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

Forum for the Implementation of Reliability Standards for Transmission (i2X FIRST) | 02/24/26

A DOE initiative supported by the Office of Critical Minerals and Energy Innovation (CMEI)

BERKELEY LAB

EPRI

ESIG

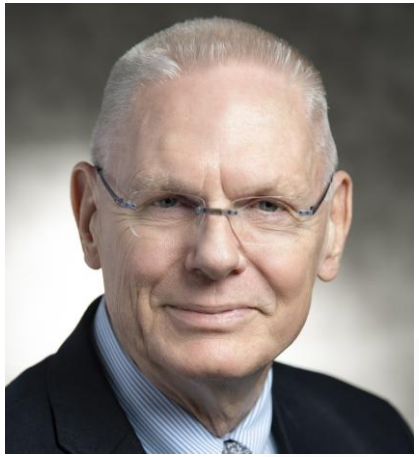
The first half of this meeting call is being recorded and may be posted on ESIG's website. If you do not wish to have your voice recorded, please do not speak during the call. If you do not wish to have your image recorded, please turn off your camera or participate by phone. If you speak during the 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 inverter-based resources.
- 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



Robert Reedy, Lindahl Reed, contractor to DOE

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 PRC-029 Implementation, Experience, and Recommended Practices

- **Meeting Introduction:** Julia Matevosyan, ESIG
- **Recap of NERC PRC-029-1 and FERC Order 909:** JP Skeath, NERC
- **OEM Perspective and Recommended Practices:** Yaw A. Akpaloo, Lucas Sales, GE Vernova
- **Recommended Practices for IBR Plant Ride-Through Evaluations:** Amin Banaie, Elevate Energy Consulting
- **Q&A and Structured Discussion**, led by Julia Matevosyan, ESIG
  - What is the best practice to identify legacy/inflight IBR plant's limitations to comply with NERC PRC-029?
  - What are the best practices to streamline the assessment of legacy/inflight plants' capability to comply with PRC-029?
  - Based on what method could NERC and RCs assess potential BPS reliability risks to inform decisions about limits to exemptions?

Meeting summary, recording & presentations are posted here

Key Themes from the Last Meeting

- **Shift to Performance-Based Ride-Through:** PRC-029-1 moves from relay settings to performance-based IBR ride-through requirements; October 2026 deadlines make early assessments essential.
- **Evolving Rules & Exemptions:** Ongoing FERC-driven updates leave open questions on legacy assets, HVDC/choppers, exemptions, and documentation timing.
- **OEM- and Fleet-Specific Compliance Paths:** Solutions vary by technology and vintage; software upgrades may help some legacy assets, while hardware limits must be assessed with OEMs.
- **As-Left Data Matters Most:** Credible evaluations depend on verified site configurations, hidden protections, and OEM logic—often more critical than running extensive simulations.
- **Model Fidelity Over Model Type:** PRC-029-1 requires the best available model; EMT adds insight, but phasor models are often sufficient when limits are understood.
- **Early Coordination & Scalable Processes:** Proactive owner-OEM-consultant alignment and repeatable methods are key to achieving compliance at scale.

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 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**
9. January 27, 2026, 11 a.m.- 1 p.m. ET **– NERC PRC-029 Implementation, Experience, and Recommended Practices**
10. February 24, 2026, 11 a.m. - 1 p.m. ET **– IBR Standards – How to Make Sense of it All?**
11. March 16, 2026, hybrid 1-day workshop during ESIG Spring Workshop: Grid Forming IBR Needs, Specifications, Projects – 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

i2X FIRST Grid Forming IBR Workshop

- **Hybrid format**: In-person and Virtual, Tucson, AZ, March 16th, 8:00-5:15 **MST**

REGISTER FOR VIRTUAL ATTENDANCE

REGISTER FOR IN-PERSON ATTENDANCE

Agenda

- **Educational tutorial covering GFM fundamentals**, including how GFM controls differ from grid-following (GFL) approaches, what capabilities they offer, and where current limitations remain.
- **Panel Discussion: Why and where grid-forming is being required** by some ISOs and utilities, and why others have taken more cautious approaches (MISO, ISO-NE, SPP, SRP)
- **Emerging grid-forming requirements and standards**, including regional implementations and ongoing joint IEEE/IEC efforts (UNIFI, VDE FNN Germany, and Electranix covering HECO/AEMO/MISO/ERCOT)
- **Real-world project experience** from utilities, developers, OEMs, and planners implementing grid-forming inverters in the field (HECO, AEMO, Tesla, Fluence, Zenobe)

The workshop is intended for participants seeking a **practical, systems-oriented view of grid-forming inverters**, grounded in current experience and forward-looking collaboration.

DOE i2x What's Next?

- **I2x FIRST Season 3:** Four meetings May through December covering emerging topics, e.g.:
  - IEEE2800.2 deep dive and adoption pathways
  - PRC-029 Implementation Process Updates (prior to 01/10/2026 effective date)
  - NERC Milestone 4 projects and NERC Project 2022—04 EMT Modeling
  - Update on new IEEE 2800 series efforts (including GFM requirements)
- **i2x Studies Forum:** Facilitate a forum (similar format to i2x FIRST) to:
  - summarize current interconnection studies approaches
  - identify opportunities to standardize/harmonize interconnection study methods,
  - identify industry best practices, and
  - discuss remaining gaps in this focus area.

  The aim will also be to note where uniformity and/or wide heterogeneity of study methods and assumptions exists, understand where differences are justified due to regional specific contexts, and where the differences are unnecessary and rather lead to confusion, interconnection time delays, additional costs to the developers.
- **i2x Technical Assistance Hours -** provide technical assistance to interconnection stakeholders focused on adoption of a harmonized and/or comprehensive interconnection requirements or standards. One-one sessions with ESIG and Elevate Energy Consulting for key interconnection stakeholders.

ESIG O&M UG Meeting – New IBR Developer Track

- Introduction to Developer Track
- Roundtable 1: IBR Unit Model Validation
- Roundtable 2: IBR Plant Design Evaluation
- Tech Talk: IBR Plant Model Verification at Commissioning
- Roundtable 3: Model Verification and Commissioning Testing
- Roundtable 4: IBR Plant Modeling Throughout the Interconnection Process
- Roundtable 5: NERC and Other Standards/Requirements
- Roundtable 6: Post-Commissioning

New this year: **the new Developer Track** focused on challenges associated with interconnection studies, performance standards for IBRs, and emerging best practices for ensuring reliable grid integration.

The Developer Track will feature an intro session, discussion roundtables and tech talks. The roundtables will provide the opportunity for frank and open discussion among users to promote knowledge and experience sharing.

Participation in the roundtables is limited to ESIG member organizations that own, develop or operate generation resources and consultants that are ESIG members and actively working with generator developers, owners and operators.

Two Trainings – Nov & Dec 2025, Materials Posted

ESIG Interconnection Studies Short Course

WHEN: November 17-19, 2025

WHERE: Manatee Lagoon, 6000 N Flagler Dr, West Palm Beach, FL 33407

MORE DETAILS:

This 3-day in-perso
knowledge and abi
focused on best p
necessary **to inter**
power system reliably. Training participants will learn practical methods and best practices that can be leveraged into enhanced study practices across the industry. These training modules will **focus on the expected day-to-day needs of engineers performing interconnection studies, model quality tests, or inverter-based resource model and simulation work** as well as managing study practices within their organization.

SLIDES AND RECORDINGS ARE POSTED HERE

DOE i2x / ESIG Electromagnetic Transient Training

WHEN: December 16 - 19, 2025

WHERE: Texas RE's Rio Grande Room, Austin, Texas

MORE DETAILS:

ed to **enhance the** workforce through **MT simulations** n the paradigm. Training participants will learn **practical methods and best practices that can be leveraged into enhanced study practices across the industry**. These training modules will **focus on the expected day-to-day needs of engineers performing EMT analysis** as well as managing EMT study practices within their organization.

SLIDES AND RECORDINGS ARE POSTED HERE

Stay tuned! Both Trainings coming up again in 2026!

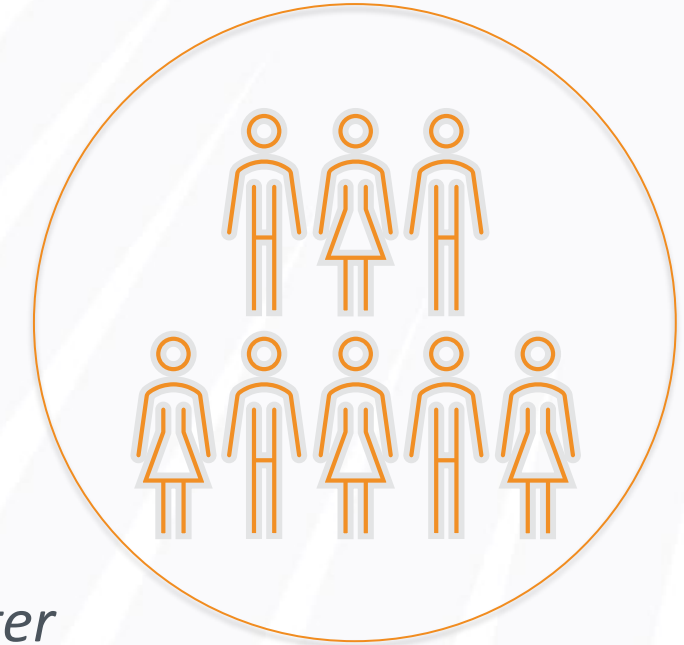
Thanks to NextEra and Texas Reliability Entity for hosting at their facilities!

IBR Standards – How to Make Sense of it All? – Agenda

- **Meeting Introduction:** Ryan Quint, Elevate Energy Consulting
- **IBR Standards – How to Make Sense of it All?:** Jens Boemer, EPRI
- **Utility Perspective: Operational Readiness for Inverter-Based Resources:** Scott Anderson, SRP
- **Raising the Bar Through the IBR Lifecycle:** Ryan Quint, Elevate Energy Consulting
- **Q&A and Structured Discussion**, led by Ryan Quint, Elevate Energy Consulting
  - What is the best practice framework to keep up with the changing standards landscape?
  - What can developer/generator owners do to pre-position themselves for upcoming changes/updates in standards?
  - What OEMs can do to future-proof their equipment for upcoming changes/updates in standards?

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*
6. *Please go to slido to ask questions: **slido.com** and enter event code **FIRST10***



Mutual Respect . Collaboration . Openness

Stakeholder Presentations

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4. *Please self-edit and encourage others to speak up*
5. *Seek to learn from others*

Mutual Respect . Collaboration . Openness

Q & A Session

Interactive Group Discussion Topics

Topic #1: What is the best practice framework to keep up with the changing standards landscape?

- Please go to slido to make comments and add questions of your own: **slido.com** and enter event code **FIRST10**
- For verbal commentary, please use the raise hand feature and we will call on you
- Additional related / associated questions:
  - How to keep up with ever-evolving standards landscape
  - Is there any documentation that is helpful to ensure future conformity or help with exemption processes?
  - What is the role of IEEE 2800.2?

Topic #2: What can developer/generator owners do to pre-position themselves for upcoming changes/updates in standards?

- Please go to slido to make comments and add questions of your own: **slido.com** and enter event code **FIRST10**
- For verbal commentary, please use the raise hand feature and we will call on you
- Additional related / associated questions:
  - Are there any lessons emerging from NERC PRC-029 or ERCOT NOGRR 245 processes that IBR plant developers can consider to future-proof their plants?
  - What kind of testing and documentation is helpful?
  - What is the role of detailed models here?

Topic #3: What can OEMs do to future-proof their equipment for upcoming changes/updates in standards?

- Please go to slido to make comments and add questions of your own: **slido.com** and enter event code **FIRST10**
- For verbal commentary, please use the raise hand feature and we will call on you
- Additional related / associated questions:
  - Again, are there any lessons emerging from NERC PRC-029 or ERCOT NOGRR 245 processes that OEMs (and IBR plant developers) can consider to future-proof their plants?
  - What kind of testing and documentation is helpful?
  - Are there any best practices on how to "translate" standards applicable at the POI/POM to equipment capabilities and what assurances can OEMs reasonably provide to their customers?

IBR Standards
– *How to Make Sense of it All?* –

i2X FIRST—Season 2
"IBR Standards – How to Make Sense of it All?"

Jens C. Boemer (jboemer@epri.com)
Technical Executive

Tuesday, February 24th, 2026

Classification: **public**

Acknowledgements and Disclaimers

- All comments provided reflect only the view of the EPRI technical experts performing the review and do not necessarily reflect the opinions of those supporting and working with EPRI to conduct collaborative research and development.
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- Part of this work was supported in part by the National Laboratory of the Rockies (NLR, formerly known as NREL), operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office and Wind Energy Technologies Office.
- The views expressed in the presentation **do not necessarily represent the views of the DOE or the U.S. Government.**

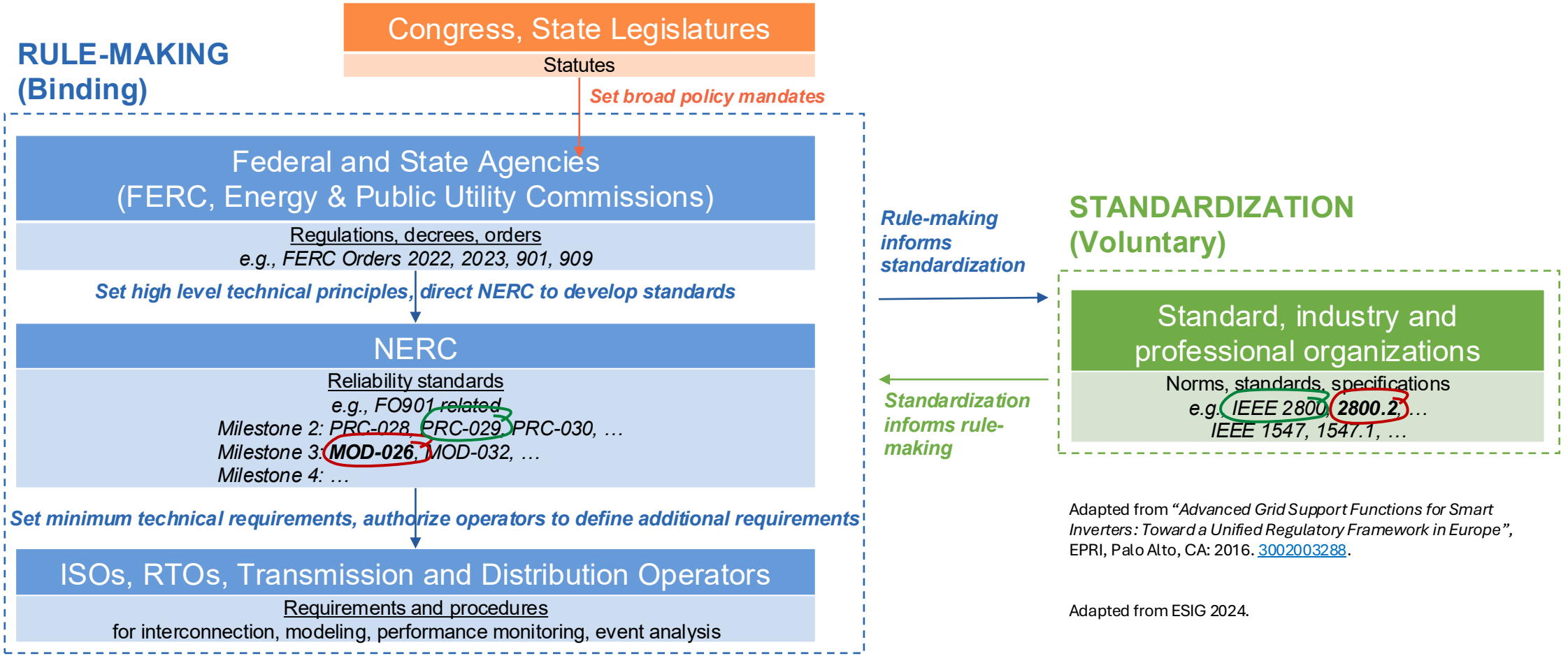
How Did We Get Here?

