Gap Analysis Between IEEE 2800 and Existing Interconnection Requirements

Piecemeal, Patchwork, and Other Possibilities—Quo Vadis IEEE 2800 Adoption?

Jens Boemer, Technical Executive

ESIG 2022 Fall Technical Workshop
Session 2: IEEE 2800 and IBR Modeling

October 25, 2022

Acknowledgements and Disclaimers

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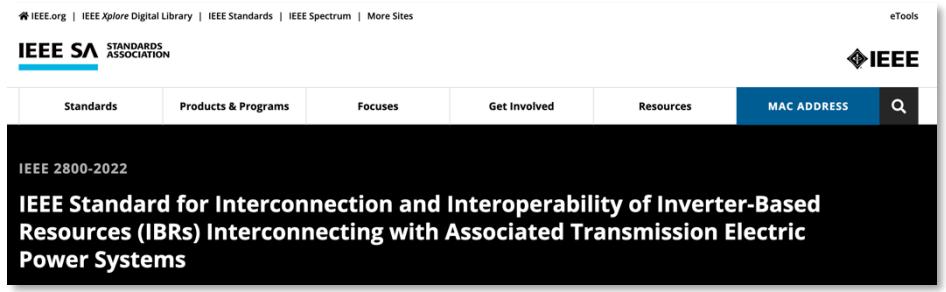
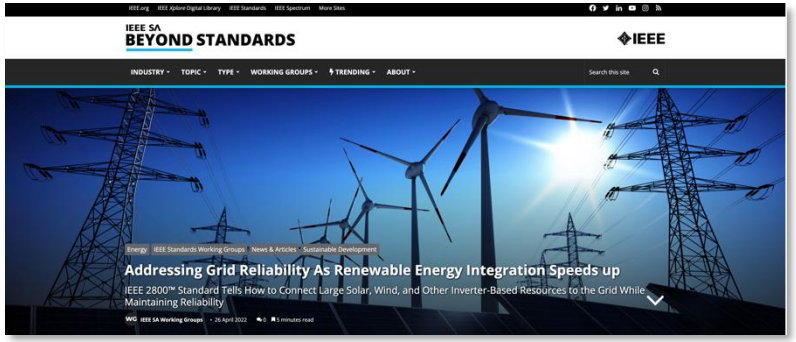
- Part of this work was **supported in part by the National Renewable Energy Laboratory**, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office and Wind Energy Technologies Office. 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). The views expressed in the presentation do **not necessarily represent the views of the DOE or the U.S. Government**.

Resources and Media

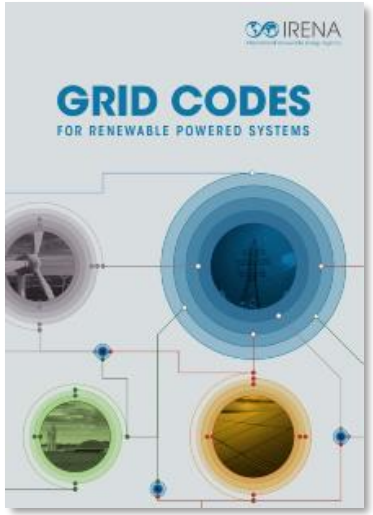


https://standards.ieee.org/project/2800.html

https://subscriber.politicopro.com/article/eenews/2022/09/20/out-of-nowhere-inside-the-fight-over-renewable-tripping-00056359



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://pv-magazine-usa.com/2022/08/17/adopting-new-ieee-standard-could-ease-interconnection-says-epri-executive/

Today's Decisions Shape Course of Energy Transition & Reliability

Risk Framework for Inverter-Based Resources Performance

$$\textbf{RISK} = \text{insufficient performance } \textbf{specifications} \times \text{insufficient performance } \textbf{verification}$$

IEEE 2800-2022

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

&

P2800.2

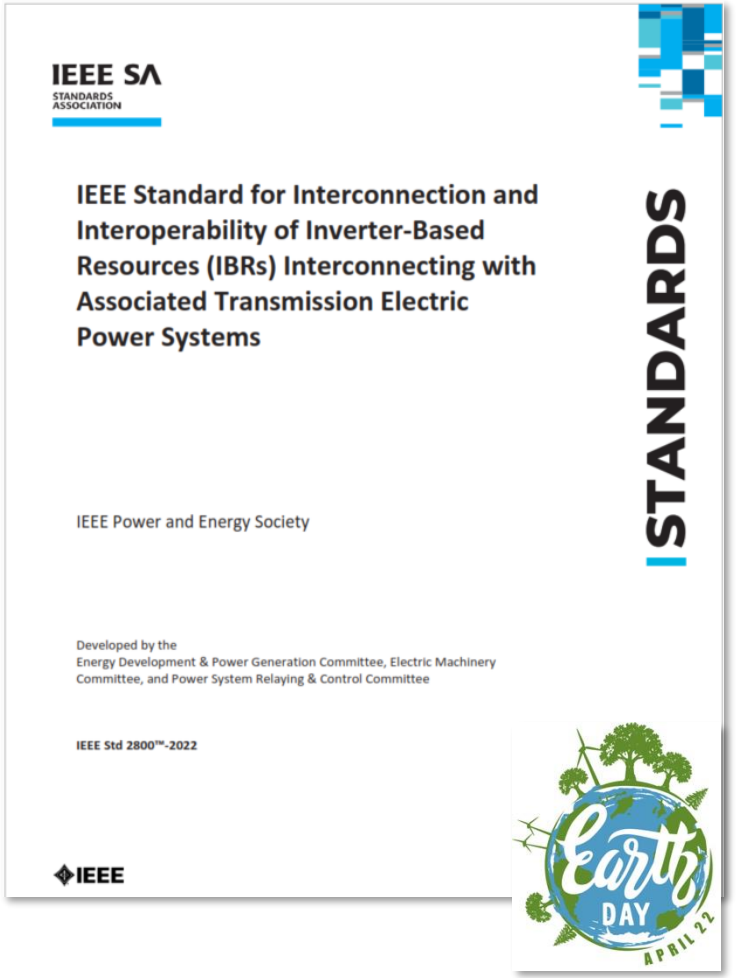
Recommended Practice for Test and Verification Procedures for Inverter-based Resources (IBRs) Interconnecting with Bulk Power Systems

Active PAR

Uncertainty in What Capabilities and Performance Should Provide to a Future Power System

IEEE Std 2800-2022

- Harmonizes **technical minimum** interconnection **capability** and performance requirements for large solar, wind and storage plants, including those connected via VSC-HVDC like offshore wind
- A **consensus-based** standard developed by over ~175 Working Group participants from utilities, system operators, transmission planners, & OEMs over 2 years
- Passed the IEEE SA ballot among 466 SA balloters with high approvals **(>94% approval**, >90% response rate)
- **Published on April 22, 2022 (Earth Day)**



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

Technical Foundation Enables Paradigm Shift Towards *Minimum* Capabilities

Capability versus Utilization

Capability:

"Ability to Perform"

Scope of IEEE 2800

- Functions
- Ranges of available settings
- Minimum performance specifications

Examples

- Frequency Response
  - Primary frequency response
  - Fast frequency response

- 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:

