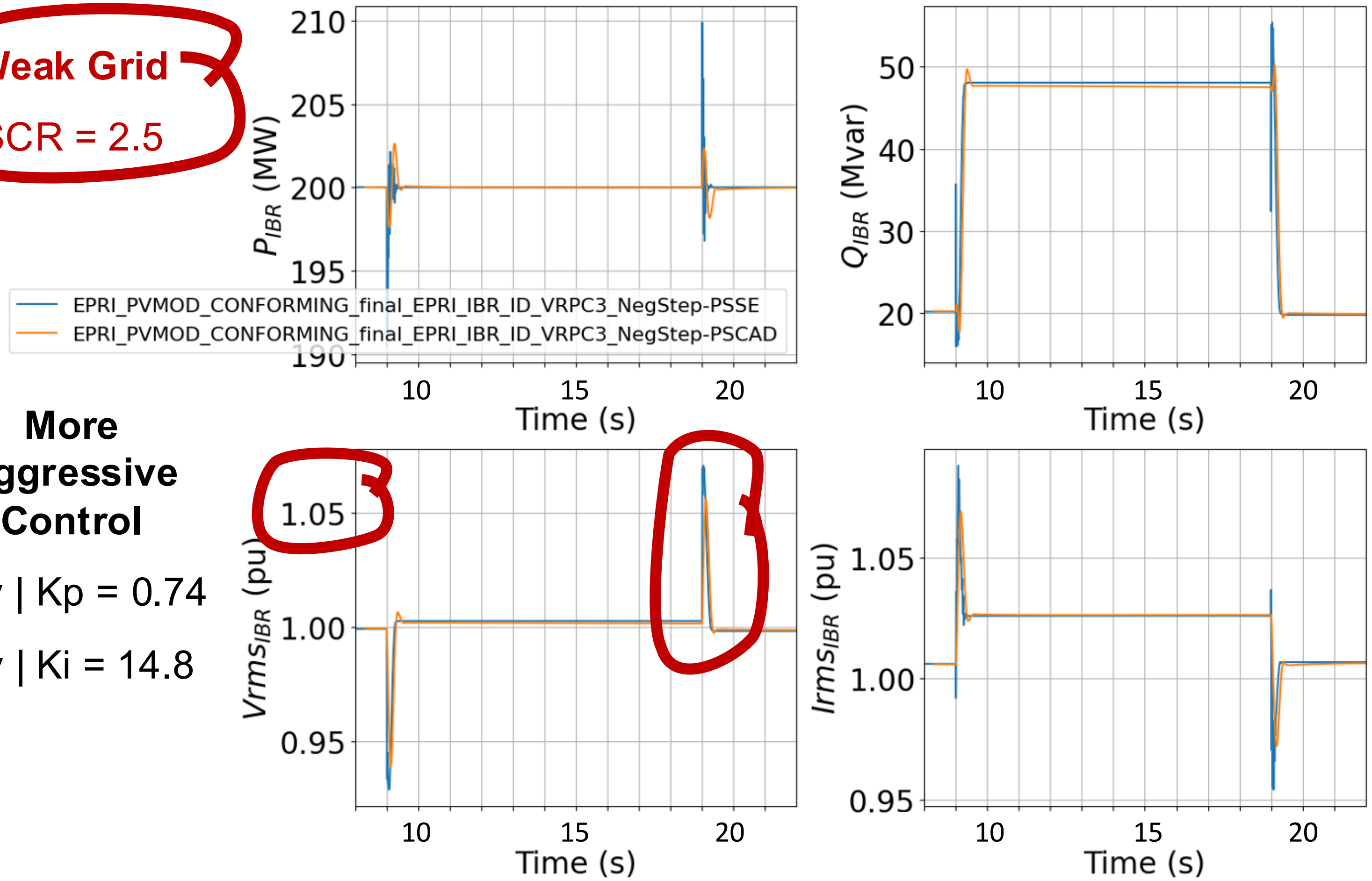
Weak Grid

SCR = 2.5

More Aggressive Control

Kpv | Kp = 0.74

Kiv | Ki = 14.8



- **Good match** between EMT and PDT models
- Both models adjust their reactive power within ~0.2 s of RPA voltage step change

➢ *Q: Does this **more aggressive** voltage control constitute a non-conformity with IEEE 2800?*

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Example: Test Results for a RPA Voltage Step Change

Reactive power control tests - Table 34/D3.0					
Test number	*Event*	*IBR plant active power*	*IBR plant reactive power*	*EMT & PDT Model Benchmarking*
V/RPC#3	RPA voltage step change as per Figure 44 (D3.0)	ICR	0	✓
V/RPC#4	RPA voltage step change as per Figure 44 (D3.0)	Pmin	0	✓