- **Unexpected** tripping, cessation of active power, oscillations, etc.
- **Mis-application of IEEE 1547** standard for Transmission connected resources
- **Opportunity for standardization of IBR** performance to reduce uncertainty of IBR unit and plant response

- **Validated and verified IBR models are *one* tool** to assess conformity of IBR plant design, understand potential reliability impacts and determine desired IBR response.
- **Trust, but verify**: lack of as-built evaluation and verification of site-specific IBR settings

Source: NERC, 2017-2022

Emerging Relationships between Voluntary and Mandatory IBR Standards in North America

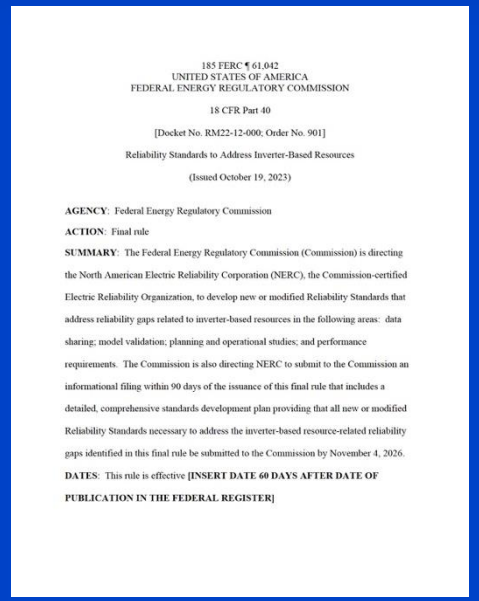


Adapted from *"Advanced Grid Support Functions for Smart Inverters: Toward a Unified Regulatory Framework in Europe"*, EPRI, Palo Alto, CA: 2016. 3002003288.

Adapted from ESIG 2024.

IEEE Standards become mandatory only when adopted by the appropriate authorities.

Emerging FERC Order 901 NERC Reliability Standards to Address Inverter-Based Resources (RM22-12)



185 FERC ¶ 61,042
UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

18 CFR Part 40

[Docket No. RM22-12-000; Order No. 901]

Reliability Standards to Address Inverter-Based Resources

(Issued October 19, 2023)

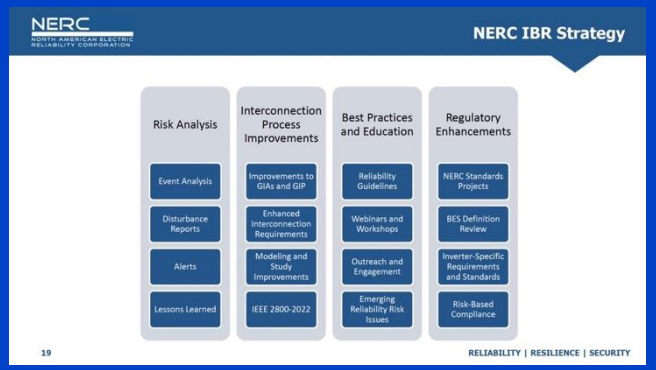
AGENCY: Federal Energy Regulatory Commission

ACTION: Final rule

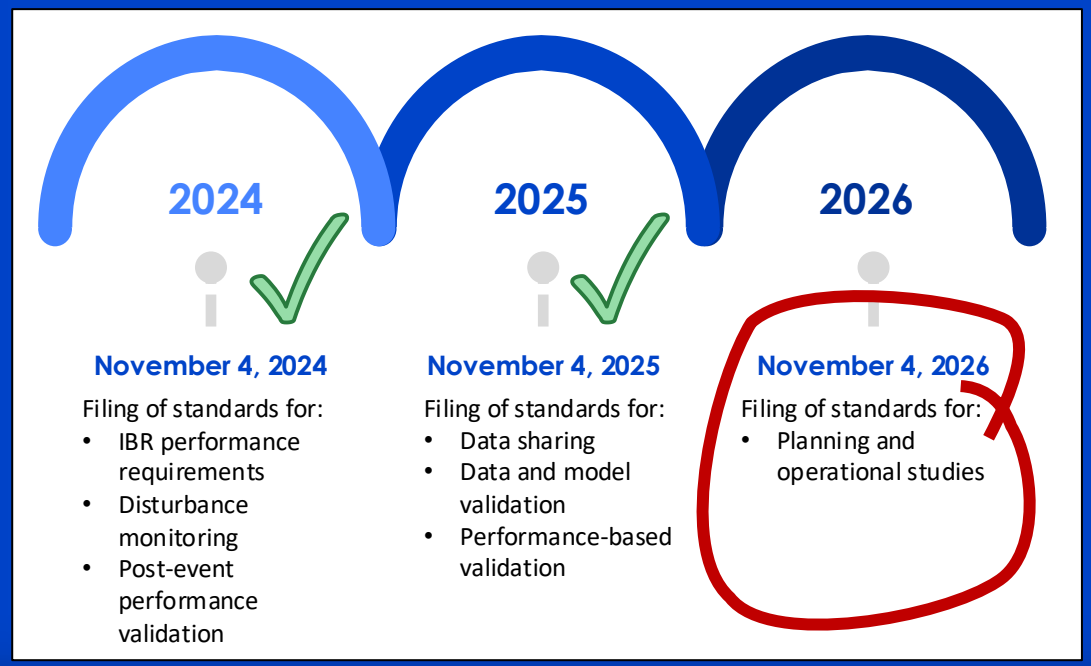
SUMMARY: The Federal Energy Regulatory Commission (Commission) is directing the North American Electric Reliability Corporation (NERC), the Commission-certified Electric Reliability Organization, to develop new or modified Reliability Standards that address reliability gaps related to inverter-based resources in the following areas: data sharing; model validation; planning and operational studies; and performance requirements. The Commission is also directing NERC to submit to the Commission an informational filing within 90 days of the issuance of this final rule that includes a detailed, comprehensive standards development plan providing that all new or modified Reliability Standards necessary to address the inverter-based resource-related reliability gaps identified in this final rule be submitted to the Commission by November 4, 2026.

DATES: This rule is effective **[INSERT DATE 60 DAYS AFTER DATE OF PUBLICATION IN THE FEDERAL REGISTER]**

https://www.ferc.gov/media/e-1-rm22-12-000



NERC IBR Webinar Series
https://www.nerc.com/comm/RSTC/Pages/IRPS.aspx

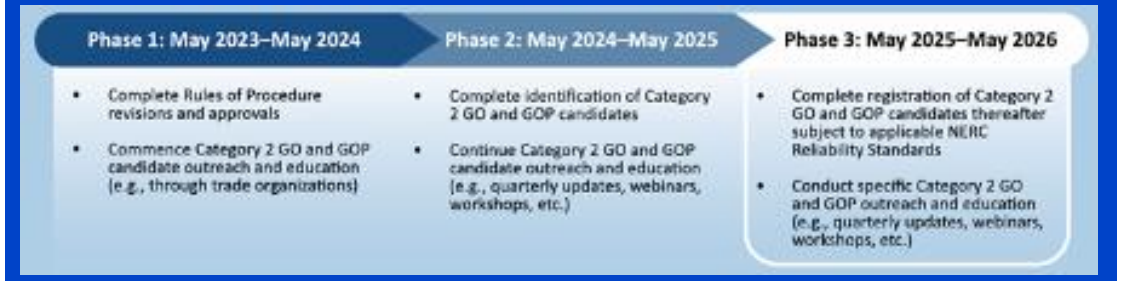


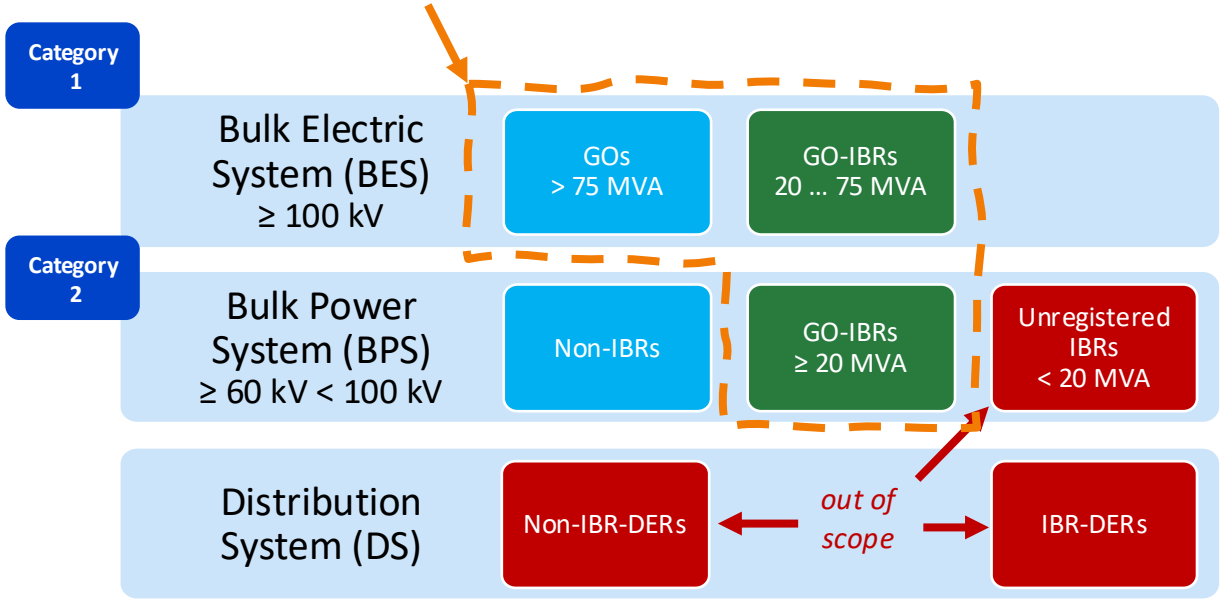
- Effective on December 29, 2023
  - Issued October 19, 2023 (link), published in federal register on October 30, 2023.
  - **NERC published a work plan (link) on January 17, 2024**.
- Directs NERC to develop new or modified Reliability Standards that address the following reliability gaps related to inverter-based resources:
  a. Data sharing ✓
  b. Model validation ✓
  c. Planning and operational studies
  d. Performance requirements ✓
- Very ambitious, 3-year timeline, given that NERC Reliability Standards must be approved by industry stakeholders.
  - FERC sees a need to have all the directed Reliability Standards effective and enforceable well in advance of 2030.
- **FERC** acknowledged potential value of IEEE 2800-2022 requirements and plant conformity assessment per P2800.2 but **declined to incorporate IEEE standards by reference.**
  - IEEE 2800-2022 and P2800.2 could inform requirements for Items b. (Model validation) and d. (Performance requirements) and possibly expedite the NERC Reliability Standards drafting and balloting process. However, **NERC has stated that their standards cannot refer to IEEE or other industry standards.**

More than 650 Category 2 IBR Identified, Still Counting…

NERC Registration Activity

—FERC IBR Registration Order (RD22)—

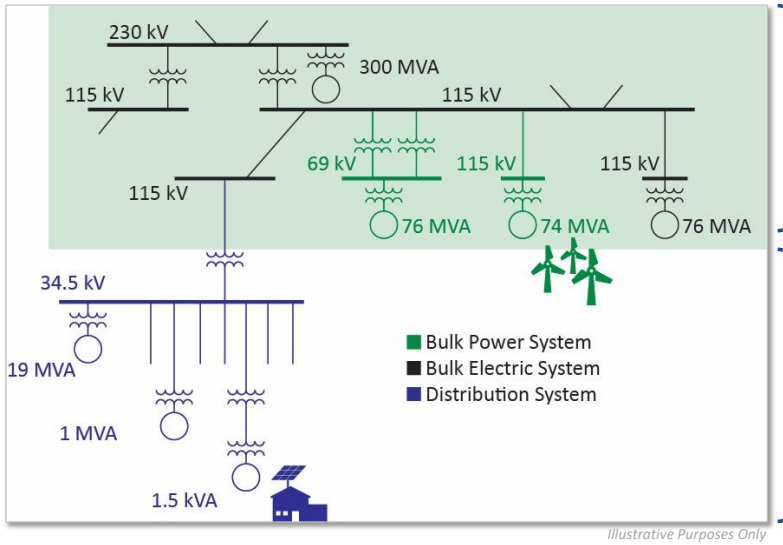




FERC IBR Registration Order (RD22)

IEEE 2800

The IEEE 2800 applies to IBRs connected to meshed and radial transmission and sub-transmission system, however, it remains silent regarding plant rating (MVA, kV). The applicability of standard remains at the discretion of the authority governing interconnection requirements.



IEEE 2800-2022
- Inverter-based resources
- Covers all BPS and BES
  - Transmission-level
  - Subtransmission-level

IEEE 1547-2018
- All power-producing resources
- Distribution-level

Source: Quick Overview of DERs, IBRs, IEEE Standards, and Other References. Presentation by Ryan D. Quint, NERC, at CanREA HUB Summit (January 2023)—*slightly modified, used with permission.*

Capability versus Utilization

Capability:

"Ability to Perform or Provide Service"

Scope of IEEE Std 2800

- Functions
- Ranges of available settings
- Minimum performance specifications

Examples

- Frequency Response
  - Primary frequency response
  - Fast frequency response

- Ride-Through
  - Voltage ride-through
  - Current injection during ride-through
  - Consecutive voltage ride-through
  - Frequency ride-through
  - ROCOF ride-through
  - Phase angle jump ride-through

Utilization of Capability:

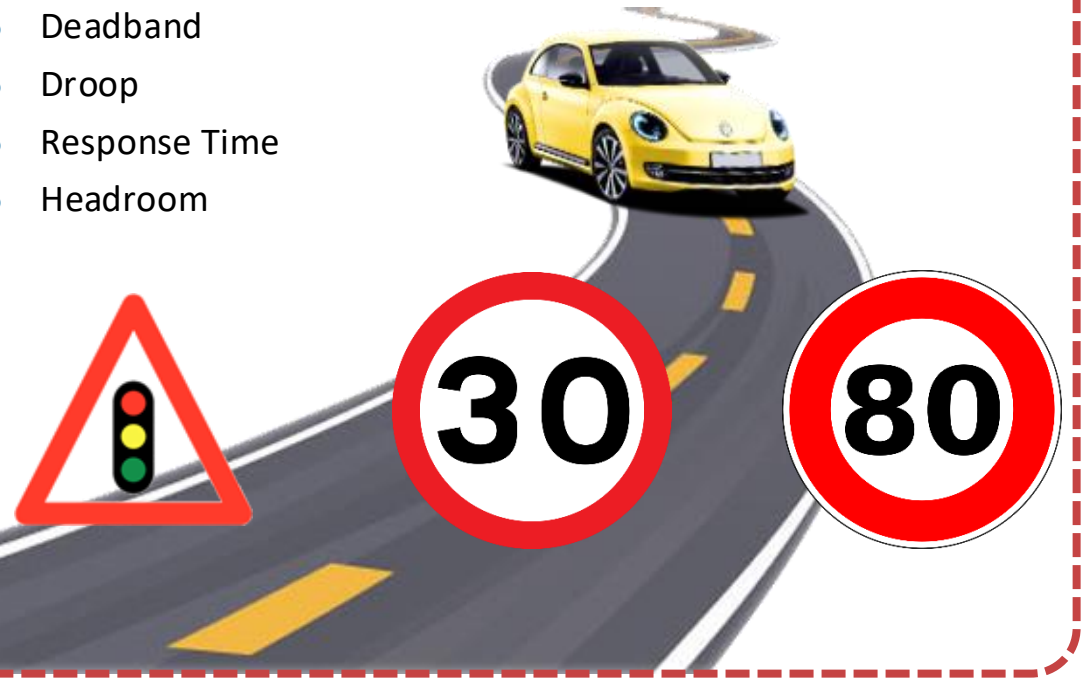
"Delivery of Performance or Service"

