CIGRE NGN Webinar
Impact of Inverter-Based Resources and Distributed Energy Resources on the Bulk Power System

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The vision for the Electric Reliability Organization Enterprise, which is comprised of NERC and the six Regional Entities, is a highly reliable and secure North American bulk power system. Our mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid.

NERC Core Functions:
- Develops and enforces Reliability Standards
- Annually assesses seasonal and long-term reliability
- Monitors the bulk power system through system awareness
- Educates, trains, and certifies industry personnel.
Let’s Talk the Same Language

NERC Reliability Standards and FERC LGIA/SGIA

Local Utility Interconnection Requirements and FERC LGIA/SGIA

States Adoption and Implementation of IEEE 1547-2018
NERC Inverter-Based Resource Performance Task Force (IRPTF)

*BPS-Connected Inverter-Based Resources*
NERC Disturbance Reports and Alerts

1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report
Southern California 8/16/2016 Event
June 2017

900 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report
Southern California Event: October 9, 2017
Joint NERC and WECC Staff Report
February 2018

April and May 2018 Fault Induced Solar Photovoltaic Resource Interruption Disturbances Report
Southern California Events: April 20, 2018 and May 11, 2018
Joint NERC and WECC Staff Report
January 2019
Various Types of Inverter Tripping

- Sub-cycle transient AC overvoltage
- DC reverse current
- Phase lock loop loss of synchronism
- Abnormal frequency (phase jump)
Momentary Cessation – NERC Alert I
Momentary Cessation – NERC Alert I

Does your inverter use momentary cessation?

- Yes: 2,657 (16%)
- No: 14,113 (84%)

Operating PV and WT Color By Plant Mover Category
- Wind Turbine
- Solar Panel

Operating PV and WT Size By Net Summer Capacity MW
- 10k to 500
- 500 to 1,000
- 1,000 to 10,000
- 10,000 and Above

In Service Lines 230 kV and Above Voltage Classes kV
- Under 50 kV
- 50 to 100
- 100 to 181
- 181 to 230
- 230 to 330
- 330 to 500
- 500 and Above

DC Line Connectivity

V_below_9
- 0
- 0.25
- 0.5
- 0.75
- 1

RELIABILITY | RESILIENCE | SECURITY
Initial IRPTF Findings
Initial IRPTF Findings
Initial IRPTF Findings

N-1-1 (Line Side Voltage)

- Line Impedance
- SEL-421 Zone 2 - 175%
- GE L90 Zone 2 - 130%
- SEL-421 Zone 4 & GE L90 Zone 3 - 130%
- SEL-421 & GE L90 Load Encroachment
Most installed inverters used momentary cessation
More than half of those inverters could eliminate its use
But about 3200 MW cannot even change settings
Of those, about 1800 MW use a MC threshold above 0.4 pu

Very few resources had positive sequence RMS models that accurately reflected reality
• Eliminate momentary cessation to the extent possible

**Recommendation: Eliminate to the greatest extent possible.**

New resources, and resources that can eliminate momentary cessation

Resources that cannot eliminate momentary cessation yet can make modifications

1) MC_V reduced
2) Delay shortened
3) Ramp rate faster
All we’ve discussed thus far are *fundamental* BPS reliability needs...

1) Avoid unnecessary tripping to the extent possible
2) Continue injecting current during abnormal grid conditions
Now the question turns to more technical issues...

- What type of behavior is expected from inverter-based resources?
- What type of current injection is recommended?
- What type of current injection is necessary (in some cases)?
NERC Reliability Guideline

Topics:
- Eliminate momentary cessation
- Active power-frequency control
- Reactive power-voltage control
- Protection aspects
- Relation with IEEE 1547 and UL 1741
- Measurement data and monitoring
- Other related topics

NERC Reliability Guideline

Reliability Guideline
Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources
September 2019

- Clear and consistent performance requirements needed for inverter-based resources
- Building from previous IRPTF guideline on performance recommendations
- Alignment with NERC Reliability Standards FAC-001-3 and FAC-002-2
- Applicability to non-BES resources
- Coordination with IEEE P2800

Current Injection to Support BPS during Fault Events

https://www.nerc.com/comm/PC/IRPTF%20Workshops/Key_Takeaways_April_2019_Inverter_Relay_Manufacturer_Meeting.pdf
## Changing BPS Fault Characteristics

