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

# Forum for the Implementation of Reliability Standards for Transmission (i2X FIRST) | 6/25/24

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

BERKELEY LAB

ESIG

EPRI

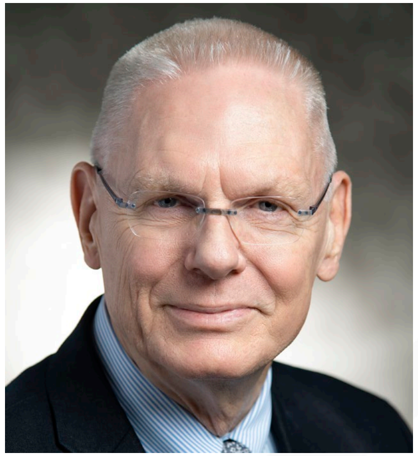
The first half of this meeting call is being recorded and may be posted on DOE's website or used internally.  If you do not wish to have your voice recorded, please do not speak during the call.  If you do not wish to have your image recorded, please turn off your camera or participate by phone.  If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

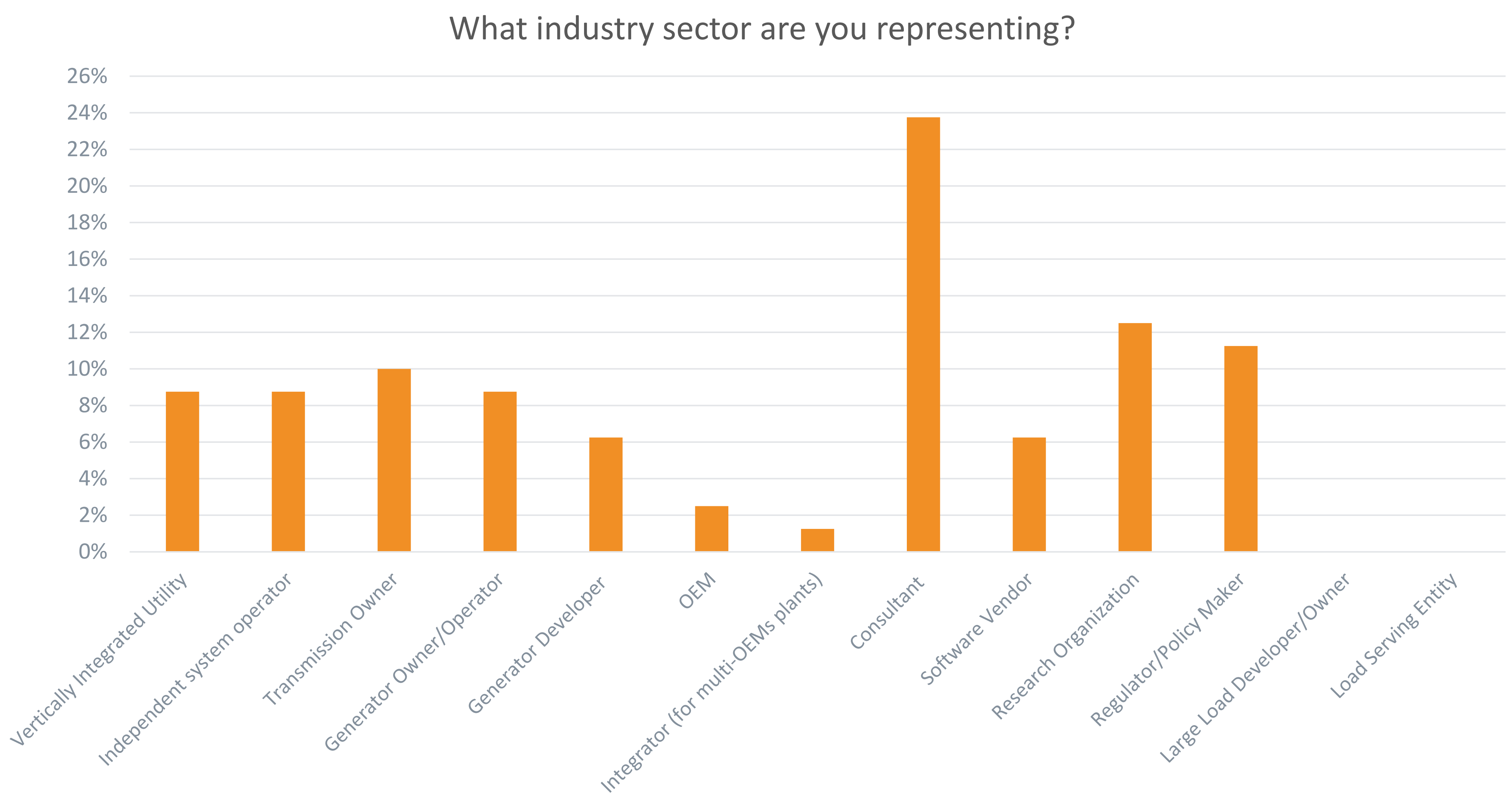
Julia Matevosyan, Energy Systems Integration Group

Ryan Quint, Elevate Energy Consulting

# Polling Question 1

## What industry sector are you representing?

[Go to **slido.com** and enter event code **i2xFIRST2**, then go to **Polls** tab]


What industry sector are you representing?
26%
24%
22%
20%
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
Vertically Integrated Utility
Independent system operator
Transmission Owner
Generator Owner/Operator
Generator Developer
OEM
Integrator (for multi-OEMs plants)
Consultant
Software Vendor
Research Organization
Regulator/Policy Maker
Large Load Developer/Owner
Load Serving Entity

# Summary of the last meeting

- Intro to i2X Roadmap – Cynthia Bothwell, BGS, contractor to DOE's WETO
- Intro to i2X FIRST – Julia Matevosyan, ESIG
- NERC Disturbance Events and Reliability Guidelines – Alex Shattuck, NERC
- IEEE 2800-2022 and Ongoing Adoption Efforts – Jens Boemer, EPRI
- IEEE P2800.2 Status Update – Andy Hoke, NREL
- FERC Order 901 and NERC Workplan – Alex Shattuck, NERC
- Interactive Group Discussion
  - Slow pace of improvement of interconnection requirements
  - Can interconnection requirements for IBRs be harmonized?
  - Role of regional interconnection requirements vs NERC Standards vs FERC Orders
- Meeting summary, recording & presentations are posted here (click on Past Events at the bottom of the page)

# Key Themes from the Last Meeting

- Transitioning the power system toward increasing levels of IBRs is an exciting engineering challenge.
- Besides the technical engineering challenges, there are significant knowledge transfer, people, and institutional challenges such as regulations, policies, training, and many other factors.
- Industry efforts need to anticipate future issues proactively and seek to address them early; this requires effective management of issues along the way, transparency and honesty, and fostering a collaborative learning environment.
- Technical standards play a major role in this process as they help inform and support the implementation of policy mandates, regulatory rulemaking, and stakeholder education. For that to be successful, alignment between level of the decision-making process is essential.
- Technical standard can streamline and expedite the interconnection process of IBRs if developed, adopted, and implemented appropriately and in a timely manner. This can help ensure a reliable and resilient grid and reduce interconnection queue backlog.
- This all requires a significant ***mindset shift*** related to the interconnection process that will necessitate an overhaul of process, practices, and technologies from multiple parties.

# Upcoming i2X FIRST Meetings

1. June 25th, 2024, 11 a.m.- 1 p.m. ET:
2. July 30th, 2024, 11 a.m.- 1 p.m. ET:
3. August 20th, 2024, 11 a.m.- 1 p.m. ET:
4. September 24th, 2024, 11 a.m.- 1 p.m. ET:
5. October 24th, 2024 hybrid full day event during ESIG Fall Workshop, Providence, RI: Conformity Assessment with Interconnection Requirements
6. November 26th, 2024, 11 a.m.- 1 p.m. ET:
7. December 17th, 2024, 11 a.m.- 1 p.m. ET:
8. January 28th 2025, 11 a.m.- 1 p.m. ET:
9. February 25th 2025
10. March 20th, 2025 hybrid full day event during ESIG Spring Workshop, Austin, Texas

**Sign up** for all future i2X FIRST Meetings here: https://www.zoomgov.com/meeting/register/vJItceuorTsiErIC-HInpPbWuTUtrYQAuoM#/registration

**Follow** DOE i2X FIRST website: https://www.energy.gov/eere/i2x/i2x-forum-implementation-reliability-standards-transmission-first for meeting materials & recordings and for future meeting details & agendas

# Ride-Through Requirements – Agenda

- Meeting Introduction (10 mins) – Julia Matevosyan, ESIG
- IEEE 2800-2022, Clause 7, Response to TS abnormal conditions (20 min) – Wes Baker, Silicon Ranch
- NERC PRC-029 Draft, Comparison with IEEE 2800-2022 (20 min) – Jens Boemer, EPRI

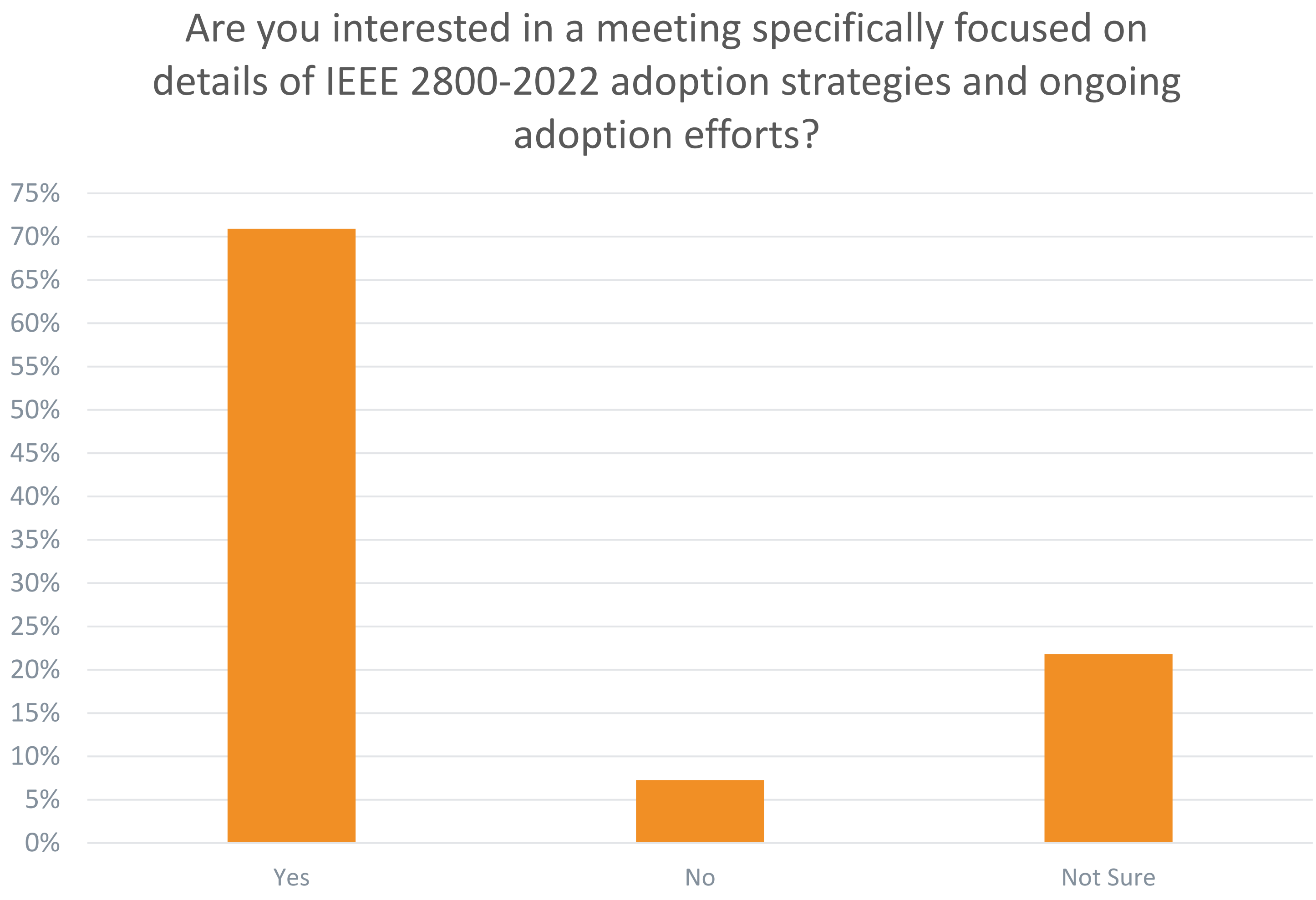
(this link is to the NERC Project 2020-02 ballot; the ballot closes at 8 p.m. Eastern, Monday, July 8, 2024)

- MISO IEEE 2800-2022 Adoption Efforts, Phase 1 (20 min) – Megan Pamperin, MISO
- Q&A (10 min)
- Interactive Group Discussion (40 min)
  - What are the BPS needs that drive Ride Through Requirements?
  - Conformity of IBR plants with new Ride Through Requirements
  - Adoption of IEEE 2800 Clause 7

# Polling Question 2:

## Are you interested in a meeting specifically focused on details of IEEE 2800-2022 adoption strategies and ongoing adoption efforts?

