# TUT-04 Introduction: Revised IEEE 1547 Standard for Interconnecting Distributed Energy Resources with Electric Power Systems

Dave Narang, IEEE 1547 Chair

IEEE T&D, April 16, 2018

# Disclaimer & Acknowledgements

- *This presentation on IEEE P1547 are the author's views and are not the formal position, explanation or position of the IEEE or NREL.*



- *Many thanks to P1547 Officers, Working Group members, and balloters who contributed their time and efforts to develop this standard.*

- *Thanks also to the U.S. Department of Energy, Solar Energy Technologies Office for supporting the author's participation.*

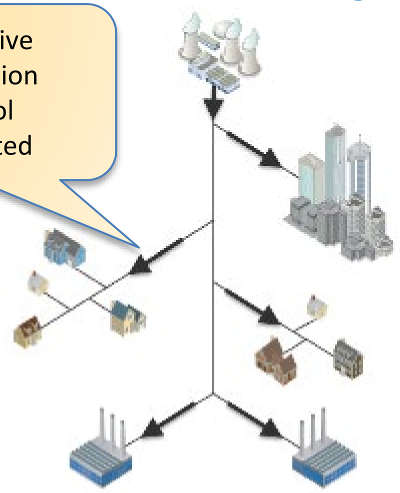
# IEEE STD 1547 TUTORIAL OUTLINE

1) **Welcome,** Babak Enayati, National Grid (10 minutes for both Welcome & Intro)
2) **1547-2018 Introduction**, Charlie Vartanian, MEPPI, for David Narang, NREL.
   Charlie will provide a high level overview of IEEE 1547, i.e. drivers, scope, applicability, and ongoing activities
3) **1547-2018 VAR Capability and Voltage Regulation**, Babak Enayati, National Grid. (30 minutes)
   Babak will present voltage regulation grid support functionality that can be provided by DER.
4) **1547-2018 Power Quality**, Babak Enayati, National Grid. (30 minutes)
   Babak will present the Power Quality impact-limitations, that have been expanded in 1547-2018
5) **1547-2018 Voltage and Frequency Ride Through**, Andy Hoke, NREL, for Jens Boemer, EPRI. (30 min's)
   Andy will present ride through capability, and other requirements related to abnormal grid conditions, and DER
6) **1547-2018 Islanding and Energy Storage**, Leo Casey, GoogleX. (30 minutes)
   Leo will present on islanding, and energy storage DER
7) **1547-2018, Interoperability**, Mark Siira, Comrent, for Bob Fox, Sunspec. (30 minutes)
   Mark will talk about information exchange between the DER and the Area Electric Power System (EPS)
8) **1547-2018, Testing Requirements,** Mark Siira, Comrent. (30 minutes)
   Mark will present the required tests that DER have to pass in order to be considered IEEE 1547 compliant
9) **IEEE P1547.1 DER Interconnection Test Procedures, Revision,** Andy Hoke, NREL. (30 minutes)
   Andy will present a status update on the IEEE 1547.1, the standard for testing the requirements set by IEEE 1547. (20 minutes)
10) **Q&A & Wrap Up,** Babak Enayati, National Grid

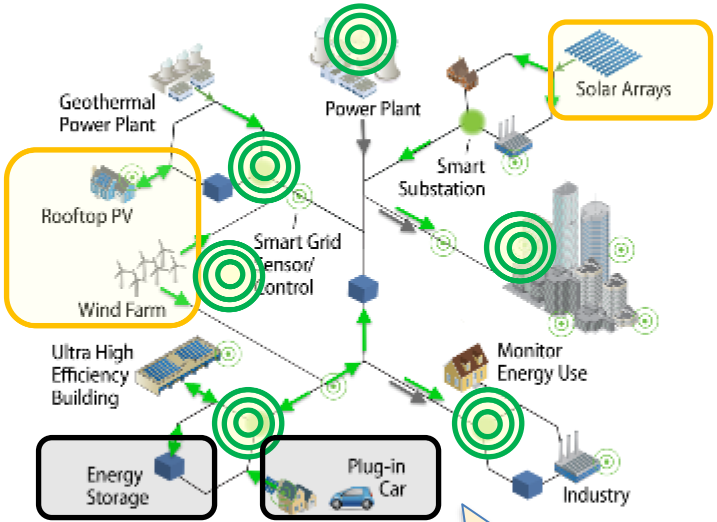
# Evolution of the Grid

## Current Power System

- Carbon Intensive
- Large Generation
- Central Control
- Highly Regulated



## Future Power Systems




**DRIVERS**

- Increased variable gen
- More bi-directional flow at distribution level
- Increased number of smart/active devices
- Evolving institutional environment

## New Challenges in a Modern Grid

- New energy technologies and services
- Increasing penetration of variable renewables in grid
- New communications and controls (e.g. Smart Grids)
- Electrification of transportation
- Integrating distributed energy storage
- A modern grid needs increased system flexibility
- updated standards – e.g. IEEE 1547-2018 (DER as grid assets)