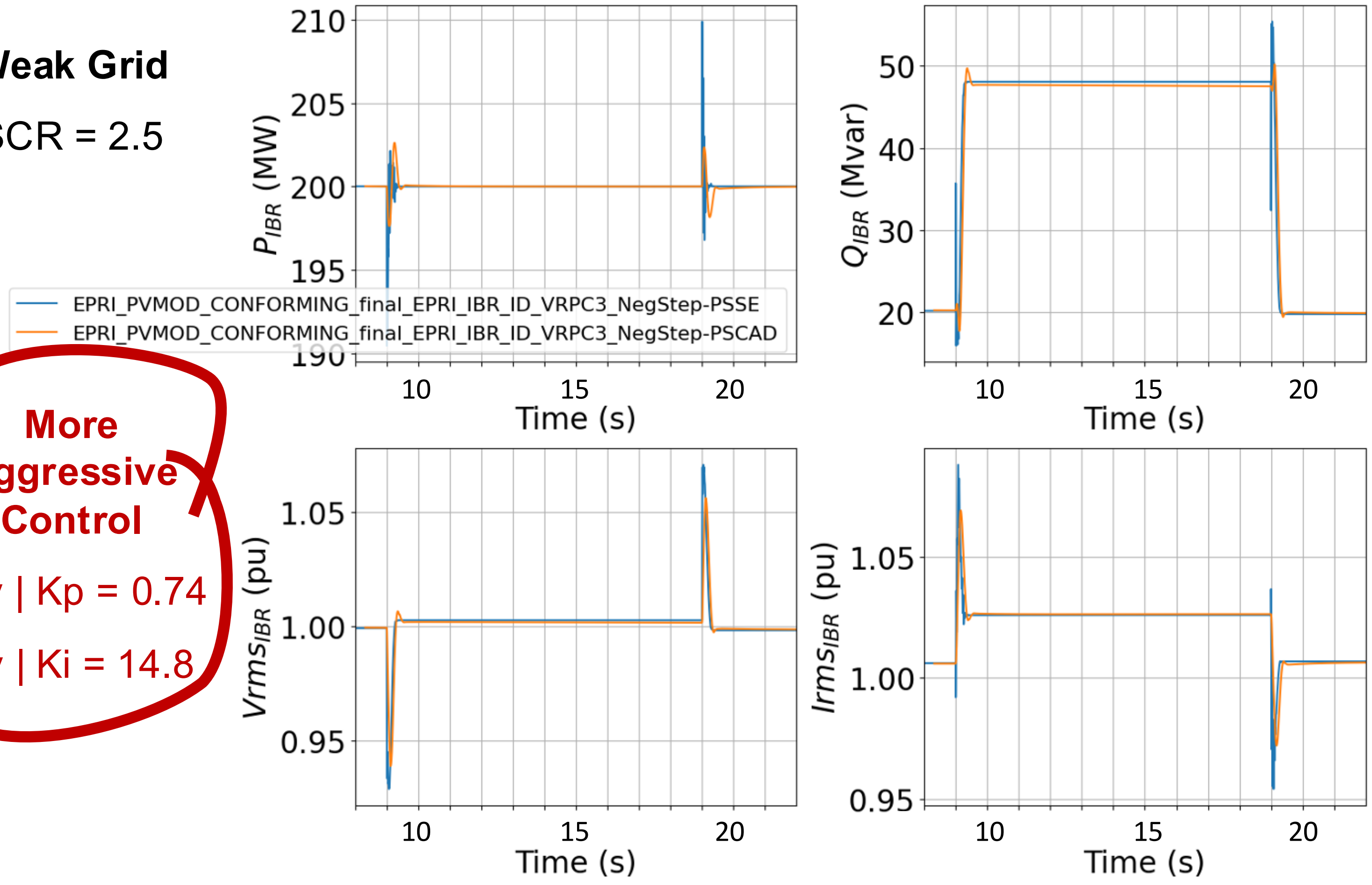
Weak Grid

SCR = 2.5

More Aggressive Control

Kpv | Kp = 0.74

Kiv | Ki = 14.8



- **Good match** between EMT and PDT models
- Both models adjust their reactive power within ~0.2 s of RPA voltage step change

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Example: Test Results for a RPA Voltage Step Change

Reactive power control tests - Table 34/D3.0					
Test number	*Event*	*IBR plant active power*	*IBR plant reactive power*	*EMT & PDT Model Benchmarking*
V/RPC#3	RPA voltage step change as per Figure 44 (D3.0)	ICR	0	✓
V/RPC#4	RPA voltage step change as per Figure 44 (D3.0)	Pmin	0	✓

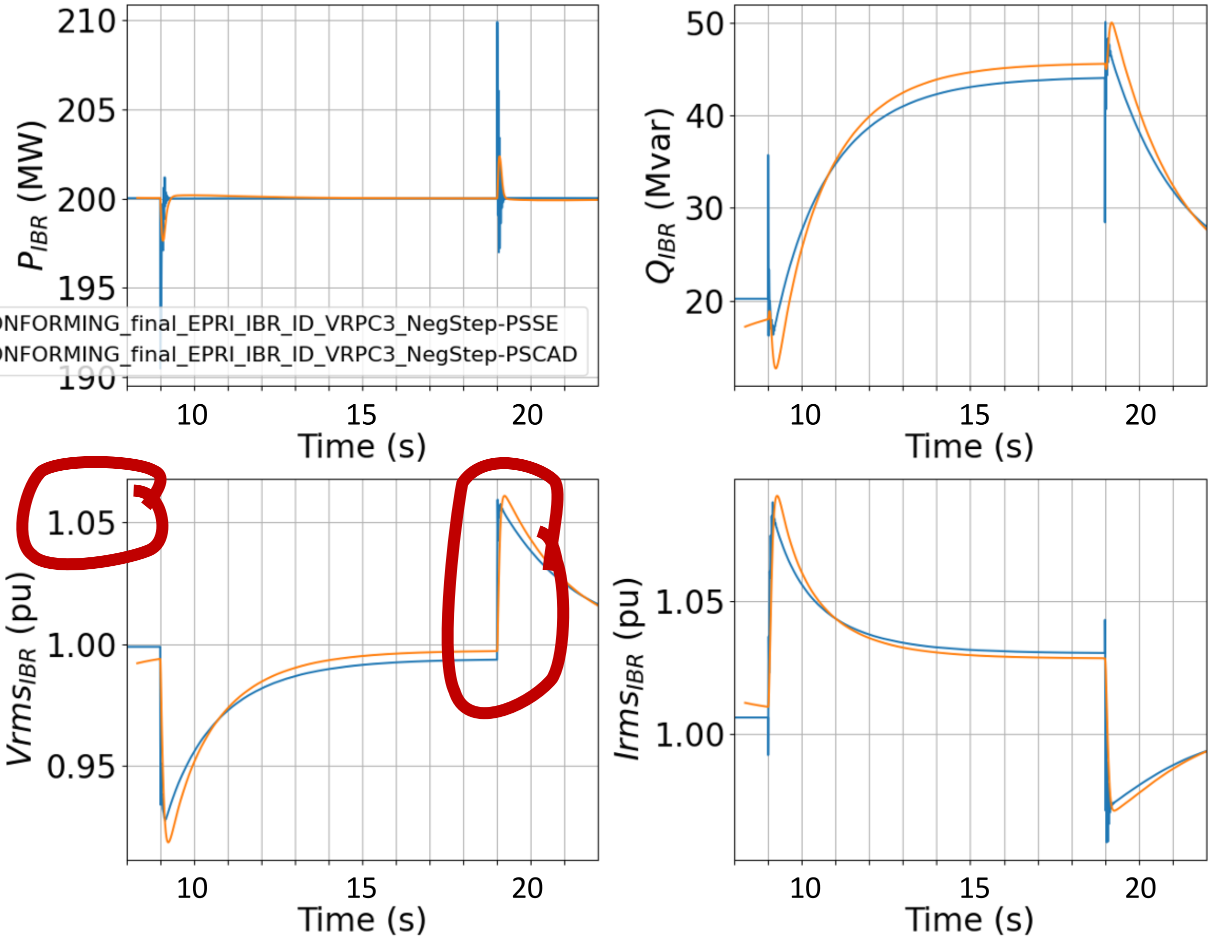
Weak Grid

SCR = 2.5

Less Aggressive Control

Kpv | Kp = 0.1

Kiv | Ki = 1



- **Good match** between EMT and PDT models
- Both models adjust their reactive power within ~6 s of RPA voltage step change

➢ *Q: Does this **less aggressive** voltage control constitute a non-conformity with IEEE 2800?*