[Go to **slido.com** and enter event code **i2xFIRST2**, then go to **Polls** tab]


Are you interested in a meeting specifically focused on details of IEEE 2800-2022 adoption strategies and ongoing adoption efforts?
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Yes
No
Not Sure

# 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

# Q & A Session

# Interactive Group Discussion Topics

# Topic #1: What are the BPS Needs that Drive Ride-Through Requirements?

- Please go to slido to make comments and add questions of your own: **slido.com** and enter event code **i2xFIRST2**
- For verbal commentary, please use the raise hand feature and we will call on you
- Additional related / associated questions:
  - Do you understand why is there is specific need around IBR ride-through?
  - Are there existing ride through requirements beyond NERC PRC-024 that apply in your area?
  - Do you think these are sufficient to protect against IBR tripping causes as reported in NERC Disturbance Event Reports?
  - Do you see a need for more comprehensive ride through requirements with growing shares of IBR (e.g. as per IEEE 2800 Clause 7)?

*Discussion Best-Practices*

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*

# Topic #2: Conformity of IBR Plants with New Ride Through Requirements

- Please go to slido to make comments and add questions of your own: **slido.com** and enter event code **i2xFIRST2**
- For verbal commentary, please use the raise hand feature and we will call on you
- Additional related / associated questions:
  - Are all of the current IBR plants compatible with some or all new ride through requirements (e.g., per IEEE 2800-2022 Clause 7)? If not, which types are and which are not, and why not?
  - Do you see the need for such compatibility?
  - Do you see any barriers for future IBR plants (not yet in the interconnection queue) to comply with new ride through requirements (e.g., per IEEE 2800-2022 Clause 7)?
  - What is the current best way to get assurance from OEMs that they can meet IEEE 2800 Clause 7 (attestations, simulation results, etc.)?

*Discussion Best-Practices*

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*

# Topic #3: Adoption of IEEE 2800 Clause 7

- Please go to slido to make comments and add questions of your own: **slido.com** and enter event code **i2xFIRST2**

- For verbal commentary, please use the raise hand feature and we will call on you

- Additional related / associated questions:
  - What challenges do you foresee with adoption of the ride-through capability and performance curves in IEEE 2800-2022 Clause 7? Are there any roadblocks that could slow the effective adoption/implementation?
  - Should transmission providers be establishing ride-through requirements beyond IEEE 2800 Clause 7? If so, why? If not, why not?
  - What questions do you have about the technical details or possible adoptions paths of IEEE 2800 Clause 7?

*Discussion Best-Practices*

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*

# Polling Question 3

Post any remaining questions related to Ride-Through Requirements that were not addressed in this meeting?

[Go to **slido.com** and enter event code **i2xFIRST2**, then go to **Polls** tab]

# High-Level Comparison of Ride-through Requirements in Draft PRC-029 and IEEE 2800-2022

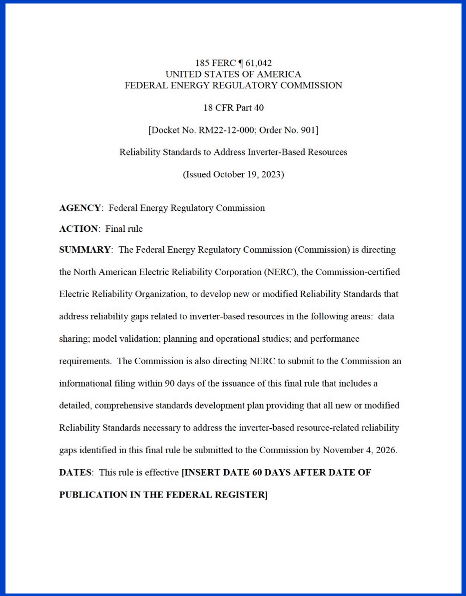
## i2X Forum for the Implementation of Reliability Standards for Transmission (i2X FIRST)

**Bulk System Integration of Renewables and Distributed Energy Resources & Transmission Planning**
Manish Patel, Jens Boemer, Nazila Rajaei, Aboutaleb Haddadi, Anish Gaikwad, Aidan Tuohy

*(inquires to ManPatel@epri.com and jboemer@epri.com)*

June 25, 2024

**Classification:** Public


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)

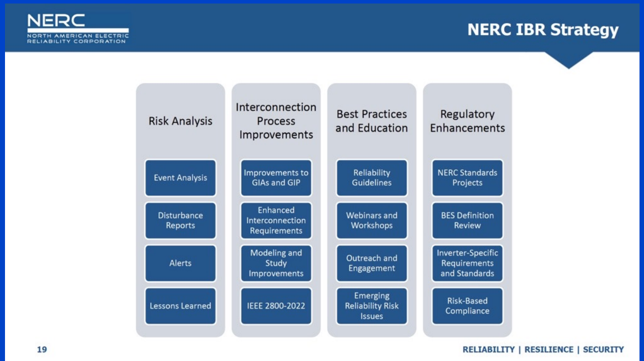
**AGENCY**: Federal Energy Regulatory Commission

**ACTION**: Final rule

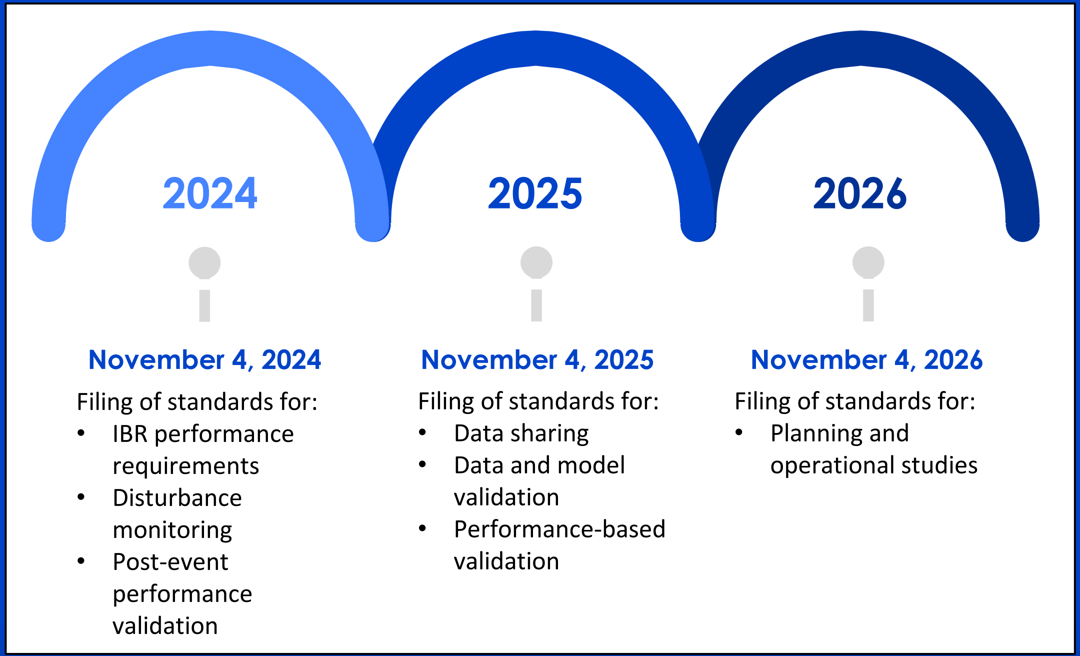
**SUMMARY**: The Federal Energy Regulatory Commission (Commission) is directing the North American Electric Reliability Corporation (NERC), the Commission-certified Electric Reliability Organization, to develop new or modified Reliability Standards that address reliability gaps related to inverter-based 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



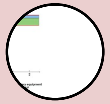
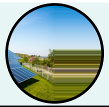
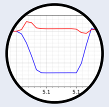

