# Inverter-Based Resource Performance Requirements (IEEE 2800) (PAC-2024-2)

Planning Advisory Committee

October 16, 2024

# Purpose & Key Takeaways

**Purpose:** Propose Inverter-Based Resource (IBR) performance requirements with implementation for DPP 2023 Cycle resources

## Key Takeaways:

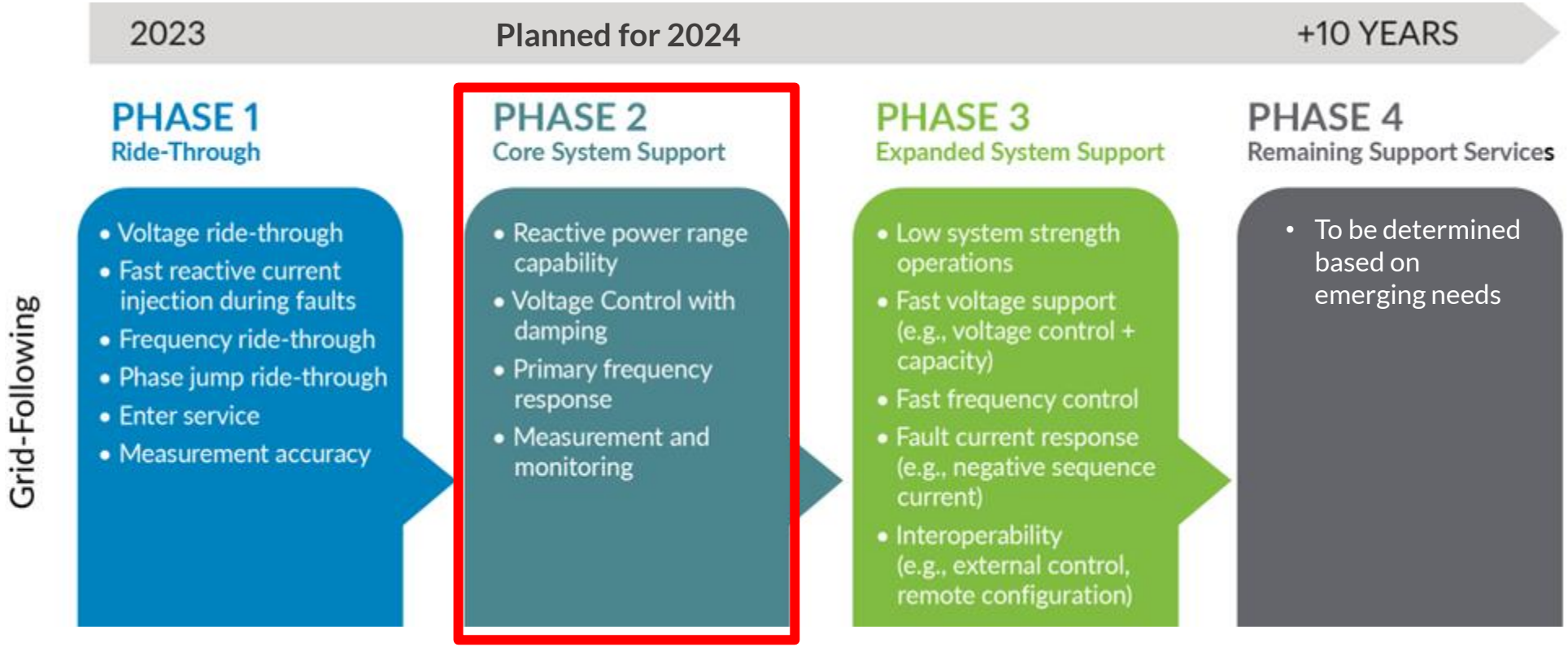
- MISO shares proposed performance requirements covering voltage and frequency support, consecutive voltage deviation ride-through, and operational measurement
- Stakeholder feedback is requested on proposed IEEE 2800 requirements and implementation plan
- MISO will consider stakeholder feedback and adjust the requirements and implementation plan as appropriate

# MISO posted draft redlines to the Generator Interconnection Agreement and is requesting feedback

- MISO proposes redlines in the October 16th PAC materials for the follow sections of MISO's Tariff Attachment X - Appendix 6[1]:
  - Appendix G - Interconnection Requirements for Inverter-Based Resource Plants
  - 9.6.1 – Power Factor Design Criteria
  - 9.6.4 – Primary Frequency Response
- Redlines references IEEE 2800 clauses for adoption, with additional language to clarify decision points left open in the standard[2]
- MISO proposes applying these IEEE 2800 requirements to the DPP-2023-Cycle, with exceptions allowed for GIAs signed before Jan 1, 2026[3]

[1] MISO, Tariff, Attachment X-Appendix 6. 4/2/24. Available at: https://misodocs.azureedge.net/miso12-legalcontent/Attachment_X-Appendix_6_-_Generator_Interconnection_Agreement_%28GIA%29.pdf
[2] See Appendix slides for summary of decision points
[3] Exceptions will also be granted for Generator Replacements and Surplus Interconnection GIAs signed before Jan 1, 2026

# IBR performance requirements were identified as a key solution to ensuring system stability, and four main phases were proposed in the Attributes roadmap




Original Equipment Manufacturer (OEM) equipment capabilities are a key input into MISO's proposed adoption of IBR performance, along with an assessment of potential risks from requirement gaps.



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

# MISO presented at five Interconnection Process Working Group meetings, requesting feedback on three occasions in developing MISO's proposal

| | Date | Objective in support of IEEE 2800 adoption Phase 2 |
|---|---|---|
| IPWG | Jan 30 | Present planned IBR performance requirements to be addressed in 2024 |
| | Mar 12 | Propose IEEE 2800 clauses for adoption **[Feedback]** |
| | May 2 | Review feedback and propose implementation plan and tariff redlines **[Feedback]** |
| | June 4 | Review feedback and share edits to tariff redlines |
| | July 23 | Share details on measurement data and implementation plan and edits to tariff redlines **[Feedback]** |
| | September 3 | Review feedback and share edits to tariff redlines |
| PAC | October 16 | Present draft tariff redlines and implementation plan **[Feedback]** |
| | November 13 | Share feedback responses and modifications |

MISO is requesting additional feedback from PAC stakeholders following today's meeting.

