

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

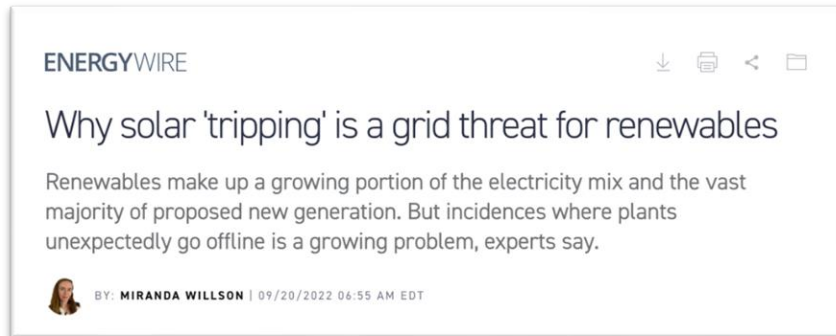
October 25, 2022



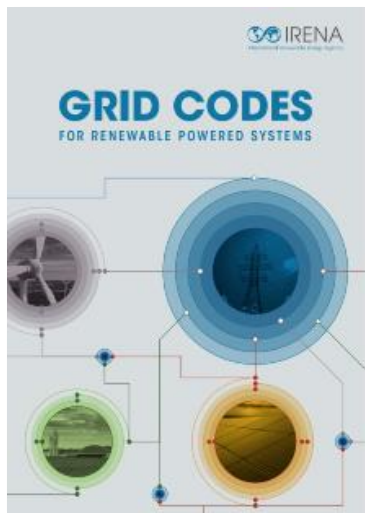
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- Part of this work was **supported in part by the National Renewable Energy Laboratory**, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department 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



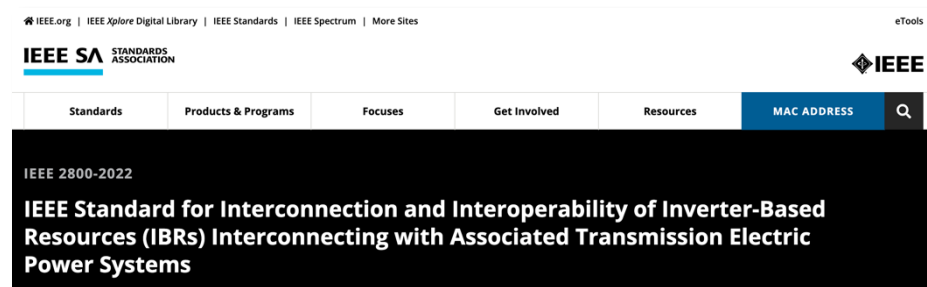
<https://subscriber.politicopro.com/article/eenews/2022/09/20/out-of-nowhere-inside-the-fight-over-renewable-tripping-00056359>



“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://standards.ieee.org/project/2800.html>



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

Adopting new IEEE standard could ease interconnection, says EPRI executive

The IEEE 2800 standard would make the transmission grid interconnection process more efficient, and updating modeling and performance requirements would help ensure system reliability, according to an executive from the Electric Power Research Institute.

AUGUST 17, 2022 WILLIAM DRISCOLL

GRIDS & INTEGRATION MARKETS MARKETS & POLICY UNITED STATES

<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

RISK = insufficient performance specifications × insufficient performance 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