NERC IBR Webinar Series
https://www.nerc.com/comm/RSTC/Pages/IRPS.aspx

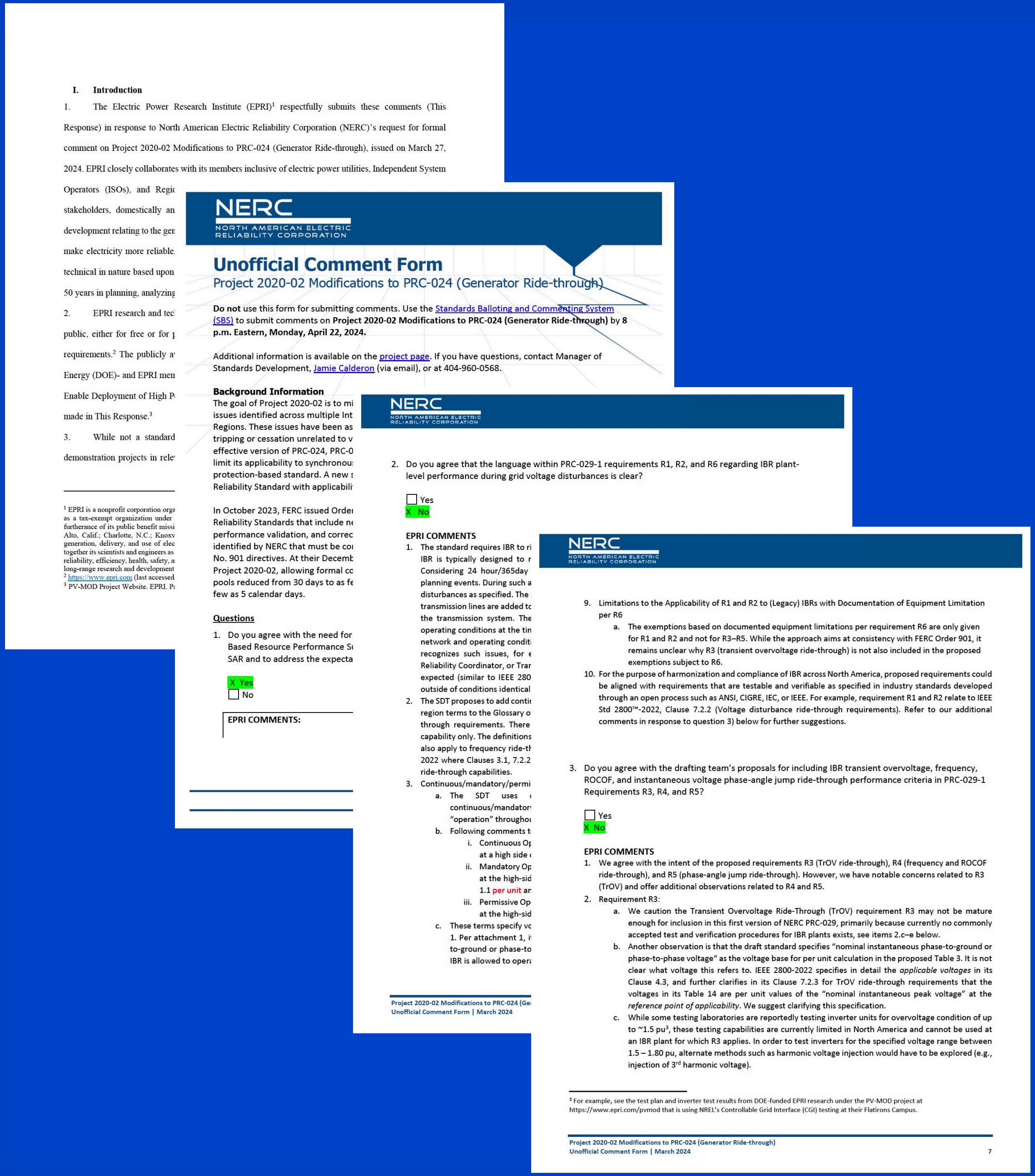



# FERC Order 901 Reliability Standards to Address Inverter-Based Resources (RM22-12)

- 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.**

# NERC Reliability Standards Affected by FERC Order 901

| Standard Family / Number | Standard Title | Purpose | Milestone |
|---|---|---|---|
| **Protection and Control (PRC)** | | | |
|  PRC-002-5 | Disturbance Monitoring and Reporting Requirements | To have adequate data available to facilitate analysis of Bulk Electric System (BES) Disturbances. | 2 |
| PRC-024-3 | Frequency and Voltage Protection Settings for Synchronous Generators and Synchronous Condensers | To set protection such that generating resource(s) remain connected during defined frequency and voltage excursions in support of the BES. | 2 |
| PRC-028 | Disturbance Monitoring and Reporting Requirements for Inverter-Based Resources | To set requirements for disturbance monitoring and reporting of inverter-based resources | 3 |
| ***Focus*** PRC-029 | Frequency and Voltage Ride-through Requirements for Inverter-Based Generating Resources | To ensure that Inverter-Based Resources (IBRs) remain connected and perform operationally as expected to support of the Bulk Power System (BPS) during and after defined frequency and voltage excursions. | 2 |
| PRC-030 | Unexpected Inverter-Based Resource Event Mitigation | To ensure that analysis is conducted by GOs for potential abnormal performance events | 2 |
| PRC-019-3 | Coordination of Generating Unit or Plant Capabilities, Voltage Regulating Controls, and Protection | To verify coordination of generating unit Facility or synchronous condenser voltage regulating controls, limit functions, equipment capabilities and Protection System settings. | 3 |
| **Facilities Design, Connections, and Maintenance** | | | |
|  FAC-001-4 | **Facility Interconnection Requirements** | To avoid adverse impacts on the reliability of the Bulk Electric System, TOs and applicable GOs must document and make facility interconnection requirements available so that entities seeking to interconnect will have the necessary information. | 3 |
| FAC-002-4 | **Facility Interconnection Studies** | To study the impact of interconnecting new or changed facilities on the Bulk Electric System | 3 |
| **Modeling, Data, and Analysis** | | | |
|  MOD-032-12 | **Data for Power System Modeling and Analysis** | To establish consistent modeling data requirements and reporting procedures for development of planning horizon cases necessary to support analysis of the reliability of the interconnected transmission system. | 3,4 |
| MOD-031-3 | **Demand and Energy Data** | To provide authority for applicable entities to collect demand, energy and related data to support reliability studies and assessments and to enumerate the responsibilities and obligations of requestors and respondents of that data. | 3 |
| MOD-025-2 | **Verification and Data Reporting of Generator Real and Reactive Power Capability and Synchronous Condenser Reactive Power Capability** | To ensure that accurate information on generator gross and net Real and Reactive Power capability and synchronous condenser Reactive Power capability is available for planning models used to assess BES reliability. | 3 |
| MOD-026-1 | **Verification of Models and Data for Generator Excitation Control System or Plant Volt/Var Control Functions** | To verify that the generator excitation control system or plant volt/var control function model (including the power system stabilizer model and the impedance compensator model) and the model parameters used in dynamic simulations accurately represent the generator excitation control system or plant volt/var control function behavior when assessing BES reliability | 3 |
| MOD-027-1 | **Verification of Models and Data for Turbine/Governor and Load Control or Active Power/Frequency Control Functions** | To verify that the turbine/governor and load control or active power/frequency control model and the model parameters, used in dynamic simulations that assess BES reliability, accurately represent generator unit real power response to system frequency variations. | 3 |
| MOD-033-2 | **Steady-State and Dynamic System Model Validation** | To establish consistent validation requirements to facilitate the collection of accurate data and building of planning models to analyze the reliability of the interconnected transmission system. | 3 |
| **Transmission Planning** | | | |
| TPL-001-5.1 | **Transmission System Planning Performance Requirements** | Establish Transmission system planning performance requirements within the planning horizon to develop a BES that will operate reliably over a broad spectrum of System conditions and following a wide range of probable Contingencies. | 4 |
| TOP-003-6.1 | **Transmission Operator and Balancing Authority Data and Information Specification and Collection** | To ensure that each Transmission Operator and Balancing Authority has the data and information it needs to plan, monitor, and assess the operation of its Transmission Operator Area or Balancing Authority Area | 3 |
| **Interconnection Reliability Operations and Coordination** | | | |
| IRO-010-5 | Reliability Coordinator Data and information Specification and Collection | To prevent instability, uncontrolled separation, or Cascading outages that adversely impact reliability, by ensuring each Reliability Coordinator has the data and information it needs to plan, monitor and assess the operation of its Reliability Coordinator Area. | 3 |



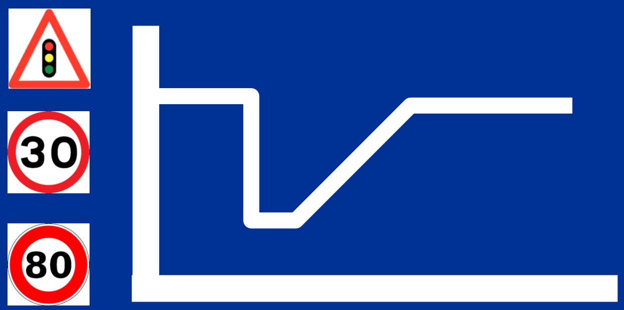

# EPRI Comments on Draft PRC-029 (IBR Ride-through) Reliability Standard

- Submitted via NERC's Commenting Tool on April 22, 2024
- EPRI research supports the need for creating reliability standards for bulk power system connected inverter-based resources ride-through capability and performance requirements:
  - *A Fundamental Evaluation of the Interactions Between Different Loads and Different Inverter Based Resources Control/Technology Types. Stability and Voltage Support Issues Driven by Current Limits of IBRs.* EPRI. Palo Alto, CA: 2022. 3002024270.
  - *Impact of Inverter-Based Resources on Protection Schemes Based on Negative Sequence Components.* EPRI. Palo Alto, CA: 2019. 3002016197.
  - *Impact of Variable Generation on Voltage and Frequency Performance of the Bulk System. Case Studies and Lessons Learned.* Technical Update. EPRI. Palo Alto, CA: 2014. 3002003685.

➢ **7-pages of detailed technical comments**

# New Draft of PRC-029 Now Includes Capability-based Requirements

## Performance-based Requirements




- define a specific **reliability objective** or outcome
- achieved by one or more **entities**
- can be measured using **power system data or trends**
- has four components: ***who***, under what conditions, shall perform ***what action***, to achieve what particular result or outcome.

## Risk-based Requirements

- define **actions**
- by one or more **entities**
- can be measured by **evaluating a particular product** or outcome
- framed as: ***who***, under what conditions, shall perform ***what action***, to achieve what particular result or outcome

## Capability-based Requirements

- define **capabilities**
- needed by one or more **entities to perform** reliability functions
- **can be measured** by demonstrating that the capability exists
- framed as: ***who***, under what conditions, shall have ***what capability***, to achieve what particular result or outcome to perform

Source: NERC Rules of Procedure. Effective November 28, 2023. Section 2.4.

| PRC-029 Requirement/Clause | Missing, Insufficient, or Questionable Requirements and Possible Remedies |
| --- | --- |
| **Applicability of Requirements**<br>**Glossary of Terms/IBR Ride-Through/Introduction—Purpose Statement** | • Specification of grid conditions for which ride-through requirements apply (IEEE 2800-2022, Clause 4.1.1) is not included in draft PRC-029.<br>• Exceptions could be permitted if IBRs fail to ride through outside of specified abnormal conditions, or after significant changes in the transmission network |
| **Ride-through Definition**<br>**Glossary of Terms** | • Draft PRC-029: Remaining connected, synchronized with the Transmission System , and continuing to operate in response to System conditions through the time-frame of a System Disturbance.<br>• IEEE 2800-2022: Ability to withstand voltage or frequency disturbances inside defined limits and to continue operating as specified. |
| **Voltage Ride Through Capability (Continuous Operation Region)** | • IEEE 2800-2022 allows for an exception for "self-protection" when negative-sequence voltage is greater than specified duration and threshold.<br>• There is no such exception in draft PRC-029.<br>• Such an exception may be required for type III WTG based plants |
| **Voltage Ride Through Capability (Continuous Operation Region)** | • For V > 1.05 and ≤ 1.10, a ride-through duration of 1800 seconds is specified in both IEEE 2800 and draft PRC-029. The IEEE 2800-2022 specifies that this ride-through duration is cumulative over a 3600 second time period. Draft PRC-029 remains silent regarding applicable cumulative time-period.<br>• Additionally, the ride-through duration for this voltage range for system nominal voltage of 500 kV shall be infinite (and not limited to 1800 second). This is clearly noted in IEEE 2800-2022. Draft PRC-029 remains silent on this. |
| **Voltage Ride-Through Capability (Mandatory Operation Region)** | • IEEE 2800-2022 includes following exception: For a voltage disturbance that reduces the applicable voltage at the RPA to less than 50% of nominal, the IBR plant shall be considered compliant with this standard if the post-disturbance apparent current of the IBR plant is not less than 90% of the pre-disturbance apparent current.<br>• There is no such exception on in draft PRC-029 |
| **Voltage Ride Through Capability (Permissive Operation Region)** | • IEEE 2800-2022 allows permissive operation when applicable voltage (phase-to-phase or phase-to-ground) is below 10% at the RPA (POM or high-side terminals of the main power transformer).<br>• Draft PRC-029 allows permissive operation when positive-sequence voltage is below 10% at the high-side terminals of the main power transformer). |

➢ **Adopt Language that Recognizes Issues or Use Language Similar to IEEE 2800-2022**

| PRC-029 Requirement/Clause | Internal Inconsistencies and Possible Remedies |
| --- | --- |
| **Consistency in Terminology**<br>**Entire Standard** | • There may be some unintentional inconsistency in various terminology within draft PRC-029 and compared to same in IEEE 2800-2022.<br>• Use consistent terminology to avoid any unintentional conflicts. |
| **Voltage Ride-Through Performance** | • For voltage ride-through, some performance requirement for continuous/mandatory/permissive operation regions is included in draft PRC-029. These seems to align well with requirements in IEEE 2800-2022. But more thorough review is necessary once a draft PRC-029 is posted for another round of balloting.<br>• However, the draft PRC-029 does not specify any performance requirements when frequency is within continuous or mandatory operation region. This approach is acceptable as industry could adopt performance requirements from the IEEE 2800-2022. Perhaps the PRC-029 SDT could take same approach and remain silent on performance requirements for voltage ride-through.<br>• The performance requirements, for both voltage and frequency ride-through, then could be specified by TP, PC, etc. |

➢ **Adopt Language that Recognizes Issues or Refer to IEEE 2800-2022**

| PRC-029 Requirement/Clause | Possible Conflicts with IEEE 2800 |
|---|---|
| General Thoughts | • Avoid any unintentional conflicts by aligning terminology in draft PRC-029 and IEEE 2800-2022. |
| **Frequency Ride Through (Capability)**<br>**Requirement R4 and Attachment 3** | • The draft PRC-029 goes over and beyond frequency ride-through capability requirements specified in IEEE 2800-2022.<br>• More stringent frequency ride-through and performance requirements.<br>• Lack of exception for the Volts/Hz limit, potentially problematic for Type III Wind Turbine Generators & transformers<br>• More stringent 15-minute time period for the cumulative specifications of frequency ride-through. |

## General thoughts:

- Inclusion of capability-based requirements in new draft PRC-029 is a significant alignment with IEEE 2800; compliance could require "design evaluations" prior to IBR plant commercial operation date.
- Only a high-level comparison is presented. More thorough comparison to be done when next round of ballot opens.
- Hoping that some inconsistencies due to use of wording will resolve over time during the development.
- Requirements in IEEE 2800 but not in draft PRC-029 is not the focus here.