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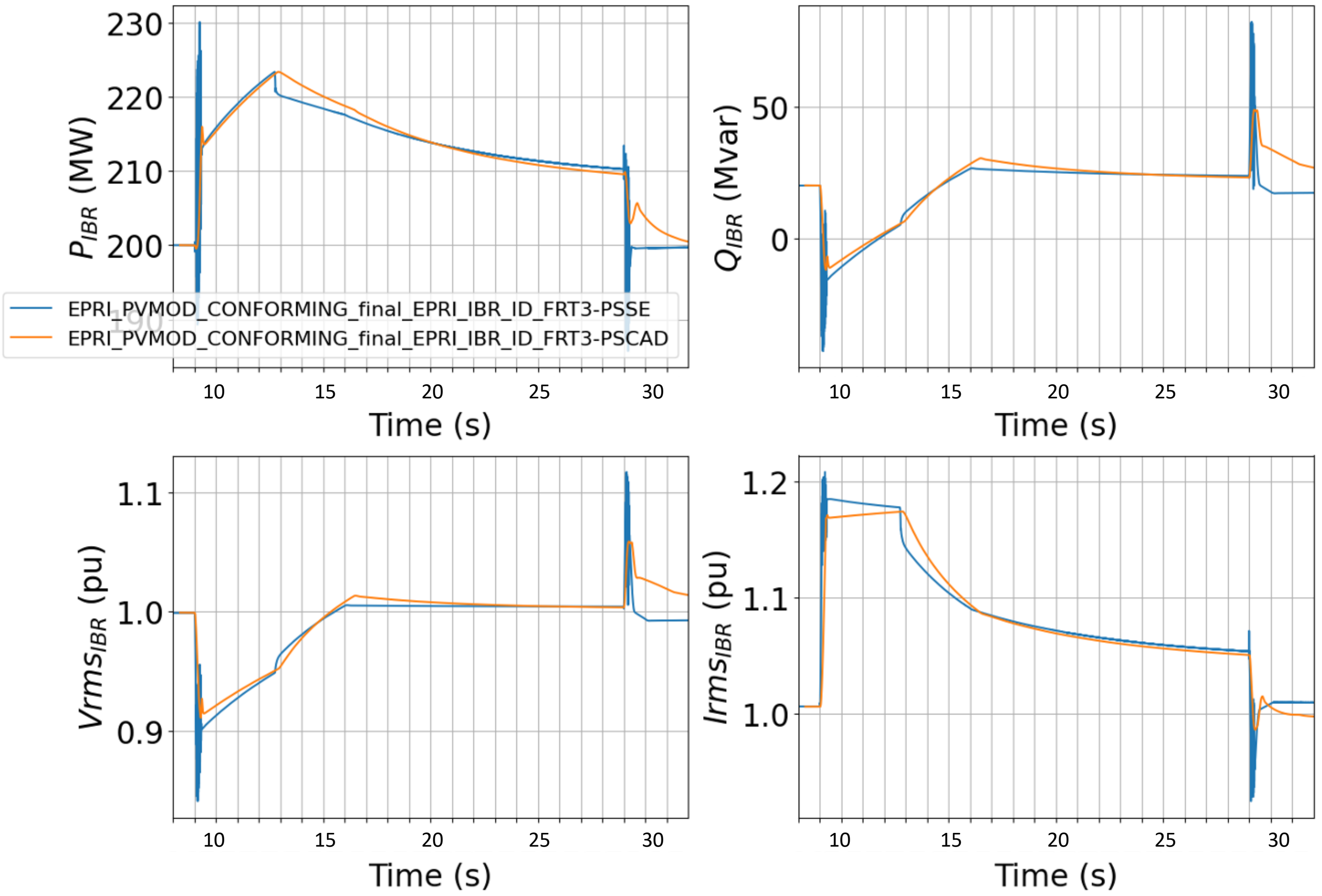
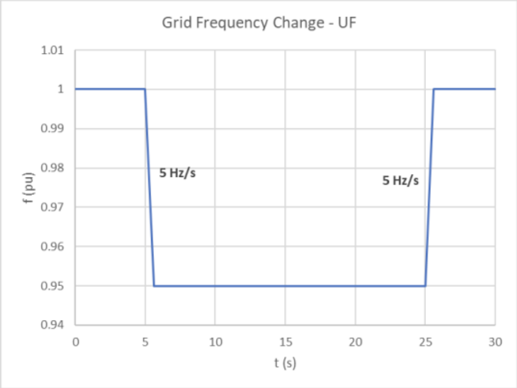
Example: Test Results for Frequency Ride-Through

Frequency ride-through capability and performance tests - Table 38/D3.0				
Test Number	*Event*	*IBR plant active power*	*IBR plant reactive power*	*Comments*
FRT#1	Overfrequency Change as per Figure 45 (D3.0)	ICR	0	✓
FRT#3	Underfrequency Change as per Figure 46 (D3.0)	ICR	0	✓



- **Good match** between EMT and PDT models
- Both models adjust their active power within ~4 s of frequency change

➢ *Q: How realistic is the test signal?*



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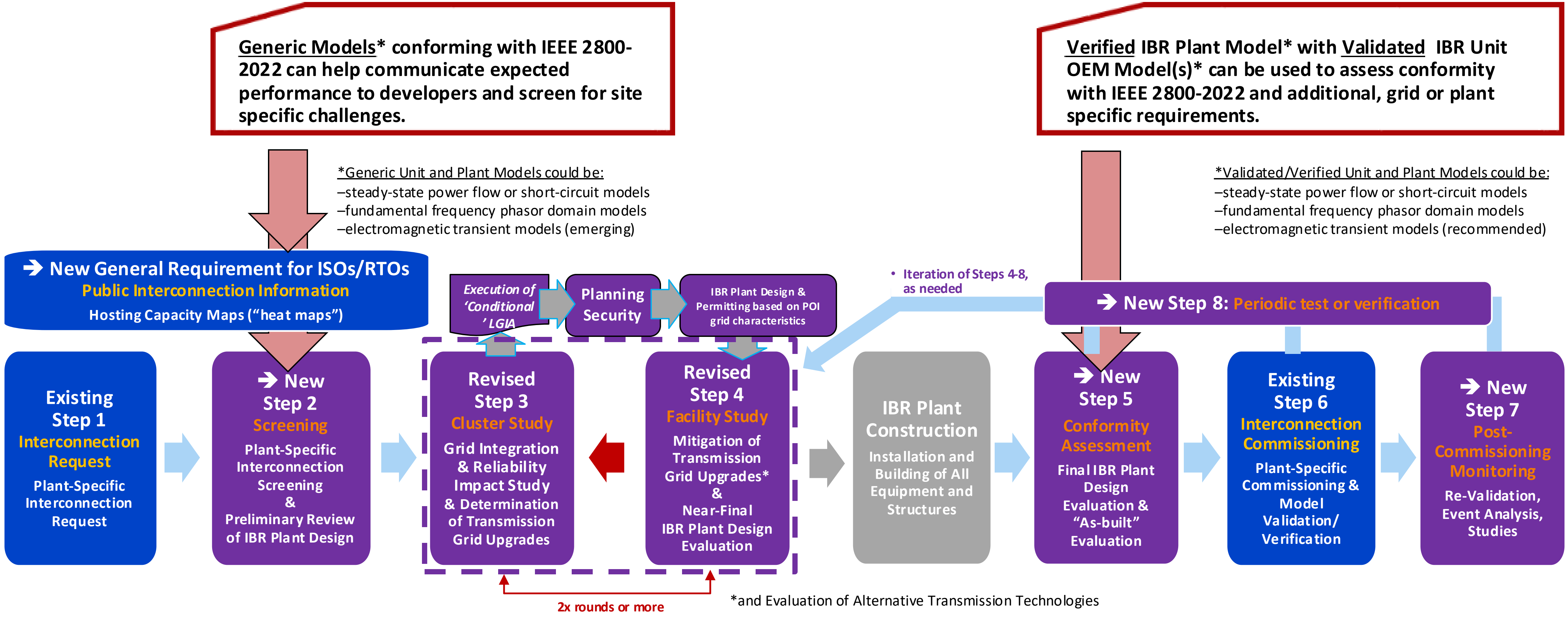
Outlook: When does IBR Model-Based Verification make sense during the Interconnection Process?

