IEEE 1547 DER Interconnection Standard and Bulk Power System Considerations

For ESIG Spring Technical Workshop's

Tutorial: Impact of DER on Bulk System

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Disclaimer and Acknowledgment

- *This presentation on IEEE 1547-2018 represents the author's views and are not the formal position, explanation or position of the IEEE, the IEEE Standards Association, or PNNL.*
- *This slide deck has been peer-reviewed by IEEE Standard Coordination Committee 21 (SCC21) and IEEE P1547 Officers.*
- *The presenter acknowledges the contribution of the IEEE 1547-2018 Working Group, Balloters and Officers*

1547 Tutorial Module Outline

1) **IEEE 1547 Introduction**, a high level overview of IEEE 1547

2) **IEEE 1547-2018 Revision Overview,** focusing on new requirements w/ BPS implications
   - General Requirements
   - Reactive Power (VAR) Capacity and Voltage Regulation Modes
   - Abnormal Condition Response

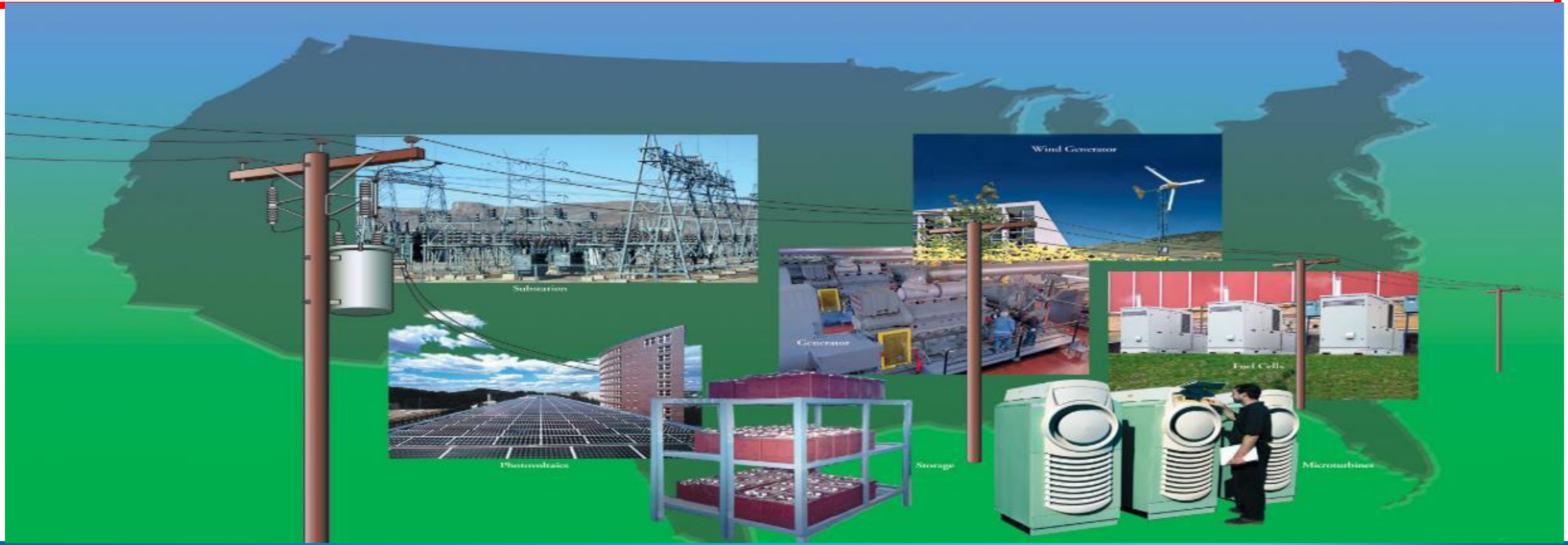
3) **NERC BPS Event Example**
   - Blue Cut Fire Event
   - NERC Inverter Based Resource Performance Guide

Backup Slides:

Example of Mitigating a DER penetration impact
   - FERC Order 842 Compliance
   - FRR BESS with Inertia Replacement/Active Damping

Importance of IEEE 1547

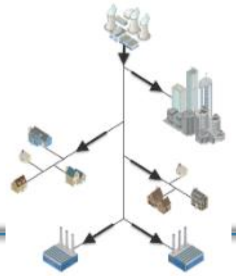
- Energy Policy Act (2005) Cites and requires consideration of IEEE 1547 Standards and Best Practices for Interconnection; all states use or cite 1547.
- Energy Independence and Security Act (2007) IEEE cited as a standards development organization partner to NIST as Lead to coordinate framework and roadmap for Smart Grid Interoperability standards and protocols {IEEE 1547 & 2030 series being expanded};
- Federal ARRA (2009) Smart Grid & High Penetration DER projects {*use IEEE stds*}.



