IEEE 2800-2022 Adoption

A Preliminary Detailed Gap Assessment of ERCOT's Nodal Protocols and Nodal Operating Guides relate to IEEE 2800-2022

ERCOT Inverter-Based Resources Task Force (IBRTF)

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May 23, 2022

Classification: Public

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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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This assessment is ongoing. We explicitly encourage stakeholders to provide feedback!

Introduction & Refresher

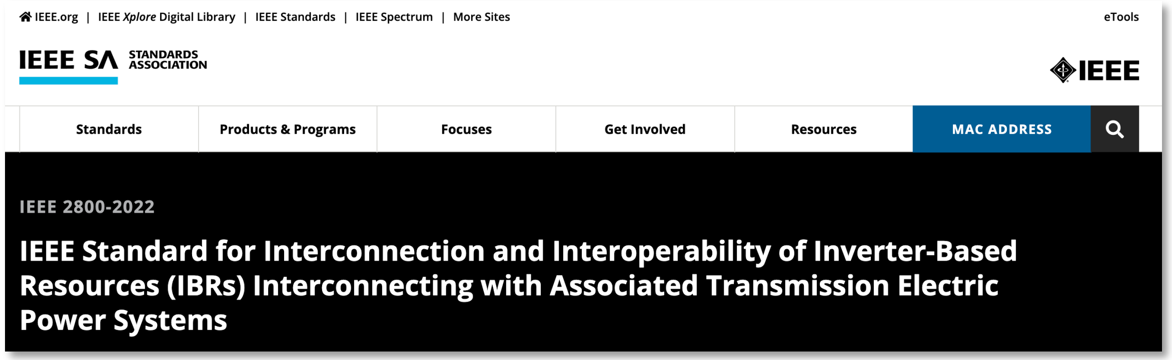
Meetings to Date with IEEE 2800-2022 Scope

Date	Scope	Presentation
[Mar 18, 2022 - IBRTF Meeting by Webex Only]	General Overview	Posted
[Apr 08, 2022 - IBRTF Meeting by Webex Only]	Voltage Ride-Through, Reactive Power, and Voltage Support	Not posted
[May 23, 2022 - IBRTF Meeting by Webex Only]	Primary Frequency Response, Fast Frequency Response, Frequency Ride-Through, RoCoF Ride-Through, etc.	Not posted
TBD	Requirements in Scope of Transmission Service Provider (TSP) and not of ERCOT Other Requirements of IEEE 2800 by Mutual Agreement (Optional) Conformity Assessment: OEM equipment readiness, self-certification, etc.	

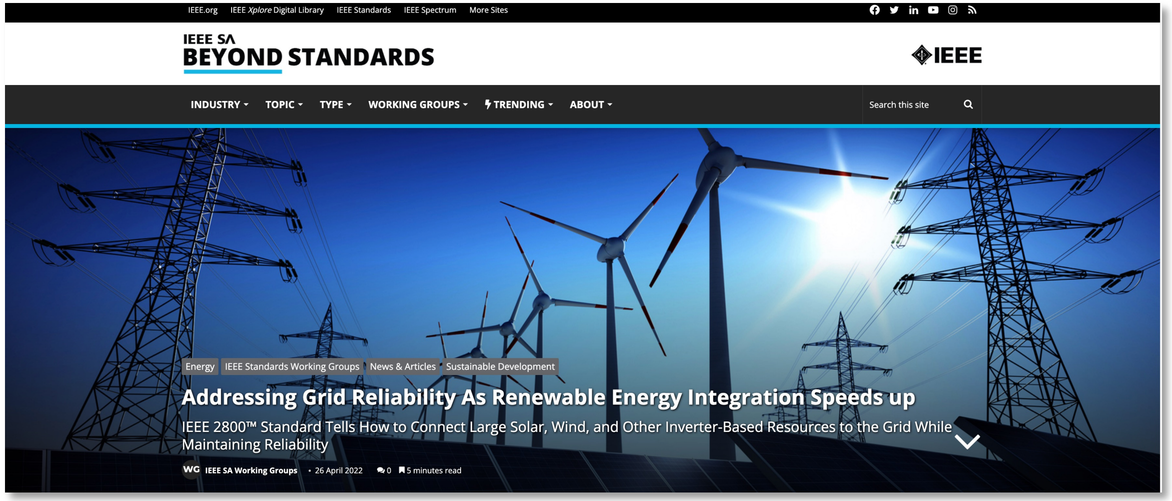
Recap on discussion from April 8, 2022

- Reactive vs. active power/current priority
  - Reactive priority needed for LVRT?
  - Active power/current withdrawal at HVRT may lead to further voltage increase?
- Coordination of *IBR unit* and *IBR plant controller* during and after faults?
- Feedback received for further action:
  - PG 7.5 – PGRR 75 and 85 Update? No!?
  - NOG 2.9.1 – voltage recovery to 90% in 1.75 seconds?
  - NOG 2.6.2 and 2.9?
  - TrOV requirement only for HVDC ties today?

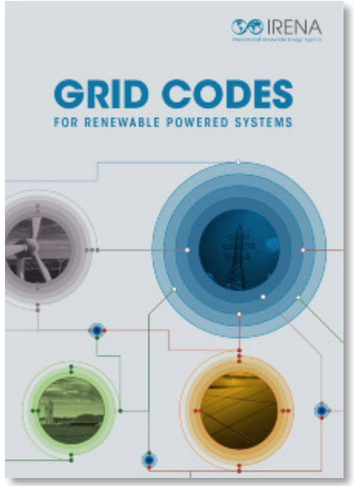
Resources and Media



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



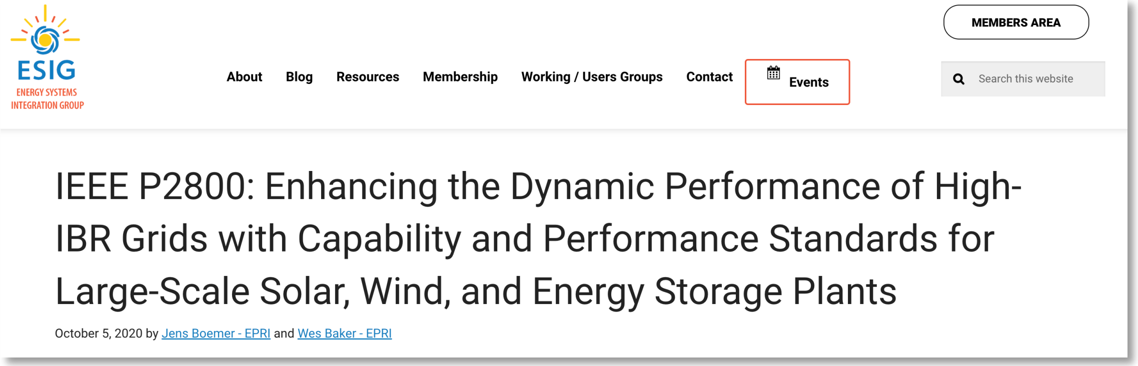
https://beyondstandards.ieee.org/addressing-grid-reliability-as-renewable-energy-integration-speeds-up/



"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/

Webinar Recording Available:
https://engagestandards.ieee.org/IEEE-2800-Update-Registration-LP.html

EPRI

IRENA Report: Key Messages

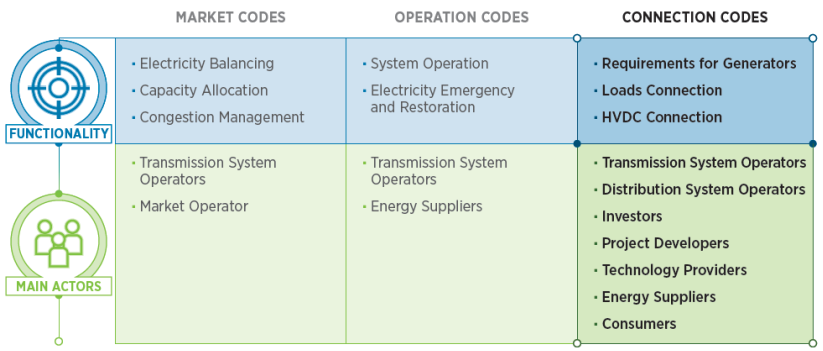
*“Power system transformation towards decentralisation, digitalisation and electrification calls for **evolving grid codes**”*

- **[Inverter-based resources, IBR] impact** the way power systems are operated
- The role of grid codes in **building trust** between different actors
- An **imperfect grid code** is, in many cases, better than no grid code at all
- Grid codes should be **technology-neutral** and should **evolve** to meet system needs
- Grid codes should **enable innovations** to connect safely to the grid
- Ensuring **compliance** with the code is key
- International **standardization** and regional grid codes facilitate sharing of flexibility and increased economy of scale for equipment manufacturers

What does that mean for IEEE 2800-2022?

