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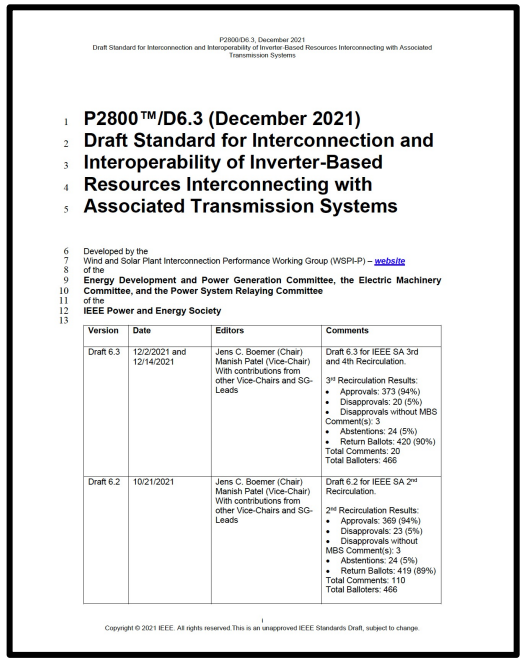
This assessment is ongoing. We explicitly encourage stakeholders to provide feedback!

Introduction & Refresher

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**



P2800/D6.3, December 2021
Draft Standard for Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associated Transmission Systems

P2800™/D6.3 (December 2021)
Draft Standard for Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associated Transmission Systems

Developed by the
Wind and Solar Plant Interconnection Performance Working Group (WSPI-P) – website
of the
Energy Development and Power Generation Committee, the Electric Machinery Committee, and the Power System Relaying Committee
of the
IEEE Power and Energy Society

Version	Date	Editors	Comments
Draft 6.3	12/2/2021 and 12/14/2021	Jens C. Boemer (Chair) Manish Patel (Vice-Chair) With contributions from other Vice-Chairs and SG-Leads	Draft 6.3 for IEEE SA 3rd and 4th Recirculation. 3rd Recirculation Results: • Approvals: 373 (94%) • Disapprovals: 20 (5%) • Disapprovals without MBS Comment(s): 3 • Abstentions: 24 (5%) • Return Ballots: 420 (90%) Total Comments: 20 Total Balloters: 466
Draft 6.2	10/21/2021	Jens C. Boemer (Chair) Manish Patel (Vice-Chair) With contributions from other Vice-Chairs and SG-Leads	Draft 6.2 for IEEE SA 2nd Recirculation. 2nd Recirculation Results: • Approvals: 369 (94%) • Disapprovals: 23 (5%) • Disapprovals without MBS Comment(s): 3 • Abstentions: 24 (5%) • Return Ballots: 419 (89%) Total Comments: 110 Total Balloters: 466

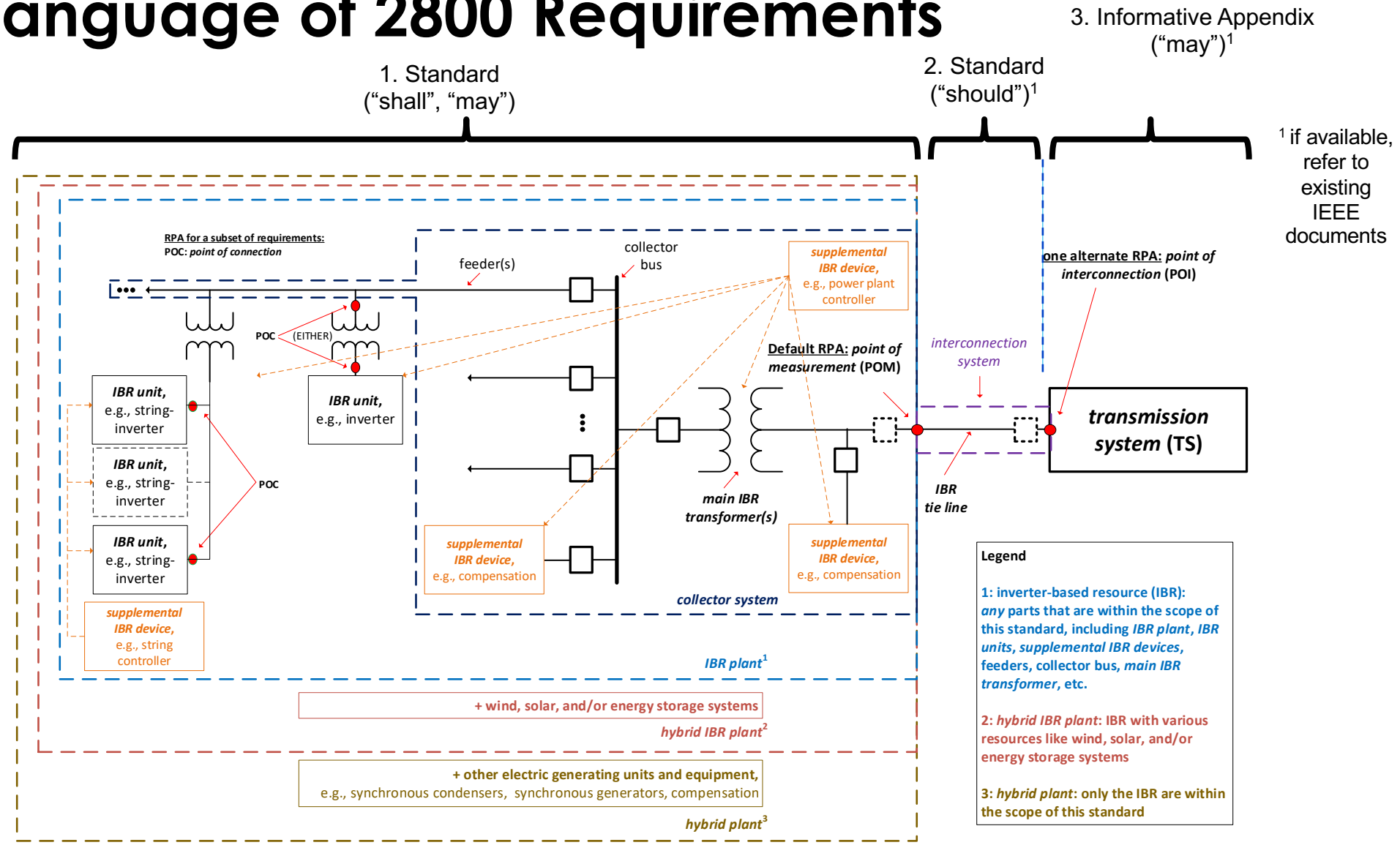
Latest draft is available from IEEE at https://standards.ieee.org/project/2800.html