*Slide courtesy of Dr. Ben Kroposki, NREL*

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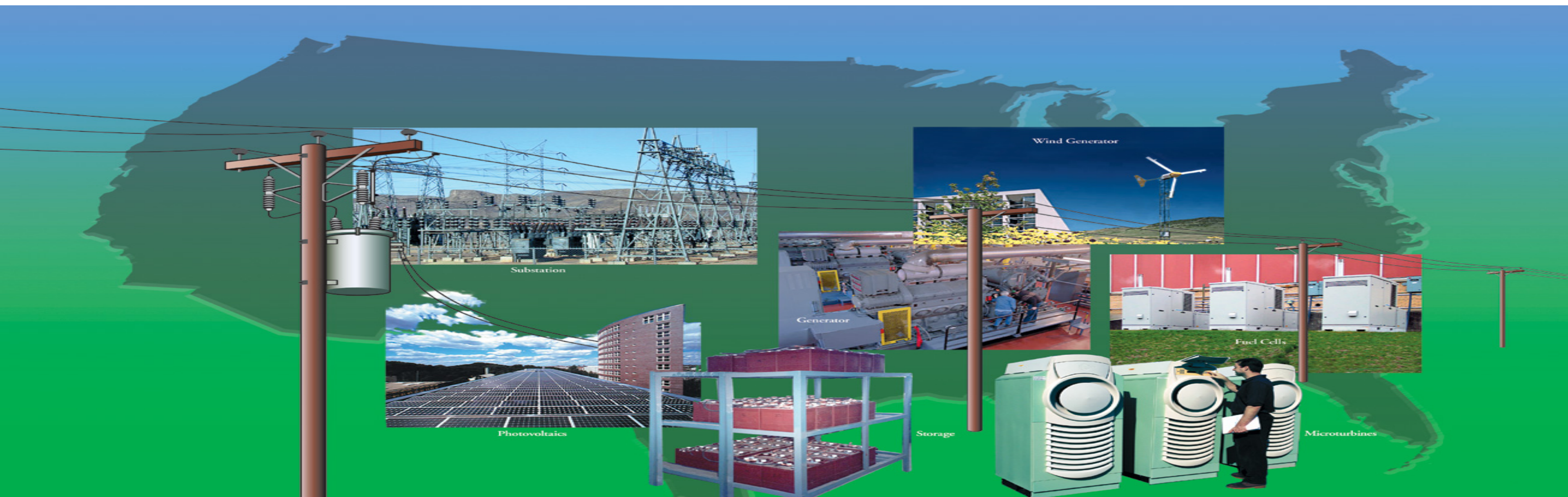
# Importance of IEEE 1547

- 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*}.



# IEEE 1547 Uses

**IEEE 1547 is:**

- A technical standard—functional requirements for the interconnection itself and interconnection testing
- A single (whole) document of mandatory, uniform, universal, requirements that apply at the point of common coupling (PCC) or point of DER connection (PoC)
- Technology neutral—i.e., it does not specify particular equipment or type
- Should be sufficient for most installations

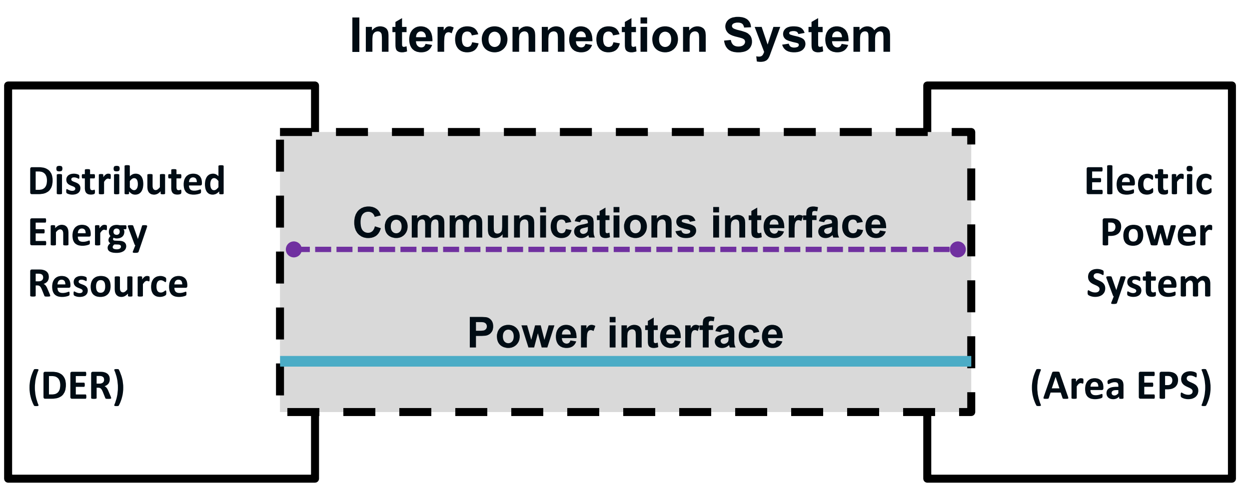
**IEEE 1547 is not:**

- A design handbook
- An application guide (see IEEE 1547.2)
- An interconnection agreement
- Prescriptive—i.e., it does not prescribe other important functions and requirements such as cyber-physical security, planning, designing, operating, or maintaining the area EPS with DER

# IEEE 1547 Scope and Purpose, P1547 Revision

***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.*

*Interconnection system: The collection of all interconnection equipment and functions, taken as a group, used to interconnect DERs to an area EPS. Note: In addition to the power interface, DERs should have a communications interface.*