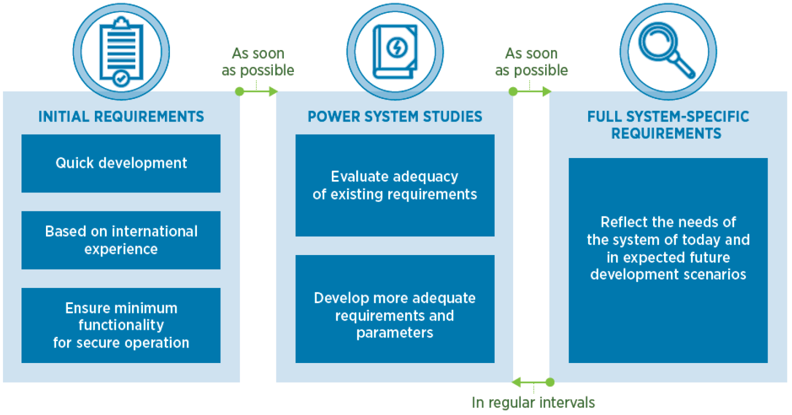
➢ Cornerstone in a transforming power system
➢ Tailored to North American context

Figure ii **Categories of grid codes in Europe, functionality and main actors**



Note: HVDC = high voltage direct current.

Figure iii **Grid code parameter development and revision process**



© IRENA (2022), *Grid codes for renewable powered systems*, International Renewable Energy Agency, Abu Dhabi. [Online]

Common Ground: IEEE 2800-2022

- **Harmonizes technical minimum capability** for Large Solar, Wind, and Storage Plants at the time of interconnection, including those connected via VSC-HVDC like offshore wind
  - Could create a "level playing field" for IBR developers, *if adopted*
- A **consensus-based, voluntary IEEE performance standard**
  - Developed by over 175 working group participants from transmission owners, OEMs, developers, and consultants
  - Successfully passed the industry peer review by 466 IEEE SA balloters **(>94% approval**, >90% response rate)
- Approved in January 2022, **publication in April/May 2022**

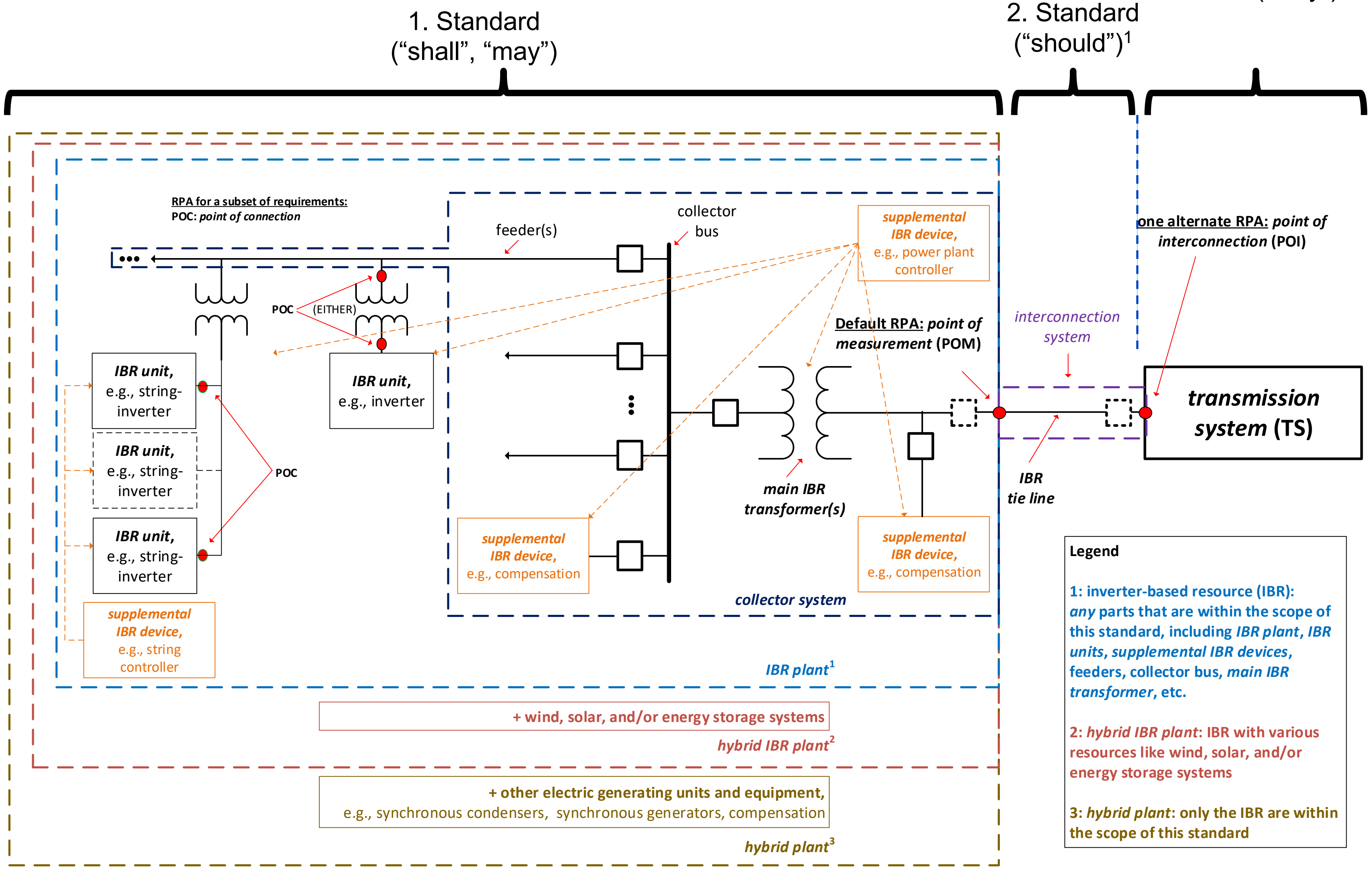
Available from IEEE at https://standards.ieee.org/project/2800.html
and via IEEEExplore: https://ieeexplore.ieee.org/document/9762253/

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

Scope and Language of 2800 Requirements

Important Terms

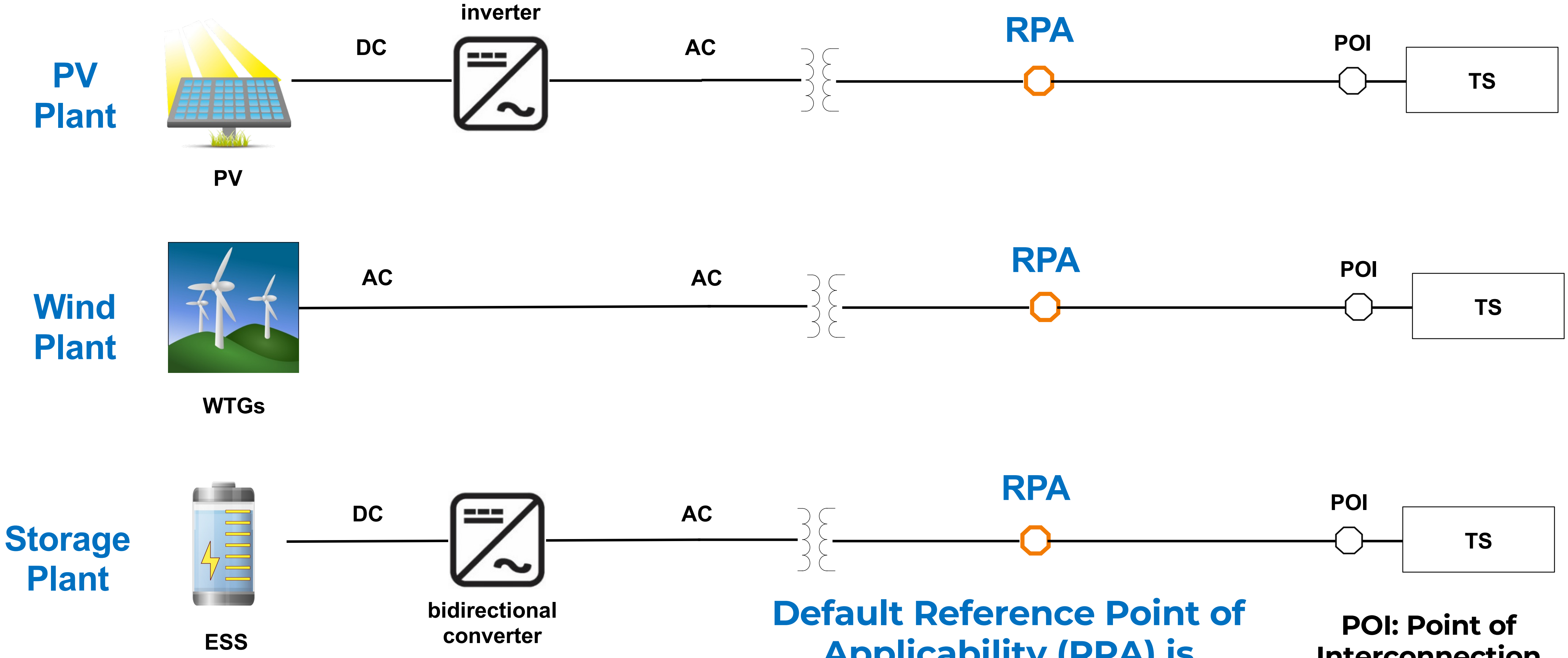
- *point of connection* (POC)
  - *IBR unit* terminals
- *point of measurement* (POM)
  - *IBR plant*
- *point of interconnection* (POI)
  - *interconnection system*
  - *IBR tie line*
- *transmission system* (TS)
  - Transmission
  - Sub-transmission
- *supplemental IBR device*
  - Compensation
  - Plant controller
  - Etc.