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

Scope and Language of 2800 Requirements

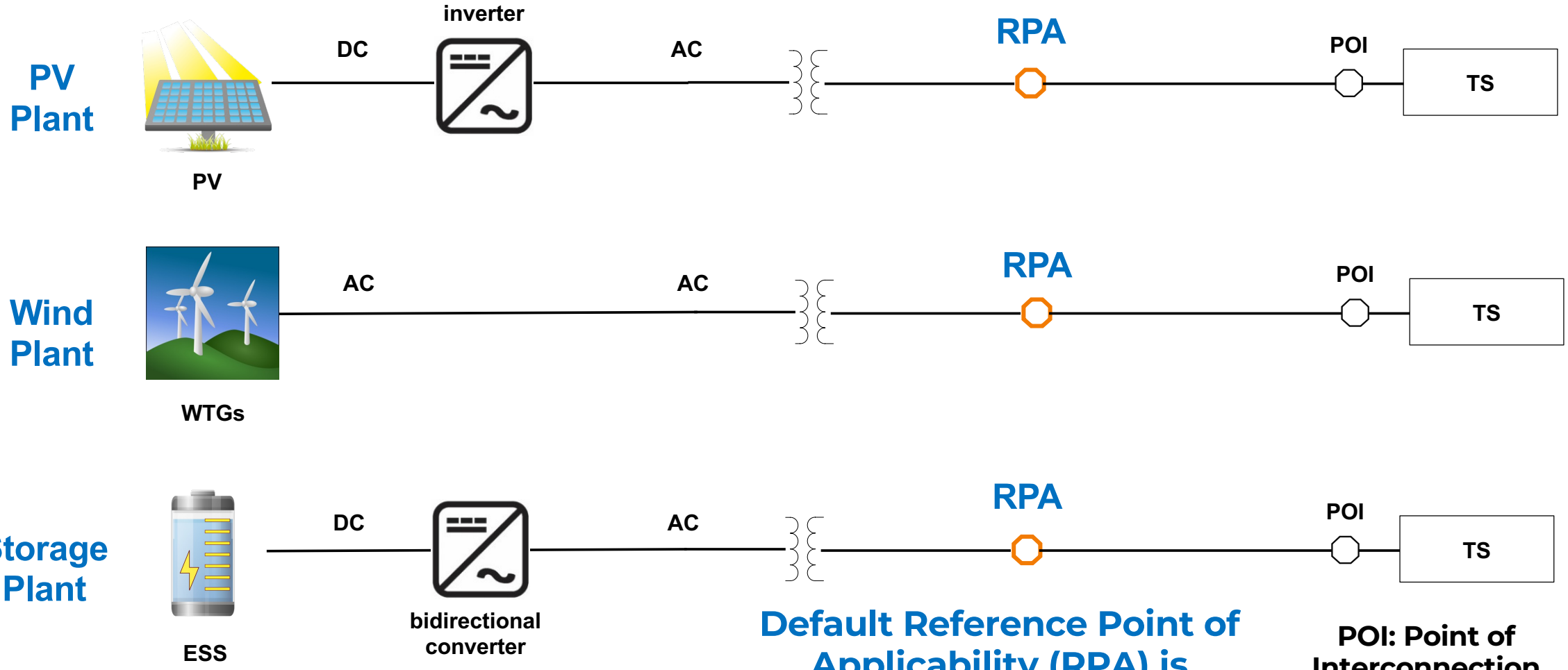
Important Terms

- *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.



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

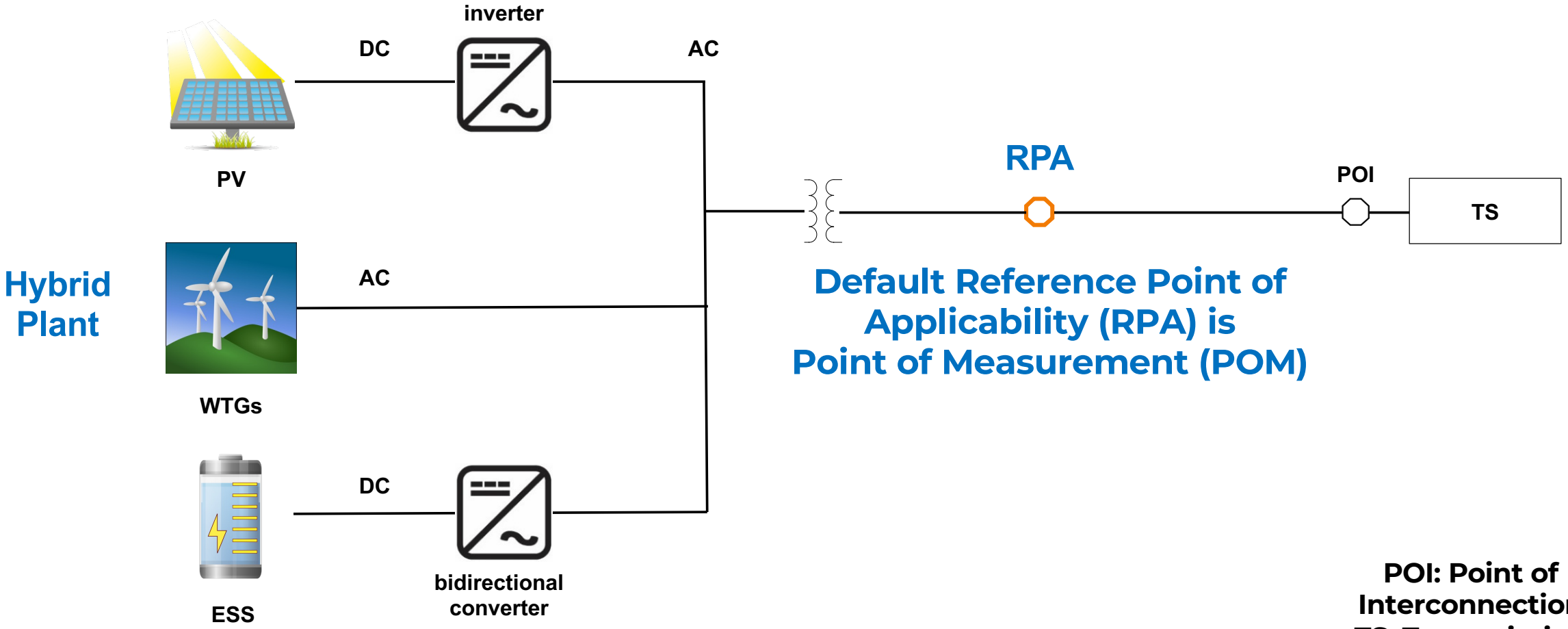
Examples for Inverter-Bases Resources (*IBR*) Plants *in scope*



