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Inverter-Based Resource Modeling Guidelines and Experience

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Energy Systems Integration Group (ESIG) Webinar
December 2020

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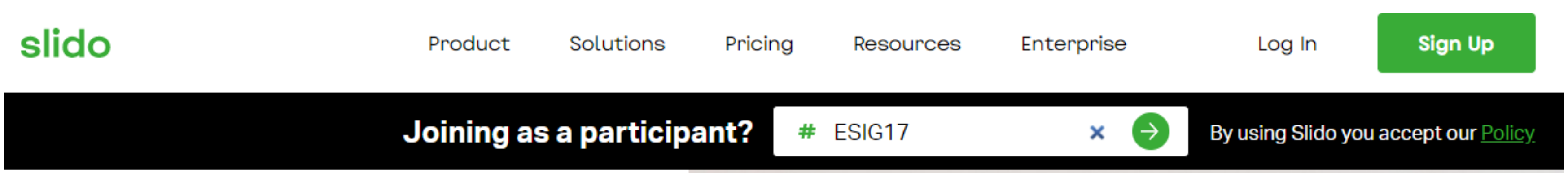
Logistics

- **Q&A:**
  - Go to slido.com
  - Enter event code **ESIG17**
  - Submit your questions!

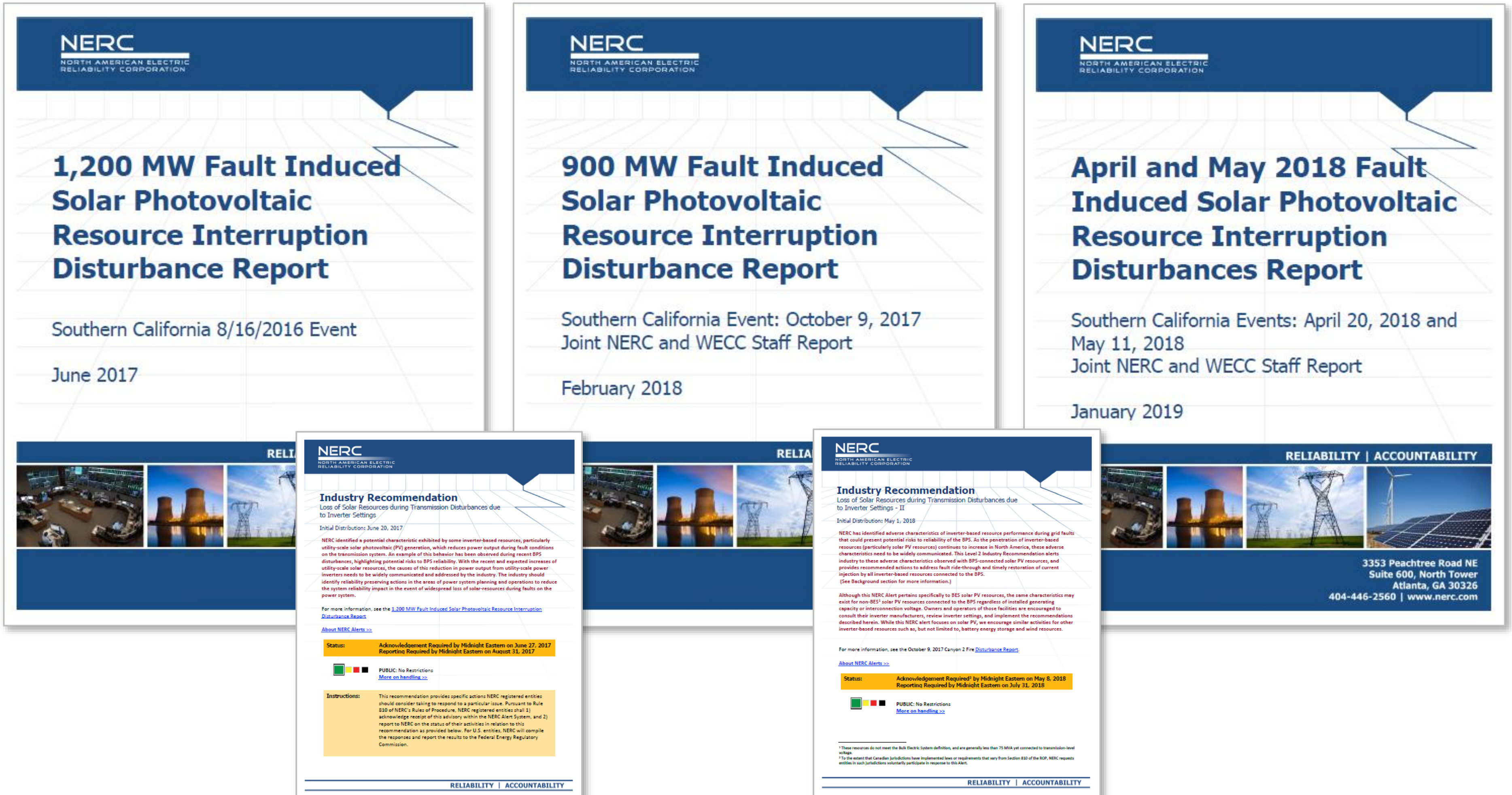
- **Recording:**
  - This presentation is being recorded.
  - Presentation materials will be posted after the webinar.



Disclaimer

- *Materials presented here…*
  - *Are not intended as compliance guidance.*
  - *Are intended to describe the technical aspects of inverter-based resource modeling and verification.*
  - *Are based on my experience and engagement with industry stakeholders, and may not necessarily be the opinions of NERC.*
- *Questions related to compliance can be directed to NERC Compliance Assurance department.*

NERC Disturbance Reports of Solar PV Events



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1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report

Southern California 8/16/2016 Event

June 2017

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900 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report

Southern California Event: October 9, 2017
Joint NERC and WECC Staff Report

February 2018

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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

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Industry Recommendation
Loss of Solar Resources during Transmission Disturbances due to Inverter Settings

Initial Distribution: June 20, 2017

NERC identified a potential characteristic exhibited by some inverter-based resources, particularly utility-scale solar photovoltaic (PV) generation, which reduces power output during fault conditions on the transmission system. An example of this behavior has been observed during recent BPS disturbances, highlighting potential risks to BPS reliability. With the recent and expected increases of utility-scale solar resources, the causes of this reduction in power output from utility-scale power inverters needs to be widely communicated and addressed by the industry. The industry should identify reliability preserving actions in the areas of power system planning and operations to reduce the system reliability impact in the event of widespread loss of solar-resources during faults on the power system.

For more information, see the 1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report

About NERC Alerts >>

Status: Acknowledgement Required by Midnight Eastern on June 27, 2017
Reporting Required by Midnight Eastern on August 31, 2017

PUBLIC: No Restrictions
More on handling >>

Instructions: This recommendation provides specific actions NERC registered entities should consider taking to respond to a particular issue. Pursuant to Rule 810 of NERC's Rules of Procedure, NERC registered entities shall 1) acknowledge receipt of this advisory within the NERC Alert System, and 2) report to NERC on the status of their activities in relation to this recommendation as provided below. For U.S. entities, NERC will compile the responses and report the results to the Federal Energy Regulatory Commission.

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Industry Recommendation
Loss of Solar Resources during Transmission Disturbances due to Inverter Settings - II

Initial Distribution: May 1, 2018

NERC has identified adverse characteristics of inverter-based resource performance during grid faults that could present potential risks to reliability of the BPS. As the penetration of inverter-based resources (particularly solar PV resources) continues to increase in North America, these adverse characteristics need to be widely communicated. This Level 2 Industry Recommendation alerts industry to these adverse characteristics observed with BPS-connected solar PV resources, and provides recommended actions to address fault ride-through and timely restoration of current injection by all inverter-based resources connected to the BPS.
(See Background section for more information.)

Although this NERC Alert pertains specifically to BES solar PV resources, the same characteristics may exist for non-BES[1] solar PV resources connected to the BPS regardless of installed generating capacity or interconnection voltage. Owners and operators of those facilities are encouraged to consult their inverter manufacturers, review inverter settings, and implement the recommendations described herein. While this NERC alert focuses on solar PV, we encourage similar activities for other inverter-based resources such as, but not limited to, battery energy storage and wind resources.

For more information, see the October 9, 2017 Canyon 2 Fire Disturbance Report.

About NERC Alerts >>

Status: Acknowledgement Required[2] by Midnight Eastern on May 8, 2018
Reporting Required by Midnight Eastern on July 31, 2018

PUBLIC: No Restrictions
More on handling >>

[1] These resources do not meet the Bulk Electric System definition, and are generally less than 75 MVA yet connected to transmission-level voltage.
[2] To the extent that Canadian jurisdictions have implemented laws or requirements that vary from Section 810 of the ROP, NERC requests entities in such jurisdictions voluntarily participate in response to this Alert.