Scope of Interconnection or Ancillary Services Agreement

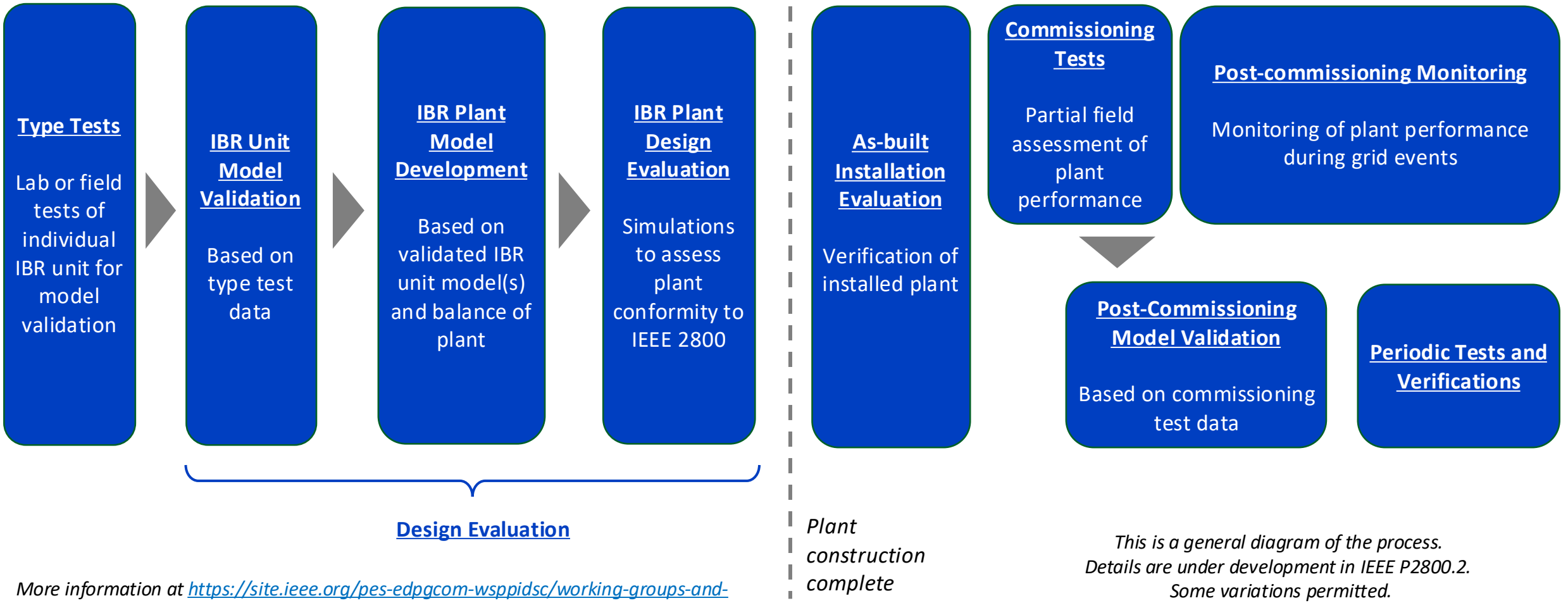
- Enable/disable functions
- Functional settings / configured parameters
- Operate accordingly (e.g., maintain headroom, if applicable)

Examples

- Deadband
- Droop
- Response Time
- Headroom



IEEE 2800-2022 and IEEE P2800.2 Conformity Framework

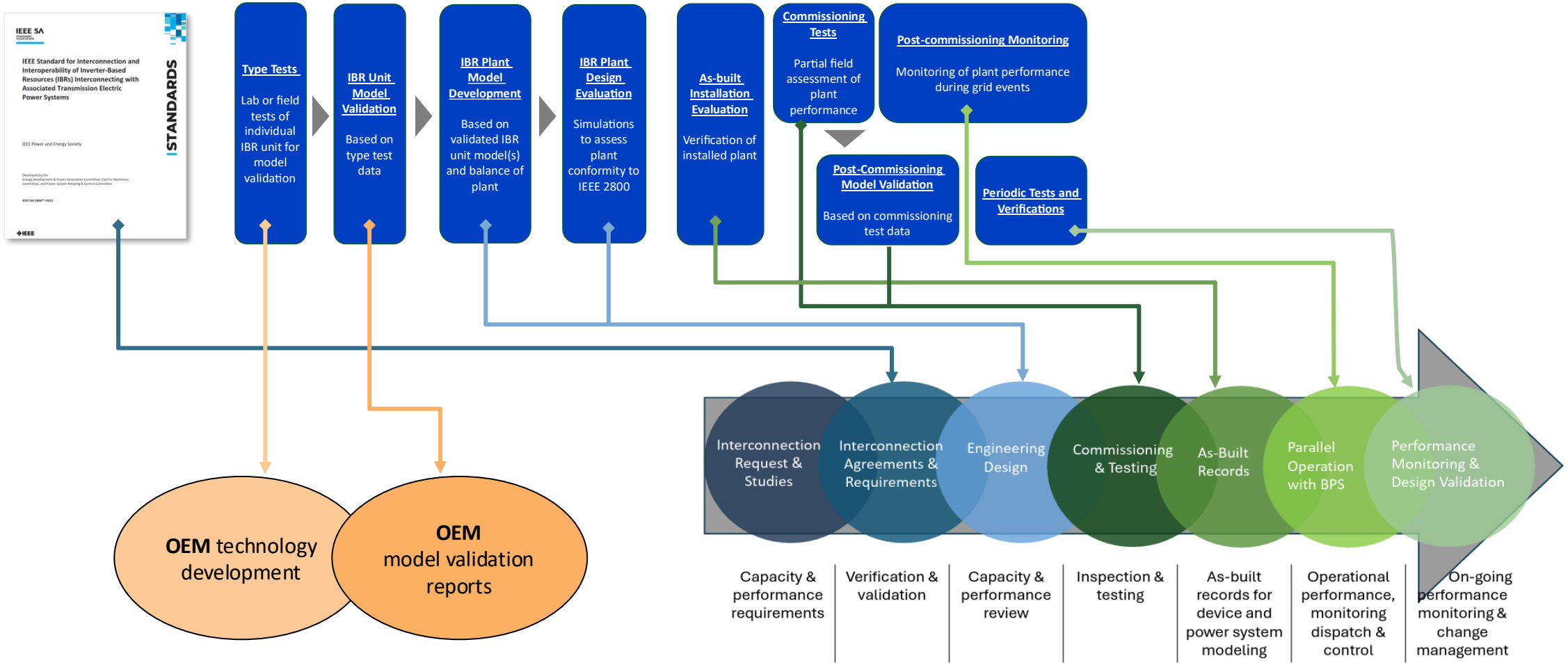


More information at https://site.ieee.org/pes-edpgcom-wsppidsc/working-groups-and-task-forces/ and expression of interest to participate here.

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

➢ **IEEE P2800.2 approved by IEEE SA Standards Board and on track for publication in Q1/2026**

Application of IEEE 2800-2022 and IEEE P2800.2 in IBR Lifecycle



Source: Modified, based on Andy Hoke (NLR) and NATF Inverter-Based Resource Interconnection Lifecycle: Interconnection Requests and Studies Practices. North American Transmission Forum (NATF). 2025. [Online] https://www.natf.net/docs/natfnetlibraries/documents/resources/planning-and-modeling/natf-ibr-interconnection-requests-and-studies-practice.pdf

Figure 1. IBR Interconnection Lifecycle

How Could Voluntary IBR Standards Support with Implementation of Mandatory IBR Standards? Some initial thoughts…

Mandatory IBR Standards (NERC)

- Capability and performance standards:
  - Voltage and frequency ride-through: **PRC-029**
  - …
- Measurement and performance monitoring standard: **PRC-028**
  - Equipment-level
  - Collector system feeder-level
  - Plant-level
- Model validation & verification standard: **MOD-026**
  - Equipment-level
  - Plant-level
- Performance mitigation standard: **PRC-030**
- Facility standards: **FAC-001, FAC-002**

Voluntary IBR Standards (IEEE)

- **IEEE 2800** (IBR Interconnection Standard)
  - Capability and performance requirements: **Clauses 4–9**
  - Measurement data for performance monitoring and model validation: **Clauses 11**
  - Test and verification requirements: **Clause 12**
    - …
    - Post-commissioning monitoring: Subclause **12.2.7**
    - Periodic tests: Subclause **12.2.8**
    - Periodic verification: Subclause **12.2.9**
- **IEEE P2800.2** (Conformity assessment standard)
  - Type test of IBR equipment: **Clause 5**
  - Equipment model validation: **Clause 6**
  - IBR plant design evaluation: **Clause 7**
  - Post commissioning model validation: **Clause 10**
  - Post-commissioning monitoring: **Clause 11**

ISOs/RTOs Implementation and Adoption

- **IBR Facility Interconnection Requirements**
- **IBR Modeling Guidelines** / Performance Verification Tests

Continuous Industry Collaboration

IEEE 2800-2022
2800.2-2026
(1st edition)

- For the time being, adopting IEEE 2800-2022 and 2800.2-2026 with an "**hybrid integration**" approach may be preferred because it can account for known deficiencies and gaps in the 1st edition of the standard.
  - ➢ *Future revisions should be informed by the adjustments entities made in their "hybrid integrations"—**call to action for all stakeholders to get engaged in the ongoing revisions and amendments***

IEEE 2800-202x
2800.2-202x
(2nd edition)

- After the forthcoming revision, a "**detailed reference & customization**" approach may be preferred because it allows for partial adoption via clause-by-clause references to the 2nd edition
  - ➢ *Not all gaps identified during the adoption of the 1st edition may be sufficiently addressed in this revision.*
  - ➢ *A detailed reference to a new **IEEE 2800.1 Recommended Practice for GFM equipment** may be included.*

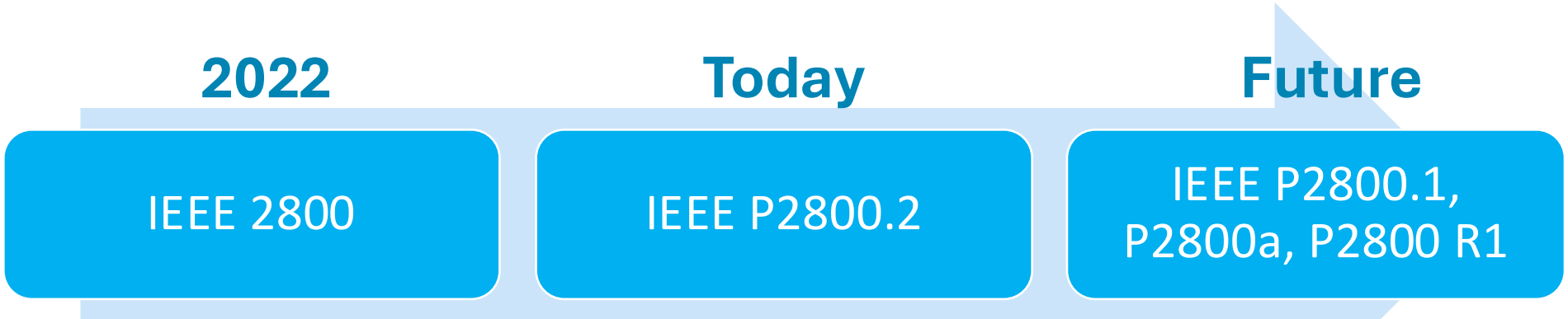
+ IEEE P2800.1 for GFM

IEEE 2800-203x
2800.2-203x
(3rd edition)

- For subsequent editions, a "**general reference**" approach **with the necessary specification of** technical minimum **capability** (where **options** are provided) **and** functional **settings** (where no default settings are provided) may be preferred, because it provides the broadest possible harmonization.
  - ➢ *Standards may be incrementally revised or amended as technology further matures.*

➔ *Consider updating existing **IBR modeling requirements** to align with IEEE 2800.2-2026.*

Summary and Outlook IEEE standards for BPS-IBRs



- **Interconnection requirements for IBRs on transmission and subtransmission**
- 2800 (mostly) applies at the plant level
- Adopted by >20 utilities and ISOs and counting
- Ride-through aspects incorporated into NERC PRC-029-1

- **Recommended conformity assessment procedures for 2800**
- IEEE-SA balloting completed in late 2025. 96% approval among 231 balloters
- Up for IEEE RevCom approval Jan 28
- Expected to publish around March/April 2026

- **P2800a:** Amendment to reduce barriers to grid-forming (GFM)
- **P2800.1:** Recommended practice for GFM equipment requirements and tests
- **P2800:** Full revision
- …

Source: Andy Hoke (NRL)

➔ Now, … what about IEEE standards for "Large Loads"?

See https://standards.ieee.org/industry-connections/activities/data-centers-standards-needs-analysis-and-recommendations/

Related EPRI Offerings

(1) IBR CA Module – *Inverter Based Resource Conformity Assessment Module*

v1.0 (2025) 3002034455 and v1.1 (2026) forthcoming

Need

- Ability to **assess performance of IBR plants** to **verify conformity** against any standards/grid codes that may be present and based on specified criteria.

Objective

- **Develop and deliver** an **IBR Conformity Assessment Module** that can be used to assess IBR plant response, either based on **verified plant-level models** or by use of **on-site disturbance monitoring** and field measurements.

Scope

1. Define **list of tests, measurements, and criteria** to be used to assess IBR plant performance and verify conformity.
2. Develop **software modules** that can apply and carry out the conformity assessment in automated ways.
3. Can use responses from **both generic and user defined IBR models** in **both time and frequency domain** simulations.
4. Can use IBR measurements from on-site digital fault recording (**DFR**) and dynamic disturbance recording (**DDR**).
5. Deliver (pre-)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

Confirmed participating funders: 7x as of 02/18/26

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SRP's Operational Readiness Program

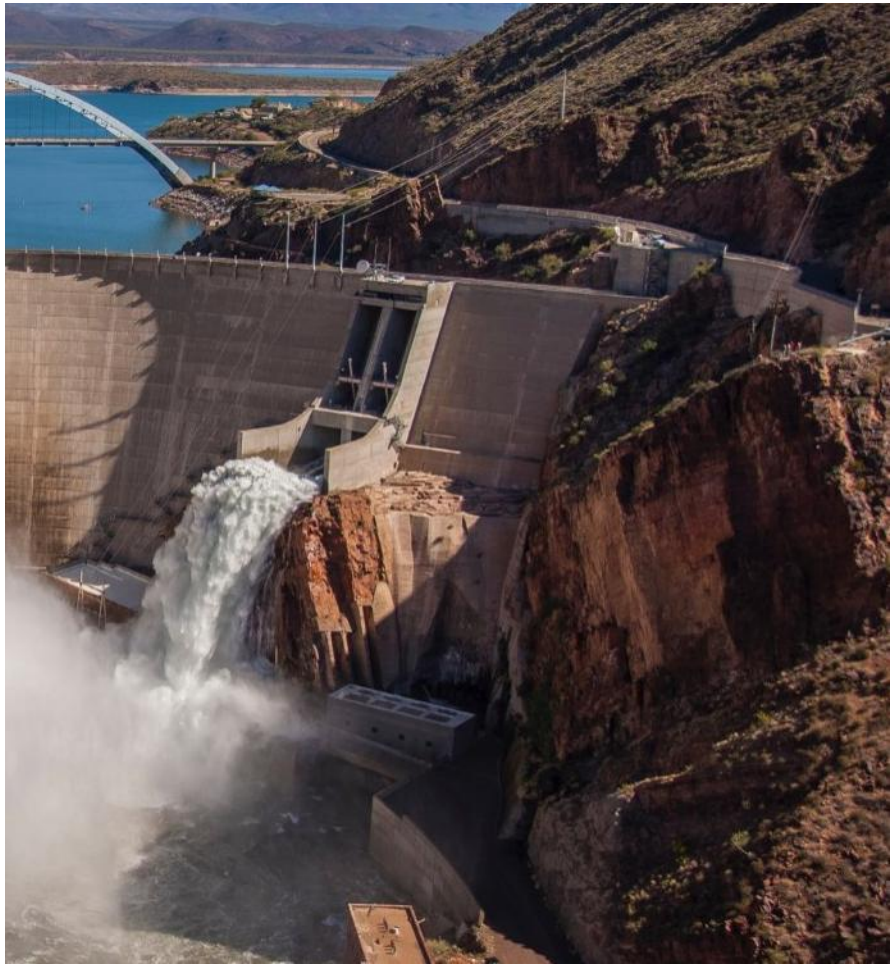
Scott Anderson, Salt River Project

2-24-2026

What is Operational Readiness?