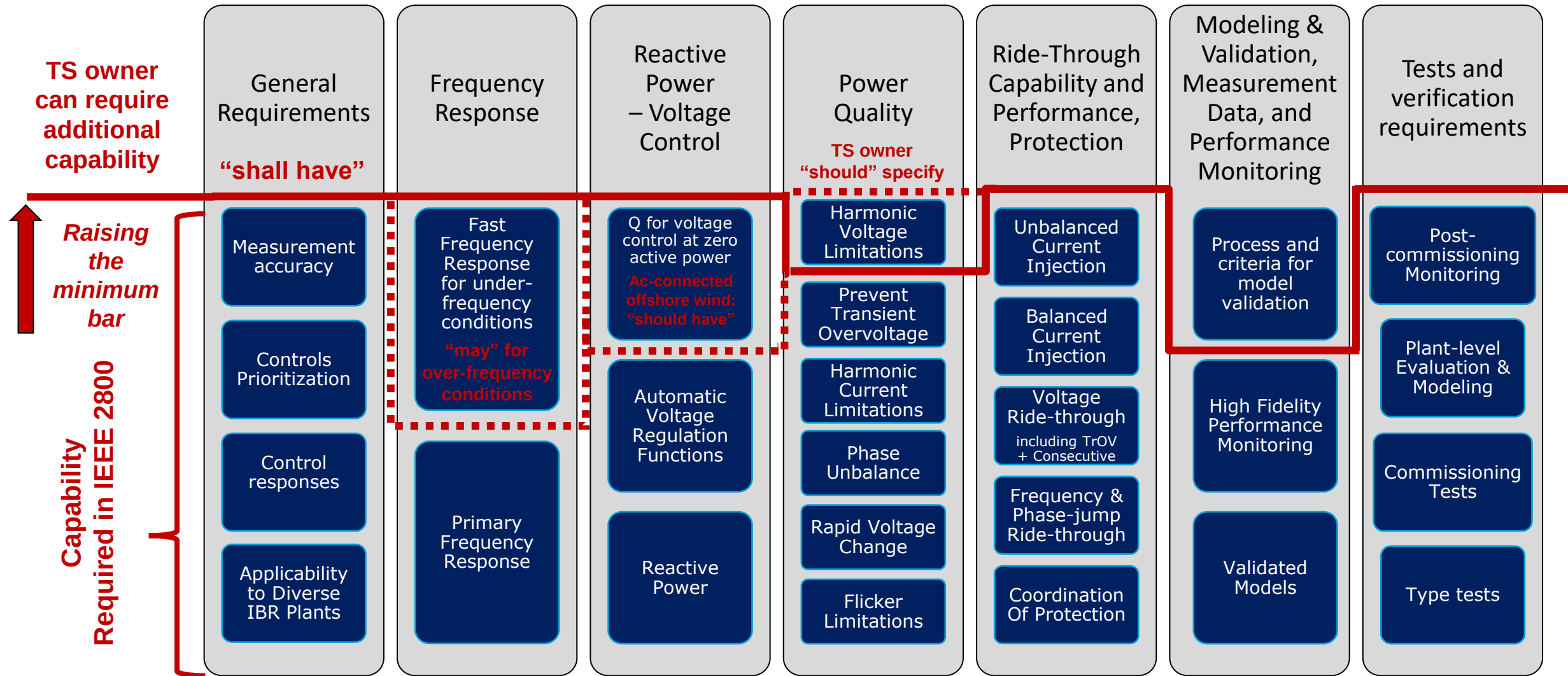
- Enable/disable functions
- Functional settings / configured parameters
- Operate accordingly (e.g., maintain headroom, if applicable)

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

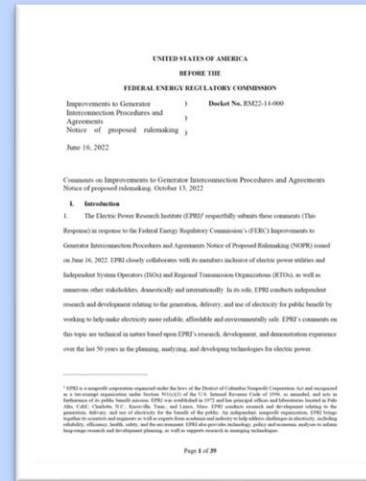
- Slide decks, recordings, and summary report available to the public at <https://www.esig.energy/event/joint-generator-interconnection-workshop/>

- **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

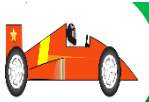
- Slide deck and recording available to EPRI members at <https://www.epri.com/research/programs/067418/events/351679F6-DEB7-470C-96CA-292CC96FD8FD>