- Existing Process under FERC Order 2023
- Possible Modification or Addition



*and Evaluation of Alternative Transmission Technologies

Preliminary *IBR Plant* ***Conformity Assessment*** *Prior to IBR Interconnection?*

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Related EPRI Offerings

(1) **IBR ID/CA Tool –** ***I****nverter* ***B****ased* ***R****esource Performance* ***Id****entification and* ***C****onformity* ***A****ssessment* ***Tool***

forthcoming

Need

- Ability to **identify performance characteristics** of an IBR simulation model and validate its performance across various simulation domains. Also to **verify conformance** against any standards/grid codes that may be present

Objective

- **Develop and deliver a** performance identification and conformance verification **tool** that can be used to test IBR models across various simulation domains.

Scope

1. Define **list of tests**, both time domain and frequency domain to be used to identify performance and verify conformance.
2. Develop **software modules** that can apply and carry out the tests across EMT and positive sequence domain
3. Verify performance and conformance of **both generic and user defined models**.
4. Deliver software

(2) Application of IBR Standards – ***Collaborative Forum***

More information at: 3002032085

Need

- New **IBR interconnection and reliability standards** apply to **plant owners/ developers** and will shape design and operation of IBR plants. Same standards are being adopted and enhanced by **transmission companies**.

Objective

- **Provide a collaborative forum** to exchange challenges and learnings, considering **new and existing plants.** Improve operational efficiency and **mitigate compliance risks.**

Scope

1. Support ***interpretation*** of various IBR standards (***IEEE and NERC***) and ***provide conformity/compliance procedures***
2. Provide generic IBR model parameters for existing grid-following (GFL) and advanced ***grid-forming (GFM)*** IBRs that conform with IEEE 2800, NERC Reliability Standards, etc.
3. Provide application examples:
   - Use of ***conformity assessment tool***
   - ***Guidelines*** for ***utilization*** of IBR capabilities
4. Provide ***thought leadership*** and ***facilitate development*** of IBR standards

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Outlook: An Alternative to IBR Model-Based Verifications

Category	Performance Capability	IEEE 2800-2022		Commissioning Test / Secondary Injection	Impedance Divider	Voltage Source Converter
		Requirements	Clause			
General	Range of Available Settings	R	4.10.2, 4.10.3, 5.1, 5.2, 6.2.2, 6.2.3			
	Measurement accuracy	R	4.4			
	Prioritization of Functions	R	4.7	Limited	Limited	Yes
	Ramping for control parameter change	R	4.6.2	Yes		
Monitoring, Control, and Scheduling	Responding to external control inputs	R	4.6	Yes		
	Remote Configurability	R	5.2.2, 5.2.3, 5.2.4			
Voltage Support	Capability at Zero Active Power	R	5.1			
	Constant Reactive Power	R	5.2.4	Yes		
	Current injection during voltage ride-through – balanced	R	7.2.2.3.4		Yes	Yes
	Current injection during voltage ride-through – unbalanced	R	7.2.2.3.4		Yes	Yes
Dynamic Responses and Reliability Services	Frequency Ride-Through	R	7.3.2.1			Yes
	ROCOF Ride-Through	R	7.3.2.3.5			Yes
	Voltage Ride-Through	R	7.2.2.1		Yes	Yes
	Transient Overvoltage Ride-Through	R	7.2.3		Limited – Cap Switch	Yes - Design
	Consecutive Voltage Deviation Ride-Through	R	7.2.2.4		Yes	Yes
	Restore Output After Voltage Ride-Through	R	7.2.2.6		Yes	Yes
	Voltage Phase Angle Jump	R	7.3.2.4			Yes
	Underfrequency Fast Frequency Response	R	6.2.1	Yes		Yes
	Overfrequency Fast Frequency Response	R	6.2.1	Yes		Yes
	Primary Frequency Response	R		Yes		Yes
	Return-to-Service (Enter Service) Criteria and Performance	R	4.10.2 and 4.10.3; 7.4		Yes	Yes
Harmonics And Impedance	Harmonic injection and mitigation testing					Yes
	Sub-harmonic and impedance scanning					Yes

How Practical are Field Tests of Existing Plants with Mobile IBR Test Systems?

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Outlook: Assessing Pros and Cons of Different IBR Plant-level Performance Verification Approaches

Expedited** Path* ⇩ *Risk: **Higher	***Recommended** Path* ⇩ *Risk: **Lower***
equipment performance **specification** **+ checklist**	**equipment** performance **characterization** **+ modeling**
+ may expedite plant-level conformity assessment because it **does not rely on the availability of validated models**	+ may reduce risk of unreliable IBR plant performance because it **relies on validated models**
+ reduces responsibility of IBR developers and/or TP (who may lack skills or resources) and **shift burden to OEMs (where it is welcomed)**	+ provides IBR developer with **more flexibility for plant design**
- may **not ensure adequate plant design** and **reduces IBR developer's flexibility** for plant design	+ enables **reliable plant-level conformity assessment** also for “weak grid” POIs
- may be **insufficient for "weak grid" POIs**	- may **require significant skills and resources** from IBR developer and/or TP

What could be metrics to decide which approach is “sufficient”?