[1] if available, refer to existing IEEE documents

ERCOT > IEEE 2800: adopt and exceed 2800 with POI as RPA?

Examples for Inverter-Bases Resources (*IBR*) Plants *in scope*



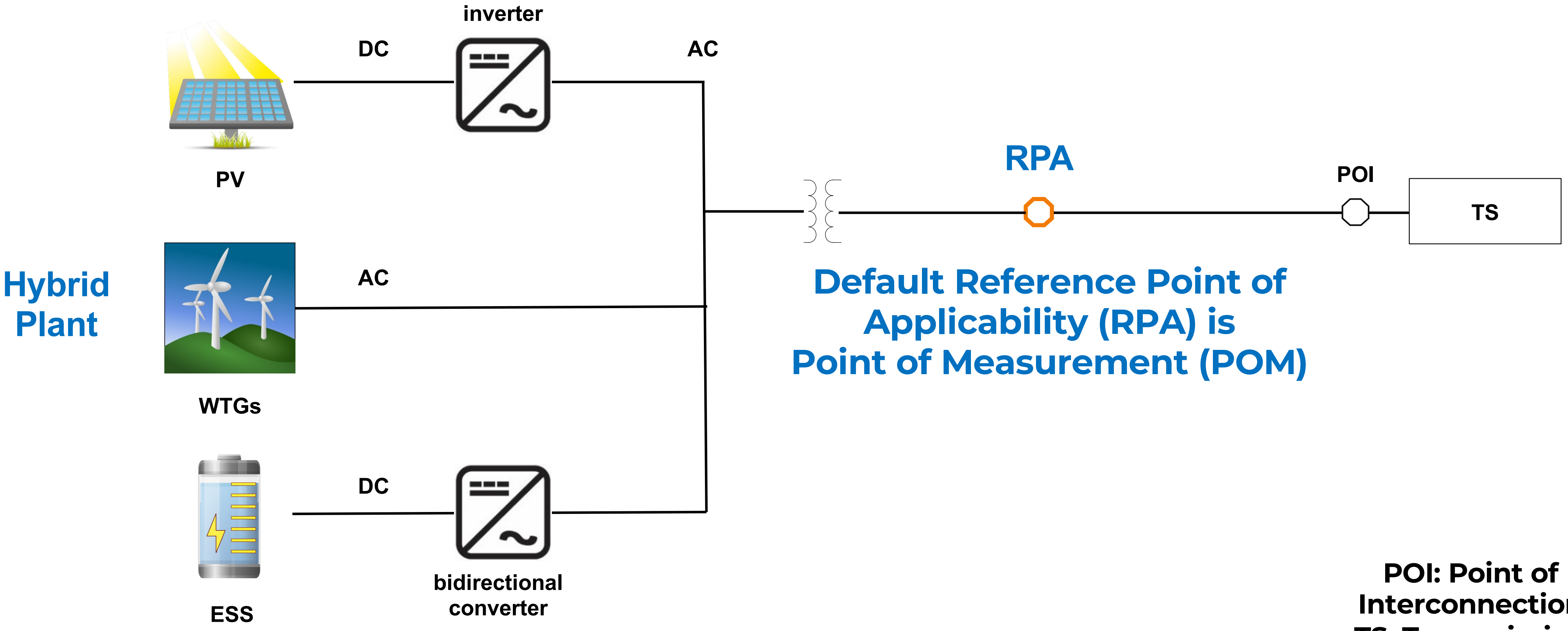
Default Reference Point of Applicability (RPA) is Point of Measurement (POM)

POI: Point of Interconnection
TS: Transmission System

ERCOT > IEEE 2800: adopt and exceed 2800 with POI as RPA?

Example *hybrid IBR plant*, ac-coupled

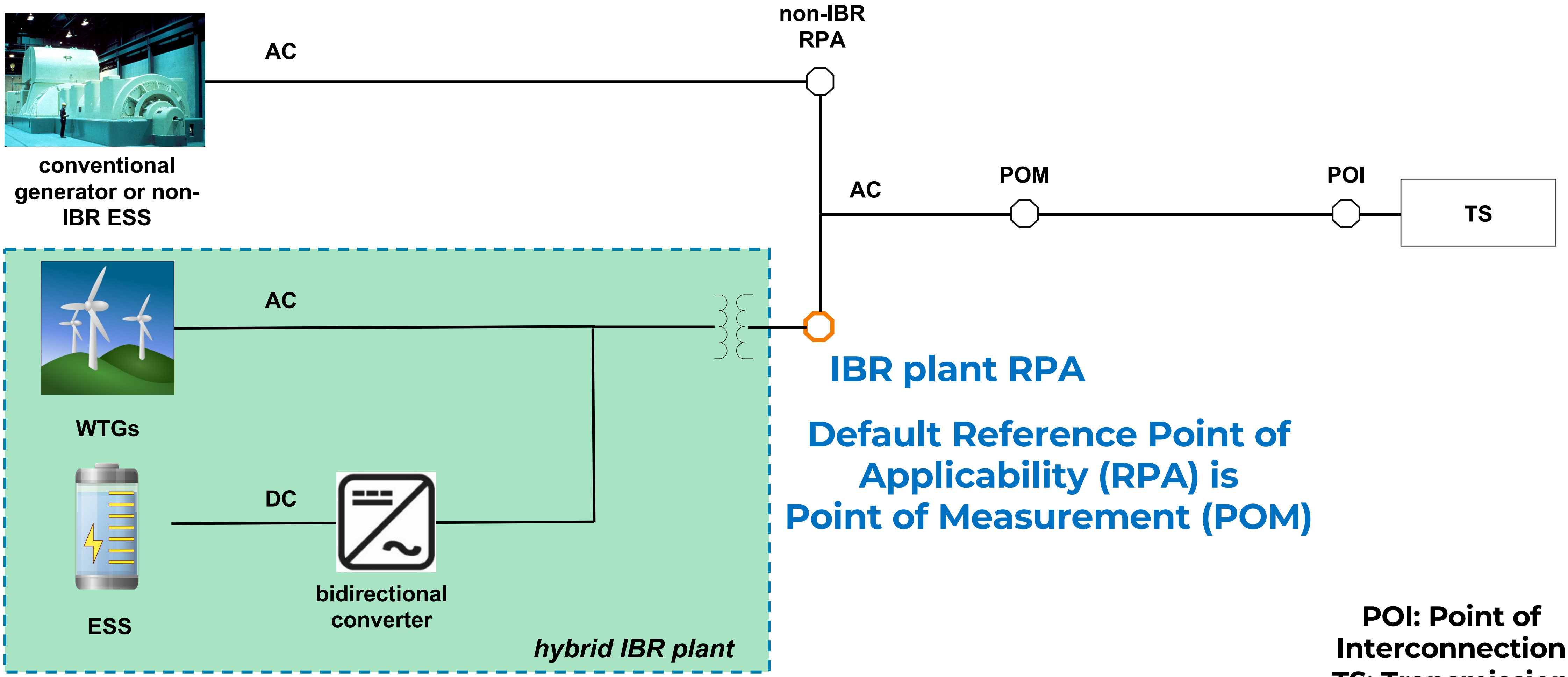
in scope



POI: Point of Interconnection
TS: Transmission System

ERCOT > IEEE 2800: adopt and exceed 2800 with POI as RPA?