Little Bit About SRP

- One of the nation's largest public power utilities
- Vertically integrated
- Wear many NERC functional entity hats
  - Balancing Authority
  - Generator Operator/Generator Owner
  - Transmission Owner/Operator/Planner
  - Distribution Planner
  - Resource Planner
- Energy Market participant (WEIM → Markets +)



Operational Readiness at SRP (OpR)

- **Operational Readiness** is the capability for SRP to operate the future grid **safely**, **reliably,** and **cost-effectively** as intermittent resources are added
- **Operational Readiness Strategy**
  - Clearly and accurately represents what SRP needs to do to operate this new future grid
  - Address the **who**, **what**, **where** and **why** with an emphasis on systems, processes and tools

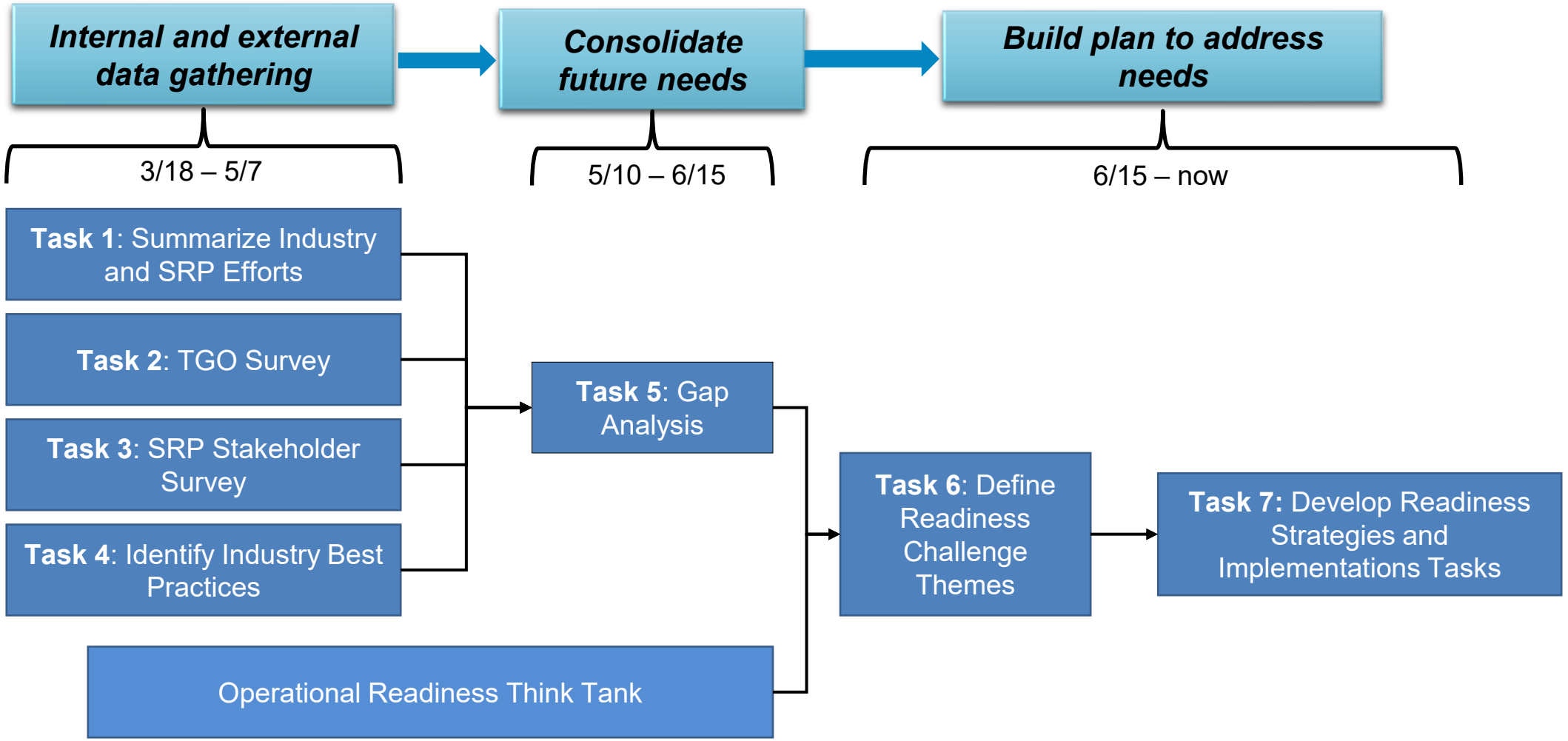
May 03, 2021

SRP to more than Double its Utility Scale Solar to 2,025 Megawatts by 2025

Salt River Project today announced plans to more than double its 2025 utility-scale solar commitment to now add a total of 2,025 megawatts (MW) of new utility-scale solar energy to its power system by the end of fiscal year 2025, driven in part by dedicated customer demand for new renewables. This is more than 1,000MW beyond SRP's original 2025 commitment of 1,000MW, announced in November 2018. As part of this 1,025MW solar increase, 450MW is enabled by an SRP commercial customer to meet its renewable energy commitments. All the renewable energy purchased is expected to be from solar energy developments built in Arizona or on the Navajo Nation and will ultimately be used by SRP commercial and residential customers.

"As we plan for our customers' increasing need for energy and their desire for a cleaner environment, solar energy is a key solution that is significantly growing our sustainable generation portfolio," said SRP's CEO and General Manager Mike Hummel. "Doubling solar purchases over the

Development of OpR Strategy



Gaps Identified

GENERATION

Dispatchability

Reserves

Grid Services

New Technology

TOOLS

Forecasting

Situational Awareness

Analysis

Software Integration

PEOPLE

Training

Expertise

Collaboration & Feedback

Mission

Operational Readiness Projects Today

✓1A Bolster testing ✓ EMS Enablement ✓1C/D EMT modeling ✓2A/B PPA improvements ✓11 TGO/DOC coordination ✓12B System Protection ✓23 Interconnection requirements	 Fully Leverage New Resource Capabilities	3 / 4 / 13 Value stream analysis* Q4FY26 89%	10 TGO renewables desk Q4FY26 70%	12A Inverter tech standards (Inc Grid Forming)* Q4FY27 65%	24 IBR tech & performance requirements Q4FY26 80%	27 IBR modeling improvements* Q1FY27 50%
✓8A IBR data & comms ✓ 8B Displays ✓9 Intra-hour solar variability ✓18 System power quality & inertia ✓19 EIM process & tools ✓20 Software ecosystem ✓22 Control issues/mitigation	 Software & Situational Awareness	17 Control room IBR video wall Q4FY26 99%				
✓14 Fleet ramping capability analysis	 Economic Dispatch with Solar + Storage	25 Metrics, contract compliance & settlements* Q1FY27 83%				
✓21 Improve IBR deployment (PPAs)	 Enabling Projects	26 IBR training* Q2FY27 25%				
✓6/7 Solar forecasting tools & integration ✓16 CAISO load forecasting	 Advanced Forecasting Tools					
✓5 Flex reserves & governance ✓15 System variability analysis	 Risk Adjusted Reserve Requirements					

OpR has Enterprise-Wide Stakeholder Engagement

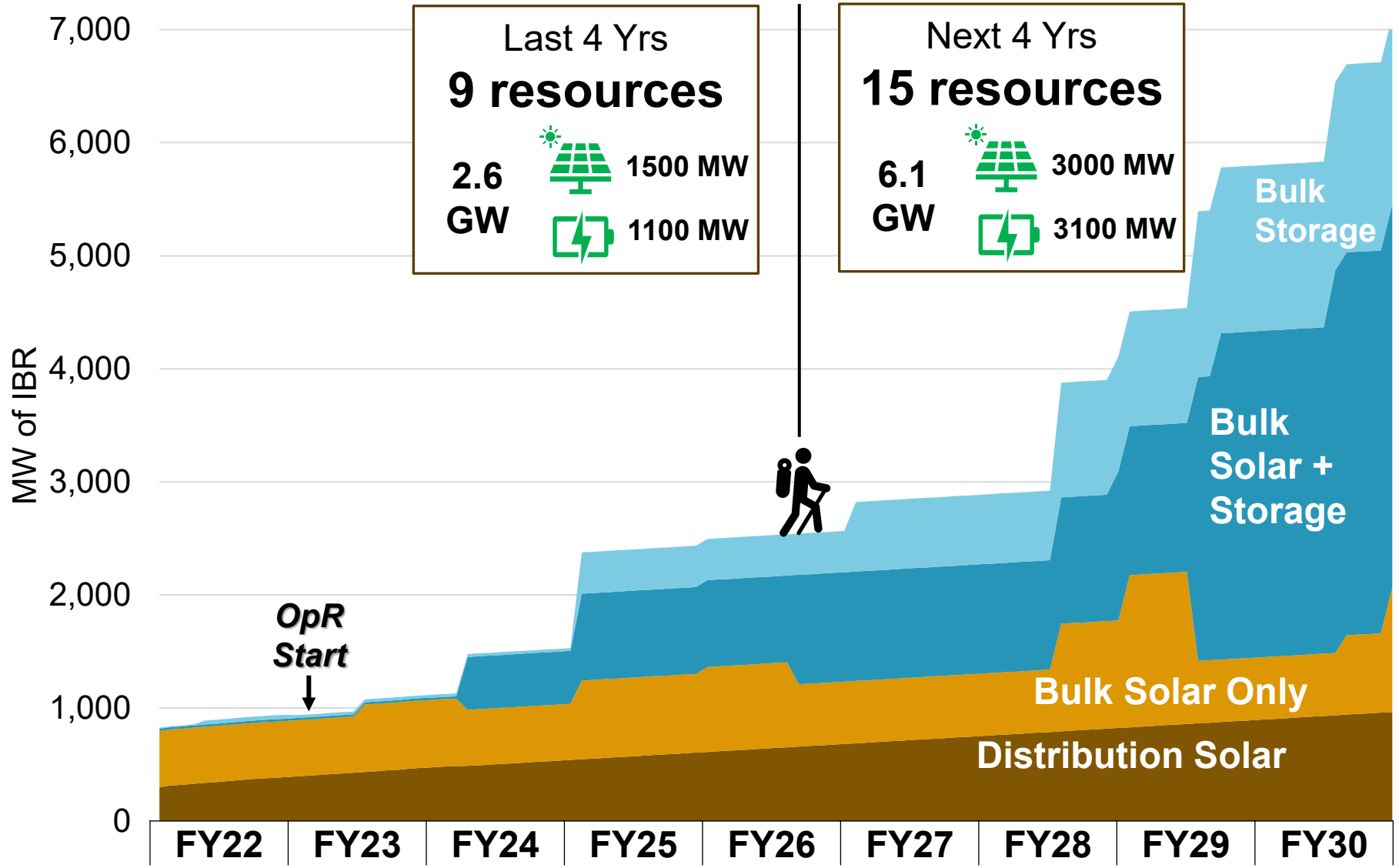
GENERATION | TRANSMISSION | DISTRIBUTION

Transmission & Generation Operations (AGC & PDO)		Distribution Operations
Resource Planning & Acquisition	Transmission Planning	Distribution Strategy
Supply & Trading	Project Management	
Generation	Apparatus & Standards	
Integrated System Planning		
Operational Technology Applications (EMS, ADMS)		
Protection, Communication & Control		
Power Quality		
Metering & Power Accounting		

No….Really…..What is OpR?

	Resource Plan	SRP OpR	
		NERC IBR Strategy	Process + Cost Elements
Time Horizon	20+ years	Real-time to 5 years	Real-time to 10 years
Core Question	Do we have enough capacity?	Will the system remain stable?	Can SRP operate reliably and cost-effectively?
Granularity	Systemwide	Device/plant-level	Systemwide + operational processes
Primary Metrics	PRM, ELCC, LOLE	Ride-through, inertia, voltage control	Performance + forecasting + economic dispatch
Tools	Long range, many scenarios (hourly)	Dynamic/EMT + protection coordination (Sub-cycle)	Operational models, testing, dispatch rules (Intra-hour)
Focus Area	Resource adequacy and portfolios	Stability and reliability behavior	Engineering, operations, economics, processes, training

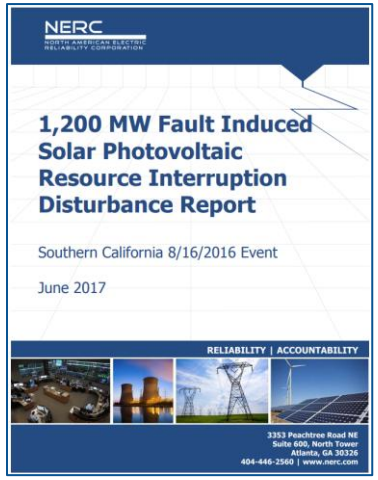
OpR Odyssey


Last 4 Yrs
9 resources
2.6 GW
1500 MW
1100 MW
Next 4 Yrs
15 resources
6.1 GW
3000 MW
3100 MW
MW of IBR
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
OpR Start
Bulk Storage
Bulk Solar + Storage
Bulk Solar Only
Distribution Solar
FY22
FY23
FY24
FY25
FY26
FY27
FY28
FY29
FY30

Defining Technical Requirements

IBR Technical Requirements Journey

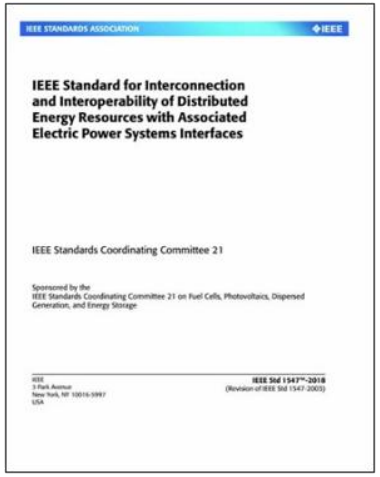
2016+



NERC Reports

Blue Cut Report
Odessa Report
IBR Strategy
IBR Recommendations

2018



IEEE 1547

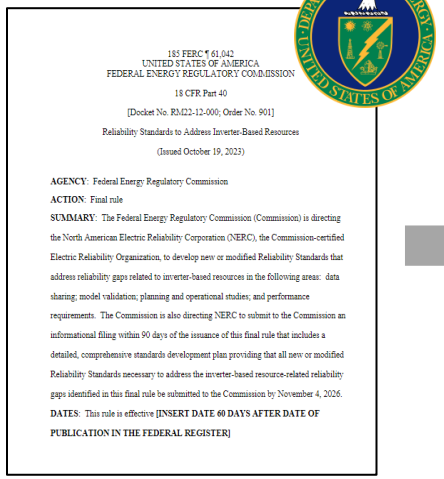
Distributed Energy Resources connecting to Distribution

2022

IEEE 2800

IBRs connecting to Transmission

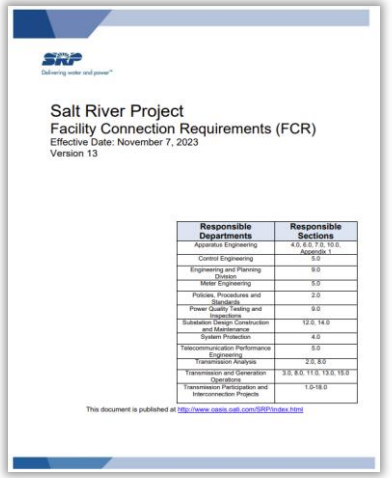
2023-2026



FERC Order 901

Directing NERC to develop new IBR stds

2023+



SRP Requirements

1. Power Purchase Agreements (OpR 2)
2. Facility Connection Requirements (OpR 23)

IBR Technical Requirements Journey in OpR Context

OpR 2 – IBR PPA Improvements

IBR Power Purchase Agreements Technical Requirements

OpR 12 – Inverter Technical Standards

Review of IEEE 2800

OpR WIP
Applying IEEE 2800.2
Test & Verification

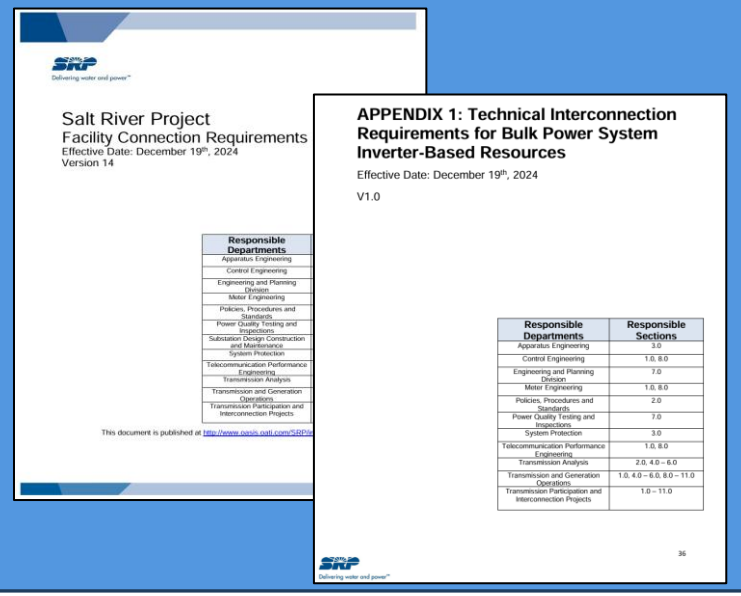
OpR 23

Peer Utility Benchmarking

OpR 23

Pain points from past interconnection projects

OpR 23 IBR Technical Requirements



- **FCR is referenced in SRP's Large Generator Interconnection Process/Agreement**
- **Appendix 1 is for IBRs**
- **Documents are publicly available on OASIS**

PPA Sample Improvements (OpR 2)

Requirement Category		Description
1	**Plant Dispatch**	How and by whom plant dispatch is accomplished, including curtailment, and overall plant operability. Prior to Facility Connection Requirements included ride-through.
2	**Data & Telemetry**	Defining the data, control points, and format required to be communicated between the plant and SRP.
3	**Communications**	Communication protocol and hardware and network requirements to enable SRP/plant communication.
4	**Forecasts**	Technology, methodology and responsibility for creating and sending plant output forecasts, including partial operations (Outages).
5	**Operating Procedures and Dispatch Constraints**	Process and limit by which the plant can be operated and dispatched.

