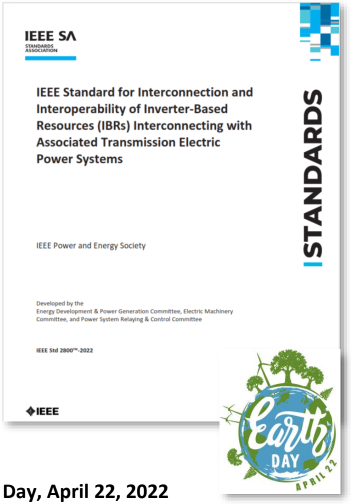
IEEE Std 2800™-2022

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

SEIA-ACP Joint Webinar

May 31, 2022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IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems

IEEE Power and Energy Society

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

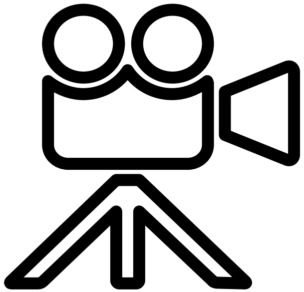
IEEE Std 2800™-2022

IEEE

STANDARDS

Published on Earth Day, April 22, 2022
Available from IEEE at https://standards.ieee.org/project/2800.html
and via IEEExplore: https://ieeexplore.ieee.org/document/9762253/

Webinar tips



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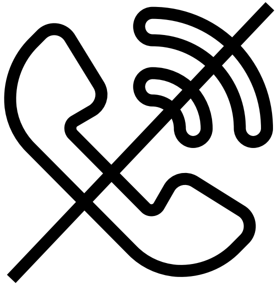
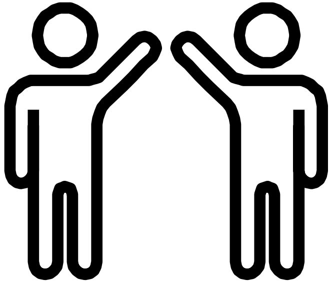
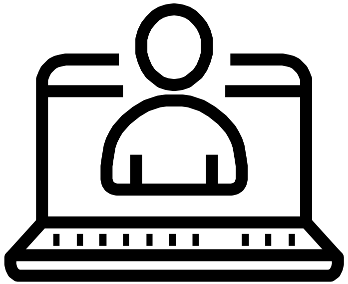


Participants have joined in listen only mode



Please type in any questions to the chat window at any time



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- Part of this work is supported by the U.S. Department of Energy, Solar Energy Technologies Office under Award Number DE-EE0009019 Adaptive Protection and Validated MODels to Enable Deployment of High Penetrations of Solar PV (PV-MOD).

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Outline – Joint SEIA-ACP Webinar – May 31, 2022

- **Welcome by host organizations – *5 min.***
  - Jeremiah Miller, SEIA
  - Michele Myers-Mihelic, ACP
- **Presentation by Mahesh Morjaria (WG Vice-Chair) – 50 min.**
  - IEEE P2800: motivation, purpose, scope, schedule
  - High-level review of selected requirements
  - Potential adoption of IEEE 2800 in North America
- **Comments by OEMs and developers – *5 min.***
  - Moderated by Jens Boemer (WG Chair) and Jeremiah Miller
- **Q&A (Mahesh & Jens) - 15 min.**

Joint Webinars

Past Webinars:

- Joint **IEEE–ESIG–PSERC–CURENT Webinar** for Subject Matter Experts & Academia
  Monday, May 2, 2022
  Speakers: **Jens C. Boemer (WG Chair)** (**slide deck**) (recording)
- Joint **NERC–NATF–NAGF–EPRI Webinar** for Transmission Planners
  Tuesday, May 3, 2022
  Speakers: **Manish Patel (WG Vice-Chair)** (**slide deck**) (recording)

Today:

- Joint **SEIA–ACP Webinar** for OEMs & Developers
  Tuesday, May 31, 2022 (11:00am ET | 08:00am PT | 17:00 CET)
  Speakers: **Mahesh Morjaria (WG Vice-Chair)** (announcement) (**slide deck** forthcoming) (recording forthcoming)

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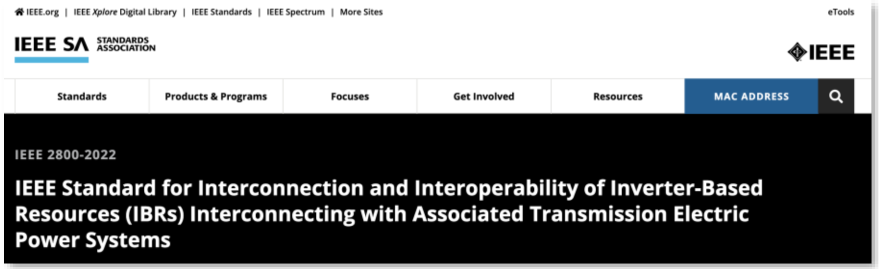
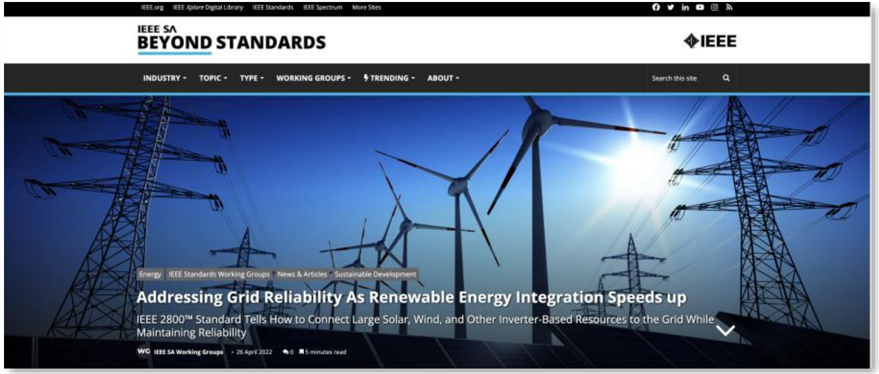
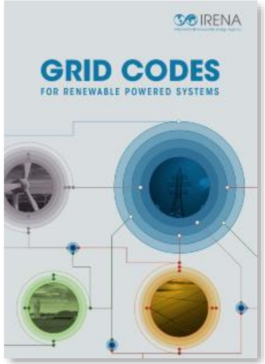


https://standards.ieee.org/project/2800.html



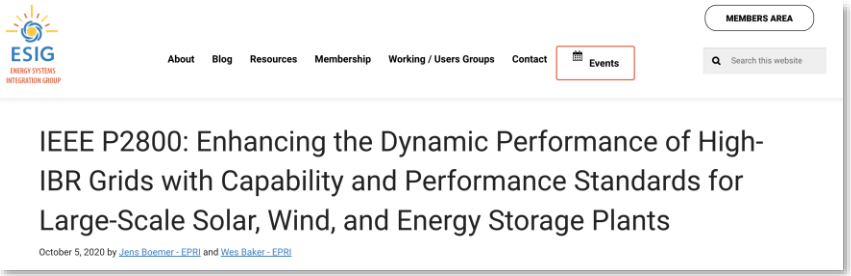
https://beyondstandards.ieee.org/addressing-grid-reliability-as-renewable-energy-integration-speeds-up/



“Grid Codes for Renewable Powered Systems” report by the International Renewable Energy Agency, published April 2022; pages 87-88:

"[IEEE 2800] will be [a] regional grid cod[e] for North America, with the main area of applicability being the United States, but [is] designed to go beyond this scope. [It] can clearly be recommended as [an] optio[n] for internationally standardised technical requirements for generators."

https://www.irena.org/publications/2022/Apr/Grid-codes-for-renewable-powered-systems



https://www.esig.energy/ieee-p2800-enhancing-the-dynamic-performance-of-high-ibr-grids/

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Speaker Bio – Dr. Mahesh Morjaria

- **Vice-Chair, IEEE P2800** >2 years
- **EVP at Terabase Energy** from 2021
  Plant controls and SCADA for solar and hybrid plants
- **VP First Solar** 10 years
  Utility-scale solar and storage plant controls, grid integration, and 1500V DC plant architecture
- **Engr Mgr., GE** for 20 years
  Wind turbine and plant controls
- **Ph.D. Engineering** – Cornell University

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- If a body wants to pursue "requiring" IEEE P2800 via rulings or placing the standard on their respective approved lists for use, that is up to them
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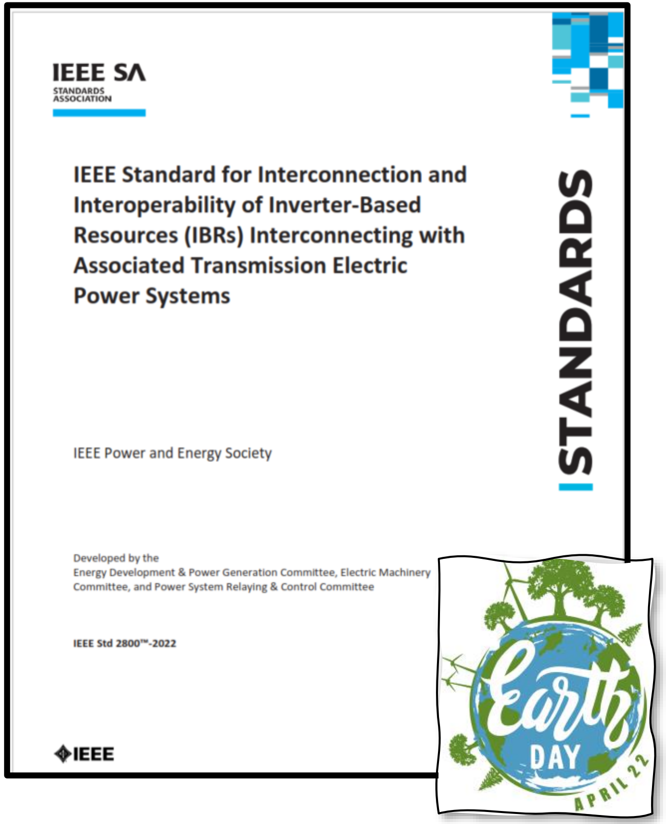
Summary of IEEE 2800 Standard

- The standard ***provides*** Interconnection Requirements for Large Solar, Wind and Storage Plants
- It is a ***consensus-based*** standard developed by over ~175 Working Group participants from utilities, system operators, transmission planners, & OEMs over 2 years
- It has ***successfully passed*** the IEEE SA ballot among 466
SA balloters **(>94% approval**, >90% response rate)
- ***Published on April 22, 2022 (Earth Day)***

More Info at https://sagroups.ieee.org/2800/



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Insufficient Solar, Wind & Storage Interconnection Requirements