*Interface: A logical interconnection from one entity to another that supports one or more data flows implemented with one or more data links.*

*Image based on IEEE 1547-2018*

# New Expectations → New Requirements

reactive power support

ride-through

AGIR

LVRT

interoperability

volt-var

ROCOF

performance categories

area EPS faults

momentary cessation

communications protocols

power quality

constant power factor

composite

synchronization

Intentional islanding

# Grid Planning and Operation Challenges

*Increasing DER penetration was a major driver for revising IEEE 1547*

- Grid performance support
- Ride-through, stabilizing frequency response, voltage support

- Safety and reliability: Do no harm.
- Anti-islanding, no interference with primary voltage regulation

# IEEE 1547 Interconnection Example Use in United States

## IEEE 1547

**Interconnection System and Test Requirements**

- Voltage Regulation
- Ride-through
- Interoperability
- Islanding
- ….

## IEEE 1547.1

**Conformance Test Procedures**

- Utility interactive tests
- Islanding
- Reconnection
- O/U Voltage and Frequency
- Synchronization
- DC injection
- ….

## UL 1741

**Interconnection Equipment Safety, Performance Certification**

- 1547.1 Tests
- Protection against risks of injury to persons
- Specific tests for various technologies
- ..

## NFPA70 (NEC)

**Installation Code**

- Article 690 PV Systems
- Article 705: interconnection systems (shall be suitable per intended use per UL1741)

(NEC info. Based on NEC 2011)

**Local interconnection processes and procedures**

# Major 1547 Revision Achievements

- Consensus standard – 120+ industry experts in Working Group, 4-year effort
- Robust public balloting – 389-member public ballot pool, 1500+ comments resolved
- 93% Approval (75% required)

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- More coordinated operation under normal conditions
- Maintain grid safety
- Grid support under abnormal conditions
- New guidance for interoperability & open communications
- New guidance for intentional islands
- Strikes a balance between needs for large and small installations.

# IEEE 1547 Document Outline (Clauses)

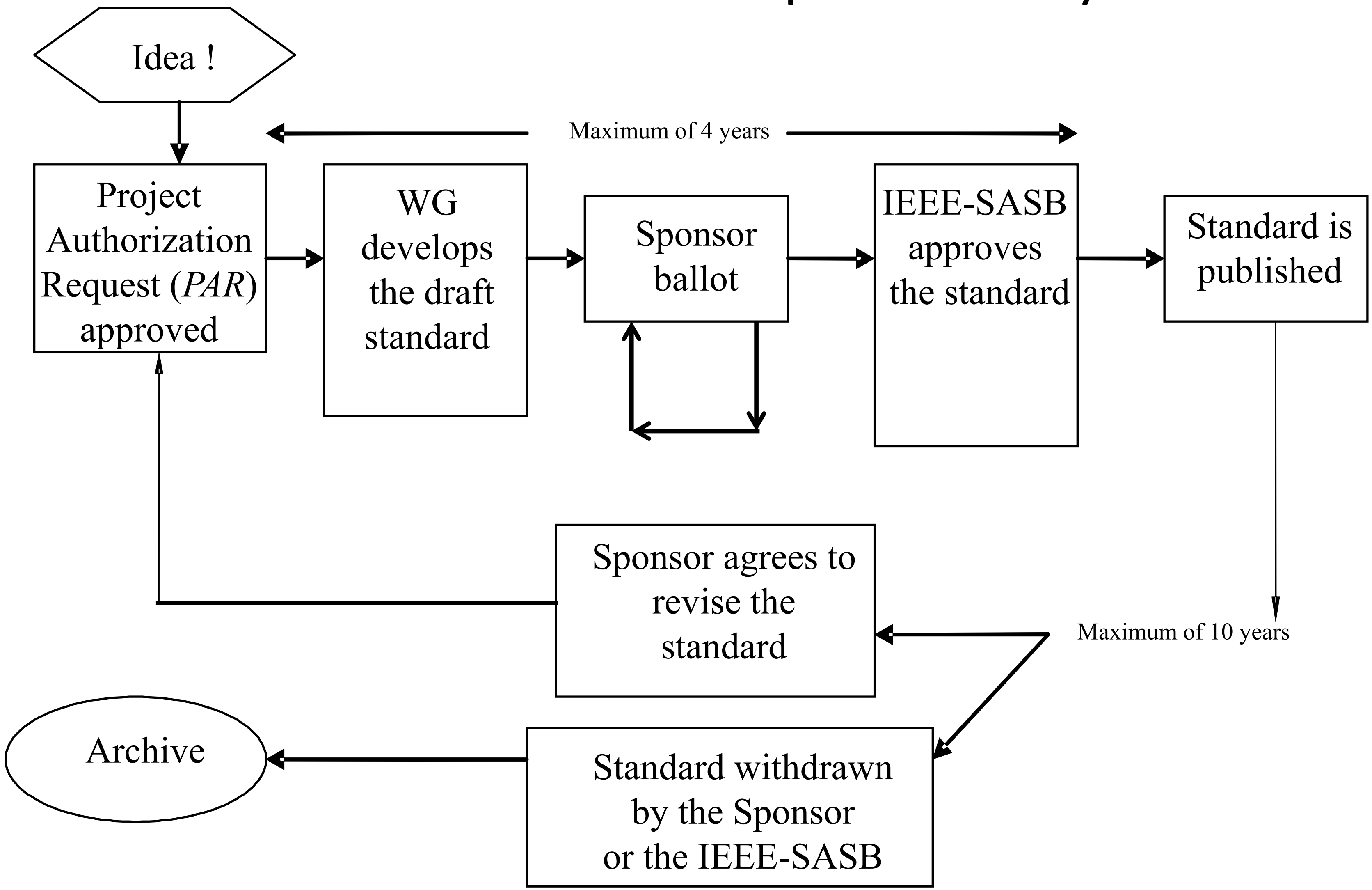
1. Overview
2. Normative references
3. Definitions and acronyms
4. General specifications and requirements
5. *[normal grid]* Reactive power, voltage/power control
6. Response to Area EPS abnormal conditions
7. Power quality
8. Islanding
9. Distribution secondary grid and spot networks
10. Interoperability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