Example *hybrid plant*: operated as a single resource *in scope*



Default Reference Point of Applicability (RPA) is Point of Measurement (POM)

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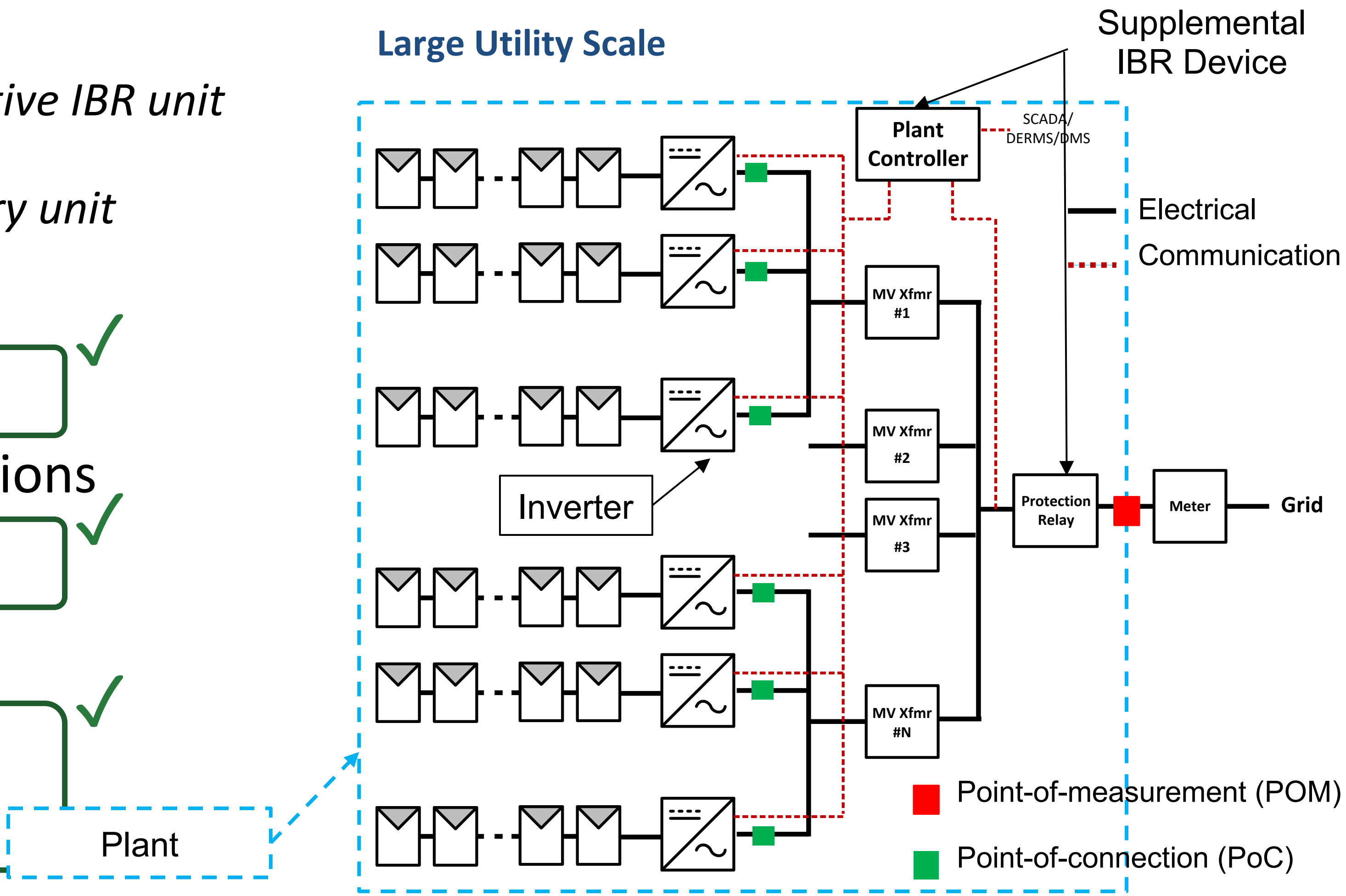
TS: Transmission System

ERCOT > IEEE 2800: adopt and exceed 2800 with POI as RPA?

IEEE 2800-2022 Test and Verification Methods

IEEE 2800-2022 requires IBR plant-level conformity → more than just IBR unit conformity

1. Type Tests – *performed on representative IBR unit*
2. Production Tests – *performed on every unit*
3. Pre-Commissioning Verifications ✓
   a. Design Evaluation (desk study)
4. Commissioning Tests and Verifications ✓
   a. As-built Installation Evaluation (on-site)
5. Post-Commissioning Verifications ✓
   a. Post-Commissioning Monitoring
   b. Periodic Interconnection Tests



Modified based on *DER Plant-Level Performance Verification and Commissioning Guideline: First Edition.* Technical Update. EPRI. Palo Alto, CA: December 2020. 3002019420

ERCOT > IEEE 2800: adopt and exceed 2800 with POI as RPA?

IEEE 2800-2022 Technical Minimum Capability Requirements

Reviewed in past meetings | To be reviewed in today's meeting | To be reviewed in a future meeting

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
Responsibility of TSP?

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**

EPRI

Preliminary High-Level Gap Assessment of ERCOT Nodal Protocols (4/8/22)

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	?	?
	Reference Point of Applicability	POI	POM
	Adjustability in Ranges of Available Settings	NR (!!!)	‡
	Prioritization of Functions	‡	‡
Monitoring, Control, and Scheduling	Ramp Rate Control		
	Communication Interface	‡	‡
	Disable Permit Service (Remote Shut-Off, Remote Disconnect/Reconnect)	‡	‡
	Limit Active Power	‡	‡
	Monitor Key Data	‡	‡
	Remote Configurability		√
	Set Active Power	‡	√
	Scheduling Power Values	‡	√
Reactive Power & (Dynamic) Voltage Support	Constant Power Factor	‡	‡
	Voltage-Reactive Power (Volt-Var)	‡	‡
	Autonomously Adjustable Voltage Reference	?	
	Capability at zero active power ("VArs at night")	NR (!!!)	‡
	Active Power-Reactive Power (Watt-Var)		
	Constant Reactive Power	NR (!!!)	‡
	Voltage-Active Power (Volt-Watt)	NR	NR
	Dynamic Voltage Support / Current Injection during VRT: Balanced	‡	‡
	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)	‡	‡
	Rate-of-Change-of-Frequency (ROCOF) Ride-Through	NR (!!!)	‡
	Voltage Ride-Through (VRT)	‡	‡
	Transient Overvoltage Ride-Through	√ (!!!)	‡
	Consecutive Voltage Dip Ride-Through	NR (!!!)	‡
	Restore Output After Voltage Ride-Through	NR (!!!)	‡
	Voltage Phase Angle Jump Ride-Through	NR (!!!)	‡
	Frequency Droop / Frequency-Watt	‡	‡
	Fast Frequency Response / Inertial Response: Underfrequency FFR	√ (!!!)	‡
	Fast Frequency Response / Inertial Response: Overfrequency FFR	NR	√
	Return to Service (Enter Service)	?	‡
	Black Start	NR	√
Protection Functions and Coordination	Abnormal Frequency Trip	NR	√
	Rate of Change of Frequency (ROCOF) Protection	?	√
	Abnormal Voltage Trip	NR	√
	AC Overcurrent Protection	?	√
	Unintentional Islanding Detection and Trip	NR	√
	Interconnection System Protection	?	√
Power Quality	Limitation of DC Current Injection		
	Limitation of Voltage Fluctuations	NR (!!!)	‡
	Limitation of Current Distortion	NR (!!!)	‡
	Limitation of Voltage Distortion	NR	√
	Limitation of (Transient) Overvoltage	NR (!!!)	‡

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

Detailed Gap Assessment

Objective and Approach

Objective

Inform strategic decision on IEEE 2800 adoption method:

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

Approach

Answer the following questions for where ERCOT and IEEE 2800 both specify requirements:

i. Where IEEE 2800 are more specific or more stringent than ERCOT requirements ("<"), e.g.,
   - longer ride-through capability, or
   - detailed functional specification versus non-prescriptive specification as for dynamic voltage support / short circuit current injection during fault

ii. Where ERCOT requirements and P2800 already align in stringency and level of specificity ("~")

iii. Where ERCOT requirements exceed IEEE 2800 either in stringency or specificity (">")

iv. Analysis not yet completed or clarifying questions

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 P2800 Draft 6.3 (December 2021)

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.

Question: shall comparison be relative to current language or approved revisions (grey boxes)?