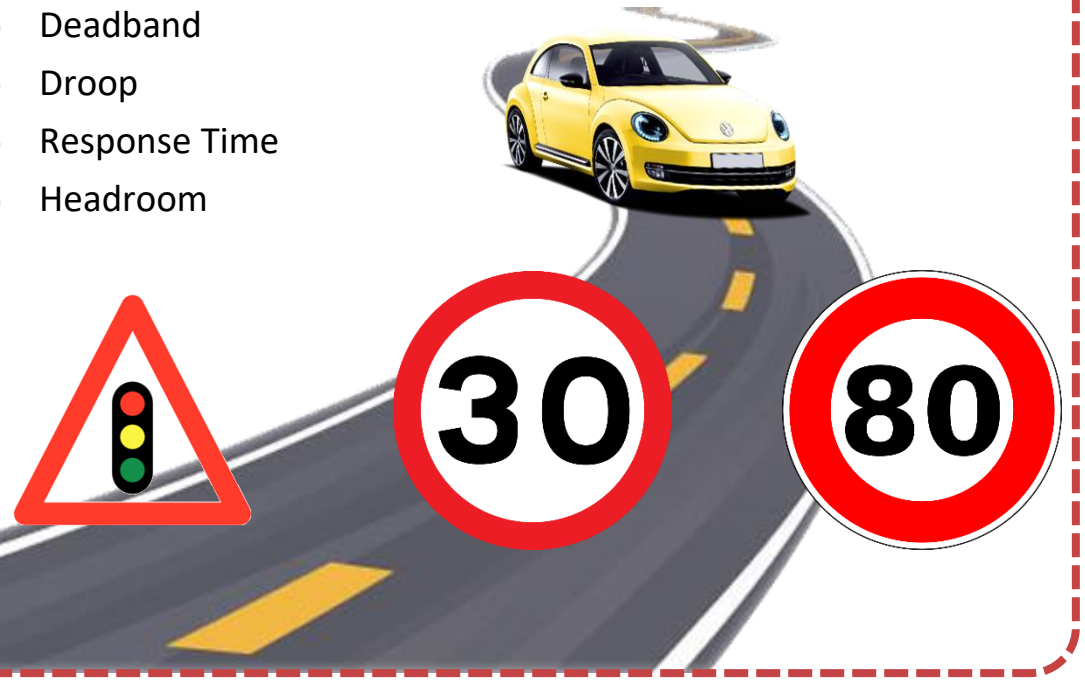
"Delivery of Performance"

Scope of Interconnection or Ancillary Services Agreement

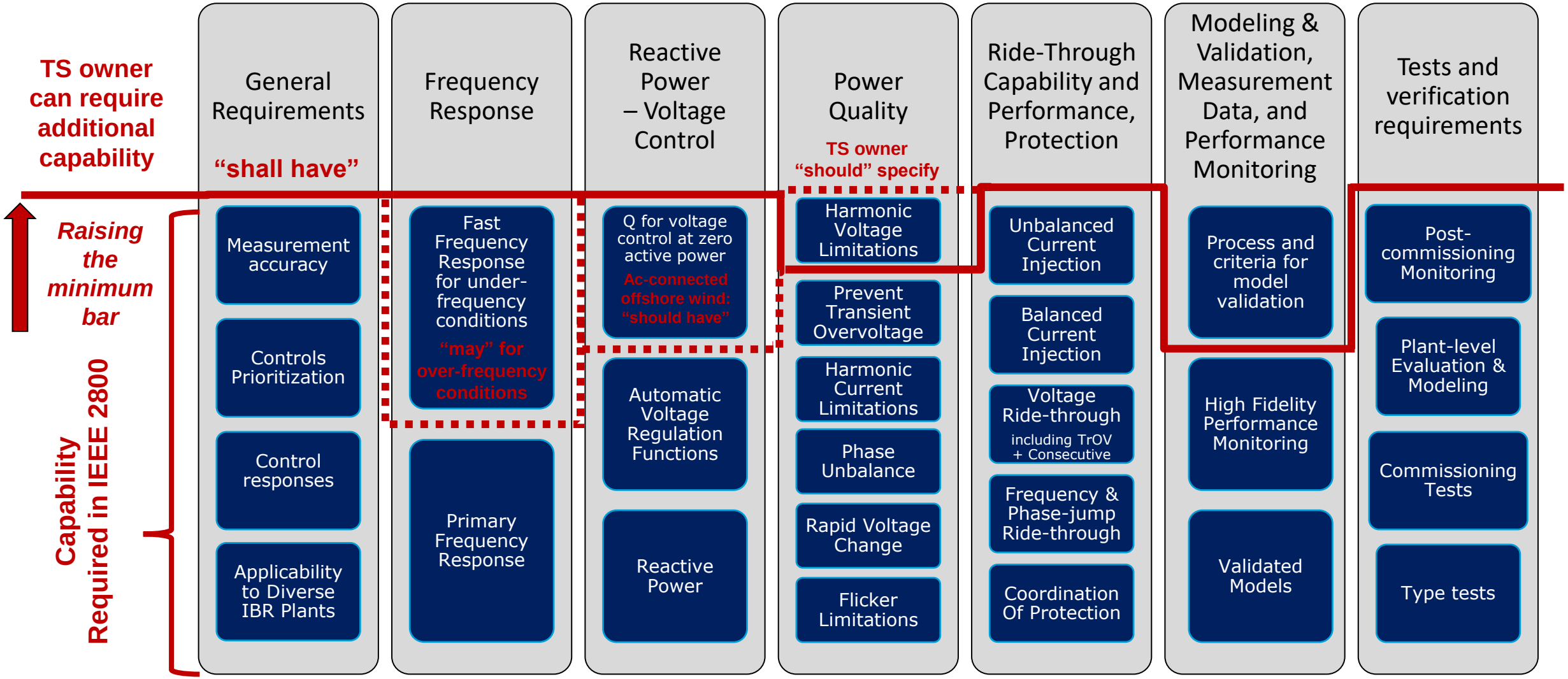
- Enable/disable functions
- Functional settings / configured parameters
- Operate accordingly (e.g., maintain headroom, if applicable)

Examples

- Deadband
- Droop
- Response Time
- Headroom



IEEE 2800-2022 Technical Minimum Capability Requirements

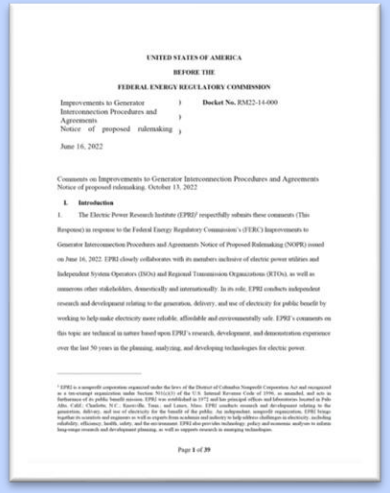


Requiring *All* Capabilities May Conflict with *Current* Market Rules

EPRI Activities To Date Supporting IEEE 2800-2022 Adoption

- **March 2022 – ongoing:** work with two early-interest EPRI members

- **May 3, 2022:** Joint NERC-NATF-NAGF-EPRI Webinar on Publication of IEEE 2800-2022 ~ 1,000 attendees
  - Slide deck and recording available to the public at https://www.epri.com/research/programs/067417/events/621D26F1-00A5-4F90-8AA8-C68959393DBC
- **August 9-11, 2022:** Joint ESIG-NAGF-FERC-NERC-EPRI Interconnection Workshop ~ 700 attendees
  - Slide decks, recordings, and summary report available to the public at https://www.esig.energy/event/joint-generator-interconnection-workshop/
- **September 22, 2022:** EPRI Informational Webinar on FERC NOPR on Generator Interconnection (Transmission) ~ 130 attendees
  - Slide deck and recording available to EPRI members at https://www.epri.com/research/programs/067417/events/33867756-483F-47E9-9ABF-B6235342F9FE
- **October 12, 2022:** EPRI Utility Field Experience Interest Group on FERC's Small Generator Interconnection Procedure (SGIP) ~ 120 attendees
  - Slide deck and recording available to EPRI members at https://www.epri.com/research/programs/067418/events/351679F6-DEB7-470C-96CA-292CC96FD8FD



UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

Improvements to Generator Interconnection Procedures and Agreements
Notice of proposed rulemaking

Docket No. RM22-14-000

June 16, 2022

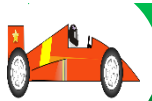
Comments on Improvements to Generator Interconnection Procedures and Agreements Notice of proposed rulemaking, October 13, 2022

I. Introduction

- **October 13, 2022:**
  EPRI Comments filed on FERC's Improvements to Generator Interconnection Procedures and Agreements NOPR issued on June 16, 2022
  - available in FERC's eLibrary at https://elibrary.ferc.gov/eLibrary/filedownload?fileid=AD71793A-769B-C856-91EB-83D327900000

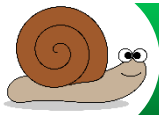
- Milestone reports from DOE- and EPRI member-funded **PV-MOD project** substantiate many of EPRI's comments.
  - These are available at https://www.epri.com/pvmod.
- EPRI recommends **adoption of IEEE Standards like 1547-2018 for SGIP/SGIA and 2800-2022 for LGIP/LGIA** to set clear expectations for DER and Large IBR plants' technical minimum capabilities.
  - Supported—to different extent—by 7 other entities, including NERC, SEIA, ACP, IREC, Orsted, SoCo, AEP.
- EPRI recommends all **models should be validated** and appropriately parameterized; modeling as a **method for pre-commissioning conformity assessment**.

Possible IEEE 2800-2022 Adoption Methods



General Reference

- Full adoption of standard by general reference
- Specification of
  - technical minimum capability per IEEE 2800-2022
  - functional settings/ performance (in ranges of available settings)
- Decision whether to specify additional requirements or not
  - e.g., for non-exhaustive reqs.



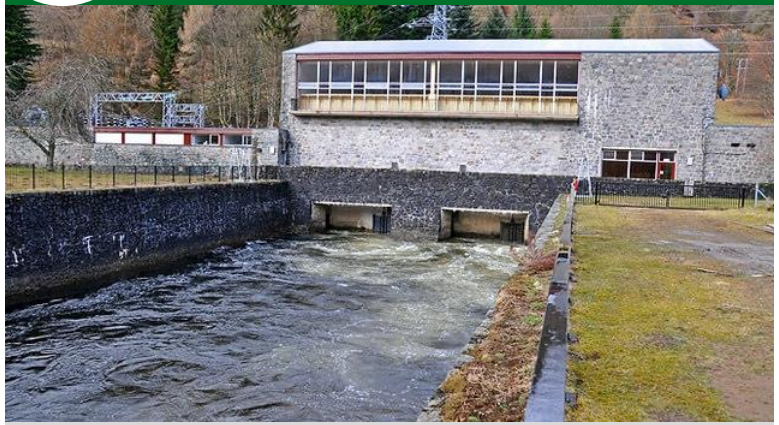
Detailed Reference

- Full or partial adoption of std
- Clause-by-clause references
- Any additional requirements

Benefit: *Consistency to standard*

Risk: *Fragmentation of requirements, certification challenges, additional costs*

Full Specification



- All on the left
- Clause-by-clause own language
- Any additional requirements

Benefit: *No need to buy standard*

Risk: *Inconsistencies to standard and fragmentation of requirements, certification challenges, additional costs*

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
Gap

1 2 3 Priorities per ERCOT presentation at IBRTF Meeting of Sep 13, 2022

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

Function Set	Advanced Functions Capability	ERCOT Nodal Protocols	IEEE 2800-2022
Sec 4 General	Definitions	?	?
	Reference Point of Applicability	POI	POM
	Adjustability in Ranges of Available Settings	NR (!!!)	‡
	Prioritization of Functions	‡	‡
Sec 11 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	‡	√
Sec 5 Reactive Power & (Dynamic) Voltage Support	Constant Power Factor	‡	‡
	Voltage-Reactive Power (Volt-Var)	‡	‡
	Autonomously Adjustable Voltage Reference	?	
	1 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
	2 Dynamic Voltage Support / Current Injection during VRT — Balanced	‡	‡
	2 Dynamic Voltage Support / Current Injection during VRT — Unbalanced	NR (!!!)	‡

Function Set	Advanced Functions Capability	ERCOT Nodal Protoc.	IEEE 2800-2022
Sec 6&7 Bulk System Reliability & Frequency Support	Frequency Ride-Through (FRT)	‡	‡
	2 Rate-of-Change-of-Frequency (ROCOF) Ride-Through	NR (!!!)	‡
	Voltage Ride-Through (VRT)	‡	‡
	2 Transient Overvoltage Ride-Through	√ (!!!)	‡
	2 Consecutive Voltage Dip Ride-Through	NR (!!!)	‡
	2 Restore Output After Voltage Ride-Through	NR (!!!)	‡
	2 Voltage Phase Angle Jump Ride-Through	NR (!!!)	‡
	Frequency Droop / Frequency-Watt	‡	‡
	3 Fast Frequency Response / Inertial Response — Underfrequency FFR	√ (!!!)	‡
	3 Fast Frequency Response / Inertial Response — Overfrequency FFR	NR	√
	Return to Service (Enter Service)	?	‡
	Black Start	NR	√
Sec 9 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	?	√
Sec 8 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

High-Level Gap Assessment of EPRI Member Utility Owning Sub-Transmission

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

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

Function Set	Advanced Functions Capability	EPRI Member with S/T	IEEE 2800-2022
Bulk System Reliability & Frequency Support	Frequency Ride-Through (FRT)	‡ - 1547 Cat III	‡
	Rate-of-Change-of-Frequency (ROCOF) Ride-Through	√ - 1547	‡
	Voltage Ride-Through (VRT)	‡ - 1547 Cat III	‡
	Transient Overvoltage Ride-Through	n/a	‡
	Consecutive Voltage Dip Ride-Through	n/a	‡
	Restore Output After Voltage Ride-Through	‡ - 1547	‡
	Voltage Phase Angle Jump Ride-Through	√ - 1547	‡
	Frequency Droop / Frequency-Watt	√ - 1547	‡
	Fast Frequency Response / Inertial Response — Underfrequency FFR	n/a	‡
	Fast Frequency Response / Inertial Response — Overfrequency FFR	n/a	√
	Return to Service (Enter Service)	‡ - 1547	‡
	Black Start	n/a	√
Protection Functions and Coordination	Abnormal Frequency Trip	‡ - 1547 Cat III	√
	Rate of Change of Frequency (ROCOF) Protection	√ - 1547	√
	Abnormal Voltage Trip	‡ - 1547 Cat III	√
	AC Overcurrent Protection	√ - 1547	√
	Unintentional Islanding Detection and Trip	‡ - 1547	√
	Interconnection System Protection	‡	√
Power Quality	Limitation of DC Current Injection	n/a	
	Limitation of Voltage Fluctuations	‡	‡
	Limitation of Current Distortion	n/a	‡
	Limitation of Voltage Distortion	n/a	√
	Limitation of (Transient) Overvoltage	√ - 1547	‡

