IEEE 2800 Conformity Assessment Pathways

ERCOT IBR Task Force

October 02, 2023

Andy Hoke, IEEE P2800.2 WG Chair
Manish Patel, Secretary
Jens Boemer, Bob Cummings, Divya Kurthakoti,
Julia Matevosyan, Mahesh Morjaria, Steve Wurmlinger, Vice Chairs

Disclaimers

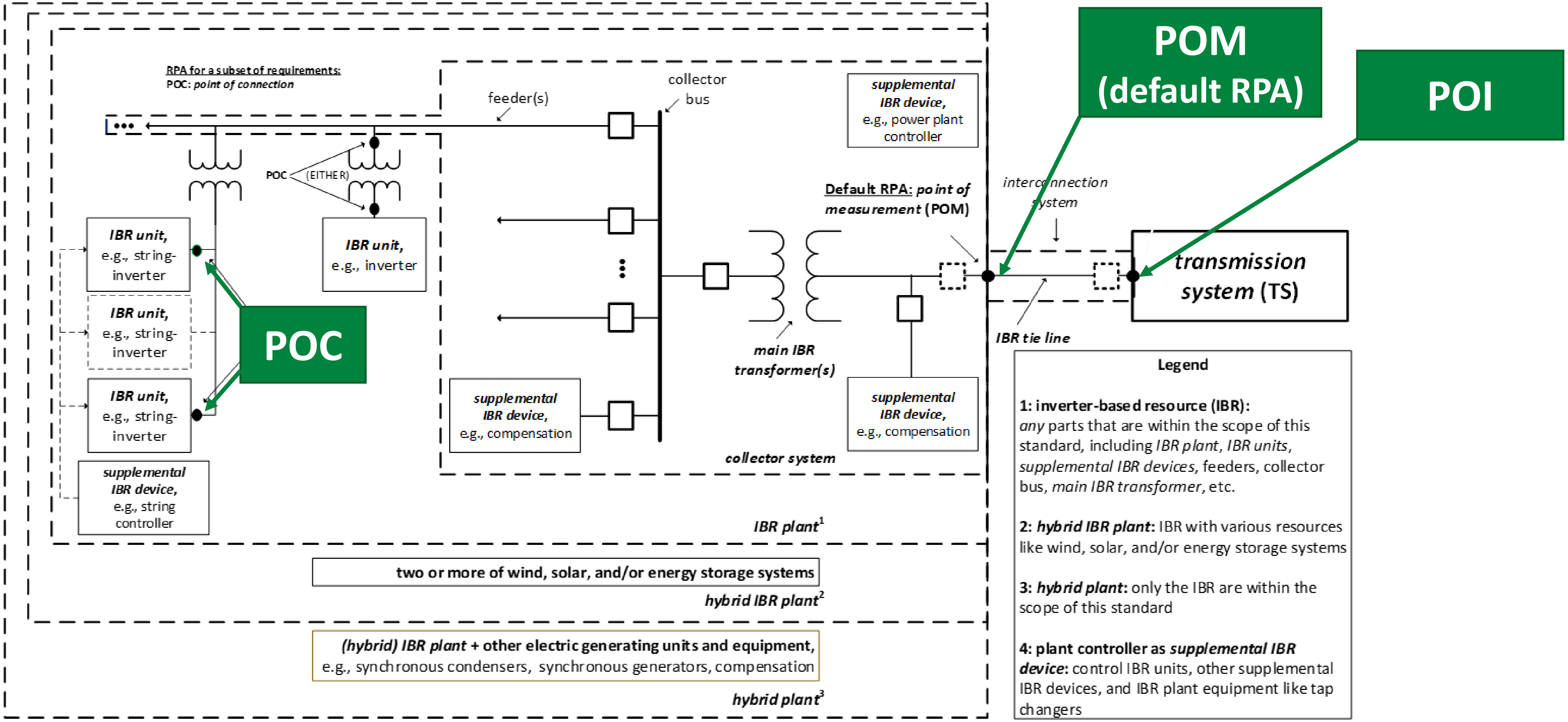
This work was supported in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar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

Presentation summary

- **Review of IEEE 2800 conformity assessment process**
- **Phase angle jump ride through**
  - IEEE 2800 requirement
  - Potential IBR conformity assessment methods
- **ROCOF ride through**
  - IEEE 2800 requirement
  - Potential IBR conformity assessment methods
- **Consecutive voltage excursion ride through**
  - IEEE 2800 requirement
  - Potential IBR conformity assessment methods
- **Are IBR vendors ready to comply with IEEE 2800?**