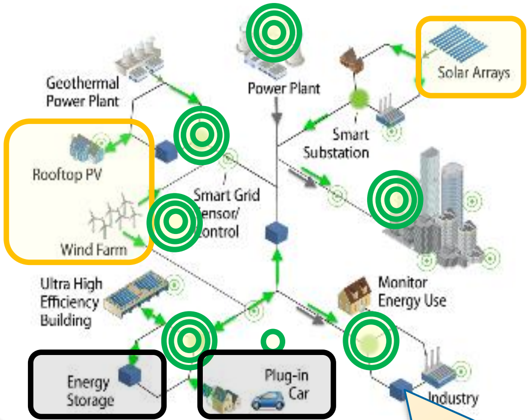
Evolution of the Grid

- Large generation systems
- Central control
- Highly regulated

Current Power System



Future Power Systems



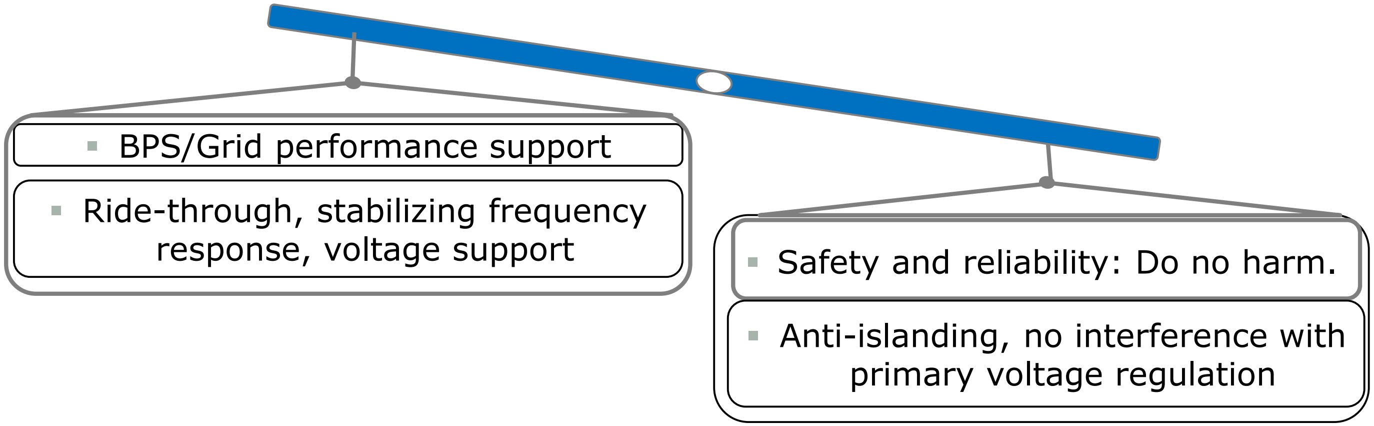
DRIVERS
- Increased variable generation
- More bi-directional flow at distribution level
- Increased number of smart/active devices

New Challenges

- New energy technologies and services
- Penetration of variable renewables in grid
- New communications and controls (e.g., Smart Grids)
- Electrification of transportation
- Integration of distributed energy storage
- Regulatory advances

Balancing Distribution Needs with BPS Considerations

Increasing DER penetration was a major driver for revising IEEE 1547-2003



Example Adoption of IEEE Std 1547-2018

ISO New England

- Coordination between ISO-NE and the MA’s utilities in the Massachusetts Technical Standards Review Group
- Reference to UL 1741 SA as a stopgap to verify DER ride-through capability in the interim
- Harmonization of voltage & frequency trip settings with IEEE Std 1547-2018 ranges of allowable settings

PJM Interconnection

- Two ad-hoc stakeholder workshops in 2018 for DER ride-through categories and trip settings (PJM website)
- Initiation of formal stakeholder proceedings in 2019
- Aiming at full adoption of IEEE Std 1547-2018 for jurisdictional DER by early 2020

Minnesota Public Utilities Commission

- Phase 1 (2017): Interconnection Process, Applications, Agreements
- Phase 2 (2018): Technical Requirements consistent with IEEE Std 1547-2018 (MN PUC website)
- Coordination with regional reliability coordinator, e.g., MISO

IEEE 1547-2018 Scope and Purpose

Title: *Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*

Scope: *This standard establishes criteria and requirements for interconnection of distributed energy resources (DER) with electric power systems (EPS), and associated interfaces.*

***Purpose**: This document provides a uniform standard for the interconnection and interoperability of distributed energy resources (DER) with electric power systems (EPS). It provides requirements relevant to the interconnection and interoperability performance, operation, and testing, and, safety, maintenance and security considerations.*

Changes from IEEE 1547-2003 shown in red

IEEE 1547-2018 Document Outline (Clauses)

1. Introduction
2. Overview
3. Normative references, definitions and acronyms
4. ***General specifications and requirements***
5. ***Reactive power, voltage/power control***
6. ***Response to Area EPS abnormal conditions***
7. Power quality
8. Islanding
9. Distribution secondary grid and spot networks
10. Interoperability
11. Test and verification

Focus for this tutorial

1547-2018 General Specifications & Requirements

Clause 4

1.4 General remarks and limitations

- Applicable to all DERs connected at typical primary or secondary distribution voltage levels.
  - Removed the 10 MVA limit from previous versions.
  - BUT: Not applicable for transmission or networked sub-transmission connected resources.
- Specifies performance and not design of DER.
- Specifies capabilities and functions and not the use of these.
- Does not address planning, designing, operating, or maintaining the Area EPS with DER.
- Emergency and standby DER are exempt from certain requirements of this standard.
  - E.g., voltage and frequency ride-through, interoperability and communications.
- Gives precedence to synchronous generator (SG) standards for DER with SG units rated 10 MVA and greater.
  - E.g., IEEE Std C50.12, IEEE Std C50.13.