**➢Adopt Language that Aligns with, or Refers to IEEE 2800-2022**

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# Overview of IEEE 2800-2022 Clause 7 “Response to TS abnormal conditions”

Wes Baker, PhD, PE

Sr. Principal Engineer, Modeling and Dynamic Studies

Silicon Ranch

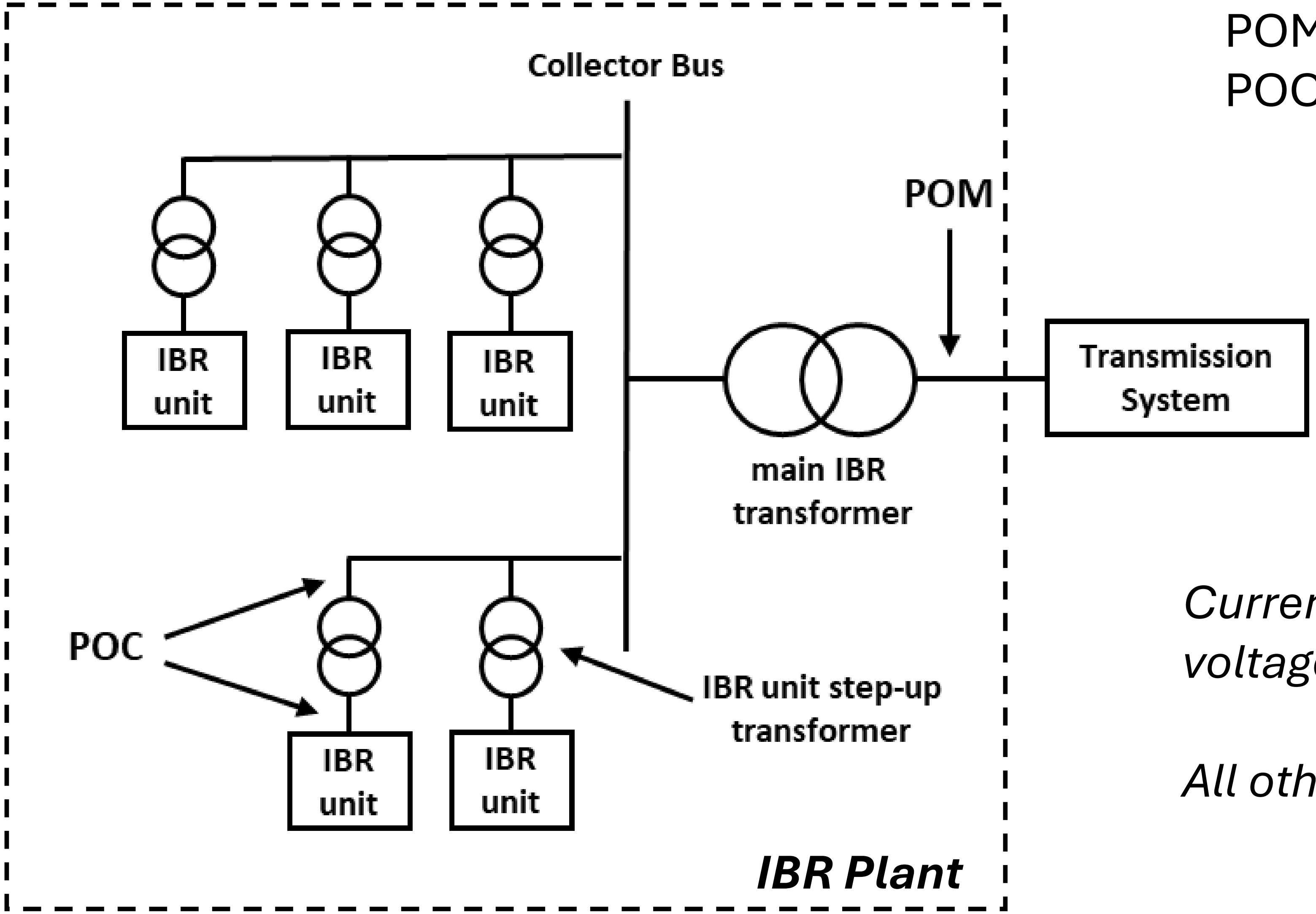
i2X Forum for the Implementation of Reliability Standards for Transmission

6/25/2024

# Clause 7: Response to TS abnormal conditions

- Voltage ride-through
  - What voltage magnitude / time durations does the IBR have to ride-through?
  - How is the IBR required to respond during voltage ride-through?
  - How is the IBR required to respond post voltage ride-through?
- Frequency ride-through
  - What frequency magnitude / time durations does the IBR have to ride-through?
  - How is the IBR required to respond during frequency ride-through?

# Reference Point of Applicability (RPA)




POM → Point of Measurement
POC → Point of Connection

*Current injection during abnormal voltage requirements apply at POC*

*All other requirements apply at POM*

# Voltage ride-through requirements

| Applicable voltage (pu) at RPA (Default: POM) | Operating mode/response | Min. ride-through time (s) (w/ aux. limits) Ref. Table 11 | Min. ride-through time (s) (w/ out aux. limits) Ref. Table 12 |
|---|---|---|---|
| V > 1.20 | May ride-through or may trip | NA | NA |
| V > 1.10 | Mandatory | 1.0 | 1.0 |
| V > 1.05 | Continuous | 1800 | 1800 |
| V < 0.90 | Mandatory | 3.0 | 6.0 |
| V < 0.70 | Mandatory | 2.5 | 3.0 |
| V < 0.50 | Mandatory | 1.2 | 1.2 |
| V < 0.25 | Mandatory | 0.16 | 0.32 |
| V < 0.10 | Permissive | 0.16 | 0.32 |

- Applicable voltage: fundamental frequency phasor of line-to-line or line-ground
- Table 11. IBRs with auxiliary limits (e.g., WTG – see footnote 89)
- Table 12. IBRs without auxiliary limits (e.g., PV, ESS – see note 3)
- Interpretation: Voltage versus time (See Appendix D1)
- Cumulative over 10-s moving window (3600-s for $1.05 < V_{RPA} \leq 1.10$pu)
- 500 kV: the Continuous Operation – Infinite time region extends to 1.10 pu. (see Note 1)

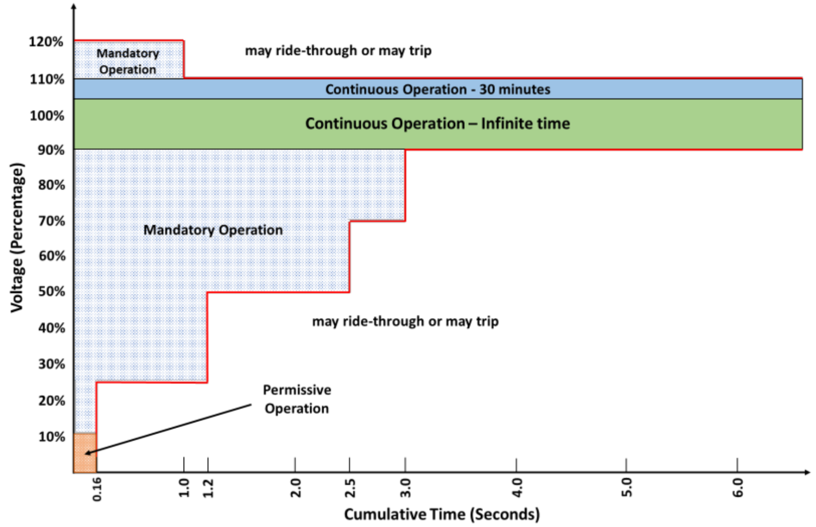



**Figure D.5—Voltage ride-through requirements for *IBR plants* with auxiliary equipment limitations interconnecting at any nominal voltage except for 500 kV**

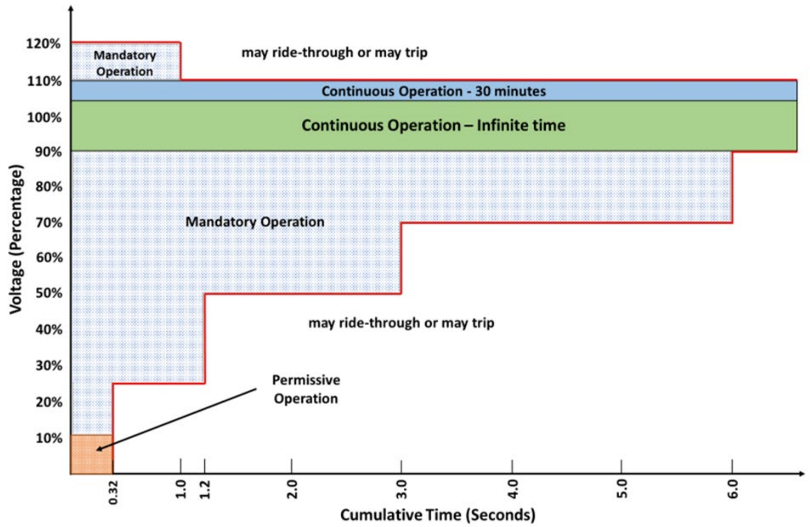



**Figure D.7—Voltage ride-through requirements for *IBR plants* without auxiliary equipment limitations interconnecting at any nominal voltage except for 500 kV**

# Voltage ride-through requirements

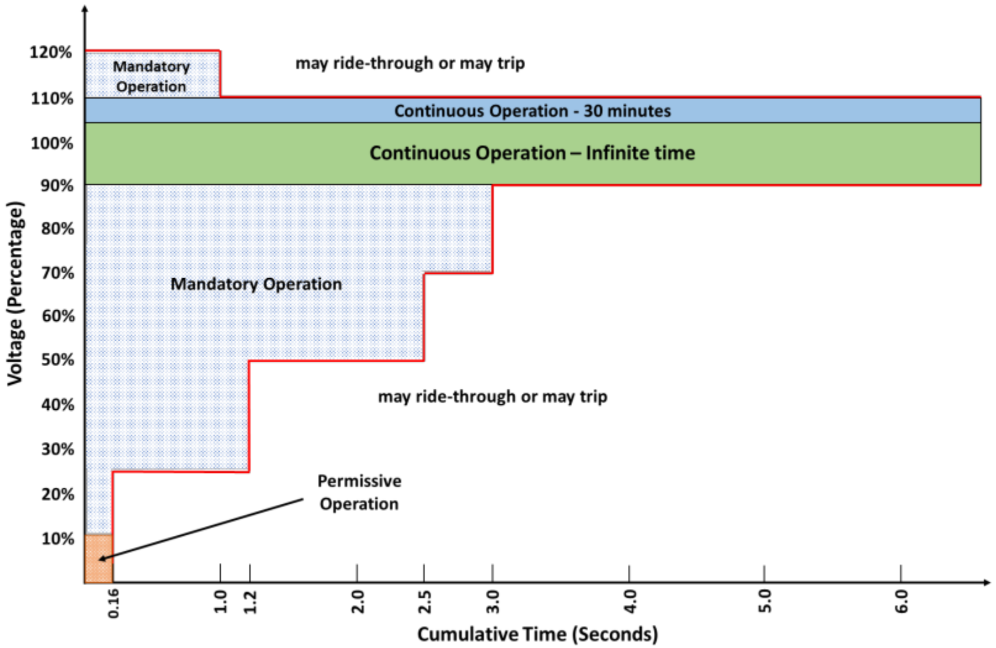



Figure D.5—Voltage ride-through requirements for *IBR plants* with auxiliary equipment limitations interconnecting at any nominal voltage except for 500 kV

