NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Industry Webinar

Reliability Guideline: Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources

October 11, 2019

RELIABILITY | RESILIENCE | SECURITY



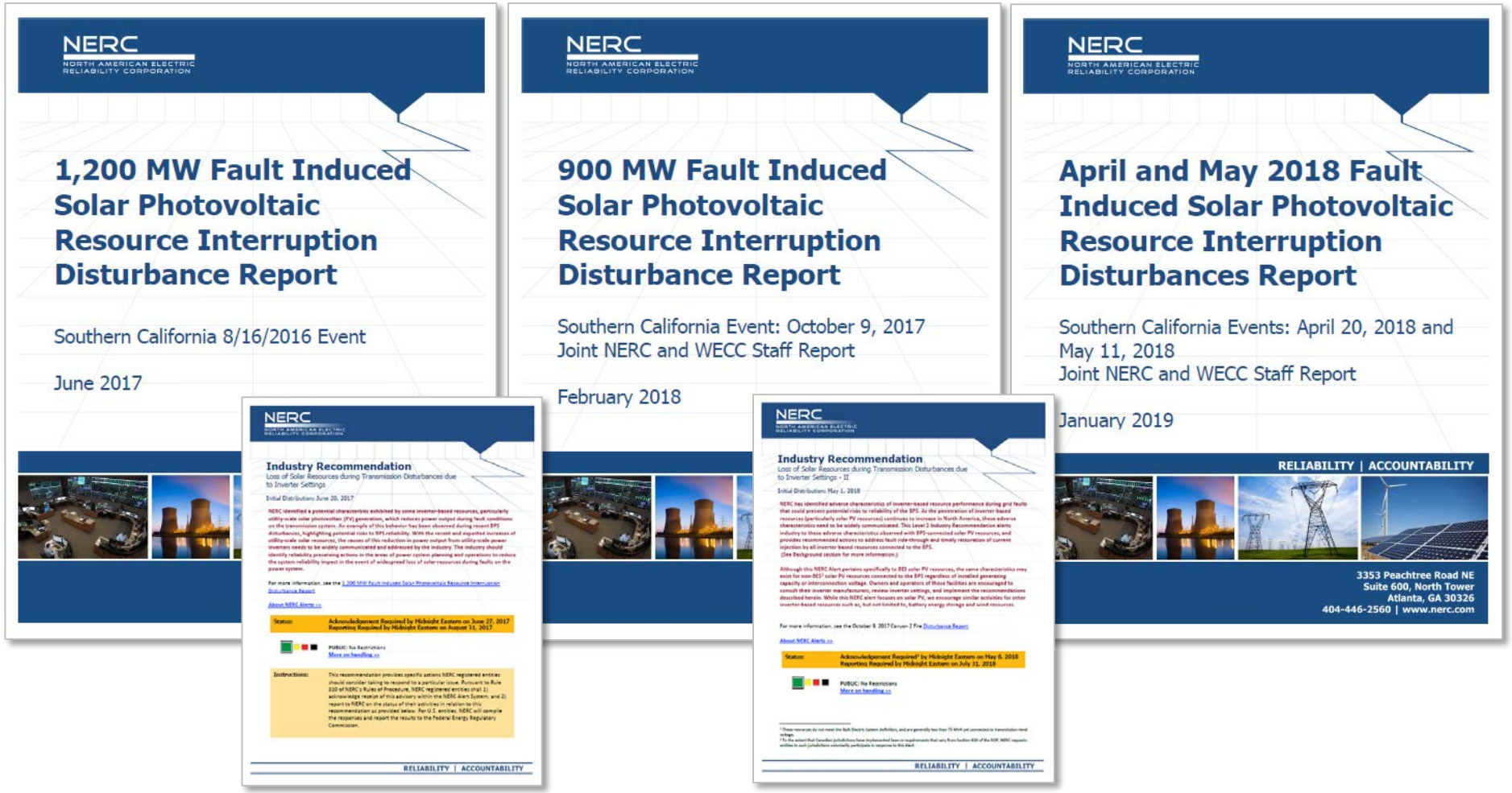

Overview of Webinar

Topic	Presenters
Introduction & Kickoff - *Summary of NERC IRPTF Activities*	Al Schriver, NextEra

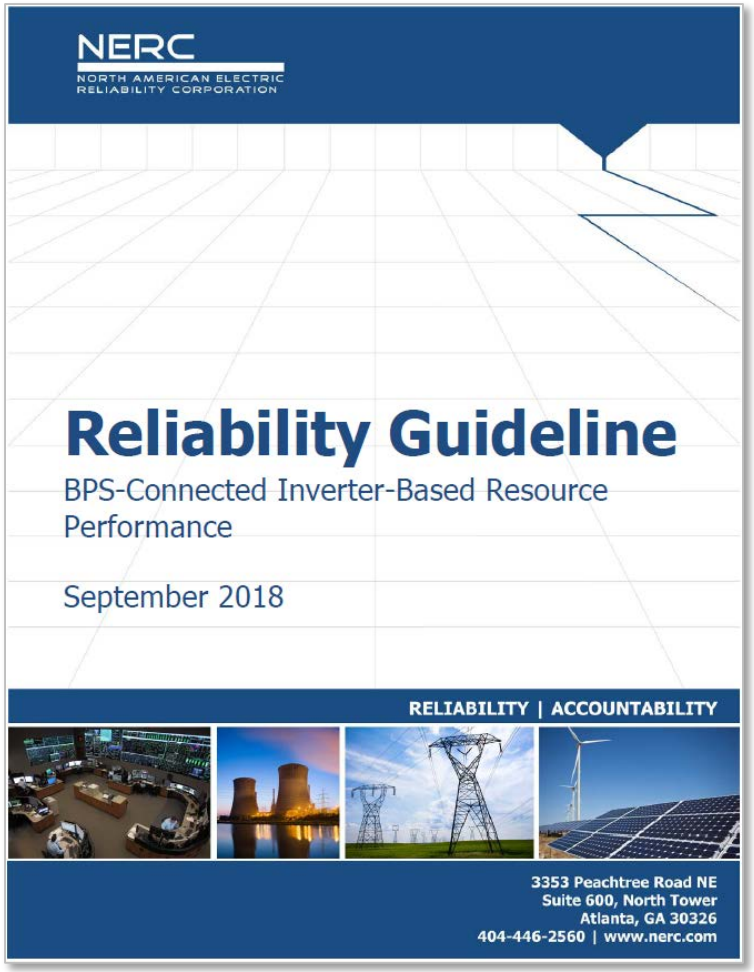
Reliability Guideline Summary
- *Background and Applicability*
- *Guideline Key Takeaways and Recommendations*
  - *Description of Requirements Improvements*
  - *Description of Modeling Improvements*
- *Next Steps for Implementation*
	Ryan Quint, NERC
	Rich Bauer, NERC

Industry Experience with Developing Interconnection Requirements and Performing Interconnection Studies - *Improvements to Interconnection Requirements* - *Updates to Interconnection Studies and Modeling*	Jeff Billo, ERCOT Brad Marszalkowski, ISO-NE
Wrap Up - *Key Takeaways & Recommendations*	Ryan Quint, NERC
Q&A	All