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

Example *hybrid IBR plant*, ac-coupled

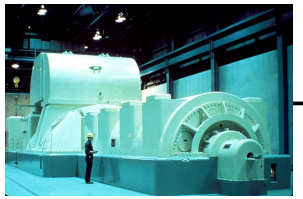
in scope



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*



conventional generator or non-IBR ESS

AC

non-IBR RPA

AC

POM

POI

TS

WTGs

AC

ESS

DC

bidirectional converter

hybrid IBR plant

IBR plant RPA

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

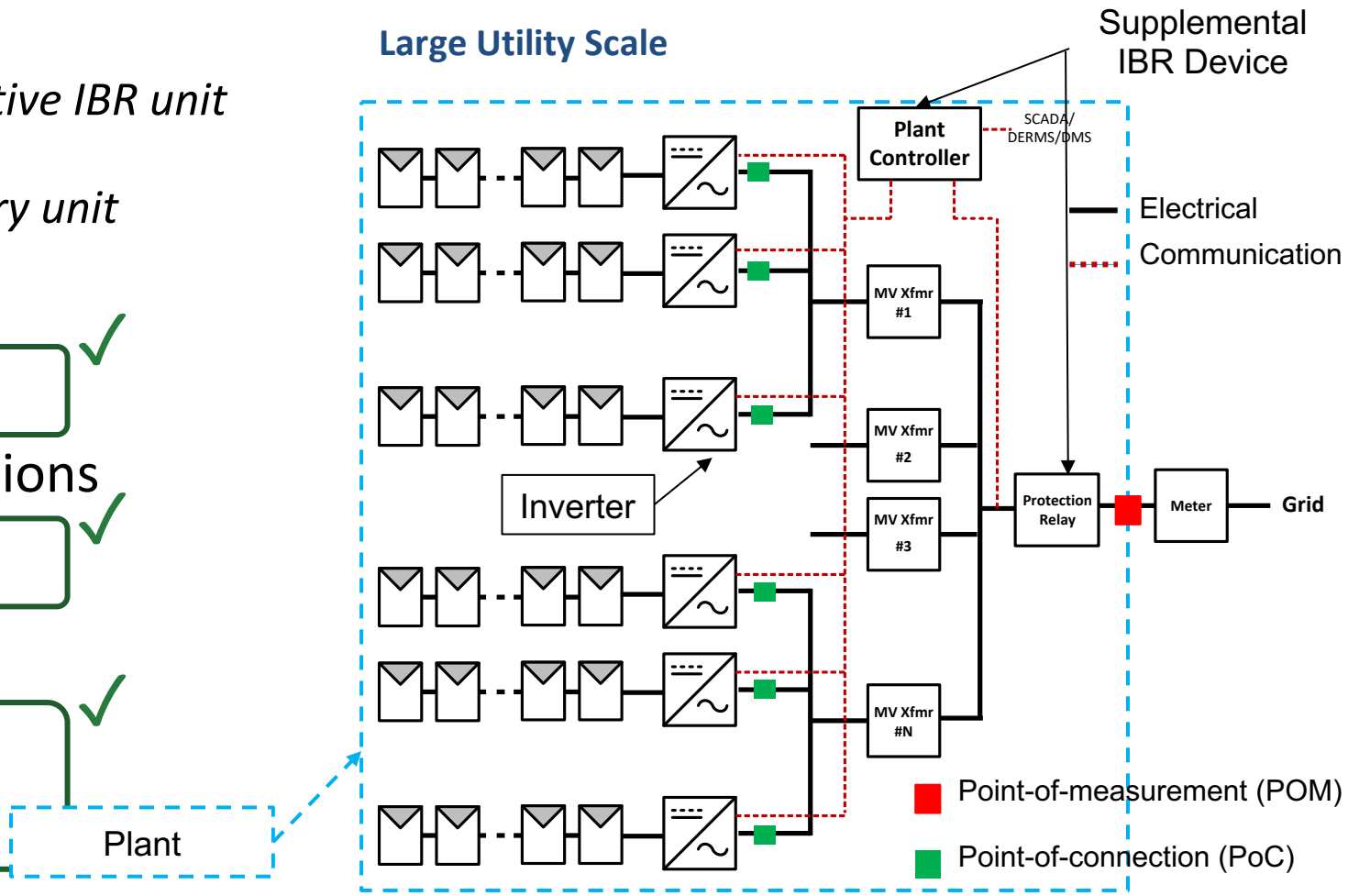
POI: Point of Interconnection
TS: Transmission System

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

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

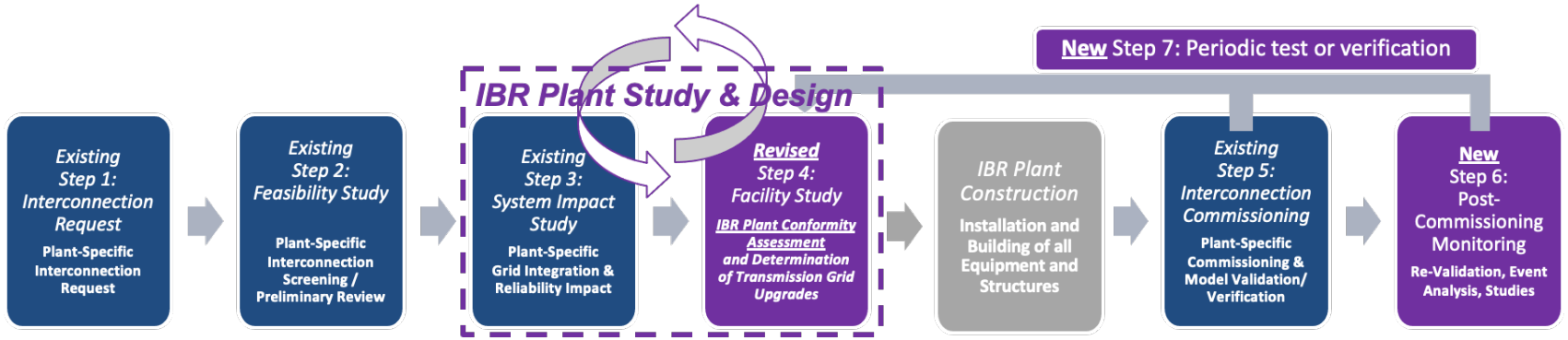


Modified based on *DER Plant-Level Performance Verification and Commissioning Guideline: First Edition.* Technical Update. EPRI. Palo Alto, CA: December 2020. 3002019420

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

Some Thoughts on IEEE 2800-2022 Adoption

- Transmission Owners / Planners may play a key role
  - **Gap assessment**, improvement of existing requirements, preferably "full adoption" of IEEE 2800
- Adoption may not be contingent on publication of IEEE P2800.2 *Draft Recommended Practice for Test and Verification Procedures*
  - Determine reasonable interconnection application enforcement date, grandfathering
- Opportunities for further improvements of interconnection process
  - Potential implications for FERC Large-Scale Generators Interconnection Process (LGIP) and *pro-forma* Agreement (LGIA), e.g., reference for "good utility practice"



Preliminary High-Level Gap Assessment of ERCOT Nodal Protocols (3/18/22)

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

Additions/changes for 4/8/22 in red font

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

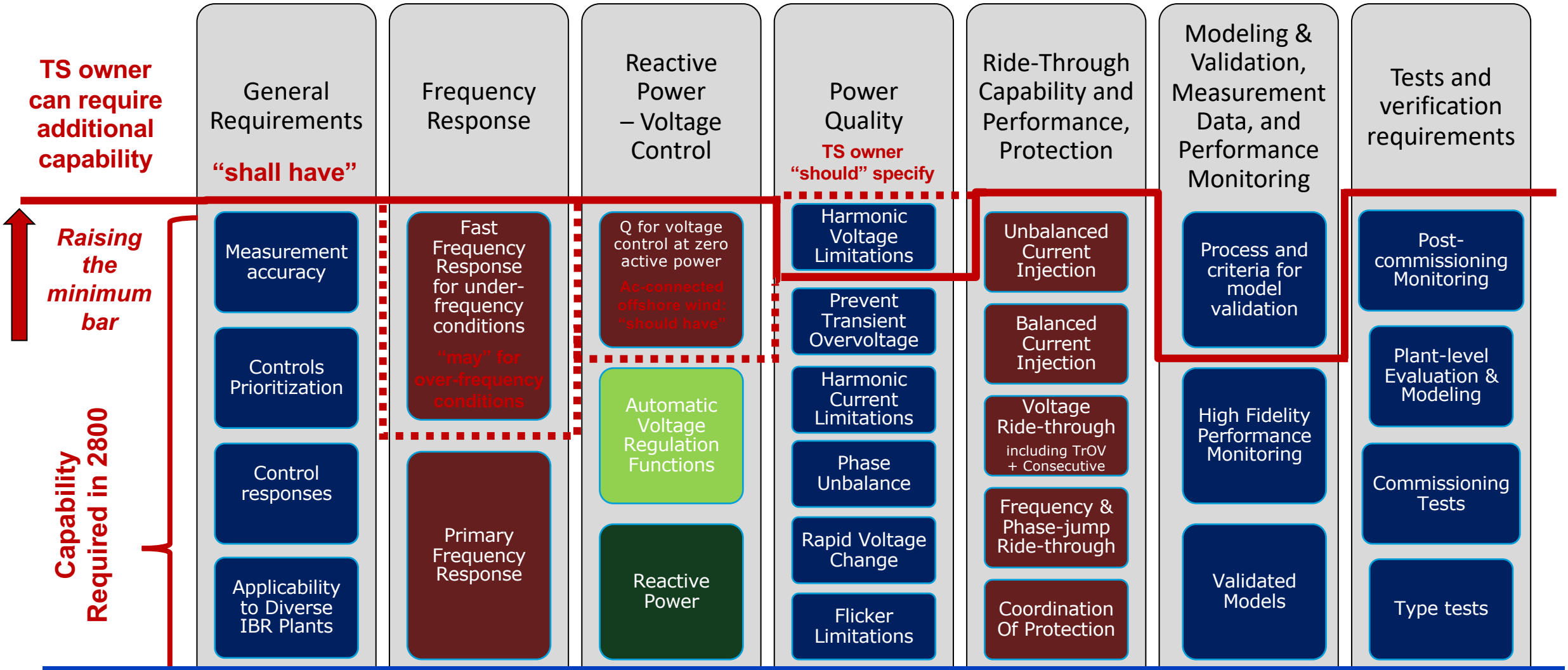
- IEEE P2800 Draft 6.3 (December 2021)