Reference Point of Applicability

Almost all requirements of IEEE 2800 apply at Point of Measurement (POM) by default



P2800.2 Summary

Includes:

- Type tests
  - Unit level, **not full compliance with 2800**
  - Test results are used to validate unit level model
- Design evaluation using verified plant model
  - Includes procedures to validate unit level model
- As-built evaluation and commissioning tests
- Post-commissioning model validation, monitoring, periodic tests & verifications

- **Recommended Practice**: uses "should" language, not "shall" language
  - In recognition that prescribing uniform procedures across all IBR types and interconnecting locations would be very challenging.

Overview of conformity assessment steps in IEEE P2800.2

Type Tests

Lab or field tests of individual IBR unit for model verification

IBR Unit Model Validation

Based on type test data

IBR Plant Model Development

Based on validated IBR unit model(s) and balance of plant

IBR Plant Design Evaluation

Simulations to assess plant conformity to IEEE 2800

Design Evaluation

As-built Installation Evaluation

Verification of installed plant

Commissioning Tests

Partial field assessment of plant performance

Post-commissioning Monitoring

Monitoring of plant performance during grid events

Post-Commissioning Model Validation

Based on commissioning test data

Periodic Tests and Verifications

Plant construction complete

This is a general diagram of the process. Details are under development in IEEE P2800.2. Some variations permitted.

Equipment certification?

- Except for a few, most requirements (including ride through) in IEEE 2800 apply to the IBR plant (not the inverter/WTG)
- The type tests in IEEE P2800.2 will not generally have pass/fail criteria
- Type tests are done to:
  - ✓ Verify inverter/WTG capability
  - ✓ Generate data (e.g. test waveforms) to validate the unit-level model
- Certification of inverters/WTGs by a Nationally Recognized Test Laboratory (NRTL, e.g. UL) is unlikely

Equipment certification?

- Even “self-certification” of inverters/WTGs is not possible because compliance is at the plant level

- Therefore an “IEEE 2800 *certified* inverter/WTG” probably will not exist
  - ✓ Instead, inverters/WTGs could perhaps be considered “2800 compatible” if 2800 requirements have been taken into consideration so that they can be used to build a 2800-compliant plant.

- This is different from the IEEE 1547/1547.1/UL 1741 paradigm on the distribution system, where pass/fail type tests and NRTL certification play a large role in conformity assessment

Adoption of IEEE 2800:

- Adoption of IEEE 2800 is not contingent upon publication/adoption of IEEE P2800.2
  - ✓ ***In the absence of IEEE P2800.2*, IBR owners, TS owners/operators, OEMs, etc. could develop their own assessment procedures or use existing procedures**
- For systems experiencing IBR ride-through events/problems, some requirements may be higher priority than others (ride through of low voltage, TOV, ROCOF, phase jump)
- Needs consideration of enforcement date, grandfathering, etc.
- Possible adoption methods:
  - ✓ Full adoption by simple reference
  - ✓ Full or partial adoption, clause-by-clause reference, additional requirements
- Many utilities/ISOs are already moving towards adoption

IEEE 2800 phase-jump ride-through requirement

- IBR plant shall ride through positive sequence phase angle changes ≤25° **within a sub-cycle to cycle timeframe**
  - May be caused by fault occurrence or clearance, line switching, load rejection, etc.
  - Post disturbance, positively damped oscillations permitted
  - Current blocking (momentary cessation) not permitted
  - **This does not mean the IBR should trip for changes >25°**, just that it's not in violation if it does

- So, requirement only applies to near-instantaneous angle changes. A gradual change in pos seq phase angle over > 1 cycle is not included in this requirement.
- ROCOF ride-through is considered separately
- IEEE 2800 does not specify internal details of IBR controls or data analysis methods, and IEEE P2800.2 will not either

IEEE 2800 phase-jump ride-through requirement full text

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.[116]

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.

---

[116] Typically caused by line switching (in or out), load rejection, etc., and depends on pre- and post-network flows.