# Several themes emerged in stakeholder feedback and MISO made significant changes to the proposal

| Topic | Stakeholder feedback theme | MISO response |
|---|---|---|
| ***Reactive power*** | Remove requirement to utilized capability for reactive power at zero active power (a.k.a. "VArs at night") | MISO removed proposed requirement for utilization |
| ***Operational monitoring*** | Wait for PRC-028 to be complete before considering IEEE 2800 Clause 11 on operational monitoring | MISO proposed minor additions to existing tariff monitoring requirements to clarify and to add PMU data which will be required by PRC-028 |
| ***Voltage control*** | Modify voltage control performance requirements based on certain plant designs | MISO lengthened proposed reaction time for voltage control based on Interconnection Customer feedback and adopted Transmission Owner feedback for default step response time |

# Most of IEEE 2800-2022 requirements for Phase 2 adoption are refinements of existing requirements, adding more specificity and clarity

*Summary of MISO requirements proposed for adoption*

| Category | Performance Capability[1] | IEEE 2800 Clause[2] | Refinement[1] | New Requirement |
|---|---|---|---|---|
| Voltage Support | Minimum Reactive Power Capabilities | 5.1 | X | |
| | Reactive Power Capability at Zero Active Power | 5.1 | | X |
| | Voltage and Reactive Power Control Modes - General | 5.2.1 | X | |
| | Voltage Control | 5.2.2 | X | |
| | Constant Power Factor | 5.2.3 | X | |
| | Constant Reactive Power | 5.2.4 | | X |
| Frequency Response | Primary Frequency Response (PFR) | 6.1 | X | |
| Dynamic Responses/Reliability Services | Consecutive Voltage Deviation Ride-Through | 7.2.2.4 | | X |

[1] items are performance areas that are currently included in MISO's tariff (Generator Interconnection Agreement). See Appendix (Slide 21) for details on existing MISO requirements in each area

[2] IEEE 2800-2022, IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems

# MISO's approach to adopt IBR standards from IEEE 2800 is aligned with NERC Standards development activities resulting from FERC Order 901

- A significant increase in IBR interconnection requests, after years of relatively low penetration, presented MISO with an opportunity to address potential IBR performance risks.
- While FERC Order 901 is now requiring NERC to act with greater urgency to address IBR performance and modeling risks, MISO viewed waiting for NERC standards as posing a reliability risk began work in January 2023.
  - **Operation monitoring:** NERC PRC-028 was considered, and MISO is holding off implementing the more comprehensive IEEE 2800 monitoring requirements at this point but may do so as future plant operational monitoring capabilities are better understood.
  - **Ride-through:** NERC PRC-029 on ridethrough appears to be aligning with MISO's IEEE 2800 Phase 1 adoption based on the September 4-5 NERC Technical Conference and the Draft 4 of the standard posted September 17th, 2024.

# Stakeholder Feedback Request

- MISO is requesting feedback on the **Recommended IBR Performance Requirements (PAC-2024-2)** presented today by October 30, 2024.
  - Suggested edits to the proposed Generator Interconnection Agreement redlines posted with today's materials
  - Timing to implement requirements for DPP 2023 Cycle
- Feedback requests and responses are managed through the Feedback Tool on the MISO website: https://www.misoenergy.org/engage/stakeholder-feedback/

# Phase I implementation update on exceptions for Generator Replacements and Surplus Interconnections

- Existing tariff language for Phase I IEEE 2800 requirements only allows documented exceptions before Jan 1, 2025 for projects in DPP-2022
- MISO will allow Generator Replacements and Surplus Interconnections that sign GIAs before Jan 1, 2025 to use old Appendix G language (prior to IEEE 2800 requirements)
  - If there is an OEM-documented exception to the IEEE 2800 requirements
- Replacements and Surplus Interconnections that sign a GIA after Jan 1, 2025 will be required to use the current version of Appendix G language

# Questions?

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# Appendix

# Links to previous 2024 MISO presentations:

- 20240130 IPWG Item 04 IBR Performance Requirements
- 20240312 IPWG Item 04c IBR Performance Requirements IEEE 2800 (PAC-2024-2)
- 20240502 IPWG Item 04a IBR Performance Requirements IEEE 2800 (PAC-2024-2)
- 20240604 IPWG Item 04a IBR Performance Requirements IEEE 2800 (PAC-2024-2)
- 20240723 IPWG Item 04a IBR Performance Requirements IEEE 2800 (PAC-2024-2).pdf
- 20240903 IPWG Item 03c IBR Performance Requirements (IEEE 2800) (PAC-2024-2).pdf

# FERC approved MISO's tariff updates to implement the first phase of IEEE 2800-2022 requirements for IBRs

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

**Clause 4** General
- Reference Point of Applicability
- Applicable Voltages and Frequency
- Measurement Accuracy
- Return-to-Service (Enter Service)

**Clause 7.2** Voltage Ride-Through
- Voltage Ride-Through (VRT)
- Current Injection During VRT
- Transient Overvoltage Ride-Through
- Restore Output after VRT

**Clause 7.3** Frequency Ride-Through
- Frequency Ride-Through
- Rate-of-Change-of-Frequency (ROCOF) Ride-Through
- Voltage Phase Angle Jump Ride-Through

- FERC issued an Order accepting the tariff revisions, subject to conditions, in early June
- In response, MISO proposed a small revision to the Applicability section of Appendix G to clarify that the Phase I IEEE 2800 requirements are applicable to the DPP-2022-Cycle and beyond (not to any IBR plants in prior queue cycles)

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# MISO recommends moving forward with the following performance requirements from IEEE 2800-2022 to refine existing requirements in MISO's GIA

| *Category* | *Performance Capability*[1] | *IEEE 2800 Clause*[2] | *Summary of Performance Improvement Opportunity* |
|---|---|---|---|
| **Voltage Support** | **Minimum Reactive Power Capabilities** | **5.1** | **Define more specific reactive power requirements for IBRs, with additional details for Battery Energy Storage Systems (BESS) and Type III wind turbines** |
| | Reactive Power Capability at Zero Active Power | 5.1 | Require the capability to provide reactive power support when the primary energy source is not available |
| | **Voltage and Reactive Power Control Modes - General** | **5.2.1** | **List three required operating modes and specify voltage control as the default** |
| | **Voltage Control** | **5.2.2** | **Clearly define the voltage control mode, require a damping ratio of 0.3 or higher and other dynamic performance requirements** |
| | **Constant Power Factor** | **5.2.3** | **Clearly define the constant power factor control mode, require a damping ratio of 0.3 or higher** |
| | Constant Reactive Power | 5.2.4 | Clearly define the constant reactive power control mode, require a damping ratio of 0.3 or higher |
| **Frequency Response** | **Primary Frequency Response (PFR)** | **6.1** | **Add ranges of available settings for PFR droop and deadband values. Define dynamic performance parameters for PFR.** |
| **Dynamic Responses/Reliability Services** | Consecutive Voltage Deviation Ride-Through | 7.2.2.4 | Define consecutive voltage deviation ride-through to increase general ridethrough robustness |
| **Measurement** | **Measurement Data for Monitoring and Validation** | **11** | **Clear requirements for data types, format, sampling/recording, and retention** |

[1] **Bolded** items are performance areas that are currently included in MISO's tariff (Generator Interconnection Agreement). See Appendix (Slide 21) for details on existing MISO requirements in each area