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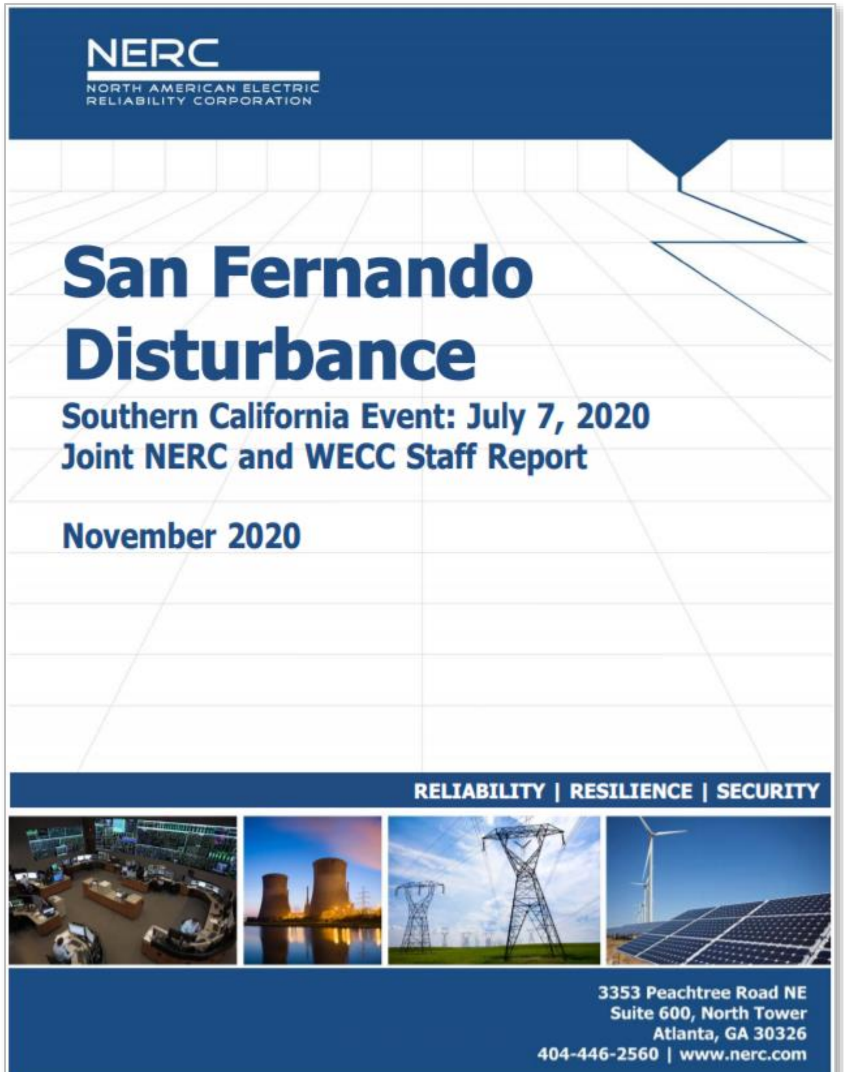
San Fernando Disturbance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San Fernando Disturbance

Southern California Event: July 7, 2020
Joint NERC and WECC Staff Report

November 2020

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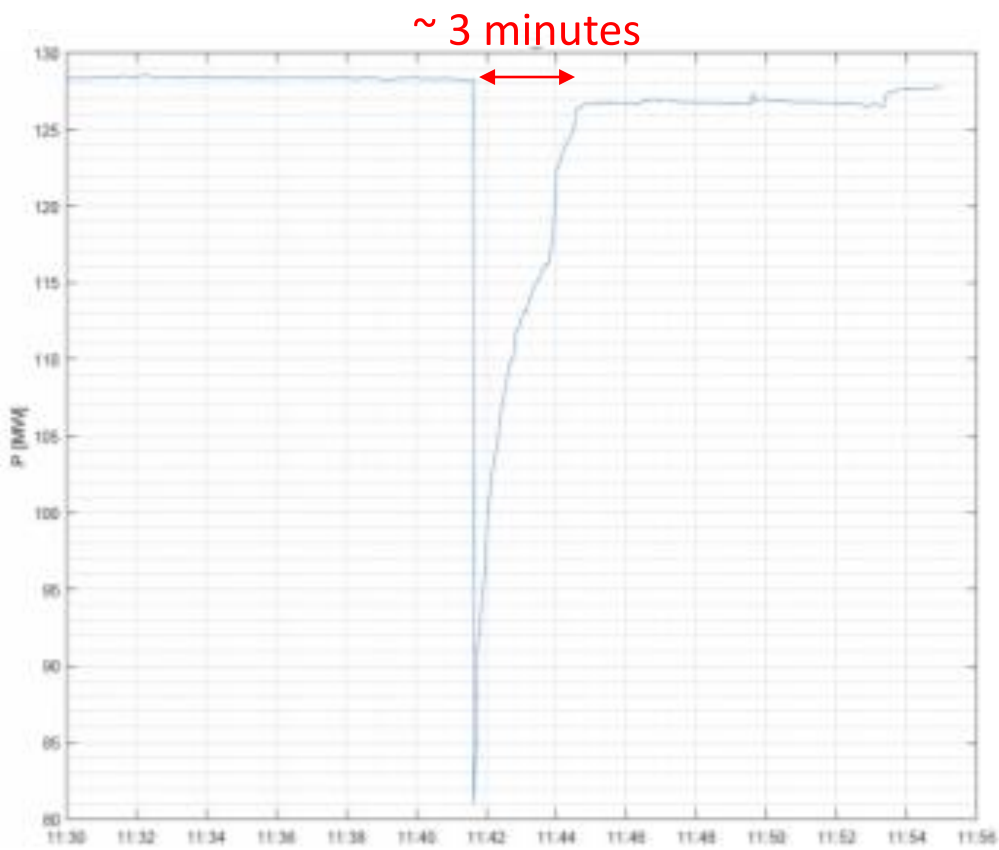
Table ES.2: Overview of Resource Performance

Area	Fault Event #1 [MW]	Fault Event #2 [MW]
BPS-Connected Solar PV Reduction		
CAISO	122	901
SCE	100	535
PG&E	6	79
LADWP	83	62
IID	0	37
Total*	**205**	**1,000**
Net Load Increases (Possible DER Tripping)		
SCE	5	80
Total*	**5**	**80**

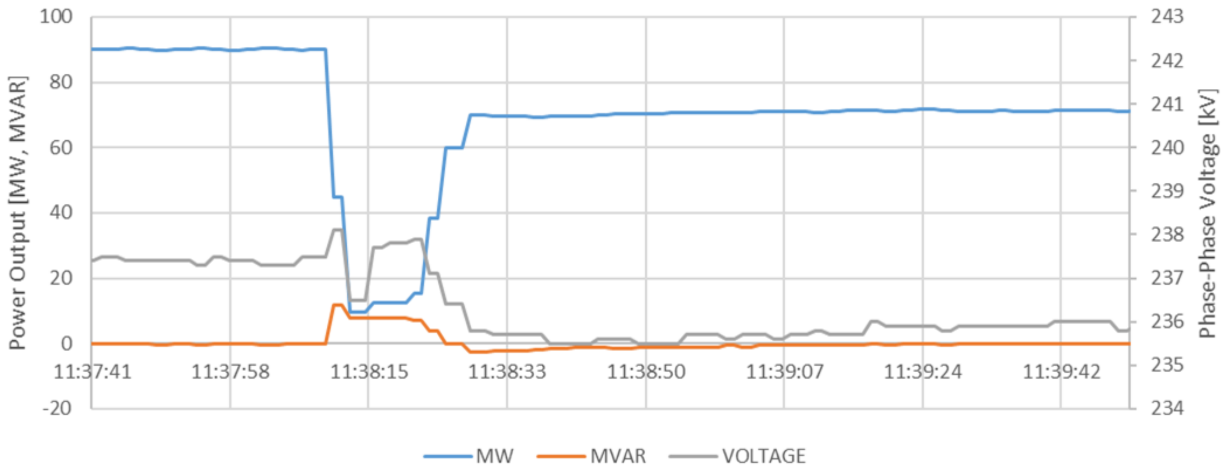
* Summation of CAISO, LADWP, and IID BA footprints.

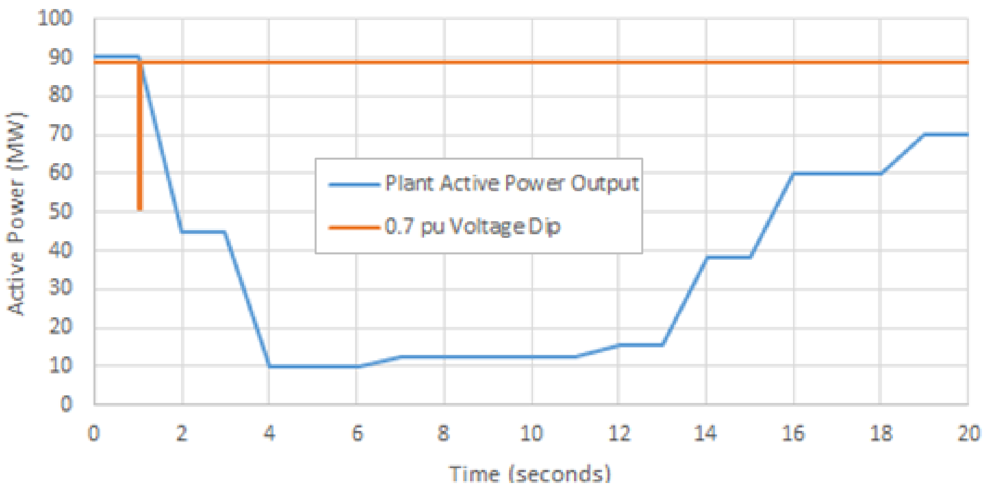
San Fernando Disturbance: Plant using Momentary Cessation



- Actual:
  - Momentary cessation at 0.9 pu
  - 3 minutes return to pre-disturbance output
- Model:
  - Vdip = 0.85 pu
  - Rrpwr = 1.0 pu/sec
  - Thld2 = 0.1 sec
- Plant-level controller interactions not modeled