SRP Approach to IEEE 2800: "Hybrid Integration"

General Reference
(Cite IEEE 2800 in Full)

"Point to standard in existing requirements"

- ✓Minimal effort to adopt
- × **Missing system-specific (TO) details**
- × Lacks clarify and specificity
- × **Leaves gaps in implementation and understanding**
- × IBR owners must purchase standard

Detailed Reference
(Cite Specific IEEE 2800 Clauses)

"Point to specific clauses in existing requirements"

- ✓Targeted enhancements
- ✓Allows phased approach
- × **Missing system-specific (TO) details**
- × IBR owners must purchase standard

Hybrid Integration
(Organic Integration)

"Point to specific clauses and add language for clarity in existing requirements"

- ✓Targeted enhancements
- ✓Allows phased approach
- ✓Allows adaptation, if
- ✓**Specific and clear**
- ✓Enables conformity language additions
- × IBR owners must purchase standard
- × More work for AGIR

Detailed Spec
(Recreate Specs of IEEE 2800)

"Recreate requirements language entirely"

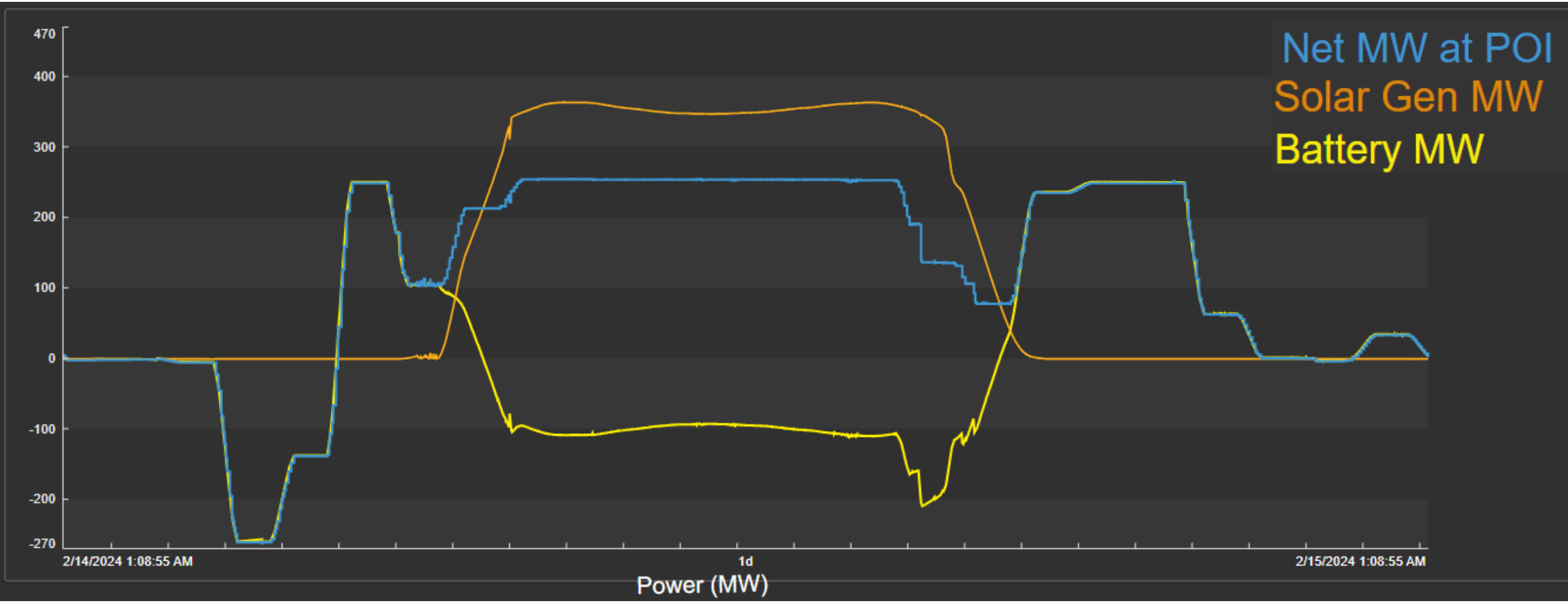
- ✓Targeted enhancements
- ✓Allows phased approach
- ✓Allows adaptation and tailored solution for specific rules framework
- ✓Enables conformity language
- × **Significant work and duplication for AGIR**
- × Copyright concerns

Facility Connection Requirement Summary (OpR 23)

Requirement Category		Description
1	**Plant Models**	Requirements for EMT Models, short-circuit models, and other models SRP needs from the customer for transmission and protection studies
2	**Reliability**	Defines plant capability and operation requirements for voltage control, frequency response, and abnormal grid conditions (ride-through)
3	**Metering & Monitoring**	Requirements for interconnection meters and metering locations, device telemetry collected from the site, and monitoring for disturbances
4	**Testing & Commissioning**	Procedures to validate plant reliability requirements and site capabilities and equipment prior to declaring COD
5	**General**	Requirements for naming approval and additional language for power quality requirements

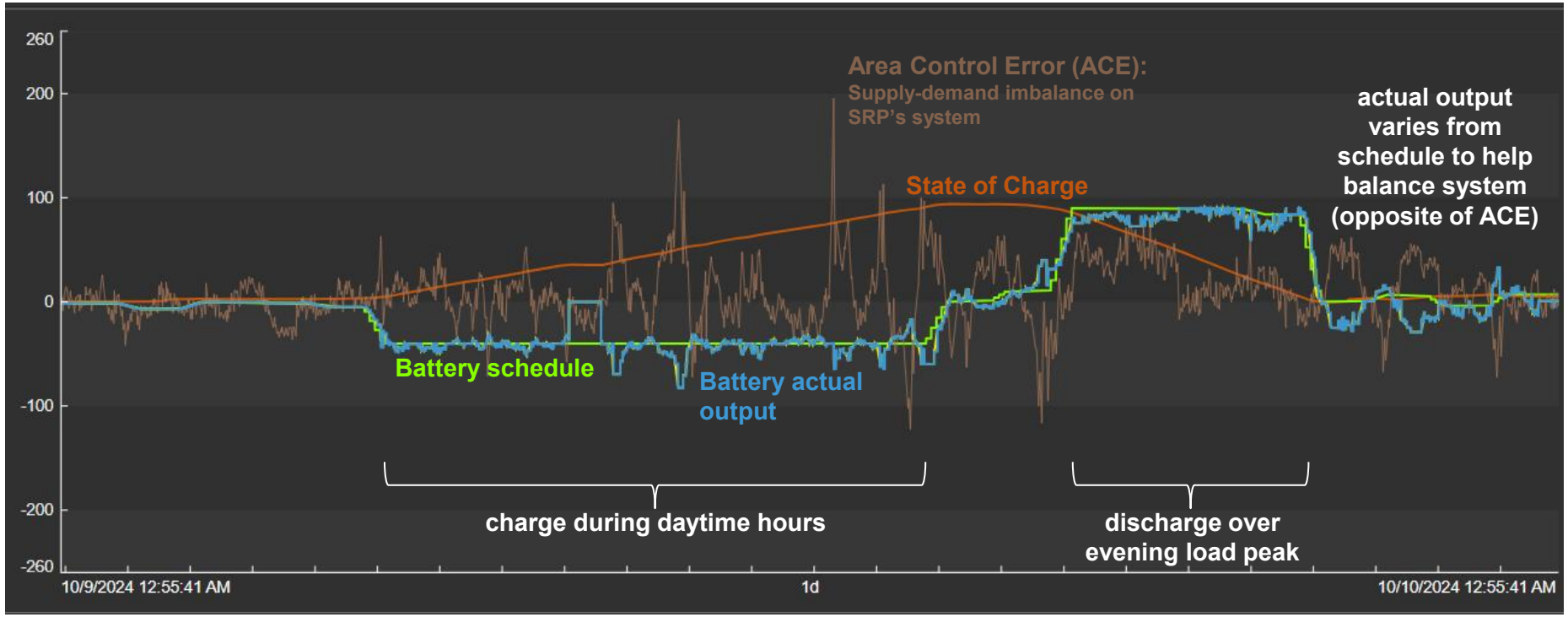
Operating Examples

Operating Solar and Storage Site on a Sunny Day

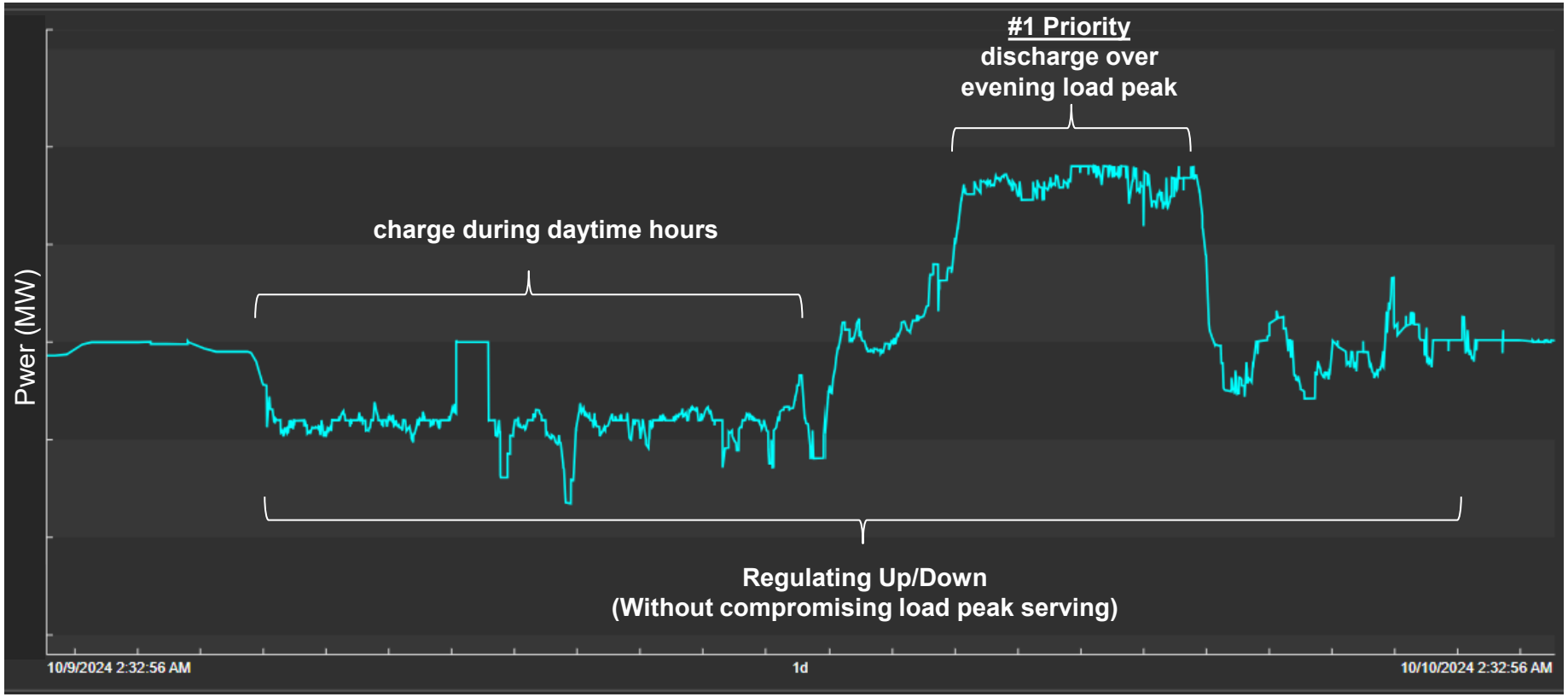


POI = Point of Interconnection

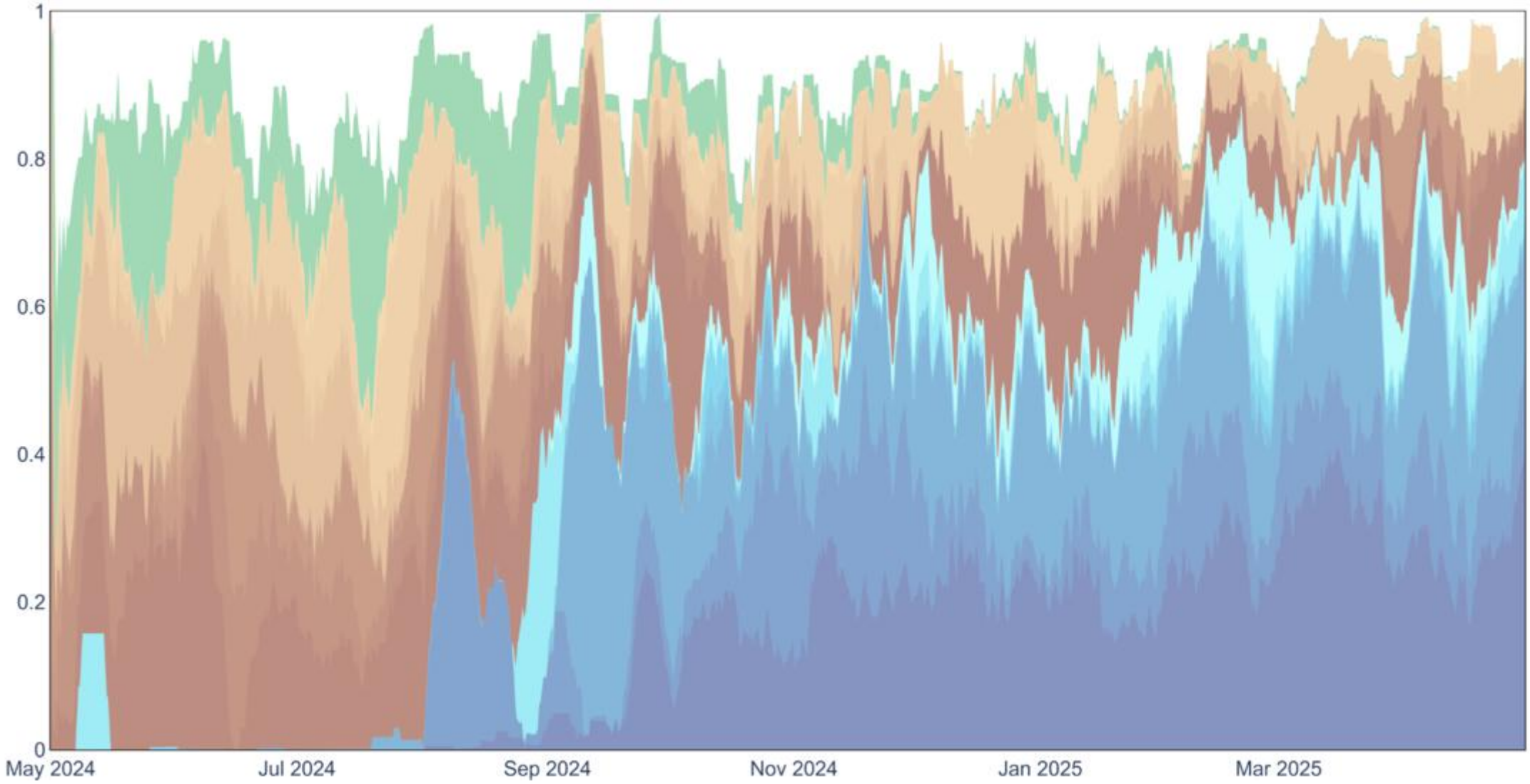
Operating Battery Storage (Actual)