- **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



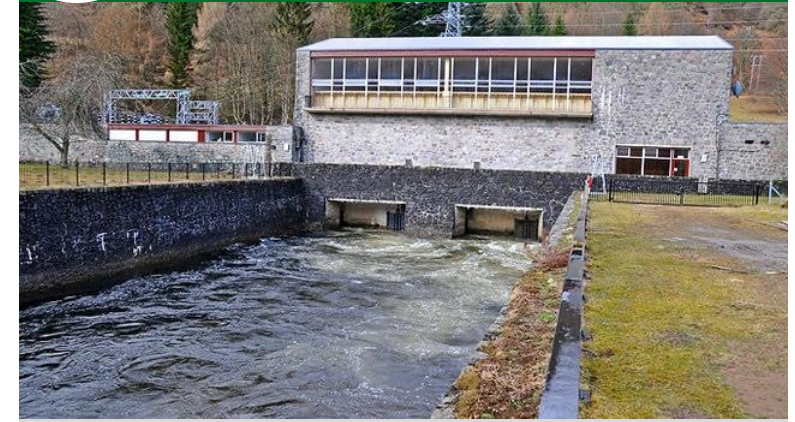
- Full or partial adoption of std
- Clause-by-clause references
- Any additional requirements

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, V 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 /	Balanced	‡
	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	√ (!!!)	‡
	Overfrequency FFR	NR	√
Sec 9 Protection Functions and Coordination	Return to Service (Enter Service)	?	‡
	Black Start	NR	√
	Abnormal Frequency Trip	NR	√
	Rate of Change of Frequency (ROCOF) Protection	?	√
	Abnormal Voltage Trip	NR	√
Sec 8 Power Quality	AC Overcurrent Protection	?	√
	Unintentional Islanding Detection and Trip	NR	√
	Interconnection System Protection	?	√
	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, V 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	v	
	Communication Interface	‡	(‡)
	Disable Permit Service (Remote Shut-Off, Remote Disconnect/Reconnect)	‡	‡
	Limit Active Power	n/a	‡
	Monitor Key Data	‡	‡
	Remote Configurability	v	v
	Set Active Power	n/a	v
	Scheduling Power Values	n/a	v
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	v	‡
	Voltage-Active Power (Volt-Watt)	NR	NR
	Dynamic Voltage Support / Current Injection during VRT	v	‡

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	v - 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	v - 1547	‡
	Frequency Droop / Frequency-Watt	v - 1547	‡
	Fast Frequency Response / Inertial Response	n/a	‡
	Underfrequency FFR	n/a	v
	Overfrequency FFR	n/a	v
	Return to Service (Enter Service)	‡ - 1547	‡
Protection Functions and Coordination	Black Start	n/a	v
	Abnormal Frequency Trip	‡ - 1547 Cat III	v
	Rate of Change of Frequency (ROCOF) Protection	v - 1547	v
	Abnormal Voltage Trip	‡ - 1547 Cat III	v
	AC Overcurrent Protection	v - 1547	v
Power Quality	Unintentional Islanding Detection and Trip	‡ - 1547	v
	Interconnection System Protection	‡	v
	Limitation of DC Current Injection	n/a	
	Limitation of Voltage Fluctuations	‡	‡
	Limitation of Current Distortion	n/a	‡
	Limitation of Voltage Distortion	n/a	v
	Limitation of (Transient) Overvoltage	v - 1547	‡

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

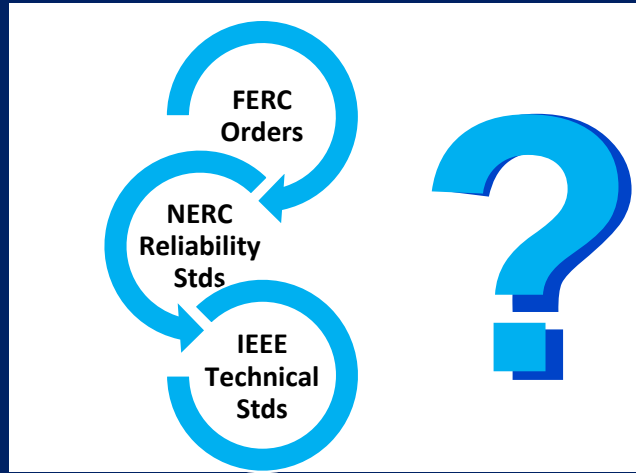
Lessons Learned So Far About IEEE 2800-2022 Adoption