Cease to Energize performance requirement

In the ***cease to energize*** state, the DER shall not deliver active power during steady-state or transient conditions.

- **Aggregate DER rating < 500 kVA:** *reactive power exchange shall be less than 10%* of nameplate DER rating and shall exclusively result from passive devices.

- **Aggregate DER rating ≥ 500 kVA:** the *reactive power exchange shall be less than 3%* of nameplate DER rating and shall exclusively result from passive devices..

Enter Service criteria

- Prior to *Enter Service* or *Return to Service* after a trip, power system's voltage must be within specified voltage magnitude and frequency range continuously for a defined period
- *Permit Service* flag must be set to *Enabled*
- Power system voltage and frequency limits, and DER delay period are all adjustable within a defined range
- The DER must be capable of ramping up its power either continuously or in small steps (<20%) after entering service
  - Exception: Smaller DER installations (<500 kVA) can alternatively return to service in one step after a randomized additional delay

Reactive power, voltage/power control

Clause 5

Categories of DER grid support – DER’s VAR capacity and voltage regulation capabilities

Category A

- Meets minimum performance capabilities needed for Area EPS voltage regulation
- Reasonably attainable by all state-of-the-art DER technologies
- Reactive power capability: 0.25 p.u. lagging, 0.44 p.u. leading

Category B

- Meets all requirements in Category A plus…
- Supplemental capabilities for high DER penetration, where the DER power output is subject to frequent large variations.
- Attainable by most smart inverters
- Reactive power capability: 0.44 p.u. lagging, 0.44 p.u. leading

Category assignment specified by Area EPS Operator

Active voltage regulation capability requirements

DER must possess <u>capability</u> – <u>implementation</u> is at the discretion of area EPS Operator (mode and parameters)

Capability required of all DER – (Cat A, B)

Constant power factor mode

Constant reactive power mode (“reactive power priority”)

Voltage-reactive power mode (“volt-var”)

“State-of the art” DER – Cat B

Active power-reactive power mode (“watt-var”)

Voltage-active power mode (“volt-watt”)

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Response to abnormal conditions

Clause 6

Performance Categories – Abnormal Operating Conditions

Ride Through Capabilities

Category I

- Essential bulk power system needs
- Attainable by all state-of-the-art DER technologies.

Category II

- Supports bulk power system reliability requirements, e.g. ride through
- Coordinated with existing reliability standards to avoid tripping for a wider range of disturbances (more robust than Category I)

Category III

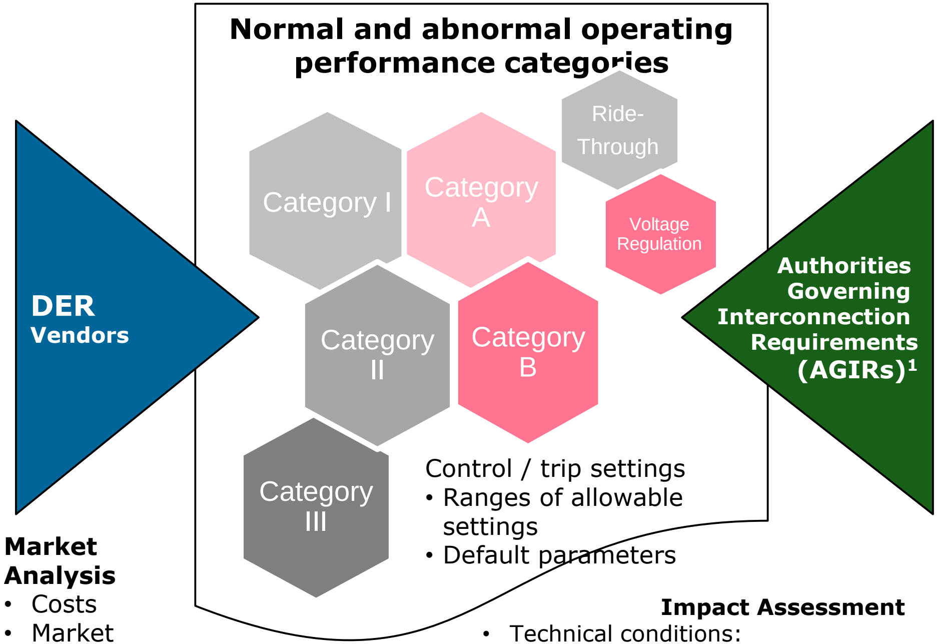
- Designed for bulk system needs, and distribution system reliability/power quality needs
- Coordinated with existing standards for very high DER levels

Categories for DER response to abnormal EPS conditions

Category	Objective	Foundation
I	Essential bulk system needs and reasonably achievable by all current state-of-art DER technologies	German grid code for synchronous generator DER
II	Full coordination with bulk power system needs	Based on NERC PRC-024, adjusted for distribution voltage differences (delayed voltage recovery)
III	Ride-through designed for distribution support as well as bulk system	Based on California Rule 21 and Hawaii Rule 14H

Category II and III are sufficient for bulk system reliability.