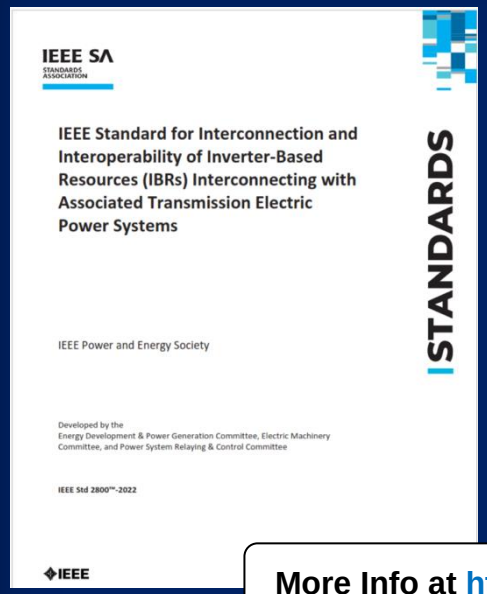
Thirty (30) High-level gaps in EPRI Member Utility relate to 2800 mandatory requirements

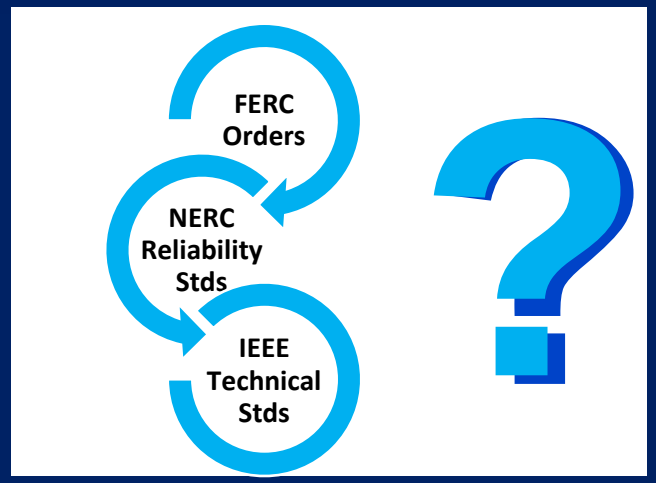
Lessons Learned So Far About IEEE 2800-2022 Adoption

- Transmission Owners / Planners play a key role
  - Gap assessment relative to, and improvement of existing requirements
  - Determine reasonable interconnection application enforcement date for new IBR plants; signal early IEEE 2800 adoption
  - **Adoption requires TO to make ~120 decisions, e.g., specification of settings other than default values**
- Requiring certain capabilities may conflict with current market rules
  - Focus stakeholder discussions of IBR requirements on *capabilities* and separate from their *utilization*
  - Work with stakeholders—and with FERC—to consider implementation of paradigm shift towards IBR minimum capabilities with grandfathering ➔ emphasize readiness of technology, economic viability, and international precedence
  - **Instead of "piecemeal" adoption of IEEE 2800, use "general reference" and add a list of excepted clause and sub-clause numbers ➔ allows for successive striking of exceptions once market rules are reformed over time**
- Verification of IBR plant capabilities and performance is the biggest challenge
  - Not contingent on publication of IEEE P2800.2 *Draft Recommended Practice for Test and Verification Procedures*
  - **Interim conformity assessment by unit certification and plant checklist; could use existing IBR unit type test procedures and unit certifications from other countries, e.g., IEC[1], ENTSO-e, German VDE and FGW[2], AEMO, et al.**

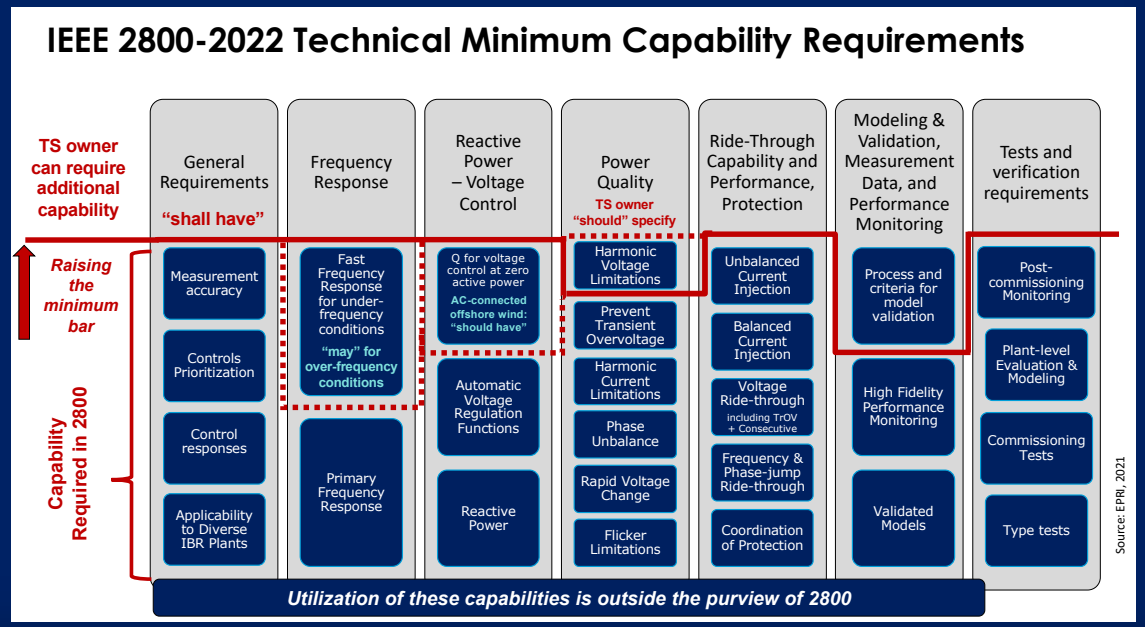
[1] IEC TS 63102:2021 Grid Code Compliance Assessment Methods For Grid Connection Of Wind And PV Power Plants
[2] VDE-AR-N 41xx, FGW Technical Guidelines TG3 (Measurements), TG4 (Modeling & Validation), and TG8 (Certification)

A Patchwork of IEEE 2800 Adoption Around the U.S. Could Have Limited Benefits





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



Could a FERC Reference in LGIP/LGIA to IEEE 2800 Help Expedite the Adoption Process?

- There is **precedence for references** to IEEE standards in FERC Orders and NERC Reliability Standards, for example IEEE standards as "good utility practice"
- Would reduce regulatory barriers to harmonized IBR plant **technical minimum capability** and performance requirements
- Would align with **international practices** of regulatory orders referencing consensus technical standards that are developed in an open process with relevant stakeholders

➢ **Reply Comments to FERC on Docket RM22-14-000 are due Nov 14, 2022, or Dec 14, 2022***

*At least one stakeholder requested a motion for extension.