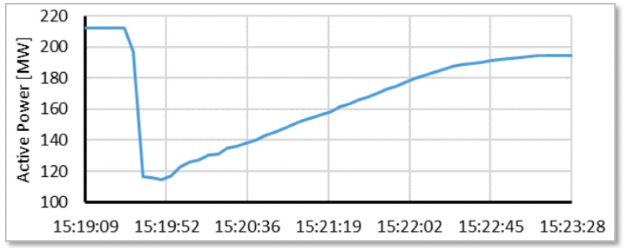
Focus Today:
Voltage Ride-Through, Reactive Power, and Voltage Support

Recent NERC/WECC Event Analysis and Engineering

Example Findings

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Plant Controller Interactions Persist



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

Example: Plant with Legacy Inverters

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

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

19 RELIABILITY | RESILIENCE | SECURITY

- ➢ Momentary cessation occurs above 10% pu voltage
- ➢ Plant controller slows restore output after fault beyond 1 s

IEEE 2800-2022 Conformity Assessment

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

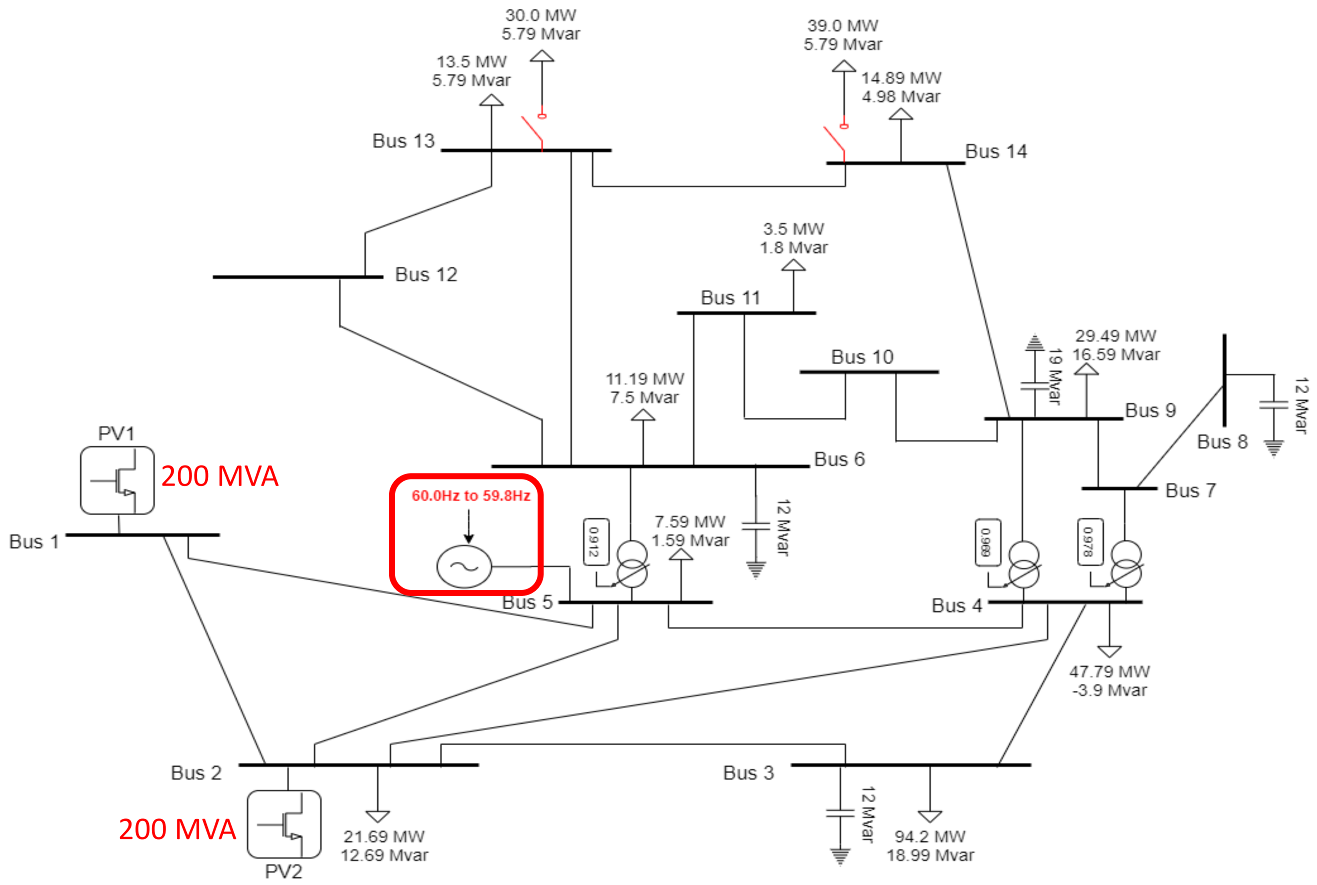
IEEE 2800-2022 requirements apply to the IBR plant*

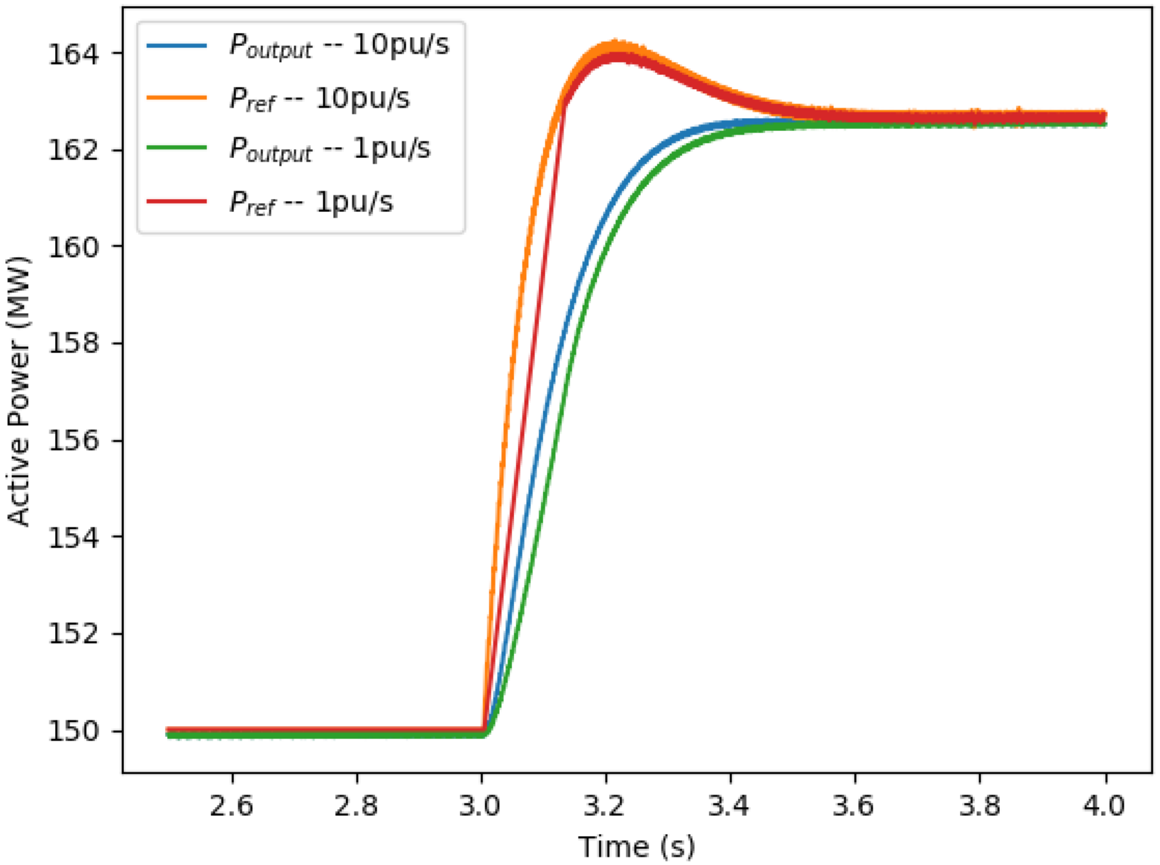
- ➢ IBR units and IBR plant controller (= “supplemental IBR device”)

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

Focus Today:
Primary Frequency Response, Fast Frequency Response, Frequency Ride-Through, RoCoF Ride-Through, etc.

Example: Two PV plants in an existing strong network





- Each 200 MVA PV plant is a full switching model[1]
- Frequency control with 17mHz dead band and 5% droop at inverter level
- Comparison with 1pu/s and 10pu/s ramp rate on active power command