- 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., IEC¹, ENTSO-e, German VDE and FGW², AEMO, et al.**

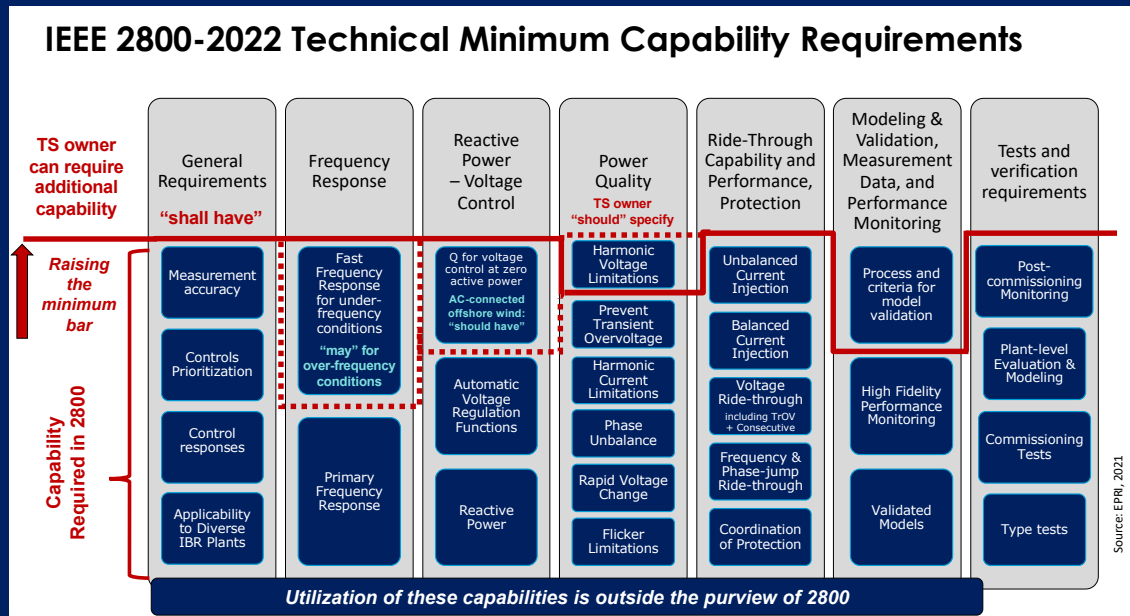
¹ IEC TS 63102:2021 Grid Code Compliance Assessment Methods For Grid Connection Of Wind And PV Power Plants