[2] IEEE 2800-2022, IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems



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# There are decision points associated with MISO's recommended performance requirements that will be detailed in the tariff language

| Category | Performance Capability | *IEEE 2800 Clause* | *Decision Points* |
|---|---|---|---|
| **Voltage Support** | Minimum Reactive Power Capabilities | 5.1 | None (adopt by reference) |
| | Reactive Power Capability at Zero Active Power | 5.1 | None (adopt by reference) |
| | Voltage and Reactive Power Control Modes - General | 5.2.1 | None (adopt by reference) |
| | Voltage Control | 5.2.2 | Dynamic performance requirements decisions: max *step response time* and range of conditions for requirement applicability |
| | Constant Power Factor | 5.2.3 | Determine minimum active power level for power factor control mode |
| | Constant Reactive Power | 5.2.4 | None (adopt by reference) |
| **Frequency Response** | Primary Frequency Response (PFR) | 6.1 | Specify utilization of PFR capability |
| **Dynamic Responses/Reliability Services** | Consecutive Voltage Deviation Ride-Through | 7.2.2.4 | None (adopt by reference) |
| **Measurement** | Measurement Data for Monitoring and Validation | 11 | Specify exact data categories, data points, recording rates, retention and duration times |



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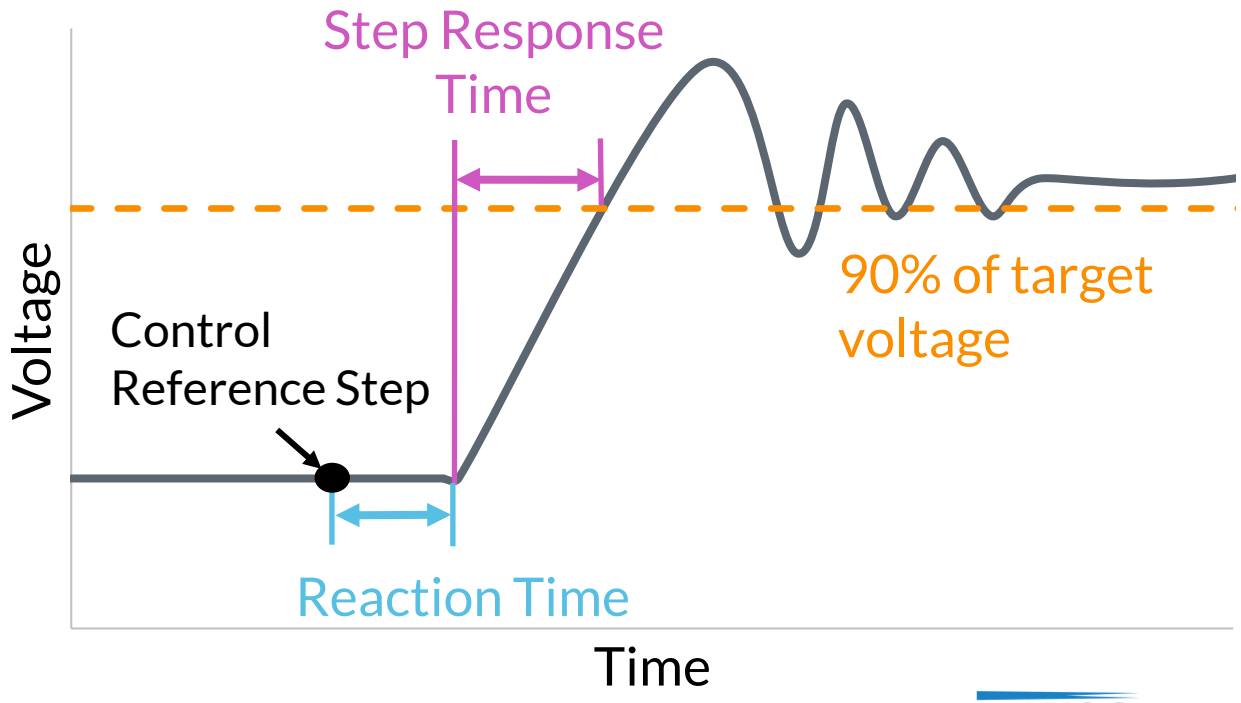
# Clarification and update to voltage control dynamic performance requirements

- IEEE 2800 provides dynamic performance requirements that apply to the **voltage control mode**
- **Maximum *step response time*** is not defined in the standard, MISO has proposed a default value of 30 seconds, subject to modification by the Transmission Owner based on local system needs.
- Stakeholders have shared concerns about the ability of DC-coupled battery systems to achieve the IEEE 2800 ***reaction time*** of 200 ms
  - MISO is proposing to extend the ***reaction time*** requirement to 250 ms

| Parameter | Performance Target |
|---|---|
| *Reaction time* | < 250 ms |
| Maximum *step response time*[1] | 30 s |
| Damping ratio | 0.3 or higher |

Requirements in this table shall only be applicable to a defined range of TS equivalent impedance at the POM, specified by the *TS operator.*






[1] The standard states that the slowest response shall be tuned based on the *TS operator* requirements for response time and stability given grid strength, local voltage control devices, and overshoot requirements

# Consecutive voltage deviation is the only remaining requirement needed to complete adoption of all ride-through capabilities in the standard

- Requires the IBR plant to ride through multiple voltage excursions outside of the continuous operation region
  - Exceptions provided in tables[1]
- This clause was not included in Phase I of 2800 requirement adoption due to concerns about original equipment manufacturer (OEM) readiness
- MISO is requesting feedback about technology readiness for this clause, now that there has been more time to evaluate the impacts of 2800 requirements on different inverter models

| Time Period | May Trip for this number of Voltage Deviations |
|---|---|
| 10s | 5+ |
| 120s | 7+ |
| 30min (1,800s) | 11+ |

| Time Period | May Trip for this number of Voltage Deviations Below 50% of Nominal Voltage |
|---|---|
| 10s | 3+ |
| 120s | 4+ |



[1] Additional exceptions are listed in the Appendix (Slide 33)

# MISO proposes to require PMUs to meet DDR requirements

- Dynamic Disturbance Recording (DDR) data requirements in the June draft of PRC-028-1 (at the high-side of main power transformer, or POM):

**Measured Electrical Quantities**
- Phase-to-neutral or positive sequence voltage
- Phase or positive sequence current
- Three-phase real and reactive power
- Frequency

**Input Sampling Rate**
- At least 960 samples per second

**Output Recording Rate**
- At least 60 times per second

- MISO is proposing to require that the DDR requirements be met using phasor measurement units (PMUs)[1]
  - PMU data should be locally stored per retention requirements in the tariff redlines (60 days)
  - Streaming requirements for PMU data will be addressed through a separate topic at IPWG later this year

[1] A PMU can be a stand-alone physical unit or can be a functional unit within another physical unit (such as a protective relay)

# Existing MISO transient data recording requirements from Appendix G of the GIA

| Requirement | Existing Tariff Language |
|---|---|
| Plant-Level Data | • Plant three-phase voltage, current and power factor<br>• Status of:<br>  • Ancillary reactive devices<br>  • Plant circuit breakers<br>  • Plant controller<br>  • Main plant transformer no load taps<br>  • Main plant transformer tap changer<br>• Plant control set points<br>• Protective relay trips |
| Inverter-Level Data | • Frequency, current, and voltage during frequency ride-through events<br>• Voltage and current during:<br>  • Momentary cessation for transient high-voltage events (when used)<br>  • Reactive current injection for transient low or high-voltage events<br>• Inverter alarm and fault codes<br>• DC current and voltage |