San Fernando Disturbance: Plant using Current Injection





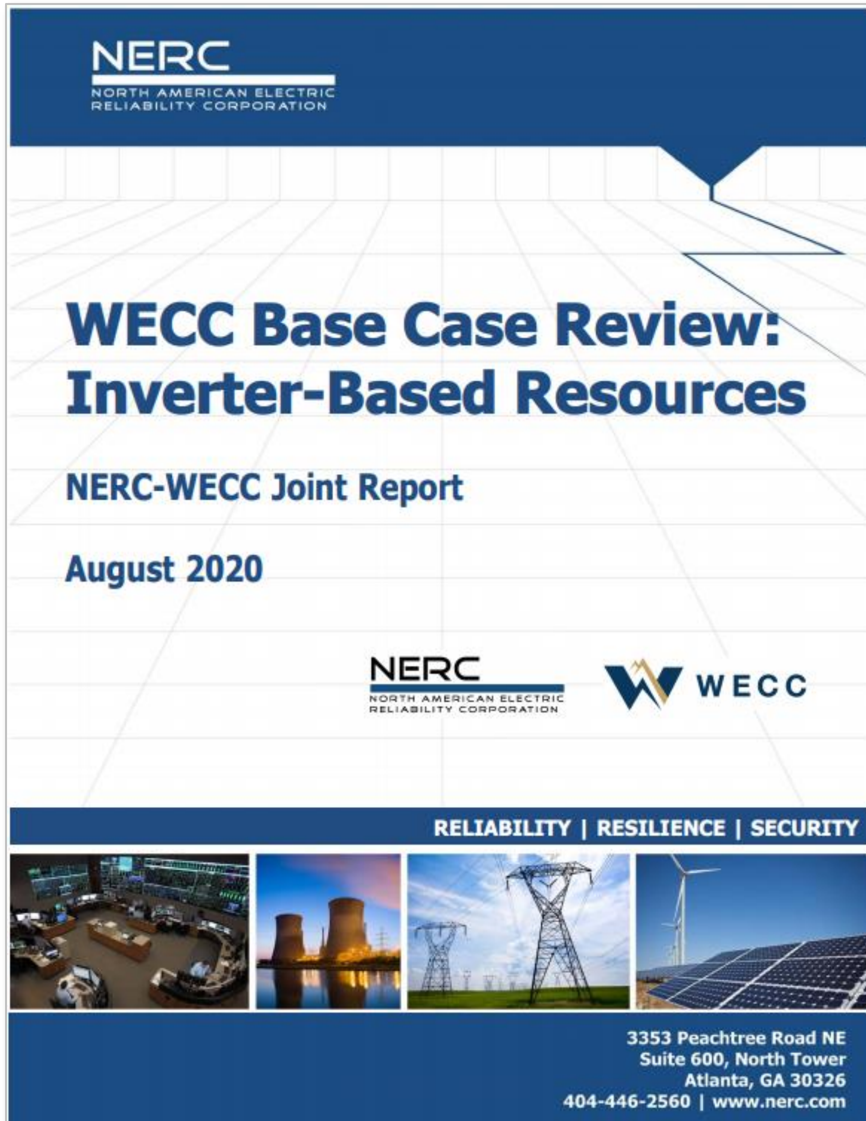
- Actual:
  - K-factor dynamic voltage control
  - Some inverters trip on ac overcurrent protection
  - Plant reduces P for about 10 seconds; Q increase during and after fault
- Model: speaks for itself…

Modeling Issues Persist

- Basic model quality checks failed
- Incorrect parameterization – model does not match reality
- Solar PV resources modeled using *reec_b* rather than *reec_a*
- Default parameters abound
- Uncoordinated parameters (e.g., VDL tables, Vdip, etc.)
- Changes being made to equipment but models not updated
  - Confusion with “material modifications”
- TPs/PCs lack info to check validity of models provided
- MOD-026/-027 give false impression model accuracy for large disturbances
- Interconnection timeline crunch
- BESSs and hybrid plants add to complexity

And this is just the fundamental-frequency, positive-sequence dynamic models.

NERC-WECC Joint Report: WECC Base Case Review of IBR Models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WECC Base Case Review: Inverter-Based Resources

NERC-WECC Joint Report

August 2020

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WECC

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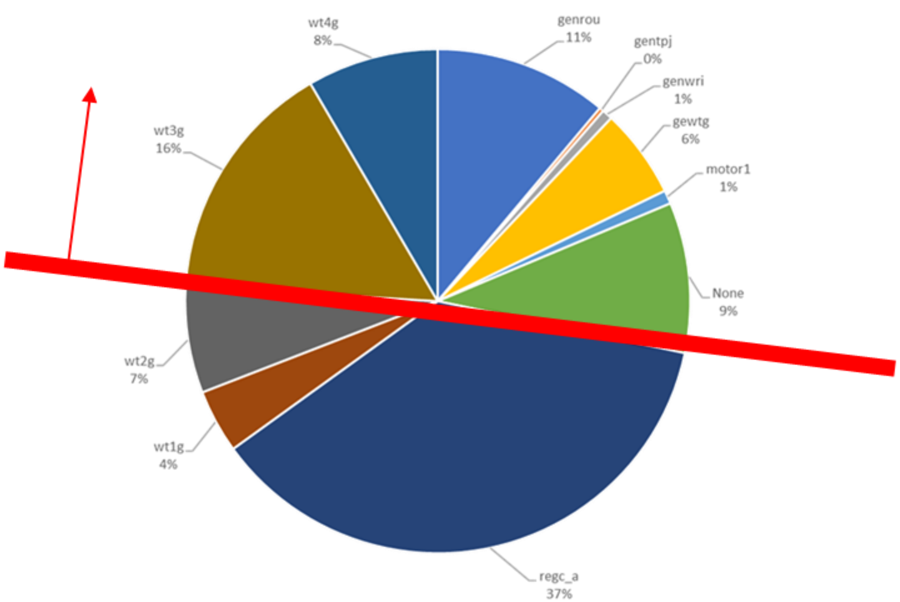
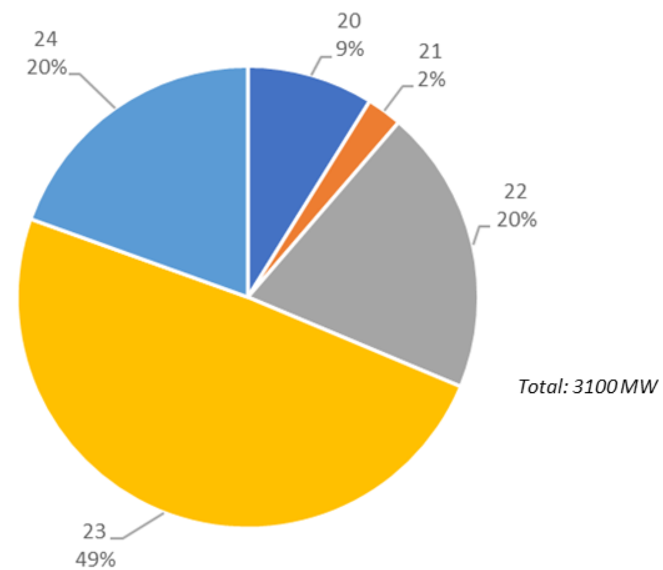
NERC-WECC Joint Report: Wind Models