Assignment of new IEEE 1547-2018 Performance Categories



Market Analysis
- Costs
- Market segment
- Etc.

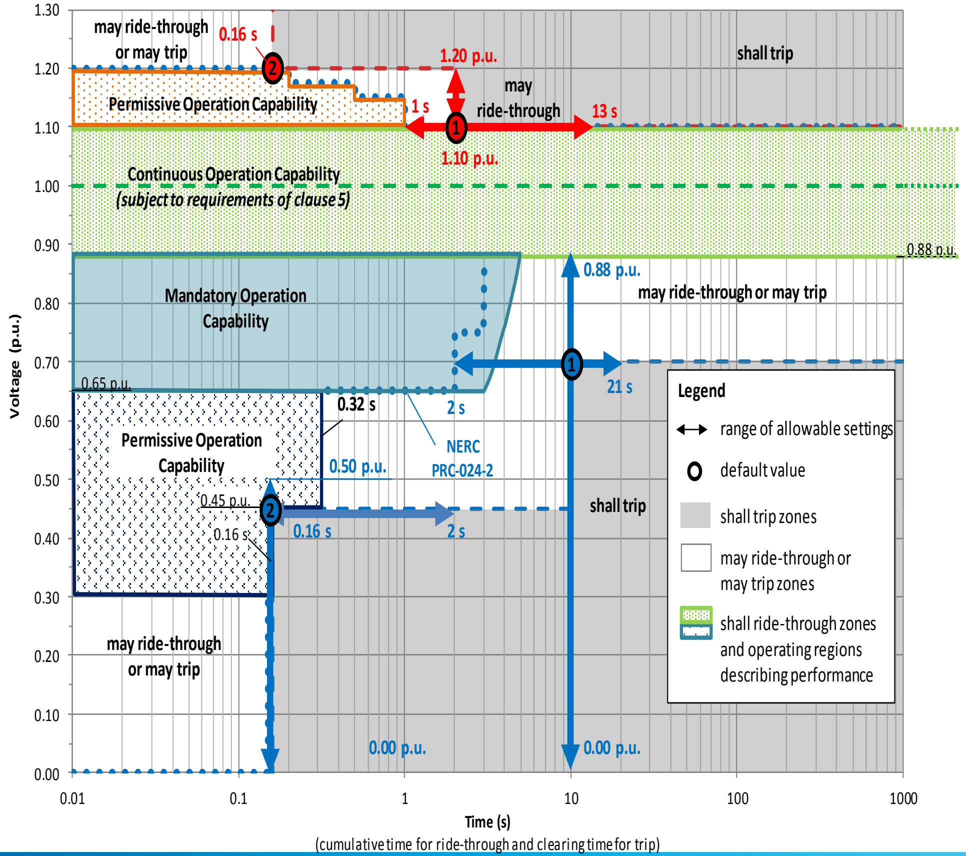
Impact Assessment
- Technical conditions:
  - Type, capacity, & future penetration of DERs
    - Type of grid configuration, etc.
- Non-technical issues: DER use case, impacts on environment, emissions, and sustainability, etc.

Stakeholder Engagement
- Distribution utilities
- Bulk system operators & planners
- DER developers
- Others

[1] State Regulator, Area EPS or bulk system operator, etc.

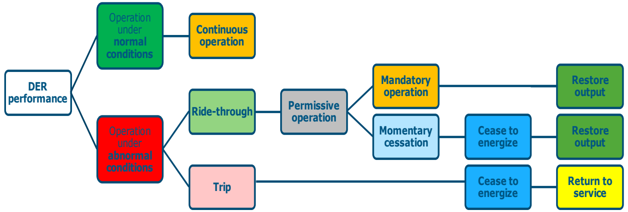
- **Category III ~ Greatest ride-through capabilities**
- **Category B ~ Greatest voltage support capabilities (most inverter-based DERs)**

IEEE Std 1547-2018 Abnormal Performance Category II



- **Mandatory operation:**
  - Continuance of active current and reactive current exchange
- **Momentary cessation**:
  - Temporarily cease to energize the utility's distribution system
  - Capability of immediately restoring output of operation
- **Permissive operation**:
  - Either mandatory operation or momentary cessation.

Frequency trip and ride-through

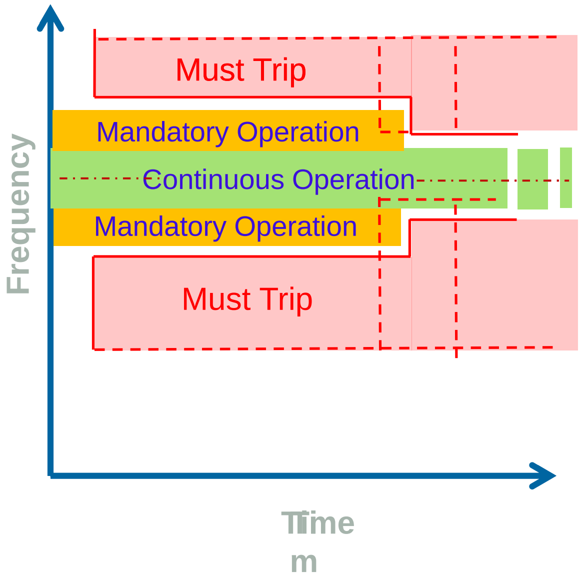


- Frequency is an interconnection-wide parameter
- Underfrequency tripping needs to be coordinated with UFLS
- IEEE 1547-2018 allows wide range of must-trip settings to accommodate small, isolated grids
  - OF: 61.8 – 66.0 Hz
  - UF: 50.0 – 57.0 Hz