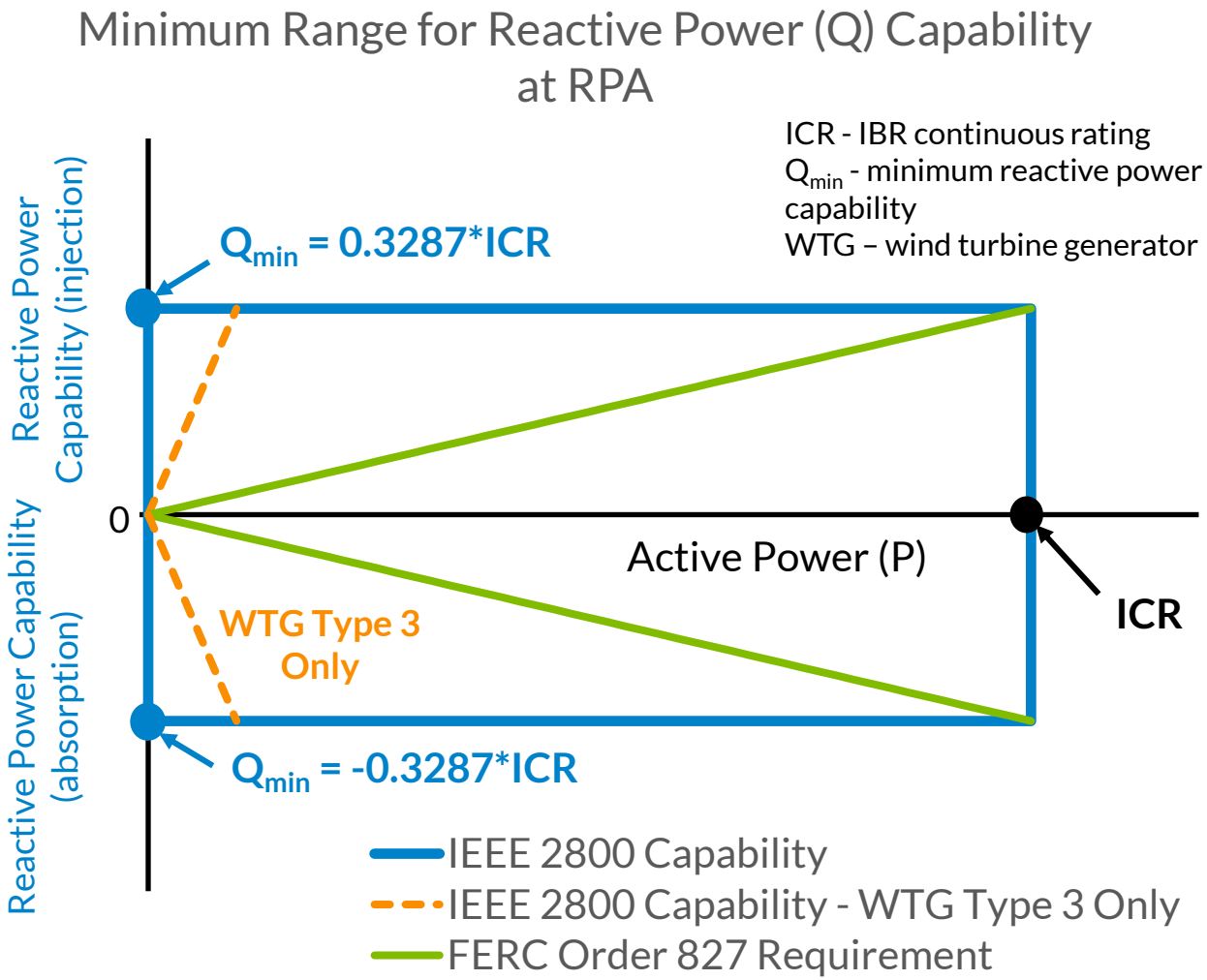
Additional requirements:

- Data must be time synchronized to 1 ms of resolution
- Data must be sampled at least every 10 ms
- Data storage for a minimum of 60 calendar days
- Data shall be made available within 10 calendar days of request

| Category | Performance Capability | *IEEE 2800 Clause* | *Current MISO Tariff Requirement* | *Summary of Performance Improvement Opportunity* |
|---|---|---|---|---|
| **Voltage Support** | Minimum Reactive Power Capabilities | 5.1 | Attachment X Appendix 6 Section 9.6.1.2: Plant shall be "capable of maintaining a composite power delivery at continuous rated power output at the high-side of the generator substation at all power factors over 0.95 leading to 0.95 lagging". Attachment X Appendix 6, Appendix G, Section A.ii. : Plant "shall maintain a factor within the range of 0.95 leading to 0.95 lagging … measured at the high side of the generator substation." | Define more specific reactive power requirements for IBRs, with additional details for BESS and Type III WTGs |
| | Reactive Power Capability at Zero Active Power | 5.1 | Not required | Require the capability to provide reactive power support when the primary energy source is not available |
| | Voltage and Reactive Power Control Modes - General | 5.2.1 | Attachment X Appendix 6 Section 9.6.2: "Interconnection Customer shall operate the Generating Facility to maintain the specified output voltage or power factor" | List three required operating modes and specify voltage control as the default |
| | Voltage Control | 5.2.2 | Attachment X Appendix 6 Section 9.6.2.1: "Interconnection Customer shall operate the Generating Facility with its speed governors and voltage regulators in automatic operation." | Clearly define the voltage control mode, require a damping ratio of 0.3 or higher and other dynamic performance requirements |
| | Constant Power Factor | 5.2.3 | Attachment X Appendix 6 Section 9.6.2: "Interconnection Customer shall operate the Generating Facility to maintain the specified output voltage or power factor" | Clearly define the constant power factor control mode, require a damping ratio of 0.3 or higher |
| | Constant Reactive Power | 5.2.4 | Not required | Clearly define the constant reactive power control mode, require a damping ratio of 0.3 or higher |
| **Frequency Response** | Primary Frequency Response (PFR) | 6.1 | Attachment X Appendix 6 Section 9.6.4: IC "is required to install a governor or equivalent controls with the capability of operating with a maximum 5 percent droop and +-0.036 Hz deadband...". Attachment X Appendix 6 Section 9.6.4.2: IC shall ensure that the plant's real power response is automatic, immediate, and sustained until the frequency returns to a value within the deadband. See additional language in sections 9.6.4, 9.6.4.1, 9.6.4.2. 9.6.4.3, and 9.6.4.4 | Add ranges of available settings for PFR droop and deadband values. Define dynamic performance parameters for PFR. |
| **Dynamic Responses/Reliability Services** | Consecutive Voltage Deviation Ride-Through | 7.2.2.4 | Not required | Define consecutive voltage deviation ride-through to increase general ridethrough robustness |
| **Measurement** | Measurement Data for Monitoring and Validation | 11 | Attachment X Appendix 6, Appendix G, Section A.iv. : "Non-synchronous generating facilities with generating capacities of more than 20 MW must monitor and record data for all frequency ride-through events, transient low-voltage disturbances that initiated reactive current injection, reactive current injection or momentary cessation for transient high-voltage disturbances, and inverter trips. See full tariff section for more details. | Clear requirements for data types, format, sampling/recording, and retention |