12. Seven new annexes (Informative)

# 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 utilization 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) design standards for DER with SG units rated 10 MVA and greater.
  - E.g., IEEE Std C50.12, IEEE Std C50.13.

# IEEE Standards Development Lifecycle




**Standards Process Overview:** http://standards.ieee.org/develop/overview.html

# Your Input and Participation is Needed

- P1547.1 Test Procedures, Revision

  Andy Hoke, Chair

- P1547.2 User's Guide, Revision

  Wayne Stec, Chair

- P1547.9 Guide to ES-DER Interconnection, *New*

  Mike Ropp, Chair

Dave Narang, NREL | david.narang@nrel.gov

Charlie Vartanian, MEPPI | charlie.vartanian@meppi.com

# THANK YOU

# IEEE Std 1547-2018

# Clause 5: Reactive Power and Voltage Regulation

Babak Enayati, PhD, PE

2018 IEEE PES T&D
Date: April 16, 2018

# P1547 Voltage regulation

(Work In Progress-section 1.4)

Two performance categories are defined for DERs with voltage regulation capabilities:

a) Category A covers minimum performance capabilities needed for Area EPS voltage regulation and are reasonably attainable by all DER technologies as of the publication of this standard. This level of performance is deemed adequate for applications where the DER penetration in the distribution system is lower, and where the overall DER power output is not subject to frequent large variations

b) Category B covers all requirements within Category A and specifies supplemental capabilities needed to adequately integrate DERs in local Area EPSs where the aggregated DER penetration is higher or where the overall DER power output is subject to frequent large variations

Per Draft 7.1 Nov 2017

# P1547 Example New Reactive Power Requirements

## 5.2 Reactive power capability of the DER

The DER shall be capable of injecting reactive power (over-excited) and absorbing reactive power (under-excited) for active power output levels greater than or equal to the minimum steady-state active power capability ($P_{min}$), or 5% of rated active power, $P_{rated}$ (kW) of the DER, whichever is greater.

When operating at active power output greater than 5% and less than 20% of rated active power, the DER shall be capable of exchanging reactive power up to the minimum reactive power value given in Table 7 multiplied by the active power output divided by 20% of rated active power.

Operation at any active power output above 20% of rated active power shall not constrain the delivery of reactive power injection or absorption, up to the capability specified in Table 7, as required by the active control function at the time, as defined in 5.3. Curtailment of active power to meet apparent power constraints is permissible. These reactive power requirements are illustrated in informative Figure H.3.[60]

**Table 7—Minimum reactive power injection and absorption capability**

| Category | Injection capability as % of nameplate apparent power (kVA) rating | Absorption capability as % of nameplate apparent power (kVa) rating |
|---|---|---|
| A (at DER rated voltage) | 44 | 25 |
| B (over the full extent of ANSI C84.1 range A) | 44 | 44 |

# Section 5.3.1:
# Voltage and Reactive Power Control

The DER shall provide voltage regulation capability by changes of reactive power. The approval of the Area EPS Operator shall be required for the DER to actively participate in voltage regulation.

The voltage and reactive power control functions do not create a requirement for the DER to operate at points outside of the minimum reactive power capabilities specified in of 5.2.

The DER shall, as specified in Table 6, provide the capabilities of the following mutually exclusive modes of reactive power control functions:

- Constant power factor
- Voltage-reactive power
- Active power-reactive power
- Constant reactive power

| DER Category | Category A | Category B |
|---|---|---|
| **Voltage regulation by reactive power control** | | |
| Constant power factor mode | mandatory | mandatory |
| Voltage – reactive power mode[63] | mandatory | mandatory |
| Active power – reactive power mode[64] | not required | mandatory |
| Constant reactive power mode | mandatory | mandatory |
| **Voltage and active power control** | | |
| Voltage – active power (volt-watt) mode | not required | mandatory |

Per Draft 7.1 Nov 2017

# Constant Power factor mode

When in this mode, the DER shall operate at a constant power factor. The target power factor shall be specified by the Area EPS operator and shall not require reactive power exceeding the reactive capability requirements specified in 5.2. The power factor settings are allowed to be adjusted locally and/or remotely as specified by the Area EPS operator. The maximum DER response time to maintain constant power factor shall be 10 s or less.