- Diverse & different requirements across various jurisdictions

  …requires more effort and time to address

- Inverter-based resources (IBR) are different from synchronous generators

  …higher (and sometimes lower) capability

- Requirements may not be balanced

  …some too stringent & not taking advantage of new capability

Source: https://www.natf.net/

IBR: inverter-based resources like wind, solar, storage

Recurring Reliability Issues with IBRs

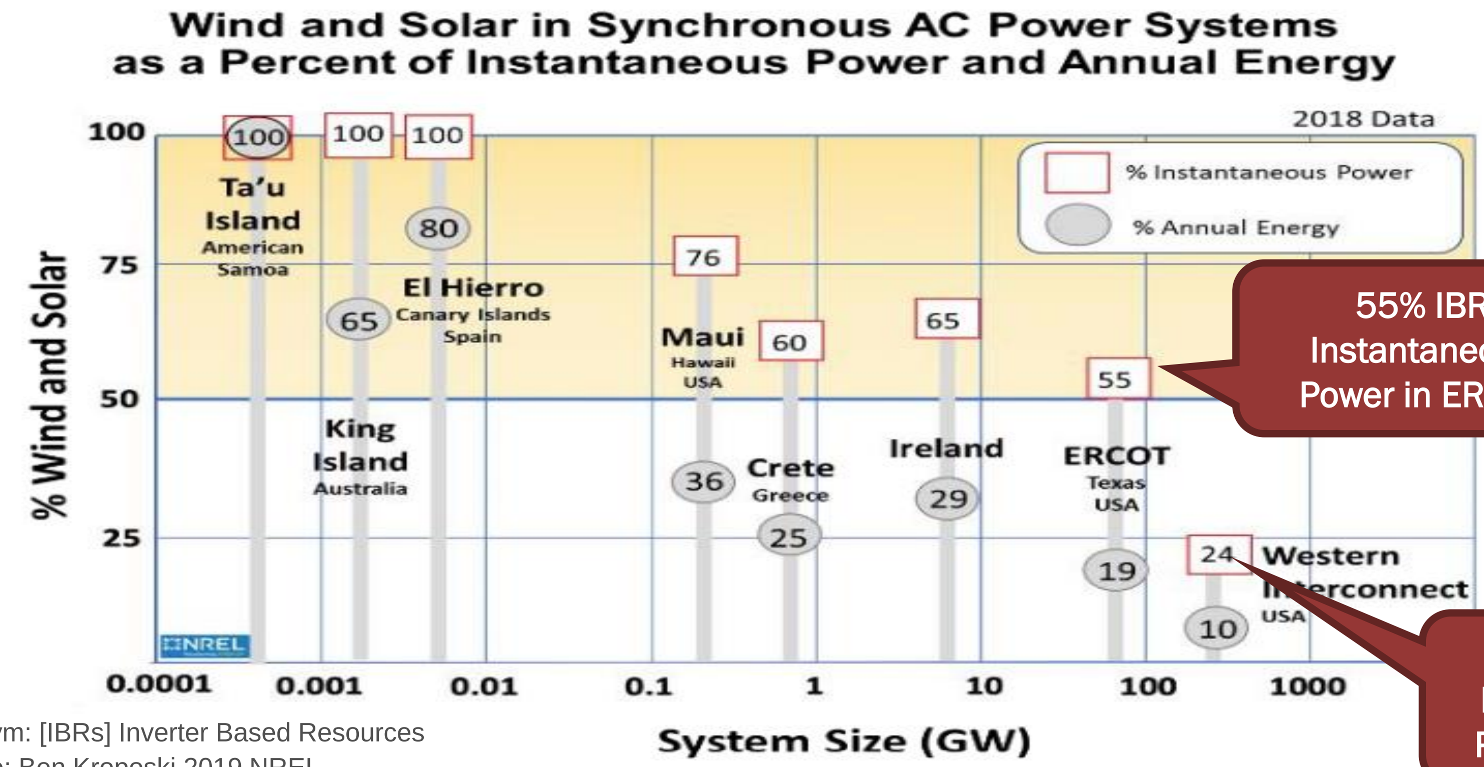
- Unexpected tripping, cessation of active power, oscillations, etc.
- ***Mis-application*** of IEEE 1547 standard for Transmission connected resources
- Analysis found ***opportunity for standardization*** of IBR performance to maintain grid reliability

NERC Recommendations

- Improvements to NERC Reliability Standards needed to address systemic issues with inverter-based resources
- Significant updates and improvements needed to the FERC Large Generator Interconnection Agreements (LGIA)

Source: NERC, 2017-2022

Instantaneous vs Average IBR Penetration



55% IBR Instantaneous Power in ERCOT

24% IBR Instantaneous Power in WECC

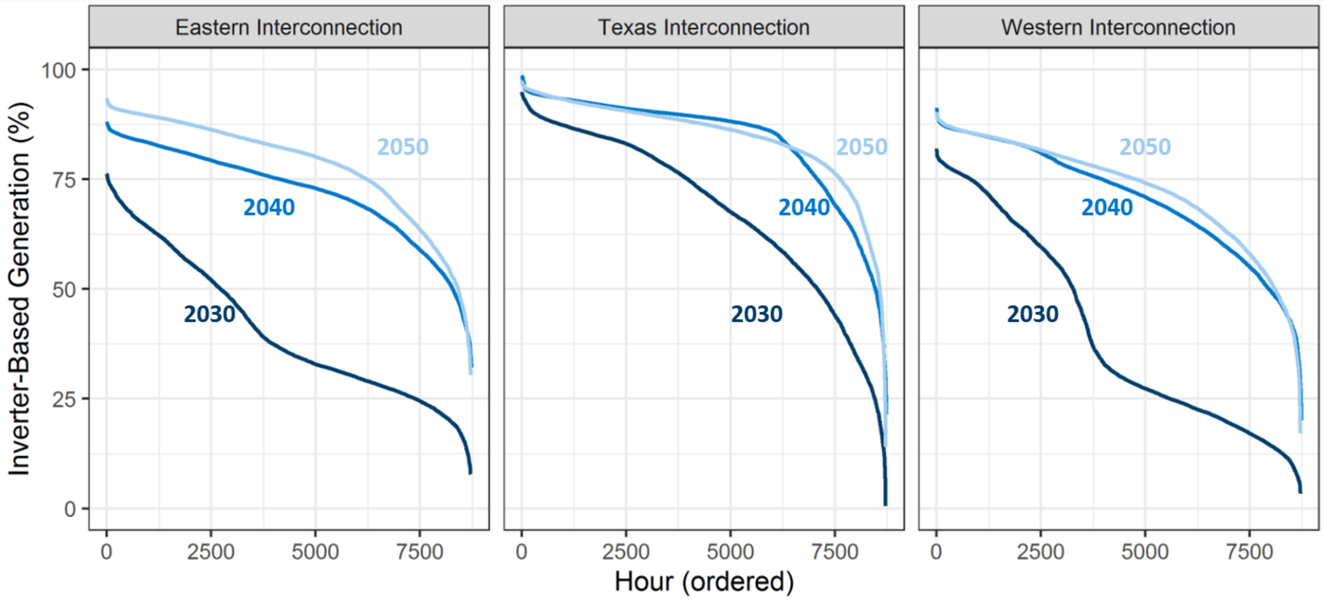
Acronym: [IBRs] Inverter Based Resources

Source: Ben Kroposki 2019 NREL

IBR Penetration is increasing

All major U.S. interconnections ar expected to reach peak **instantaneous IBR levels of 75-98%** within the lifetime of IBRs being connected today.

- These plants will need to contribute to system recovery and reliability.
- IEEE 2800 addresses minimum technical requirements to be met by IBRs.

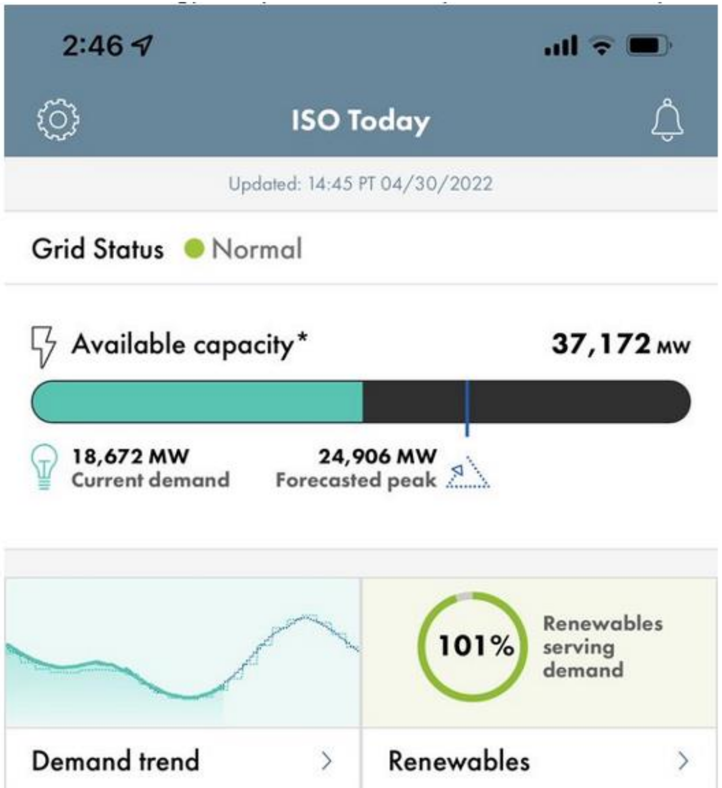


Data from 2021 DOE/NREL Solar Futures Study: https://www.nrel.gov/analysis/solar-futures.html

IBR: inverter-based resources like wind, solar, storage

100% CA Demand matched by RE generation for 15 minutes

- For the first time in history, ***California's demand was 100% matched by renewable energy generation*** … on Saturday April 30, 2022 for 15 minutes
- ***69% of demand*** was supplied by solar PV
- The remainder from wind, geothermal, and other renewable sources.



Scope of IEEE 2800 Standard

This standard establishes the required interconnection capability and performance criteria for inverter-based resources interconnected with transmission and sub-transmission systems for reliable integration into the bulk power system

These include:

> ***voltage and frequency ride-through, active and reactive power control, dynamic active power support under abnormal frequency conditions, dynamic voltage support under abnormal voltage conditions, power quality, negative sequence current injection, and system protection.***

Applicable to IBRs like *wind, solar & energy storage*, and any *IBR connected via VSC-HVDC*.

- "Type 3" wind turbines (doubly-fed induction generators) are in scope
- HVDC-VSC connected resources, e.g., onshore connection point of a VSC-HVDC tie-line interconnecting an offshore resource is also in scope.

Complementing North American Reliability Standards

		Performance	Test & Verification & Model Validation
FERC / NERC?	**Transmission**	• FERC Orders • NERC Reliability Standards & Guidelines	• NERC compliance monitoring & enforcement
NARUC / State PUCs?	**Sub-Transmission**	• Not available	• Not available
	Distribution (for DER)	• IEEE Std 1547-2018 • IEEE Std 1547a-2020	• IEEE 1547.1-2020 • Ul 1741 (SB) • IEEE ICAP

IEEE 2800-2022

IEEE P2800.2

DER: Distributed Energy Resources

Source: EPRI, 2021

Only when <u>adopted</u> by the appropriate authorities, IEEE standards become mandatory

IEEE Standards Classification and Consensus Building

IEEE 1547

IEEE 1547.1

Standards
documents specifying mandatory requirements (***shall***)

IEEE 2800

Recommended Practices
documents in which procedures and positions preferred are presented (***should***)

IEEE P2800.2

IEEE P1547.2

IEEE P1547.3

IEEE P1547.9

Guides
documents that furnish information – e.g., provide alternative approaches for good practice, suggestions stated but no clear-cut recommendations are made (***may***)

IEEE P2800.1

What to expect from IEEE 2800-2022?