Phase-jump ride-through conformity assessment

- Four potential methods of determining conformity:
  1. Type test (lab or field)
  2. EMT simulation
  3. Intentionally apply phase jump in field. (Utility may not permit)
  4. Field performance monitoring. Needs waveform-level data (e.g., from DFR)
- IEEE P2800.2 includes items 1, 2, and 4
  - Type test is **just to validate EMT model**, not pass/fail
    - Can be done using container-based testing by inserting an impedance in series with IBR unit. Not all existing container-based test apparatus are capable
    - Alternatively, can be done using programmable power source. See IEEE 1547.1-2020 for example
  - EMT simulation is done at plant level using validated IBR unit model plus balance of plant
  - Monitoring of field performance is the ultimate conformity assessment

What can be done to assess phase jump performance prior to P2800.2 publication?

- OEMs can test their equipment using methods on previous slide or others
  - Even if not required by ISO/utility, reduces risk of issues in field
- An EMT simulation of the plant (using SMIB system or more complex) can be performed
  - Only of value if the IBR unit model used in the plant model is highly accurate
- Monitoring of field performance
  - Needs waveform data (DFR or similar)
  - This alone could be sufficient in the absence of other steps

IEEE 2800 ROCOF ride-through requirement

- IBR plant shall ride through |ROCOF| ≤5 Hz/s **over a 0.1 s averaging window**
  - Ride-through of high ROCOFs may required via mutual agreement
  - **This does not mean the IBR should trip for ROCOF >5 Hz/s**, just that it's not in violation if it does

- So, requirement only applies to ROCOF events lasting 0.1 second or longer
- IEEE 2800 does not specify internal details of IBR controls or measurement methods, and IEEE P2800.2 will not either

IEEE 2800 ROCOF ride-through requirement full text

7.3.2.3.5 Rate of change of frequency (ROCOF) ride-through

Within the *mandatory operation region* and *continuous operation region* (frequency range and corresponding cumulative duration, time), the *IBR plant* shall ride through and shall not trip for frequency excursions having an absolute rate of change of frequency (ROCOF) magnitude that is less than or equal to 5.0 Hz/s. As specified in 4.3, the ROCOF shall be the average rate of change of frequency over an averaging window of at least 0.1 s. Upon mutual agreement between the *TS operator* and the *IBR operator*, the *IBR plant* may be required to ride-through and not trip for higher ROCOF levels.

ROCOF ride-through conformity assessment

- Three potential methods of determining conformity:
  1. Type test (lab or field)
     - Via signal injection inject fictitious frequency, or
     - Via programmable power supply to modulate real frequency. This is more accurate but not feasible for larger IBRs
  2. EMT simulation (using validated model)
  3. Field performance monitoring
- IEEE P2800.2 will include items 1, 2, and 3
  - Type test is **just to validate EMT model**, not pass/fail
  - EMT simulation is done at plant level using validated IBR unit model plus balance of plant
  - Monitoring of field performance is the ultimate conformity assessment

What can be done to assess ROCOF performance prior to P2800.2 publication?

- OEMs can test their equipment using methods on previous slide or others
  - Even if not required by ISO/utility, reduces risk of issues in field
- An EMT simulation of the plant (using SMIB system or more complex system) can be performed
  - Only of value if the IBR unit model used in the plant model is highly accurate
- Monitoring of field performance
  - This alone could be sufficient in the absence of other steps

IEEE 2800 consecutive voltage disturbance ride-through requirement

- IBR plant shall ride through consecutive voltage disturbances except when one of the exceptions at right are met
  - Given long list of exceptions, criteria takes some effort to understand
  - Intent is avoid use of disturbance counters (which lead to system-wide stability risks) and instead only trip when IBR is *unable* to stay online
  - **This does not mean the IBR should trip when one of the exceptions is met**, just that it's not in violation if it does

- **Exceptions**:
  - Cumulative duration in any 10 s window exceeds base ride-through criteria in Table 11/12
  - >4 voltage deviations in any 10 s period
  - >6 voltage deviations in any 120 s period
  - >10 voltage deviations in any 30 minute period
  - A deviation starts within 20 cycles of end of previous deviation
  - >2 deviations below 0.5 pu in any 10 s period
  - >3 deviations below 0.5 pu in any 120 s period
  - For wind, a mechanical resonance exceeding equipment limits

IEEE 2800 consecutive voltage disturbance ride-through requirement full text

7.2.2.4 Consecutive voltage deviations ride-through capability[109]

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:

[109] The primary intent of voltage ride-through requirements for consecutive voltage deviations is for the *IBR plant* to ride through a reasonable tripping and reclosing sequence associated with short-circuit faults on TS. Other causes for consecutive disturbances are separate faults that might occur in a severe storm, or dynamic voltage oscillations that cyclically transition in and out of the *continuous operation region*. The *IBR plant* is not expected to ride through opening and reclosing of a tie-line connecting the *IBR plant* to an interconnecting TS.