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.

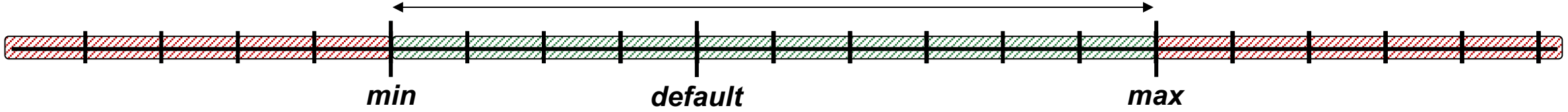
Question: shall comparison be relative to current language or approved revisions (grey boxes)?

IEEE 2800-2022 Technical Minimum Capability Requirements



Question: shall ERCOT only adopt capabilities that are immediately utilized?

What are ranges of available settings?



Example: Frequency Droop Settings

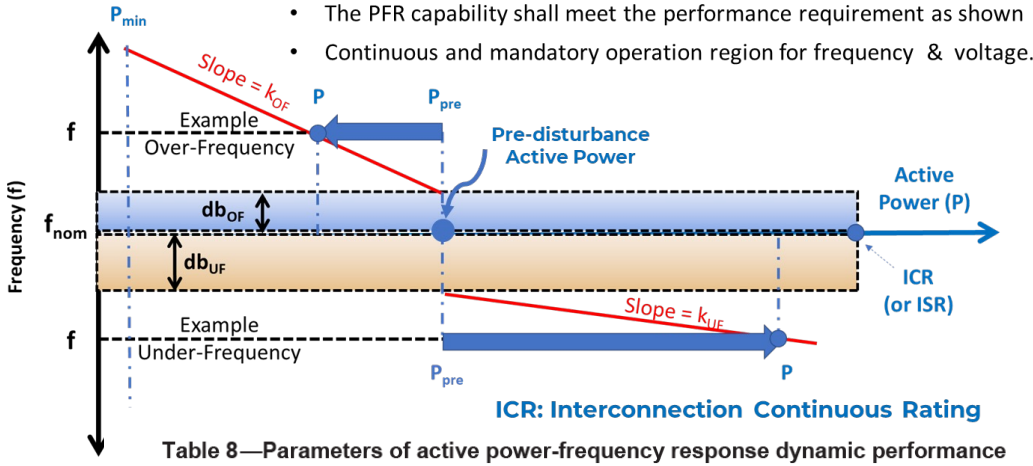


Table 8—Parameters of active power-frequency response dynamic performance for *IBR plant*

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

Meaning of Droop Functional Settings

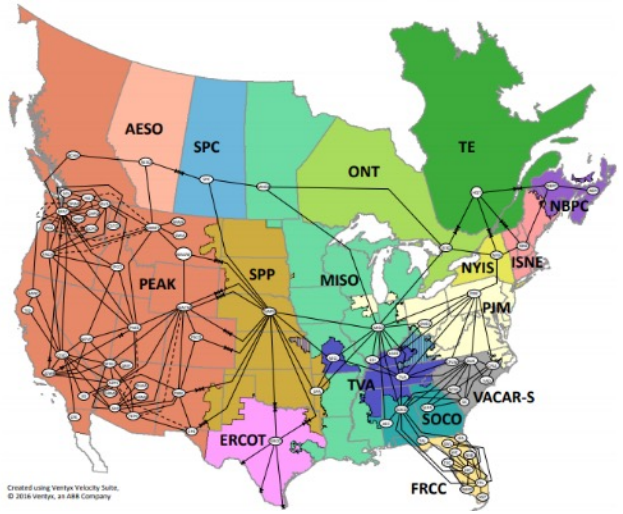
- Not an adjustability of frequency droop capability.
- Depending on the function, sometimes a
  - Limiting requirement: the setting shall not be set to lower values.
  - Minimum requirement: the setting may be set above this value.
- Report droop settings to ERCOT.

Question: Shall ERCOT specify 'ranges of available settings' or only "default" values?

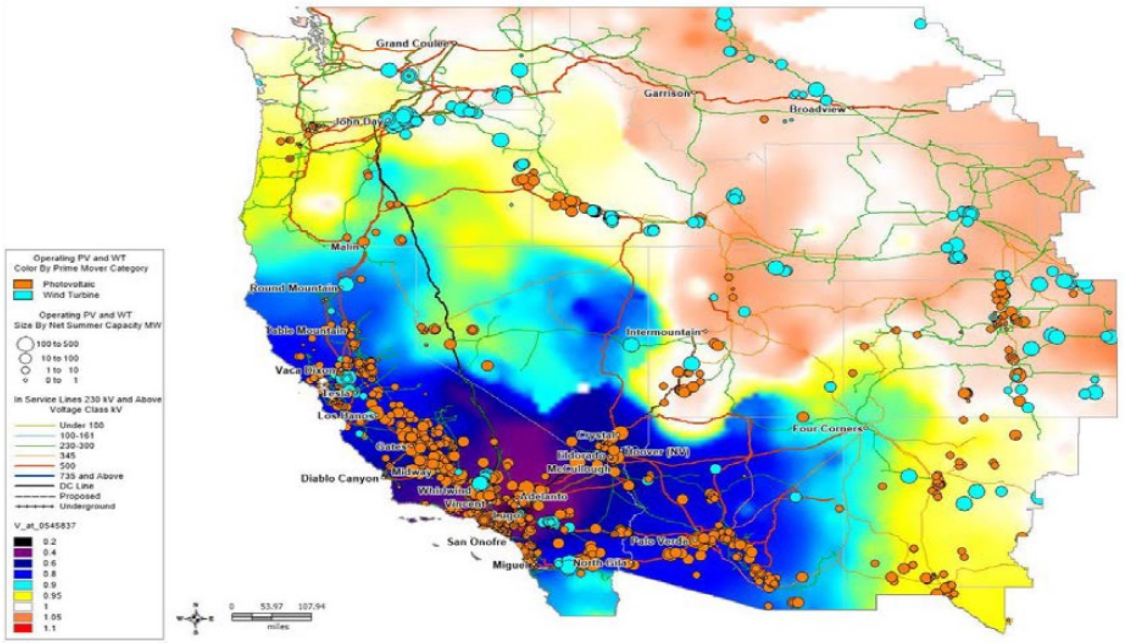
Focus Today:
Voltage Ride-Through, Reactive Power, and Voltage Support