# Volt-Reactive Power Capability (Volt/Var Mode– Section 5.3.3)

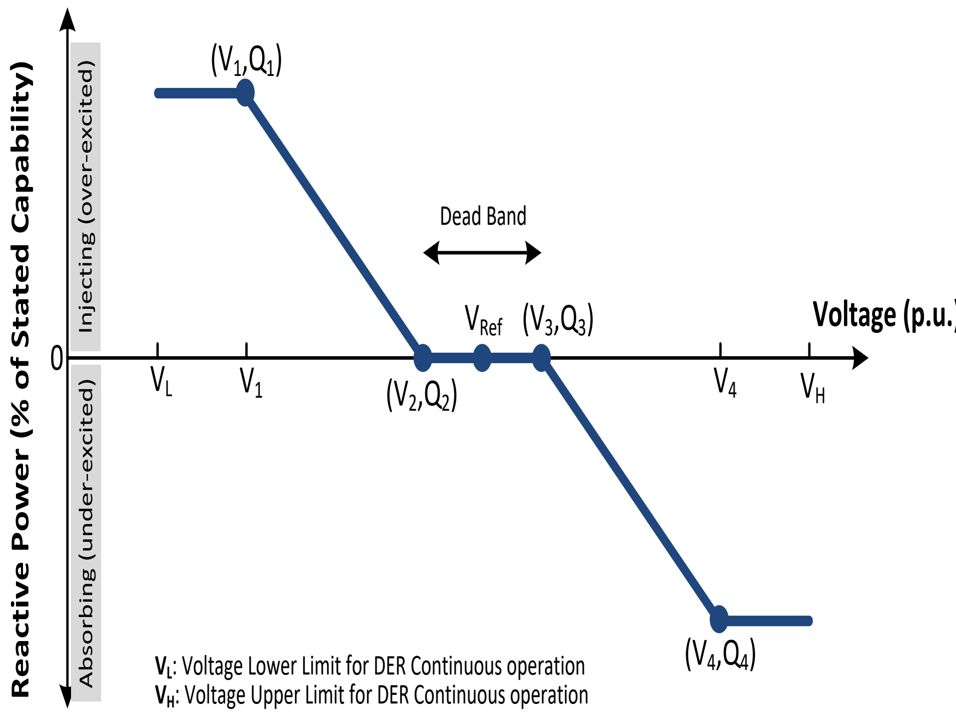



Figure 5—Example voltage-reactive power characteristic

# The Volt/VAR characteristics curve is adjustable

| Volt-var parameters | Definitions | Default Settings for Cat A DER | Default Settings for Cat B DER | Range of Allowable settings | |
|---|---|---|---|---|---|
| | | | | Minimum | Maximum |
| $V_{Ref}$ | Reference voltage | Nominal voltage ($V_N$) | Nominal voltage ($V_N$) | 0.95 $V_N$ | 1.05 $V_N$ |
| $V_2$ | Dead band lower voltage limit | Nominal voltage ($V_N$) | $V_{Ref}$ – 0.02 $V_N$ | Cat A: $V_{ref}$<br>Cat B; $V_{Ref}$ – 0.03 $V_N$ | $V_{Ref}$ [c] |
| $Q_2$ | Reactive power injection or absorption at voltage $V_2$ | 0 | 0 | 0 | 100% of stated reactive capability |
| $V_3$ | Dead band upper voltage limit | Nominal voltage ($V_N$) | $V_{Ref}$ + 0.02 $V_N$ | $V_{Ref}$[c] | Cat A: $V_{ref}$<br>Cat B: $V_{Ref}$ + 0.03 $V_N$ |
| $Q_3$ | Reactive power injection or absorption at voltage $V_3$ | 0 | 0 | 0 | 100% of stated reactive capability |
| $V_1$ | Voltage at which DER shall inject $Q_1$ reactive power | 0.9 $V_N$ | $V_{Ref}$ – 0.08 $V_N$ | $V_{Ref}$ - 0.18 $V_N$ | $V_2$ [c]-0.02 $V_N$ |
| $Q_1$ | Reactive power injection at voltage $V_1$[a] | 25% of nameplate kVA | 100% of stated reactive capability | 0 | 100% of stated reactive capability[b] |
| $V_4$ | Voltage at which DER shall absorb $Q_4$ reactive power | 1.1 $V_N$ | $V_{Ref}$ + 0.08 $V_N$ | $V_3$ [c]+0.02 $V_N$ | $V_{Ref}$ + 0.18 $V_N$ |
| $Q_4$ | Reactive power absorption at voltage $V_4$ | 25% of Nameplate kVA | 100% of stated reactive capability | 0 | 100% of stated reactive capability [b] |
| Open loop response time | Time to 90% of the reactive power change in response to the change in voltage | 10 s | 5 s | 1 s | 90 s |

[a] The DER reactive power capability may be reduced at lower voltage
[b] If needed DER may reduce active power output to meet this requirement
[c] Improper selection of these values may cause system instability

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# Active Power – Reactive Power Capability (Watt-Var or P - Q – Section 5.3.4)

When in this mode, the DER shall actively control the reactive power output as a function of the active power output following a target piecewise linear active power–reactive power characteristic, without intentional time delay. In no case shall the response time be greater than 10s. The target characteristics shall be configured in accordance with the default parameter values shown in Table 9. The characteristics shall be allowed to be configured as specified by the Area EPS Operator using the values specified in the optional adjustable range .