<table>
<thead>
<tr>
<th>Factor</th>
<th>Synchronous World</th>
<th>Inverter-Based World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault Current Magnitude</td>
<td>Consistent, High</td>
<td>Consistent, Low</td>
</tr>
<tr>
<td>Fault Current Phase Relationship</td>
<td>Consistent, Predictable</td>
<td>Consistent, Unpredictable</td>
</tr>
<tr>
<td>Short Circuit Model Accuracy and Certainty</td>
<td>Mature</td>
<td>Immature, Evolving</td>
</tr>
</tbody>
</table>
• BPS challenges with increasing penetration of inverter-based resources
• Transmission protection impacts
• Large system stability issues
• Design and control philosophy changes
• Considerations for a future BPS

https://resourcecenter.ieee-pes.org/technical-publications/technical-reports/PES_TR_7-18_0068.html
Interconnection Studies

Available Models

*Do we have adequate models to be able to capture the behaviors of inverter-based resources?*

Modeling Practices

*Are we correctly/reasonably using the models to capture the critical characteristics of inverter-based resources?*

Interconnection Studies

*Are sufficient studies being performed to adequately capture potential reliability risks?*

Reliable Operation

*Are interconnection studies serving to ensure reliable operation of BPS?*
• Recommendations:
  - Address existing performance issues
    o Provide updated models for existing equipment settings
  - Identify performance improvements
    o Provide proposed performance improvements via updated model
  - Reliability studies for existing settings and proposed changes
    o Approve proposed changes and coordinate with generators
  - Report updates to Regional Entity
Modeling Issue Simply Put

- Areas for Modeling Concern:
  - Incorrect models
  - Mismatched NERC Alert and model data
  - Defective or unusable models
• 19 recommendations related to inverter-based resource modeling, modeling practices, and studies
• Topics:
  ▪ NERC Alert findings – modeling challenges
  ▪ Challenges with relying on MOD-026/-027 test reports
  ▪ Parameterization of dynamic models
  ▪ IRPTF stability study findings
  ▪ Accurate models at time of interconnection
WECC Solar Modeling Advisory Group

• Address systemic modeling issues in interconnection-wide base cases
• Coordinate with generator owners to educate and support accurate model development
• Accountability to inverter-based resource modeling in interconnection-wide base case
NERC-WECC Joint Report: WECC Base Case Review of IBR Models

Wind Plant Generator/Converter Models

Wind Plants Modeled with GENROU

Everything is grey is “not acceptable” per WECC modeling list and per EVERY major solar PV OEM...
# Reliability Guideline Modeling Recommendations

## Table 1.2 Recommended Improvements to Modeling Requirements

<table>
<thead>
<tr>
<th>Topic</th>
<th>Recommended Improvement</th>
</tr>
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<tbody>
<tr>
<td>Steady-State Modeling</td>
<td>TOIs should have clearly documented requirements for steady-state modeling that ensures that sufficient data is gathered to model these resources in local and interconnection-wide powerflow 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 to the TO with the accompanying model. The TO should also 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.</td>
</tr>
<tr>
<td>Positive Sequence Dynamics Modeling</td>
<td>TOIs have different requirements based on their local modeling and studies practices, which may differ from any interconnection-wide case creation requirements. The TO may only allow standard &quot;generic&quot; simulation library models with accurate parameters to reflect each specific facility, may require detailed user-defined models, or may require both a detailed user-defined model and a generic model in some cases. Detailed models are often used for local interconnection reliability studies (localized studies as well as interconnection study process studies) while generic models are typically used in the interconnection-wide base cases per MOD-032-1. In any case, the TO should be clear in the types of models that are expected to be provided for the interconnection process. The latest library models used for dynamic simulations should be required; these are updated occasionally by industry stakeholder groups. TOIs should refer to the NERC list of acceptable models for more guidance on interconnection-wide modeling.</td>
</tr>
<tr>
<td>Short-Circuit Modeling</td>
<td>TOIs should 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; however, necessary data should be collected to have the information needed for the TO to improve these models as they evolve in coordination with the GO. The current recommendation from IEEE Power System Relaying and Control Committee C24 Working Group is to provide a table of positive and negative sequence current injection for different positive sequence voltage levels for different fault types. Refer to Chapter 3 of this guideline for more information. The GO can obtain this data from the inverter manufacturer, who can provide it with any other necessary short-circuit models and modeling data.</td>
</tr>
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• Timing and Quality of Modeling Data Submittals
  ▪ Continually updated models during interconnection process
  ▪ Assurance of as-built data following commissioning