NERC Disturbance Reports and Alerts



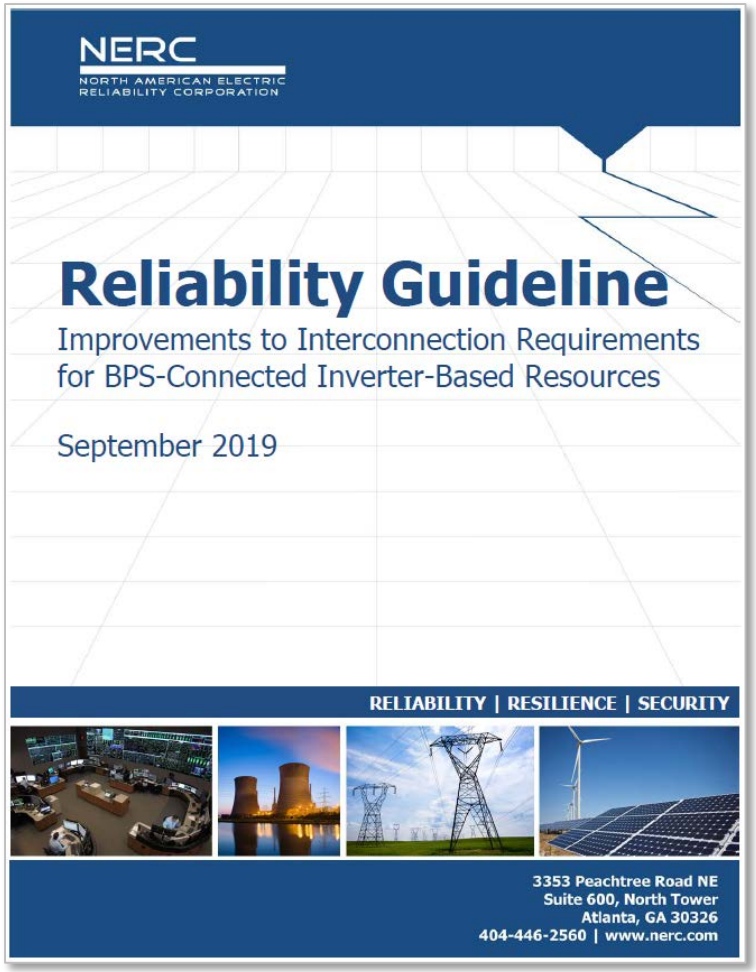
Reliability Guideline: Inverter-Based Resource Performance



- Recommended performance for BPS-connected inverter-based resources
  - Applicable to ALL – BES and non-BES resources
  - Transmission and sub-transmission
- Based on recommendations and findings from NERC disturbance reports
- Intended as cornerstone document for industry moving forward
  - Foundation for IEEE P2800
- Published September 2018

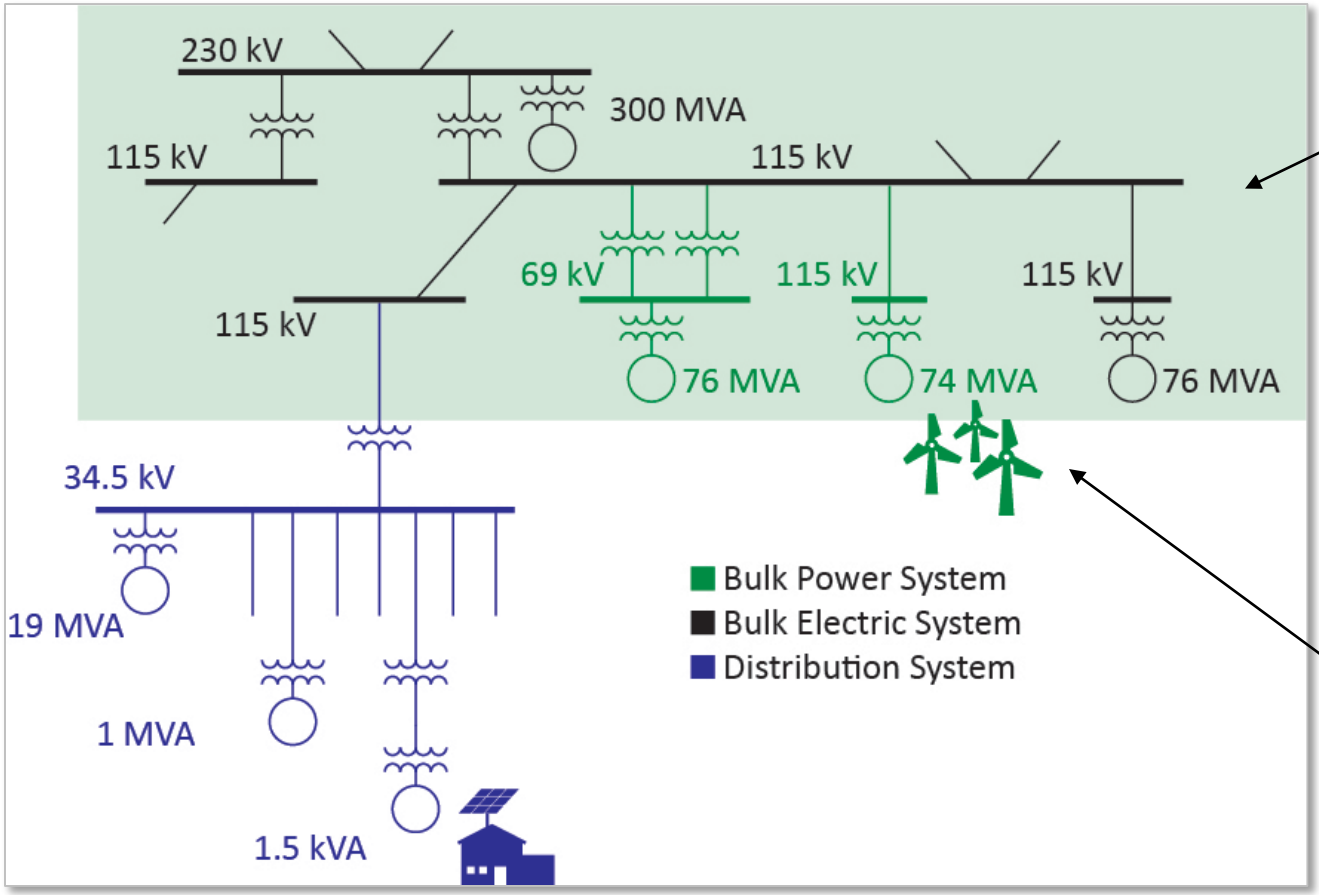
Reliability Guideline:
Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources

Reliability Guideline:
Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources



- Need for clarity and consistency of interconnection requirements
- Align with NERC Reliability Standards FAC-001-3 and FAC-002-2
- Based on previous IRPTF guideline and industry experience
  - Covers wide array of operational and performance issues that should be addressed
- Intended as another cornerstone document for industry moving forward
  - Coordination with IEEE P2800
- Published September 2019