# MISO's adoption of IEEE 2800 reactive power requirements is currently constrained by FERC Order 827

- MISO proposes to adopt IEEE 2800 requirements for reactive power **capabilities**, including at zero active power
- MISO will not require **utilization** of the reactive power capability from IEEE 2800 beyond what is required by FERC Order 827 (0.95 leading to 0.95 lagging across the active power range) at this time
- MISO's proposed redlines also add clarity for IBR performance of voltage control

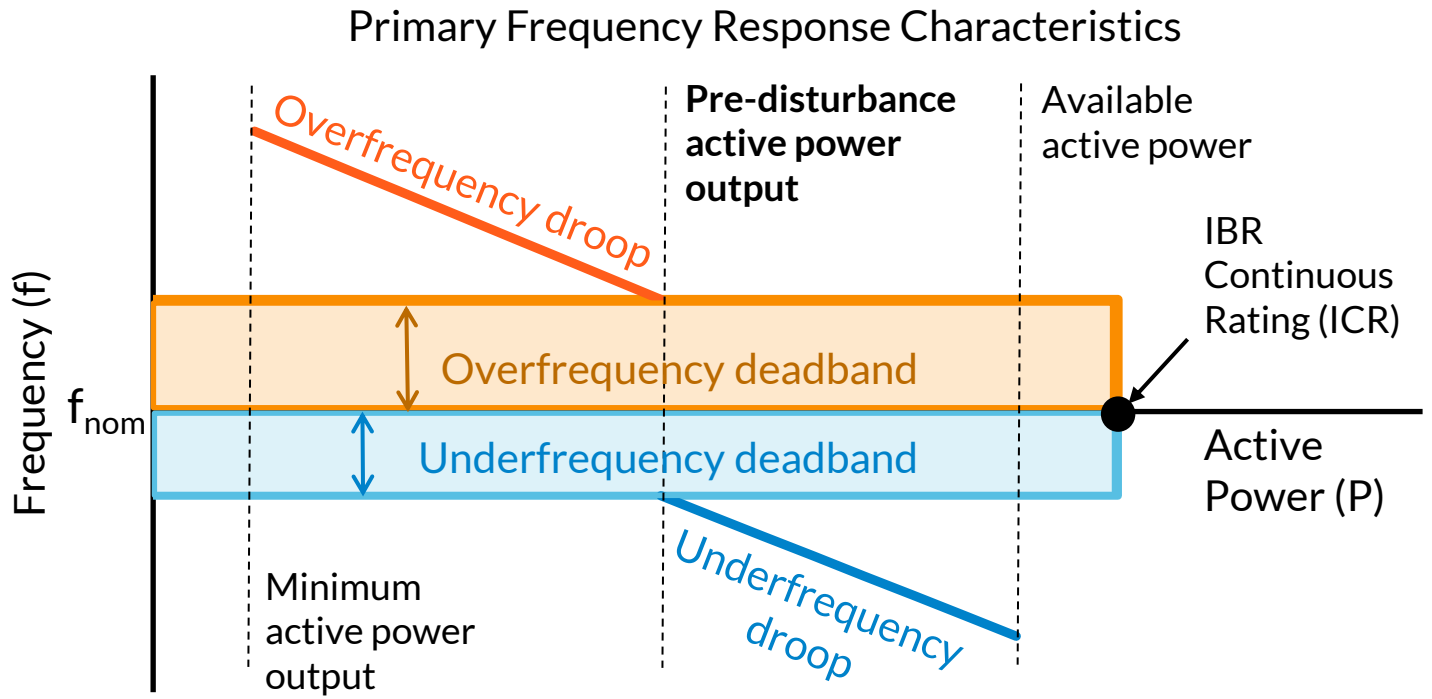





Reference Point of Applicability (RPA) shall be the Point of Measurement (POM)

# IEEE 2800 primary frequency response (PFR) requirements will enhance existing PFR requirements for IBRs

- Adoption of the PFR section of the standard would add dynamic performance requirements, along with range of available setting guidance for droop and deadband parameters
- IBR plants will **NOT** be required to operate with headroom to address under-frequency disturbances, as is the case today.
- MISO will evaluate language in the standard to ensure there are no conflicts with the requirements from FERC Order 842[1] in MISO's tariff, especially for battery energy storage systems (BESS)






[1] Federal Energy Regulatory Commission, Docket No. RM16-6-000; Order No. 842. Essential Reliability Services and the Evolving Bulk-Power System—Primary Frequency Response. Issued February 15, 2018.

# MISO proposes to add only DDR and PMU requirements, and will address the remaining data recording items in the future

- The draft NERC standard PRC-028 was undergoing rapid and substantial revisions during MISO's Phase 2 IBR requirements[1]
- MISO proposed waiting until PRC-028 is completed to substantially alter the existing data recording language in MISO's GIA
  - MISO will evaluate Clause 11 of IEEE 2800 at that time as well
- In the meantime, to fill a MISO monitoring need being addressed in PRC-028, MISO proposed new tariff redlines to clarify existing requirements applied to dynamic disturbance recording (DDR) and MISO is requiring phasor measurement unit (PMU) data to meet DDR requirements

[1] PRC-028 is being developed under Project 2021-04 Modifications to PRC-002 - Phase II: https://www.nerc.com/pa/Stand/Pages/Project-2021-04-Modifications-to-PRC-002-2.aspx
[2] Slide 17 in the Appendix summarizes the existing data recording requirements in the GIA that will not be altered at this time

# Additional information on IEEE 2800-2022 performance requirements

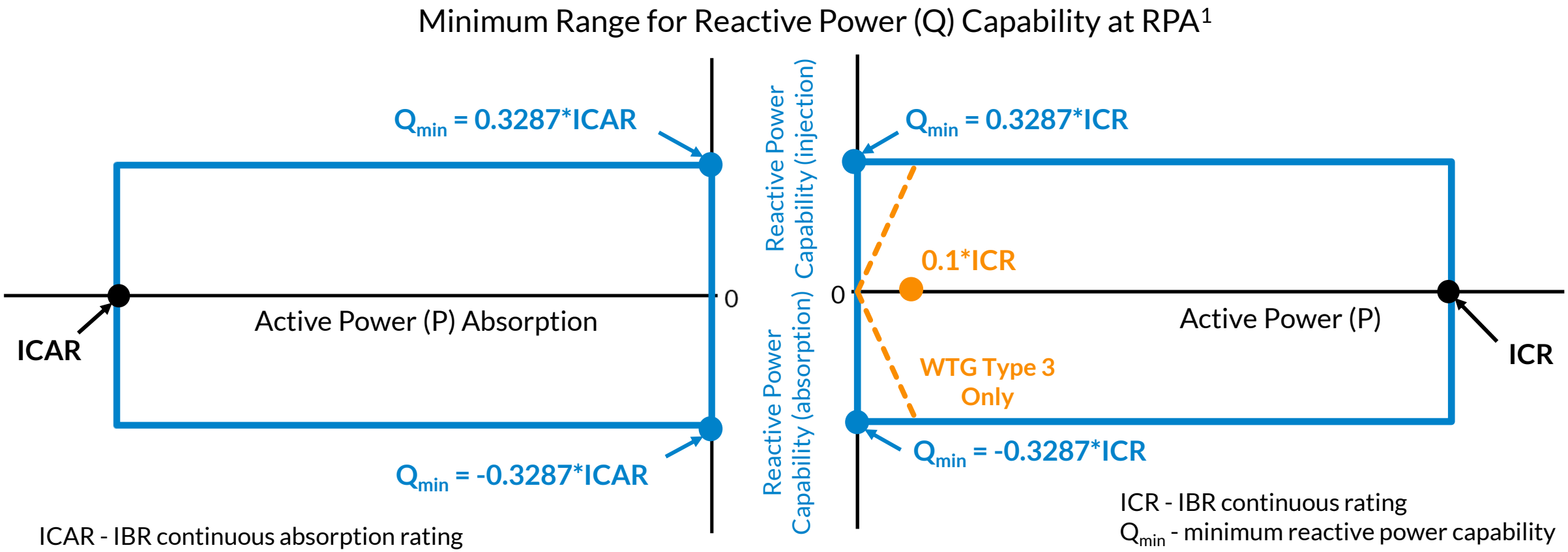
Slides contain MISO's summary of the standard, see the IEEE 2800-2022 publication for complete details