- **Provides Value**
  - widely-accepted, unified technical *minimum* requirements for IBRs
  - simplifies and speeds-up technical interconnection negotiations
  - flexibility for IBR developers & OEMs ➔ not an equipment design standard
- **Specifies**
  - performance and functional capabilities *and not* utilization & services
  - functional default settings and ranges of available settings
  - performance monitoring and model validation
  - type of tests, plant-level evaluations, and other verifications means, but not detailed procedures (➔ *IEEE P2800.2)*
- **Scope**
  - All transmission and sub-transmission connected, large-scale wind, solar, energy storage and HVDC-VSC

What <u>not</u> to expect from IEEE 2800?

- **No exhaustive requirements for evolving IBR technology solutions**
  - IEEE 2800 applies to all IBRs (including grid-forming ones), but was designed with conventional grid-following IBRs in mind
  - Considers synchronous condensers as ”supplemental IBR devices” but allows for exceptions when used in IBR plants
- **No definition of an interconnection process**
  - This is up to transmission system owners and their stakeholders and regulators
  - IEEE 2800 may be used as *<u>part</u>* of such a process
- **No procedures to verify that IBRs comply with requirements**
  - **Procedures are currently being developed in IEEE P2800.2:**

P2800.2

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

Active PAR

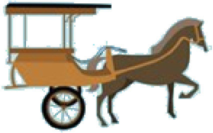
IEEE SA: https://standards.ieee.org/ieee/2800.2/10616/
P2800.2 WG: https://sagroups.ieee.org/2800-2/

Capability versus Utilization

Capability:

“Ability to Perform”

- Functions
- Ranges of available settings
- Minimum performance specifications



Examples

- Frequency Response
  - Frequency Droop Response
  - Ramp rate limitations
- 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”

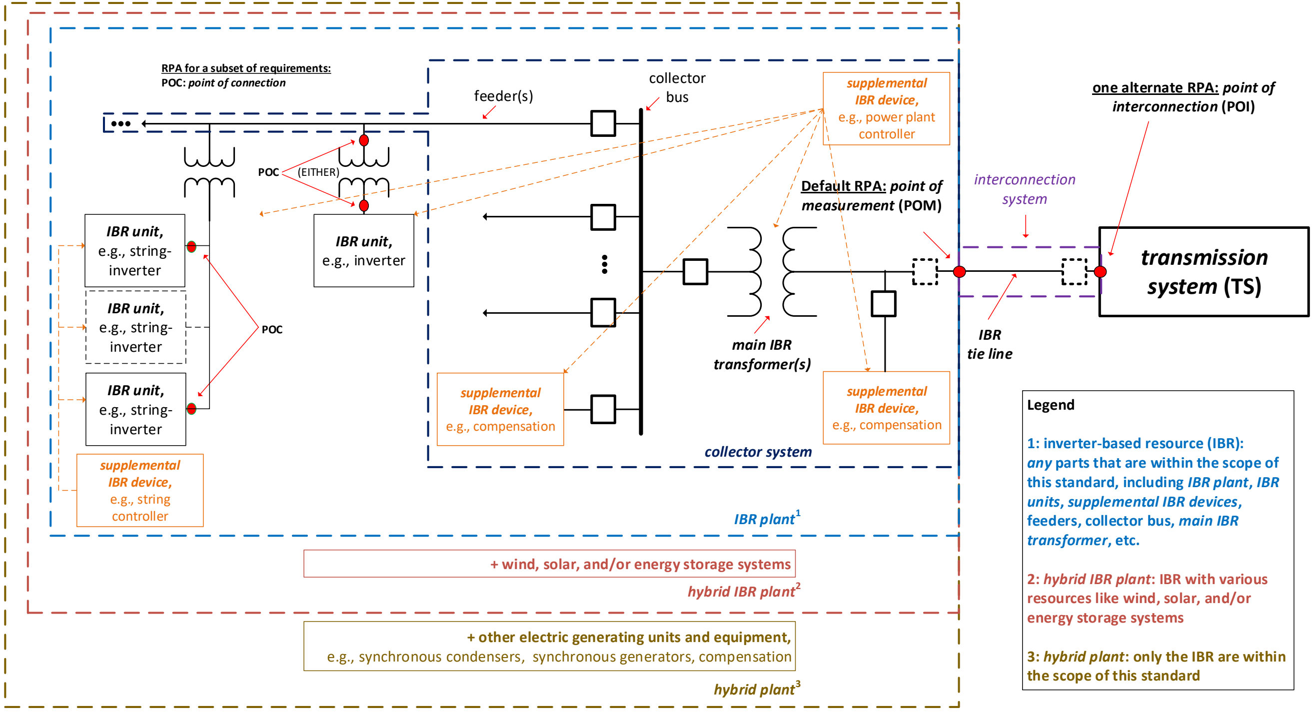
- Enable/disable functions
- Functional settings / configured parameters
- Operate accordingly (e.g., maintain headroom, if applicable)

Examples

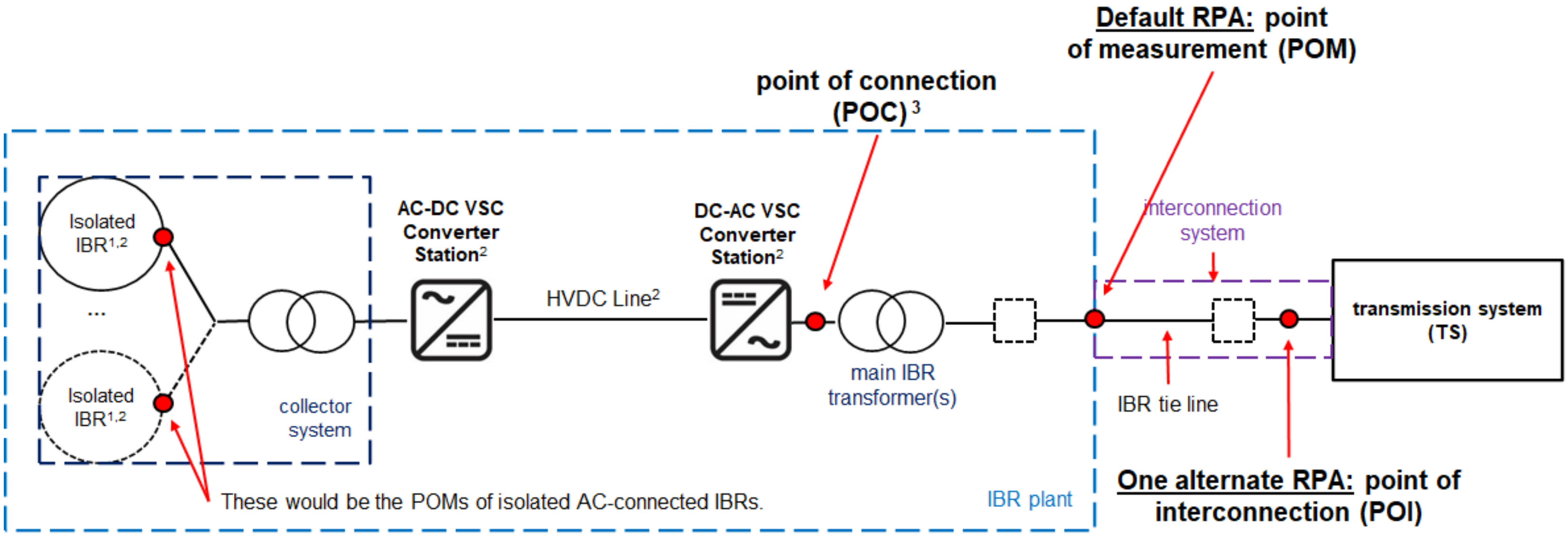
- Deadband
- Droop
- Response Time
- Headroom

Source: EPRI, 2021

Reference Point of Applicability – AC Interconnection



Reference Point of Applicability – DC Interconnection



[1] Includes IBR units like type IV wind turbine generators

[2] May serve as a supplemental IBR device that is necessary for the IBR plant with VSC-HVDC to meet the requirements of this standard at the RPA

[3] Depending on design, the POC may be on the TS side of the main IBR transformer.

IEEE 2800-2022 Technical Minimum Capability Requirements

TS owner can require additional capability

Raising the minimum bar

Capability Required in 2800

General Requirements
"shall have"
- Measurement accuracy
- Controls Prioritization
- Control responses
- Applicability to Diverse IBR Plants

Frequency Response
- Fast Frequency Response for under-frequency conditions — **"may" for over-frequency conditions**
- Primary Frequency Response

Reactive Power – Voltage Control
- Q for voltage control at zero active power — **AC-connected offshore wind: "should have"**
- Automatic Voltage Regulation Functions
- Reactive Power

Power Quality
TS owner "should" specify
- Harmonic Voltage Limitations
- Prevent Transient Overvoltage
- Harmonic Current Limitations
- Phase Unbalance
- Rapid Voltage Change
- Flicker Limitations

Ride-Through Capability and Performance, Protection
- Unbalanced Current Injection
- Balanced Current Injection
- Voltage Ride-through including TrOV + Consecutive
- Frequency & Phase-jump Ride-through
- Coordination of Protection

Modeling & Validation, Measurement Data, and Performance Monitoring
- Process and criteria for model validation
- High Fidelity Performance Monitoring
- Validated Models

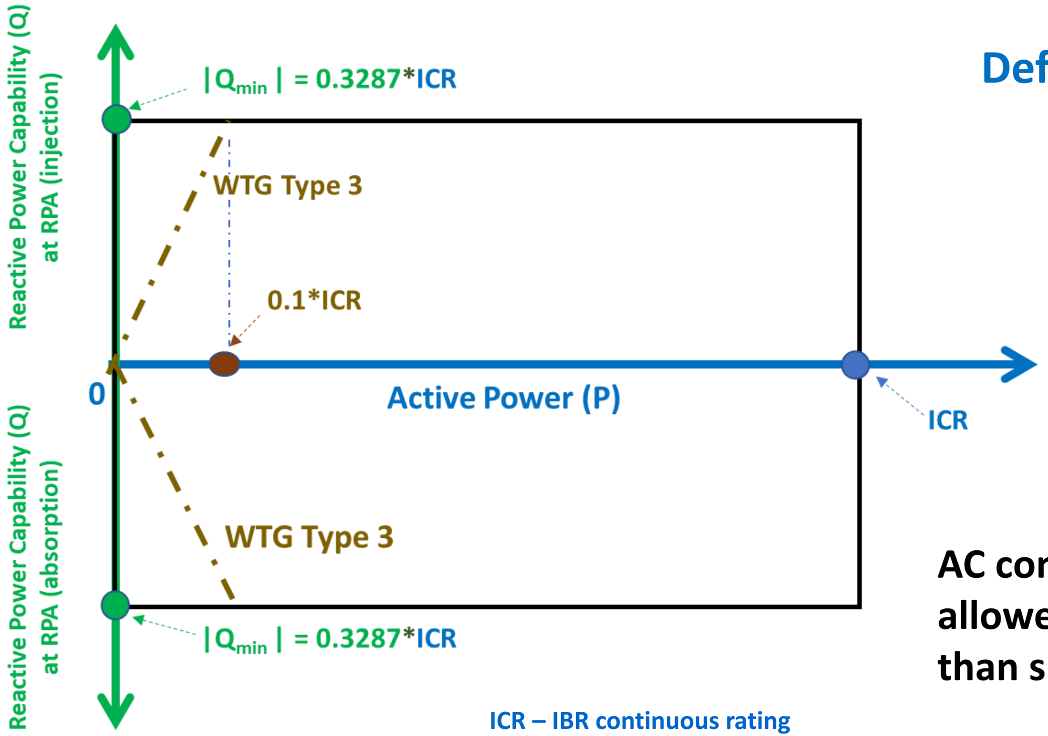
Tests and verification requirements
- Post-commissioning Monitoring
- Plant-level Evaluation & Modeling
- Commissioning Tests
- Type tests