BPS vs. BES vs. Distribution System



NERC Reliability Standards and FERC LGIA/SGIA

Local Utility Interconnection Requirements and FERC LGIA/SGIA

Illustrative Purposes Only

States Adoption and Implementation of IEEE 1547-2018

NERC SPIDERWG

Applicable NERC Facility Interconnection Standards

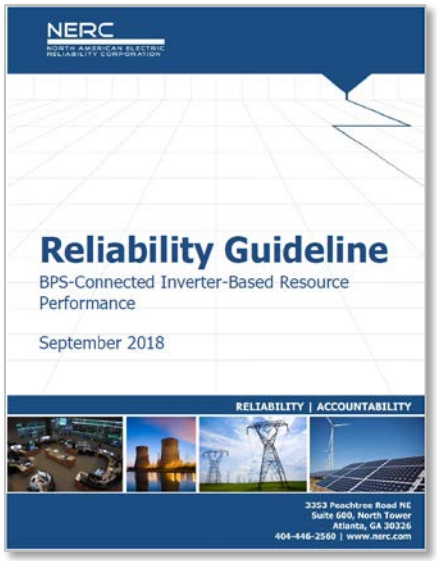
FAC-001-3: Facility Interconnection Requirements

R1. Each Transmission Owner shall document Facility interconnection requirements, update them as needed, and make them available upon request. Each Transmission Owner's Facility interconnection requirements shall address interconnection requirements for: *[Violation Risk Factor: Lower] [Time Horizon: Long-term Planning]*

FAC-002-2: Facility Interconnection Studies

R1. Each Transmission Planner and each Planning Coordinator shall study the reliability impact of: (i) interconnecting new generation, transmission, or electricity end-user Facilities and (ii) materially modifying existing interconnections of generation, transmission, or electricity end-user Facilities. The following shall be studied: *[Violation Risk Factor: Medium] [Time Horizon: Long-term Planning]*

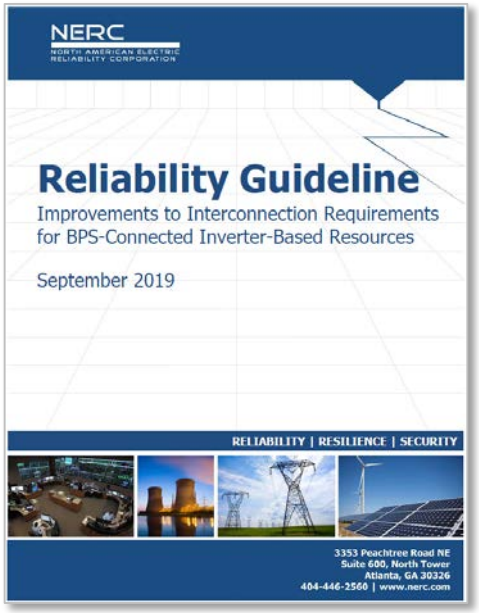
Coordination with IEEE P2800



- *Recommended Performance from BPS-Connected Inverter-Based Resources*

"Bridge Strategy"

- *Standardized equipment capability and operational performance*



- *Establishment of interconnection requirements for newly interconnecting and materially modified resources*

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Improvements to Interconnection Requirements

Topics Considered

Table 1.1: Recommended Improvement to Interconnection Requirements	
• Momentary Cessation	• Return to Service following Tripping
• Phase Jump Immunity	• Balancing
• Capability Curve	• Monitoring
• Active Power-Frequency Controls	• Low Short Circuit Strength Operations
• Fast Frequency Response	• Fault Ride-Through Capability
• Reactive Power-Voltage Control	• Grid Forming Inverters
• Reactive Current-Voltage Control	• System Restoration and Blackstart
• Reactive Power at No Active Power	• Protection Settings
• Inverter Current Injection during Faults	• Power Quality

- Recommendations in context of interconnection requirements

"TOs should…"

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Table 1.1: Recommended Improvement to Interconnection Requirements	
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"TOs should…"

Active Power-Frequency Control

- Ensure performance from newly interconnecting generating resources aligns with FERC Order No. 842
  - BPS reliability needs (specific system characteristics and studies) may drive need for additional requirements
- Specify dynamic active power-frequency response performance to ensure consistent and expected performance across BPS generating fleet
  - Refer to NERC *Reliability Guideline: BPS-Connected Inverter-Based Resource Performance*, Appendix A, Item 3.3.

Table 2.1: Dynamic Active Power-Frequency Performance

Parameter	Description	Performance Target
For a step change in frequency at the POM of the inverter-based resource		
Reaction Time	Time between the step change in frequency and the time when the resource active power output begins responding to the change[50]	< 500 ms
Rise Time	Time in which the resource has reached 90% of the new steady-state (target) active power output command	< 4 sec
Settling Time	Time in which the resource has entered into, and remains within, the settling band of the new steady-state active power output command	< 10 seconds
Overshoot	Percentage of rated active power output that the resource can exceed while reaching the settling band	< 5%**
Settling Band	Percentage of rated active power output that the resource should settle to within the settling time	< 2.5%**

Reactive Power-Voltage Control (Small Disturbance Behavior)

- Ensure performance from newly interconnecting generating resources aligns with FERC Order No. 827
  - Additional requirements may be needed for BPS reliability needs based on specific system characteristics.
- Clearly differentiate between large and small disturbance behavior for voltage response
  - For small disturbance behavior, where voltage remains within the continuous operating range of the inverters and plant controller, the TO should have clear specifications for the time in which voltage support should be provided.

Reactive Current-Voltage Control (Large Disturbance Behavior)

- Ensure that large disturbance behavior from inverter-based resources provides dynamic voltage support through their reactive current-voltage controls
  - Applicable when voltage falls outside the continuous operating range of the inverters – local inverter controls take over
  - This includes both the magnitude and timing of reactive current injection, and the prioritization between reactive and active current.

Reactive Power-Voltage Control

Table 2.2: Small Disturbance Reactive Power-Voltage Performance		
Parameter	**Description**	**Performance Target**
For a step change in voltage at the POM of the inverter-based resource…		
Reaction Time	Time between the step change in voltage and when the resource reactive power output begins responding to the change[57]	< 500 ms*
Rise Time	Time between a step change in control signal input (reference voltage or POM voltage) and when the reactive power output changes by 90% of its final value****	< 1-30 sec**
Overshoot	Percentage of rated reactive power output that the resource can exceed while reaching the settling band	< 5%***

* Reactive power response to change in POM voltage should occur with no intentional time delay.
** Depends on whether local inverter terminal voltage control is enabled, any local requirements, and system strength (response should be stable for the lowest possible grid strength). Response time may be modified based on
*** Any overshoot in reactive power response should not cause BPS voltages to exceed acceptab
**** See Appendix F of NERC *Reliability Guideline: BPS-Connected Inverter-Based Resource Per* settled (steady-state) value of reactive power following the change in voltage set point value.