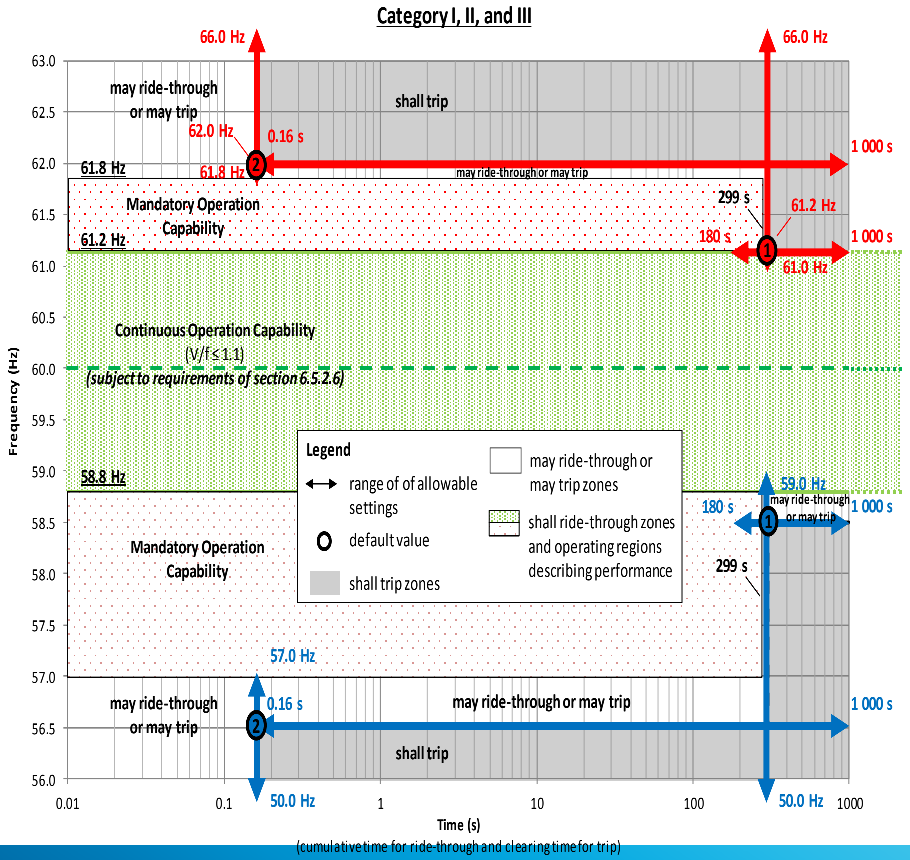
  Short duration 0.16 – 1.0 s

  - OF: 61.0 – 66.0 Hz
  - UF: 50.0 – 59.0 Hz

  Long duration 180 – 1000 s

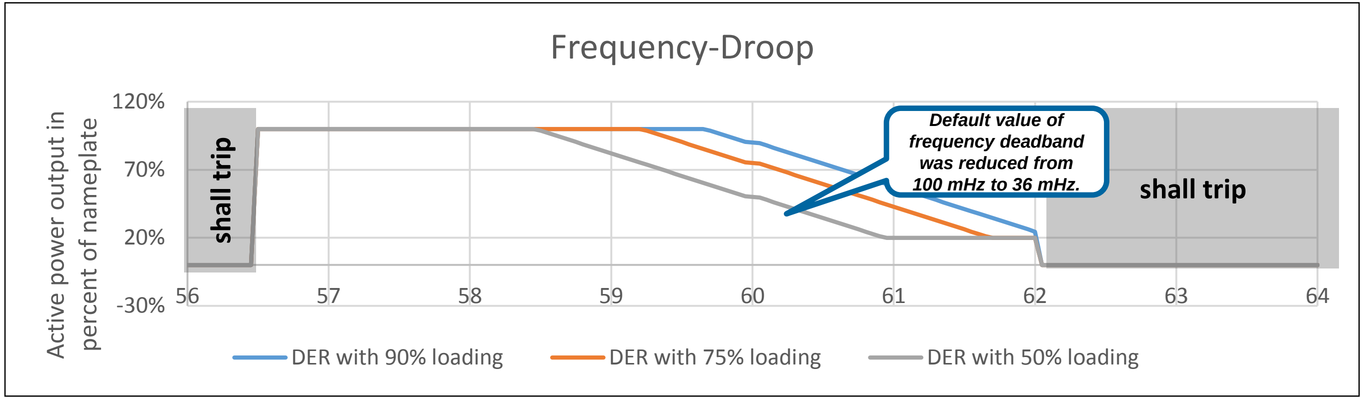


IEEE Std 1547-2018 Frequency Ride-Through and Trip



- **Continuous operation:**
  - Exchange of current between the DER and EPS within prescribed behavior while connected to the Area EPS and
  - while the *applicable voltage* and the system frequency is within specified parameters.
- **Mandatory operation:**
  - Continuance of active current and reactive current exchange