Utilization of these capabilities is outside the purview of 2800

Source: EPRI, 2021

MINIMUM REACTIVE POWER CAPABILITY REQUIREMENTS

Min. Reactive Power Capability vs Active Power Injection



Default RPA: Point of Measurement

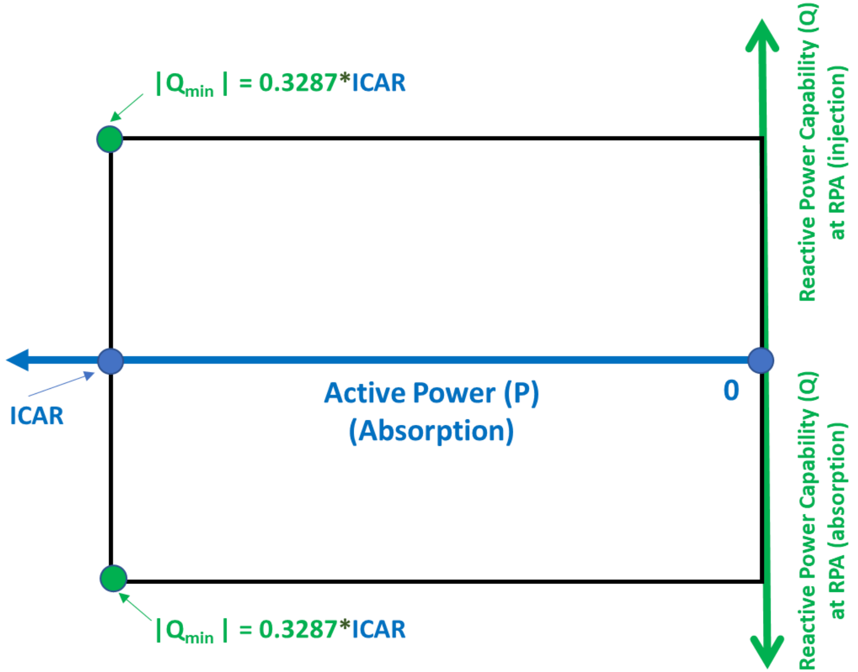
AC connected off-shore plant: exception allowed but shall not require capability less than specified for type III WTG-based IBR Plant.

ICR – IBR continuous rating

Q_{min} – minimum reactive power capability

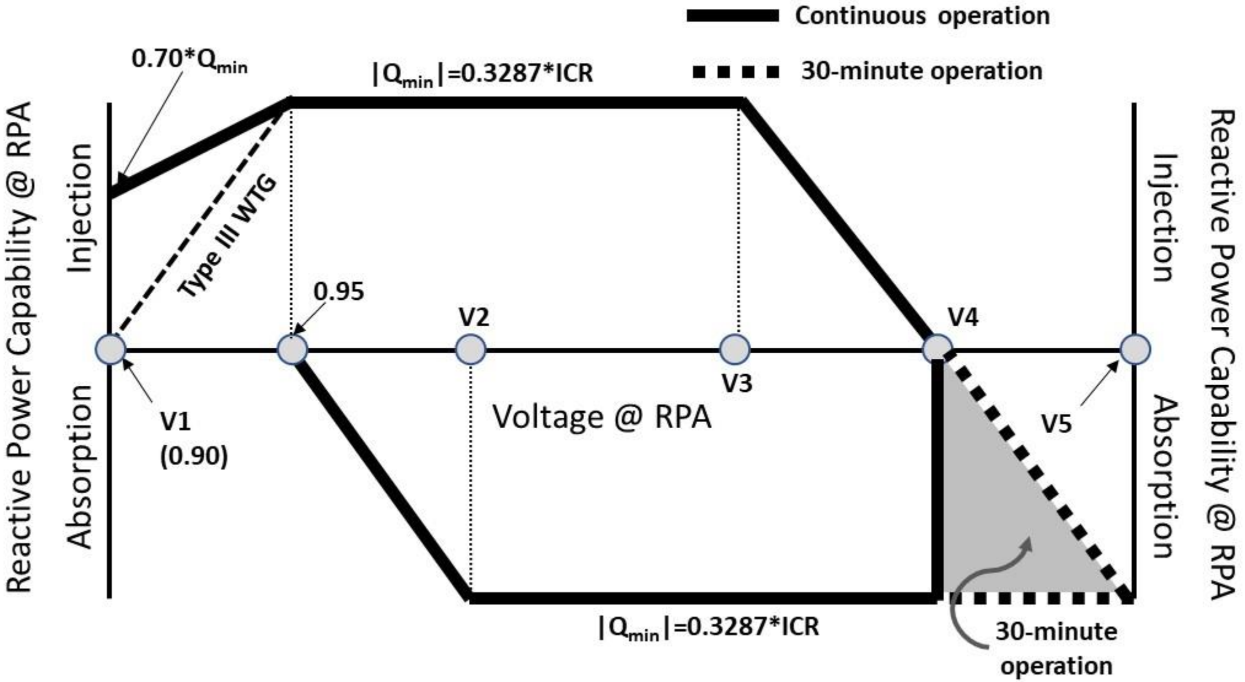
Min. Reactive Power Capability vs Active Power Absorption

Default RPA: Point of Measurement



ICAR – IBR continuous absorption rating
Q_{min} – minimum reactive power capability

Min. Reactive Power Capability at RPA vs Voltage



TS Nominal Voltage at RPA	V1 (p.u.)	V2 (p.u.)	V3 (p.u.)	V4 (p.u.)	V5 (p.u.)
< 200 kV	0.90	0.99	1.03	1.05	1.10
>= 200 kV except 500 kV and 735 kV as below	0.90	1.00	1.04	1.05	1.10
500 kV	0.90	1.02	1.06	1.10	1.10
735 kV	0.90	1.02	1.06	1.088	1.10
TS Owner/Operator may specify different values/thresholds.					

Voltage and Reactive Power Control Modes

The *IBR plant* shall provide the following mutually exclusive modes of reactive power control functions:

- RPA voltage control mode
- Power factor control mode
- Reactive power set point control mode

<u>RPA voltage control</u>

Closed-loop automatic control to regulate the voltage at the RPA

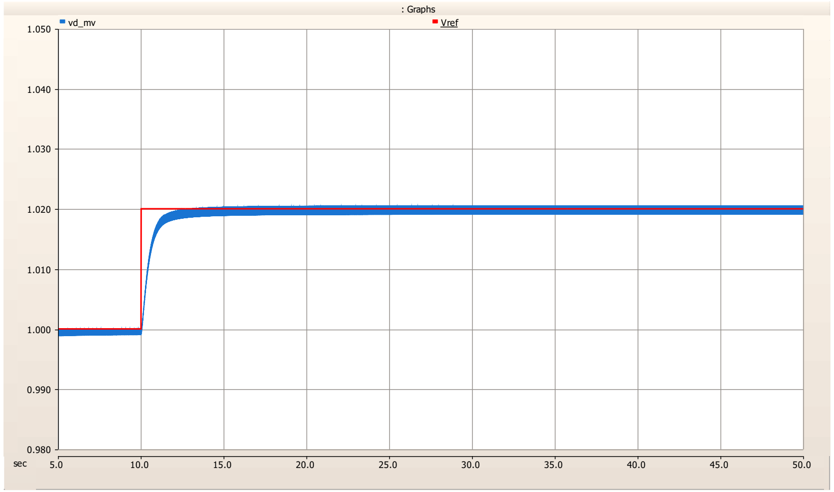
Capable of reactive power droop to ensure a stable and coordinated response

Any switched shunts or LTC transformer tap change operation needed to restore the dynamic reactive power capability shall respond within 60 s.

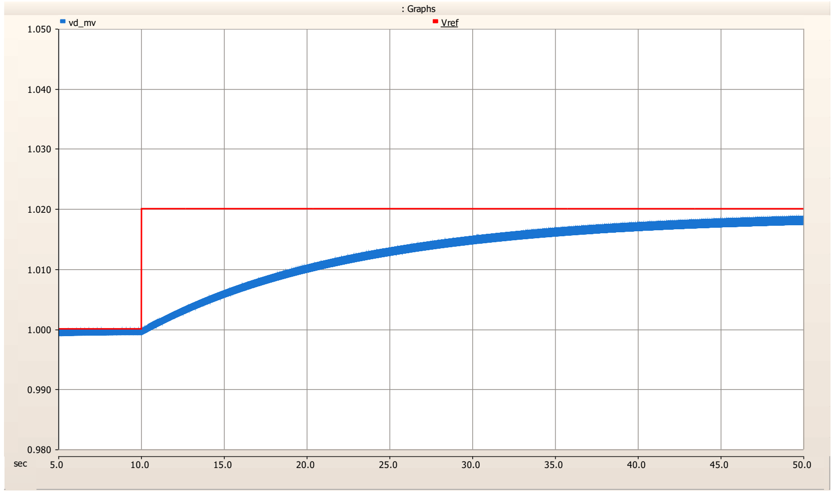
Parameter	Performance target	Notes
Reaction time	< 200 ms	
Max. *step response time*	As required by the *TS operator*	Typical *step response time* ranges between 1 s and 30 s.
Damping	Damping ratio of 0.3 or higher	Damping ratio, indicative of control stability, depends on grid strength.