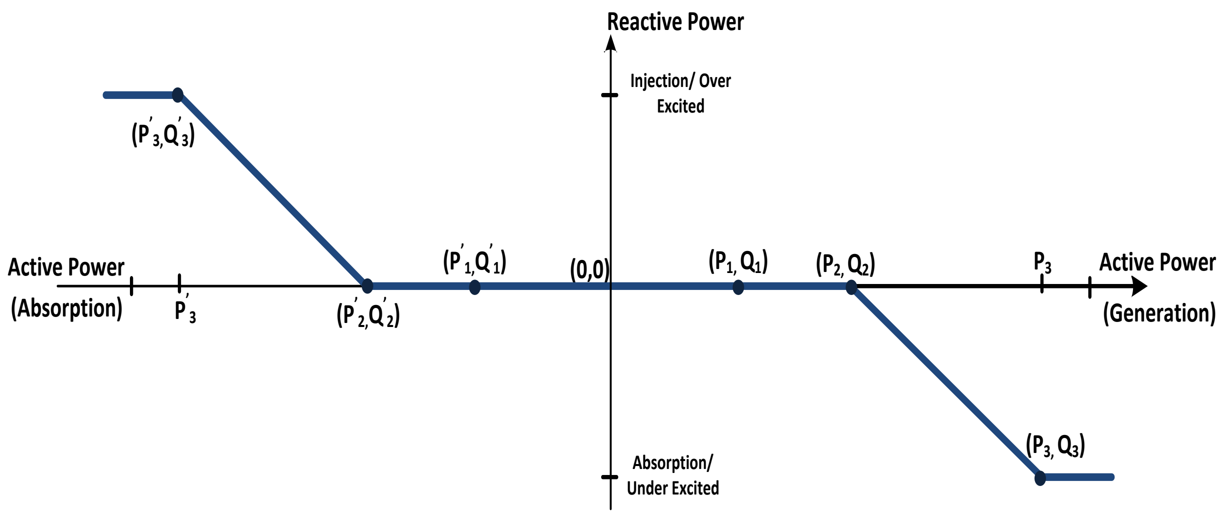


Figure 6—Example active power-reactive power characteristic

# Watt-Var settings for Category A and Category B types of DER

| Point/ Parameter | Default | Range of allowable settings | |
|---|---|---|---|
| | Cat A and B | Min | Max |
| $P_3$ | $P_{rated}$ | $P_2+0.1P_{rated}$ | $P_{rated}$ |
| $P_2$ | $0.5P_{rated}$ | $0.4P_{rated}$ | $0.8P_{rated}$ |
| $P_1$ | The greater of $0.2P_{rated}$ and $P_{min}$ | $P_{min}$ | $P_2- 0.1P_{rated}$ |
| $P'_1$ | The lesser of $0.2P'_{rated}$ and $P'_{min}$ | $P'_2- 0.1P'_{rated}$ | $P'_{min}$ |
| $P'_2$ | $0.5P'_{rated}$ | $0.8P'_{rated}$ | $0.4P'_{rated}$ |
| $P'_3$ | $P'_{rated}$ | P'rated | $P'_2+0.1P'_{rated}$ |
| $Q_3$ | 40% of Nameplate Apparent Power (kVA) absorption or $Qmin_s$ | 100% of nameplate reactive power absorption capability | 100% of nameplate reactive power injection capability |
| $Q_2$ | 0 | | |
| $Q_1$ | 0 | | |
| $Q'_1$ | 0 | | |
| $Q'_2$ | 0 | | |
| $Q'_3$ | 44% of nameplate apparent power rating, injection | | |

**Note: $P_{max}$ is the maximum active power that the DER can deliver.**

# Constant Reactive Power Capability

When in this mode, the DE shall operate at a constant power factor. The target power factor shall be specified by the Area EPS operator and shall not require reactive power exceeding the reactive capability requirements specified in 5.2. The power factor settings are allowed to be adjusted locally and/or remotely as specified by the Area EPS operator. The maximum DER response time to maintain constant power factor shall be 10 s or less.

# Voltage Active Power Capability

When in this mode, the DER shall actively limit the active power output as a function of the voltage following a Volt-Watt piecewise linear characteristic. Two example Volt-Watt characteristics are shown in Figure 7. The characteristic shall be configured in accordance with the default parameter values specified in Table 10 for the given DER *normal operating performance category*. The characteristic may be configured as specified by the Area EPS Operator using the values in the adjustable range.

If enabled, the Volt-Watt function shall remain active while any of the voltage-reactive power modes are enabled.