Operating Battery Storage (Actual)

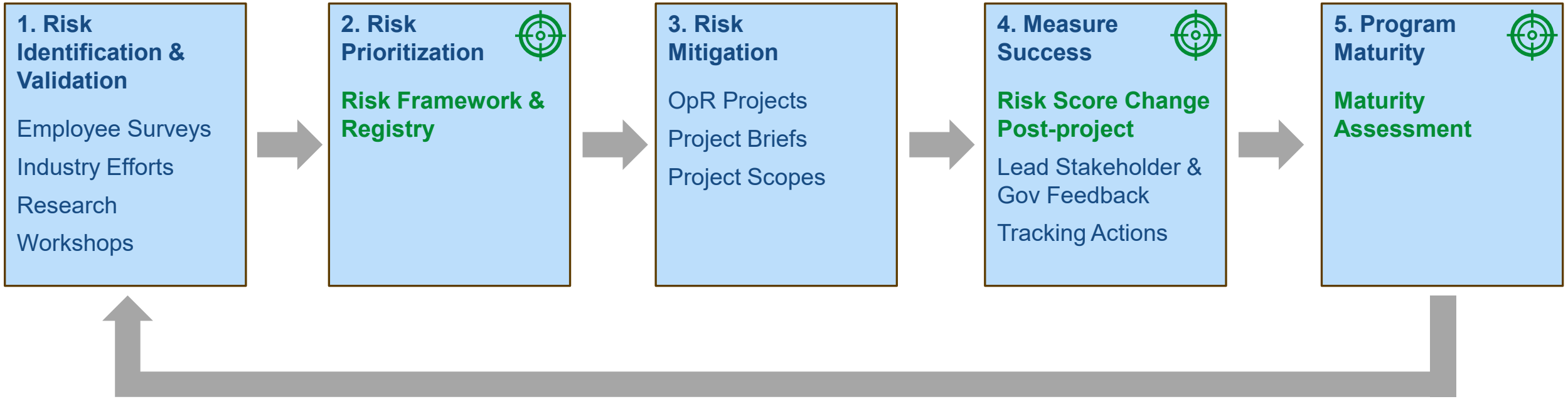


Regulating Reserves Shifts to IBRs



What’s Next?

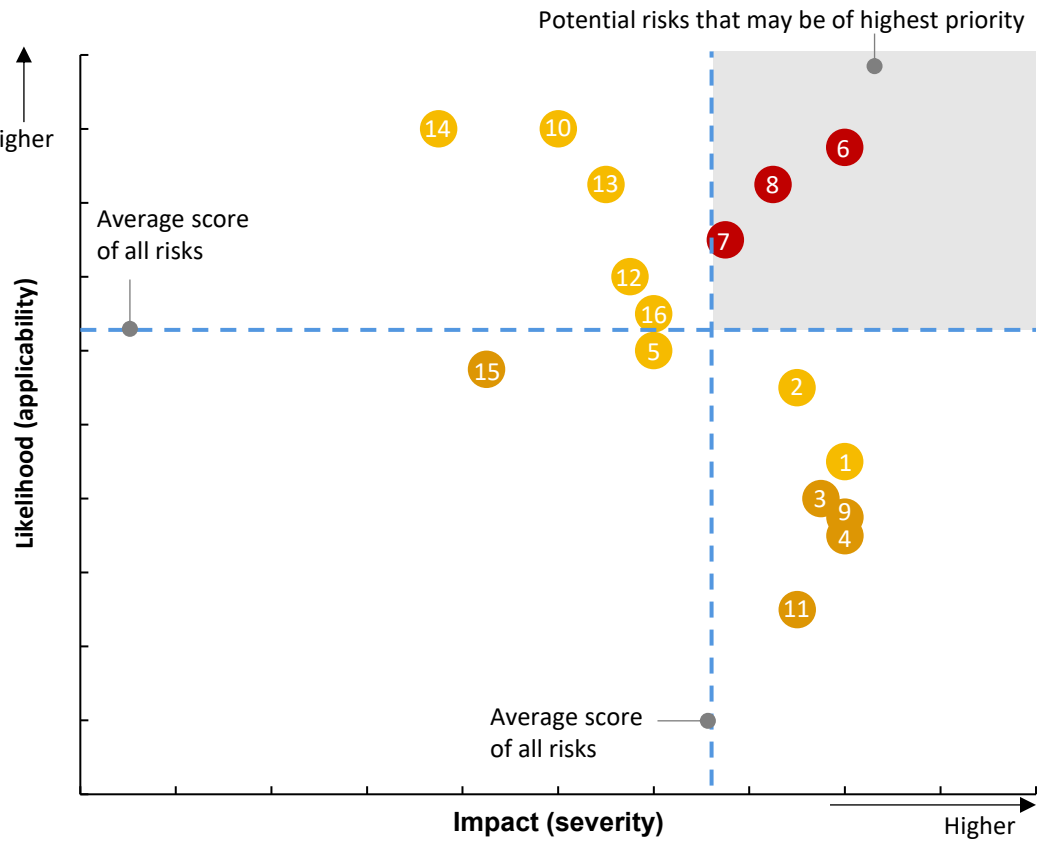
OpR Process with New Risk Based Framework



Changes

Quadrant mapping highlights risk of inadequate tools, data, procedures and controller interactions

How workshop attendees ranked the risks based on potential impact and likelihood, *on average*



x High priority x Medium priority x Low priority

* May pose greater risk (i.e., high risk variance)

Relative importance[1] of risks identified

6	Inadequate **situational awareness** tools and operating procedures to observe and manage risks
8	IBR **controller interactions** between IBRs (HVDC, solar, BESS, wind, etc.)
7	**Poor or intermittent monitoring data** quality and visibility
13	Difficulties **coordinating with IBR plant** developers/owners/operators
10	**Model quality** and study result issues with IBRs*
2	Insufficiently designed system **voltage control strategy and solutions**
12	IBR **commissioning***
16	**Training and education** across departments and companies
1	Interarea, local, or forced **oscillations** and possible adverse operator actions
5	Insufficient **operational planning** studies and assessments, and coordination with long-term planning
14	**Monitoring and enforcement** (on IBR developers/owners) of requirements and policies*
3	Insufficient **dynamic reactive power resources** with high IBR conditions
9	**Weak grids** and low inertia conditions
4	**Generator ride-through** failures resulting in large loss of generation
15	**Distribution-connected generator performance**
11	System **restoration and blackstart**

1. Risk score calculated by multiplying impact average and likelihood average, and rounding to the nearest integer

thank you!

Scott Anderson
Director Operational Readiness
Salt River Project
scott.anderson@srpnet.com
602-809-0850

Raising the bar through the IBR lifecycle

Ryan Quint, PhD, PE

President and CEO, Elevate Energy Consulting

President and Chief Engineer, GridStrong

February 24, 2026

Elevate Energy Consulting

Helping enable a reliable, resilient, affordable, and sustainable energy future for generations to come.

- ***Outstanding technical expertise*** in inverter-based technologies, grid interconnection, transmission planning and operations, protection system engineering, regulatory compliance, dynamic modeling and studies, data center modeling, etc. ***#trust***

- ***Elevating our industry partners*** including large utilities, system operators, renewables developers, asset owner/operators, regulators, nonprofits, trade organizations, national laboratories, research institutes, and more to tackle complex challenges facing the electricity sector ***#impact***

ELEVATE
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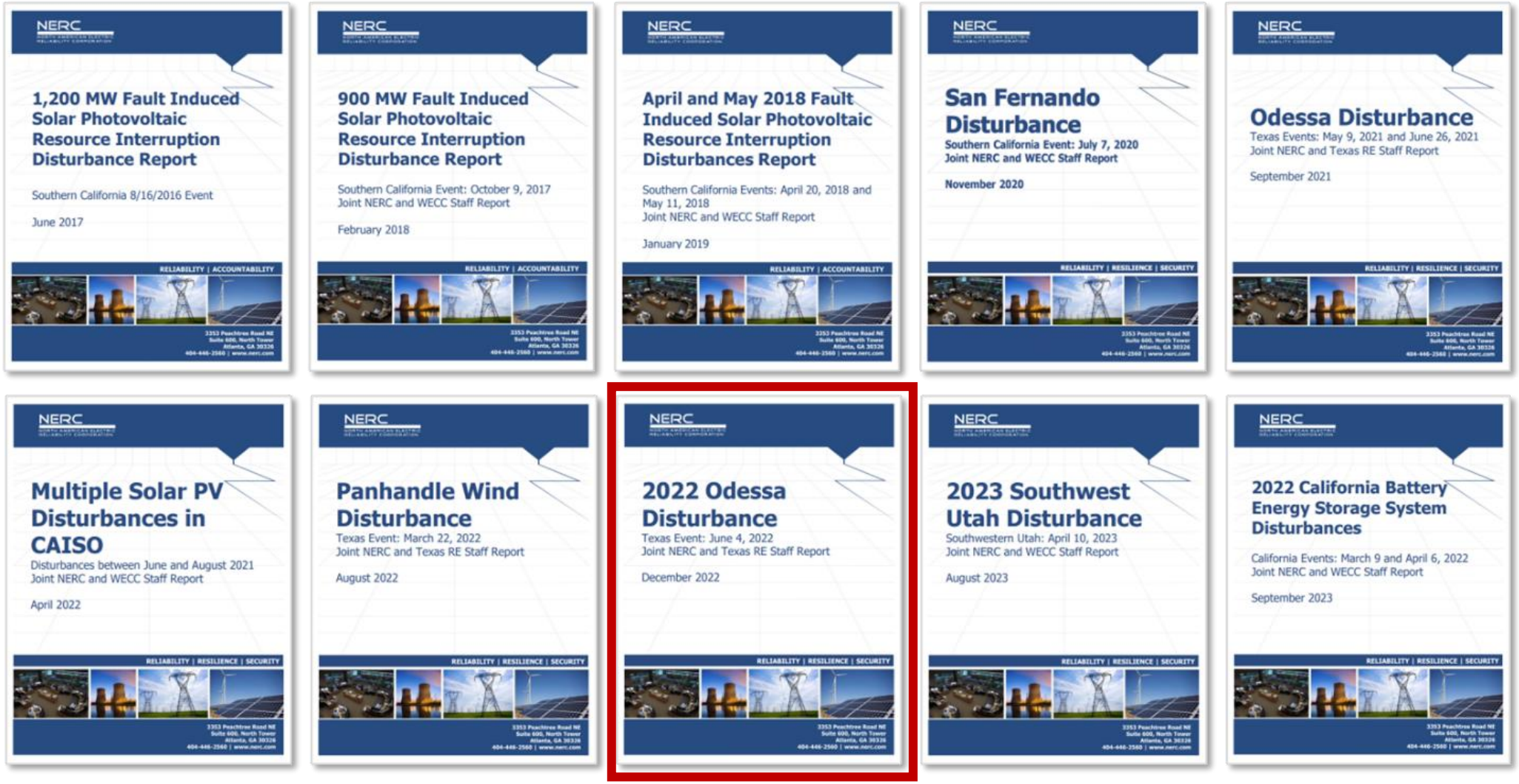
The current interconnection process needs to be improved



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IBR reliability depends on lifecycle alignment

Performance requirements	Plant design	Model requirements
• Clear and harmonized requirements for newly connecting IBRs • Without performance requirements, we cannot (should not?) have model requirements	• IBR plants designed to meet harmonized performance requirements	• IBR plant models that accurately reflect planned or as-built facility • IBR plant models across simulation domains that match each other

Accurate models support studies and decision making

Goal is a streamlined interconnection process that minimizes errors and inefficiency

ELEVATE
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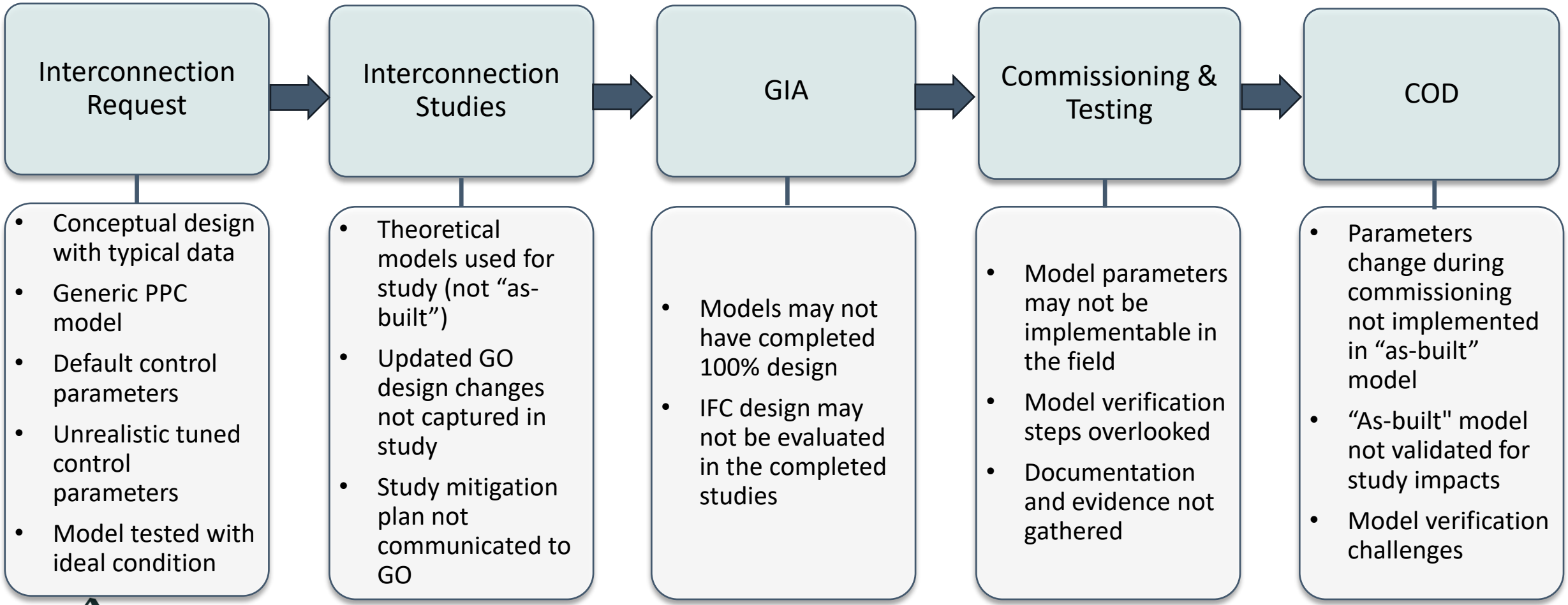
Alignment can break at multiple points of the lifecycle



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This results in a markedly different final product

Category	Studied plant		Commissioned plant
A **Plant design and configuration**	Early development stages; equipment not finalized		Finalized through procurement, construction, and commissioning
B **OEMs**	Often not selected or engaged under contract		May not be finalized until after GIA; may go unstudied until true-up at commissioning
C **Dynamic models**	Assumptions on OEM selection, controls, protections, etc.; defaults		Inverter and PPC settings tuned during commissioning; change from studies
D **IBR plant design evaluation**	Part of IBR modeling requirements; early checks, challenges later in process		May not be adequately reconfirmed at commissioning
E **Performance characteristics**	Generically aligned with performance requirements		Site-specific performance may not be adequately verified and validated
F **Model submission/checks**	Interconnection application and possible milestone updates		Models may not be verified, validated, and updated during commissioning
G **Interconnection agreements**	Signed after studies; IBR plant design continues to evolve		May not reflect as-studied plant; commissioning checks may not occur

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Examples of recent modeling-related breaks

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Industry Recommendation
Inverter-Based Resource Model Quality Deficiencies

Initial Distribution: June 4, 2024

NERC has analyzed 10 large-scale disturbances on the bulk power system (BPS) that involved the widespread and unexpected reduction in output of inverter-based resources (IBR) since 2016. These 10 disturbances totaled nearly 15,000 MW of unexpected IBR output reduction with approximately 10,000 MW occurring between 2020 and 2024. The increase of IBR-related events coincides with an increase in IBR penetration across the BPS. Two contributing causes to these events are poor modeling and study practices to assess the performance of these resources.