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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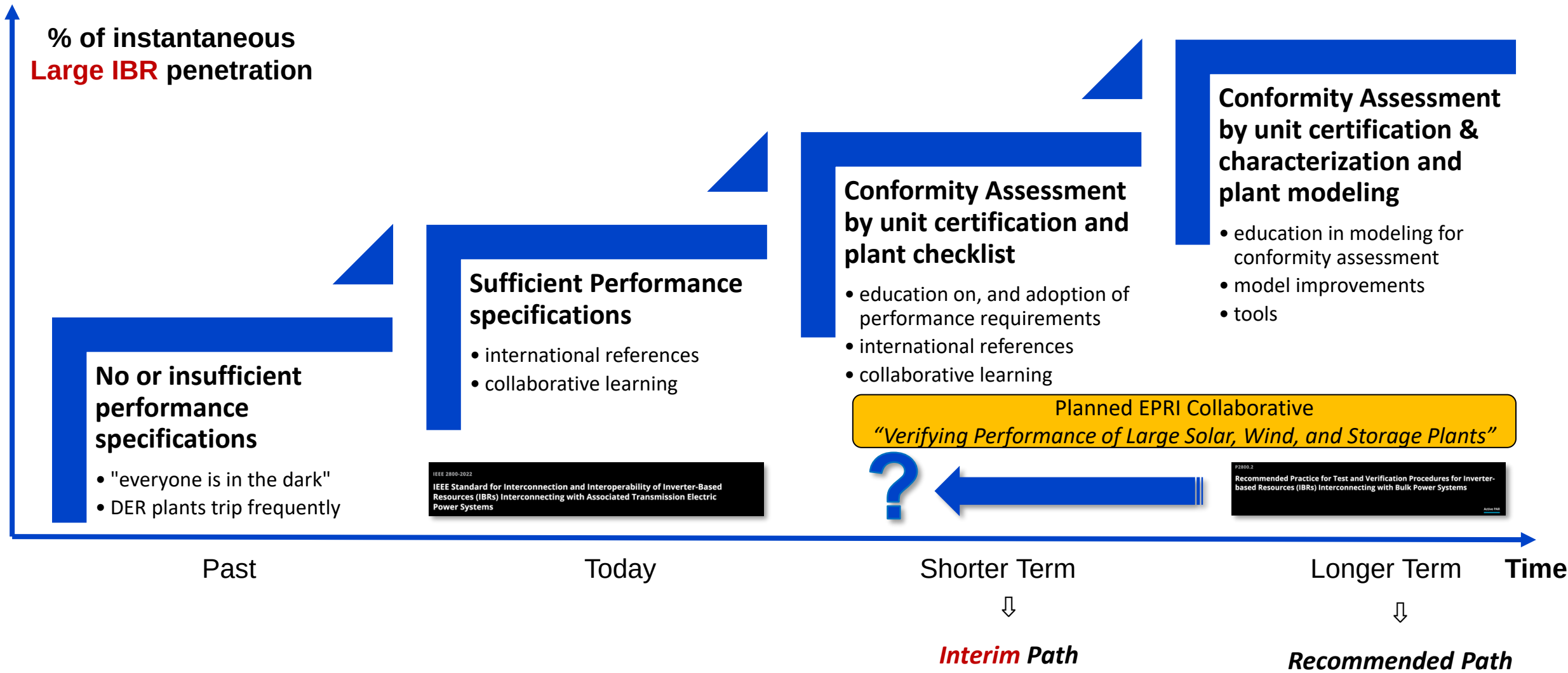
MHajian@epri.com

Thank you!

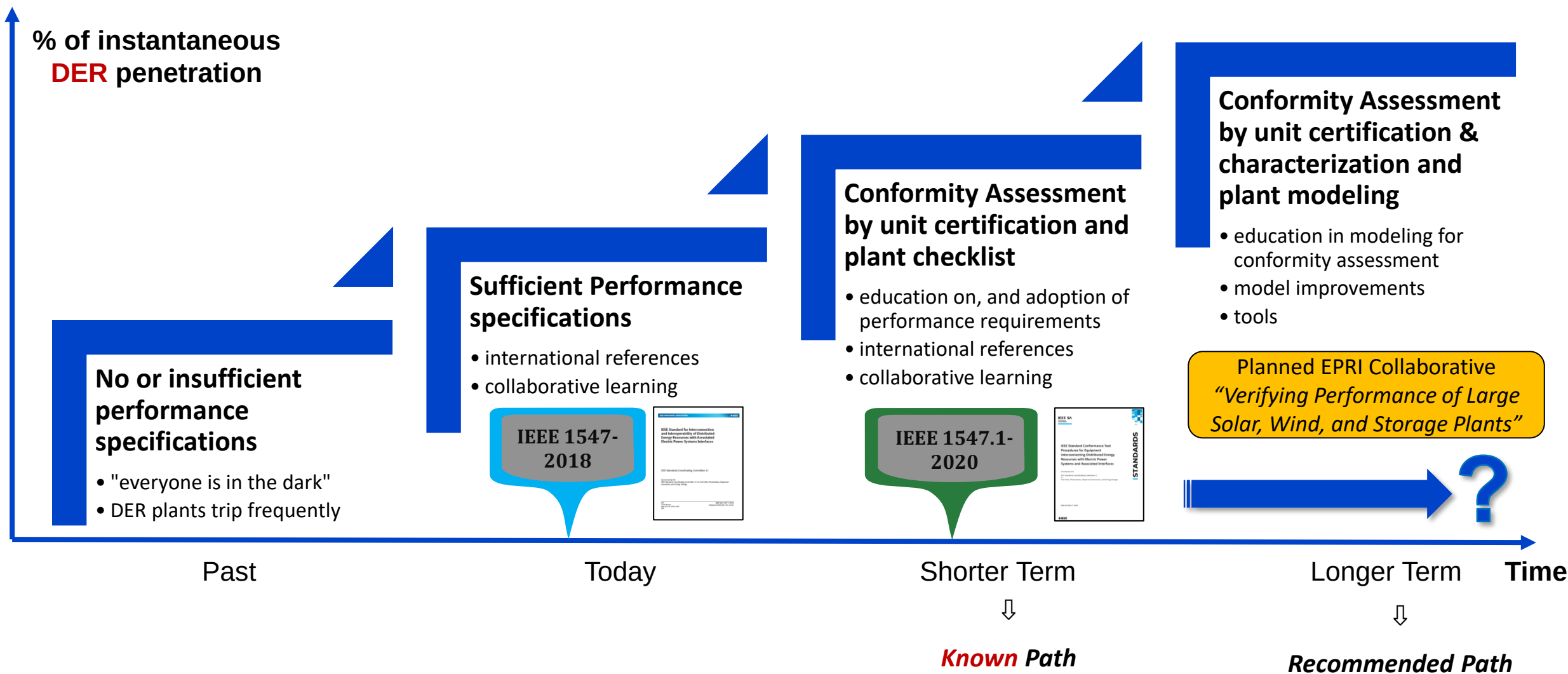
A blue-tinted photograph of four people standing in a row. From left to right: a man with curly hair and glasses in a lab coat; a man with glasses in a lab coat; a woman wearing a hard hat and safety glasses in a lab coat; and a man with glasses in a button-down shirt. The text 'Together...Shaping the Future of Energy™' is overlaid in white in the center.