Plant level voltage control
rise time = 1.0 sec vs 30.0 seconds

Red trace is the plant controller voltage setpoint (pu)
Blue trace is the measured 34.5 kV voltage (pu)



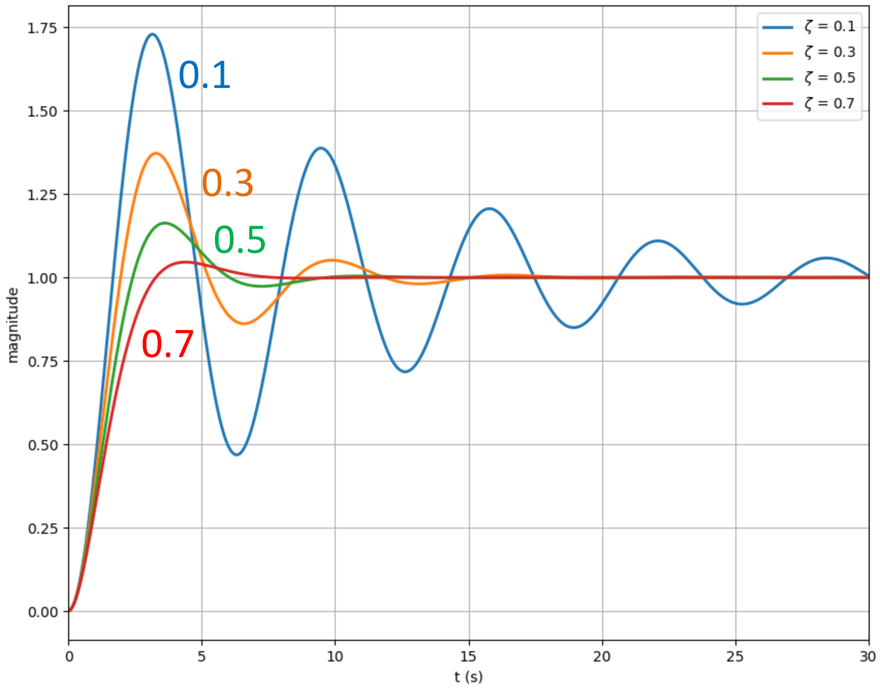
1 second rise time



30 second rise time

Source: EPRI, 2022

Plant level voltage control response damping > 0.3



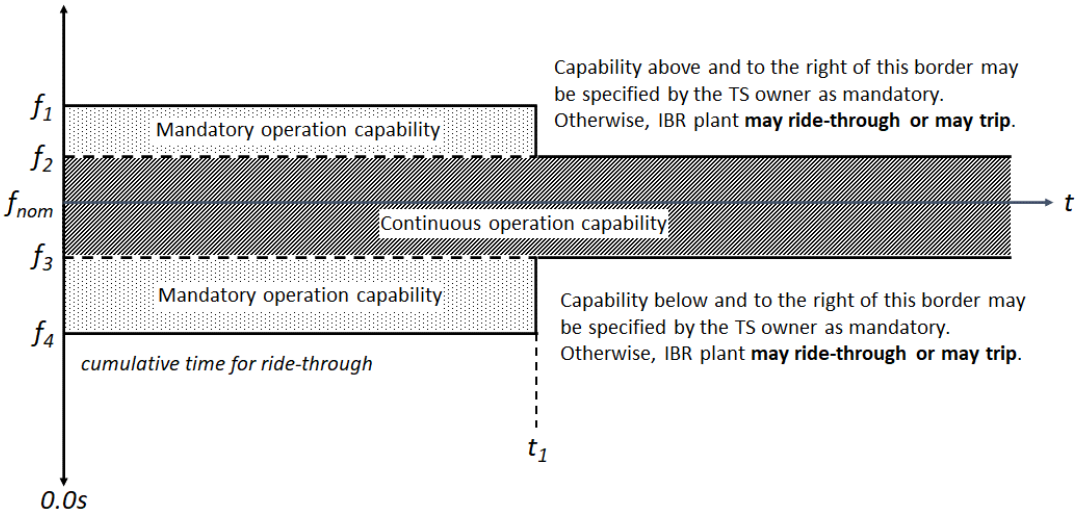
Source: EPRI, 2022

FREQUENCY DISTURBANCE RIDE-THROUGH CAPABILITY AND PERFORMANCE REQUIREMENTS

Frequency Disturbance Ride-Through Capability Requirements

The IBR plant shall be capable to ride-through and:

- maintain **synchronism** with the TS.
- meet **active power** requirements of **PFR and/or FFR** as applicable or **maintain pre-disturbance active power** output
- maintain its **reactive power** output. **Adjustment allowed** to stay in V/Hz limit



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

Exception

- Within **V/Hz capability** of IBR units, transformers & supplemental IBR devices.

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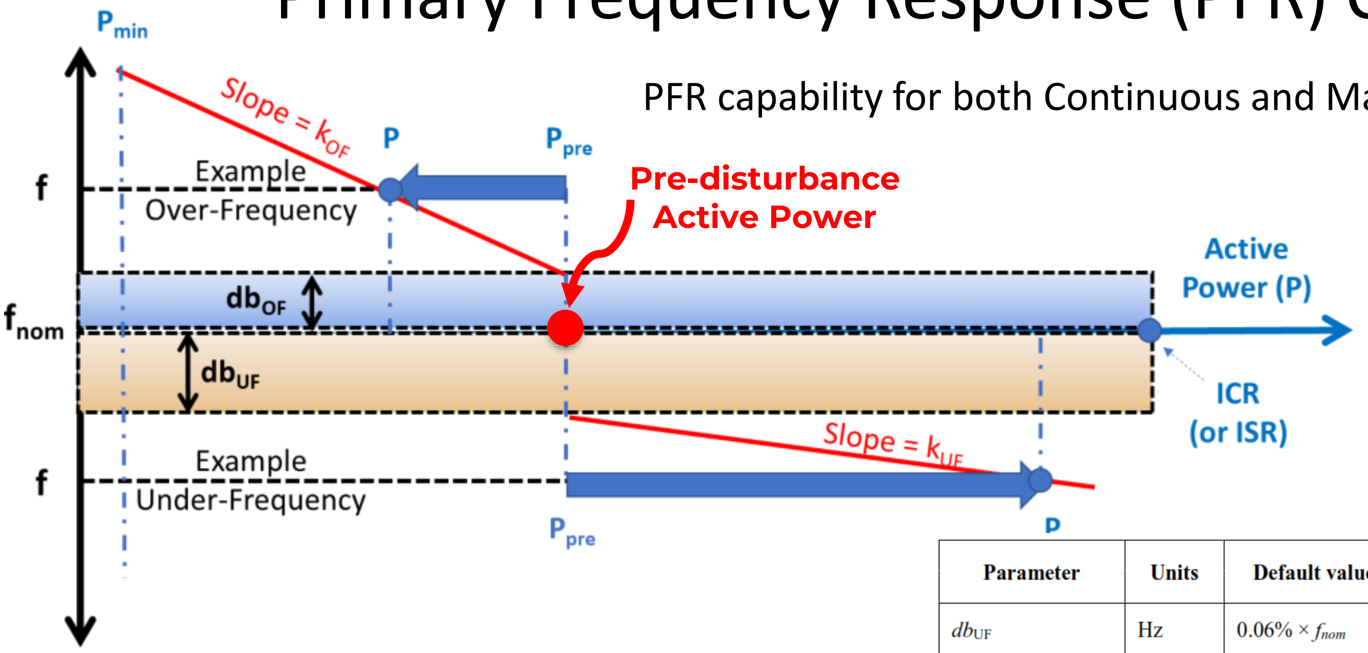
Primary Frequency Response (PFR) Capability

PFR capability for both Continuous and Mandatory Operation Regions



ICR: IBR Continuous Rating
ISR: IBR Short-Term Rating

Parameter	Units	Default value	*Ranges of available settings*	
			Minimum	Maximum
db_{UF}	Hz	0.06% × f_{nom}	0.025% × f_{nom}	1.6% × f_{nom}
db_{OF}	Hz	0.06% × f_{nom}	0.025% × f_{nom}	1.6% × f_{nom}
k_{UF}[68]		5%	2%[69]	5%
k_{OF}		5%	2%	5%

Primary Frequency Response (PFR) Dynamic Performance

Parameter	Units	Default value	*Ranges of available settings*	
			Minimum	**Maximum**
Reaction time	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 (2.5% of change or 0.5% of ICR)	1	5

Stable and damped response shall take precedence over *rise time* and *settling time*.

Fast Frequency Response (FFR) *Capability* Requirements

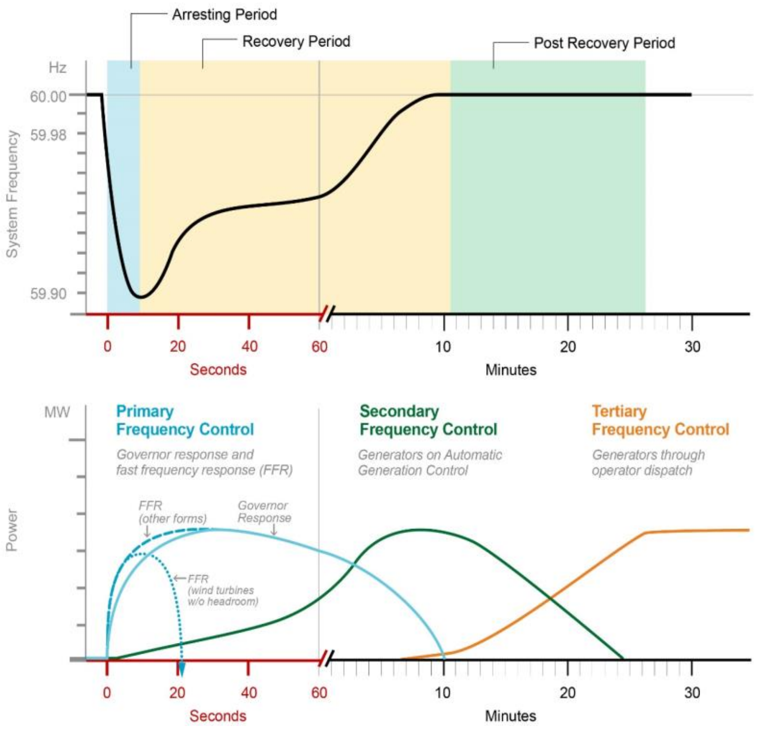
Inertial Response is also known as FFR in North America

Definition of FFR

*active power injected to the grid **in response to changes in measured or observed frequency** during the arresting period of a frequency excursion event **to improve the frequency nadir or initial rate-of-change of frequency***

Requirements for FFR from IBR

- *Capability* required for under-frequency conditions
- *Utilization* of FFR capability of IBR plant shall not be enabled by default
- FFR capability may be deployed for the purposes of ancillary service offering



Source: LBNL 2020

FFR Performance Requirements (General)

- FFR capability shall be an autonomous function
- The FFR response time capability, shall be adjustable to no greater than 1 second, including the reaction time for triggering FFR
- The response shall be stable and any oscillations shall be positively damped with a damping ratio of 0.3 or better
- Stable and damped response shall take precedence over response time
- *IBR plant* shall be capable of sustaining FFR for as long as the *IBR plant* energy resource is available or until supplanted by primary, secondary or tertiary frequency response, whichever is less
- Active power response during FFR actuation may temporarily exceed the *IBR continuous rating* (ICR) but shall not exceed the *IBR short-term rating* (ISR)
- FFR and PFR may actuate independently from each other or may complement each other