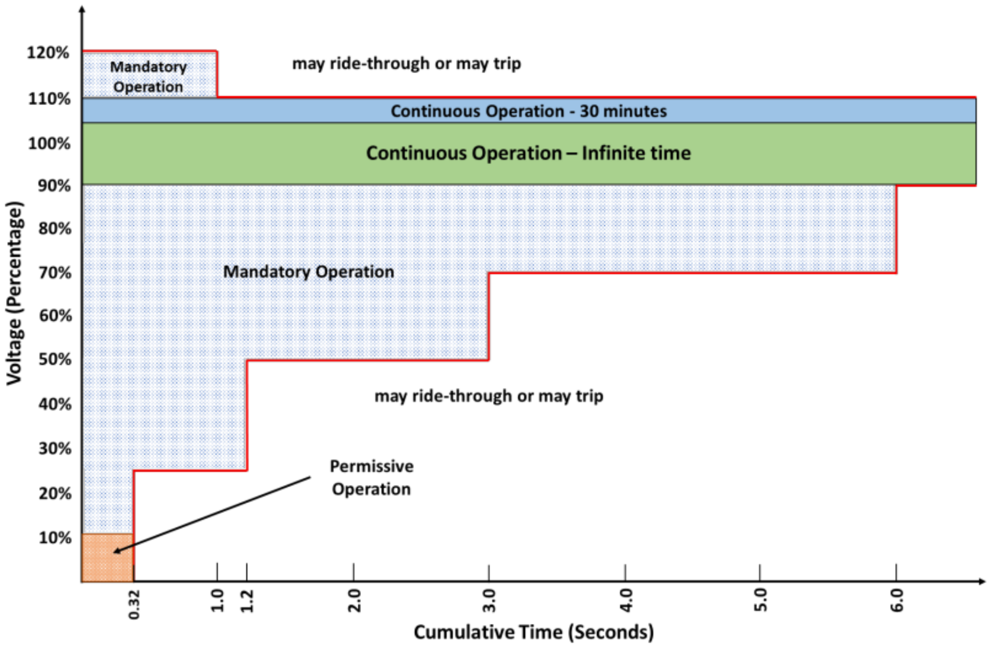



Figure D.7—Voltage ride-through requirements for *IBR plants* without auxiliary equipment limitations interconnecting at any nominal voltage except for 500 kV

Operating Modes (see Clause 3.1 for formal definitions)

- **Continuous operation**: Continued exchange of current between IBR and TS as prescribed. (Normal operation)
- **Mandatory operation**: Continued exchange of active and reactive current between IBR and TS as prescribed.
- **Permissive operation**: Mandatory operation **OR** current blocking[1]

[1]Restart current injection ≤ 5 cycles of RPA voltage returning to Mandatory or Continuous Operating Region

# Low- and high-voltage ride-through within the <u>mandatory operation region</u> (7.2.2.3)

- IBR unit capable of:
  - Selecting active current priority or reactive current priority for high or low voltage ride-through. Default: reactive current priority.
  - Separately setting the required level of reactive current injection for low and during high-voltage ride-through modes of operation. E.g., capability to set ‘K-factor’ differently for HVRT from LVRT.
  - Inject current to its maximum limit
- The plant controller shall not inhibit or prevent the IBR units and any supplemental IBR devices to meet the ride-through performance requirements.

# Current injection during ride-through mode (7.2.2.3.4)

- RPA: POC
- When POM voltage is outside of the continuous operating region (i.e., ride-through mode of operation), IBR unit:
  - Maintain automatic voltage control (K-factor allowed but not required – See footnotes 98 &100)
  - Current injection (type and magnitude) shall be dependent on the voltage deviation at the POC.
    - Positive sequence voltage ($V_1$) for balanced faults
    - Negative sequence voltage ($V_2$) for unbalanced faults
  - Current injection shall be at the fundamental frequency of the POC voltage
    - Exceptions for off nominal frequency during transients, PLL tracking during severe faults, and Type III WTG when crowbarred or when rotor current is lost

# Current injection during ride-through mode (7.2.2.3.4)

**Balanced faults**

- Inject incremental positive sequence reactive current ($\Delta$IR1) dependent on POC voltage
- $\Delta$IR1: difference between fault and pre-fault reactive current output
- $\Delta$IR1 shall not be negative
- Priority shall be given to reactive current with <u>any residual capacity being supplied as active current</u> (Unless TS owner specifies active current priority)

**Unbalanced faults**

- In addition to $\Delta$IR1, inject negative sequence current:
  - Dependent on POC negative sequence voltage ($V_2$)
  - Leads POC $V_2$ by 90-100° for full converters (90-150° for Type III WTG).
- $\Delta$IR2: incremental negative sequence reactive current
- If the IBR unit's current limit is reached:
  - Either $\Delta$IR1, $\Delta$IR2 or both can be reduced with a <u>preference of equal reduction in $\Delta$IR1 and $\Delta$IR2</u>
  - $\Delta$IR1 shall not be reduced below $\Delta$IR2
  - Type III WTG: acknowledges this is driven by the machine parameters and control dynamics and may not be controllable in this manner

# Current injection during ride-through mode (7.2.2.3.4)

**Incremental current injection**

- This standard intentionally does not specify magnitude of incremental positive and negative sequence reactive current injection during a fault condition.

**IBR unit minimum capability**:

- Prioritize active or reactive current equal to its maximum current rating when the POC voltage ≤ 0.5 pu
- Absorbing reactive current of 30% of its maximum current rating when the POC voltage ≥ 1.15 pu.
- Injecting negative-sequence reactive current of 50% of its maximum current rating when the POC negative sequence voltage ≥ 0.25 pu. Applicable to full converter-based IBR units.

# Performance specifications (7.2.2.3.5)

- Applicable to both balanced and unbalanced faults
- Current components (active and reactive, positive and negative sequence) calculated via a DFT with one-cycle moving window

**Table 13—Voltage ride-through performance requirements**

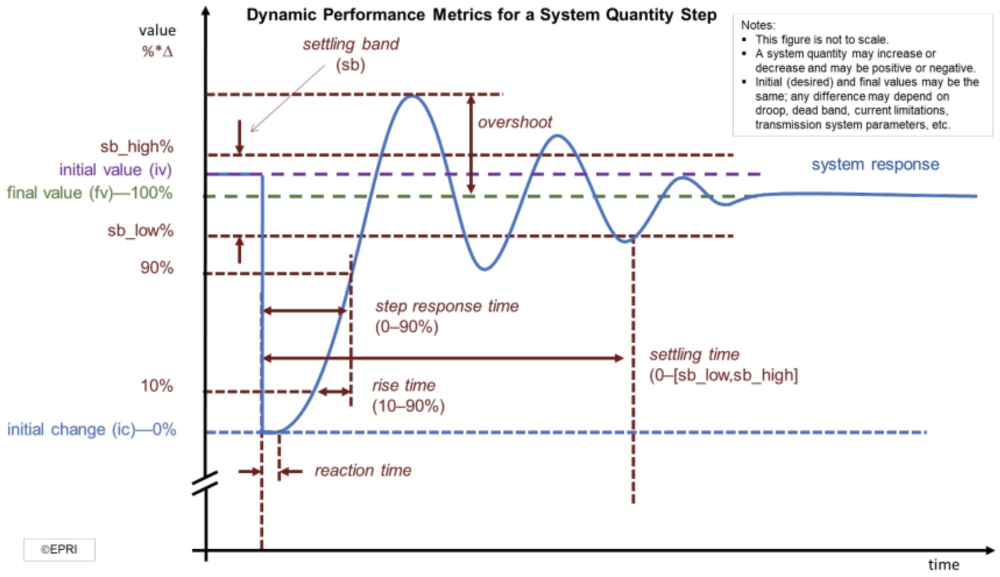
| Parameter | Type III WTGs | All other IBR units |
|---|---|---|
| *Step response time*[b, c, d] | NA[a] | ≤ 2.5 cycles |
| *Settling time*[b, c, d] | ≤ 6 cycles | ≤ 4 cycles |
| *Settling band* | −2.5%/+10% of *IBR unit maximum current* | −2.5%/+10% of *IBR unit maximum current* |

[a] The initial response from the type III WTG is driven by machine characteristics and not the control system. DC component, if present, has an impact on response, which is driven by machine parameters and time of fault occurrence. Even though the control system takes an action, it cannot control machine's natural response. As such, defining response time for type III WTGs is not necessary.

[b] System conditions may require a slower response time, or *IBR units* may not be able to meet response times noted in this table for certain system conditions. If so, greater response time and *settling time* are allowed with mutual agreement between an *IBR owner* and the *TS owner*.

[c] The DFT with a one-cycle moving average window is used to derive phasor quantities such as active, reactive, positive-sequence, negative-sequence currents, etc. The time delay required for the DFT measurements is included in the *step response time* and *settling time* specified in this table.

[d] The specified *step response time* and *settling time* applies to both 50 Hz and 60 Hz systems.




(b) Dynamic performance metrics for a system quantity step (e.g., voltage regulation, power factor regulation)

*Figure 5 reprinted with permission from the Electric Power Research Institute (EPRI), © 2020.*

**Figure 5—Step response characteristics and defined terms**

# Consecutive voltage ride through ride-through (7.2.2.4)

- Primarily to ensure IBR plant rides through reasonable tripping and reclosing sequences on for faults on the TS
- Other examples may be separate faults due to storm or voltage oscillations causing POM voltage to cycle in and out of Continuous operating region

# Restore output after voltage ride-through (7.2.2.6)

- Applicable when the POM voltage returns to continuous operating region (from mandatory or permissive)
- IBR plant: Restore active power output to 100% of pre-disturbance level at an average rate of:

$$\frac{100\%\ ICR}{active\ power\ recovery\ time}$$

- Active power recovery time is configurable in a range from 1 to 10s. Therefore,
  - **Average $dp(t)/dt$ is configurable in the range: 0.1xICR/sec to 1.0xICR/sec**
- Tolerance: > of +/-0.2 s or +/-10% of configured active power recovery time
- Exceptions listed based on available active power
- When the POM voltage returns to continuous operating region, the IBR units shall cease injection of $\Delta$IR1 and $\Delta$IR2 per the response requirements in Table 13
- *"**IBR continuous rating (ICR):** The steady-state, <u>continuous active power rating</u> of an inverter-based resource (IBR) plant or hybrid IBR plant registered by the IBR owner at the transmission system (TS) operator's or authority governing interconnection requirements (AGIR)'s registry" (Clause 3)*

# Transient overvoltage ride-through requirements (7.2.3)

- Intent: ensure that the IBR plant does not trip during switching events in the TS.
- RPA: POM
- The IBR plant shall ride-through transient overvoltage that
  - fundamental frequency voltage components do not exceed overvoltage ride-through requirements in 7.2.2.1
  - greater of instantaneous phase-to-phase or phase-to-ground voltage magnitudes do not exceed the cumulative durations specified in Table 14.