Together...Shaping the Future of Energy™

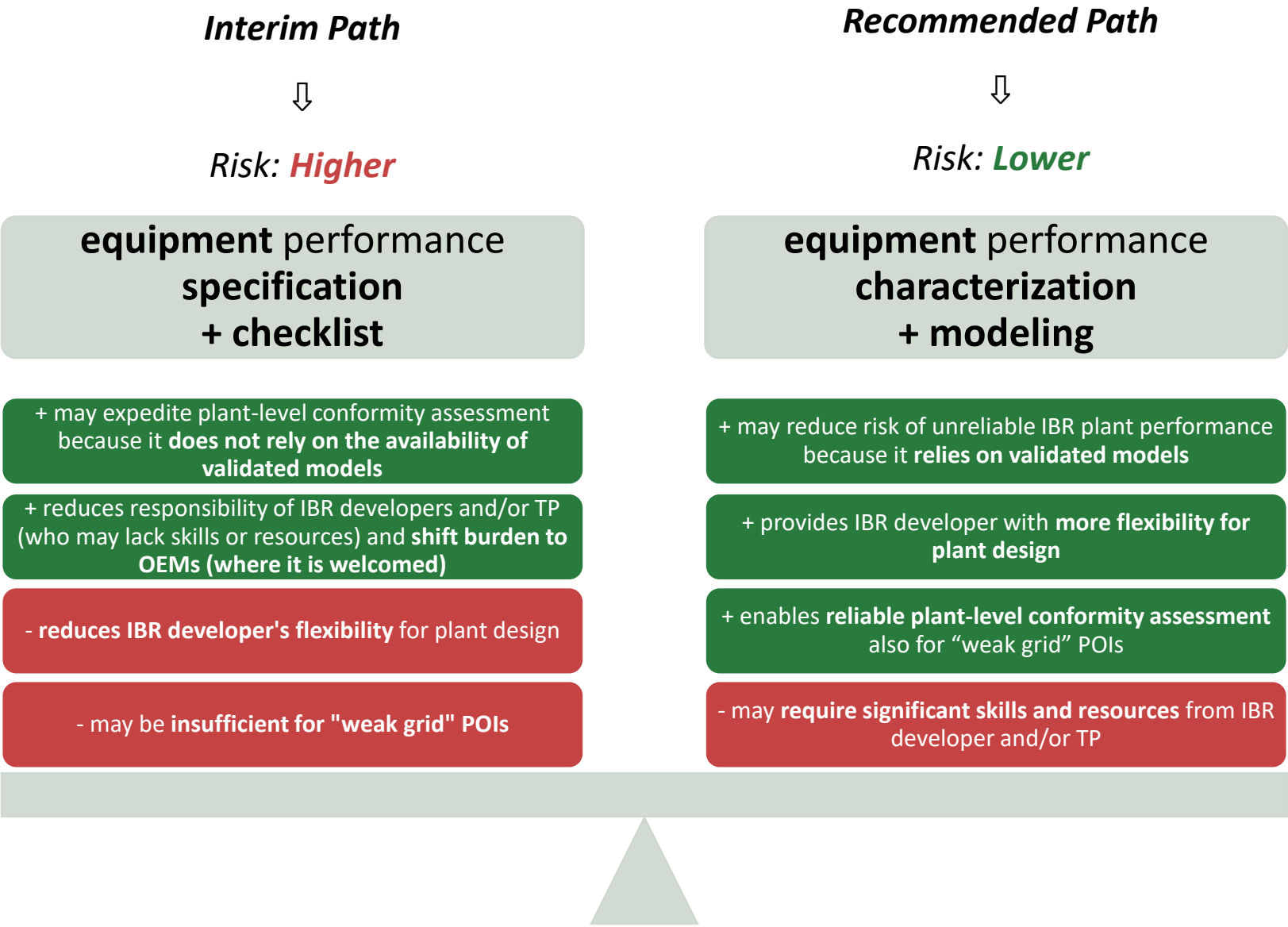
Large IBR Plant Performance Reliability Roadmap