• Steady-State Modeling
  ▪ Suitable powerflow representation of inverter-based resources

• Positive Sequence Dynamics Modeling
  ▪ Suitable dynamic models for local and interconnection-wide studies

• Short-Circuit Modeling
  ▪ Reasonable short-circuit modeling data available

• Electromagnetic Transient Modeling
  ▪ Availability and accuracy of EMT models for complex reliability studies

• Benchmarking Positive Sequence and EMT Models
  ▪ Assurance that dynamic models match suitably for all expected conditions
Need for EMT Studies and Advanced Engineering

Active power recovery is perfectly smooth in PSSE

Oscillatory reactive power response in PSCAD as inverters struggle to control Voltage

Fast reactive power response quickly drives voltage high in PSSE

Instantaneous rms voltage measurements in PSSE

[Source: NERC, Electranix, ERCOT]
Need for EMT Studies and Advanced Engineering

Osteds’s report advises the following:

Initially, Osteds understood that the Dynamic Reactive Compensator (DRC) was responsible for the rapid de-load of Hornsea-1. Osteds have since concluded that the DRC worked as designed and was not the cause of the de-load.

The configuration of the Hornsea network, with one SGT and one offshore transmission system user asset (OTSUA Circuit) on outage, was a contributory factor as it created a weak internal network environment. Subsequently Osteds have reviewed and reconfigured their network.

The wind turbine settings were standard settings from the manufacturer. During the incident, the turbine controllers reacted incorrectly due to an insufficiently damped electrical resonance in the sub-synchronous frequency range, so that the local Hornsea voltage dropped and the turbines shut themselves down.

Osteds have since updated the control system software for the wind turbines and have observed that the behaviour of the turbines now demonstrates a stable control system that will withstand any future events in line with Grid Code and CUSC requirements.
• System strength concept
  ▣ Low short circuit strength (i.e., “weak grid”)

• Short circuit ratio (SCR)-based metrics

• Issues with low short circuit strength networks

• Planning study considerations

• Need for detailed modeling and studies

• Coordination and solutions to low short circuit issues

https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Item_4a_Integrating%20Inverter-Based_Resources_into_Low_Short_Circuit_Strength_Systems_-_2017-11-08-FINAL.pdf
Historically...

Possible Future...

Fast Frequency Response Concepts and Bulk Power System Reliability Needs

NERC Inverter-Based Resource Performance Task Force (IRPTF)
White Paper
March 2020
• IRPTF sub-group performed detailed review of NERC Standards and identified any issues with BPS-connected inverter-based resources
  - PRC-002-2 (disturbance monitoring)
  - FAC-001-3 and FAC-002-2 (interconnection requirements and studies)
  - MOD-026-1 and MOD-027-1 (dynamic model verification)
  - TPL-001-4 (clarifications to TPL planning assessments)
  - VAR-002-4.1 (generator voltage control)

• SARs endorsed by RSTC and submitted to NERC Standards Committee
• Increasingly common
• Increasingly important
• Growing industry capabilities and expertise
• Sufficient time to execute studies
• Key aspect of reliable operation of the BPS
• Interconnection queues flooded with requests from BESSs and hybrids

• Recommended performance – need for clarity and consistency

• Growing complexity with planning studies:
  ▪ How do we model?
  ▪ How do we set dispatch assumptions?
  ▪ How do we execute studies?
  ▪ How do we handle increasing uncertainty?
• Changing nature of the grid
  § What challenges will we face?
  § What solutions do we have available?
  § Where are our gaps?
Coordination between Transmission, Generation, and OEM

Transmission Owner
- Models & Data, Performance
- Interconnection Requirements, Studies

Generator Owner
- (Future) IEEE Std. 2800
  - Performance & Capability Requirements

Original Equipment Owner
- Equipment Capabilities
- Interconnection Specifications
- Design Requirements
NERC System Planning Impacts of Distributed Energy Resources Working Group (SPIDERWG)

*Aggregate Impacts of Distribution-Connected Energy Resources*
What Else is SPIDERWG Up To?