**If current blocking used:** restart current exchange ≤ 5 cycles following instantaneous voltage falling below, and remaining below, 1.2 p.u.

**Table 14—Transient overvoltage ride-through requirements at the RPA**

| Voltage[c] (p.u.) at the RPA | Minimum ride-through time (ms)[d] (design criteria)[b] |
|---|---|
| V > 1.80 | See footnote[a] |
| V > 1.70 | 0.2 |
| V > 1.60 | 1.0 |
| V > 1.40 | 3.0 |
| V > 1.20 | 15.0 |

[a] Appropriate surge protection shall be applied at the RPA as well as within the *IBR plant*, including *IBR unit* terminals (POC), as necessary.
[b] The minimum ride-through times specified in Table 14 apply to both 50 Hz and 60 Hz systems.
[c] Specified voltage magnitudes are the residual voltages with surge arresters applied
[d] Cumulative time over a 1-min time window.

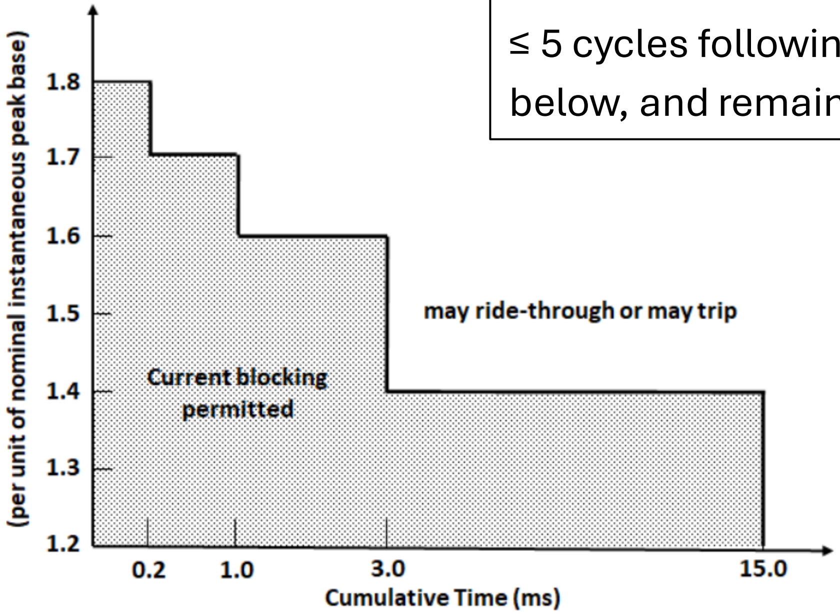
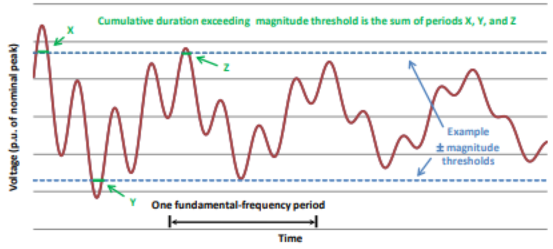



Figure 11—Transient overvoltage ride-through requirements for *IBR plant* (informative)

[110] Cumulative duration is illustrated as follows:



# Frequency (7.3)

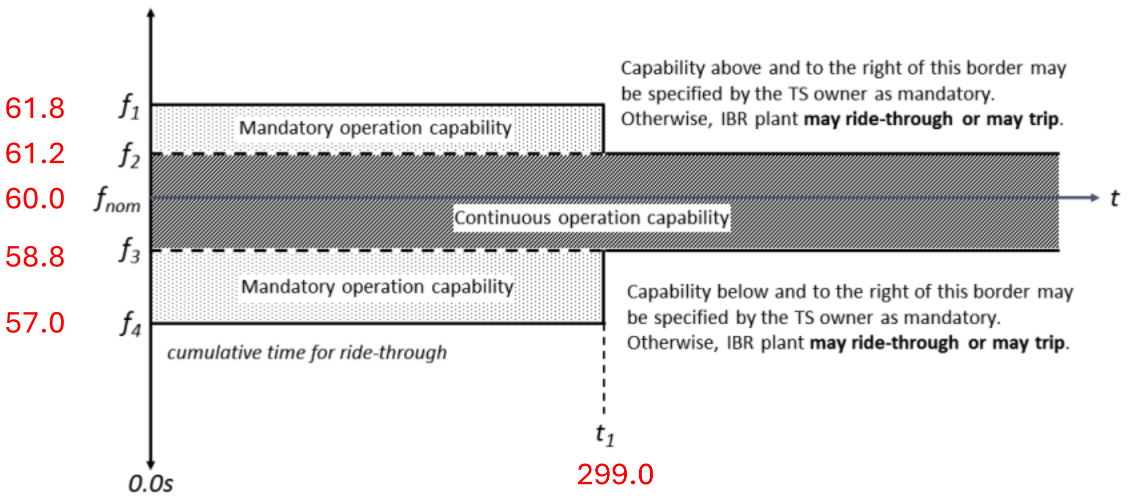



**Figure 12—Frequency ride-through capability requirements for *IBR plant***

**Table 15—Frequency ride-through capability for an *IBR plant* (see Figure 12)**

| Frequency range (Hz) | Percent from $f_{nom}$ | Minimum time (s) (design criteria) | Operation |
|---|---|---|---|
| $f_1$, $f_4$ | +3, −5 | 299.0 ($t_1$) | Mandatory operation |
| $f_2$, $f_3$ | +2, −2 | ∞ | Continuous operation |

- Cumulative over a 10-minute period
- While within the V/Hz capability of the IBR plant equipment

**Continuous operation**

- IBR plant shall exchange active and reactive power with the TS within its IBR continuous rating (ICR)
- the IBR plant shall operate in accordance with PFR and/or FFR[1] control requirements as applicable.

**Mandatory operation**

- Maintain synchronism with TS and continue to exchange current with the TS
- Modulate active power as specified in 6.1 (PFR) and 6.2 (FFR[1])

[1]FFR capability is only required for under-frequency conditions (see Clause 6.2)

# Rate of change of frequency (ROCOF) Ride-through (7.3.2.3.5)

- IBR plant shall ride through for frequency excursions with a ROCOF ≤ 5 Hz/s while the frequency is in the mandatory or continuous operating region.
- ROCOF is the average rate of change of frequency over an averaging window of at least 0.1 s. (Clause 4.3)

# Voltage phase angle change ride through (7.3.2.4)

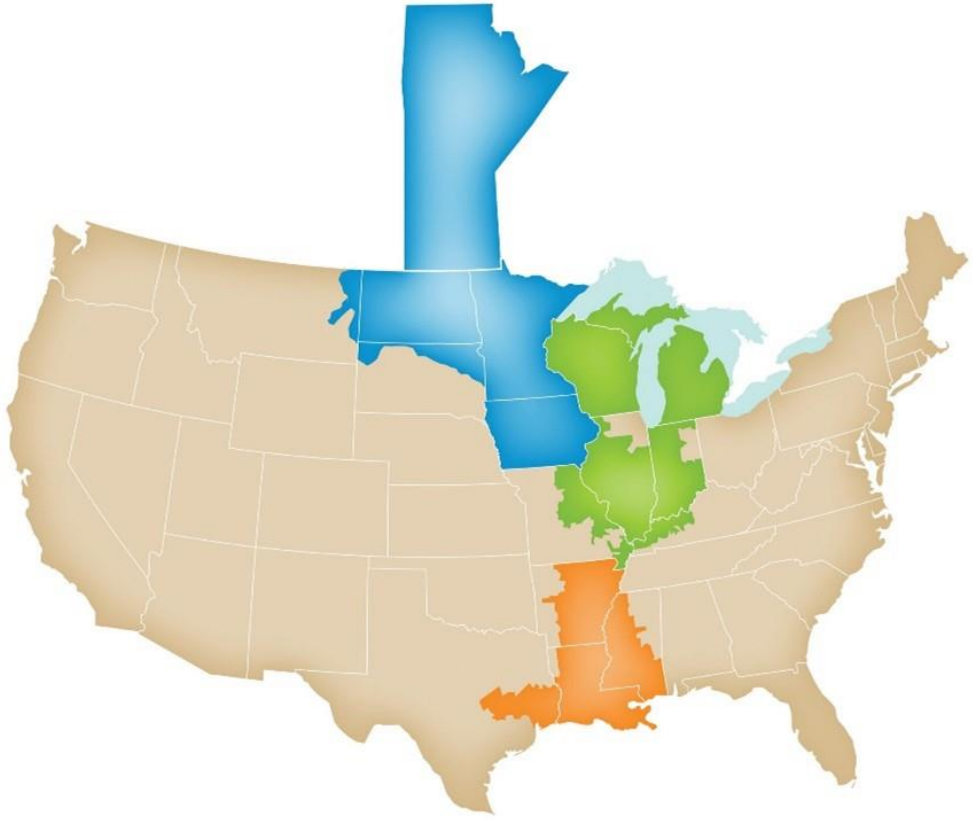
- IBR plant shall ride through positive sequence phase angle changes within a sub-cycle-to-cycle time frame of ≤ 25 deg.
- IBR plant shall ride through phase angle changes of individual phases as long as the positive sequence phase angle change ≤ 25 deg.
- Active and reactive current oscillations in the post-disturbance period that are positively damped are OK.

# Inverter-Based Resource Performance Requirements at MISO

i2X First

June 25, 2024

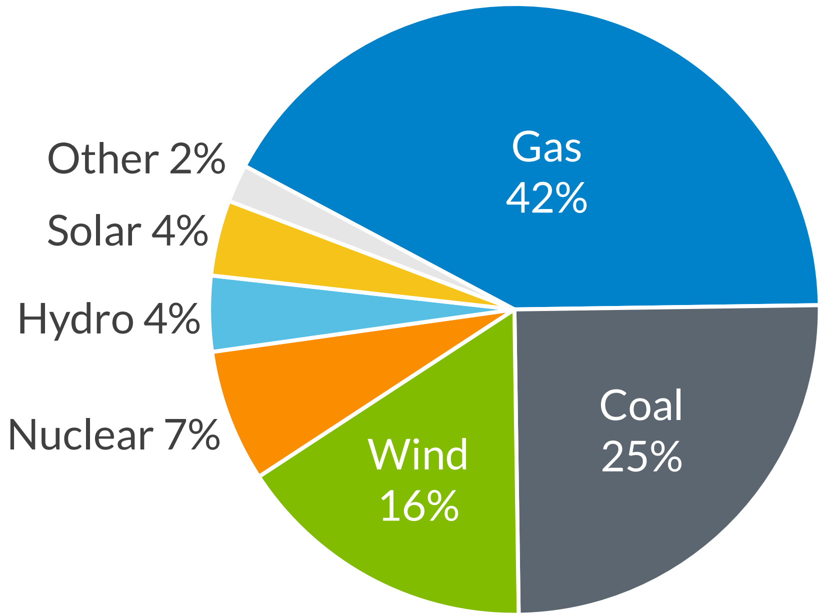
# About MISO



MISO's reliability footprint

- MISO's core responsibilities:
  - **Operations** - Managing the flow of high-voltage electricity across 15 states and Manitoba
  - **Markets** - Facilitating one of the world's largest energy markets
  - **Planning** – Planning the grid of the future