Frequency Support



- Overfrequency: all DERs required to provide droop response
- Underfrequency: Cat II and III DERs required to provide droop response *if power is available*
- Only a functional capability requirement
  - Utilization remains outside the scope of IEEE 1547-2018
- Adjustable dead bands and droop
- Response time requirements (not “as fast as technically possible”)

BPS Event Example, NERC Information

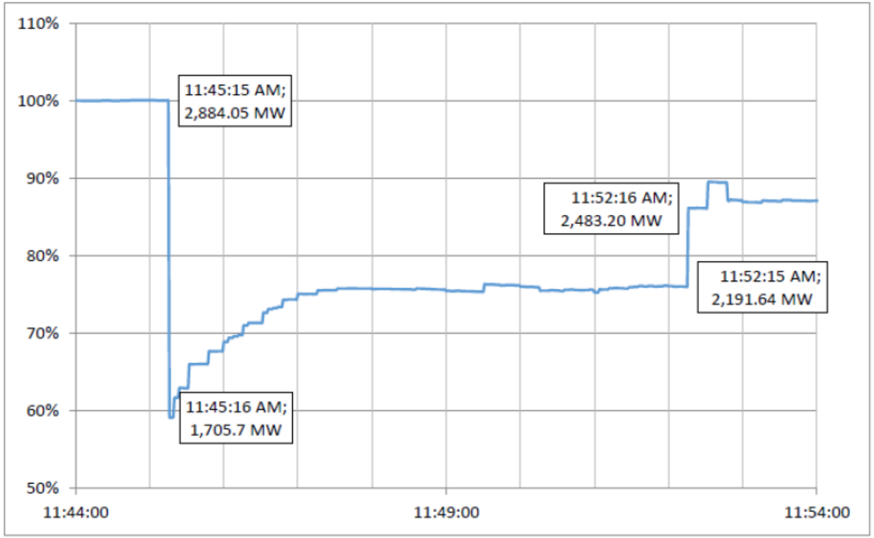
August 16, 2016 Blue Cut Fire Disturbance

NERC content used with permission.

http://www.nerc.com/pa/rrm/ea/Pages/1200-MW-Fault-Induced-Solar-Photovoltaic-Resource-Interruption-Disturbance-Report.aspx

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Solar Resource Loss



- 26 utility-scale (most at 500 kV and 230 kV) solar developments
- 10 different inverter manufacturers

RELIABILITY | ACCOUNTABILITY

Source, NERC

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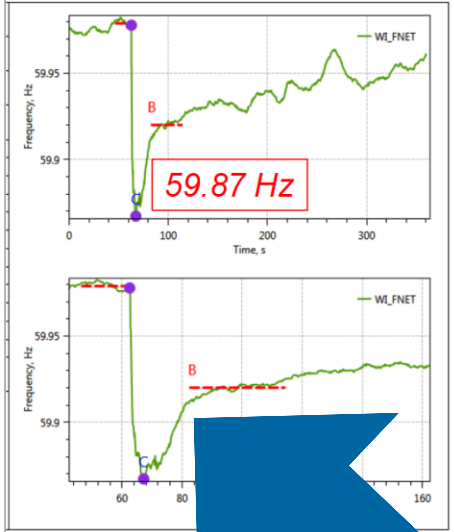
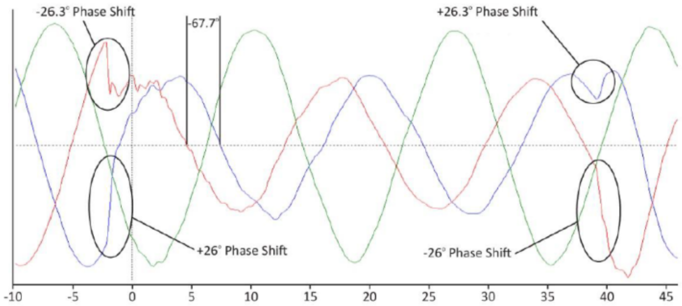
Key Finding #1

- Largest solar PV loss (~700 MW) due to underfrequency tripping
  - Inverter sensed near instantaneous frequency of < 57 Hz and tripped