Everything above the line has an incorrect model or no model…

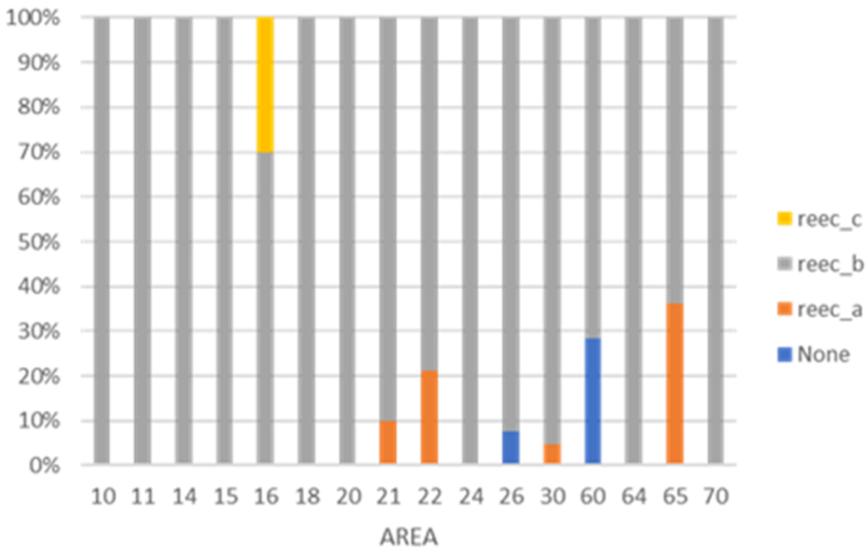


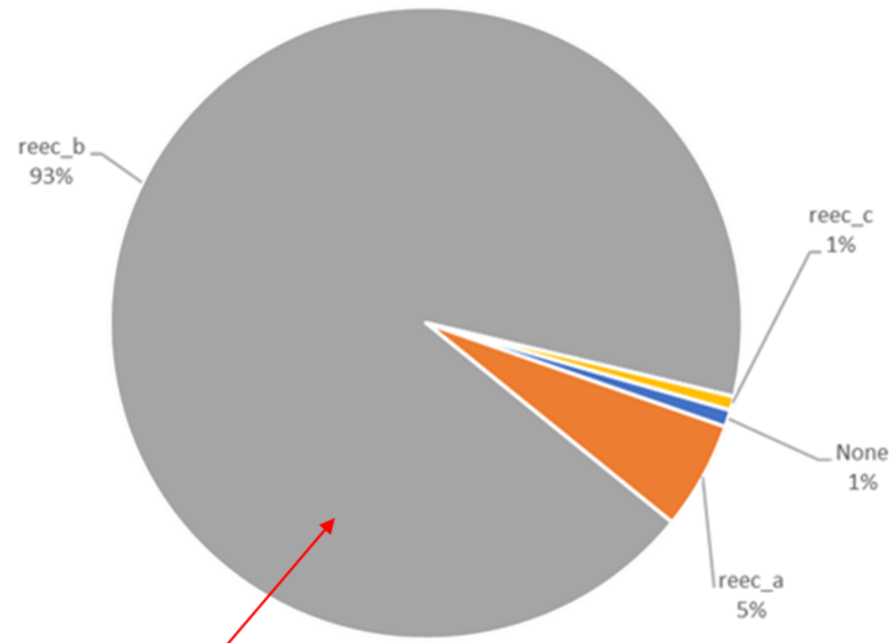
Wind Plant Generator/Converter Models



Wind Plants Modeled with GENROU

NERC-WECC Joint Report: Solar PV Models





Everything in grey is "not acceptable" per WECC modeling list and every major solar PV inverter OEM...

Timeline of Models Submitted

Feasibility Study
- Little information known about plant
- Expected plant design (basic), powerflow
- TP/PC sets requirements

↓

System Impact Study
- More information known about plant
- Expected plant design (detailed), dynamics
- TP/PC sets requirements

↓

Commissioning
- As built designs, plant information, settings
- May deviate from expected models slightly
- Updates need to be provided to TP/PC asap

↓

MOD-032 Case Creation
- Regular data submittal process
- Most up-to-date plant data and models
- TP/PC review of data submitted

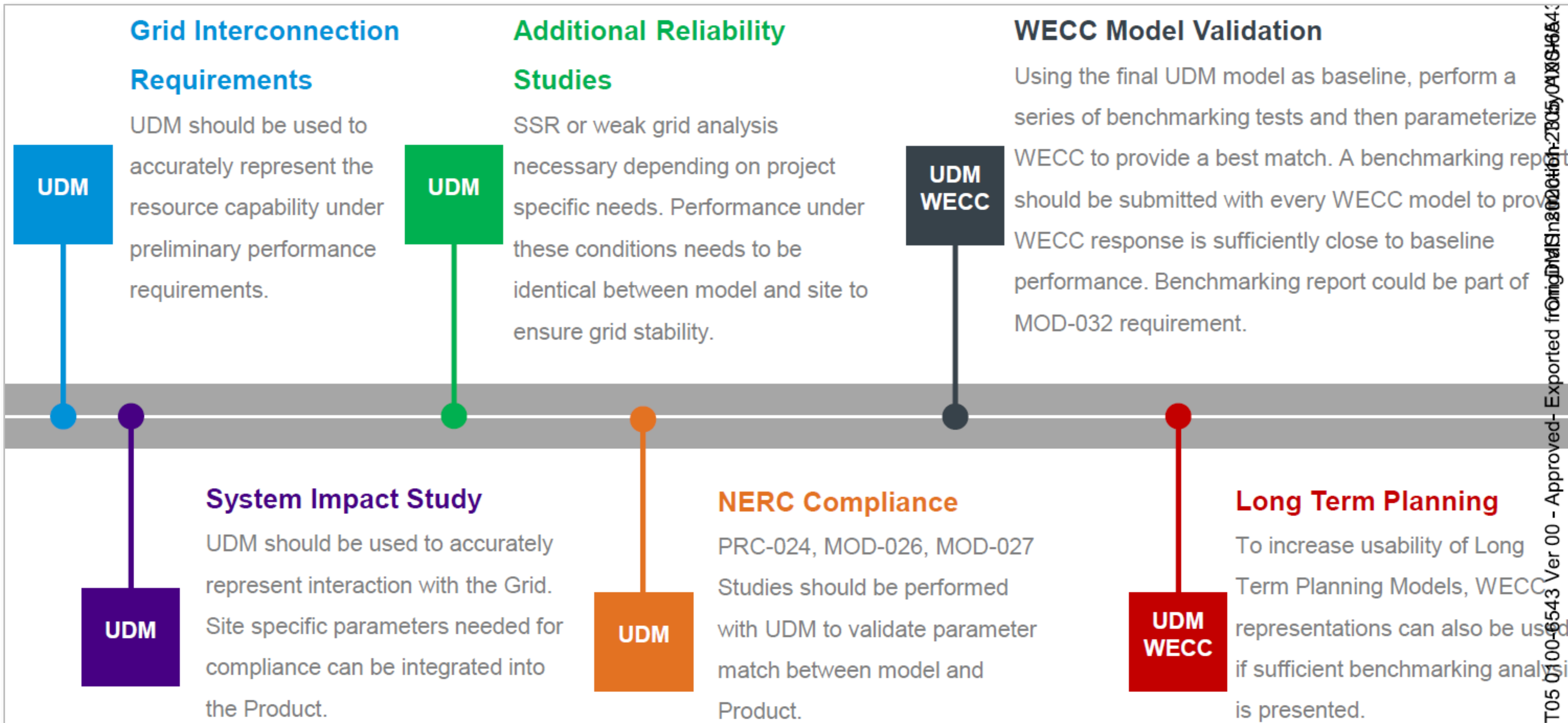
↓

MOD-026 and MOD-027 Verification
- Verification of actual plant performance and docs
- TP review of report and data submitted
- Latest expected performance from resource

↓

MOD-033 Verification
- TP/PC verification of wide-area performance
- Direction to GO to check model/settings

Modeling and Verification Process: Example by Vestas



Source: Vestas

“Material Modification”

NERC FAC-002-2 Consideration ≠ FERC LGIP/SGIP Consideration

NOT THE SAME INTENTION OR PURPOSE

- Any changes to electrical behavior of the facility need to be re-studied to ensure reliable operation of the BPS
  - Inverter make, model, software version, control settings
  - Plant-level controller made, model, software version, control settings
  - Changes to steady-state or dynamic controls
  - Changes in plant capacities or equipment capabilities

NERC Consideration for "Material Modification"

FAC-002-2: Facility Interconnection Studies

B. Requirements and Measures

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]*

1.1. The reliability impact of the new interconnection, or materially modified existing interconnection, on affected system(s);

1.2. Adherence to applicable NERC Reliability Standards; regional and Transmission Owner planning criteria; and Facility interconnection requirements;

1.3. Steady-state, short-circuit, and dynamics studies, as necessary, to evaluate system performance under both normal and contingency conditions; and

Guidelines and Technical Basis

Entities should have documentation to support the technical rationale for determining whether an existing interconnection was "materially modified." Recognizing that what constitutes a "material modification" will vary from entity to entity, the intent is for this determination to be based on engineering judgment.

FERC Definition of "Material Modification"

Material Modification shall mean those modifications that have a material impact on the cost or timing of any Interconnection Request with a later queue priority date.

Customer; and (c) a Permissible Technological Advancement for the Large Generating Facility after the submission of the Interconnection Request. Section 4.4.6 specifies a separate technological change procedure including the requisite information and process that will be followed to assess whether the Interconnection Customer's proposed technological advancement under Section 4.4.2(c) is a Material Modification. Section 1 contains a definition of Permissible Technological Advancement.

Permissible Technological Advancement [Transmission Provider inserts definition here].

NERC MOD-026-1 and MOD-027-1

A. Introduction

1. **Title:** Verification of Models and Data for Generator Excitation Control System or Plant Volt/Var Control Functions

2. **Number:** MOD-026-1

3. **Purpose:** To verify that the generator excitation control system or plant volt/var control function[1] model (including the power system stabilizer model and the impedance compensator model) and the model parameters used in dynamic simulations accurately represent the generator excitation control system or plant volt/var control function behavior when assessing Bulk Electric System (BES) reliability.

4. **Applicability:**

   4.1. Functional Entities:

   4.1.1 Generator Owner

   4.1.2 Transmission Planner

   4.2. Facilities:

   For the purpose of the requirements contained herein, Facilities that are directly connected to the Bulk Electric System (BES) will be collectively referred to as an "applicable unit" that meet the following:

   4.2.1 Generation in the Eastern or Quebec Interconnections with the following characteristics:

   4.2.1.1 Individual generating unit greater than 100 MVA (gross nameplate rating).

   4.2.1.2 Individual generating plant consisting of multiple generating units that are directly connected at a common BES bus with total generation greater than 100 MVA (gross aggregate nameplate rating).

   4.2.2 Generation in the Western Interconnection with the following characteristics:

   4.2.2.1 Individual generating unit greater than 75 MVA (gross nameplate rating).

   4.2.2.2 Individual generating plant consisting of multiple generating units that are directly connected at a common BES bus with total generation greater than 75 MVA (gross aggregate nameplate rating).

[1] Excitation control system or plant volt/var control function:

a. For individual synchronous machines, the generator excitation control system includes the generator, exciter, voltage regulator, impedance compensation and power system stabilizer.

b. For an aggregate generating plant, the volt/var control system includes the voltage regulator & reactive power control system controlling and coordinating plant voltage and associated reactive capable resources.