Support Reforms by Education and Collaboration

ESIG Reliability Working Group	•Scope: modeling, grid codes and interconnection requirements, weak grids, grid forming converters, etc. •Contact: Jason MacDowell, GE Power | Web: https://www.esig.energy/reliability-working-group/ •Deliverables: technical reports, webinars | meets 3-4x times per year
NERC IRPS Subgroup Work Item #8	•Scope: interconnection process and studies •Contact: Ryan Quint, NERC | Web: https://www.nerc.com/comm/RSTC/Pages/IRPWG.aspx •Deliverables: NERC reliability guideline | meets every other week
IEEE P2800.2 Working Group	•Scope: recommended practices for test and verification procedures for plant-level conformance •Contact: Andy Hoke, NREL | Web: https://sagroups.ieee.org/2800-2/ •Deliverables: IEEE recommended practice | WG meets 3-6x times per year; subgroups meet every other week
NERC Reliability Standards Drafting Teams	•MOD 026/027 Revision: Brad Marszalkowski | Web: https://www.nerc.com/pa/Stand/Pages/Project-2020_06-Verifications-of-Models-and-Data-for-Generators.aspx •TPL-001-5.1 and MOD-032-1 Modifications: Ben Wu | Web: https://www.nerc.com/pa/Stand/Pages/Project2022-02ModificationstoTPL-001-5-1andMOD-032-1.aspx •Modifications to FAC-001 and FAC-002: | Web: https://www.nerc.com/pa/Stand/Pages/Project-2020-05-Modifications-to-FAC-001-and-FAC-002.aspx
Open or Future FERC Dockets	•Scope based on Federal Power Act •Section 205 and 206: Office of Energy Markets and Regulations (OEMR) – transmission generation interconnection process •Section 215: Office of Electric Reliability – reliability standards •FERC NOPR on Improvements to Generator Interconnection Procedures and Agreements (RM22-14) – reply comments due to FERC on Nov 14, 2022, or Dec 14, 2022

EPRI Members: join the launch of EPRI's Collaborative "Verifying Performance of Large Solar, Wind, and Storage Plants" on November 10, 2022, @2:05p–3:25p ET

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Thank you!

Large IBR Plant Performance Reliability Roadmap

% of instantaneous Large IBR penetration

No or insufficient performance specifications

- "everyone is in the dark"
- DER plants trip frequently

Sufficient Performance specifications

- international references
- collaborative learning

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

Conformity Assessment by unit certification and plant checklist

- education on, and adoption of performance requirements
- international references
- collaborative learning

Conformity Assessment by unit certification & characterization and plant modeling

- education in modeling for conformity assessment
- model improvements
- tools

Planned EPRI Collaborative
"Verifying Performance of Large Solar, Wind, and Storage Plants"

?

P2800.2
Recommended Practice for Test and Verification Procedures for Inverter-based Resources (IBRs) Interconnecting with Bulk Power Systems