Both ramp rates meet requirements mentioned in IEEE P2800 Draft Standard

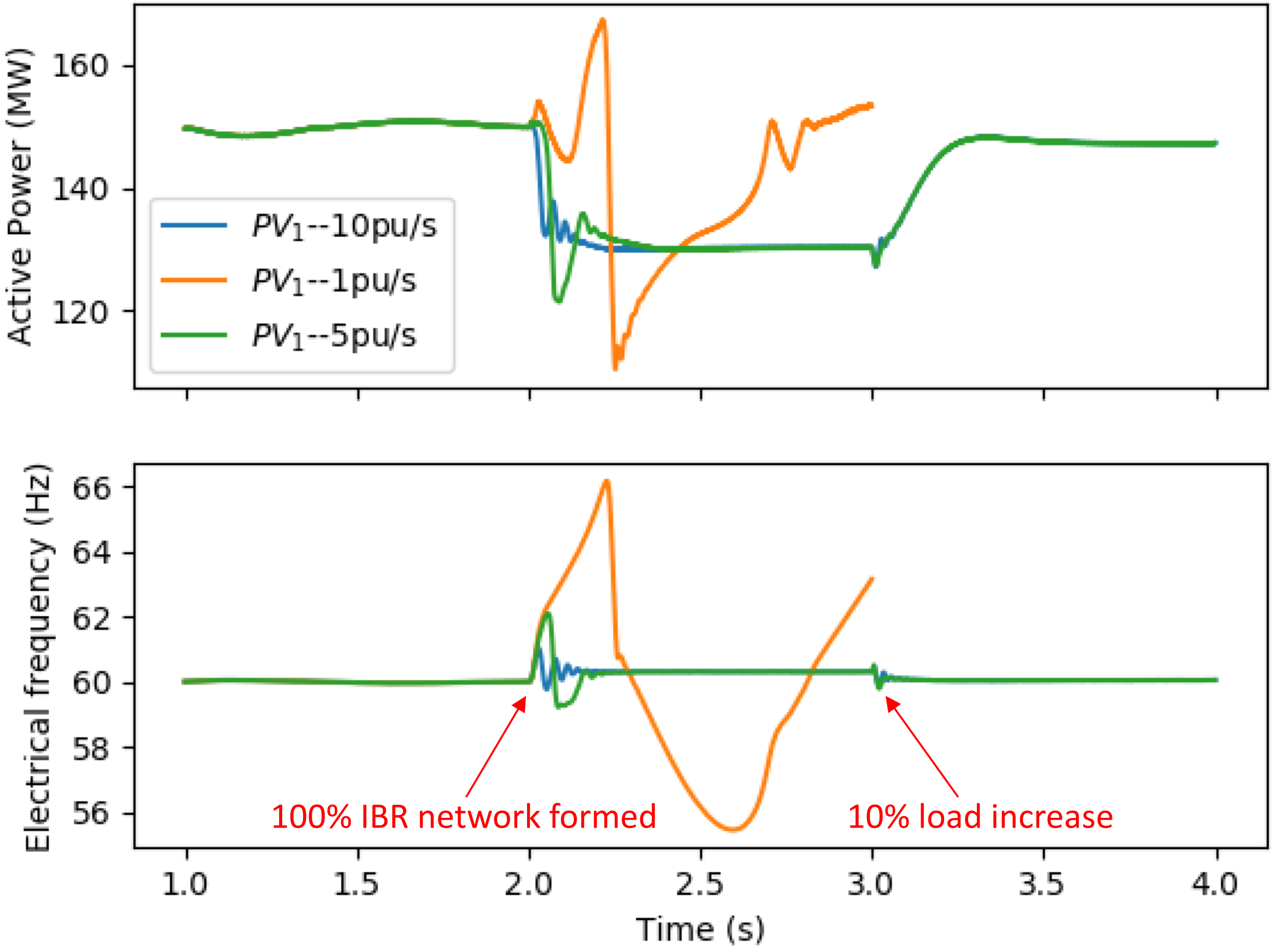
[1]https://www.pscad.com/knowledge-base/article/521

Source behind resource may influence delivery of response

- A low inertia power network needs fast injection of current to mitigate imbalances.
- Suitable choice of ramp rate limit can bring about a stable response

Maximum ramp rate **influenced by source behind the inverter**

Batteries can tolerate higher ramp rates as opposed to wind turbines

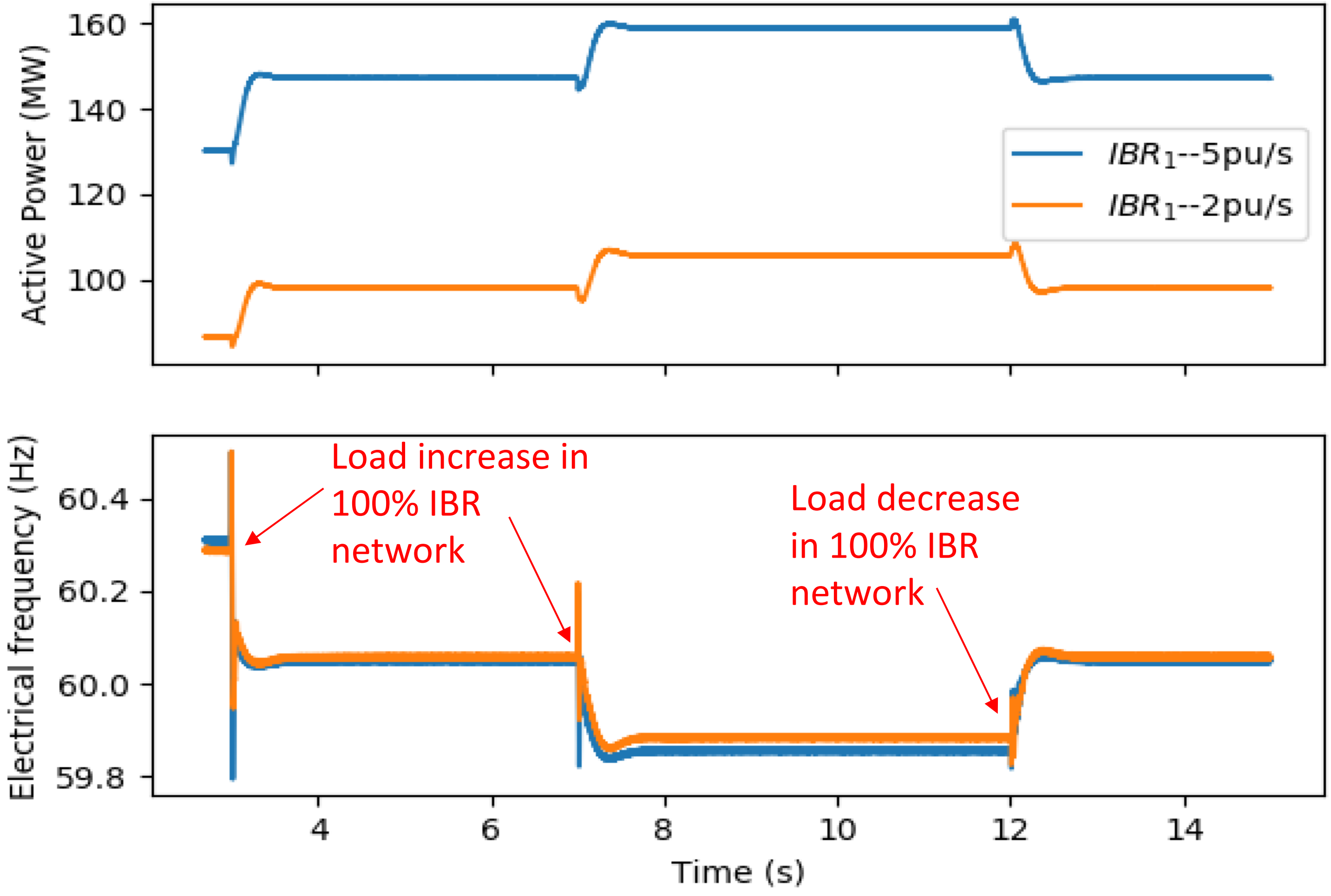


- 100% IBR network created at t=2.0s
- Load increase at t=3.0s

Lower ramp rate requires more responsive resources

- Possible to obtain stable frequency control in a 100% IBR network, with lower ramp rates
- Requires more resources to share the change in energy burden
- Any form of IBR device/control can have inherent ramp rate limits

Important to recognize this if newer IBRs have to additionally support older IBRs



5pu/s – Two PV plants of 200 MVA each
2pu/s – Three PV plants of 100 MVA each

Primary Frequency Response

ERCOT – Nodal Protocols: 8.5 Primary Frequency Response Requirements and Monitoring

[NPRR863, NPRR989, NPRR995, and NPRR1011: Insert applicable portions of paragraph (2) below upon system implementation for NPRR863, NPRR989, and NPRR995; or upon system implementation of the Real-Time Co-Optimization (RTC) project for NPRR1011:]

(2) Generation Resources and ESRs that do not have an RRS or Regulation Service Ancillary Service award shall set their Governor Dead-Band no greater than ±0.036 Hz from nominal frequency of 60 Hz. A Generation Resource or ESR that widens its Governor Dead-Band greater than what is prescribed in Nodal Operating Guide Section 2.2.7, Turbine Speed Governors, must update its Resource Registration data with the new dead-band value.