# IEEE 2800 defines minimum reactive power capabilities

- IBR minimum reactive power capability to inject or absorb at least 32.87% of IBR continuous rating (ICR) at the point of measurement (POM).
  - Applies only when applicable voltage and frequency are within the *continuous operation region*
  - Applies both when IBR is injecting and absorbing active power[1].
  - Applies at all levels of active power, with several exceptions[2]
    - Type III wind turbine generators have reduced reactive requirement at low active power levels.
  - Equates to +/-0.95 power factor, consistent with FERC Orders 2003[3] and 827[4]
  - Capability requirement applies regardless of primary energy source availability status.[5]
    - Under mutual agreement, the capability may be used to participate in reactive power exchange at zero active power.
    - If IBR is designed to cease operation below a specified minimum active power capability that's greater than zero, the IBR plant will not produce reactive power after operation ceases.

[1] Absorbing active power applies to energy storage. The continuous active power absorption rating is used for determining reactive power during absorption.
[2] An exception related to off-shore wind exists in IEEE 2800-2022 clause 5.1.
[3] Federal Energy Regulatory Commission, Docket No. RM02-1-000; Order No. 2003. Standardization of Generator Interconnection Agreements and Procedures. Issued July 24, 2003.
[4] Federal Energy Regulatory Commission, Docket No. RM16-1-000; Order No. 827. Reactive Power Requirements for Non-Synchronous Generation. Issued June 16, 2016.
[5] Type III WTG may have reduced reactive power capabilities when primary energy source is not available.

# Minimum reactive power capability requirements apply during both active power injection and active power absorption (if applicable)




Reference Point of Applicability (RPA) shall be the Point of Measurement (POM)

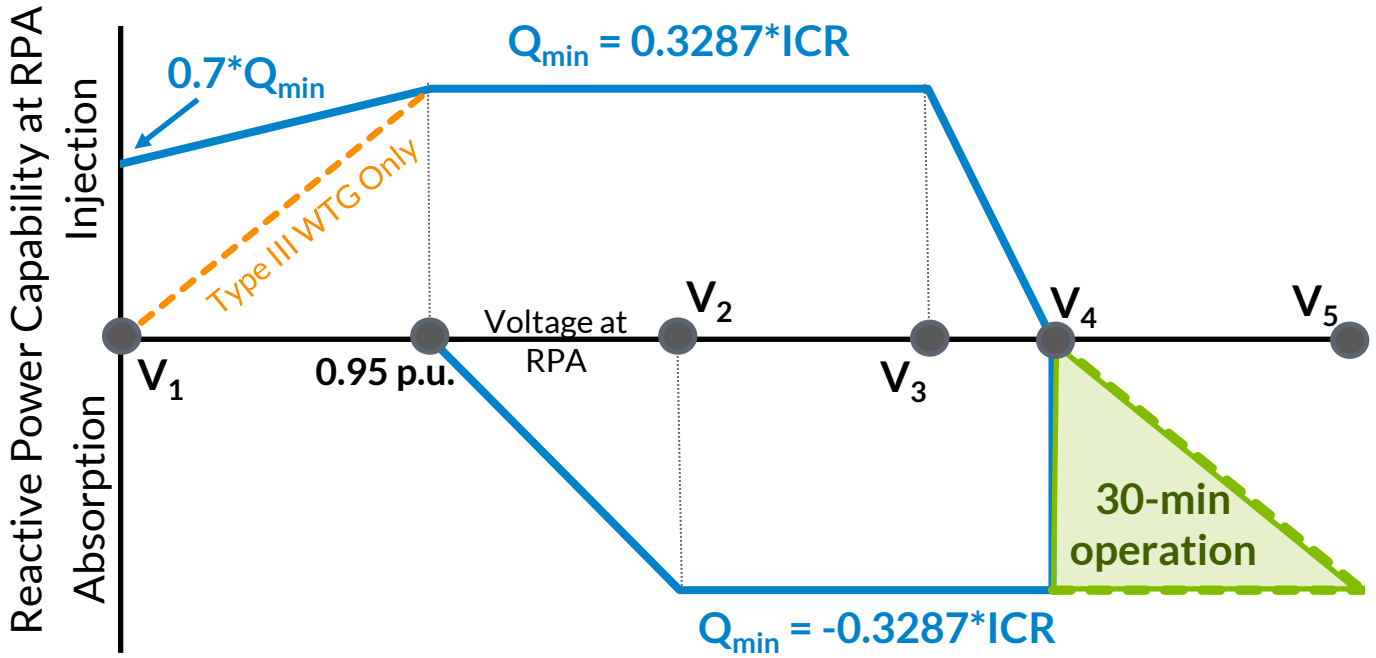


[1] Figures shows minimum reactive power capability, actual reactive power capability can go beyond this

# Additional reactive power capability requirements apply for non-nominal voltage conditions

- Minimum reactive power capability requirements differ by nominal RPA voltage, as shown in the table below.[1]
- Different requirements exist for continuous versus 30-minute operation.
- IBR shall maintain voltage schedule provided by transmission operator, within required capability[2]

| TS nominal voltage at the RPA[3] | V1 (p.u.) | V2 (p.u.) | V3 (p.u.) | V4 (p.u.) | V5 (p.u.) |
|---|---|---|---|---|---|
| < 200 kV | 0.90 | 0.99 | 1.03 | 1.05 | 1.10 |
| >= 200 kV (except 500 kV and 735 kV) | 0.90 | 1.00 | 1.04 | 1.05 | 1.10 |
| 500 kV | 0.90 | 1.02 | 1.06 | 1.10 | 1.10 |
| 735 kV | 0.90 | 1.02 | 1.06 | 1.088 | 1.10 |