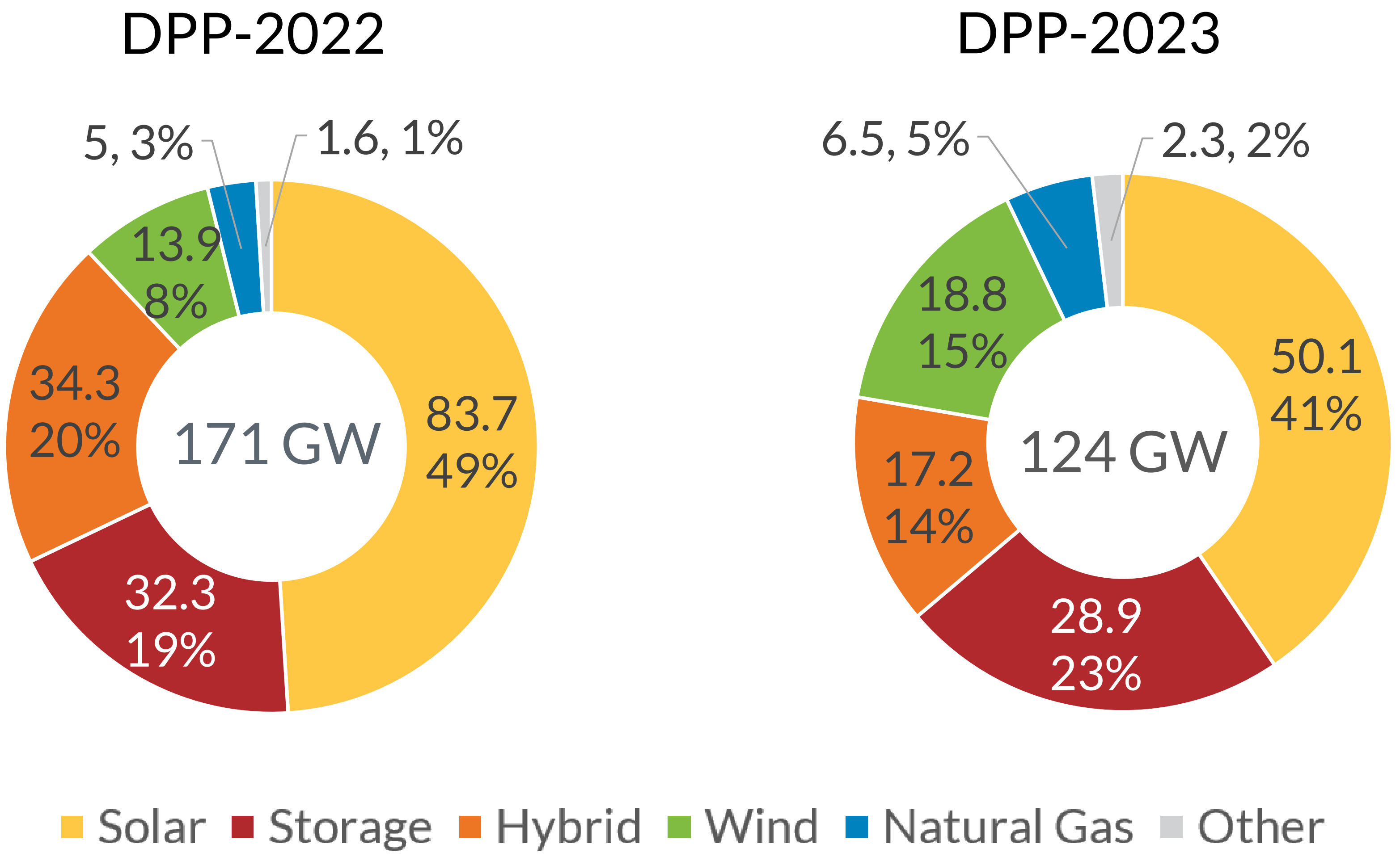
**Installed Capacity – December 2023**




191 GW Total Installed Capacity

# MISO's 2022 and 2023 generator interconnection queues have large amounts of inverter-based resource (IBR) capacity

96% is likely inverter-based




93% is likely inverter-based

DPP: Definitive Planning Phase



MISO 2022 Generator Interconnection Queue Submissions: https://cdn.misoenergy.org/2022%20GIQ%20Submission%20Statistics626443.pdf
MISO 2023 Generator Interconnection Queue Submissions: https://cdn.misoenergy.org/MISO%20DPP%202023%20Requests%20Overview632629.pdf

# NERC has been sounding the alarm on need for "Immediate Industry Action on Inverter-Based Resources"

- NERC reports on IBR tripping events illustrate the growing impact of IBRs and a need to improve performance requirements

**Recently released:**
- 2022 California BESS Disturbance
- 2023 Southwest Utah Disturbance


Image source: NERC, 2022 Odessa Disturbance: Overview, Key Findings, and Recommendations. January 4th, 2023. Available at: https://www.nerc.com/comm/RSTC/IRPS/2022_Odessa_Disturbance_Webinar.pdf


https://www.nerc.com/pa/rrm/ea/Pages/Major-Event-Reports.aspx

# MISO's IEEE 2800-2022 adoption effort began in 2022, tariff changes for selected priority requirements were filed in February 2024 and have been approved by FERC

**April 2022**

IEEE 2800-2022 published

**September 2022**

MISO begins 2800 adoption process

**December 2022**

MISO completes gap analysis

**January 2023**

MISO brings topic to the Interconnection Process Working Group (IPWG) stakeholder forum

**February 2023**

MISO completes 2800 requirement prioritization, selecting highest priority items for initial implementation

**October 2023**

MISO presents final tariff (GIA) redlines for performance requirements to stakeholders

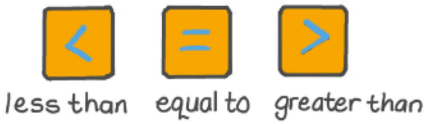
**February 2024**

MISO files tariff changes, first round of priority requirements are implemented

# The team first followed a gaps analysis approach to focus potential IBR recommendations before applying a prioritization framework

**IEEE 2800 Requirement ("Shall")**

**Compared against**




**MISO Tariff Generator Interconnection Agreement (GIA) Requirement**

**Determination:**
- Gap & nature of gap
- No Gap

From the gaps analysis, 21 requirements emerged as areas for further focus and prioritization

**General**
1. Measurement accuracy
2. Range of available settings
3. Prioritization of functions
4. Ramping for control parameter change

**Monitoring, Control, and Scheduling**

5. Responding to external control inputs
6. Remote configurability

**Voltage Support**

7. Capability at zero active power
8. Constant reactive power
9. Current injection during voltage ride through – balanced
10. Current injection during voltage ride-through - unbalanced

**Dynamic Responses and Reliability Services**

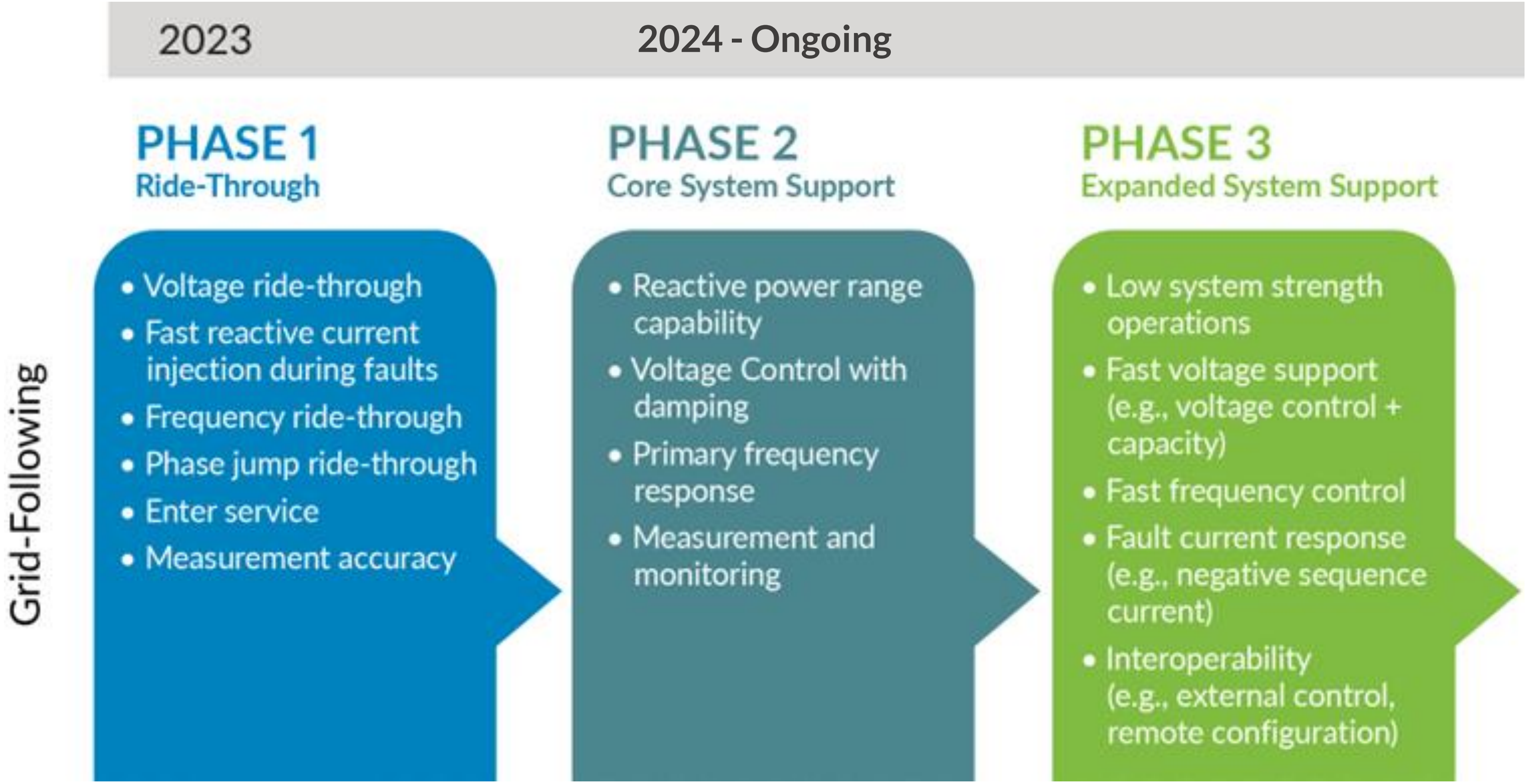
11. Frequency ride-through
12. ROCOF ride-through
13. Voltage ride-through
14. Transient overvoltage ride-through
15. Return-to-service (enter service) criteria and performance
16. Restore output after voltage ride-through
17. Voltage phase angle jump ride-through
18. Consecutive voltage deviation ride-through
19. Underfrequency fast frequency response
20. Overfrequency fast frequency response
21. Primary frequency response

# MISO used a reliability lens to prioritize IEEE 2800 performance requirements

- NERC disturbance reports were given highest weight
  - Results in a bias towards historical events and tripping related issues
- Revealed a need to address dynamic responses, with voltage and frequency ride-through performance emerging as priority focus areas for 2023

| Category | IEEE 2800 Performance Capability | *NERC Disturbance Cause Code?* | *FERC IBR NOPR Topic?* | *UNIFI Performance Need?* | *Reliability Attributes Area?* | Resulting Priority |
|---|---|---|---|---|---|---|
| General | Measurement accuracy | X | | | | Highest |
| | Range of Available Settings | | | | | Lower |
| | Prioritization of Functions | | | | | |
| | Ramping for control parameter change | | | | | |
| Monitoring and Control | Responding to external control inputs | | | | | Lower |
| | Remote Configurability | | | | | |
| Voltage Support | Capability at Zero Active Power | | | | X | Medium |
| | Constant Reactive Power | | | | X | |
| | Current injection during voltage ridethrough - balanced | X | | X | X | |
| | Current injection during voltage ridethrough - unbalanced | X | | X | X | |
| Dynamic Responses and Reliability Services | Frequency Ride-Through | X | X | X | X | Highest |
| | ROCOF Ride-Through | X | X | X | X | |
| | Voltage Ride-Through | X | X | X | X | |
| | Transient Overvoltage Ride-Through | X | X | X | X | |
| | Return-to-Service (Enter Service) | X | X | | X | |
| | Restore Output After Voltage Ride-Through | X | X | | X | |
| | Voltage Phase Angle Jump Ride-Through | X | X | X | X | |
| | Consecutive Voltage Deviation Ride-Through | | | X | X | Medium |
| | Underfrequency Fast Frequency Response | | | X | X | |
| | Overfrequency Fast Frequency Response | | | X | X | |
| | Primary Frequency Response | | | X | X | |