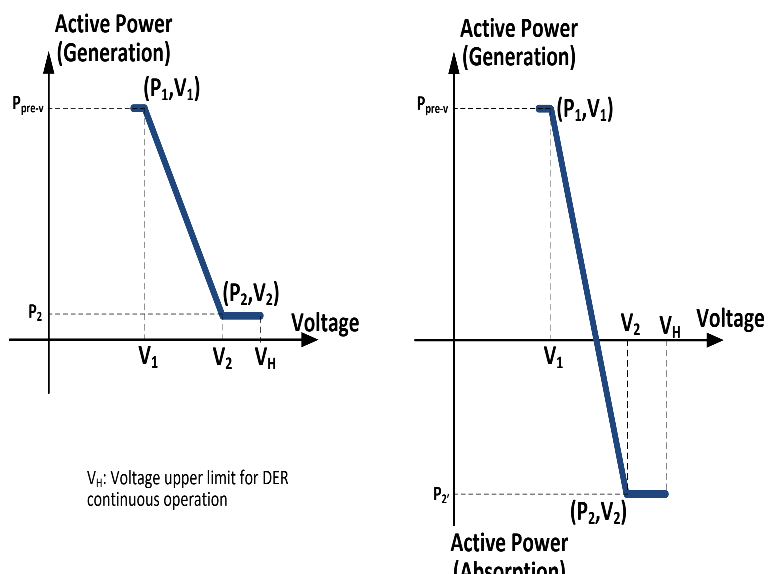


Figure 7—Example voltage-active power characteristic

# Are the voltage regulation requirements proposed to be mandatory?

Voltage regulation capability is mandatory but the performance is proposed to be at the utility’s discretion (The DER will provide this capability and the utility will decide to enable/disable it and choose the proper operating modes).

# Impacts of IEEE 1547 on Interconnection Screens used by some utilities

- System protection (Supplemental review and full impact studies)
- Anti-islanding protection screens may need to be revised
- System DER hosting capacity
- Modeling the Advanced DER. Lack of modeling tools that are widely used by the utilities for protection and load flow studies

✓ Interconnection study time and cost

# IEEE Std 1547-2018

# Clause 7:
# Power Quality

**Babak Enayati, PhD, PE**

**2018 IEEE PES T&D**
**Date: April 16, 2018**

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# New Power Quality Requirements Flicker (section 7.2.3)

**Flicker-** Flicker is the subjective impression of fluctuating luminance caused by voltage fluctuations.

Assessment and measurement methods for flicker are defined in IEEE1453and IEC 61000-3-7.

- EPst –Emission limit for the short-term flicker severity. If not specified differently, the Pst evaluation time is 600 s.
- EPlt – Emission limit for long-term flicker severity. If not specified differently, the Plt evaluation time is 2 h.

**Table 25—Minimum Individual DER Flicker Emission Limits[a]**

| $E_{Pst}$ | $E_{Plt}$ |
|---|---|
| 0.35 | 0.25 |

[a] 95% probability value should not exceed the emission limit based on a one week measurement period.

# New Power Quality Requirements

# Limitation of Current Distortion (section 7.3)

- Harmonic current distortion and total rated-current distortion (TRD) at the *reference point of applicability* (RPA) shall not exceed the limits stated inTable 26 and Table 27.
- The harmonic current injections shall be exclusive of any harmonic currents due to harmonic voltage distortion present in the Area EPS without the DER connected.

**Table 26—Maximum odd harmonic current distortion in percent of rated current ($I_{rated}$) [a]**

| Individual odd harmonic order h | h < 11 | 11≤ h < 17 | 17 ≤ h < 23 | 23 ≤ h < 35 | 35 ≤h < 50[120] | Total rated current distortion (TRD) |
|---|---|---|---|---|---|---|
| Percent (%) | 4.0 | 2.0 | 1.5 | 0.6 | 0.3 | 5.0 |

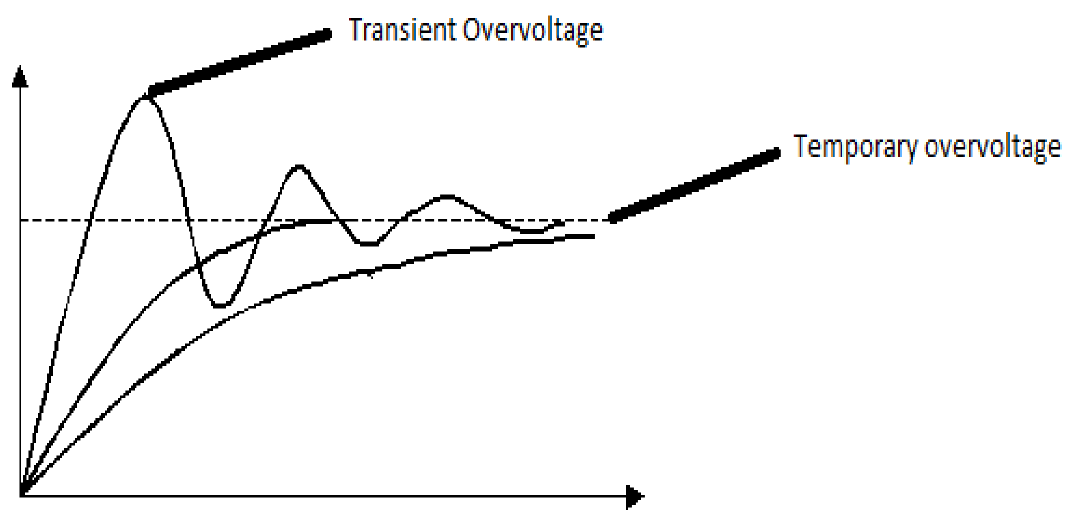
[a] $I_{rated}$ = the DER unit rated current capacity (transformed to the RPA when a transformer exists between the DER unit and the RPA).