- DER Modeling Survey
- **DER_A Parameterization** Guideline
- DER Data Collection Guideline
- MOD-032-1 Review/SAR
- Modeling Notification

- Guideline on BPS Planning Practices with DER
- **White Paper: TPL-001 Standard Review**
- Recommended Simulation Improvements
- Guidance on UFLS and UVLS
- White Paper: Beyond Positive Sequence

- DER Verification Guideline
- DER Forecasting Practices Guideline

- **IEEE Std. 1547-2018 Review and BPS Recommendations**
- Guideline on Communicating across T-D Interface
- Education Materials
- Coordination of Terminology
- NERC Standards Review
- Tracking DER Growth
**DER:** Any source of electric power located on the distribution system.
IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

Reliability Guideline
Bulk Power System Reliability Perspectives on the Adoption of IEEE 1547-2018
March 2020

IEEE Standards Coordinating Committee 21

Sponsored by the IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage
NERC Recommendations to NARUC and States regarding IEEE 1547-2018

- **Aggregate** amounts of DER can and will impact the BPS
  - NERC Goal: provide support where needed in this area; ensure BPS reliability

- Adoption of IEEE 1547-2018
  - Encouraged, from BPS perspective
  - Coordination led by **AGIRs** (e.g., States), engagement from RCs

- Educational materials abound
  - NERC SPIDERWG, NERC Reliability Guideline, EPRI reports, etc.

- Coordination necessary for successful IEEE 1547-2018 implementation (BPS perspectives needed in some areas)
  - DER Category Selection
  - Voltage Tripping
  - Voltage Ride-Through
  - Frequency Tripping
  - Frequency Ride-Through
  - Restore Output
  - Frequency-Droop
  - Phase Angle Change Ride-Through
  - Enter and Return to Service
  - Unintentional Islanding
  - Intentional Islanding
  - Interoperability
• **Question:** How best can we coordinate between NERC, the Regions, and our stakeholders?

• **My Answer:** “Make It Personal”
  - NERC Guidelines providing clear recommendations for areas where industry will need to *dig in* moving forward
  - Providing unified guidance for industry-wide modeling, simulation, planning, data collection, and other practices
  - HOWEVER ... you all know your system best!
    - What is the highest priority issues in your footprint?
    - What emerging risks could be coming?
    - Have those been articulated to the Region and to NERC?
      - Why? Because we want to help address them together!
Summary of Activities:
Key Takeaways

- Distribution System
  - State regulator and local utility adoption of IEEE 1547-2018
  - Coordinated stakeholder engagement

- Bulk Power System
  - Majority of newly interconnecting IBR
  - Improvements to Transmission Owner interconnection requirements (FAC-001-3)
  - IEEE P2800 standard development
  - Coordination with FERC staff to facilitate changes to pro-forma LGIA and SGIA
  - Mitigation of emerging reliability issues

- Bulk Electric System
  - NERC IRPTF developing guidelines and reviewing NERC Reliability Standards
  - Ensuring clear and consistent requirements

Related Activities – Get Involved!

• NERC Inverter-Based Resource Performance Task Force (here)
• NERC System Planning Impacts from DER Working Group (here)
• Reliability Guidelines (here)
• Guideline: Recommended Performance for BPS-Connected IBR (here)
• Guideline: Improvements to Interconnection Requirements (here)
• Guideline: BPS Reliability Perspectives on the Adoption of IEEE 1547-2018 (here)
• Guideline: Parameterization of the DER_A Model (here)
• Blue Cut Fire Disturbance Report (here)
• Canyon 2 Fire Disturbance Report (here)
• Palmdale Roost and Angeles Forest Disturbance Report (here)
• NERC Alert: Loss of Solar Resources I (here)
• NERC Alert: Loss of Solar Resources II (here)
• Summary of ERO Activities for IBRs and DERs (here)
• IEEE P2800 (here)
• NERC-WECC Report: WECC Base Case Review of Inverter-Based Resources (here)
• Report: BPS-Connected Inverter-Based Resource Modeling and Studies (here)
• White Paper: FFR Concepts and BPS Reliability Needs (here)
• NERC List of Acceptable Models (here)
• SPIDERWG Working Definitions for DER (here)
Questions and Answers

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