DER Plant Performance Reliability Roadmap



IBR plant-level performance verification



Verifying Performance of Large Solar, Wind, and Storage Plants

Joint with P174
(DER Integration)

PROGRAM 40/173

PROJECT 16/3

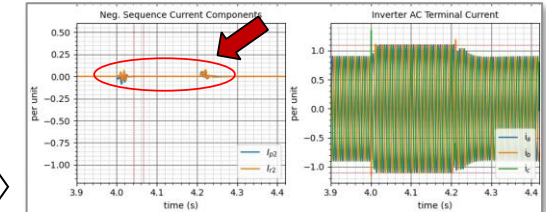
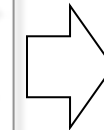
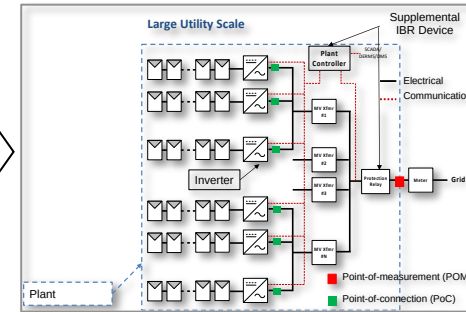
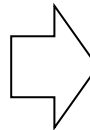
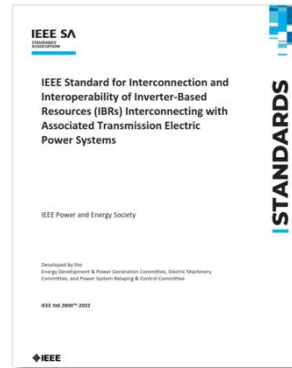
TASK FORCE MOD

COORDIN. 174

Motivation

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.

Roll-out: Fall 2022, Duration: 2 years



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

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

- Jens C. Boemer, (206) 471-1180 | jboemer@epri.com
- Aminul Huque, (865) 218-8051 | mhuque@epri.com

➤ **Balancing Interconnection Process Efficiency and Reliability**

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	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
	Over-/under-voltage protection				
Resource Protection/Trip	Direct transfer trip (DTT)	Yes	<u>F.5 Unintentional islanding protection</u> 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 <i>IBR plant</i> 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 <i>IBR plant</i> 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

✦

Generation Interconnection Queue Process

Technical Update

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Product ID: 3002020483

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www.epri.com

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Generation Interconnection Queue 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