Past | Today | Shorter Term | Longer Term | **Time**

⇩

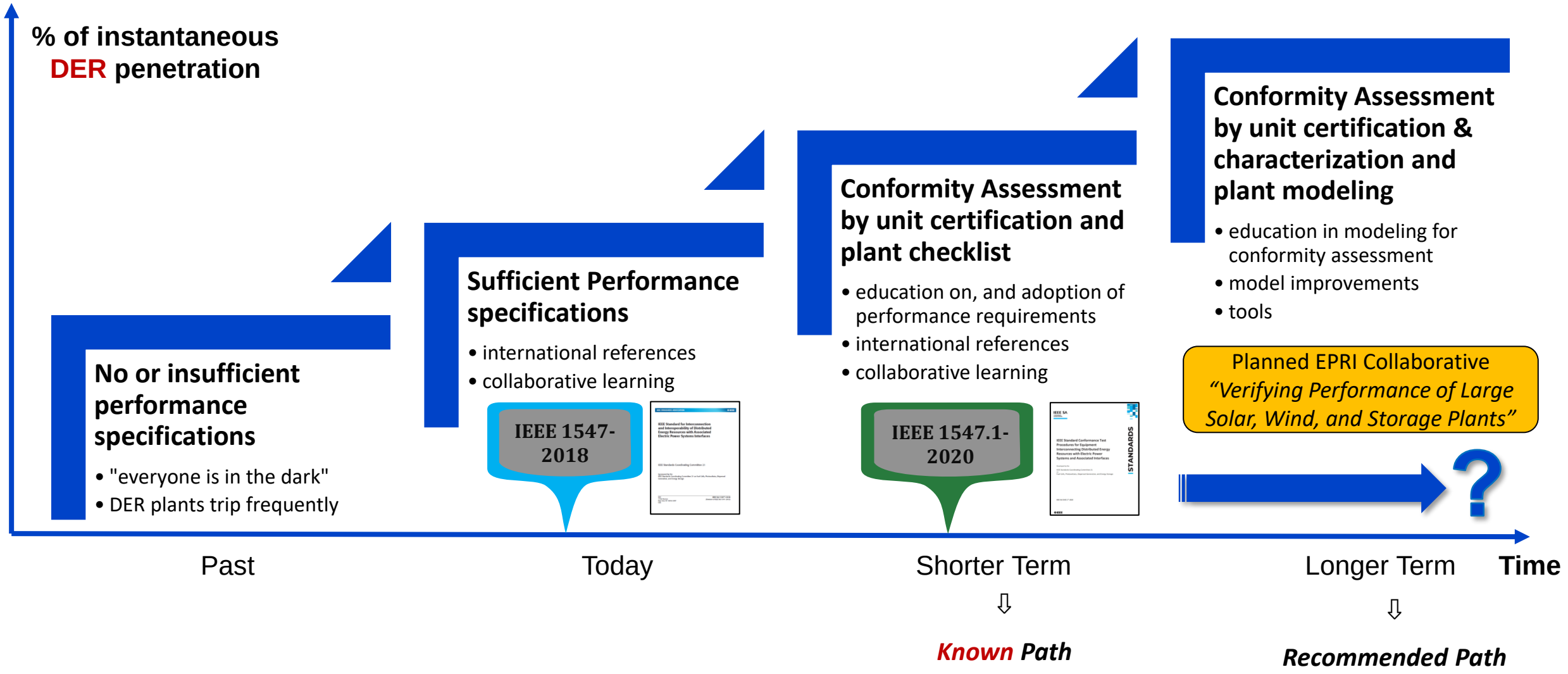
Interim Path

⇩

Recommended Path

17

DER Plant Performance Reliability Roadmap



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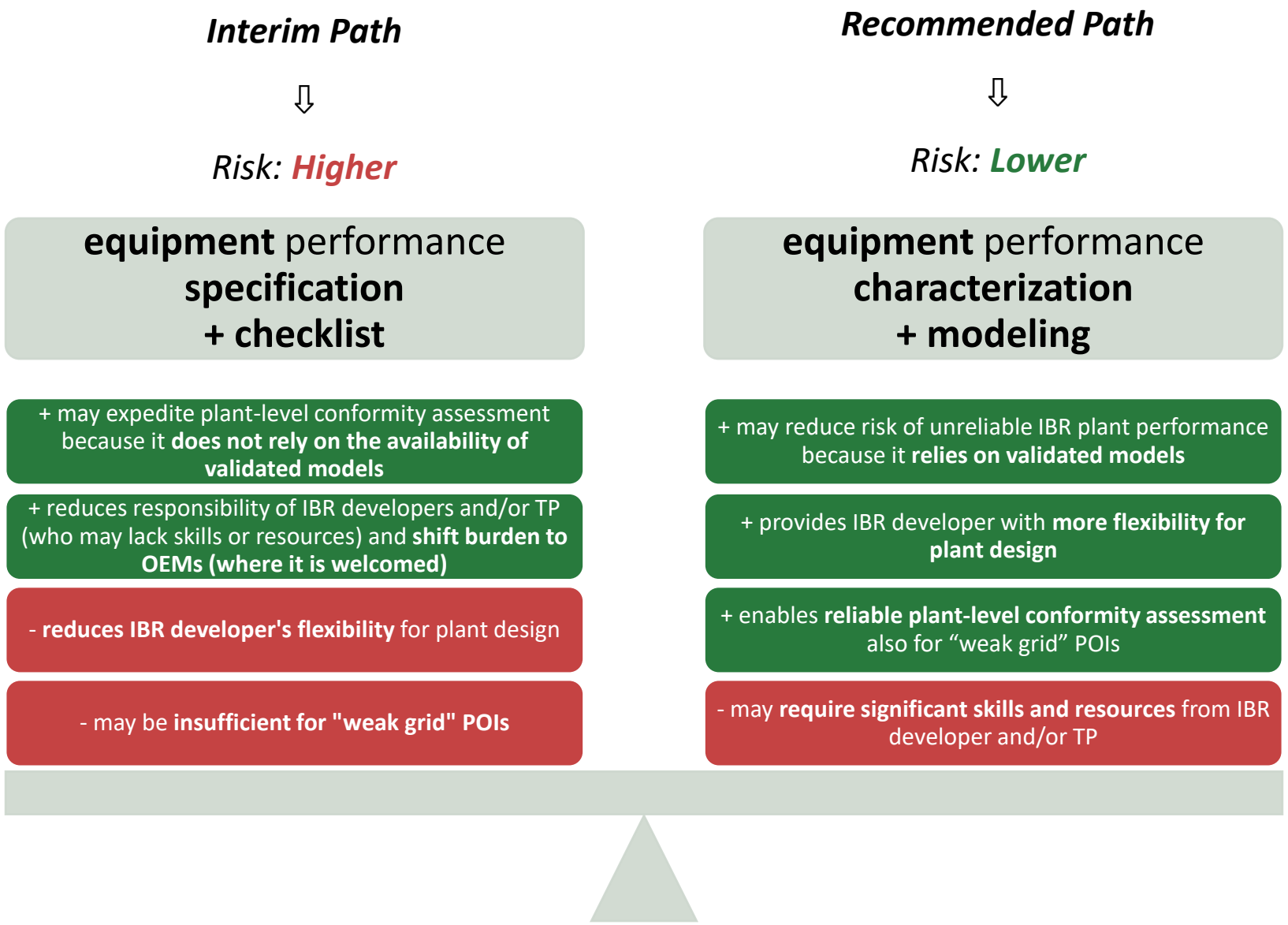
IBR plant-level performance verification



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Verifying Performance of Large Solar, Wind, and Storage Plants

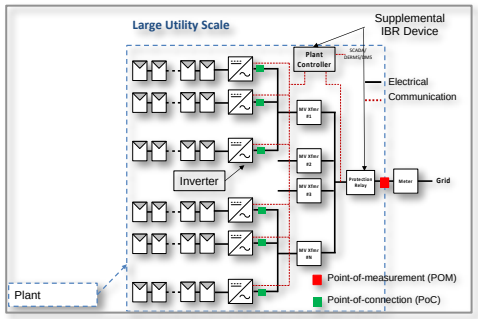
Joint with P174 (DER Integration)

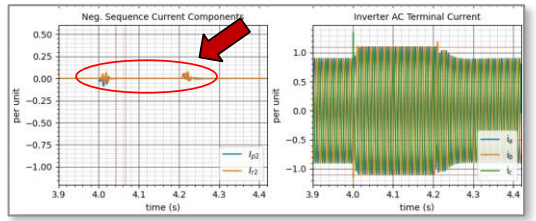
PROGRAM	40/173
PROJECT	16/3
TASK FORCE	MOD
COORDIN.	174

Motivation

Roll-out: Fall 2022, Duration: 2 years

Leading IEEE standards like 2800 and 1547 now firmly establish **capability** and **performance** requirements for large inverter-based resources (IBRs). But the testing and verification for the **plant-level conformance** remains a challenge.





Requirement		Conformity
Voltage Ride-Through (VRT)		Pass
Restore Output After Voltage Ride-Through		Pass
Dynamic Voltage Support / Current Injection during VRT	Balanced	Pass
	Unbalanced	Fail

Scope

- **Training** and review of leading IEEE interconnection standards like IEEE 2800-2022 and international practices for conformity assessment
- Assess and determine **improvements** of participants' technical interconnection requirements, processes, and impact study approaches
- Recommend **pre-commissioning conformity procedures** like inverter type tests and plant-level design evaluation, with:
  - IBR unit capabilities checklist for the shorter-term adoption of IEEE 2800
  - Application of IBR unit and IBR plant models for the longer-term adoption per 2800.2
- Recommend **post-commissioning conformity procedures** like plant as-built installation and settings evaluation, commissioning tests, performance monitoring, and model validation

➢ Balancing Interconnection Process **Efficiency** and **Reliability**

Deliverables & Contact

Deliverables

- [Webcasts] Training recordings and slide decks
- [Virtual Meetings] Monthly or bi-weekly mtgs
- [Technical Updates] (i) IEEE 2800/1547 applicability decision matrix; (ii) IEEE 2800 adoption stakeholder decisions spreadsheet; (iii) generic technical interconnection requirements template; (iv) Plant performance verification procedures report
- Close coordination with the IEEE P2800.2 Working Group and associated Subgroups

Contact

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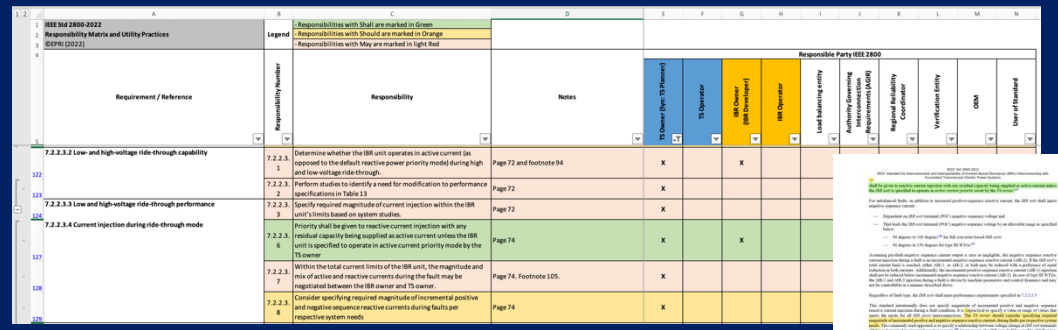
Planned Deliverables

- [Webcasts] Training recordings and slide decks
- [Virtual Meetings] Monthly or bi-weekly mtgs
- [Technical Updates]
  - i. IEEE 2800/1547 applicability decision matrix;
  - ii. IEEE 2800 adoption stakeholder decisions spreadsheet;
  - iii. generic technical interconnection requirements template;
  - iv. Plant performance verification procedures report
- Close coordination with the IEEE P2800.2 Working Group and associated Subgroups

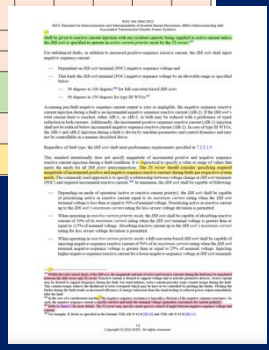
i. IEEE 2800/1547 applicability decision matrix;