Performing dynamic simulations of the BPS allows Transmission Planners (TP), in cooperation with Generator Owners (GO), to mitigate reliability risks before they occur. Accurate dynamic models of resources are critical to this analysis and to BPS reliability. Several of NERC's published disturbance reports included analyses of the models for the affected facilities, which revealed systemic dynamic model inaccuracies. These analyses also revealed that the models provided for conducting generator interconnection studies or other system studies failed to accurately reflect the dynamic performance of the plants. Accurate modeling of IBR facilities is critical in performing system studies to assess the reliable operation of the BPS.

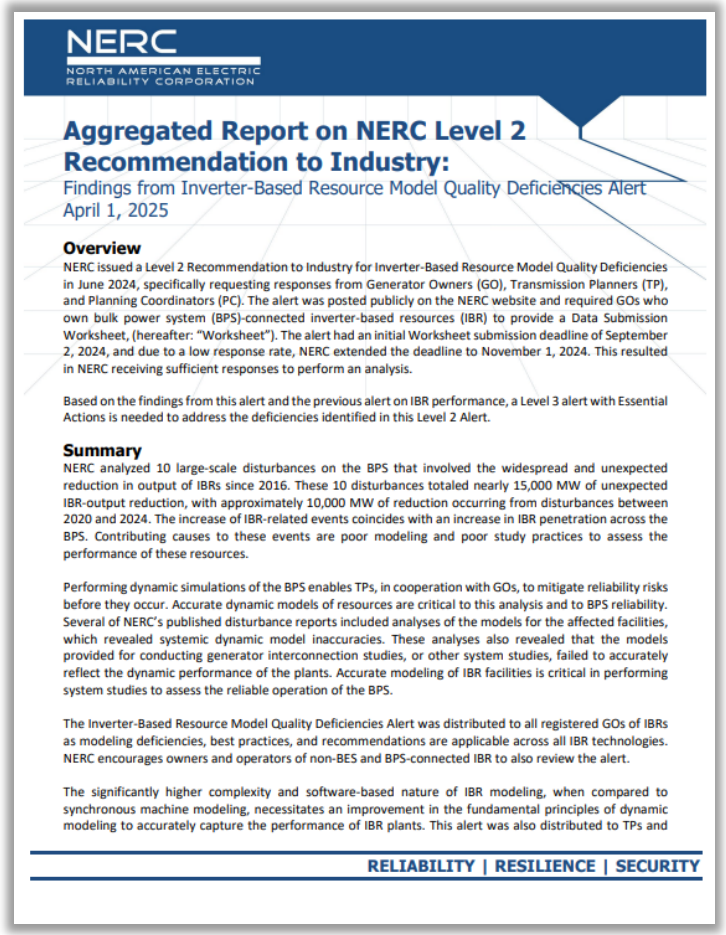
This alert is being distributed to all GOs of Bulk Electric System (BES)-connected IBRs as modeling deficiencies, best practices, and recommendations are applicable across all IBR technologies. NERC encourages owners and operators of non-BES and BPS-connected IBRs to review this alert as well.

The significantly higher complexity and software-based nature of IBR modeling when compared to synchronous machine modeling necessitates an improvement in the fundamental principles of dynamic modeling to accurately capture the performance of IBR plants. This alert is also being distributed to TPs and Planning Coordinators (PC) to provide recommendations that can be implemented to strengthen current modeling practices. TPs and PCs are required to answer a set of questions in the alert system; however, only GOs of IBRs will need to complete the Data Submission Worksheet.

This alert will gather dynamic modeling information from BES-connected IBR GOs, TPs, and PCs to understand the extent of condition of dynamic modeling for IBR, which will inform what additional actions are necessary to mitigate observed deficiencies. These GOs are strongly encouraged to coordinate with their inverter- and plant-level controller manufacturers and third-party consultants to review the parameters and controls installed in the field, review and mitigate modeling deficiencies, and implement the recommendations described in this alert. The information gathered throughout this alert should also be shared and reviewed with the associated GOPs as applicable.

RELIABILITY | RESILIENCE | SECURITY

Level 2 Alert on IBR Model Quality Deficiencies (June 2024)
here



NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Aggregated Report on NERC Level 2 Recommendation to Industry:
Findings from Inverter-Based Resource Model Quality Deficiencies Alert
April 1, 2025

Overview

NERC issued a Level 2 Recommendation to Industry for Inverter-Based Resource Model Quality Deficiencies in June 2024, specifically requesting responses from Generator Owners (GO), Transmission Planners (TP), and Planning Coordinators (PC). The alert was posted publicly on the NERC website and required GOs who own bulk power system (BPS)-connected inverter-based resources (IBR) to provide a Data Submission Worksheet, (hereafter: "Worksheet"). The alert had an initial Worksheet submission deadline of September 2, 2024, and due to a low response rate, NERC extended the deadline to November 1, 2024. This resulted in NERC receiving sufficient responses to perform an analysis.

Based on the findings from this alert and the previous alert on IBR performance, a Level 3 alert with Essential Actions is needed to address the deficiencies identified in this Level 2 Alert.

Summary

NERC analyzed 10 large-scale disturbances on the BPS that involved the widespread and unexpected reduction in output of IBRs since 2016. These 10 disturbances totaled nearly 15,000 MW of unexpected IBR-output reduction, with approximately 10,000 MW of reduction occurring from disturbances between 2020 and 2024. The increase of IBR-related events coincides with an increase in IBR penetration across the BPS. Contributing causes to these events are poor modeling and poor study practices to assess the performance of these resources.

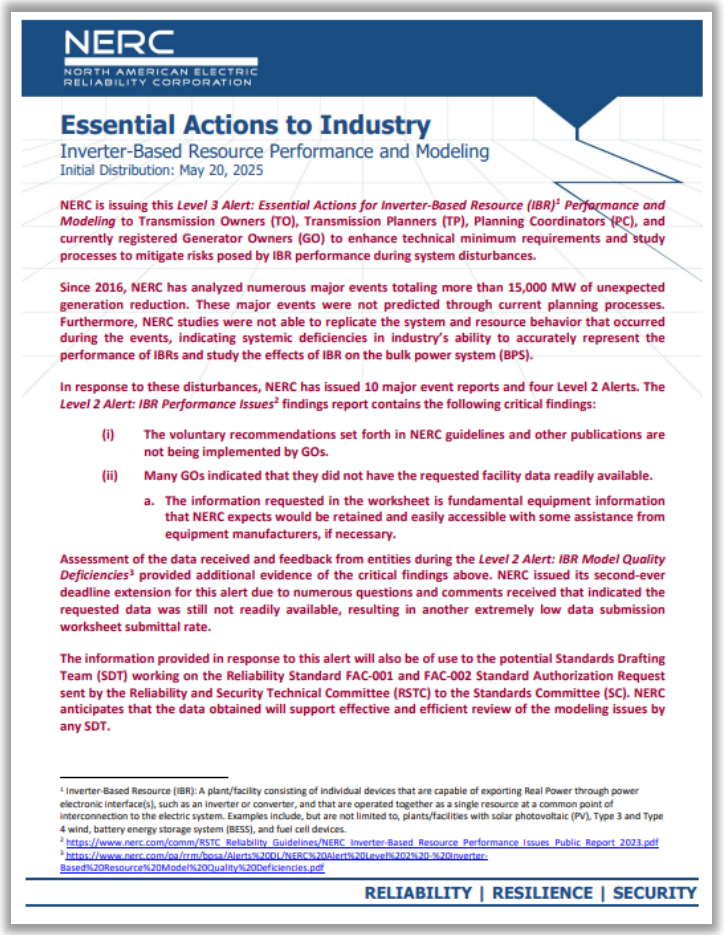
Performing dynamic simulations of the BPS enables TPs, in cooperation with GOs, to mitigate reliability risks before they occur. Accurate dynamic models of resources are critical to this analysis and to BPS reliability. Several of NERC's published disturbance reports included analyses of the models for the affected facilities, which revealed systemic dynamic model inaccuracies. These analyses also revealed that the models provided for conducting generator interconnection studies, or other system studies, failed to accurately reflect the dynamic performance of the plants. Accurate modeling of IBR facilities is critical in performing system studies to assess the reliable operation of the BPS.

The Inverter-Based Resource Model Quality Deficiencies Alert was distributed to all registered GOs of IBRs as modeling deficiencies, best practices, and recommendations are applicable across all IBR technologies. NERC encourages owners and operators of non-BES and BPS-connected IBR to also review the alert.

The significantly higher complexity and software-based nature of IBR modeling, when compared to synchronous machine modeling, necessitates an improvement in the fundamental principles of dynamic modeling to accurately capture the performance of IBR plants. This alert was also distributed to TPs and

RELIABILITY | RESILIENCE | SECURITY

Report on Level 2 Alert on IBR Model Quality Deficiencies (April 2025)
here



NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Essential Actions to Industry
Inverter-Based Resource Performance and Modeling
Initial Distribution: May 20, 2025

NERC is issuing this *Level 3 Alert: Essential Actions for Inverter-Based Resource (IBR)*[1] *Performance and Modeling* to Transmission Owners (TO), Transmission Planners (TP), Planning Coordinators (PC), and currently registered Generator Owners (GO) to enhance technical minimum requirements and study processes to mitigate risks posed by IBR performance during system disturbances.

Since 2016, NERC has analyzed numerous major events totaling more than 15,000 MW of unexpected generation reduction. These major events were not predicted through current planning processes. Furthermore, NERC studies were not able to replicate the system and resource behavior that occurred during the events, indicating systemic deficiencies in industry's ability to accurately represent the performance of IBRs and study the effects of IBR on the bulk power system (BPS).

In response to these disturbances, NERC has issued 10 major event reports and four Level 2 Alerts. The *Level 2 Alert: IBR Performance Issues*[2] findings report contains the following critical findings:

(i) The voluntary recommendations set forth in NERC guidelines and other publications are not being implemented by GOs.

(ii) Many GOs indicated that they did not have the requested facility data readily available.

a. The information requested in the worksheet is fundamental equipment information that NERC expects would be retained and easily accessible with some assistance from equipment manufacturers, if necessary.

Assessment of the data received and feedback from entities during the *Level 2 Alert: IBR Model Quality Deficiencies*[3] provided additional evidence of the critical findings above. NERC issued its second-ever deadline extension for this alert due to numerous questions and comments received that indicated the requested data was still not readily available, resulting in another extremely low data submission worksheet submittal rate.

The information provided in response to this alert will also be of use to the potential Standards Drafting Team (SDT) working on the Reliability Standard FAC-001 and FAC-002 Standard Authorization Request sent by the Reliability and Security Technical Committee (RSTC) to the Standards Committee (SC). NERC anticipates that the data obtained will support effective and efficient review of the modeling issues by any SDT.

[1] Inverter-Based Resource (IBR): A plant/facility consisting of individual devices that are capable of exporting Real Power through 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.
[2] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/NERC_Inverter-Based_Resource_Performance_Issues_Public_Report_2023.pdf
[3] https://www.nerc.com/pa/rrm/bpsa/Alerts%20DL/NERC%20Alert%20Level%202%20-%20Inverter-Based%20Resource%20Model%20Quality%20Deficiencies.pdf

RELIABILITY | RESILIENCE | SECURITY

Level 3 Alert on IBR Performance and Modeling (May 2025)
here

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IEEE 2800-2022 and P2800.2 can address these issues


IEEE SA
STANDARDS ASSOCIATION

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

STANDARDS

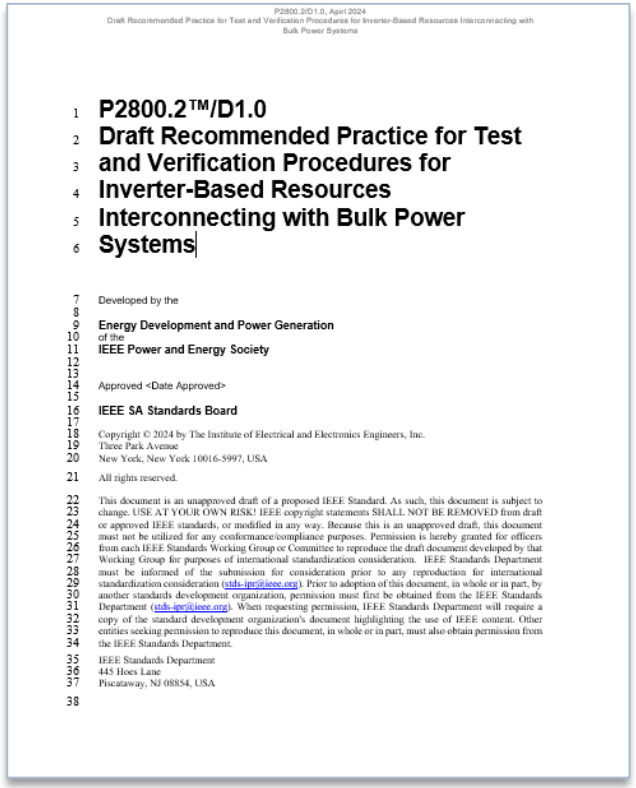
IEEE Power and Energy Society

Developed by the
Energy Development & Power Generation Committee, Electric Machinery Committee, and Power System Relaying & Control Committee

IEEE Std 2800™-2022

IEEE

THE WHAT


P2800.2/D1.0, April 2024
Draft Recommended Practice for Test and Verification Procedures for Inverter-Based Resources Interconnecting with Bulk Power Systems

P2800.2™/D1.0
Draft Recommended Practice for Test and Verification Procedures for Inverter-Based Resources Interconnecting with Bulk Power Systems