A. Introduction

1. **Title:** Verification of Models and Data for Turbine/Governor and Load Control or Active Power/Frequency Control Functions

2. **Number:** MOD-027-1

3. **Purpose:** To verify that the turbine/governor and load control or active power/frequency control[1] model and the model parameters, used in dynamic simulations that assess Bulk Electric System (BES) reliability, accurately represent generator unit real power response to system frequency variations.

4. **Applicability:**

   4.1. Functional entities

   4.1.1 Generator Owner

   4.1.2 Transmission Planner

   4.2. Facilities

   For the purpose of the requirements contained herein, Facilities that are directly connected to the Bulk Electric System (BES) will be collectively referred to as an "applicable unit" that meet the following:

   4.2.1 Generation in the Eastern or Quebec Interconnections with the following characteristics:

   4.2.1.1 Individual generating unit greater than 100 MVA (gross nameplate rating).

   4.2.1.2 Individual generating plant consisting of multiple generating units that are directly connected at a common BES bus with total generation greater than 100 MVA (gross aggregate nameplate rating).

   4.2.2 Generation in the Western Interconnection with the following characteristics:

   4.2.2.1 Individual generating unit greater than 75 MVA (gross nameplate rating).

   4.2.2.2 Individual generating plant consisting of multiple generating units that are directly connected at a common BES bus with total generation greater than 75 MVA (gross aggregate nameplate rating).

   4.2.3 Generation in the ERCOT Interconnection with the following characteristics:

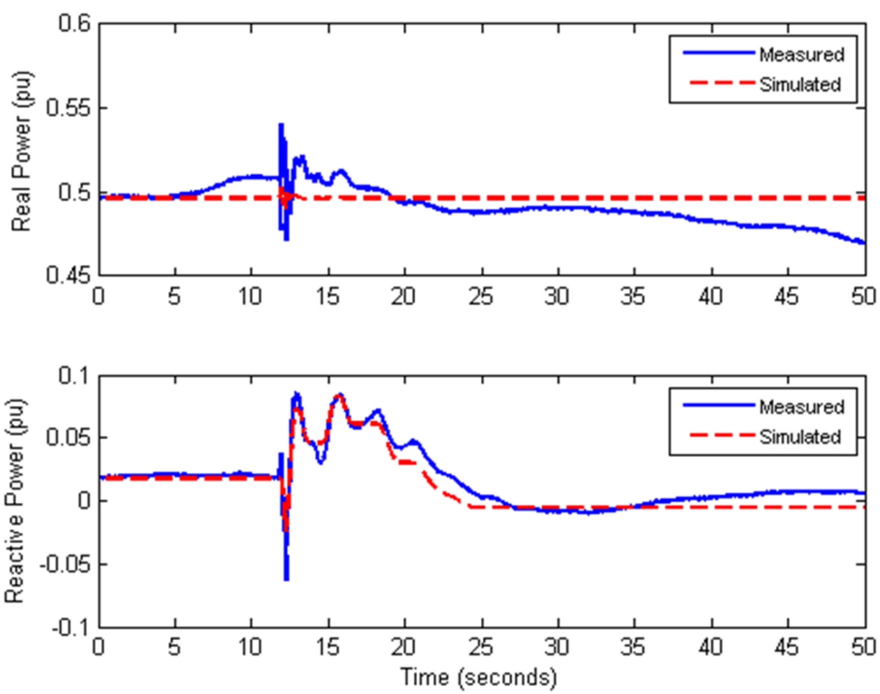
[1] Turbine/governor and load control or active power/frequency control:

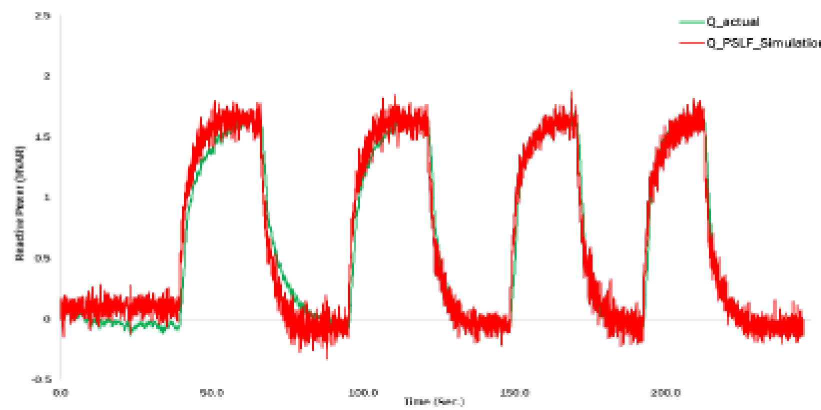
a. Turbine/governor and load control applies to conventional synchronous generation.

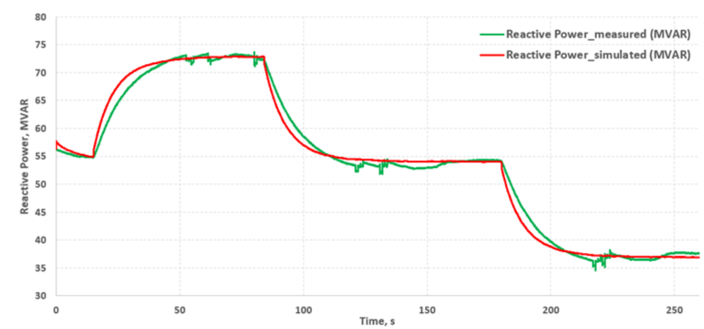
b. Active power/frequency control applies to inverter connected generators (often found at variable energy plants).

Small Disturbance Verification

- Captures response to small grid disturbances such as frequency excursions and small voltage swings
- Commonly used for verification testing
- Neglects large disturbance behavior (i.e., faults)

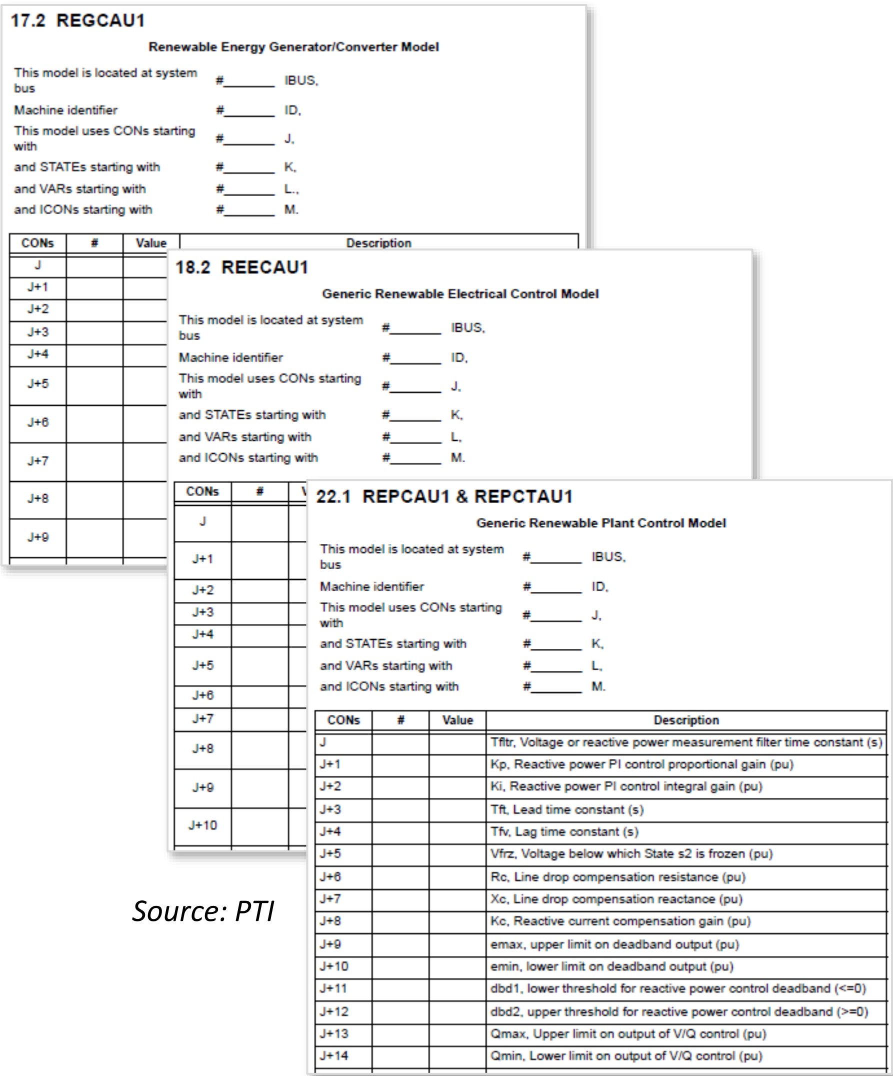






Sources: IEEE©2016, First Solar

Expectations for Verification Reports



17.2 REGCAU1

Renewable Energy Generator/Converter Model

This model is located at system bus	#_____	IBUS,
Machine identifier	#_____	ID,
This model uses CONs starting with	#_____	J,
and STATEs starting with	#_____	K,
and VARs starting with	#_____	L,
and ICONs starting with	#_____	M.

CONs	#	Value	Description
J			
J+1			
J+2			
J+3			
J+4			
J+5			
J+6			
J+7			
J+8			
J+9			

18.2 REECAU1

Generic Renewable Electrical Control Model

This model is located at system bus	#_____	IBUS,
Machine identifier	#_____	ID,
This model uses CONs starting with	#_____	J,
and STATEs starting with	#_____	K,
and VARs starting with	#_____	L,
and ICONs starting with	#_____	M.