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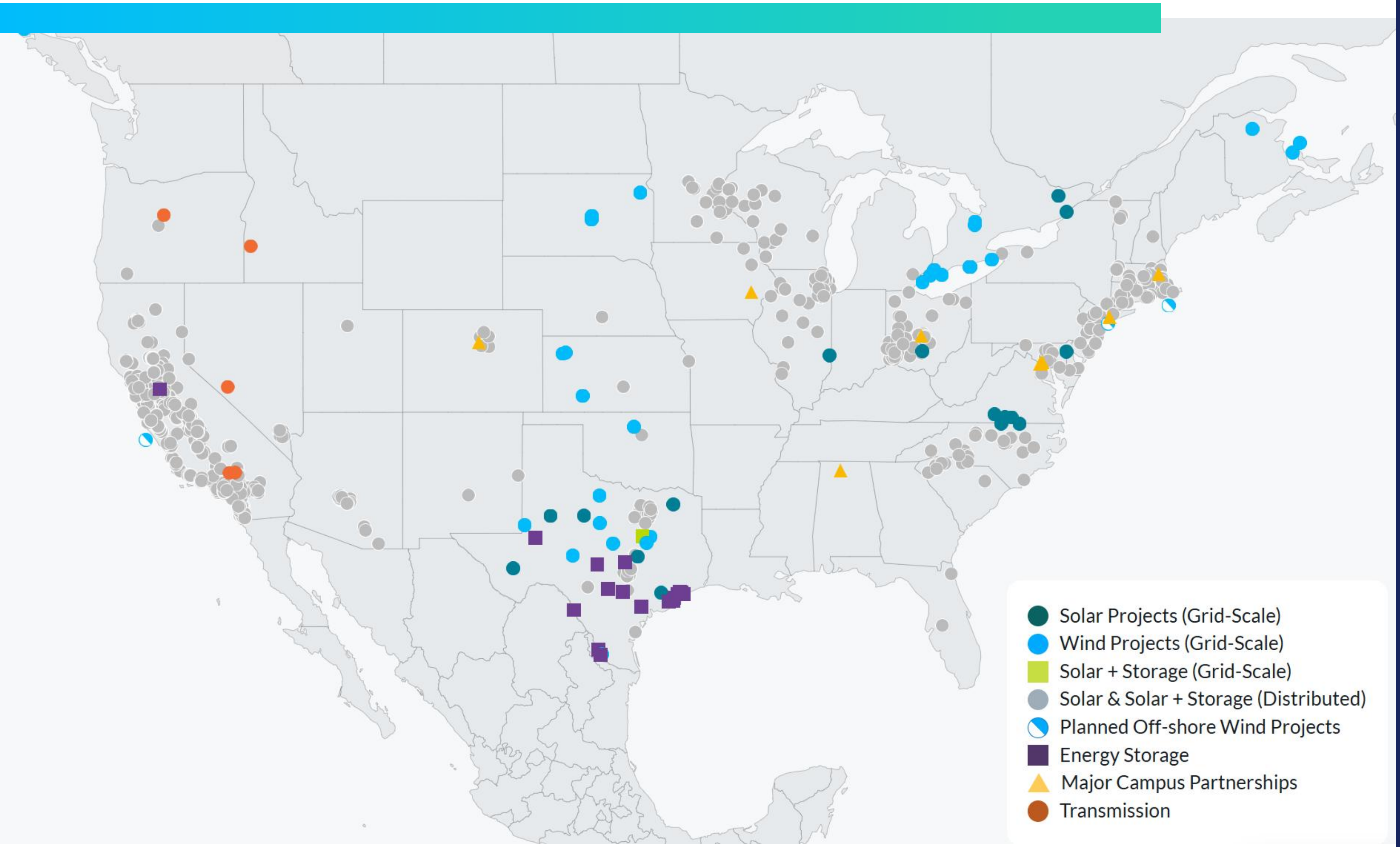
IBR Plant Conformity Assessment Gaps and Opportunities

Rishi Maharaj

July 22, 2025

ENGIE NORTH AMERICA AT A GLANCE



Data as of 4/07/25

Renewable & Flex Power + Local Energy Infrastructures

Houston
Headquarters

3,400
Employees
(Including Impact)

~9.5 GW
Renewables in Operation
~3.9 GW Onshore Wind
~ 3.2 GW Solar Power
~ 2.1 GW Battery Storage