Motivation for Frequency and Voltage Ride-Through Capability

- System **frequency** is defined by balance between load and generation
- Frequency is similar across entire interconnection; any DER exposed to large frequency deviations may trip simultaneously; special concerns for system-split conditions
- Impact the same whether or not DER is on a high-penetration feeder
- NERC Reliability Coordinators
  - Colored entities in the map to the right



Source: NERC

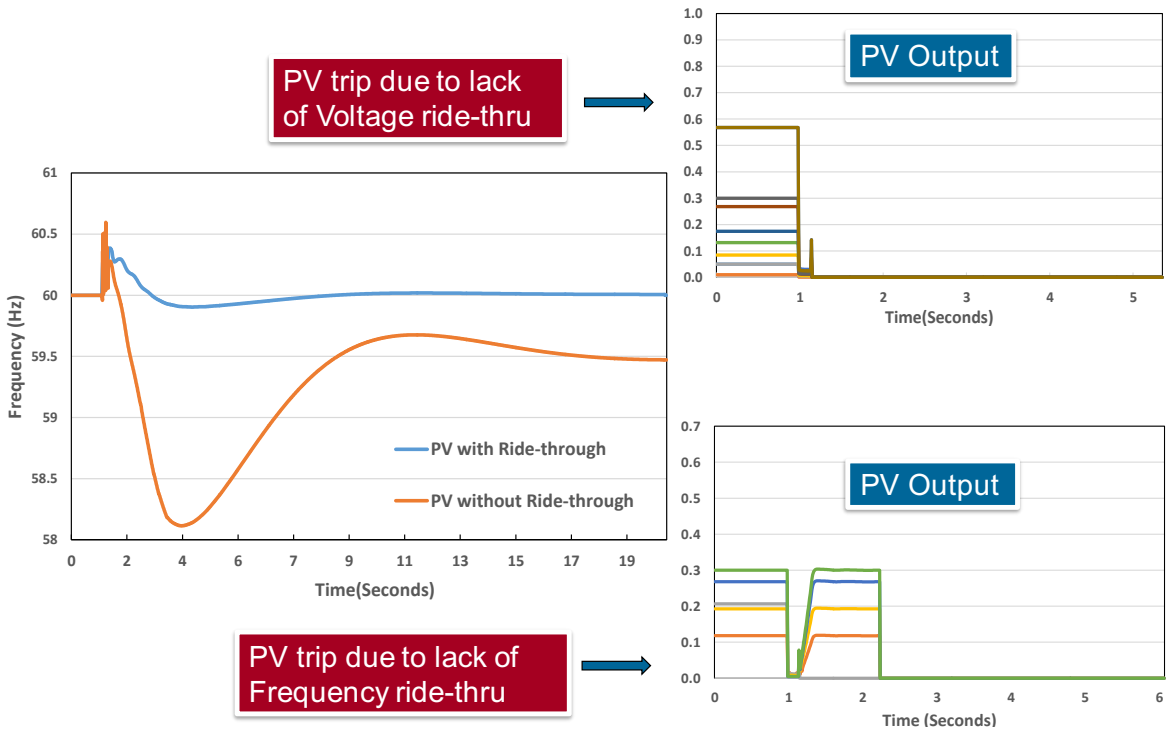


Source: SCE

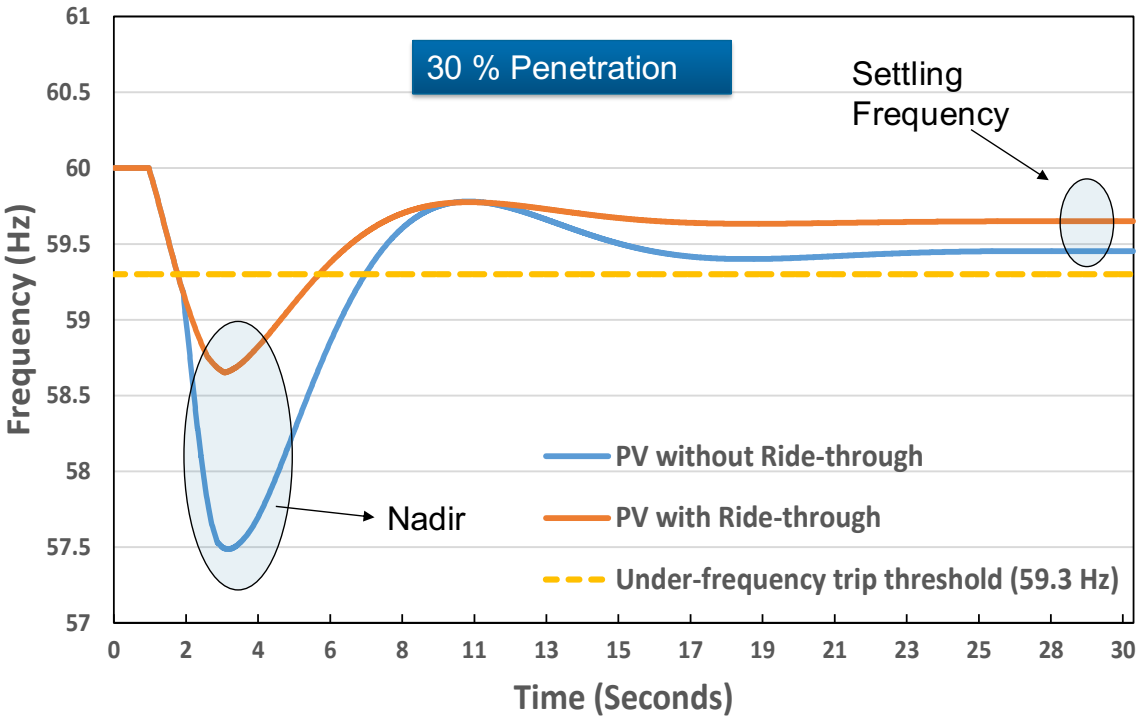
- Transmission faults can depress distribution **voltage** over very large areas
- Sensitive voltage tripping (e.g., UL 1741 certified inverters) can cause massive loss of IBR generation
- Resulting BPS event may be greatly aggravated

Case Study Results

Voltage Trip Can Cascade into Frequency Trip



Frequency Ride-Through Can Improve Nadir



Source: EPRI (2014)

Reported Reliability Issues with IBR and Mitigations

Bulk System Reliability & Frequency Support

Odessa Disturbance recommendations call for more than guidelines

- Significant Updates and Improvements Needed to the FERC Generator Interconnection Agreements
- Improvements to NERC Reliability Standards Needed to Address Systemic Issues with Inverter-Based Resources
  - Improvements to Performance-Based Requirements
  - Performance Assessment and Mitigation
  - Ride-Through Standard In Lieu Of PRC-024-3
  - Analysis and Reporting of Inverter-Based Resource Reductions
  - Electromagnetic Transient Modeling and Studies for All Newly Interconnecting Inverter-Based Resources

Causes of Solar PV Reduction to be Addressed

- PLL Loss of Synchronism
- Inverter AC Overvoltage
- Momentary Cessation
- Feeder AC Overvoltage
- Unknown
- Inverter Underfrequency
- Not Analyzed
- Feeder Underfrequency

Addressed Reliability Issue

- PLL Loss of Synchronism
- Inverter AC Overvoltage
- Momentary Cessation
- Feeder AC Overvoltage
- Unknown
- Inverter Underfrequency
- Not Analyzed
- Feeder Underfrequency