CONs	#	V
J		
J+1		
J+2		
J+3		
J+4		
J+5		
J+6		
J+7		
J+8		
J+9		
J+10		

22.1 REPCAU1 & REPCTAU1

Generic Renewable Plant Control Model

This model is located at system bus	#_____	IBUS,
Machine identifier	#_____	ID,
This model uses CONs starting with	#_____	J,
and STATEs starting with	#_____	K,
and VARs starting with	#_____	L,
and ICONs starting with	#_____	M.

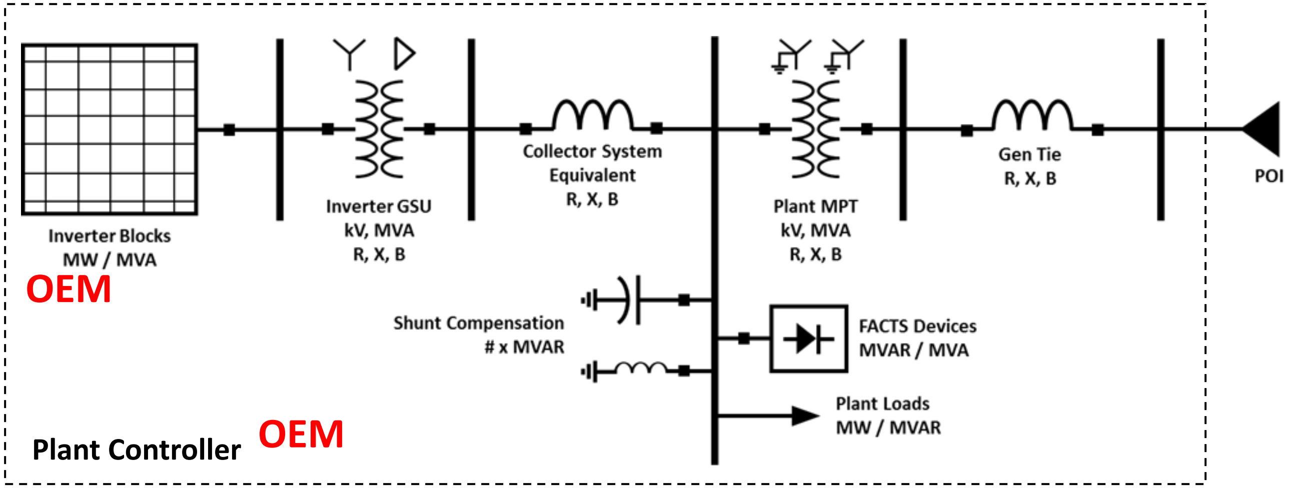
CONs	#	Value	Description
J			Tfltr, Voltage or reactive power measurement filter time constant (s)
J+1			Kp, Reactive power PI control proportional gain (pu)
J+2			Ki, Reactive power PI control integral gain (pu)
J+3			Tft, Lead time constant (s)
J+4			Tfv, Lag time constant (s)
J+5			Vfrz, Voltage below which State s2 is frozen (pu)
J+6			Rc, Line drop compensation resistance (pu)
J+7			Xc, Line drop compensation reactance (pu)
J+8			Kc, Reactive current compensation gain (pu)
J+9			emax, upper limit on deadband output (pu)
J+10			emin, lower limit on deadband output (pu)
J+11			dbd1, lower threshold for reactive power control deadband (<=0)
J+12			dbd2, upper threshold for reactive power control deadband (>=0)
J+13			Qmax, Upper limit on output of V/Q control (pu)
J+14			Qmin, Lower limit on output of V/Q control (pu)

Source: PTI

- Thorough explanations:
  - Models selected and why
  - Model data sheets (or model) with values entered
  - Validation of **EVERY** parameter
    - Commissioning, verification, or factory test reports
    - Communication with manufacturer
    - Engineering judgement
  - Small disturbance expectations
  - Large disturbance expectations
  - Model limitations and capabilities

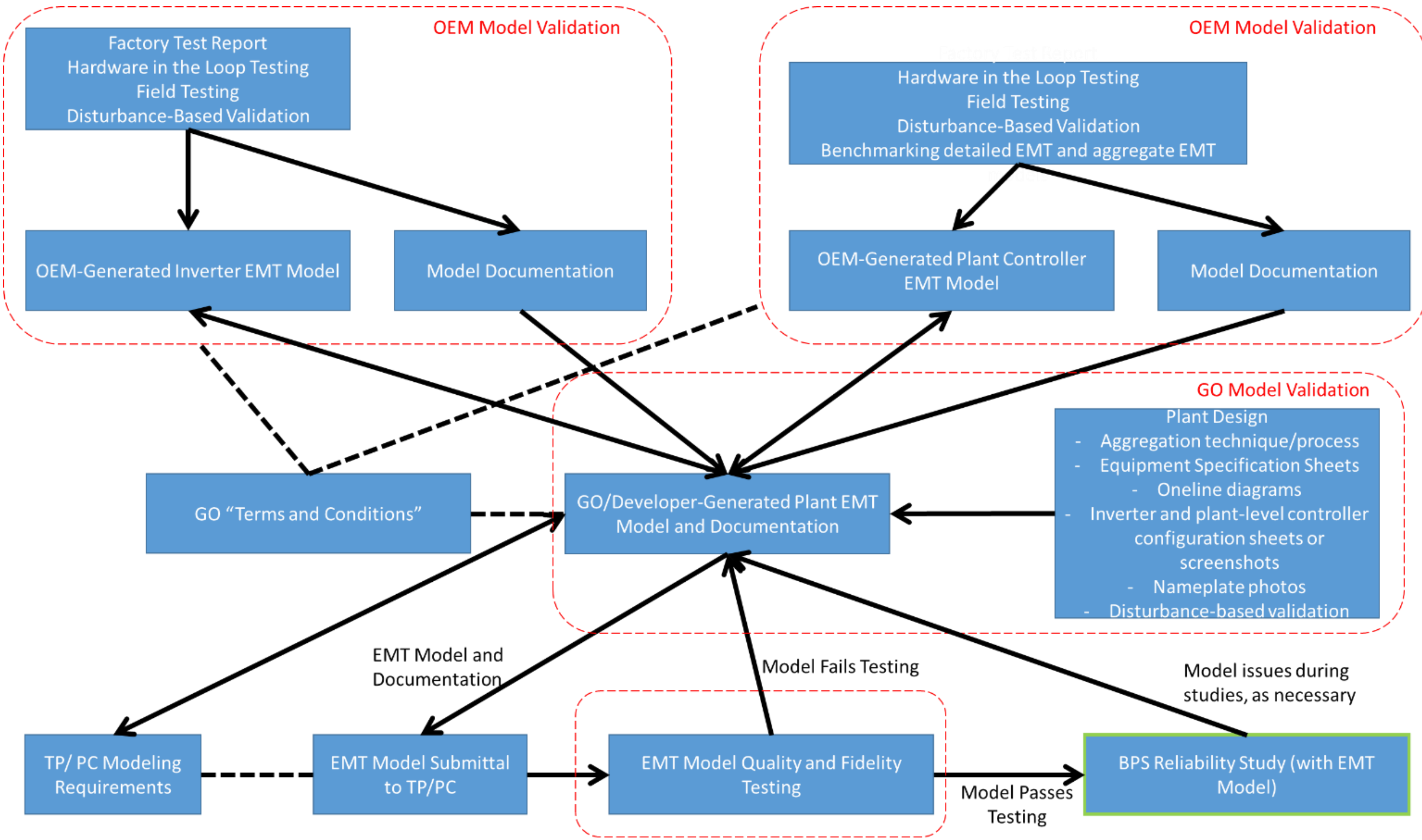
Models Used in Studies

Source: SMA

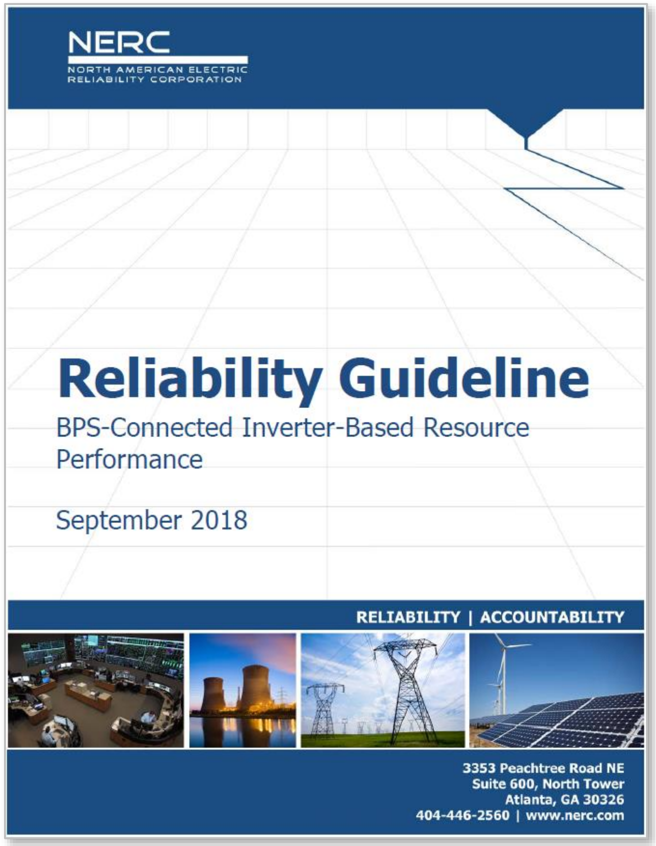


Transmission Planning Studies

Brainstormed Validation Process



NERC Reliability Guidelines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Reliability Guideline