50+ year
Heritage

1.4 GW
2024 Corporate PPAs Signed

1000+
Communities with active operations, projects or development

2.84 GW
Renewables Under Construction

45,000
Commercial and Industrial retail energy supply customers

Supply & Energy Management

295 TWh
of energy traded / 54 TWh delivered in 2024

~13.5 GW
Asset Management for internal and external assets

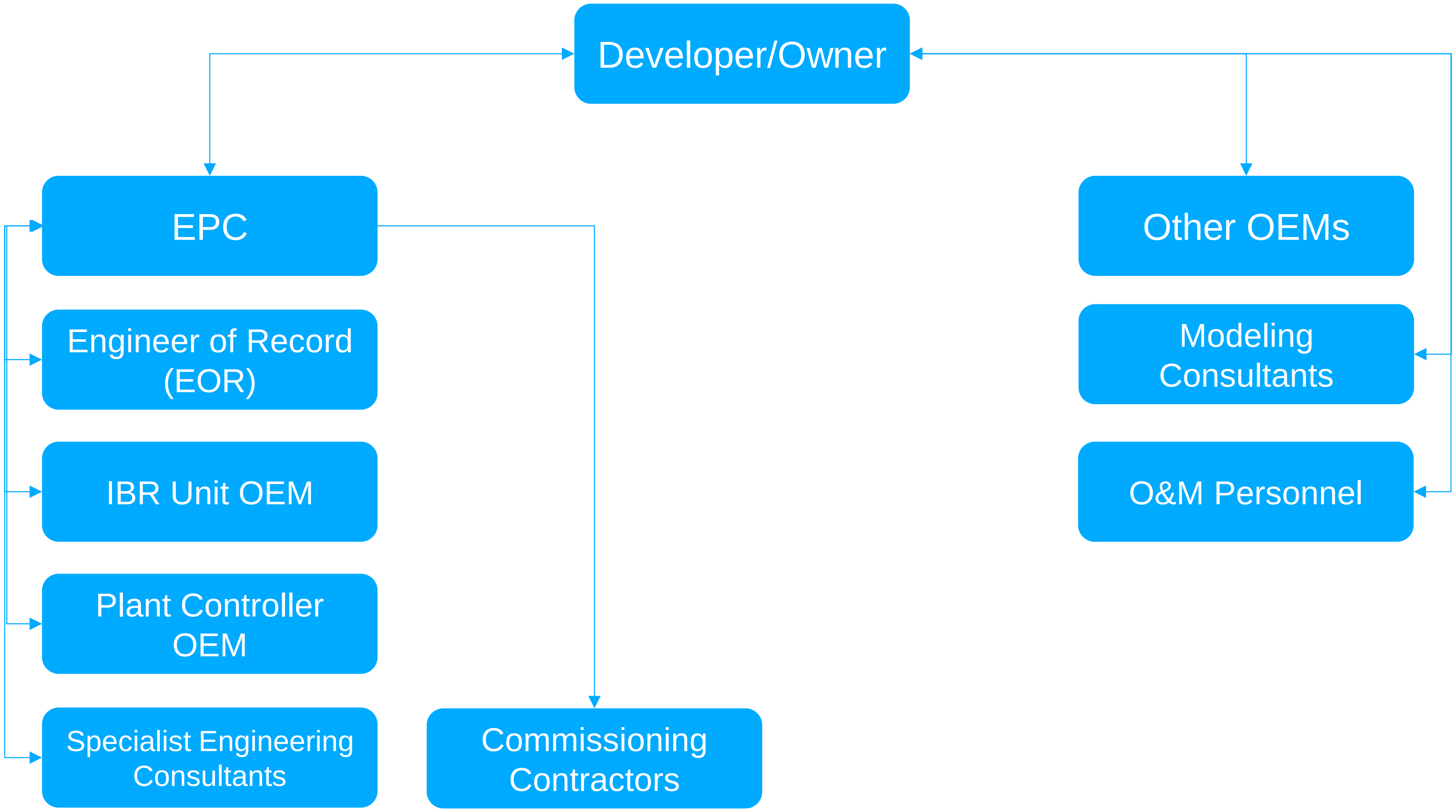
Outline

1. Typical contractual structure of IBR plant development, design and commissioning (at ENGIE)
   - Who does what?
   - How the commercial structure of a project affects technical objectives
2. Gaps, pain points and challenges in assessing conformity with existing interconnection requirements across North America (prior to IEEE 2800-2022)
3. Perspective on future conformity assessment with IEEE P2800.2
4. Recommendations for improvement

Project participants in a typical IBR plant design

- Development and operation of a new IBR plant is often seen as involving two primary categories of entities: the developer (after COD, the Generator Owner/Operator) and transmission entities such as Transmission Owners, Operators, Planners, RTOs, etc.
- While the developer or owner has the formal obligation to comply with applicable interconnection requirements, in ENGIE nearly all the work upon which the performance and conformity of the plant depends will be performed by 3rd parties:
  - OEMs
  - Engineering consultants
  - Engineering, Procurement and Construction (EPC) contractors who may subcontract either of the above
- Therefore, achieving conformity with any technical requirement – NERC, ISO, Transmission Planner, etc. – requires **coordination and communication** between many different parties through 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 and limited coordination between parties are often where problems and eventual non-conformity originate.

Simplified project hierarchy



Achieving conformity

- In a structure like the one on the previous slide, what does a developer/owner need to do to achieve conformity with new requirements?
  1. Precisely map out the required scope of work from each project participant to achieve the new requirement; and
  2. Negotiate with each party to include that scope their respective contracts; and
  3. Monitor each party's delivery of their component from their respective subcontractors at the correct time; and
  4. Perform an overall plant conformity assessment to the new requirement considering the entire project holistically - perhaps by assigning it to yet another consultant; and
  5. If possible, verify performance with commissioning tests.
- This is a lot for a non-expert developer who may not have any internal power systems expertise. There are many places to go wrong.
- 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 developer/owner to coordinate all parties.
- There is a basic conflict between the desire of 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.

Conformity assessment status quo

- Conformity assessment definition: “demonstration that specified requirements are fulfilled”. (P2800.2 referencing ISO/IEC 17000:2020)
    - OK, what requirements?
- “Interconnection requirements” applicable to a particular transmission-connected IBR plant in North America can originate from multiple sources:
    1. NERC Standards – uniform, but largely do not address important IBR performance issues (prior to Order 901 standards)
    2. ISO Rules that apply uniformly to all facilities meeting certain thresholds (e.g. ERCOT Nodal Protocols & Operating Guides)
    3. ISO, RTO or TO req’s 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. If neither party can identify what the requirements are in sufficient detail to enumerate them, how will they deliver and validate conformity?
    - Since most requirements apply at the plant level and require coordination between multiple parties, trying to write plant-level conformity into any one party’s contract is not practically workable.
- In many projects, a comprehensive understanding of “all applicable interconnection requirements” does not exist.

Conformity assessment gaps

- Comprehensive, proactive “grid code compliance” studies addressing all applicable interconnection req’s are not typically done by developers.
- The extent to which engineering studies (design evaluation) are done to assess conformity with applicable interconnection requirements is almost entirely driven by mandatory AGIR processes.
  - Reactive power studies, Transmission Planner stability studies, SSO/SSCI studies – all examples of plant evaluations that are on a mandatory path to COD.
- Mandatory studies only address a relatively small subset of interconnection req’s.
  - Various mandatory studies may be done by different project participants without coordination with each other, resulting in conflicting, inaccurate or simply wrong models being used by different entities to study the same plant.
  - Any study is only as good as the input data.
- What is verified by an AGIR prior to granting Commercial Operation will be done. Everything else is, for all practical purposes, optional.
- The net result is passive or inadvertent non-conformity with a significant fraction of the presently enforceable interconnection req’s.
  - Lack of documented conformity assessment does not necessarily mean non-conformity, but it’s a strong indicator.

Conformity assessment today

Conformity assessment gaps (cont’d)

- Plant controllers are an under-appreciated risk in design evaluation.
  - The current trend of procuring “no-name” plant controllers from EPC contractors which cannot be accurately simulated until very late in the project (if it all) limits able to perform design evaluation for certain requirements.
- Design evaluation is only one aspect of conformity assessment. Even when design evaluation is done, gaps exist in feeding required changes back into the 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” assessment but can’t be implemented in the field.
  - OEMs may be willing to update PSCAD models to provide favourable results in ways that don’t 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.
- Confusion/misunderstanding of what is or isn’t a design evaluation.
  - Widespread misconception among EPCs and EORs that Model Quality Tests are a grid code compliance study.
  - What is mandatory is what gets done – so MQT may be the *only* dynamic or transient modeling study being done by the developer for the entire plant design.

IEEE 2800 future conformity

- Many of the pain points and pitfalls that have been mentioned are directly addressed in P2800.2.
- P2800.2 does a comprehensive job of mapping how conformity assessment **should** take place, it doesn't (and can't) define exactly how plant owners/developers, TS owners, operators and planners execute that process in real projects.
- 2024 NERC Alert on IBR Model Quality Deficiencies results shows that vast numbers of IBR plant owners do not even have basic facility information available to them. A reasonable inference is these owners are not doing any type of conformity assessment.
  - Layering on 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.
- Developers/owners will need to devote significant resources to building internal expertise on IBR plant performance to successfully build plants that conform with IEEE 2800. *Conformity assessment* – proving that you've done it – is only the icing on the cake.
- Conformity assessment using P2800.2 is a much-needed opportunity for the industry to standardize on accurate, comprehensive evaluation of IBR plants to a core set of requirements. However, my prediction is that it will only be done in practice to the extent that AGIRs make it a mandatory step prior to achieving Commercial Operation.