Criteria determining sufficient IEEE standard for sub-transmission connected resources		IEEE 2800-2022		IEEE 1547-2018	
		Sufficiency of this standard	Justification and Considerations	Sufficiency of this standard	Justification and Considerations
Grid Protection	Differential Protection	Yes	Most grids that have differential protection are planned, operated, and protected like transmission grids to which IEEE 2800-2022 exclusively applies.	No	Most grids that have differential protection are planned, operated, and protected like transmission grids to which IEEE 1547-2018 does not apply.
	Impedance Protection	Yes	To operate selectively and reliably, impedance protection needs negative sequence short-circuit current injection which is only required by IEEE 2800-2022 at this time.	No	To operate selectively and reliably, impedance protection needs negative sequence short-circuit current injection which is not required by IEEE 1547-2018 at this time.
	Overcurrent protection Over-/under-voltage protection	Maybe	Need to consider whether to enable or disable the resource's current injection during faults and how to coordinate with grid protection	Yes	Need to consider whether the resource's current injection in the mandatory operating region during faults coordinates with grid protection
Resource Protection/Trip	Direct transfer trip (DTT)	Yes	F.5 Unintentional islanding protection External methods may be employed, such as direct transfer trip (DTT), in which the conditions that forms the island are monitored and should send a trip to the *IBR plant* when actuated.	Yes	Clause 8.1.1, Footnote: Reliance solely on under/over voltage and frequency trip is not considered sufficient to detect and cease to energize and trip. IEEE Std 1547.2™ may provide additional guidance on unintentional island mitigation, and additional equipment (e.g., transfer trip) may be necessary
	Slow trip (e.g., via SCADA)	Yes	Clause 4.6 The *IBR plant* shall be capable of responding to external control inputs. Examples for control capabilities include: • Capability to cease operation following disabling of the permit service setting	Yes	Clause 4.6.1 The DER shall be capable of disabling the permit service setting and shall cease to energize the Area EPS and trip in no more than 2 s.

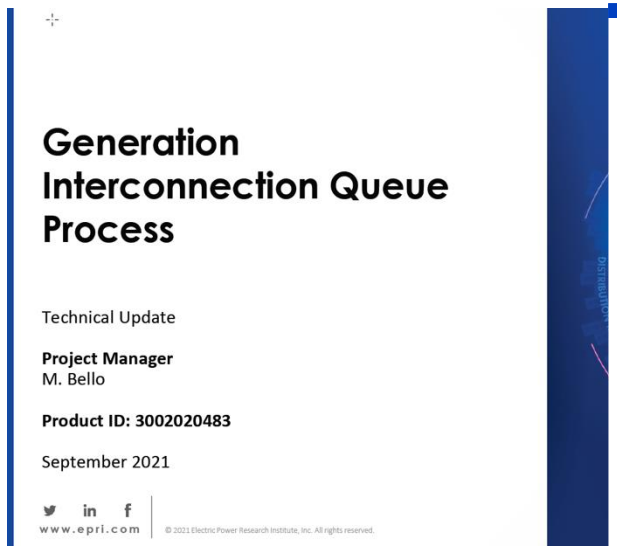
ii. IEEE 2800 adoption stakeholder decisions spreadsheet



marked-up PDF of IEEE 2800-2022



Why We Are Here: Today's Interconnection Process



- Backlog and long process
- Lack of technical standards
- Diversity of processes
- Different level of technical detail for models & studies
- Often not automated

ISOs/RTOs Interconnection Process Scope & Durations

FERC LGIP	CAISO	ISO-NE	NYISO	PJM	MISO	ERCOT	SPP	Ranges of Duration
Interconnection Request	Request Initiated							
Feasibility Study	Phase 1 Study (6 months)	Feasibility Study (3 months)	Optional Feasibility Study (3 months)	Feasibility Study (3 months)	Defining Planning Phase (DPP) Phase I Preliminary System Impact (4 ½ months)	ERCOT Screening Study (6 months)	Definitive Interconnection System Impact Study (DSIS) Phase 1 (3 months)	3 to 6 months
System Impact Study	Phase 2 Study (7 months)	System impact Study (9 months)	System Reliability Impact Study (3 months)	System Impact Study (4 months)	DPP Phase II Revised System Impact Study (2 ½ months)	Full Interconnection Study (FIS) (10 months)	DSIS Phase 2 (4 months)	**2 ½ to 9 months**
Facilities Study	System Impact and Facilities Study (4 months)	Facilities Study (3 to 6 months)	Class Year Interconnection Facilities Study (12 months)	Facilities Study (6 months)	DPP Phase III Final System Impact Study (3 ½ months)	Facility Study (3 months)	Facilities Study (4 ½ months)	3 to 12 months

Generation Interconnection Queue Process. EPRI. Palo Alto, CA: 2021. 3002020483. [Online] https://www.epri.com/research/products/000000003002020483

Generation Interconnection Queue Process. EPRI. Palo Alto, CA: 2021. 3002020483. [Online] https://www.epri.com/research/products/000000003002020483

Why We Are (Also) Here: Reliability Issues with IBR

Observed Solar PV Reliability Issues Are Rooted in Insufficient Unit Performance and Plant Design:

Inverter related causes

- PLL Loss of Synchronism
- AC Under- or Overvoltage
- Under- or Overfrequency
- Momentary Cessation
- Inverter AC Overcurrent
- Inverter DC Voltage

Plant controller related causes

- Slow Active Power Recovery

Collector system related causes

- Feeder AC Overvoltage
- Feeder Underfrequency

NERC recommendations call for more than just guidelines:

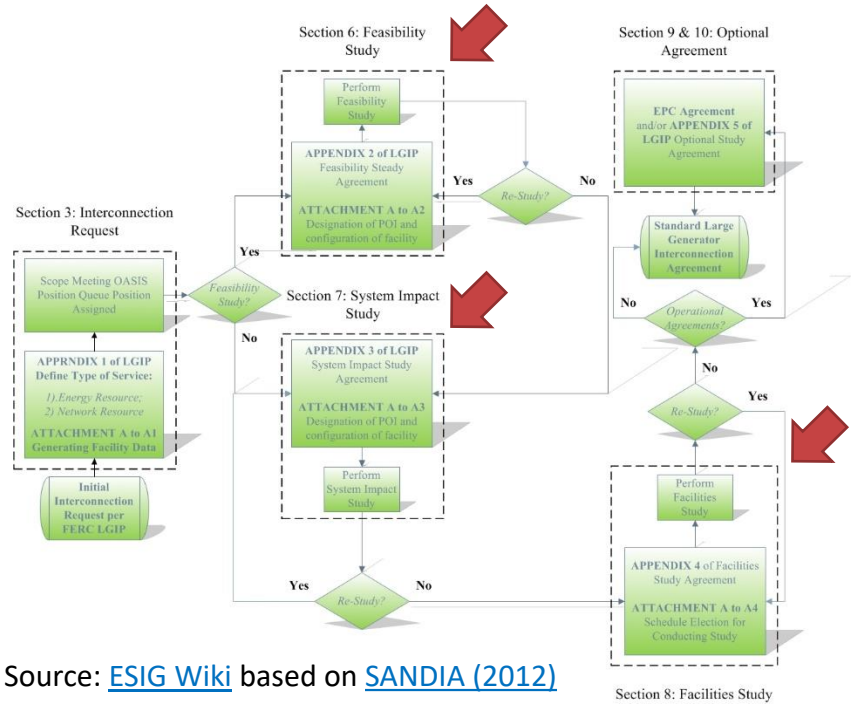
- Improvements to NERC Reliability Standards
  - Improvements to Performance-Based Requirements
  - Performance Assessment and Mitigation
  - Ride-Through Standard In Lieu Of PRC-024-3
  - Analysis and Reporting of Inverter-Based Resource Reductions
  - Electromagnetic Transient Modeling and Studies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

NERC Quick Reference Guide: Inverter-Based Resource Activities

https://www.nerc.com/pa/Documents/IBR_Quick%20Reference%20Guide.pdf

North American Interconnection Procedures

FERC pro forma
Large Generator Interconnection Procedures (LGIP)



Source: ESIG Wiki based on SANDIA (2012)

Feasibility Study

- Input: Designated/alternative POIs
- Purpose: identify thermal/voltage limit violations & estimate grid upgrade costs
- Scope: power flow and short circuit analysis (steady state)

System Impact Study

- Input: as above
- Purpose: evaluate reliability impact on transmission grid
- Scope: short-circuit, stability, power flow analysis

Facilities Study

- Purpose: estimate cost of the equipment, engineering, and construction work; identify electrical configurations of the transformer(s), switchgear, meters, and other station equipment; identify the nature and estimated cost of any transmission network upgrades

How to Improve Process Efficiency and Maintain Reliability?