— 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 s or 3600 s) 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 four deviations of the *applicable voltage* at the RPA outside of the *continuous operation region* within any 10-s period.

— The *IBR plant* may trip for more than six deviations of the *applicable voltage* at the RPA outside of the *continuous operation region* within any 120-s period.

— The *IBR plant* may trip for more than ten deviations of the *applicable voltage* at the RPA outside of the *continuous operation region* within any 30-min (1800-s) period.

— 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 two individual deviations of the *applicable voltage* at the RPA below 50% of the nominal voltage (inclusive of zero voltage) within any 10-s period.

— The *IBR plant* may trip for more than three individual deviations of the *applicable voltage* at the RPA below 50% of the nominal voltage (inclusive of zero voltage) within any 120-s period.

— 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.

Individual voltage deviations begin when the *applicable voltage* at the RPA becomes less than the lower limit of the *continuous operation region* or greater than the upper limit of the *continuous operation region*. Individual deviations end when the rms magnitude of the *applicable voltage* at the RPA, for previous one-cycle period of the fundamental frequency, is within the *continuous operation region*.

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. The characteristic of dynamic voltage oscillation may be specified by one or more of the following:

— Upper and lower limits of the oscillating *applicable voltage*

— Frequency of oscillation in the synchronous reference frame

— Damping ratio of the oscillation

The consecutive voltage deviation ride-through capability of an isolated IBR interconnected to the TS via a VSC-HVDC transmission facility may be limited by the energy absorption capability and thermal design of the dc chopper in the VSC-HVDC line, as well as by the ability of fast control of active power production by the isolated IBR. Refer to Annex M for an explanation.

The *IBR owner* of isolated IBRs that are interconnected to an ac *transmission system* via a dedicated VSC-HVDC transmission facility shall inform the *TS owner*/*TS operator* of any limitations regarding the capability of the combined IBR facility to meet the consecutive voltage deviations ride-through capability requirements specified in this clause. *IBR owner* and *TS owner*/*TS operator* shall mutually agree on remedy measures, which may include one or more of the following:

— The dc chopper may be designed to absorb ICR for at least 2 s.

— New control methods of the offshore ac-dc converter station that enable fast reduction of active power production from isolated IBRs (e.g., WTGs) by changing the offshore ac network voltage.

— Other means not specified.

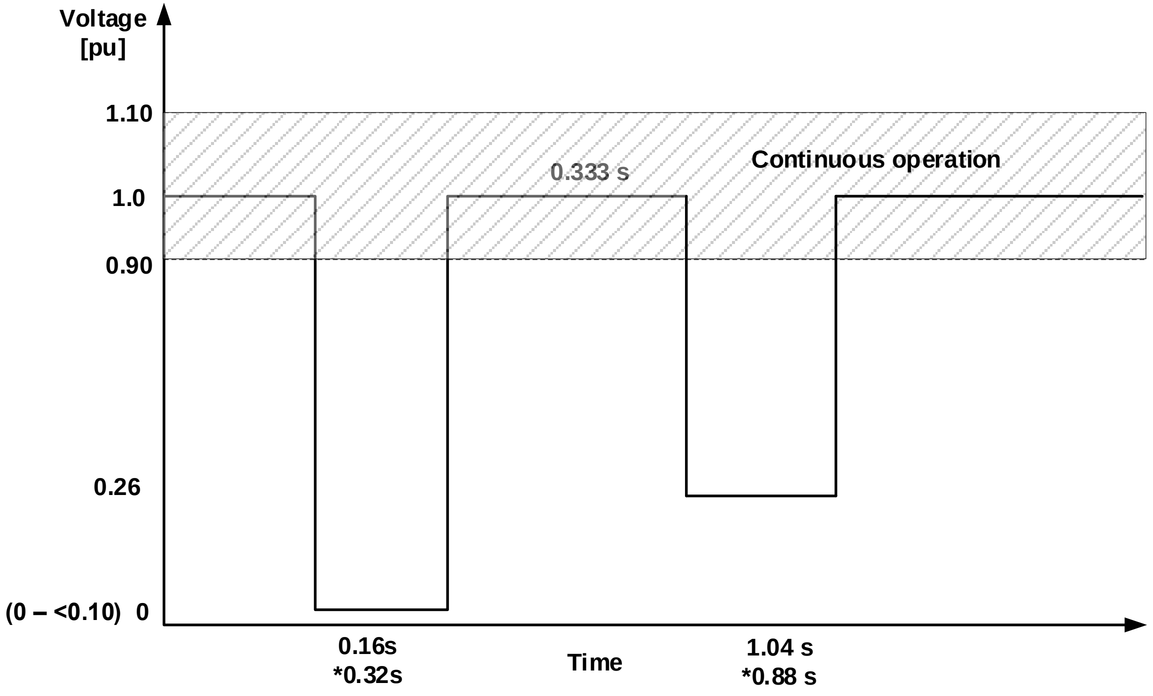
As applicable, exception from specified consecutive voltage deviations ride-through capability shall be permitted with mutual agreement between the *IBR owner* and *TS owner*/*TS operator*.