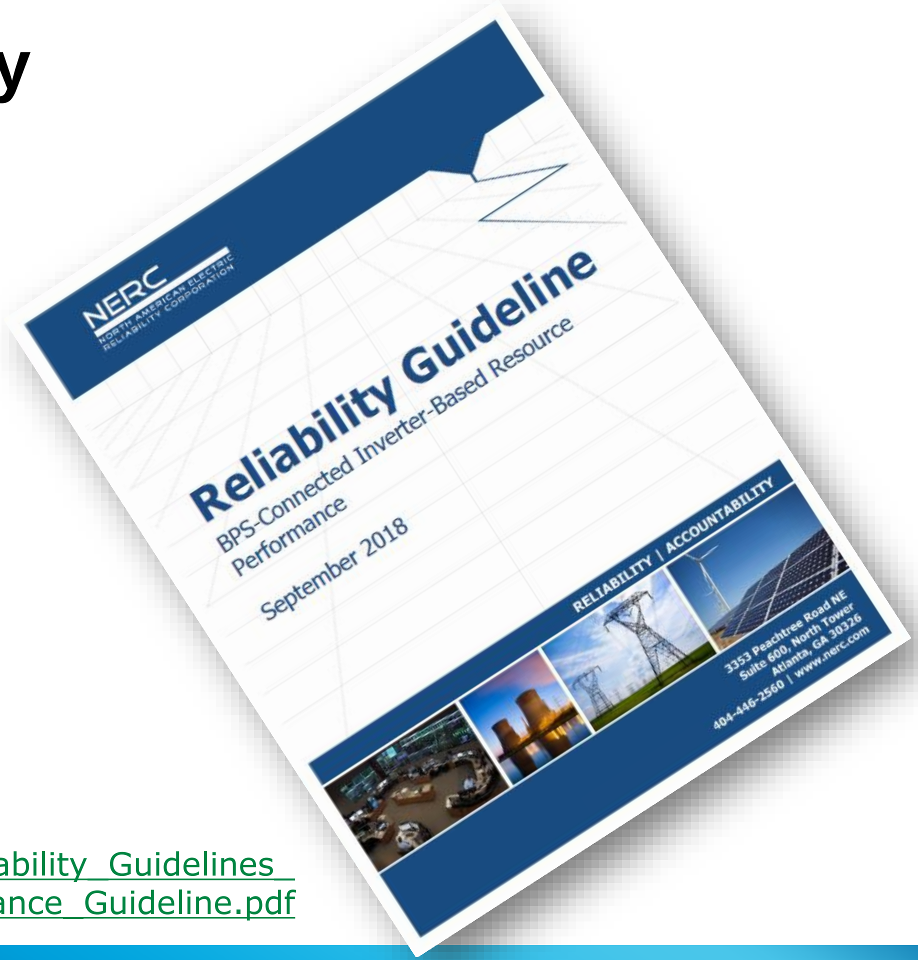




RELIABILITY | ACCOUNTABILITY

CV comment: FERC Order 842-Compliant BESS would speed up system frequency recovery. See backup slides.

NERC Reliability Guideline



Source, NERC

https://www.nerc.com/comm/OC_Reliability_Guidelines_DL/Inverter-Based_Resource_Performance_Guideline.pdf

NERC Reliability Guideline, Reference to IEEE 1547

Applicability of Guideline

This guideline focuses on inverter-based resources directly connected to the BPS. While NERC Reliability Standards only apply to BES resources, this guideline is also relevant to smaller inverter-based resources that are still connected to the BPS. This includes resources connected to the transmission and sub-transmission system voltage levels that do not meet the BES inclusion criteria (e.g., also including resources less than 75 MVA). The guideline does not cover resources connected to the distribution system (distributed energy resources (DERs)), and instead recommends the use of the new IEEE Std. 1547-2018 for these resources.

Source, NERC

Thank You

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Backup Slides

Pacific Northwest
NATIONAL LABORATORY

BPS Loss of Inertia: Early Solution Based on BESS

Successfully demo'd BESS power (MW) modulated proportionally relative to power system frequency deviations, to improve frequency oscillation damping.

FERC Order 842 Compliance, AND, Inertia Replacement

SCE procured an ESPSS system from GE and installed it on the Chino BESS in December, 1994. SCE developed specifications for special filtering bandwidth that would allow the ESPSS to respond to frequency deviations in the range of 0.3-0.7 Hz. Based on these specifications GE modified their existing PSS system to meet our needs. SCE conducted field tests and monitoring the effective performance of the ESPSS in regulating the power output of the batteries to provide damping to the 0.3 and 0.7 Hz power system oscillation modes.