- Refer to *NERC Reliability Guideline: BPS-Connected Inverter-Based Resource Performance*, Appendix A, Item 4.5.3 for small disturbance behavior

Table 2.3: Large Disturbance Reactive Current-Voltage Performance		
Parameter	**Description**	**Performance Target**
For a large disturbance step change in voltage, measured at the inverter terminals, where voltage falls outside the continuous operating range, the positive sequence component of the inverter reactive current response should meet the following performance specifications…		
Reaction Time	Time between the step change in voltage and when the resource reactive current output begins responding to the change[59]	< 16 ms*
Rise Time	Time between a step change in control signal input (reference voltage or POM voltage) and when the reactive current output changes by 90% of its final value	< 100 ms**
Overshoot	Percentage of rated reactive current output that the resource can exceed while reaching the settling band	Determined by the TP/PC***

* For very low voltages (e.g., less than around 0.2 pu), the inverter PLL may lose its lock and be unable to track the voltage waveform. In this case, rather than trip or inject a large unknown amount of active and reactive current, the output current of the inverter(s) may be limited or reduced to avoid or mitigate any potentially unstable conditions.
** Varying grid conditions (i.e., grid strength) should be considered, and behavior should be stable for the range of plausible driving point impedances. Stable behavior and response should be prioritized over speed of response.
*** Any overshoot in reactive power response should not cause BPS voltages to exceed acceptable voltage limits. The magnitude of the dynamic response may be requested to be reduced by the TP or PC based on stability studies.

- Refer to *NERC Reliability Guideline: BPS-Connected Inverter-Based Resource Performance*, Appendix A, Item 4.6.2 for large disturbance behavior

Inverter Current Injection during Fault Conditions

- Clearly articulate expected inverter behavior during and immediately following fault events, in coordination with large and small disturbance active and reactive current controls
  - This includes the magnitude of the current, the phase relationship of current with respect to voltage, and the timing of current injection
- TOs may consider establishing fault current requirements for newly interconnecting inverter-based resources since this response is dominated by controls programmed in inverter
  - Likely based on detailed EMT system studies
- Areas of BPS may require unconventional relaying techniques or additional fault current contribution (i.e., short circuit strength) to ensure secure protection schemes
  - IEEE P2800 considering standardizing fault current injection for inverter-based resources

Monitoring

- Specify data recording and real-time monitoring requirements for inverter-based resources (and all generating resources)
  - To effectively monitor resource performance and provide information necessary to perform event analysis
- This should include capturing high resolution data available at the POI, some inverter-level high speed data, and sequence of events recording.
  - Refer to NERC *Reliability Guideline: BPS-Connected Inverter-Based Resource Performance* for more information
    - Data time synchronization
    - Data retention and retrieval
    - Inverter- and plant-level event triggers
    - Recommended measurement points

Operation in Low Short-Circuit Strength Systems

- Ensure sufficient studies of potential low short-circuit strength systems, and identify when those would occur
- Ensure sufficient requirements are in place to reliably study and integrate inverter-based resources to BPS, including these areas
- In situations of potential low short-circuit strength conditions (now or in foreseeable future), ensure sufficient data and info is made available to perform studies in these areas
- Coordination with the GO is key; particularly during inter-connection studies process to obtain EMT models or provide GO with sufficient information to prove reliable control and capability to operate in these types of conditions
  - Chapter 2 provides recommended process for TO-GO coordination, and provides recommendations for effective requirements to ensure sufficient data exchanged prior to plant commissioning

Fault Ride-Through Capability

- Consider reliability need for establishing FRT requirements for interconnecting resources (synchronous and non-synchronous)
- Qualitative:
  - Resources may be required to have FRT capability for all expected (studied) credible contingency events unless exceptions granted by TP based on study
  - Applied during FAC-002 interconnection studies process
- Quantitative:
  - Typically involves a performance envelope (FRT capability) derived based on interconnection studies, grid codes, reliability standards, and other factors
  - Ensures resources, particularly inverter-based resources, are unlikely to operate in mode of operation that has not been previously studied
  - Ensures inverter manufacturers are designing equipment robust enough to withstand BPS transient events

Improvements to Interconnection Studies and Modeling

Topics Considered

Table 1.2: Recommended Improvement to Interconnection Requirements
• Timing and Quality of Modeling Data Submittals during Interconnection Process
• Steady-State Modeling
• Positive Sequence Dynamics Modeling
• Short-Circuit Modeling
• Electromagnetic Transient (EMT) Modeling
• Benchmarking Positive Sequence and EMT Models

- Recommendations in context of modeling requirements for proper and suitable interconnection studies

"TOs should…"

Timing and Quality of Modeling Data during Interconnection Process

- Modeling data submitted during feasibility study and into system impact study should be most accurate and reasonable modeling information available to the GO at the time
  - Should be screened for basic correctness as prescribed by the TP and PC
- Once interconnection studies approved, data should become final.
  - Any changes to data should become subject to material modification determinations
  - Changes to control system settings, increases in output, facility topology changes, and any other change that modifies electrical characteristics or response of the plant should trigger the need for a material modification determination

Timing and Quality of Modeling Data during Interconnection Process

- During commissioning, GOs should submit any updated control system settings to TO for review prior to implementing
  - Submission should include a side-by-side comparison with modeling data
    - Opportunity for TO to identify performance deficiency, if any
- Enforce requirements for finalized as-built modeling data to be submitted after plant commissioned and in-service within a prescribed time frame (e.g., 120 days after in-service date)
  - This final step ensures modeling data matches as-built specification sheets, oneline diagrams, and inverter and plant-level control settings
- Material modification determinations should apply during the entire time of in-service operation, and is not only applicable to the interconnection process
  - TOs should have clear specifications for what constitutes a “material modification” per NERC FAC-001-3

Steady-State Modeling

- Have clearly documented requirements for steady-state modeling that ensure sufficient data is gathered to model these resources in local and interconnection-wide base cases
- In most cases, dispersed power-producing resources (i.e., wind and solar PV) should be represented in the powerflow base case using an equivalent representation clearly specified by the TO in their requirements
- A single-line diagram showing impedances and equipment ratings should be provided with the accompanying model
- Ensure that all necessary control settings and ratings used for modeling purposes are collected during this process to ensure accurate controls configuration in the base case

Positive Sequence RMS Dynamics Modeling

- TOs have different requirements based on their modeling and studies practices
  - May be in addition to any interconnection-wide modeling requirements
- TOs may have different modeling requirements:
  - May only allow standard “generic” simulation library models with accurate parameters to reflect each specific facility
  - May only require detailed user-defined models for each specific facility
  - May require both a detailed user-defined model and a generic model
- Detailed models often used for local interconnection studies; generic models typically used in interconnection-wide base cases per MOD-032-1.

Positive Sequence RMS Dynamics Modeling

- TO should be clear in the types of models that are expected to be provided for the interconnection process.
- Latest library models used for dynamic simulations should be required; these are updated occasionally by industry stakeholder groups.
- TOs should refer to the NERC list of acceptable models for more guidance on interconnection-wide modeling.

Short-Circuit Modeling

- Have clear requirements regarding how to model inverter-based resources (and all generating resources) for short-circuit studies
  - The necessary elements for these short-circuit models should be specified in the requirements including: relevant transmission circuits, transformers, collector systems, diagrams and equipment ratings, inverter-level data, and other data for the purposes of modeling.
- Short-circuit modeling practices are evolving
  - Sufficient information should be collected during interconnection process to update and improve models as they evolve
  - Current recommendation from IEEE PSRC C24 WG is to provide table of *I1* and *I2* injection for different *V1* and *V2* levels for different fault types
- GOs can obtain this data from inverter manufacturer, who can provide it with any other necessary short-circuit models and modeling data.