Voltage Ride-Through (VRT)

Bulk System Reliability & Frequency Support

Addressed Reliability Issue
- Inverter AC Overvoltage
- Momentary Cessation
- Unknown
- Not Analyzed

ERCOT - Nodal Operating Guide: 2.9.1: Voltage Ride-Through Requirements for Intermittent Renewable Resources and Energy Storage Resources Connected to the ERCOT Transmission Grid

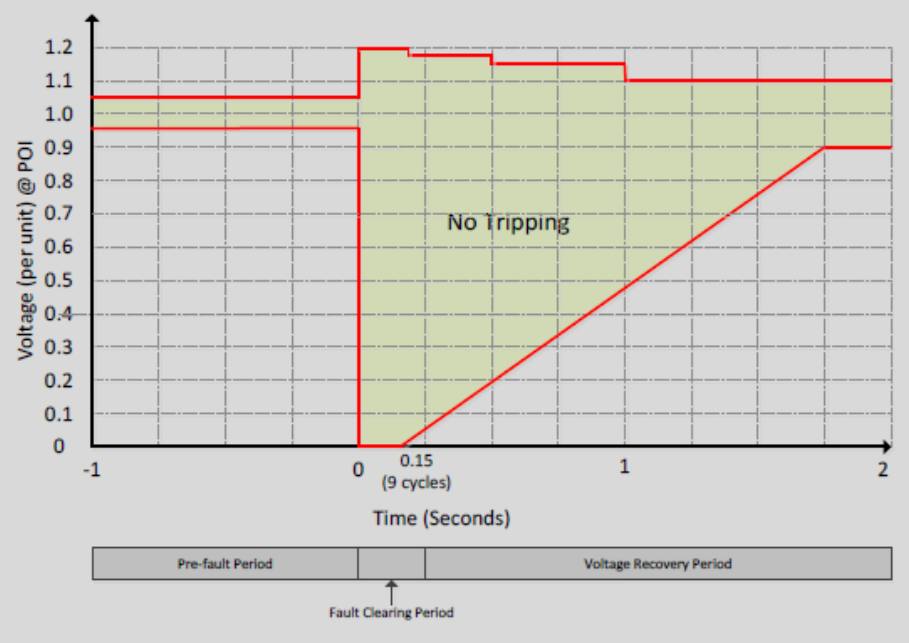
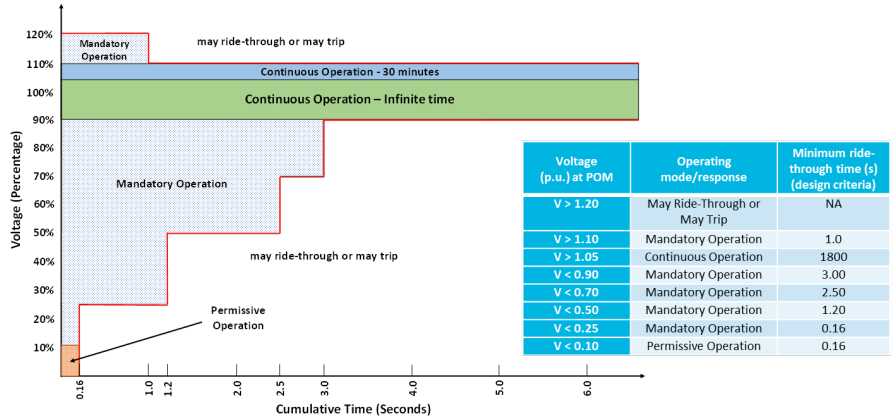


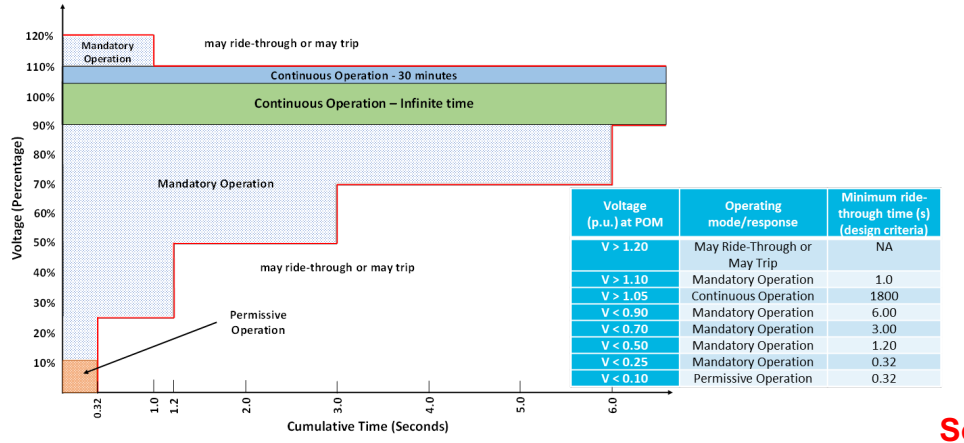
Fig. 1. Default Voltage Ride-Through Boundaries for IRRs and ESRs Connected to the ERCOT Transmission Grid

IEEE 2800 - 7.2.2.3 Low and High voltage ride-through within the mandatory operation region



Voltage (p.u.) at POM	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	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	0.16

Wind



Voltage (p.u.) at POM	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	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	0.32

Solar

ERCOT < IEEE 2800: raise to 2800 and require more stringent VRT capability?

Restore output after voltage ride-through

Bulk System Reliability & Frequency Support

Addressed Reliability Issue
- Inverter AC Overvoltage
- Momentary Cessation
- Unknown
- Not Analyzed

ERCOT MQG - LVRT Leading - Figure 6:

- The real power started to recover prior to the voltage reaching 0.9 per unit and recovered quickly upon reaching 0.9 per unit and thus was acceptable.

IEEE 2800 – 7.2.2.6 Restore output after voltage ride-through

- **restore output:** Return operation of the inverter-based resources (IBR) to the state prior to the abnormal excursion of voltage or frequency that resulted in a ride-through operation of the IBR. (Adapted from IEEE Std 1547TM -2018)
- Upon the *applicable voltage* returning to *continuous operation region*, from a *mandatory operation region* or *permissive operation region* where the *IBR plant* performs ride-through in *mandatory operation* mode, the *IBR plant* shall have 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 second.**

ERCOT < IEEE 2800: raise to 2800 and specify restore output after VRT?

Transient overvoltage ride-through requirements

Bulk System Reliability & Frequency Support

Addressed Reliability Issue
- Inverter AC Overvoltage
- Unknown
- Not Analyzed

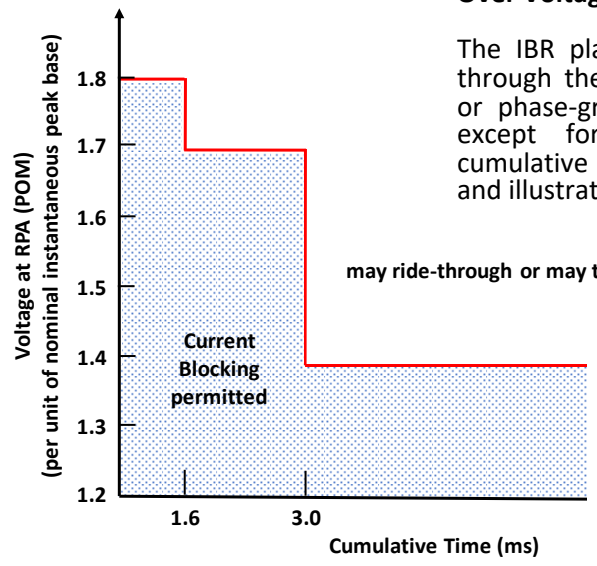
ERCOT

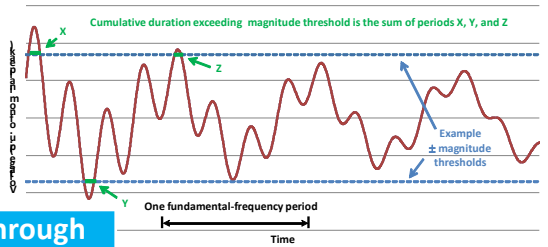
- No explicit requirement
- Per mutual agreement where a sub-synchronous resonance (SSR) study is required during the study process, if RMS voltage is still withing VRT envelope.
- See also: https://www.ercot.com/files/docs/2020/06/19/VRT_Near_Series_Capacitors.pdf