Review of Challenges and Opportunities for North America Interconnection Process

Existing Step 1: Interconnection Request

Plant-Specific Interconnection Request

- **Insufficient**, diverse, or vague RTO/ISO/TP's technical interconnection requirements (**TIRs**)
- Submission of **any available models,** often **inappropriately configured**
- **Vague model 'acceptance criteria'**

Existing Step 2: Feasibility Study

Plant-Specific Interconnection Screening / Preliminary Review

Limited screening for:

- Grid strength metrics (neither conventional nor advanced)

that could help determine **whether at all, and what type of models and system impact studies** would be needed to reliably connect the IBR.

Existing Step 3: System Impact Study

Plant-Specific Grid Integration & Reliability Impact

- System impact studies often use **insufficient and invalid models** that may **not** be **site-specific** and **may be configured with generic** parameters
- May **not represent** IBR units, supplemental IBR devices, and **the IBR plant design** ultimately commissioned in the field

Existing Step 4: Facility Study

IBR Plant Cost Estimation and Determination of Transmission Grid Upgrades

- **No common assessment of IBR plant-level conformity** with regard to RTO/ISO/TP's technical interconnection requirements (TIRs)
- Detailed **IBR plant design may change** after Interconnection Agreement (IA) is executed

IBR Plant Construction

Installation and Building of all Equipment and Structures

- What is built in the field does often not match what had been previously studied/modeled
- **No "as-built" plant-level evaluation**

Existing Step 5: Interconnection Commissioning

Plant-Specific Commissioning & Model Validation/ Verification

- Only a (limited) set of field tests are performed to validate/verify IBR plant model.
  - Limited to small-signal disturbances.
  - Often **no verification of** large-signal disturbances such as **ride-through**

- **Limited collection of field data** to validate/verify IBR plant model.
  - Often not for large-signal disturbances.

IEEE 2800-2022

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

&

P2800.2

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

Active PAR

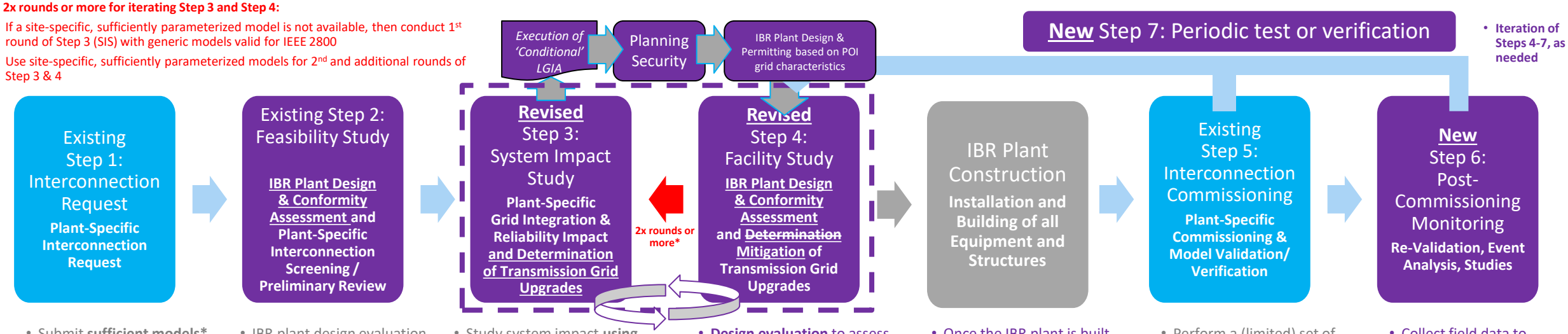
IEEE SA: https://standards.ieee.org/ieee/2800.2/10616/

P2800.2 WG: https://sagroups.ieee.org/2800-2/

Opportunities for Interconnection Process Improvements

*** 2x rounds or more for iterating Step 3 and Step 4:**

- If a site-specific, sufficiently parameterized model is not available, then conduct 1st round of Step 3 (SIS) with generic models valid for IEEE 2800
- Use site-specific, sufficiently parameterized models for 2nd and additional rounds of Step 3 & 4



- Submit **sufficient models*** configured to match applicable standards and/or TO's minimum performance requirements
- Specify **model 'acceptance criteria'**

* Such models should be as sufficient as possible based on the information available at the time, possibly a **common plant design based on applicable standards (e.g., IEEE 2800-2022)**

Guiding Principle

Open and timely communication

- IBR plant design evaluation for **conformity with TECHNICAL MINIMUM requirements** (e.g., IEEE 2800-2022)

Possible **screening criteria** may include:

- Steady state deliverability, e.g., based on "transmission hosting capacity" maps
- Grid strength metrics (both conventional and advanced)

➔ **Outcomes:**

- **IEEE 2800-2022 conforming model**
- Either **Permission to proceed** into IBR Plant Study & Design
- Or **Request for re-submission of more detailed sufficient models**, as needed, if found necessary under the screening

- Study system impact **using latest available, sufficient, site-specific** equipment models and parameters, including a description of the model limitations
- As Step 3 and Step 4 progress, update the models for IBR units, supplemental IBR devices, and the IBR plant as design choices are made
- Changes in the design could trigger either
  - a "reset in the inter-connection queue position", or
  - a "restudy of the IBR plant design"?

➔ **this could inform the definition of "material modification" per FERC LGIP/LGIA**

- **Design evaluation** to assess conformity of IBR unit & plant capability & performance with RTO/ISO/TP's TIRs **which may exceed IEEE 2800-2022 reqs, using sufficient, site-specific** equipment models and parameters
- **Design freeze** for Interconnection Agreement (IA)
  - Any changes to the IBR or supplemental units require repeat of Steps 3 and 4

➔ **Outcomes:**

- Either **Permission to proceed** into IBR plant construction
- Or **Request for re-design** to mitigate system impact and/or meet conformity
- Preliminary MOD 026/027 IBR plant small- and large-signal disturbance model verification

- Once the IBR plant is built, an **"as-built" plant-level evaluation** (see IEEE P2800 & 1547-2018) could show that what is installed matches what was studied/ designed.
  - Any changes to the IBR or supplemental units could require repeat of Step 3 and Step 4

Disclaimer

The shown process improvement is one possible solution; there may be other solutions that are equally or more effective, equitable, and practicable.

- Perform a (limited) set of field tests to validate/verify IBR plant model.
  - Likely limited to small-signal disturbances.

➔ **Final MOD 026/027 IBR plant small-signal disturbance model verification**

- Collect field data to validate/verify IBR plant model.
  - Especially for large-signal disturbances.

➔ **Continuous MOD 026/027 IBR plant large-signal disturbance model verification**

Legend

Turquoise	existing process
Purple	proposed modifications and additions
TIRs	technical interconnection requirements