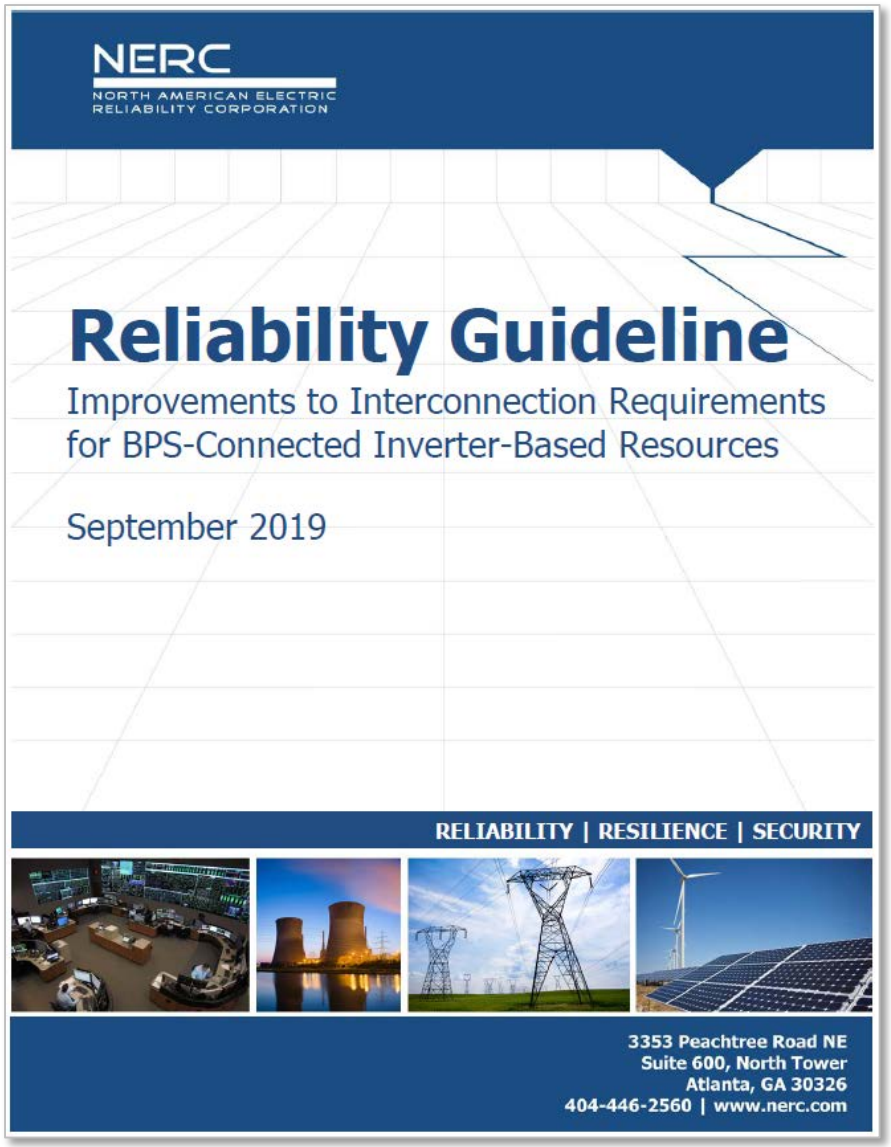
Electromagnetic Transient Modeling

- Clearly articulate the level of EMT modeling necessary as part of interconnection or modeling requirements
- EMT simulations increasingly needed in certain situations involving inverter-based resources, including:
  - Subsynchronous control interactions near series compensation
  - Interaction with other neighboring inverter-based resources
  - Low short-circuit strength networks
  - Other sub-synchronous or super-synchronous controls issues
- Specify requirements for inverter-based resources to provide EMT models in situations where an EMT-type study may be needed now or in the foreseeable future.
  - Obtaining EMT models after-the-fact becomes challenging

Benchmarking Positive Sequence and EMT Models

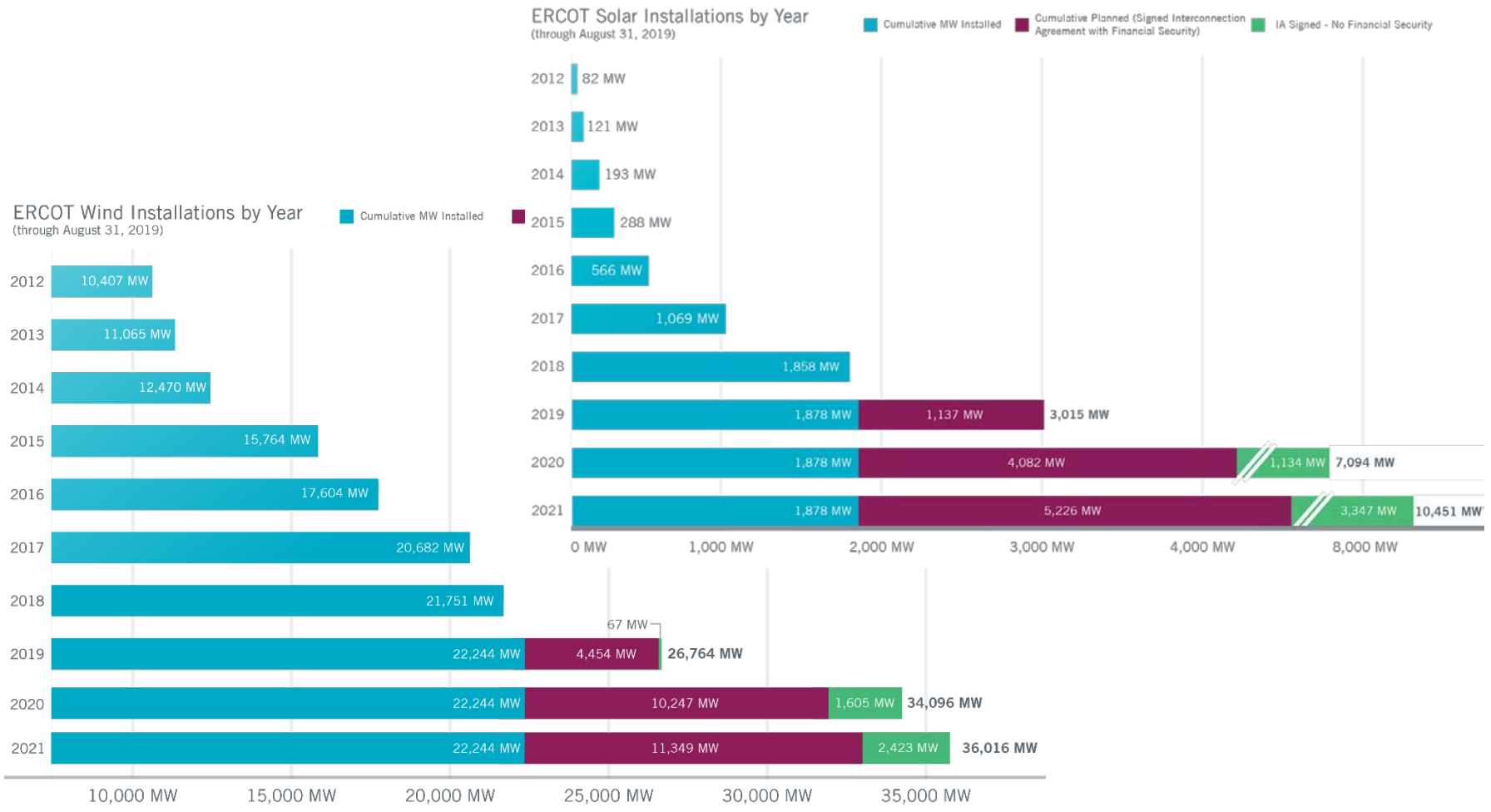
- Ensure verification that the positive sequence dynamic model reflects the behavior of the overall inverter-based resource
  - Particularly critical for large disturbance behavior that may not be captured as part of MOD-026/-027 testing activities
- Interconnection requirements should clarify and detail the necessary steps to provide the required level of verification
  - May include benchmarking simulations or testing by inverter manufacturer to ensure that the positive sequence model matches the EMT model
- EMT model should be based on real code implemented in the inverters installed in the field
  - Important for TOs to ensure that models reflect the most accurate possible assumptions during the interconnection study process, and that these models (both EMT and positive sequence RMS models) reflect as-built settings upon commissioning.