# The prioritization of IEEE 2800 requirements was used to outline a few main phases of IBR requirement implementation at MISO




MISO Attributes Roadmap, 2023: https://cdn.misoenergy.org/2023%20Attributes%20Roadmap631174.pdf

# FERC approved MISO's tariff updates to implement the highest priority IEEE 2800-2022 requirements for IBRs

IEEE 2800 requirements were added into MISO's Generator Interconnection Agreement (GIA) by detailed reference

| Clause | Requirements |
| --- | --- |
| **Clause 4** General | • Reference Point of Applicability<br>• Applicable Voltages and Frequency<br>• Measurement Accuracy<br>• Return-to-Service (Enter Service) |
| **Clause 7.2** Voltage Ride-Through | • Voltage Ride-Through (VRT)<br>• Current Injection During VRT<br>• Transient Overvoltage Ride-Through<br>• Restore Output after VRT |
| **Clause 7.3** Frequency Ride-Through | • Frequency Ride-Through<br>• Rate-of-Change-of-Frequency (ROCOF) Ride-Through<br>• Voltage Phase Angle Jump Ride-Through |

- Previous MISO IBR performance requirements were based on the 2018 NERC IBR Reliability Guideline
- MISO targeted IEEE 2800 requirements with the greatest potential reliability impact in the first phase of adoption
- Requirements will apply to IBR plants in MISO's 2022 interconnection queue* and beyond
  - First IBR plants with new requirements expected to be in operation by the end of 2026

*with GIA's signed after Jan 1, 2025

# Three subclauses from IEEE 2800 Clause 7 were not included in the first round of requirement adoption

### 7.2.1 Voltage Protection

References subclause 9.3 which has requirements for applying voltage protection.

MISO determined that protection requirements are out of scope.

### 7.2.2.4 Consecutive Voltage Deviations Ride-Through

Requires IBR plant to ride through multiple voltage excursions, and lists exceptions for specific conditions.

Stakeholders shared concerns about technology readiness and ability to demonstrate compatability with this requirement.

### 7.3.1 Mandatory Frequency Tripping

References subclauses 9.1 and 9.2 which has requirements for applying frequency and ROCOF protection.

MISO determined that protection requirements are out of scope.

Note: consecutive voltage deviations ride-through requirements are part of our second phase of IEEE 2800 adoption, which is underway in MISO's stakeholder process now

# MISO added the IEEE 2800 requirements into the Generator Interconnection Agreement using the detailed reference approach

- Clauses to be adopted were specified in the tariff language, as well as clarification for decision points left open in IEEE 2800
  - A table was also included to summarize which sub-clauses were adopted and which are not at this time

**B. <u>Response to Abnormal Conditions</u>**

The *IBR plant* shall adhere to IEEE 2800-2022 Clause 7 requirements, except for subclauses 7.2.1 (voltage protection), 7.2.2.4 (consecutive voltage deviations ride-through), and 7.3.1 (mandatory frequency tripping).

Within the adopted IEEE 2800-2022 Subclauses, the following requirements shall be incorporated as Transmission Provider and Transmission Owner decision points noted in IEEE 2800-2022.

- Subclause 7.2.2.1: The Transmission Owner shall specify the nominal voltage for use by this clause. Nominal voltages may include nominal transmission system voltages that are different from standard ANSI C84.1-2016 voltages.

*TABLE 1. SUMMARY OF ADOPTION TREATMENT OF IEEE 2800-2022 SUBCLAUSES*

| IEEE 2800-2022 Subclause | Required by Appendix G | Exception |
|---|---|---|
| 7.1 Introduction | X | |
| 7.2.1 Voltage protection | | X |
| 7.2.2.1 Voltage disturbance ride-through: General | X | |
| 7.2.2.2 Voltage disturbances within continuous operation | X | |
| 7.2.2.3 Low- and high-voltage ride-through | X | |
| 7.2.2.4 Consecutive voltage deviations ride-through | | X |
| 7.2.2.5 Dynamic voltage support | X | |
| 7.2.2.6 Restore output after voltage ride-through | X | |
| 7.2.3 Transient overvoltage | X | |
| 7.3.1 Mandatory frequency tripping | | X |
| 7.3.2 Frequency disturbance ride-through | X | |
| 7.4 Return to service | X | |



MISO's Attachment X-Appendix 6 (GIA) can be found here: https://www.misoenergy.org/legal/rules-manuals-and-agreements/tariff/

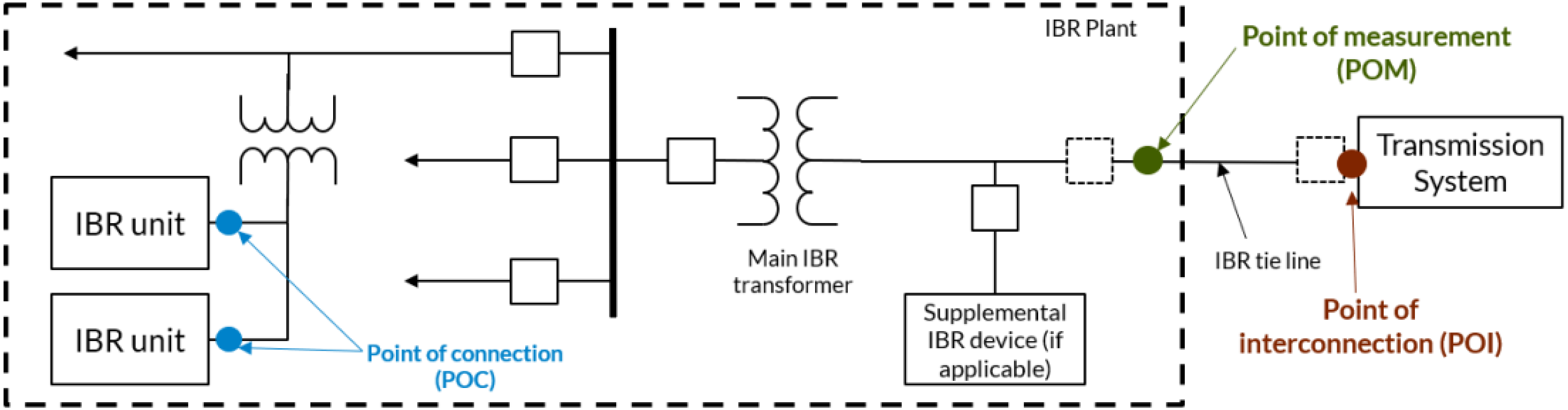
# Additional tariff language was included to address clarifications and decision points left open in the standard

| IEEE 2800 Clause | Type | Description of MISO language | Rationale |
|---|---|---|---|
| 7.2.2.1 (General requirements) | Clarification | Transmission Owner may need to specify nominal voltage if different from standard ANSI C84.1-2016 voltages. | Flag that this need may arise and provide mechanism to define nominal voltage. |
| 7.2.2.2 (Voltage disturbances in continuous operation region) | Decision point | Defining reactive power as the priority, when applicable voltage is below 95%, while minimizing any reductions in active power. | Voltage support better served by prioritizing reactive power during lower voltage conditions. |
| 7.2.2.3 (Voltage ride-through within mandatory operation region) | Clarification | For current injection during voltage ridethrough, prioritize reactive power. | Voltage recovery is better supported by prioritizing reactive current injection. |
| 7.2.2.3.4 (Current injection during ride-through mode) | Decision point | Require plant owners to submit information on plant controls relationship between incremental positive and negative sequence reactive currents and voltage change. | Given the number of control approaches, MISO seeks information on the response rather than specifying performance. |
| 7.3.2.3.1, 7.3.2.3.3 (Frequency disturbances within mandatory operation region) | Clarification/ Modification | Address reference in adopted clause to clause 6.1 (primary frequency response), which is outside the scope of the first phase of IEEE 2800 adoption. | Administrative clean-up to reference tariff section. |

Note: the modifications to subclauses 7.3.2.3.1 and 7.3.2.3.3 will be removed from the tariff language upon adoption of clause 6.1 in the second phase of adoption

# Both the POI and POM were considered for the reference point of applicability (RPA), but POM was selected based on stakeholder feedback

- Stakeholder comments indicated a preference for POM as the RPA in order to align with NERC standard compliance practices
- While preferring the POI, MISO views the POM as an acceptable location for standard conformance and will look to ongoing NERC standards development to guide evolving practices



# An implementation plan was developed based on concerns about equipment readiness from stakeholders

2022 Queue

For the DPP-2022-Cycle, MISO will allow Interconnection Customers to request exceptions to specific IEEE 2800 requirements for GIAs signed before January 1, 2025.

- Given shifts in MISO's interconnection study schedule, none of the DPP-2022 projects are anticipated to have GIAs signed before the exception end date
- The exception end date was based on expected dates for IEEE 2800 compatible equipment to be available, and is not expected to shift

2023 Queue

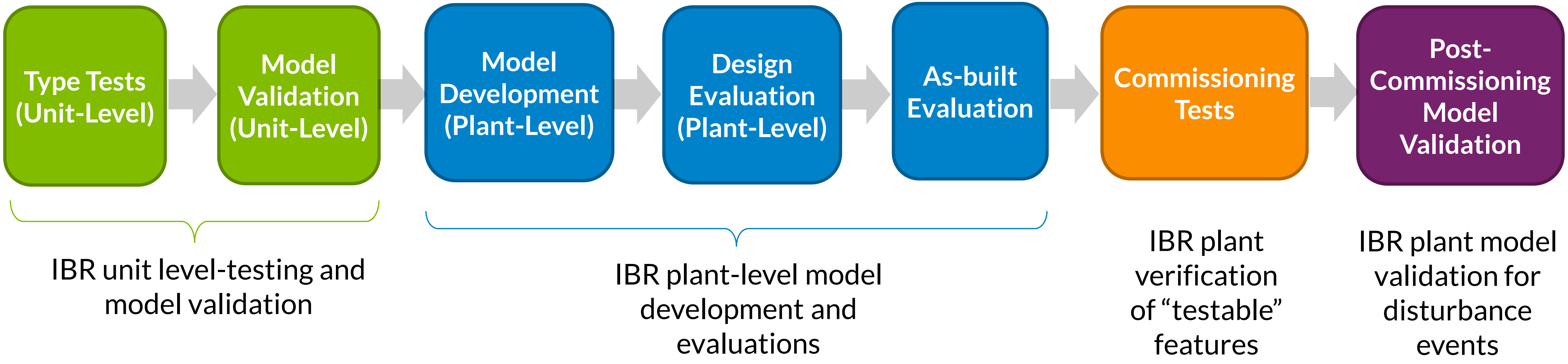
For the DPP-2023-Cycle and beyond, IBR plants will be required to fully comply with the MISO-adopted IEEE 2800 requirements



DPP: definitive planning phase

# MISO sees development of conformity assessments as a key next step after implementation of requirement language

MISO is interested in the procedures that come out of the P2800.2 standard development




The conformity assessment process is under development in standard working group IEEE P2800.2. Additional considerations are included such as post-commissioning monitoring, and periodic tests and verifications

# Next steps

- Propose alignment between NERC standards that are under development and relevant IEEE 2800 language where appropriate
- MISO will continue working with stakeholders to finalize the second phase of IEEE 2800 requirement adoption (reactive power/voltage control, primary frequency response, and consecutive voltage deviation ride-through)
  - Finalize tariff changes with stakeholders by the end of 2024 and file with FERC afterwards



MISO

# Questions?

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