ERCOT – Nodal Operating Guide: 2.2.7 Turbine Speed Governors

Table 1: Maximum Governor Dead-Band Settings

Resource Type	Max. Deadband
Steam Turbines with Mechanical Governors	+/- 0.034 Hz
Hydro Turbines with Mechanical Governors	+/- 0.034 Hz
All Other Generating Units/Generating Facilities/ESRs	+/- 0.017 Hz
Controllable Load Resources	+/- 0.036 Hz

Table 2: Maximum Governor Droop Settings

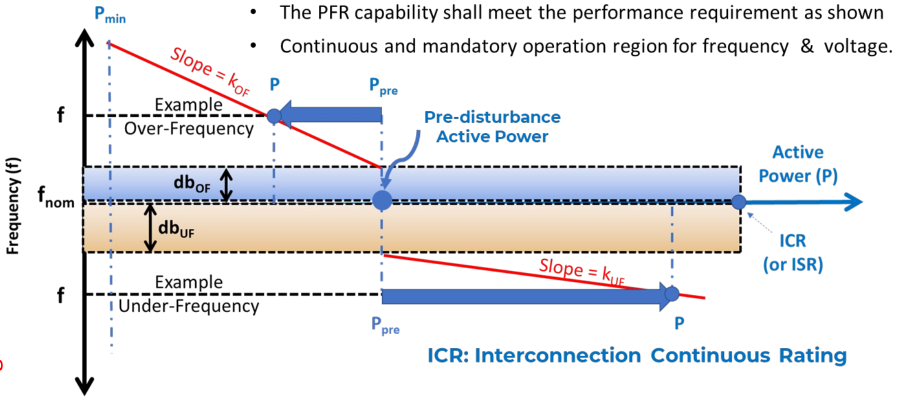
Generator Type	Max. Droop % Setting
Combustion Turbine (Combined Cycle)	4%
All Other Generating Units/Generating Facilities/ESRs/Controllable Load Resources	5%

ERCOT – NOG: Section 8, Attachment C, Turbine Governor Speed Tests

The test is considered successful after the signal becomes active if **at least 70%** of the calculated MW contribution is delivered **within 16 seconds** and the **response is maintained for** an additional **30 seconds**.

IEEE 2800 - 6.1 Primary Frequency Response (PFR)

- The PFR capability shall meet the performance requirement as shown
- Continuous and mandatory operation region for frequency & voltage.



- Table 10 specifies <u>minimum</u> capability to be met
- Change in IBR plant power output may not be required to be greater than maximum ramp rate of plant
  - Should be as fast as technically feasible
- 15mHz - 36mHz deadband with 2% - 5% droop

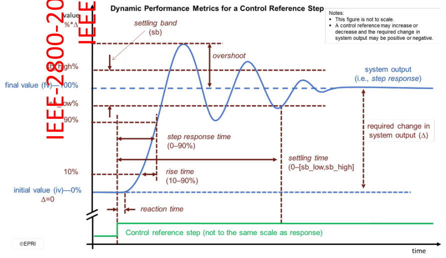


Figure 5(a) from IEEE P200 Draft 6.3 (December 2021)

Table 8—Parameters of active power-frequency response dynamic performance for *IBR plant*

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

Addressed Reliability Issue
- Unknown
- Inverter Underfrequency
- Not Analyzed
- Feeder Underfrequency

ERCOT < IEEE 2800: raise to 2800 and specify shorter PFR response times?

Fast Frequency Response

Bulk System Reliability & Frequency Support

ERCOT – NP 2 Definitions and Acronyms, 3.17.2 Responsive Reserve Service, 3.18 Resource Limits in Providing AS, 8.1.1.1 Ancillary Service Qualification and Testing

- Fast Frequency Response (FFR): The **automatic self-deployment** and provision by a Resource of their obligated **response within 15 cycles** after frequency meets or drops below a preset threshold, or a deployment in response to an ERCOT Verbal Dispatch Instruction (VDI) within 10 minutes. Resources capable of automatically self-deploying and **providing** their **full** Ancillary Service Resource **Responsibility within 15 cycles** after frequency meets or drops below a preset threshold and sustaining that full response for at least 15 minutes may provide Responsive Reserve (RRS). (Section 2)
- RRS may be provided by resources capable of providing Fast Frequency Response (FFR) and **sustaining their response for up to 15 minutes**; (Section 3.17.2)
- The **initiation setting** of the automatic self-deployment of the Resource providing RRS as FFR must be **no lower than 59.85 Hz**. (Section 3.18)
- A Resource providing RRS as FFR that is deployed shall **not recall its capacity until system frequency is greater than 59.98 Hz**. (Section 3.18)
- Once recalled, a Resource providing RRS as FFR must **restore** its **full RRS** Ancillary Service Resource Responsibility **within 15 minutes** after cessation of deployment or as otherwise directed by ERCOT. (Section 3.18)
- Resource's response **shall not be less than 95% of the requested MW** deployment, nor more than 105% of the lesser of the Resource's RRS award or MW deployment (8.1.1.1).

IEEE 2800

- All IBR shall have FFR capability **for under-frequency conditions**
  - **Specific FFR requirements for Wind Turbine Generator (WTG)**
  - **Requirement for over-frequency in future revision**
- 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

Requirements

Parameter	Units	Default Value	Minimum	Maximum
$f_{UF,FFR1}$	Hz	99.94% of f_{nom}	99.17% of f_{nom}	99.94 of f_{nom}
$k_{UF,FFR1}$	%	1%	1%	5%

- 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)**

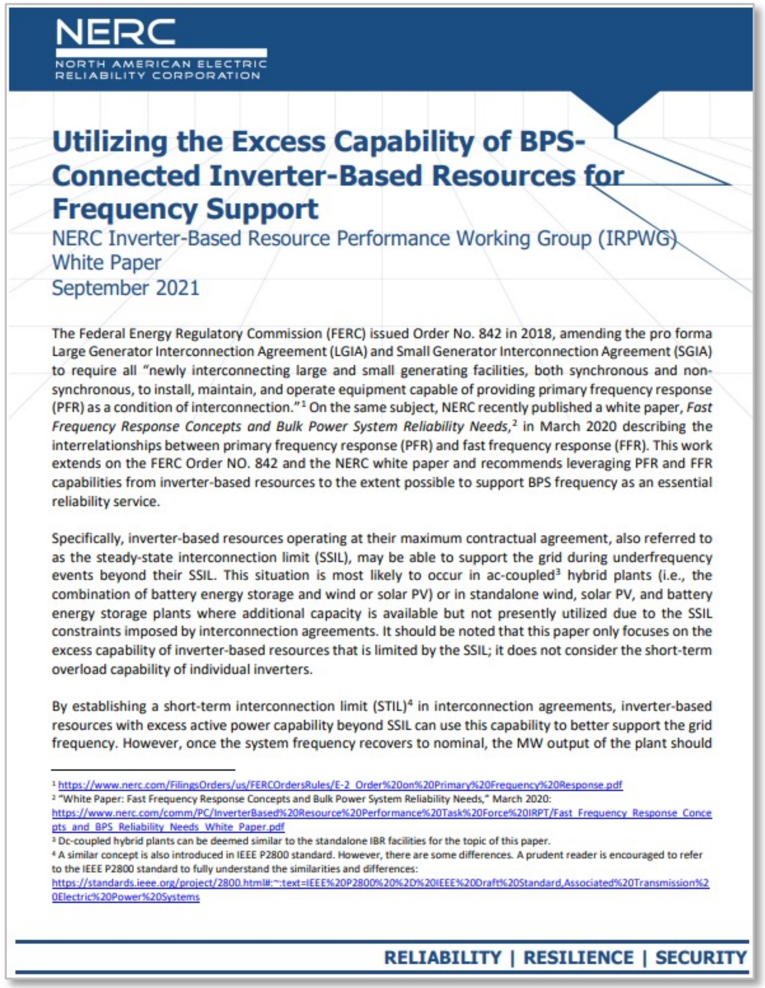
- FFR and PFR may actuate independently from each other or may complement each other

Addressed Reliability Issue

- Unknown
- Inverter Underfrequency
- Not Analyzed
- Feeder Underfrequency

ERCOT < IEEE 2800: raise to 2800 and make FFR *for UF* capability mandatory?

IEEE 2800 Terminology


NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Utilizing the Excess Capability of BPS-Connected Inverter-Based Resources for Frequency Support

NERC Inverter-Based Resource Performance Working Group (IRPWG)
White Paper
September 2021

The Federal Energy Regulatory Commission (FERC) issued Order No. 842 in 2018, amending the pro forma Large Generator Interconnection Agreement (LGIA) and Small Generator Interconnection Agreement (SGIA) to require all "newly interconnecting large and small generating facilities, both synchronous and non-synchronous, to install, maintain, and operate equipment capable of providing primary frequency response (PFR) as a condition of interconnection."[1] On the same subject, NERC recently published a white paper, *Fast Frequency Response Concepts and Bulk Power System Reliability Needs*,[2] in March 2020 describing the interrelationships between primary frequency response (PFR) and fast frequency response (FFR). This work extends on the FERC Order NO. 842 and the NERC white paper and recommends leveraging PFR and FFR capabilities from inverter-based resources to the extent possible to support BPS frequency as an essential reliability service.

Specifically, inverter-based resources operating at their maximum contractual agreement, also referred to as the steady-state interconnection limit (SSIL), may be able to support the grid during underfrequency events beyond their SSIL. This situation is most likely to occur in ac-coupled[3] hybrid plants (i.e., the combination of battery energy storage and wind or solar PV) or in standalone wind, solar PV, and battery energy storage plants where additional capacity is available but not presently utilized due to the SSIL constraints imposed by interconnection agreements. It should be noted that this paper only focuses on the excess capability of inverter-based resources that is limited by the SSIL; it does not consider the short-term overload capability of individual inverters.