Reliability Guideline



Industry Experience: Interconnection Requirements and Interconnection Studies Improvements

ERCOT: Background



ERCOT: Recent Experience

- ERCOT market and resource interconnection rules are contained in the ERCOT Protocols, Operating Guide, and Planning Guide
  - Planning Guide Section 5 contains most of the interconnection rules
  - Note: ERCOT market and resource interconnection rules are not under FERC jurisdiction
- Based in part on IRPTF work, ERCOT held an Inverter-Based Resource (IBR) Workshop on April 25, 2019 (http://www.ercot.com/calendar/2019/4/25/176762)

ERCOT: Workshop Identified Issues (1/2)

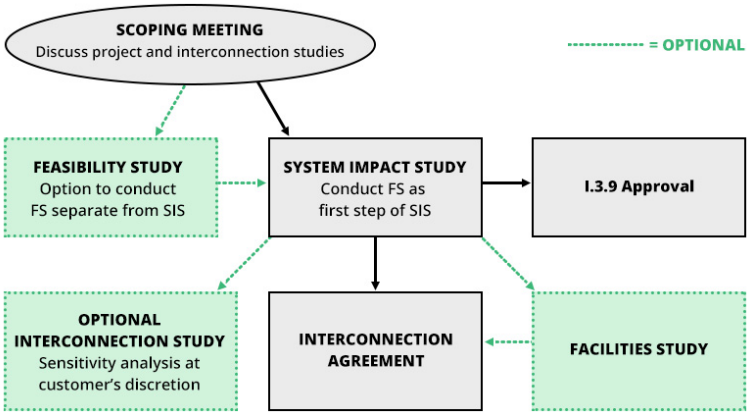
Workshop Issue	Status
1. ERCOT can better communicate existing requirements for IBRs	• ERCOT is developing a reference document for existing requirements (Q4, 2019) • Stakeholders are considering defining "Inverter-Based Resource"
2. IBRs are tripping based on previously-unknown equipment limitations	• ERCOT is working with GOs to better understand limitations
3. Voltage Ride-Through: Resources should continue to support the grid as long as there are no facility limitations	• ERCOT is considering an Operating Guide revision to clarify voltage ride-through and momentary cessation requirements (Q4, 2019) • ERCOT is considering an Operating Guide revision to add a transient overvoltage requirement (Q1, 2020) • ERCOT is considering EMT analysis as part of IBR interconnection studies (Q1, 2020)

ERCOT: Workshop Identified Issues (2/2)

Workshop Issue	Status
4. Dynamic models continue to pose simulation challenges	• ERCOT has proposed new requirements for model quality checks prior to submission during interconnection process (Q3, 2019) • ERCOT is considering additional model validation requirements (Q4, 2019)
5. Technology-specific operational requirements are needed for battery storage	• A new ERCOT task force has been developed for battery energy storage (BESTF): http://www.ercot.com/committee/bestf
6. IBR capability has evolved and improved since many of the existing requirements have been developed. The rules should be updated to accommodate advanced features	• More discussion needed

ISO-NE: Interconnection Request and Data Overview

- Interconnection Request
- Technical Data Submittal
- Scoping Meeting
  - Interconnection Studies and Options



*Type of study determines type of data submitted

Data submittal and timing requirements

	Large Generator (>20MW)	Small Generator (≤20MW)
Technical data submittal timing:	No later than the due date of execution of the System Impact Study Agreement: •All generators must submit Schedule 22, Appendix 1, Attachment A. •Wind and inverter-based generating facilities (e.g., solar, battery) must **also** submit the technical data required in Appendix 1, Attachment A-1.	**All** technical data are due at the time the interconnection request is submitted. Schedule 23, Attachment 2, and Attachment A to the IR form, provide details for the data required.
Technical data submittal: electrical one-line diagram	Required with technical data submission	Must be signed and stamped by a licensed professional engineer and included with the submission
Technical data submittal: models	All wind and inverter-based projects (e.g., solar, battery) must provide acceptable PSSE and PSCAD models along with technical data submission. Other types of generators must provide a PSSE model and may also be required to supply a PSCAD, as discussed at the scoping meeting.	All wind and inverter-based projects (e.g., solar, battery) must provide acceptable PSSE and PSCAD models. Other types of generators may also be required to supply an acceptable simulation model, as discussed at the scoping meeting.

ISO-NE: Interconnection Study Requirements

- Interconnections to the ISO Administered Transmission System must comply with ISO New England Interconnection Procedures
  - Schedule 22 – Large Generator Interconnection Procedures (>20MW)
  - Schedule 23 – Small Generator Interconnection Procedures (≤20MW)
  - Schedule 25 – Elective Transmission Upgrade Interconnection Procedures
- The ISO Tariff also contains a process for the review and approval of proposed plans to ensure no adverse reliability impact (the "I.3.9" process)
  - Applies to all generator interconnections proceeding through the either the ISO or the non-ISO (local or state) interconnection processes
  - Pursuant to I.3.9, generator interconnections > 1 MW in the non-ISO processes are still subject to ISO review

ISO-NE: Interconnection Study Requirements

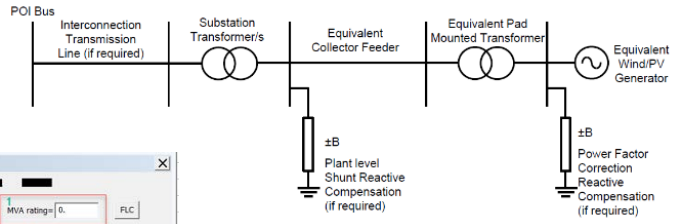
- ISO New England Planning Procedures Identify the processes, study requirements and criteria applicable to the ISO review of all generator interconnections in New England
  - PP5-1, Procedure for Review of Governance Participant's Proposed Plans
    - Describes which types of interconnections or changes need review under the I.3.9 Process
  - PP5-3, Guidelines For Conducting and Evaluating Propose Plan Application Analyses
    - Describes which types of analyses are required
  - PP5-6, Interconnection Planning Procedure For Generation and Elective Transmission Upgrades
    - Describes specific study assumptions and modeling criteria
- Any project ≥5MW's requires "level III" analysis
  - Steady State Analysis
    - Thermal & Voltage
  - Short Circuit Analysis
  - Transient Stability Analysis
  - EMT Analysis if it is deemed necessary
    - Weak Grid, Control Interactions, Sub-Synchronous Oscillations, Dynamic Performance, etc.