Conclusion and recommendations

- **Developers/owners:**
  - A **proactive** approach during design and initial commissioning has less commercial risk than being purely **reactive** to enforcement action after problems occur.
  - We need to build more internal capacity and rely less on consultants for everything.
- **AGIRs:**
  - Pair implementation new interconnection requirements with robust enforcement of conformity both before and after COD.
  - If a generator can achieve and sustain commercial operation without doing something that is “mandatory” not only will there be widespread non-conformity but owners who do comply (and incur costs to do so) are put at commercial disadvantage to their competitors who do not.
  - Specifically for adoption of 2800-2022, design evaluations should be mandatory prior to permitting first energization of the plant and as-built plant evaluation prior to final commissioning.
- **OEMs:**
  - Although IBR unit OEMs cannot single-handedly ensure plant conformity, they can take a more active role by insisting on participation in conformity assessment. e.g. requiring the customer to submit a design evaluation and the associated IBR plant models to the OEM prior to commissioning.
  - Ultimately, a non-conformant plant with your equipment is damaging to the OEM’s reputation even if the IBR unit equipment is compatibility with conformity.
- **Consultants:**
  - Need to have difficult conversations with clients, ask more questions and document caveats or limitations of work extensively.

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IBR Plant Design & Commissioning: an EPC Perspective

Mortenson

About Mortenson

An EPC that serves multiple industries:

- Serves the US Market
- Energy Storage: 9 years, 40+ projects, 27 GWh deployment
- Wind: 30 years, 270+ projects, 39+ GW deployment
- Solar: 15 years, 100+ projects, 12+ GW

We're not your standard EPC

- Actively engaged with developers and OEMs to design solutions and improve project outcomes
- Highly focused on compliance

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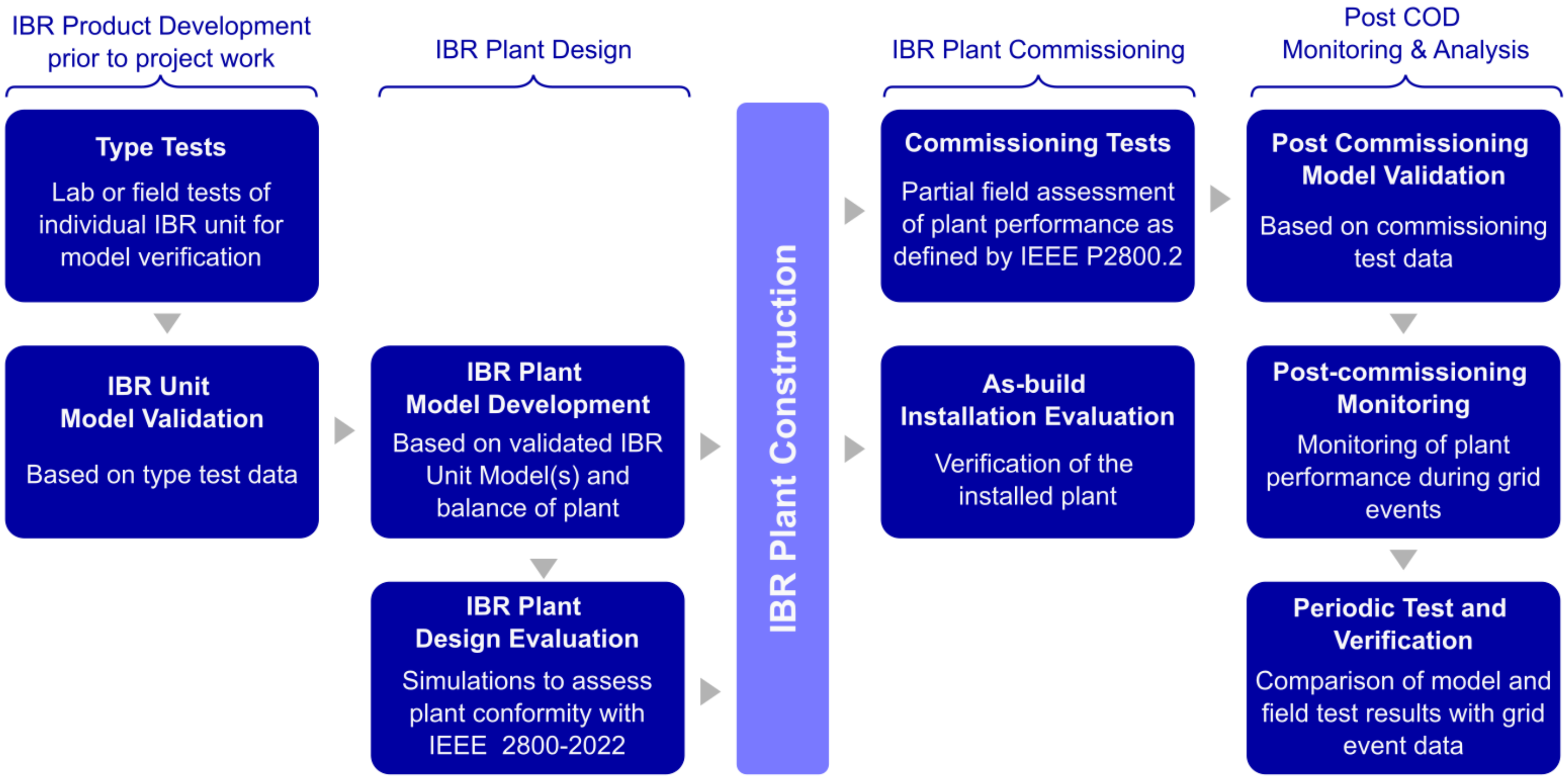
Focused on Construction

- Generally, Mortenson is involved from IBR Plant Design through IBR Plant Commissioning
- Comments provided today will be focused primarily on the Commissioning portion of our work.



Overarching Themes

Standard Work is critical for effective deployment of projects

- Missing Commercial Operation Dates (COD) can lead to significant losses for developers, owner/operators

Product Design is centered around test requirements

- If you don't test for it, it's not going to operate the way you expect

Project Design & Commissioning is centered around test requirements

- If you don't test for it, it's not going to operate the way you expect

OEM Equipment may be capable, but likely not configured correctly

- OEMs server multiple markets, and IBR equipment is designed for that variability.
- More market variability = More configuration settings = More opportunity for failure