FFR is an evolving functional and performance capability

FFR Performance Requirements

FFR1: FFR proportional to frequency deviation

$$p_{\mathrm{FFR1}} = \min\left\{ p_{\mathrm{avl}}, p_{\mathrm{pre}} + \max\left(0, \frac{f_{\mathrm{UF,FFR1}} - f}{f_{\mathrm{nom}} \times k_{\mathrm{UF,FFR1}}}\right)\right\}$$

	Units	Default value	*Ranges of available settings*	
			Minimum	Maximum
$f_{\mathrm{UF,FFR1}}$	Hz	99.94% of f_{nom}	99.17% of f_{nom}	99.94% of f_{nom}
$k_{\mathrm{UF,FFR1}}$	%	1%	1%	5%

Other variants of FFR (Informative Annex K)

- FFR2: FFR proportional to df/dt
- FFR3: Fixed magnitude FFR with frequency trigger
- FFR4: Fixed magnitude FFR with df/dt trigger

Dynamic performance

- applicable parameters such as reaction and response time
- tuning of these parameters to be carefully studied on a case-by-case basis to avoid instable IBR plant operation

In many cases, FFR is just “a faster PFR”

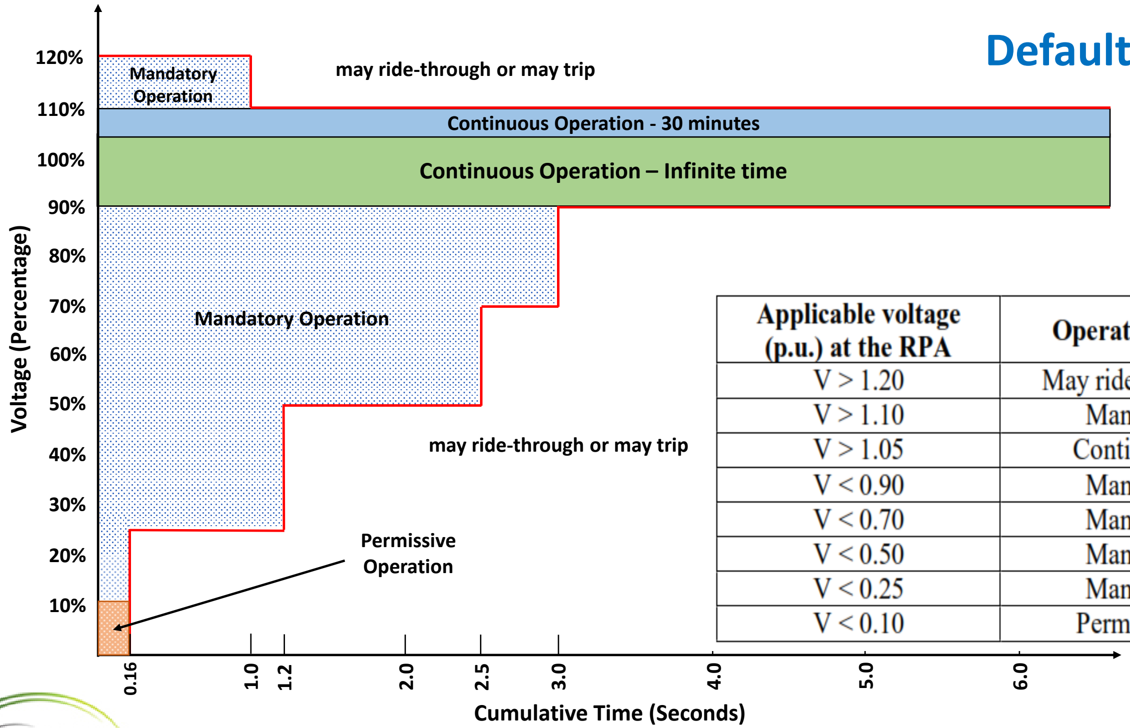
FFR Performance Requirements – WTG-Based IBR Plant

- **adjustable** frequency threshold **dead band** from -0.1 Hz to -1.0 Hz
- temporary increase of active power output, **provided wind resource is available**:
  - equal to at least 5% of rated power of each WTG in service when operating at or above 25% of rated power
  - for the duration from 5 s to 10 s
- limit **rise time** to reach maximum temporary increase of active power output to **1.5 s or less**.
- limit **decrease in active power output** during energy recovery to a **maximum of 20%** of pre-disturbance active power output.
  - energy recovery extend as long as possible to minimize the magnitude of the initial decrease of active power
- capability to **operate repeatedly** in FFR mode with a 2 minutes delay after the end of the recovery period
- **FFR shall take precedence over PFR** and **PFR shall be activated at the end of** energy recovery period following **FFR support**

VOLTAGE DISTURBANCE RIDE-THROUGH CAPABILITY AND PERFORMANCE REQUIREMENTS

Voltage Ride-Through Capability – Plants with Aux. Load limitations, i.e., Wind Plant

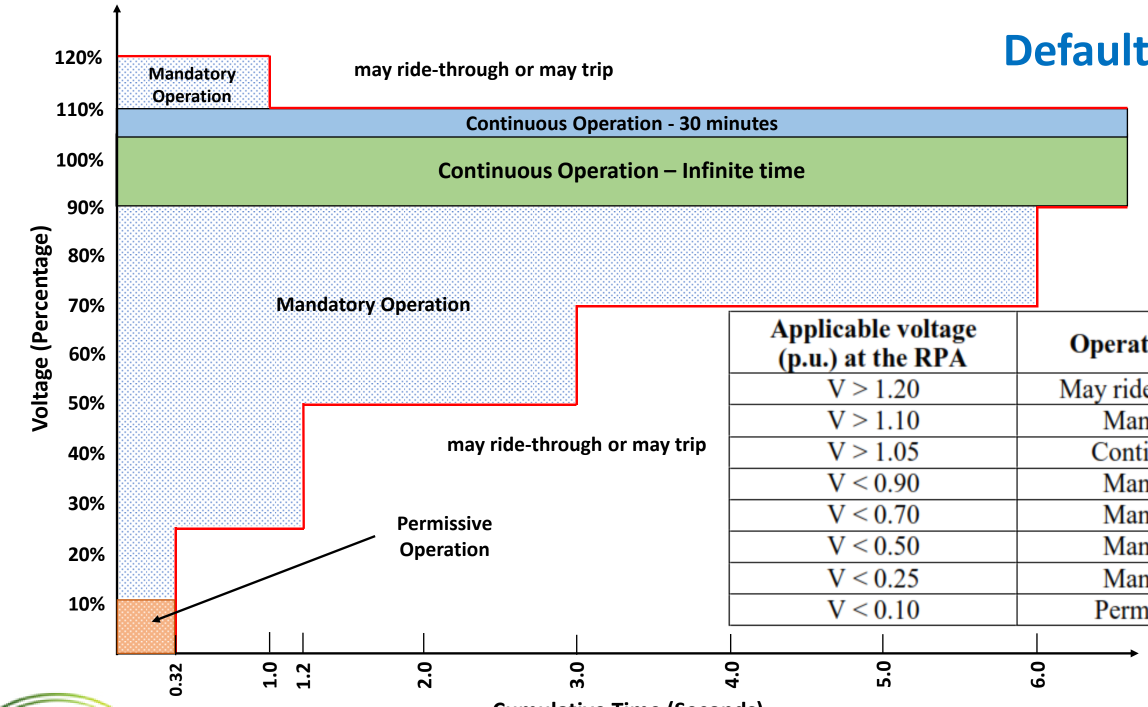
Default RPA: Point of Measurement



Applicable voltage (p.u.) at the RPA	Operating mode/response	Minimum ride-through time (s) (design criteria)
V > 1.20	May ride-through or may trip	NA
V > 1.10	Mandatory operation	1.0
V > 1.05	Continuous operation[90]	1800
V < 0.90	Mandatory operation	3.00
V < 0.70	Mandatory operation	2.50
V < 0.50	Mandatory operation	1.20
V < 0.25	Mandatory operation	0.16
V < 0.10	Permissive operation[91]	0.16

Voltage Ride-Through Capability – Plants without Aux. Load limitations, i.e., Solar Plant

Default RPA: Point of Measurement



Applicable voltage (p.u.) at the RPA	Operating mode/response	Minimum ride-through time (s) (design criteria)
V > 1.20	May ride-through or may trip	NA
V > 1.10	Mandatory operation	1.0
V > 1.05	Continuous operation[90]	1800
V < 0.90	Mandatory operation	6.00
V < 0.70	Mandatory operation	3.00
V < 0.50	Mandatory operation	1.20
V < 0.25	Mandatory operation	0.32
V < 0.10	Permissive operation[91]	0.32

Clarification of Voltage Ride-Through Capability Req.

Three possible understanding:

- Voltage versus Time curve: For a given voltage, IBR plant shall not trip until the duration at this voltage exceeds ride-through curve capability.
  - ✓Correct understanding

- Voltage Deviation *times* Time *Area*: Area between a nominal voltage (100%) and either a low or high voltage ride-through boundary.

- Voltage versus Time Envelope: Ride-through curves define an envelope to lay as a template over a voltage versus time trajectory.

Voltage Ride-Through Performance

No specification of current magnitude

The 1-cycle time required for DFT (to derive phasor quantities) is included in specified response/settling time.

	Type III WTGs	All other IBR Units
Step Response Time	NA[1]	≤ 2.5 cycles
Settling Time	≤ 6 cycles	≤ 4 cycles
Settling Band	Max of (±10% of required change or ±2.5% of IBR unit maximum current)	Max of (±10% of required change or ±2.5% of IBR unit maximum current)

Note 1: Initial response is driven by machine characteristics, & not the control system.

Slower response/settling time is permitted with mutual agreement between TS owner and IBR owner.

Voltage Ride-Through Performance Requirements

During a ride-through mode including fault conditions -

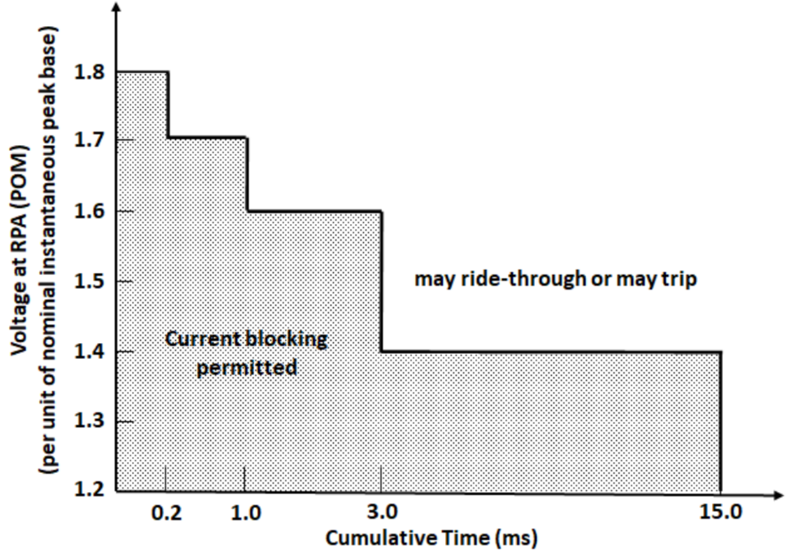
- Type & Magnitude of current injection shall be **dependent** on voltage at inverter (IBR unit) terminals. ← **RPA: Point of Connection**
- System Disturbance/Balanced Faults:
  - Capability to operate in **active or reactive current priority mode**
  - In reactive current priority mode: increased injection of reactive current
- Unbalanced faults:
  - Requirements for injection of **negative sequence reactive current**.
- Injection of current from IBR units shall be at the **same frequency** as of the terminal voltage with following **exceptions**:
  - Close-in faults (PLL fails to track system frequency, type III WTG where control of rotor current is lost
  - Transients, transformer inrushes etc….