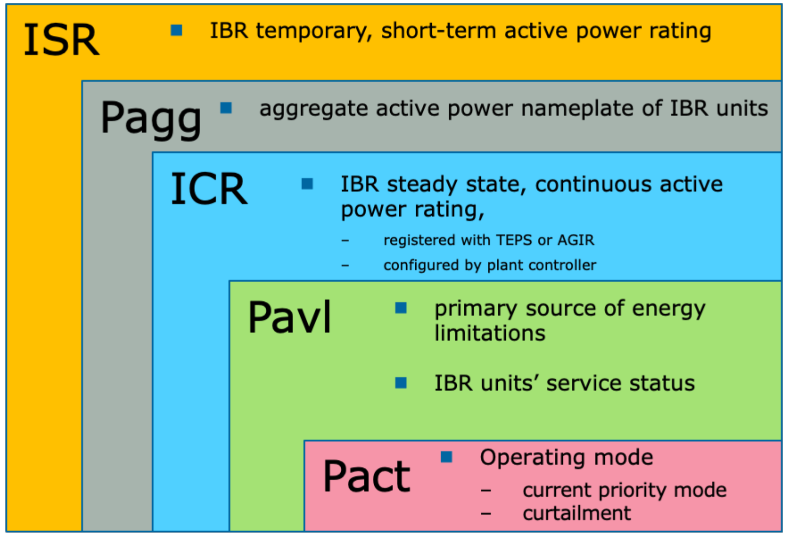
By establishing a short-term interconnection limit (STIL)[4] in interconnection agreements, inverter-based resources with excess active power capability beyond SSIL can use this capability to better support the grid frequency. However, once the system frequency recovers to nominal, the MW output of the plant should

[1] https://www.nerc.com/FilingsOrders/us/FERCOrdersRules/E-2_Order%20on%20Primary%20Frequency%20Response.pdf
[2] "White Paper: Fast Frequency Response Concepts and Bulk Power System Reliability Needs," March 2020: https://www.nerc.com/comm/PC/InverterBased%20Resource%20Performance%20Task%20Force%20IRPT/Fast_Frequency_Response_Concepts_and_BPS_Reliability_Needs_White_Paper.pdf
[3] Dc-coupled hybrid plants can be deemed similar to the standalone IBR facilities for the topic of this paper.
[4] A similar concept is also introduced in IEEE P2800 standard. However, there are some differences. A prudent reader is encouraged to refer to the IEEE P2800 standard to fully understand the similarities and differences: https://standards.ieee.org/project/2800.html#:~:text=IEEE%20P2800%20%2D%20IEEE%20Draft%20Standard,Associated%20Transmission%20Electric%20Power%20Systems

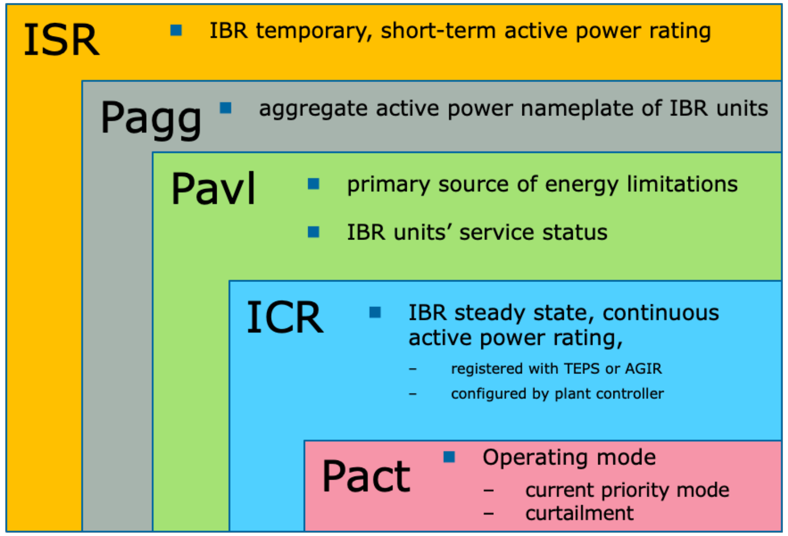
RELIABILITY | RESILIENCE | SECURITY

NERC White Paper	IEEE 2800
Not defined	Available Active Power (Pavl)
Steady-State Interconnection Limit (SSIL)	IBR Continuous Rating (ICR) IBR Continuous Absorption Rating (ICAR)
Short-Term Interconnection Limit (STIL)	IBR Short-Term Rating (ISR)

Case 1: ICR > Pavl



Case 2: Pavl > ICR



NERC White Paper Available:
https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_IBR_Hybrid_Plant_Frequency_Response.pdf

Frequency Ride-Through (FRT)

Bulk System Reliability & Frequency Support

ERCOT - Nodal Operating Guide: 2.6.2 Generators and Energy Storage Resources

Except for Generation Resources subject to Section 2.6.2.1, Frequency Ride-Through Requirements for Distribution Generation Resources (DGRs) and Distribution Energy Storage Resources (DESRs), if **under-frequency** relays are installed and activated to trip the Generation Resource, these relays shall be set such that the automatic removal of individual Generation Resources or Energy Storage Resources (ESRs) from the ERCOT System meets or exceeds the following requirements:

Underfrequency

Frequency Range	Delay to Trip
Above 59.4 Hz	No automatic tripping (Continuous operation)

Above 58.4 Hz up to And including 59.4 Hz	Not less than 9 minutes
Above 58.0 Hz up to And including 58.4 Hz	Not less than 30 seconds
Above 57.5 Hz up to And including 58.0 Hz	Not less than 2 seconds
57.5 Hz or below	No time delay required

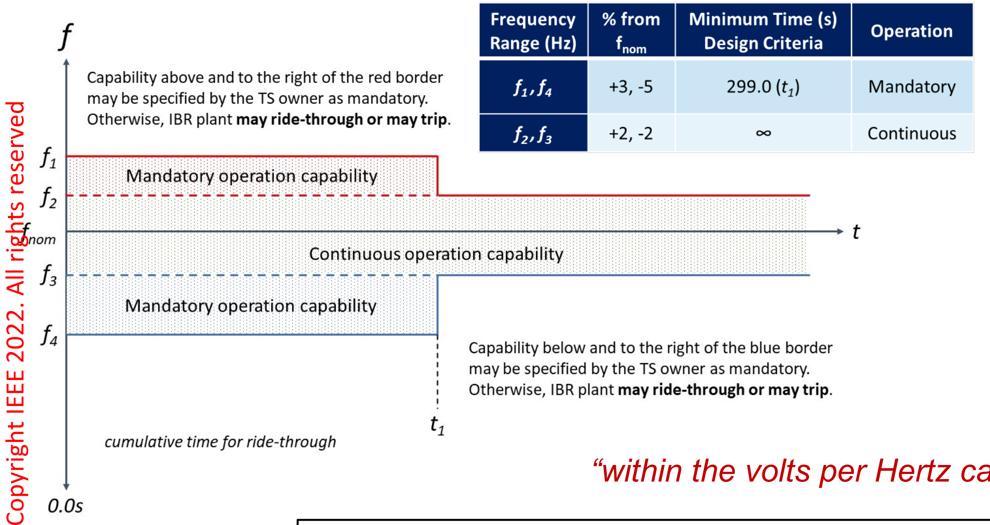
Overfrequency

Frequency Range	Delay to Trip
Below 60.6 Hz down to and including 60 Hz	No automatic tripping (Continuous operation)
Below 61.6 Hz down to and including 60.6 Hz	Not less than 9 minutes
Below 61.8 Hz down to and including 61.6 Hz	Not less than 30 seconds
61.8 Hz or above	No time delay required

2.9 Voltage Ride-Through Requirements for Generation Resources and Energy Storage Resources

(1)(c) Generator or inverter volts per hertz conditions are less than 116% of rated design voltage and frequency and last for less than 1.5 seconds;

IEEE 2800 - 7.3.2.3 Frequency disturbances within the Mandatory Operation region



"within the volts per Hertz capability"

The IBR plant shall be capable

- to ride-through as shown in the Figure
- 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
- meet the applicable requirements of PFR/FFR

Addressed Reliability Issue

- PLL Loss of Unknown
- Inverter Underfrequency
- Slow Active Power Recovery
- Not Analyzed
- Feeder Underfrequency

ERCOT > IEEE 2800: adopt and exceed 2800 with specification of V/Hz values?

Discussion

- ...

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Focus at Next Meeting: Requirements in Scope of Transmission Service Provider (TSP) and not of ERCOT

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Other Requirements of IEEE 2800 by Mutual Agreement (Optional)