IEEE 2800 - 7.2.3 Transient overvoltage ride-through requirements

Over Voltage Ride-Through

The IBR plant shall be capable to ride-through the higher of each phase-phase or phase-ground instantaneous voltages except for voltage magnitudes and cumulative durations specified in Table and illustrated in the informative Figure





Voltage (p.u.) at POM	Minimum ride-through time (ms) (design criteria)
V > 1.80	See Note 1
V > 1.70	1.6
V > 1.40	3.0
V > 1.20	15.0

ERCOT < IEEE 2800: raise to 2800 and make TrOV capability mandatory?

Voltage Phase Angle Ride-Through

Bulk System Reliability & Frequency Support

Addressed Reliability Issue

- PLL Loss of Synchronism
- Momentary Cessation
- Unknown
- Inverter Underfrequency
- Not Analyzed

ERCOT

- No requirements on the threshold.
- MQG does include a voltage phase angle jump test.

IEEE 2800 - 7.3.2.4 Voltage phase angle changes ride-through

- **The *IBR plant* shall ride through positive-sequence phase angle changes within a sub-cycle-to-cycle time frame of the *applicable voltage* of less than or equal to 25 electrical degrees.**
- In addition, the *IBR plant* shall **remain in operation for any change in the phase angle of individual phases** caused by occurrence and clearance of unbalanced faults, provided that the positive-sequence angle change does not exceed the forestated criterion.
- Active and reactive current **oscillations** in the *post-disturbance period* that are **positively damped** shall be acceptable in response to phase angle changes.
- ***Current blocking*** in the *post-disturbance period* **shall not be permitted**.

ERCOT < IEEE 2800: raise to 2800 and make phase angle ride-through capability mandatory?

Consecutive Voltage Ride-Through

Bulk System Reliability & Frequency Support

Addressed Reliability Issue
- Inverter AC Overvoltage
- Momentary Cessation
- Unknown
- Not Analyzed

ERCOT

- No requirements.

IEEE 2800 – 7.2.2.4 Consecutive voltage deviations ride-through capability

The *IBR plant* shall ride through multiple excursions outside of the *continuous operation region* with exception of the conditions and situations specified below, for which the *IBR plant* may trip to protect equipment integrity from the cumulative effects of successive voltage deviations:

- The *IBR plant* may trip for disturbances for which the cumulative duration of voltage deviations within the applicable time window specified in 7.2.2.1 (i.e., 10 seconds or 3600 seconds) exceeds (i.e., undervoltages less than or overvoltages greater than) the ride-through durations specified in Table 11 or Table 12, as applicable.
- The *IBR plant* **may trip for more than [X] deviations** of the *applicable voltage* at the RPA outside of the *continuous operation region* **within any [Y]-second period**.

X	Y
> 4	≤ 10 s
> 6	≤ 120 s
> 10	≤ 30 min

- The *IBR plant* **may trip for any voltage deviation** outside of *continuous operation region* **that follows** the end of a previous deviation **by less than 20 cycles** of the system fundamental frequency.
- The *IBR plant* **may trip for more than [X] individual deviations** of the *applicable voltage* at the RPA **below 50% of the nominal voltage** (inclusive of zero voltage) **within any [Y]-second period**.

X	Y
> 2	≤ 10 s
> 3	≤ 120 s

- **For WTG based *IBR plants***, individual ***IBR units*** **(WTGs) may trip to self-protect** for consecutive voltage deviations that result in stimulation of mechanical resonances exceeding equipment limits.

The *TS owner/TS operator* should specify ride-through requirements for dynamic voltage oscillations that may be stimulated by a TS fault, opening of a line, or tripping of a generator and that may cause the *applicable voltage* to deviate outside the *continuous operation region* multiple times.

As applicable, **exception from specified consecutive voltage deviations ride-through capability** shall be **permitted with mutual agreement** between the *IBR owner* and *TS owner/TS operator*.

ERCOT < IEEE 2800: raise to 2800, make consecutive voltage ride-through capability mandatory, and specify ride-through requirements for dynamic voltage oscillations?

Voltage-Reactive Power (Volt-Var)