Source, Southern California Edison

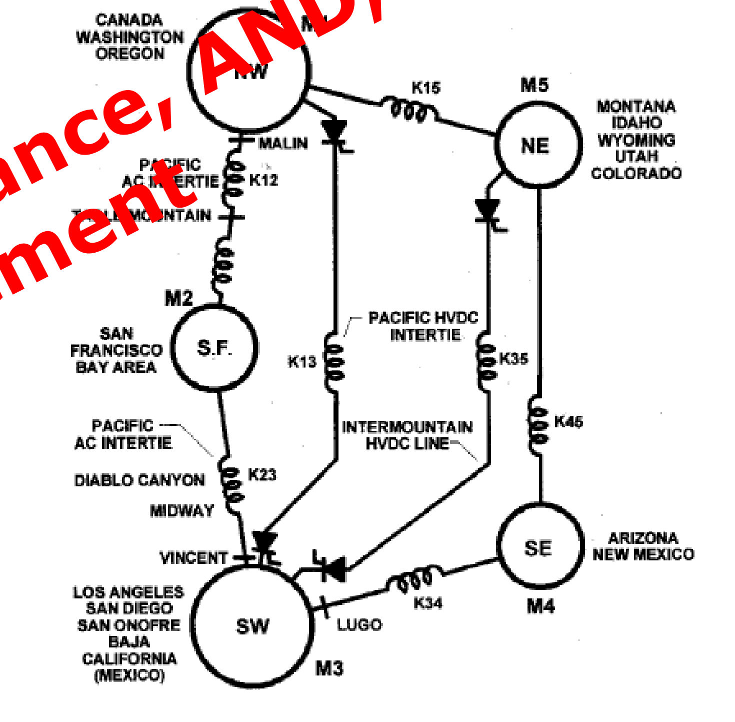
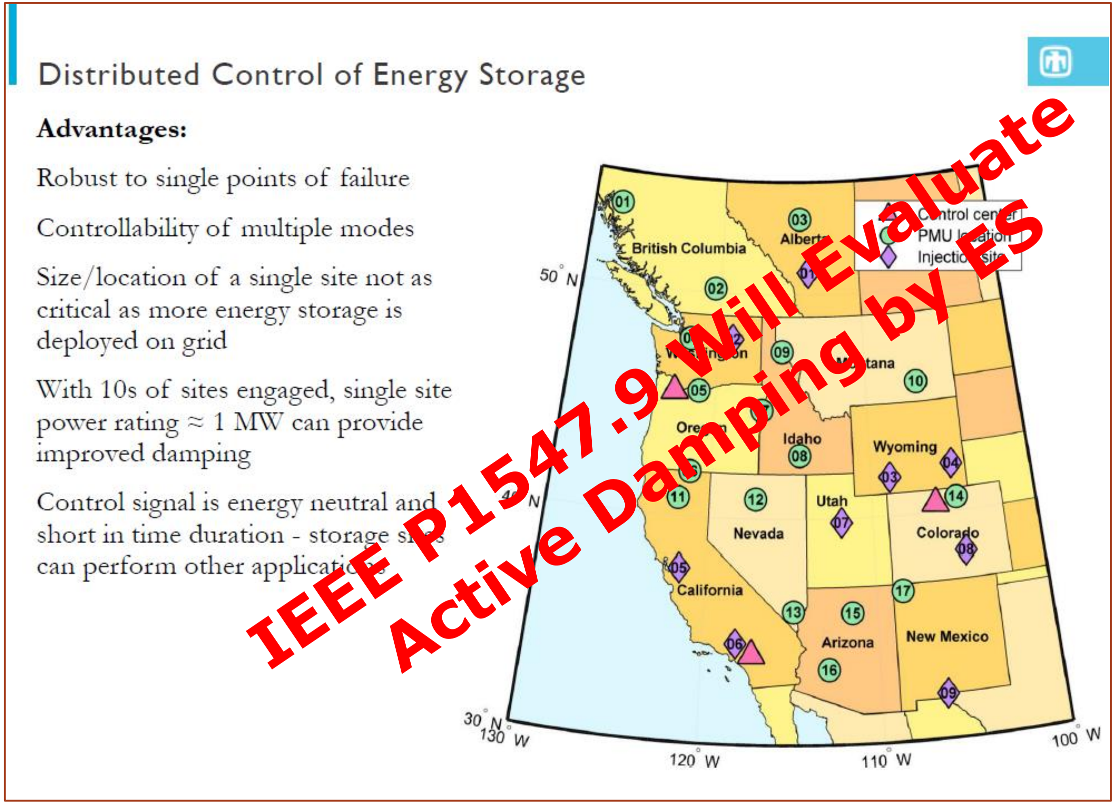


Figure 3. Equivalent Mass - Spring representation of the WSCC system.

BPS Loss of Inertia: Next Generation Solution Based on ESS (continued)



Source, R. Byrne, Sandia National Laboratory

Chino worked technically, but, key industry advances since the ’80’s include:

1) High resolution monitoring & control via synchrophasor tech

2) Superior performing and more cost effective battery and inverter tech

3) Policy advancements that open access for ES, and allow compensation for delivery of multiple ES-based services

References and Further Information

IEEE Standards Coordination Committee 21 (SCC21)

http://sites.ieee.org/sagroups-scc21/standards/1547rev/

Selected IEEE PES Power & Energy articles on DER with BPS consideration aspects

https://ieeexplore.ieee.org/document/8495051

https://ieeexplore.ieee.org/document/8070523

NERC's Blue Cut Fire Disturbance Report

http://www.nerc.com/pa/rrm/ea/Pages/1200-MW-Fault-Induced-Solar-Photovoltaic-Resource-Interruption-Disturbance-Report.aspx

NERC's Reliability Guideline BPS-Connected Inverter-Based Resource Performance

https://www.nerc.com/comm/OC_Reliability_Guidelines_DL/Inverter-Based_Resource_Performance_Guideline.pdf

NERC's April-May 2018 Disturbance Report, including DER response information

https://www.nerc.com/pa/rrm/ea/April_May_2018_Fault_Induced_Solar_PV_Resource_Int/April_May_2018_Solar_PV_Disturbance_Report.pdf

Sandia paper on inter-area oscillation damping with BESS,

https://www.sandia.gov/ess-ssl/docs/other/PES_Damping_Control.pdf