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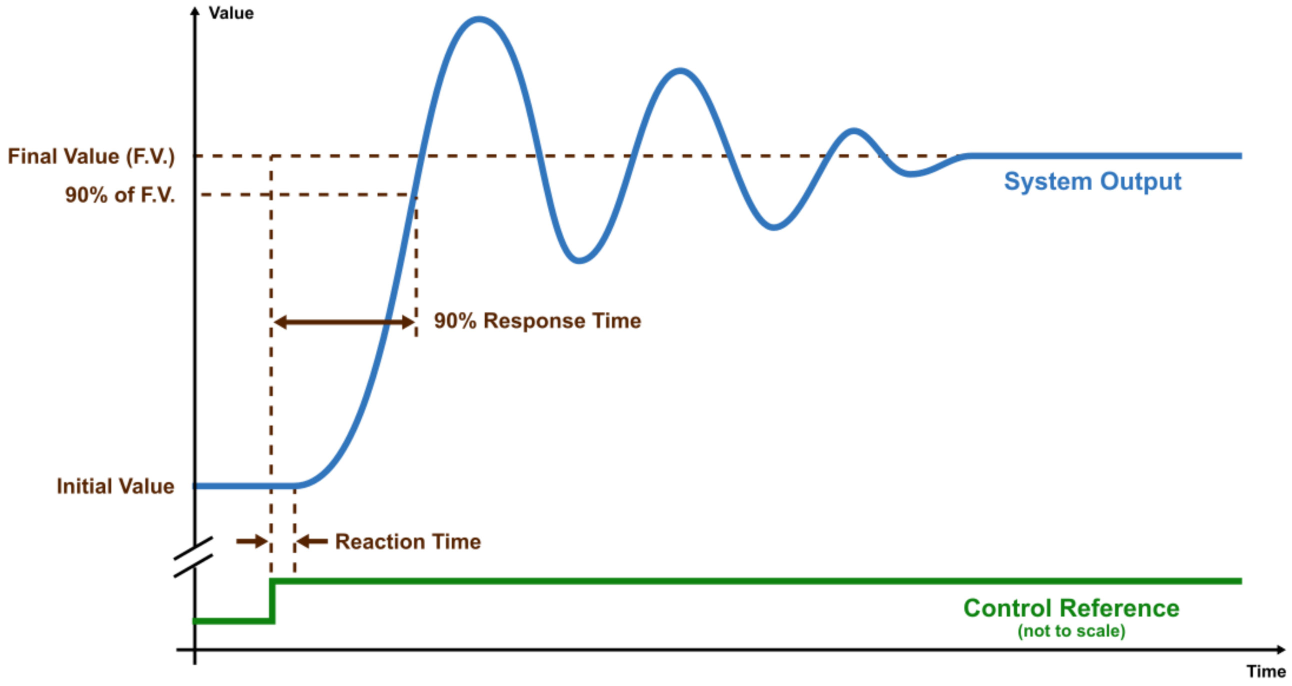
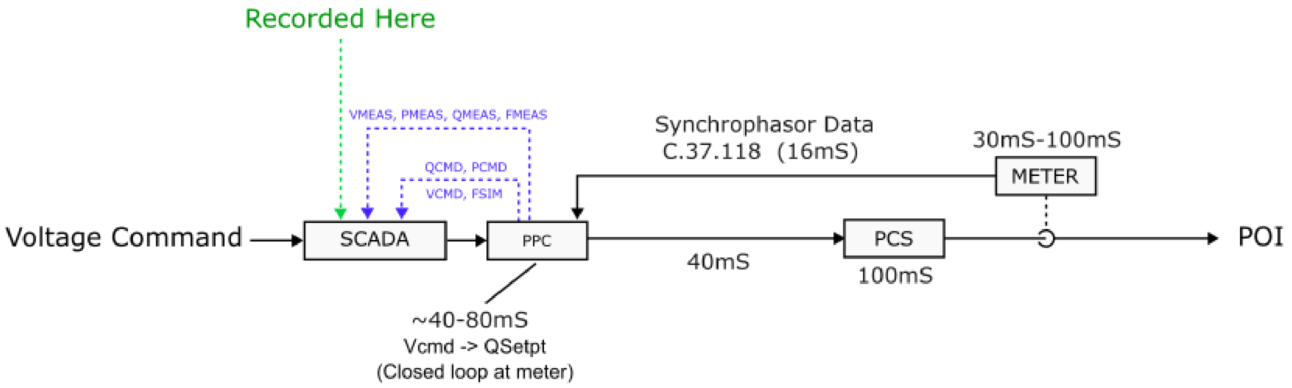
Specific Pain Points

Reaction Time Requirements (<200mS)

- Time to initial change in output after step in command (or feedback)
- More difficult to meet if working with multiple vendors (PCS OEM + PPC OEM + …). Worse still:
  - Hybrid facilities with multiple PPCs
  - String Inverter with a 'local controller'
- Where you measure has a significant impact
- Typically, a significant portion of the reaction time window is associated with coms delays and metering
- Standard communication protocols used in IBRs were not designed for real time operation
  - Modbus is not designed for 20-40mS updates
  - C.37.118 may be buffered





Specific Pain Points

Data Recording Requirements

- We have found that a large portion of PCS and EMS/PPC OEMs have not yet implemented the functionality required to log data in compliance with IEEE 2800. (see IEEE 2800 Table 19)
  - IBRs are required to log fault codes, changes in modes, and internal signals for post fault analysis
  - Measured & recorded at “many kHz” with 5 seconds of data split between pre and post trigger
  - Extraction from equipment is painful

- “Not my problem” mentality
  - Multiple IBR OEMs have pointed to their interface where the data is located. Someone else will record it.

- Product Changes to support these updates can be hard
  - If an OEM uses hardware that does not support recording at that rate, switching to a new platform can take years.
  - IBR Product updates (including software changes) can take a long time: imagine impact of a quality miss.

Specific Pain Points

Time Synchronization

- IEEE 2800 can be far more expensive to achieve than NERC PRC-028-1

	IEEE 2800-2022	NERC PRC-028-1
IBR Plant level monitoring	1 uS (IRIG-B, PTP)	1 mS (IRIG-B, PTP)
IBR Unit level monitoring	100 uS (IRIG-B, PTP)	100 mS (IRIG-B, PTP, NTP)

- IRIG-B common in substation equipment can support limited (10-32) number of devices when using electrical (TTL, RS-422, RS485)
- PTP, NTP can support more (thousands), but requires specialized hardware to yield the 1mS accuracy requirements. Receiving hardware must be PTP compliant.
- For cyber security reasons, some facilities are designed with network segmentation to limit the risk of third party or OEM access to the broader facility

- The result? Some facilities are designed with a time server per IBR unit. At the low end ($3k USD per time server) this yields an added cost of $200k for a 200MW facility (with many assumptions).

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Specific Pain Points

Control Settings – As Left

- Commissioning process has a huge impact on a project matching the expected behavior
  - Control settings are often controlled by OEM engineers
  - Visibility to control parameters are often limited
  - IBRs and EMS/PPCs can have hundreds or thousands of parameters
    - Most are associated with enabling/disabling features & shaping the response or constraints of functionality
  - Configuration setting variation from IBR unit to IBR unit within the same facility may exist

- Settings that do matter (i.e. PI Controller gains) will likely NOT match the models settings for the equivalent parameters (even if the performance between field test results and simulation match)

- Field results are often from tests run at ideal conditions. (all resources available, ideal generating resource conditions)
  - Performance at corner points of operation (where we're run into contingency cases) will likely differ from tests performed during commissioning

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Encouraging Signs

- Developers & Owner/Operators are including compliance with IEEE2800 as a contract requirement

- OEMs are working towards compliance (at the unit level)
  - Plant wide coordination of compliance is still a project effort
  - Seeing industry trends towards complying with performance-based requirements

- More industry players are getting more knowledgeable about specific requirements
  - Still a disconnect between what is required in NERC Stability Requirements and IEEE2800-2022

- Observing the development of testing requirements that evaluate performance against IEEE 2800 (even in the absence of IEEE2800.2)