Reactive Power & (Dynamic) Voltage Support

Addressed Reliability Issue

- Inverter AC Overvoltage
- Feeder AC Overvoltage
- Unknown
- Not Analyzed

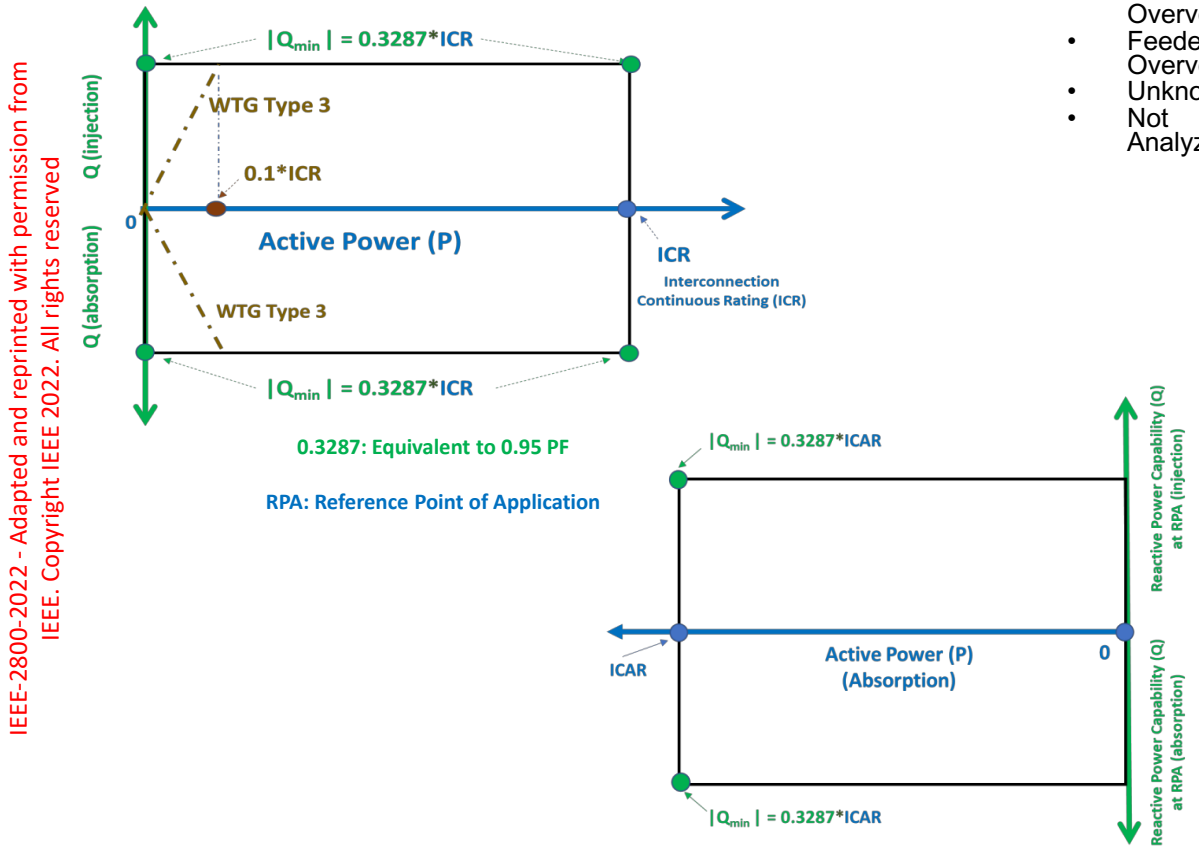
ERCOT NPs - 3.15 Voltage Support

For Generation Resources, the Reactive Power capability shall be **available at all MW output levels** and may be met through a combination of the Generation Resource's Corrected Unit Reactive Limit (CURL), which is the generating unit's dynamic leading and lagging operating capability, and/or dynamic VAr-capable devices. **This Reactive Power profile is depicted graphically as a rectangle.**

For Intermittent Renewable Resources (IRRs), the Reactive Power requirements shall be available at all MW output levels at or above 10% of the IRR's nameplate capacity. When an IRR is operating below 10% of its nameplate capacity and is unable to support voltage at the POIB, ERCOT, the interconnecting TSP, or that TSP's agent may require an IRR to disconnect from the ERCOT System for purposes of maintaining reliability.

For ESRs, the Reactive Power capability shall be **available at all MW levels**, when charging or discharging, and may be met through a combination of the ESR's CURL, and/or dynamic VAr-capable devices.

IEEE 2800 - 5.2.2 RPA voltage control



ERCOT < IEEE 2800: raise to 2800 and require "VArs at night" capability for non-WTG Type 3 IRRs?

Voltage-Reactive Power (Volt-Var)

Reactive Power & (Dynamic) Voltage Support

Addressed Reliability Issue
- Inverter AC Overvoltage
- Feeder AC Overvoltage
- Unknown
- Not Analyzed

ERCOT - Nodal Protocols: 3.15 Voltage Support

Each Generation Resource and ESR required to provide VSS shall comply with the following Reactive Power requirements in Real-Time operations when issued a Voltage Set Point by a TSP or ERCOT:

(a) An over-excited (lagging or producing) **power factor capability of 0.95 or less** determined at the unit's maximum net power to be supplied to the ERCOT Transmission Grid and **for any Voltage Set Point from 0.95 per unit to 1.04 per unit, as measured at the POIB;**

(b) An under-excited (leading or absorbing) **power factor capability of 0.95 or less**, determined at the unit's maximum net power to be supplied to the ERCOT Transmission Grid and **for any Voltage Set Point from 1.0 per unit to 1.05 per unit, as measured at the POIB;**

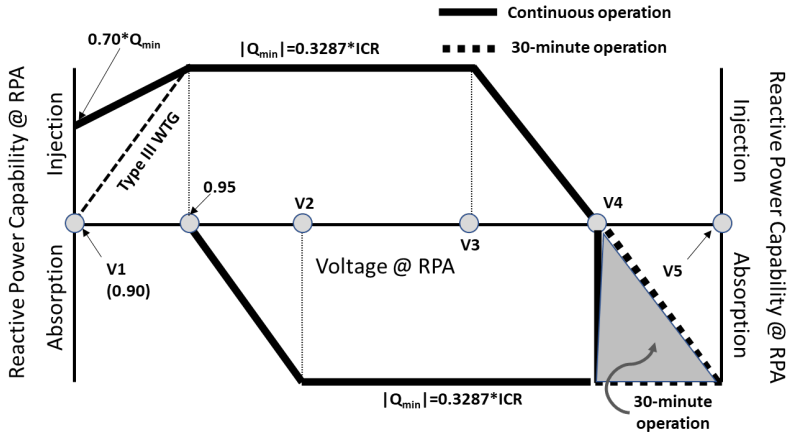
(c) For any **Voltage Set Point outside of the voltage ranges** described in paragraphs (a) and (b) above, the Generation Resource or ESR shall **supply or absorb the maximum amount of Reactive Power** available within its inherent capability and the capability of any VAr-capable devices as necessary to achieve the Voltage Set Point;

Nominal Voltage	Tolerance Band kV
345	+/- 4kV
230	+/- 3kV
138	+/- 2kV
115	+/- 2kV
69	+/- 1kV

Nodal Operating Guide Section 2.7.3.5, Resource Entity Responsibilities and Generation Resource Requirements

A Generation Resource's POI voltage may be out of the tolerance band if it has exhausted all of its reactive capability. The tolerance bands are as follows:

IEEE 2800 - 5.2.2 RPA voltage control



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.					

- Dynamic reactive power specification

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

Current Injection During Fault

Reactive Power & (Dynamic) Voltage Support

Addressed Reliability Issue
- PLL Loss of Synchronism
- Inverter AC Overvoltage
- Momentary Cessation
- Feeder AC Overvoltage
- Unknown
- Not Analyzed

ERCOT NP - 3.15.3 Generation Resource and Energy Storage Resource Requirements Related to Voltage Support

(2) Generation **Resources** and ESRs **providing VSS** shall be compliant with the ERCOT Operating Guides for **response to transient voltage disturbance**.

ERCOT NOG – 2.9 Voltage Ride-Through Requirements for Generation Resources

(3) During operating conditions listed in paragraph (1) above, each Generation Resource or ESR **shall not**, during and following a transient voltage disturbance, **cease providing real or reactive power** except to the extent needed **to provide** frequency support or **aid in voltage recovery**.

Each ESR, if it is consuming active power from the ERCOT System when operating in the charging mode, **shall reduce or cease power consumption** as necessary **to aid in voltage recovery** during and following transient voltage disturbances.

Model Quality Guide (MQG) - LVRT Leading - Figure 6:

For the LVRT stimulus applied at the POI (top figure), the plant reactive power increased promptly (bottom figure).

IEEE 2800 - 7.2.2.3.4 Current injection during ride-through mode

At minimum, **the *IBR unit*** shall be capable of following:

- **Depending on mode** of operation (active or reactive current priority), the *IBR unit* shall be capable of prioritizing active or reactive current equal to its ***maximum current* rating when the *IBR unit* terminal voltage is less than or equal to 50% of nominal voltage**.

For **balanced faults**: **positive sequence** current injection

- The difference between reactive current injection during a fault and a pre-fault reactive current output is an incremental positive-sequence reactive current (ΔIR-1). The incremental positive-sequence reactive current shall not be negative

For **unbalanced faults** - **positive and negative sequence** current injection

- Dependent on *IBR unit* terminal (POC) negative sequence voltage and
- That leads the *IBR unit* terminal (POC) negative sequence voltage by an allowable range as specified below:
  - 90 degrees to 100 degrees for full converter-based *IBR units*
  - 90 degrees to 150 degrees for type III WTGs

ERCOT < IEEE 2800: raise to 2800, adopt more detailed specifications and make negative sequence current injection capability mandatory? RPA=PoC or POI?

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Discussion

- 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?

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

Requirements in Scope of Transmission Service Provider (TSP) and not of ERCOT

Other Requirements of IEEE 2800 by Mutual Agreement (Optional)

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