Consecutive voltage disturbance ride-through conformity assessment

- Three potential methods of determining conformity:
  1. Type test (lab or field)
  2. EMT simulation (using validated model)
  3. Field performance monitoring
- IEEE P2800.2 will include items 1, 2, and 3
  - Type test is **just to validate EMT model**, not pass/fail
    - Draft test details on next slide
  - EMT simulation is done at plant level using validated IBR unit model plus balance of plant
    - EMT models do not typically contain sufficient detail to fully capture IBR performance during consecutive voltage disturbance. For some IBRs, may not be feasible to include sufficient detail. So EMT test value is limited in this case.
  - **Monitoring of field performance is the ultimate conformity assessment**
    - This is especially true for consecutive LVRT given wide variety of possible field conditions

Consecutive voltage disturbance ride-through test in P2800.2 *(draft)*

- Testing all possible consecutive voltage ride-through field events is not feasible
- Test simply confirms that model matches hardware during a very simple example event sequence (test voltage profile shown at right)
- Test is repeated for 3-phase and 2-phase faults



What can be done to assess consecutive voltage disturbance performance prior to P2800.2 publication?

- OEMs can test their equipment using methods on previous slide or others
  - Even if not required by ISO/utility, reduces risk of issues in field
- An EMT simulation of the plant (using SMIB system or more complex system) can be performed
  - Only of value if the IBR unit model used in the plant model is highly accurate
- Monitoring of field performance
  - This alone could be sufficient in the absence of other steps

Summary notes on 2800 conformance evaluation

- P2800.2 frequently recommends evaluation of test, simulation, and field traces using engineering judgement (without specifying the details, which vary too widely to be summarized in one document).
  - Therefore, **P2800.2 is not going to erase the uncertainty around 2800 conformance**.
- Calculating quantities like voltage phase angle and ROCOF accurately on fast timescales is not easy or standardized; a wise OEM will build margin into ride-through capabilities to account for calculation uncertainties.
- Consecutive LVRT requirement is complex, and P2800.2 will not remove complexity
- **Field performance monitoring is the ultimate form of conformity assessment**
  - Conceivably, field performance monitoring could be the only form of conformity assessment for some requirements, though risk to system reliability is higher
- Despite these challenges, to mitigate system reliability issues while continuing to deploy IBRs rapidly, we need robust ride-through capabilities now.

Are vendors ready for 2800?

- Answer likely varies between equipment types and between OEMs
  - Some requirements are more challenging for wind plants. 2800 makes several exceptions for wind plants.
- It is true that preparing equipment to be used in 2800-compliant plants takes a lot of work and time
- 2800 requirements have been published for 18 months (and most major vendors have had visibility into draft requirements well before that).
- It does take more than 18 months to design, build, and test a new inverter or wind turbine. How much longer?
  - Given that P2800.2 will not likely provide much additional clarity on 2800 requirements, 2800 adoption timeline does not need to be dependent on P2800.2

General Info on IEEE P2800.2

Target Dates:

- WG approved draft by Q2 2024
- IEEE SA Ballot: Q3, 2024 – Q2, 2025
- Publication: Q2-Q3, 2025

Next WG Meeting:

- Virtual meeting scheduled for **December 12 - 14**, 2023

Call for Participation:

- Please consider joining the WG and SGs of your interest to help develop P2800.2

Contacts

P2800.2 WG

Andy Hoke,
Andy.Hoke@nrel.gov

Manish Patel,
mpatel@southernco.com

https://sagroups.ieee.org/2800-2/
https://standards.ieee.org/ieee/2800.2/10616/

IEEE 2800-2022 is available at:

- https://standards.ieee.org/project/2800.html
- https://ieeexplore.ieee.org/document/9762253/