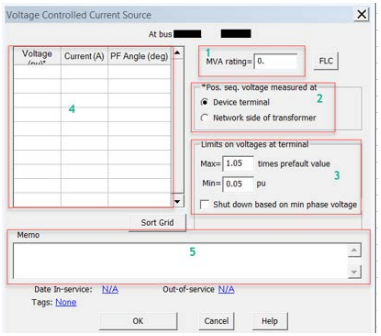
ISO-NE: Model Submittals

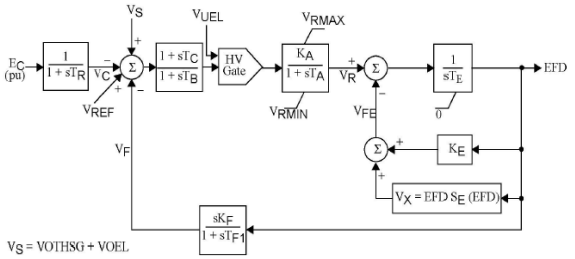
- **As-Studied Data**
  - Initially submitted with the IR
  - Used for SIS
  - Updated at end of study with any upgrades needed
- **As-Purchased Data**
  - Due At Least 180 Days prior to initial sync
  - Should be very similar to As-Studied Data
  - Must Pass Acceptance Testing
- **As-Built Data**
  - Required prior to COD
  - Should be very similar to As-Purchased Data
  - Must Pass Acceptance Testing

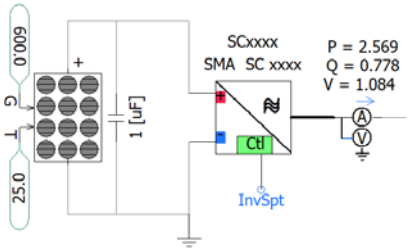
ISO-NE: Model Requirements

- **Steady State Models**
  - Usable in Siemens PTI's PSS/e
  - WECC Equivalent for Inverter Based
- **Short Circuit Models**
  - VCCS for most inverter based
  - IR Submittal Includes:
    - +/- Seq. Data
    - Current Limits
    - Voltage/Current characteristics
- **Dynamic Models**
  - PSS/e Standard Library Model
  - On NERC SAMS List of Approved Models
  - Able to Pass ISO-NE Generator Model Acceptance Testing
- **EMT Models**
  - Accuracy Features
  - Usability Features
  - Efficiency Features









Wrap Up:

Key Takeaways and Recommendations

Key Takeaways and Next Steps

Key Takeaways:

- Clarity and consistency of requirements across fleet
- Issues identified in events analyses and IRPTF activities
- Applicability to all BPS-connected inverter-based resources
- “Bridge solution” until IEEE P2800 fully implemented
- Detailed modeling and studies becoming increasingly important

TOs and Applicable Entities Encouraged To:

1. Read recently published Reliability Guideline in its entirety
2. Integrate recommendations into interconnection requirements and interconnection processes

Technical References

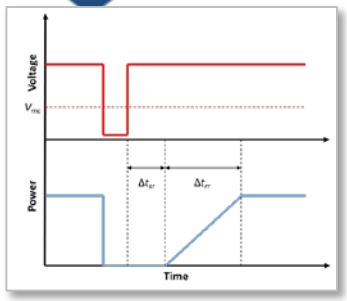
- NERC Reliability and Security Guidelines: https://www.nerc.com/comm/Pages/Reliability-and-Security-Guidelines.aspx
- NERC Reliability Guideline: Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources: https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf
- NERC Reliability Guideline: BPS-Connected Inverter-Based Resource Performance: https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Inverter-Based_Resource_Performance_Guideline.pdf
- NERC IRPTF Webpage: https://www.nerc.com/comm/PC/Pages/Inverter-Based-Resource-Performance-Task-Force.aspx
- Summary of Activities: BPS-Connected Inverter-Based Resources and Distributed Energy Resources: https://www.nerc.com/comm/PC/Documents/Summary_of_Activities_BPS-Connected_IBR_and_DER.pdf

Technical References

- Blue Cut Fire Disturbance Report:
  https://www.nerc.com/pa/rrm/ea/Pages/1200-MW-Fault-Induced-Solar-Photovoltaic-Resource-Interruption-Disturbance-Report.aspx
- Canyon 2 Fire Disturbance Report:
  https://www.nerc.com/pa/rrm/ea/Pages/October-9-2017-Canyon-2-Fire-Disturbance-Report.aspx
- Angeles Forest and Palmdale Roost Disturbances Report:
  https://www.nerc.com/pa/rrm/ea/Pages/October-9-2017-Canyon-2-Fire-Disturbance-Report.aspx
- NERC Alert I (Following Blue Cut Fire Disturbance Report):
  https://www.nerc.com/pa/rrm/bpsa/Alerts%20DL/NERC%20Alert%20Loss%20of%20Solar%20Resources%20during%20Transmission%20Disturbance.pdf
- NERC Alert II (Following Canyon 2 Fire Disturbance Report):
  https://www.nerc.com/pa/rrm/bpsa/Alerts%20DL/NERC_Alert_Loss_of_Solar_Resources_during_Transmission_Disturbance-II_2018.pdf
- NERC List of Acceptable Models:
  https://www.nerc.com/comm/PC/Pages/System-Analysis-and-Modeling-Subcommittee-(SAMS)-2013.aspx

Questions and Answers

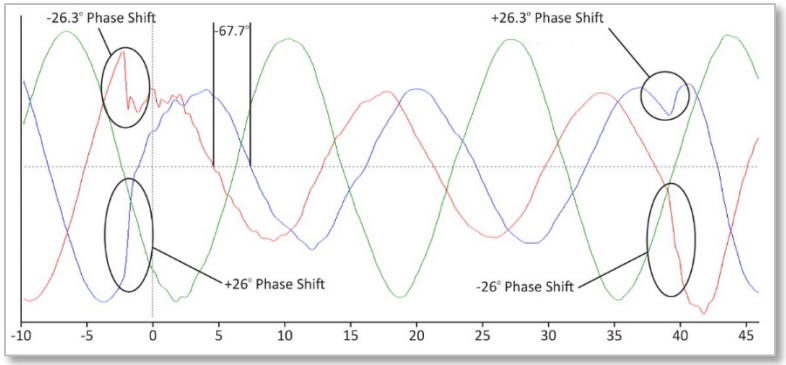
Momentary Cessation



- Momentary cessation = zero current injection
  - Implemented in majority of BPS-connected solar PV facilities
  - Identified potential reliability risk if continued
- Inverters should continue current injection inside "No Trip Zone" of the frequency and voltage curves of PRC-024
  - Unless equipment limitation or if reliability study identifies system need to cease injecting current
  - Use outside "No Trip Zone" is acceptable, particularly if it helps mitigate potential tripping conditions, based on interconnection studies
  - Return to current injection for any use should be as fast as feasibly possible while maintaining stability
- Current injection specified as active, reactive, or combination
  - Refer to NERC *Reliability Guideline: BPS-Connected Inverter-Based Resource Performance* for more information.