Reference Point of Applicability (RPA) shall be the Point of Measurement (POM)

[1] An exception exists for Type III WTG for voltages less than 0.95 p.u.
[2] Requirement applies to storage across charging or discharging statuses, including the transition between.
[3] *TS operator* can require different values for V1-V5

# IEEE 2800 provides requirements and dynamic performance requirements for the default voltage control operating mode

- Automatic voltage control mode droop shall have a range of settings from 0 to 0.3 p.u. voltage change for 1.0 per unit reactive power on the ICR base
- Dynamic reactive power response to a step change in voltage must meet the performance requirements in the table
  - A stable and damped response takes precedence over response time

**Voltage Control Mode**

Closed-loop automatic voltage control mode to regulate steady-state voltage at RPA to the reference value within 1% of the set point

| Parameter | Performance Target |
|---|---|
| *Reaction time* | < 200 ms |
| Maximum *step response time*[1] | As required by the *TS operator*[2] |
| Damping ratio[3] | 0.3 or higher |

Requirements in this table shall only be applicable to a defined range of TS equivalent impedance at the POM, specified by the *TS operator.*

[1] The standard states that the slowest response shall be tuned based on the *TS operator* requirements for response time and stability given grid strength, local voltage control devices, and overshoot requirements
[2] *Step response time* typically ranges between 1 – 30 seconds
[3] Damping ratio will depend on grid strength

# IEEE 2800 requires primary frequency response within the limits of minimum and available active power

- The IBR plant shall have the capability to provide primary frequency response in both the continuous and mandatory operation regions
  - Response to under-frequency conditions is limited by available active power
  - Response to over-frequency conditions is limited by minimum active power capability
- The IBR plant PFR controller shall have the following default values and ranges of possible settings
  - Default values for deadband and droop match what is currently required in the MISO Generator Interconnection Agreement[1]

| Parameter | Units | Default Value | Ranges of available settings | |
|---|---|---|---|---|
| | | | Minimum | Maximum |
| Underfrequency deadband ($db_{UF}$) | Hz | 0.06% x $f_{nom}$ | 0.025% x $f_{nom}$ | 1.6% x $f_{nom}$ |
| Overfrequency deadband ($db_{OF}$) | Hz | 0.06% x $f_{nom}$ | 0.025% x $f_{nom}$ | 1.6% x $f_{nom}$ |
| Underfrequency droop ($k_{UF}$) | | 5% | 2% | 5% |
| Overfrequency droop ($k_{OF}$) | | 5% | 2% | 5% |



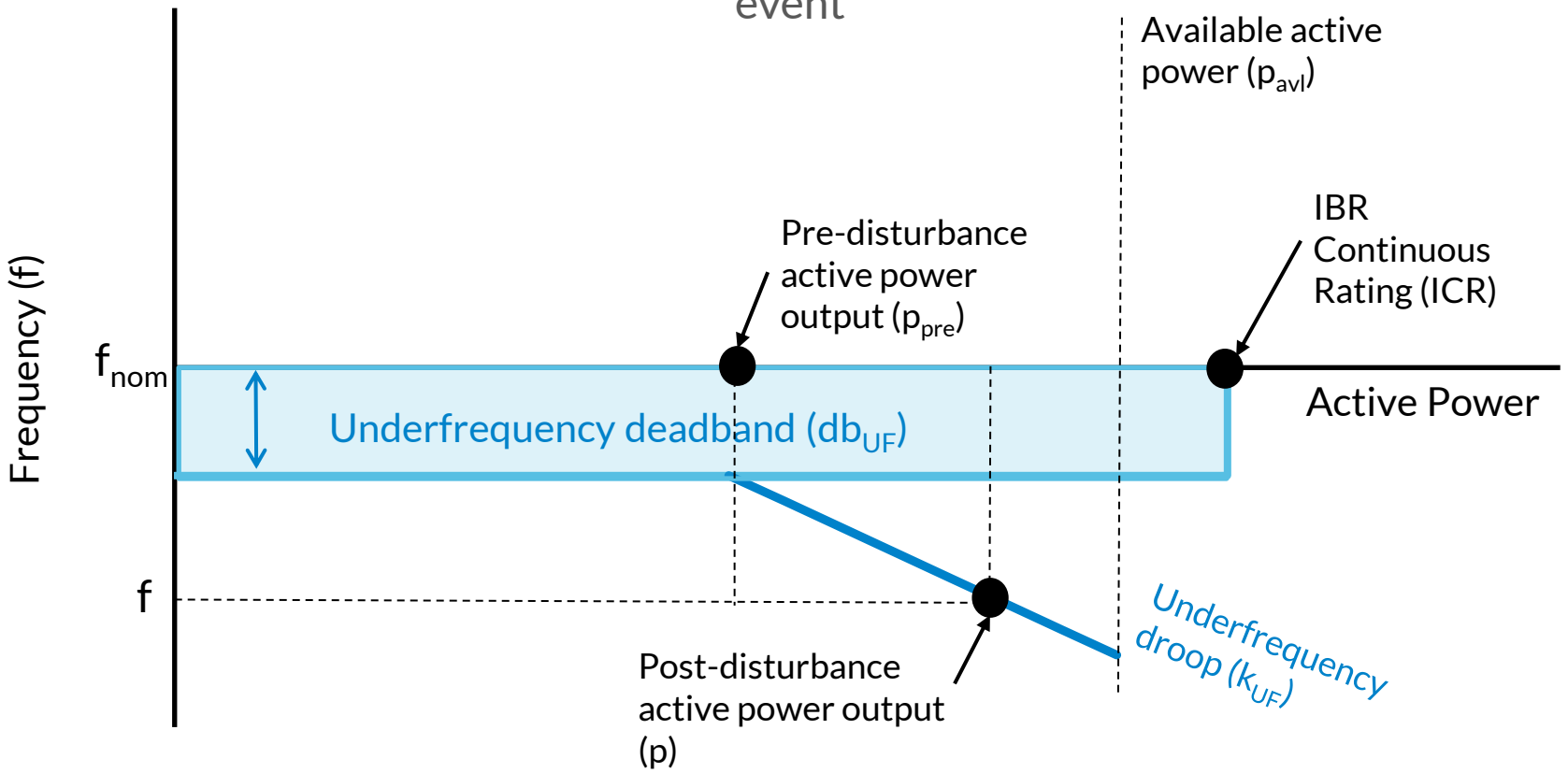
[1] With an $f_{nom}$ value of 60 Hz, the default underfrequency and overfrequency deadbands show in the table are 0.036 Hz

# PFR - Underfrequency Event Example

- Calculate the desired active power output with PFR response following the provided equation
- Active power output will be the desired active power output with PFR response, unless available active power is limiting

$$p = \min\left\{p_{avl}, p_{pre} + p_{PFR}\right\} = \min\left\{p_{avl}, p_{pre} + \max\left(0, \frac{f_{nom} - f - db_{UF}}{f_{nom} \times k_{UF}}\right)\right\}$$