Transient overvoltage ride-through requirements

Default RPA: Point of Measurement

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.



The ***IBR unit*'s TOV ride-through capability may differ from the *IBR plant*'s TOV ride-through requirement** specified in this subclause. The *IBR plant* design should coordinate an *IBR unit*'s TOV ride-through capability with surge protection implemented within the *IBR plant* to allow the *IBR plant* to meet specified TOV ride-through requirements.

OTHER REQUIREMENTS

Other Capability/Performance Requirements

- **Consecutive voltage dip ride-through**

  Capability to ride-through specified combination of successive voltage dips

- **Phase angle jump ride-through**

  shall ride through positive-sequence phase angle changes in sub-cycle-to-cycle time frame ≤ 25 electrical degrees

- **Rate of change of frequency ride-through**

  Capability to ride through an absolute ROCOF magnitude that is less than or equal to 5.0 Hz/s

- **Restore active power output after voltage disturbance**

  Capability to restore active power output to 100% of pre-disturbance level at an average rate equal to 100% of ICR divided by specified active power recovery time. The default active power recovery time shall be 1.0 s.

Power Quality Requirements

- **Voltage fluctuations** induced by IBR Plant
  - Limits for frequent/infrequent rapid voltage changes & Flicker are specified
- **Harmonic distortion**
  - Limits for current harmonic limits are specified
  - Limits for voltage harmonic limits are not specified. TS owner should specify voltage harmonic limits
- **Overvoltage contribution** by IBR Plant
  - Limits for instantaneous as well as over fundamental frequency period overvoltage are specified

Protection Requirements

- Standard does <u>not require </u>specific type of protection to be applied within IBR Plant.
- If protection is applied (including on auxiliary load), shall allow IBR plant to meets its ride-through requirements
- Some requirements for frequency, ROCOF, overvoltage, overcurrent protection.
- **Unintentional Islanding** protection

  if not permitted by TS owner, protection shall be implemented in accordance with requirements of TS owner
- **Interconnection System** protection

  shall be in accordance with requirements of TS owner

Modeling Data

- Some specified requirements **cannot** be verified based on tests (type, commissioning etc.)
- Verification of such requirements is **done using models and simulations**
- IBR owner is **required** to provide **verified models** to TS owner/operator

  such as, power flow, stability dynamic model, short-circuit, EMT, harmonics etc.
- Development of **verified models** is outside the scope of this standard; however, some guidance is provided.
- **Annex G** provides recommended practice for modeling data

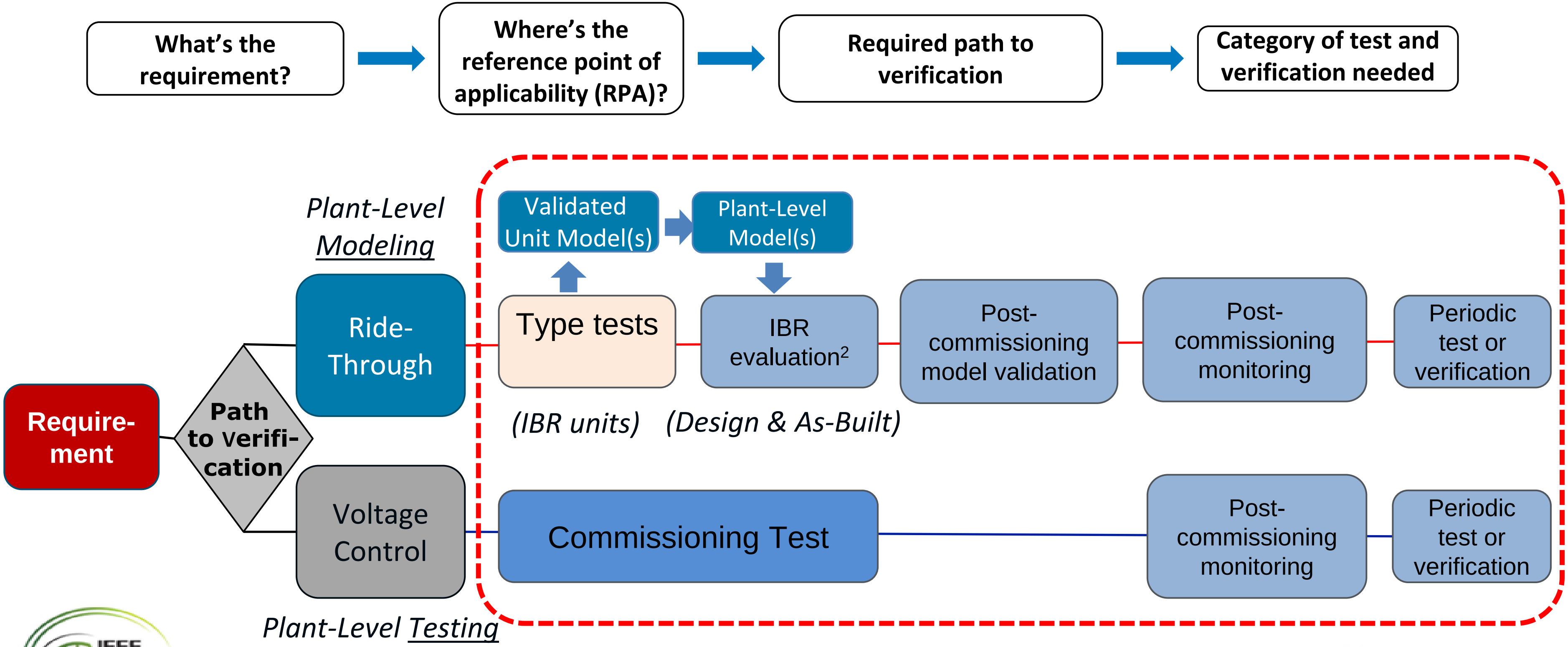
  i.e., details in each type of model

Measurements for Performance Monitoring/Model Validation

IBR plant is required to take measurements at specified points throughout the resource, from individual IBR units to the POM, using various technologies

Data Type	Data Points	Recording Rate	Retention	Duration
Plant SCADA Data	Voltage, frequency, P, Q, etc.	One record per second	One year	One year
Plant Equipment Status Log	Breakers, shunt devices, LTCs, collector system, IBR units, etc.	Static, as changed	One year	NA
Sequence of Event Recordings	Date/Time stamp, type of event, sequence number etc.	Static, as changed	One year	NA
Digital Fault Recordings	Each L-G voltage, phase & neutral currents, etc.	>128 samples/cycle, triggered	90 days	5 second data
Dynamic Disturbance Recordings	Voltage, current, frequency, calculated P and Q	Input: ≥ 960 samples/second Output: ≥ 60 times/second; continuous	One year	NA
IBR Unit Data	Fault & alarm codes, PLL loss of synchronism, dc/ac voltage and current etc.	Many kHz, triggered	90 days	5 second data

Test and Verification Framework



Summary & Conclusion

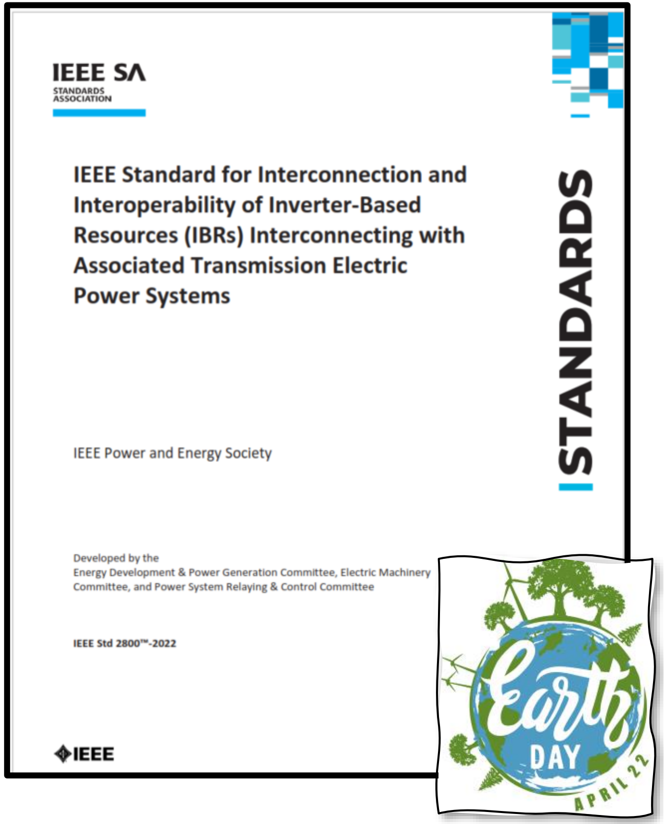
- The standard ***provides*** Interconnection Requirements for Large Solar, Wind and Storage Plants
  - Expected to mitigate most reliability issues identified by NERC
- As a voluntary IEEE standard, it ***requires adoption*** by the appropriate authorities to become mandatory
  - Adoption is not contingent on IEEE P2800.2
- Drafting of **conformance procedures** has commenced under IEEE P2800.2
  - ***Get involved***

P2800.2

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

Active PAR

IEEE SA: https://standards.ieee.org/ieee/2800.2/10616/
P2800.2 WG: https://sagroups.ieee.org/2800-2/


IEEE SA STANDARDS ASSOCIATION

STANDARDS

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

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

Available from IEEE at https://standards.ieee.org/project/2800.html
and via IEEEExplore: https://ieeexplore.ieee.org/document/9762253/

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https://sagroups.ieee.org/2800/

P2800.2 WG

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- Manish Patel, mpatel@southernco.com

https://sagroups.ieee.org/2800-2/

IEEE 2800-2022

Available from IEEE at https://standards.ieee.org/project/2800.html
and via IEEExplore: https://ieeexplore.ieee.org/document/9762253/

Outline – Joint SEIA-ACP Webinar – May 31, 2022

- **Welcome by host organizations *– 5 min.***
  - Jeremiah Miller, SEIA
  - Michele Myers-Mihelic, ACP
  - Michele Mihelic, American Clean Power Association
- **Presentation by Mahesh Morjaria (WG Vice-Chair) – 50 min.**
  - IEEE P2800: motivation, purpose, scope, schedule
  - High-level review of selected requirements
  - Potential adoption of IEEE 2800 in North America
- **Comments by OEMs, developers & transmission planners *– 5 min.***
  - Moderated by Jens Boemer (WG Chair) and Jeremiah Miller
- **Q&A (Mahesh & Jens) - 15 min.**