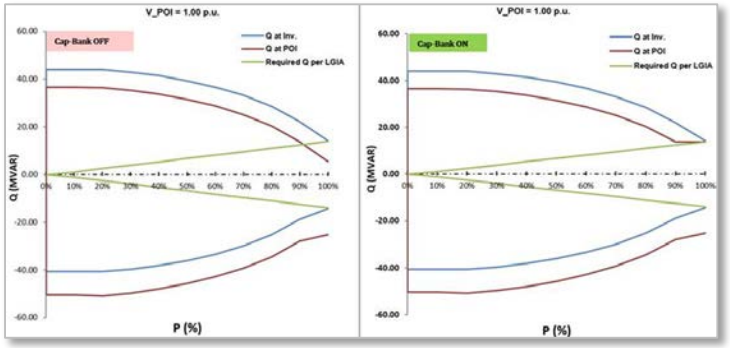
Phase Jump Immunity

- Phase jumps caused by faults and line switching events
- Establish dialogue with interconnecting GOs to understand what could cause phase jump tripping
- Perform system studies to identify possible worst-case phase jumps at point of interconnection (POI) of resource
- Consider identifying worst case balanced phase jump limits or state that inverter-based resources should not trip for studied credible contingency events (similar to fault ride through (FRT)).



Capability Curve

- Require a “composite capability curve” provided, including active and reactive capability measured at Point of Measurement (POM).
  - Includes a complete P-Q graph (or table of data representing these data points) at nominal voltage.
  - Note that the reactive capability within that curve should be “dynamic” per FERC Order No. 827.
- Require that capability curve of each type of individual inverter be provided, since this helps verify aggregate capability in the planning models (along with overall capability curve).



Fast Frequency Response

- TO (BA), in coordination with the TP/PC, should ensure sufficient frequency response capability to arrest large frequency deviations for credible contingency events.
- Interconnection studies should identify system needs for FFR, where applicable
  - Ensure the capability is available for grids where FFR may be needed.
- Requirements should clearly state:
  - Whether nonsustained forms of FFR are acceptable
  - Any additional requirements pertaining to the timing aspects of FFR
- Issues not specific to only inverter-based resources

Reactive Power at No Active Power Output

- TOs may require inverter-based resources to exchange reactive power with the BPS (to provide voltage control) when no active power is generated
  - Refer to NERC *Reliability Guideline on BPS-Connected Inverter-Based Resource Performance* for more details
- Used particularly as a solution option rather than requirement
- GO costs associated with providing this feature (e.g., powering all inverters during all hours)

Return to Service following Tripping

- Specify expected performance of inverter-based resources following a tripping event.
- May include automatic reconnection after a predefined period of time or may include manual reconnection by BA
- Considerations that should be made:
  - Differences between full and partial tripping
  - Differences between plant ac circuit breaker and inverter operation
  - Ramp rates during return to service conditions
- Following “system black” conditions, inverter-based resources should not attempt to automatically reconnect to grid unless directed by BA, so as to not interfere with blackstart procedures

Balancing

- Require capability to limit active power ramp rates (in both directions) to mitigate any significantly large power swings over a short period of time (e.g., depending on weather).
- This is a balancing ramp rate typically expressed in terms of percentage output change per minute.
  - Should not be confused with any ramp rates regarding dynamics or recovery from abnormal voltage or frequency excursions
- Require inverter-based resources to receive automatic generation control (AGC) dispatch signals, if the market or agreement structure indicates this.

Grid Forming Inverters

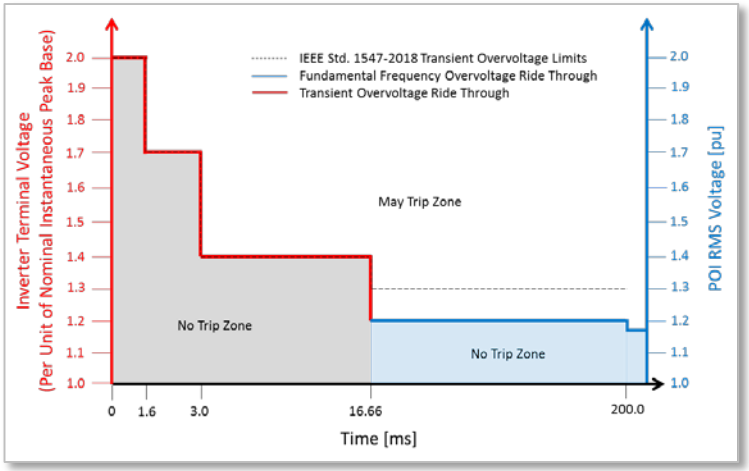
- Thoroughly understand when and where grid forming inverter capability may be needed on the BPS prior to specifying its use in any interconnection requirements
  - Systems with a high penetration of inverter-based resources (localized or widespread)
  - Systems utilizing inverter-based resources for blackstart purposes
  - Etc.
- Industry still developing technology and its recommended use, in conjunction with other solution options
- If inverters employ grid forming technology, this information should be provided to the TO in all cases

System Restoration and Blackstart Capability

- System restoration and blackstart capability considerations are part of NERC EOP-005-3 and EOP-006-3.
- While not specifically part of interconnection requirements, two considerations worth highlighting include :
  - During system restoration, TOP and BA typically require coordination and instruction prior to a GO returning to service. This should be explicitly stated such that inverter-based resources do not unexpectedly automatically reconnect during the system restoration process.
  - Inverter-based resources are not required to have blackstart capability; however, if they do, that information should be provided to the TOP and TO as part of the interconnection process.

Protection Settings

- Incorporate key findings from solar PV disturbance reports
  - PRC-024 sets minimum performance requirements; inverter protection should be set based on equipment limitations
  - Frequency-related tripping should use accurately measured frequency over time window
  - Inverter sub-cycle overvoltage protection should be set as high as possible within equipment limitations (not related to PRC-024 filtered RMS values)
  - Specify performance during successive fault events
  - DC reverse current and phase lock loop loss of synchronism protection should not result in inverter tripping for BPS fault events within the “No Trip Zone” of PRC-024
  - Inverter rate-of-change-of-frequency (ROCOF) protection should be disabled unless equipment limitation exists



Power Quality

- Specify outage scenarios for inverter-based resources to assess power quality impacts
  - GOs may request grid harmonic impedance characteristics from TO – reactive facility data
- Measure background power quality prior to interconnection
  - Design reference and later power quality responsibility separation
- Permanent power quality monitoring recommended for commercial operations
- Characterize actual harmonic distortion performance during trial operation (plant commissioning) prior to commercial operation
  - Any issues should be addressed based on requirements established by TO
- Require GOs to provide advanced notification prior to firmware updates (potential effects to performance)