Developed by the

Energy Development and Power Generation
of the
IEEE Power and Energy Society

Approved <Date Approved>

IEEE SA Standards Board

THE HOW

IMPLEMENTATION

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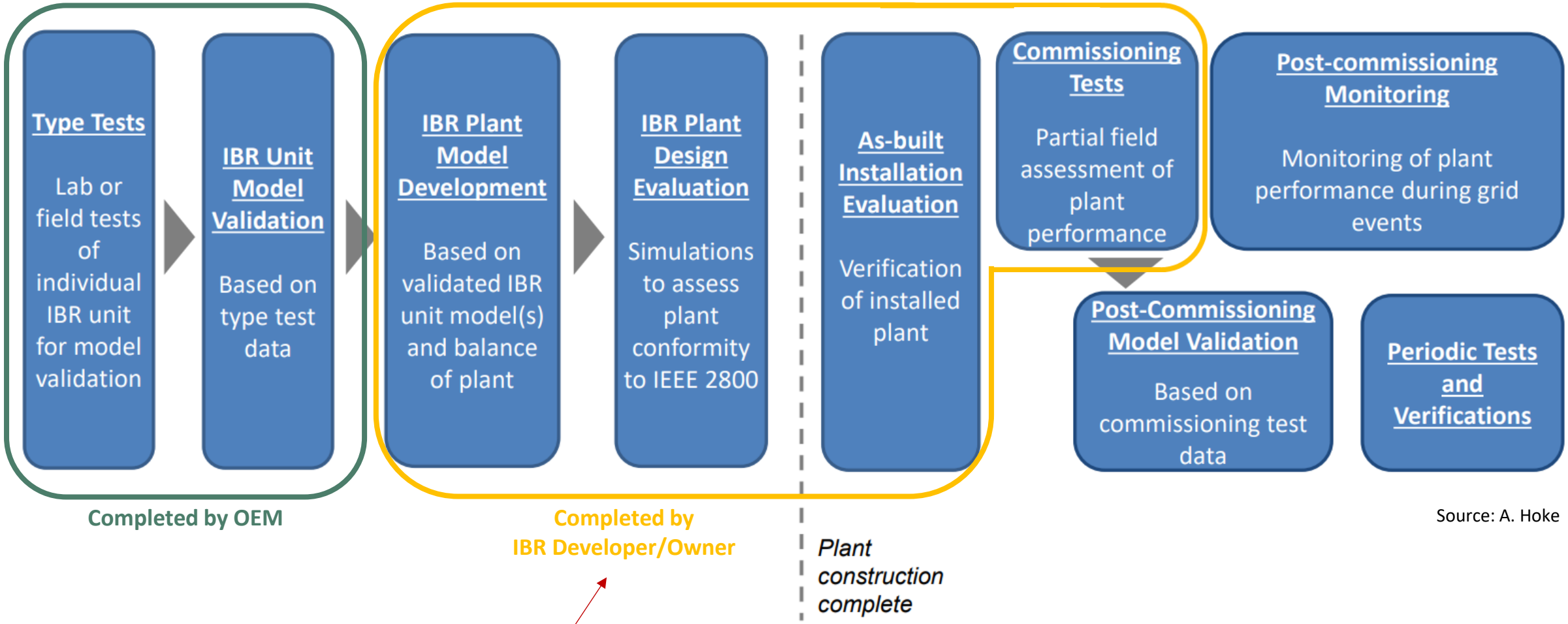
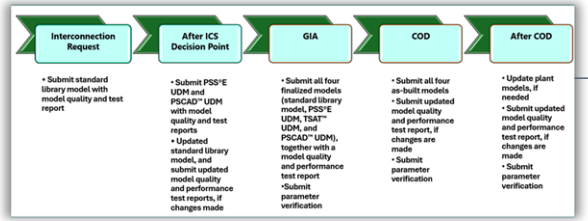
IEEE P2800.2 conformity assessment steps still need to be adopted and codified



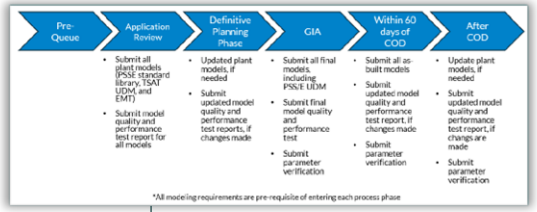
Source: A. Hoke

These steps need to be adopted and codified, to some extent, to ensure they are adequately completed.

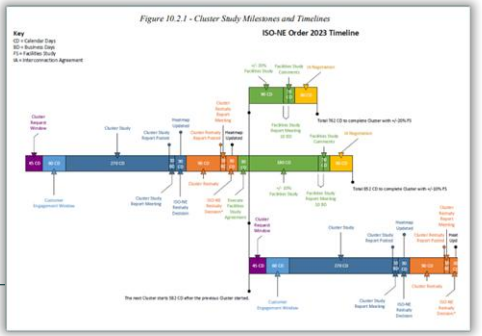
Current implementation is fragmented by region



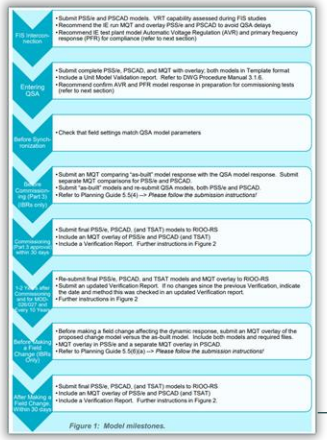
SPP MDAG Meeting Materials Feb 2026



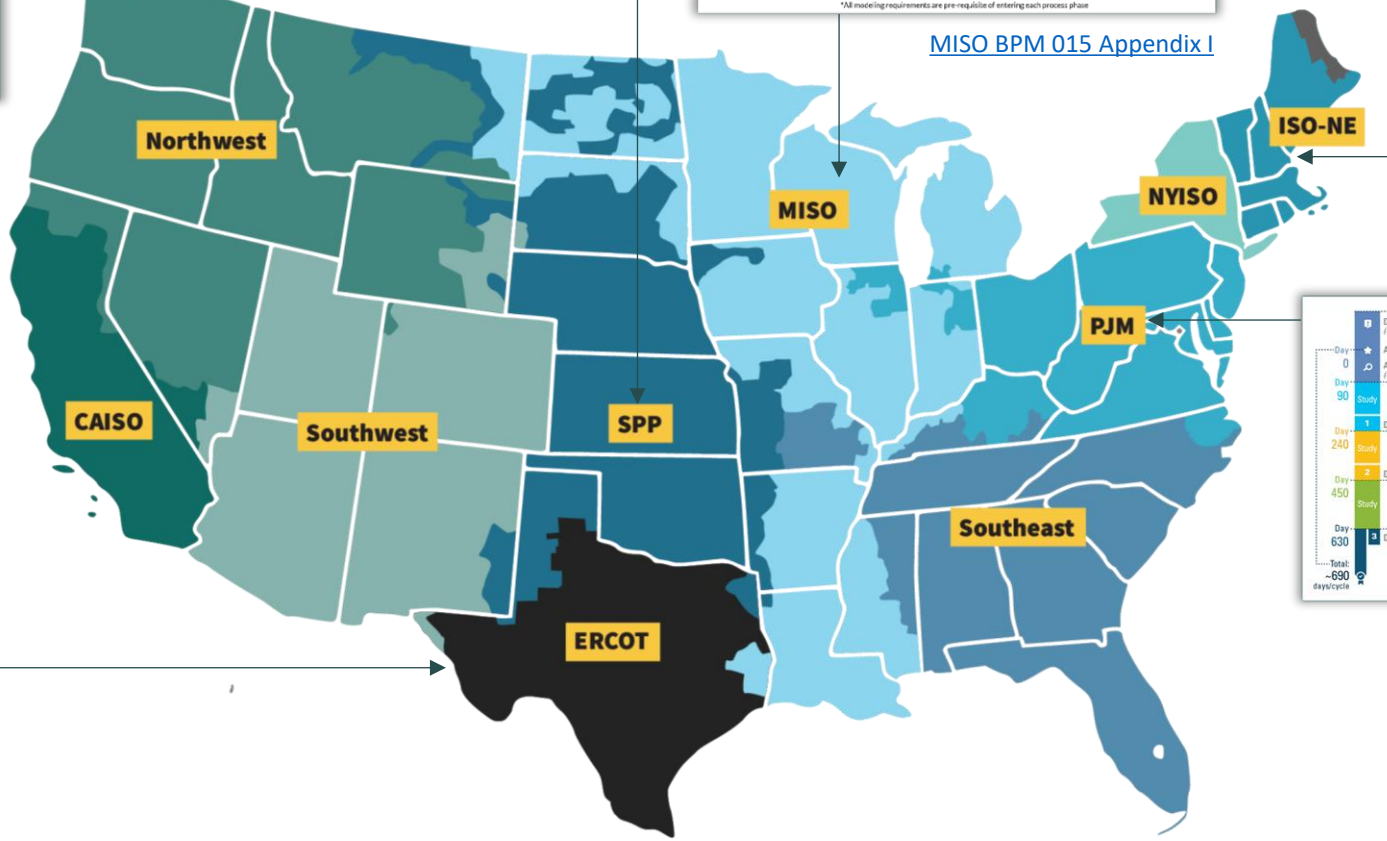
MISO BPM 015 Appendix I

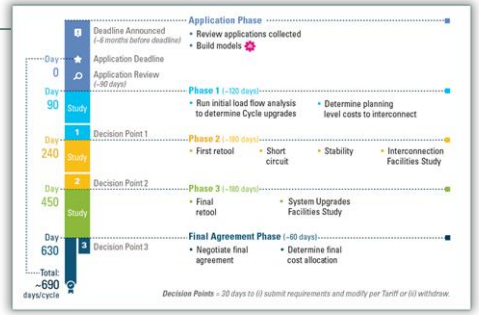


ISO-NE Planning Procedure No.5-6



ERCOT Model Quality Guide - Version 1.10

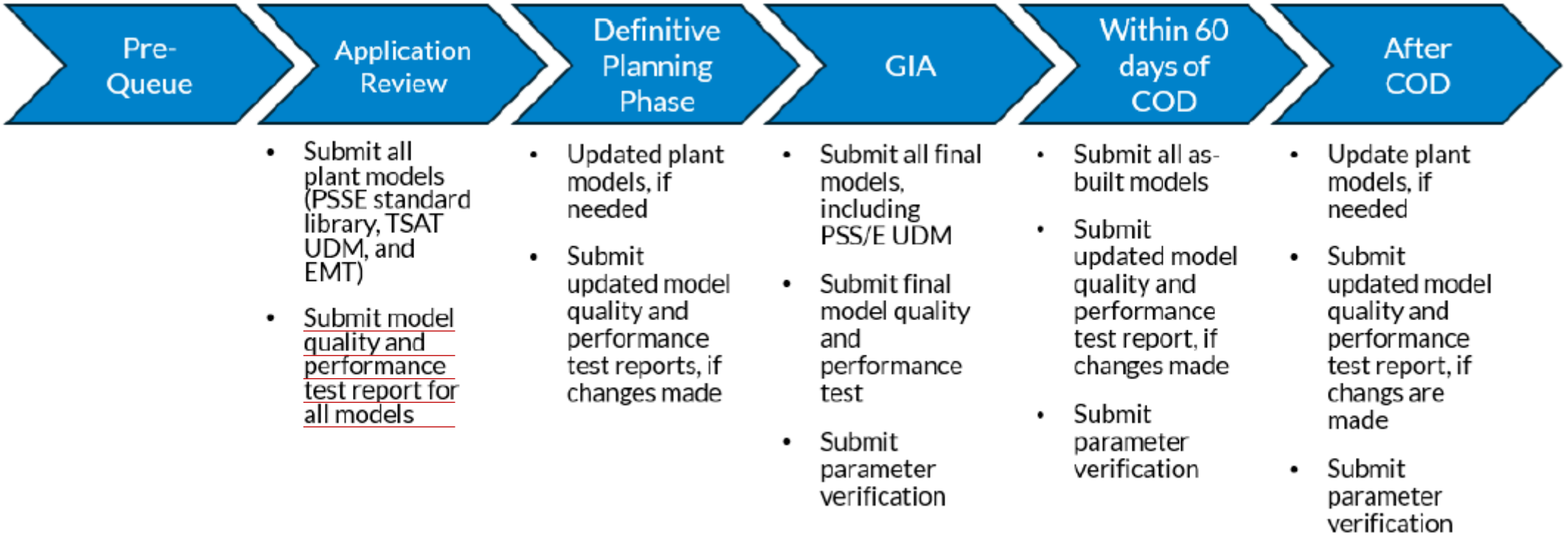




PJM Manual 14H

Source: FERC

Example: MISO modeling milestones create checks



*All modeling requirements are pre-requisite of entering each process phase

MISO BPM 015 Appendix I

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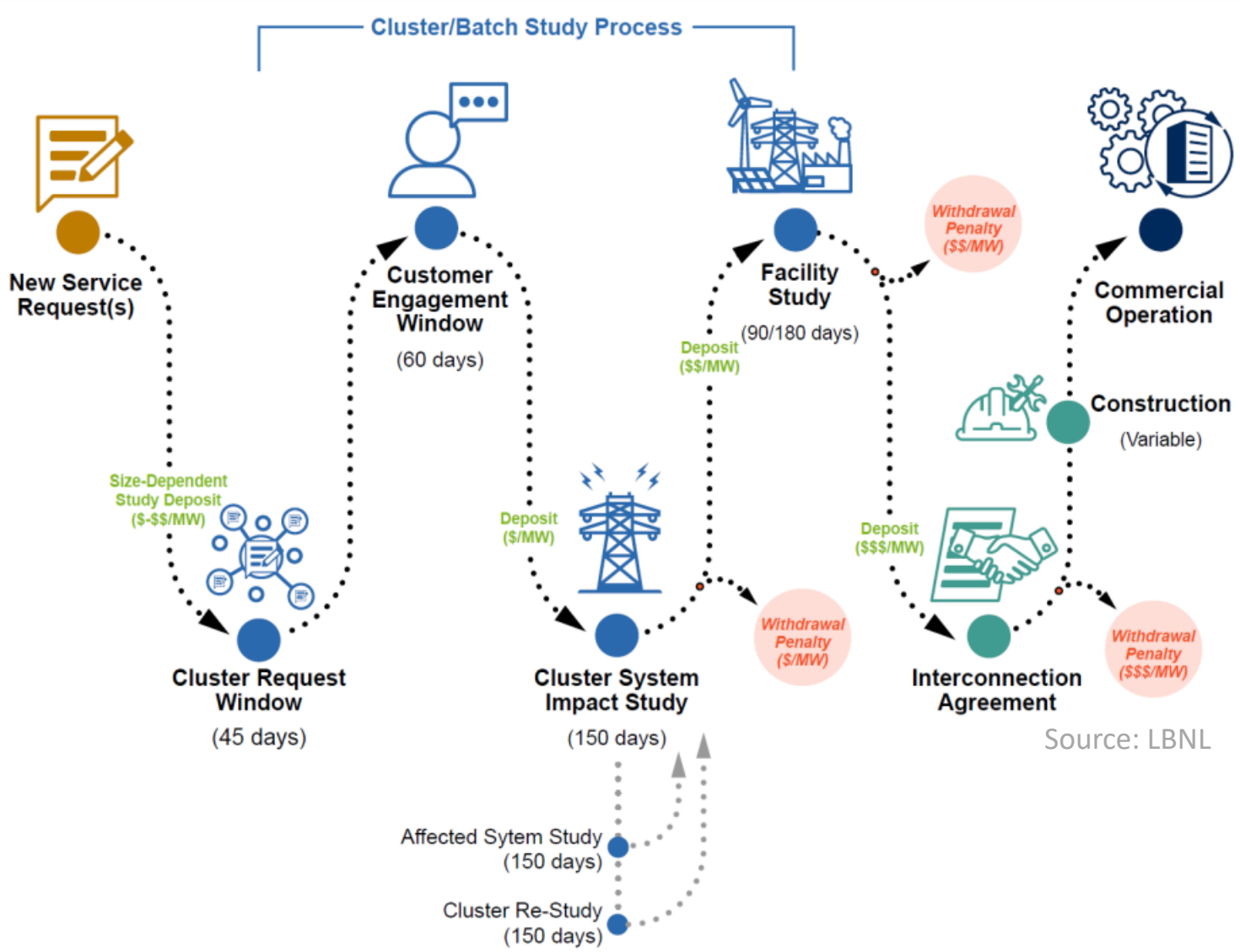
Recognizing process constraints are real



Source: LBNL

Recommended path forward

Interconnection request	Interconnection studies	GIA	Commissioning & Testing	COD
Harmonized performance requirements aligned with IEEE 2800 defined at start, including OEM expectations Modeling requirements tied to performance requirements Interconnection Customers and OEMs aligned contractually on meeting requirements	Modeling requirements harmonized (e.g., initial dynamic model submission standards, model quality checks, performance tests, etc.) Design changes are captured throughout studies and toward GIA Clear processes for screening and detailed EMT studies Model checks using a standardized practices and reporting	IFC design and selected equipment gets solidified, needs compared against studies IBR developer submits proof of benchmarked, verified models that pass performance tests Milestone-based requirements and clear re-study triggers are included in the agreement	Transmission providers deeply involved with IBR commissioning oversight Performance testing is standardized and aligned with IEEE 2800 Commissioning test data and site information collected and retained for effective use	Commissioning test data used for model verification and validation of as-left configuration and settings Comparison against as-studied models assessed and addressed, as needed Post-COD model verification/validation occurs quickly and effectively

Milestone-based model updates required to check alignment with IEEE 2800

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