IEEE PES Power & Energy Society

IEEE

Thoughts on Adoption of IEEE 2800

- **Gap Analysis** – comparing existing IC requirements with IEEE 2800 requirements
- Adoption of IEEE 2800 is not contingent upon publication/adoption of IEEE P2800.2 (recommended practice for test & verification procedures)
- Needs consideration of **enforcement date, grandfathering/flexibility** for IBR Plants being built at the time of adoption
- Possible Adoption methods
  - **Full adoption** by simple reference
  - **Full or partial adoption**, clause-by-clause reference, additional requirements

IEEE P2800.2 Motivation

IEEE 2800 contains performance requirements for IBRs, and a table of methods to verify each requirement

- Details of verification methods not included

P2800.2 will develop details through "individual standard" process (like 2800, 1547, 1547.1, etc)

Requirement	RPA at which requirement applies	*IBR unit*-level tests (at the POC)	*IBR plant*-level verifications (at the RPA)						
		Type tests[157]	Design evaluation (including modeling)	As-built installation evaluation	Commissioning tests	Post-commissioning model validation	Post-commissioning monitoring	Periodic tests	Periodic Verification
		Responsible Entity							
		IBR Manufacturer	Developer /TS owner/TS operator	Developer /TS owner/TS operator	Developer /TS owner/TS operator	Developer / IBR Operator /TS owner/TS operator	IBR Operator /TS owner/TS operator	IBR operator /TS owner/TS operator	IBR operator /TS owner/TS operator
6.1 Primary Frequency Response (PFR)	POC & POM	NR[158]	R	R	R	R	D	D	D
6.2 Fast Frequency Response (FFR)	POC & POM	R[159]	R	R	R	R	D	D	D
Clause 7 Response to TS abnormal conditions									
7.2.2 Voltage disturbance ride-through requirements	POC[160] & POM[161]	R	R	R	NR	R	R	D	D
7.2.3 Transient overvoltage ride-through requirements	POM	R	R	R	NR	R	R	D	D
7.3.2 Frequency disturbance ride-through requirements	POM	R	R	R	NR	R	R	D	D
7.4 Return to service after IBR plant trip	POM	refer to line entries for 4.10 (Enter service)							

Anticipated Timeline, and What Comes Next?

	Jan 2019-Dec 2020	Q1-Q2/2021	Q2-Q4/2021	Q4/2021	Q1-Q2/2022	2022	2023	2024
2800	WG Drafting in Parallel SubGroups	Initial Sponsor Ballot	Recirculation	Submit to RevCom	**Publication**			
P2800.1 *entity project*								
P2800.2 *individual project**					Kick-Off Jan 18, 2022	WG Drafting in Parallel SubGroups	Balloting	Publication
Related activities	IEEE 1547.1 is published		NERC IRPWG Guidelines	…	IEEE P2882	**Potential 2800 Adoption**	→	**Potential P2800.2 Adoption**

P2800.1 entity project is **inactive**

*Project authorization request (PAR) approved by NesCom on May 21, 2021 (https://development.standards.ieee.org/myproject-web/app#viewpar/12623/9133); contact andy.hoke@nrel.gov and sign up for P2800.2 Working Group and Task/Project on IEEE SA myProject at https://development.standards.ieee.org/myproject-web/app#interests

Now that IEEE 2800 has been published, the drafting of conformance procedures has commenced under IEEE P2800.2

Adoption by ERCOT Inverter-Based Resources Task Force (IBRTF) Objective, Approach, and Timeline

Objective

Inform strategic ERCOT decision on IEEE 2800 adoption method:

- General reference (‘wholesale adoption’)
- Detailed reference (‘piecemeal adoption – per reference’)
- Full specification (‘piecemeal adoption – own language’)

Timeline by Priority

- Wholesale or High: June – Dec 2022
- Medium: Oct 2022 – Dec 2023
- Low: 2024

Approach

1) EPRI gap analysis
   a. High-level gap analysis: identify where ERCOT has no requirements but IEEE 2800 does
   b. Detailed gap analysis: identify where ERCOT and IEEE 2800 both specify requirements and
      Where IEEE 2800 are more specific or more stringent than ERCOT requirements (“<”)
      ii. Where ERCOT requirements and P2800 already align in stringency and level of specificity (“~“)
      Where ERCOT requirements exceed IEEE 2800 either in stringency or specificity (“>“)
2) Stakeholder discussion in ERCOT’s Inverter-Based Resources Task Force (IBRTF)

Adoption by ERCOT Inverter-Based Resources Task Force (IBRTF)

Preliminary High-Level Gap Assessment of ERCOT Nodal Protocols

Legend: X Prohibited, √ Allowed by Mutual Agreement, ‡ Capability Required, NR Not Required
(‡) Procedural Step Required as specified, Δ Test and Verification Defined, !!! Important Gap

Acknowledgements for contributions and peer-review: Julia Matevosyan (ESIG)

Function Set	Advanced Functions Capability	ERCOT Nodal Protocols	IEEE 2800-2022
General	Definitions	?	?
General	Reference Point of Applicability	POI	POM
General	Adjustability in Ranges of Available Settings	NR (!!!)	‡
General	Prioritization of Functions	‡	‡
Monitoring, Control, and Scheduling	Ramp Rate Control		
Monitoring, Control, and Scheduling	Communication Interface	‡	‡
Monitoring, Control, and Scheduling	Disable Permit Service (Remote Shut-Off, Remote Disconnect/Reconnect)	‡	‡
Monitoring, Control, and Scheduling	Limit Active Power	‡	‡
Monitoring, Control, and Scheduling	Monitor Key Data	‡	‡
Monitoring, Control, and Scheduling	Remote Configurability		√
Monitoring, Control, and Scheduling	Set Active Power	‡	√
Monitoring, Control, and Scheduling	Scheduling Power Values	‡	√
Reactive Power & (Dynamic) Voltage Support	Constant Power Factor	‡	‡
Reactive Power & (Dynamic) Voltage Support	Voltage-Reactive Power (Volt-Var)	‡	‡
Reactive Power & (Dynamic) Voltage Support	Autonomously Adjustable Voltage Reference	?	
Reactive Power & (Dynamic) Voltage Support	Capability at zero active power ("VArs at night")	NR (!!!)	‡
Reactive Power & (Dynamic) Voltage Support	Active Power-Reactive Power (Watt-Var)		
Reactive Power & (Dynamic) Voltage Support	Constant Reactive Power	NR (!!!)	‡
Reactive Power & (Dynamic) Voltage Support	Voltage-Active Power (Volt-Watt)	NR	NR
Reactive Power & (Dynamic) Voltage Support	Dynamic Voltage Support / Current Injection during VRT: Balanced	‡	‡
Reactive Power & (Dynamic) Voltage Support	Dynamic Voltage Support / Current Injection during VRT: Unbalanced	NR (!!!)	‡

Function Set	Advanced Functions Capability	ERCOT Nodal Protoc.	IEEE 2800-2022
Bulk System Reliability & Frequency Support	Frequency Ride-Through (FRT)	‡	‡
Bulk System Reliability & Frequency Support	Rate-of-Change-of-Frequency (ROCOF) Ride-Through	NR (!!!)	‡
Bulk System Reliability & Frequency Support	Voltage Ride-Through (VRT)	‡	‡
Bulk System Reliability & Frequency Support	Transient Overvoltage Ride-Through	√ (!!!)	‡
Bulk System Reliability & Frequency Support	Consecutive Voltage Dip Ride-Through	NR (!!!)	‡
Bulk System Reliability & Frequency Support	Restore Output After Voltage Ride-Through	NR (!!!)	‡
Bulk System Reliability & Frequency Support	Voltage Phase Angle Jump Ride-Through	NR (!!!)	‡
Bulk System Reliability & Frequency Support	Frequency Droop / Frequency -Watt	‡	‡
Bulk System Reliability & Frequency Support	Fast Frequency Response / Inertial Response: Underfrequency FFR	√ (!!!)	‡
Bulk System Reliability & Frequency Support	Fast Frequency Response / Inertial Response: Overfrequency FFR	NR	√
Bulk System Reliability & Frequency Support	Return to Service (Enter Service)	?	‡
Bulk System Reliability & Frequency Support	Black Start	NR	√
Protection Functions and Coordination	Abnormal Frequency Trip	NR	√
Protection Functions and Coordination	Rate of Change of Frequency (ROCOF) Protection	?	√
Protection Functions and Coordination	Abnormal Voltage Trip	NR	√
Protection Functions and Coordination	AC Overcurrent Protection	?	√
Protection Functions and Coordination	Unintentional Islanding Detection and Trip	NR	√
Protection Functions and Coordination	Interconnection System Protection	?	√
Power Quality	Limitation of DC Current Injection		
Power Quality	Limitation of Voltage Fluctuations	NR (!!!)	‡
Power Quality	Limitation of Current Distortion	NR (!!!)	‡
Power Quality	Limitation of Voltage Distortion	NR	√
Power Quality	Limitation of (Transient) Overvoltage	NR (!!!)	‡

Source: EPRI, 2022

Thirteen (13) high-level gaps in ERCOT relate to 2800 mandatory requirements

Adoption by ERCOT Inverter-Based Resources Task Force (IBRTF)

Comparison Basis and Remarks

ERCOT

1. ERCOT Nodal Protocols (NPs) – applicable Sections available at https://www.ercot.com/mktrules/nprotocols/current and published on or prior to February 11, 2022.

   –The [Nodal] Protocols outline the procedures and processes used by ERCOT and Market Participants for the orderly functioning of the ERCOT system and nodal market.

2. Nodal Operating Guides (NOGs) – applicable Sections available at https://www.ercot.com/mktrules/guides/noperating/current and published on or prior to March 1, 2022

   –The Nodal Operating Guides, which supplement the Protocols, describe the working relationship between ERCOT and the entities within the ERCOT Region that interact with ERCOT on a minute-to-minute basis to ensure the reliability and security of the ERCOT System.

3. Planning Guide (PG) – applicable Sections available at https://www.ercot.com/mktrules/guides/planning/current and published on or prior to `January 1, 2022

   –The Planning Guide, which supplements the ERCOT protocols, provides ERCOT stakeholders and market participants with information and documentation concerning the ERCOT transmission planning process.

4. Model Quality Guide (MQG) – applicable Sections available at https://www.ercot.com/services/rq/integration and published on or prior to April 20, 2021

   –Assists REs/IEs submit stability models per Planning Guide Section 6.2, including the new Model Quality Testing requirements. Also includes the UDM Model Guideline and PSCAD Model Guideline.

IEEE 2800-2022

IEEE 2800-2022 (April 2022)

Remarks on ERCOT documents:

- Both NPs and NOGs are mandatory.
- NPs are broad in scope and tend to high level.
- NOGs tend to be narrower in scope and provide guidance on more practical/ operational aspects.
- The language in NPs and NOGs should not be in conflict; if it is in conflict, it should be pointed out as a finding.
- Some requirements only apply to resources providing ancillary services (AS); this would be explicitly stated, or it is obvious from the Section of the NPs.
  - For example, where an entire section is on Responsive Reserve (RRS) qualification or performance.

Thirteen (13) high-level gaps in ERCOT relate to 2800 mandatory requirements

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