BPS-Connected Inverter-Based Resource Performance

September 2018

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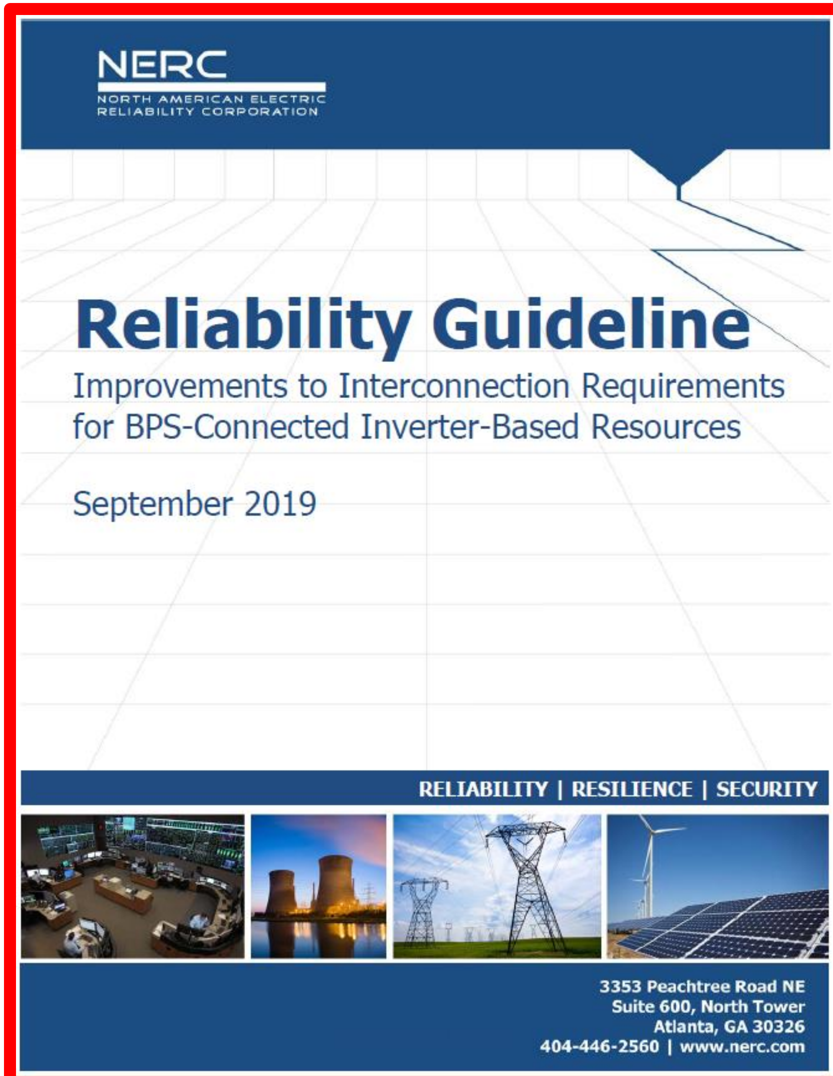
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Reliability Guideline

Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources

September 2019

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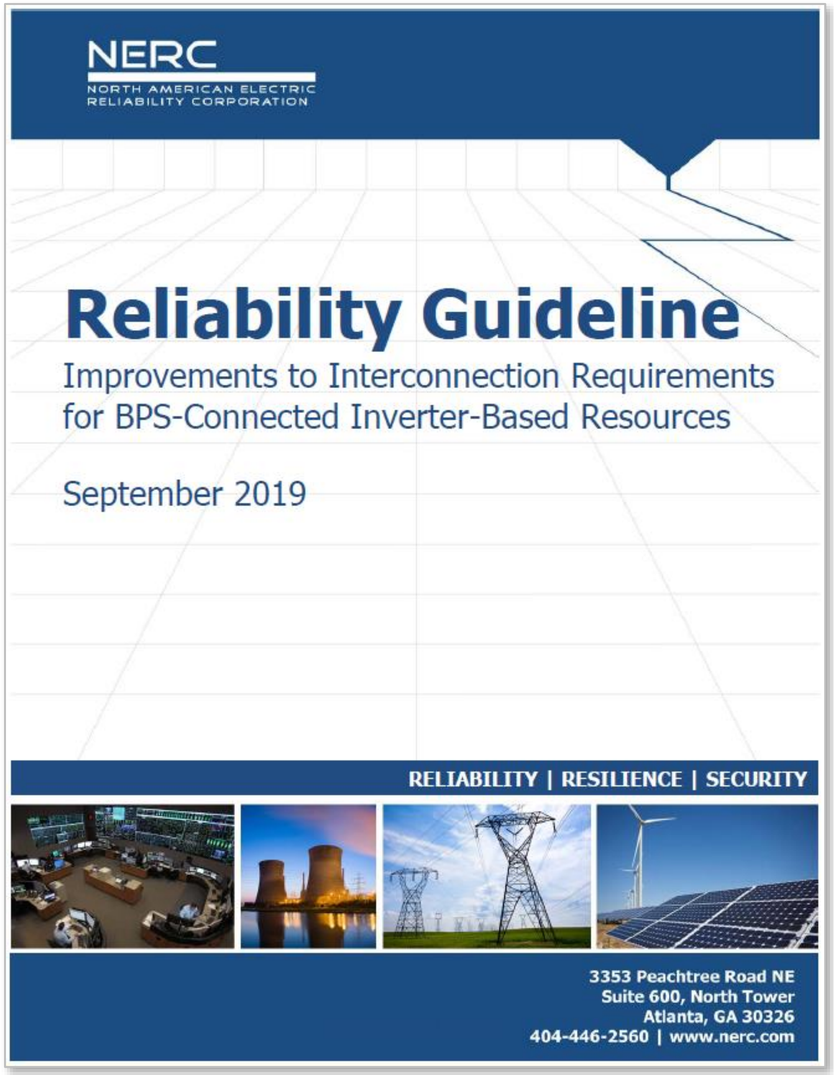
Improvements to Interconnection Requirements for BPS-Connected IBR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Reliability Guideline

Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources

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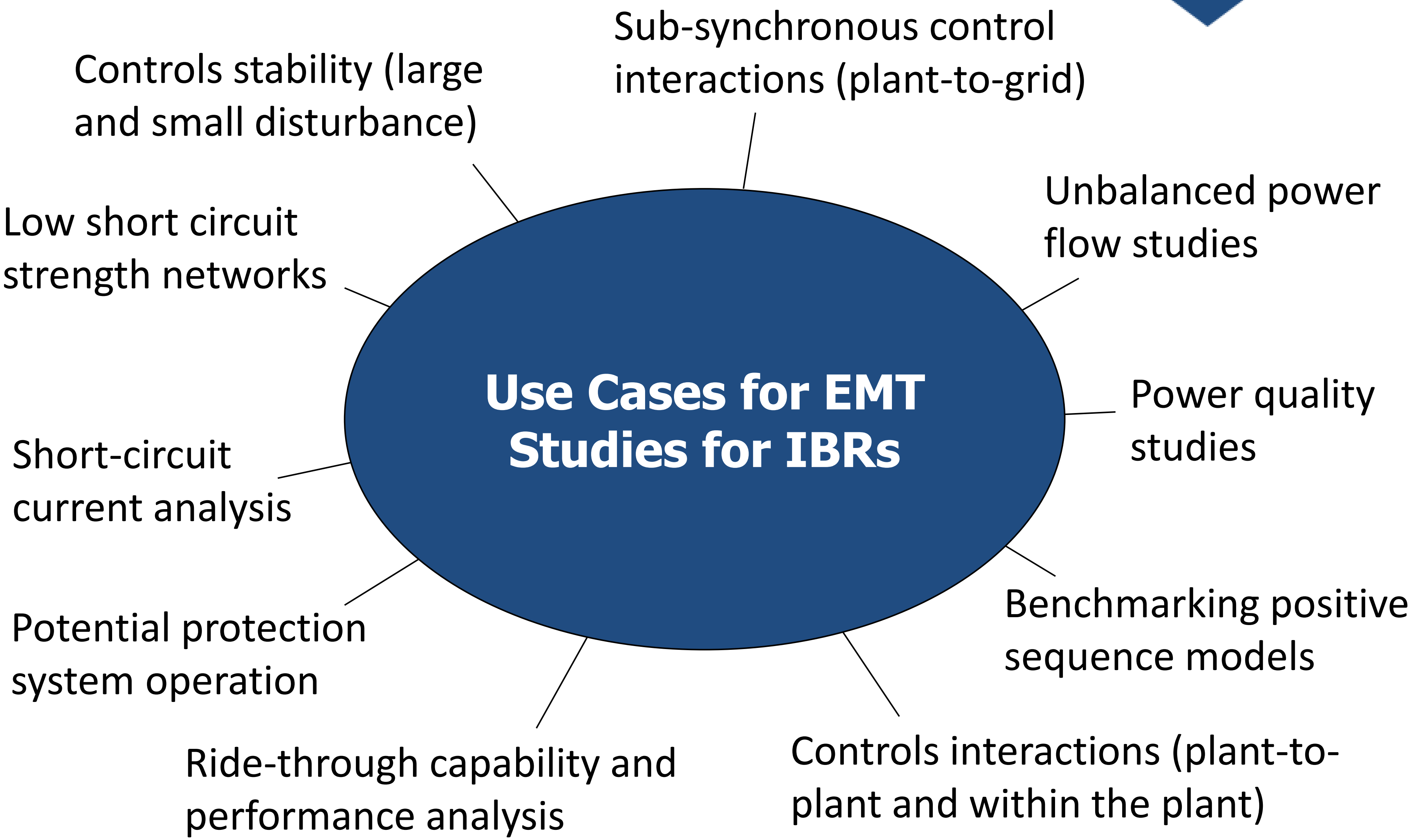
NOTICE:

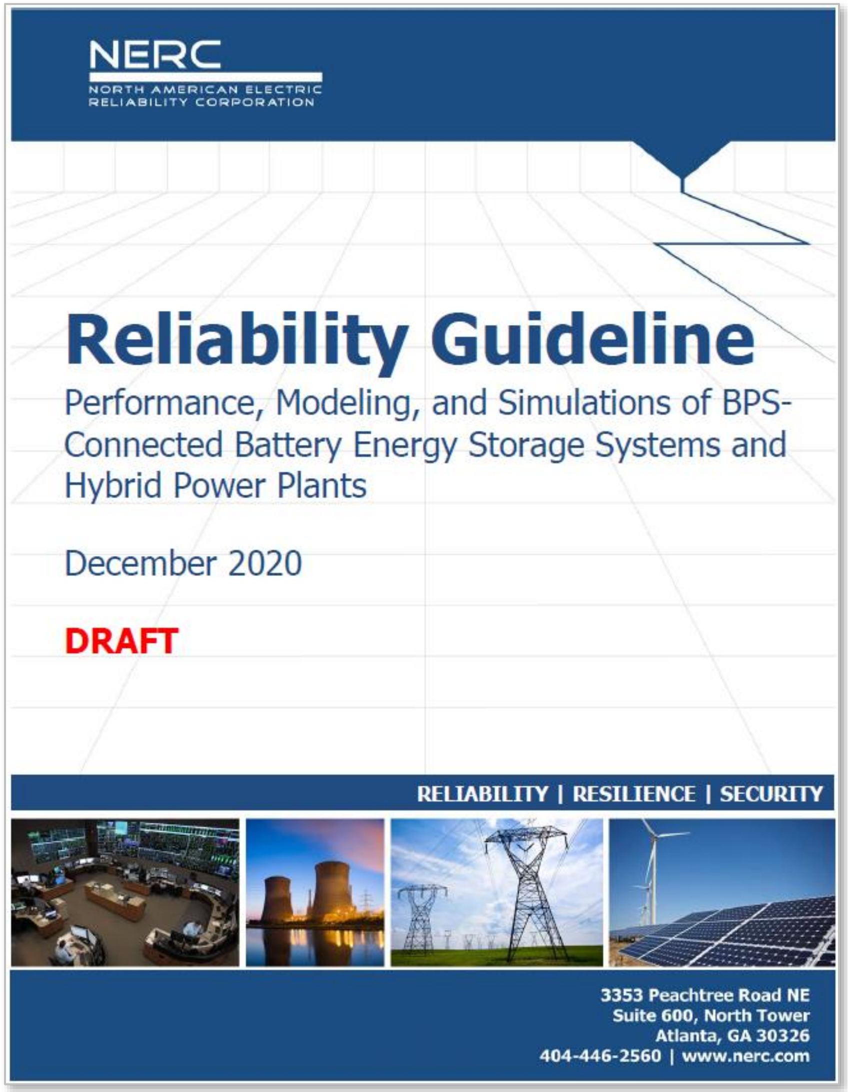
ACTIONABLE RECOMMENDATIONS CONTAINED WITHIN!

- Strong recommendations to improve interconnection requirements AND interconnection study processes
- All TOs/TPs/PCs should be considering this guideline and adopting its recommendations, as applicable

Possible Studies using EMT Models



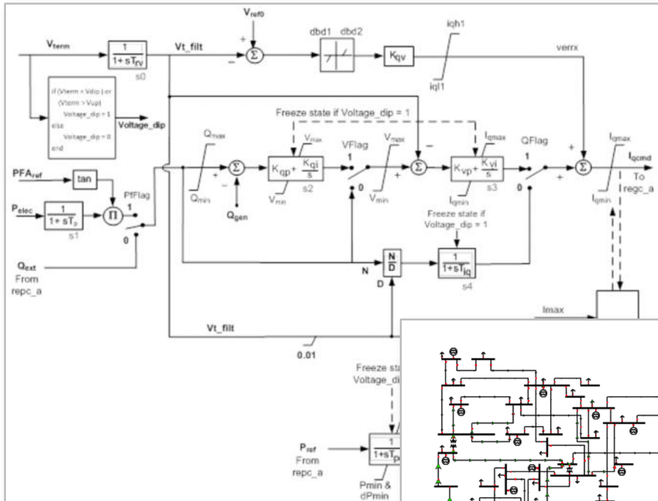
Reliability Guideline on BESSs and Hybrid Plants



- **Performance:** How should BESSs and hybrid plants behave when connected to the BPS?
- **Modeling:** What are the recommended modeling techniques for capturing the characteristics of BESS and hybrid plant technology?
- **Studies:** What types of studies should be conducted to ensure reliable operation of the BPS with BESSs and hybrid plants?

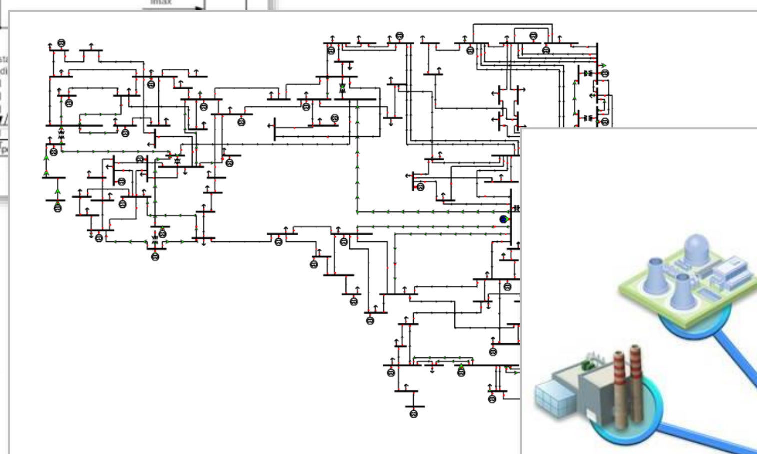
Accurate Models are ESSENTIAL

Modeling



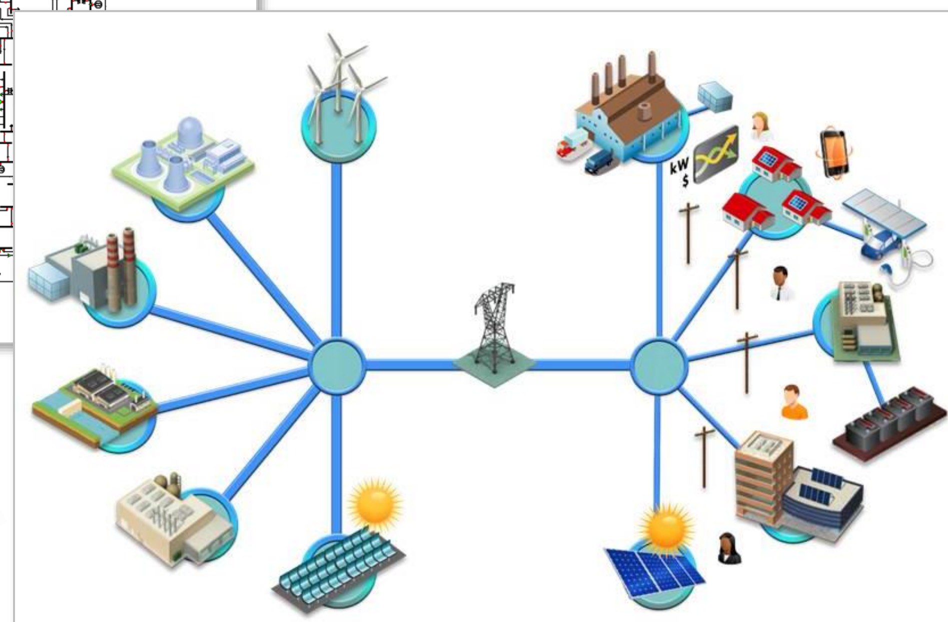
Source: GE

Studies



Source: IEEE

Reliability Decisions



Source: BPA

Get Engaged with NERC Activities

- Reliability Guidelines (here)
- NERC Inverter-Based Resource Performance Task Force (here)
- Guideline: Recommended Performance for BPS-Connected IBRs (here)
- Guideline: Improvements to Interconnection Requirements (here)
- Blue Cut Fire Disturbance Report (here)
- Canyon 2 Fire Disturbance Report (here)
- Palmdale Roost and Angeles Forest Disturbance Report (here)
- San Fernando Disturbance Report (here)
- NERC Alert: Loss of Solar Resources I (here)
- NERC Alert: Loss of Solar Resources II (here)
- NERC-WECC Modeling Report (here)
- IRPTF Modeling and Studies Report (here)
- Summary of ERO Activities for IBR (here)
- IEEE P2800 (here)

Questions and Answers

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