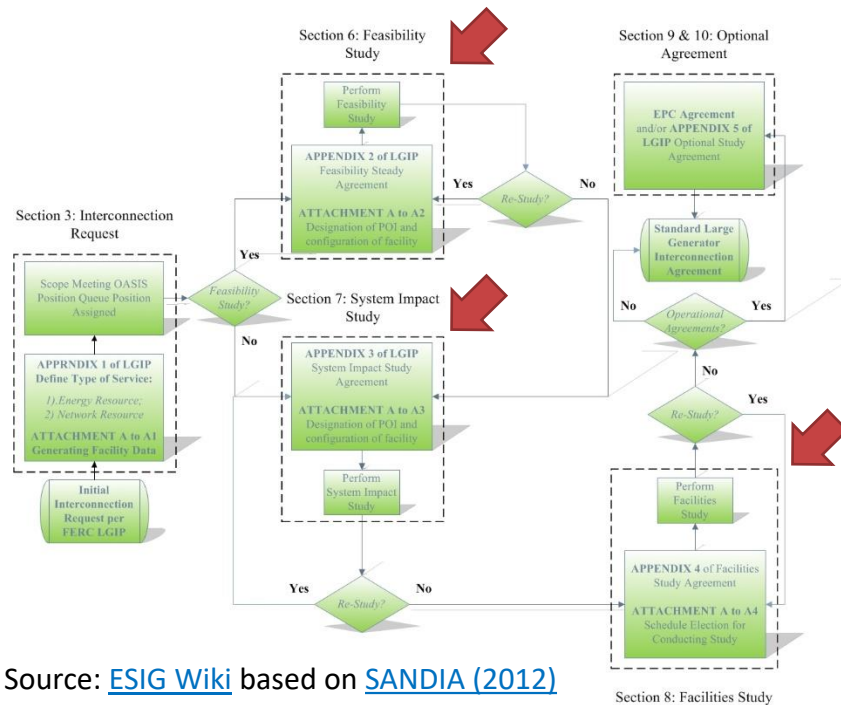


NERC Quick Reference Guide: Inverter-Based Resource Activities

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

North American Interconnection Procedures

FERC pro forma Large Generator Interconnection Procedures (LGIP)



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

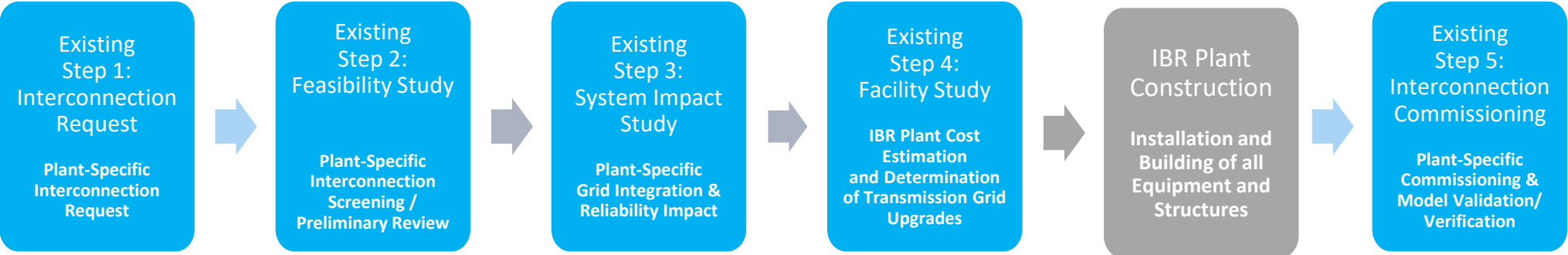
- Input: as above
- Purpose: evaluate reliability impact on transmission grid
- Scope: short-circuit, stability, power flow analysis

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



- **Insufficient**, diverse, or vague RTO/ISO/TP's technical interconnection requirements (**TIRs**)
 - Submission of **any available models**, often **inappropriately configured**
 - **Vague model 'acceptance criteria'**
- **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.
- 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
- **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
- What is built in the field does often not match what had been previously studied/modelled
 - **No "as-built" plant-level evaluation**
- 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

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