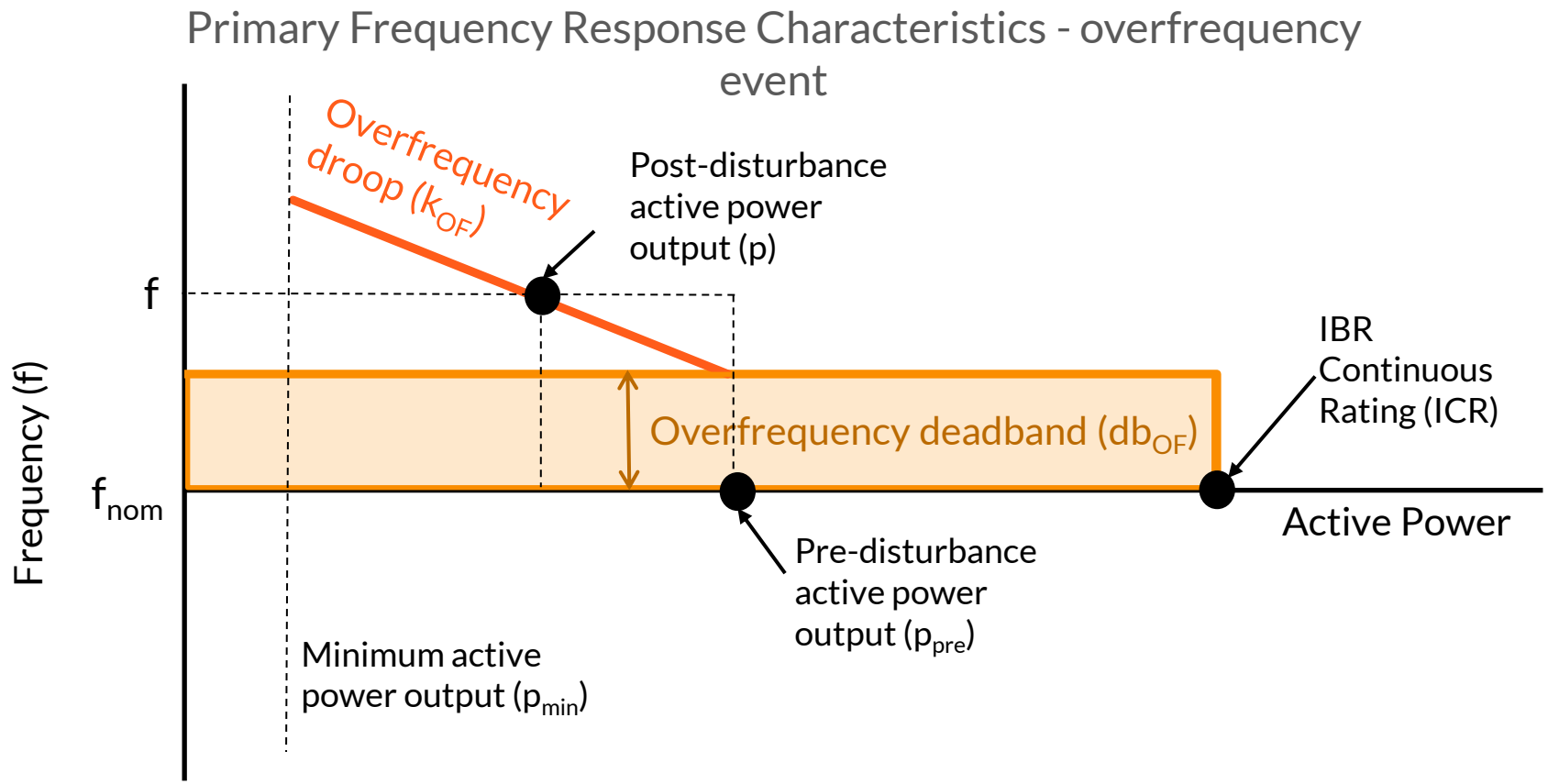
Primary Frequency Response Characteristics - underfrequency event



# PFR Overfrequency Event Example

- Calculate the desired active power output with PFR response following the provided equation
- Active power output will be the desired active power output with PFR response, unless minimum active power is limiting

$$p = \max\left\{p_{\min}, p_{\text{pre}} + p_{\text{PFR}}\right\} = \max\left\{p_{\min}, p_{\text{pre}} + \min\left(0, \frac{f_{\text{nom}} - f + db_{\text{OF}}}{f_{\text{nom}} \times k_{\text{OF}}}\right)\right\}$$



# Dynamic performance capabilities are defined for primary frequency response

- IBR plant shall sustain PFR for as long as the primary energy source is available
- Dynamic response for a step change in applicable frequency shall adhere to the parameters in the table below
- IBR plant will not be required to change its active power output at a rate greater than its ramping capability
- Response shall be stable and positively damped with a ratio of 0.3 or higher
  - A damped response takes priority over the rise and settling time parameters

| Parameter | Units | Default Value | Ranges of available settings | |
|---|---|---|---|---|
| | | | Minimum | Maximum |
| Reaction time[1] | Seconds | 0.50 | 0.20 (0.5 for WTG) | 1 |
| Rise time | Seconds | 4.0 | 2.0 (4.0 for WTG) | 20 |
| Settling time | Seconds | 10.0 | 10 | 30 |
| Damping ratio | Unitless | 0.3 | 0.2 | 1.0 |
| Settling band | % of change | Max of: 2.5% of change or 0.5% of ICR | 1 | 5 |



[1] Reaction time starts when the applicable frequency deviates outside of the PFR deadband

# IEEE 2800 also contains clarifications for the utilization of PFR in operations

- If the IBR plant is in curtailed operation, response to under-frequency disturbances is required up to the IBR plant's available active power
- Total active power output may be allowed to temporarily exceed the ICR of the IBR plant up to its IBR short-term rating (ISR)
- IBR plant shall return to normal operation when the frequency returns within the PFR deadbands, at that point the PFR magnitude will inherently become zero
- For energy storage systems, the dynamic performance during PFR when changing from exporting to importing active power (and vice versa) shall not prevent the IBR plant from meeting the dynamic performance requirements



ICR: IBR continuous rating

# Consecutive voltage deviation ride-through is required, but exceptions are provided for high numbers of voltage deviations

- IBR plant shall ride through multiple voltage excursions outside of the continuous operation regions except:
  - May trip for the cases shown in the tables below
  - May trip if the cumulative duration of voltage deviations exceeds the voltage ride-through durations
  - May trip for any voltage deviation outside of continuous operation regions that follows the end of a previous deviation by less than 20 cycles of system fundamental frequency
  - Individual WTG units may trip to self-protect for consecutive voltage deviations that result in mechanical resonances that exceed equipment limits

**Voltage Deviation Definition**

- Begins when the voltage leaves the continuous operation region
- End when the rms magnitude of the voltage is within the continuous operation region

| Time Period | May Trip for this number of Voltage Deviations |
|---|---|
| 10s | 5+ |
| 120s | 7+ |
| 30min (1,800s) | 11+ |

| Time Period | May Trip for this number of Voltage Deviations Below 50% of Nominal Voltage |
|---|---|
| 10s | 3+ |
| 120s | 4+ |