**Table 27—Maximum even harmonic current distortion in percent of rated current ($I_{rated}$) [a]**

| Individual even harmonic order h | h=2 | h=4 | h=6 | 8≤h<50 |
|---|---|---|---|---|
| Percent (%) | 1.0 | 2.0 | 3.0 | Associated range specified in Table 26 |

[a] $I_{rated}$ = the DER unit rated current capacity (transformed to the RPA when a transformer exists between the DER unit and the RPA).

# Transient vs Temporary overvoltage



# New Power Quality Requirements Limitation of Over Voltage Contribution- (section 7.4)

**Limitation of over-voltage over one fundamental frequency period**

The DER shall not contribute to instantaneous or RMS over voltages with the following limits:

a) The DER shall not cause the fundamental frequency line-to-ground voltage on any portion of the Area EPS that is designed to operate effectively grounded, as defined by IEEE Std C62.92.1, to exceed 138% of its nominal line-to-ground fundamental frequency voltage for a duration exceeding one fundamental frequency period.

b) The DER shall not cause the line-to-line fundamental frequency voltage on any portion of the Area EPS to exceed 138% of its nominal line-to-line fundamental frequency voltage for a duration exceeding one fundamental frequency period.

**Limitation of cumulative instantaneous over-voltage**

The DER shall not cause the instantaneous voltage on any portion of the Area EPS to exceed the magnitudes and cumulative durations shown in Figure 13. The cumulative duration shall only include the sum of durations for which the instantaneous voltage exceeds the respective threshold over a one-minute time window

# P1547 Example New Power Quality Requirements Over Voltage Contribution-Transient Over-voltage (TOV)

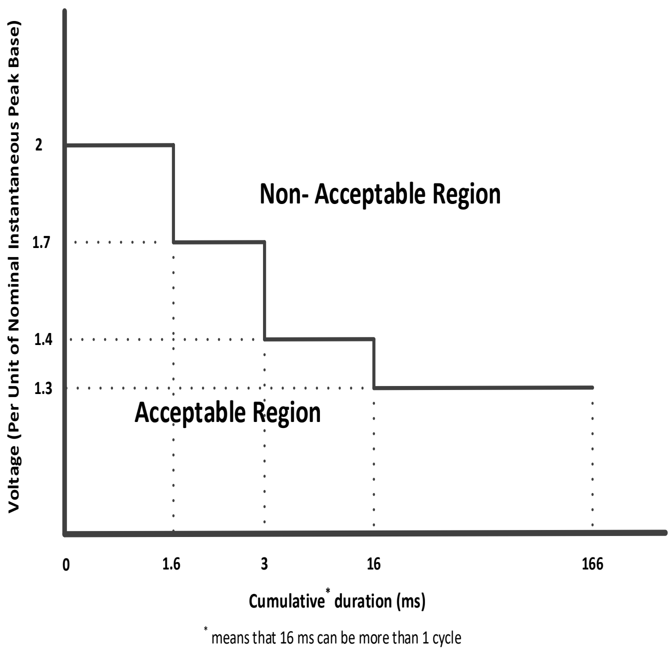
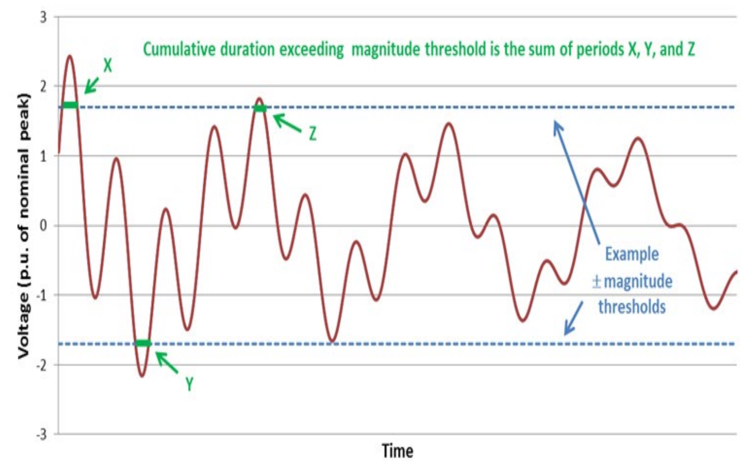



Figure 13—Transient overvoltage limits




An example of the cumulative duration is provided in this figure

# More Information on IEEE P1547

Go to IEEE SCC21's P1547 Revision Grouper Website,

http://grouper.ieee.org/groups/scc21/1547_revision/1547revision_index.html

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# TUT-04:
# IEEE Standard 1547-2018
# Clause 6:
# Response to Area EPS Abnormal Conditions

**Andy Hoke**, PhD, PE (NREL)
On behalf of Jens Boemer (EPRI)

IEEE T&D Conference Tutorial
April 16, 2018

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# Disclaimer & Acknowledgements

- *This presentation and discussion here on IEEE 1547-2018 are the author's views and are not the formal explanation or position of the IEEE.*
- *Note that all information in the proposed standard is the output of IEEE's balloting process and subject to editorial changes during publication of the standard.*

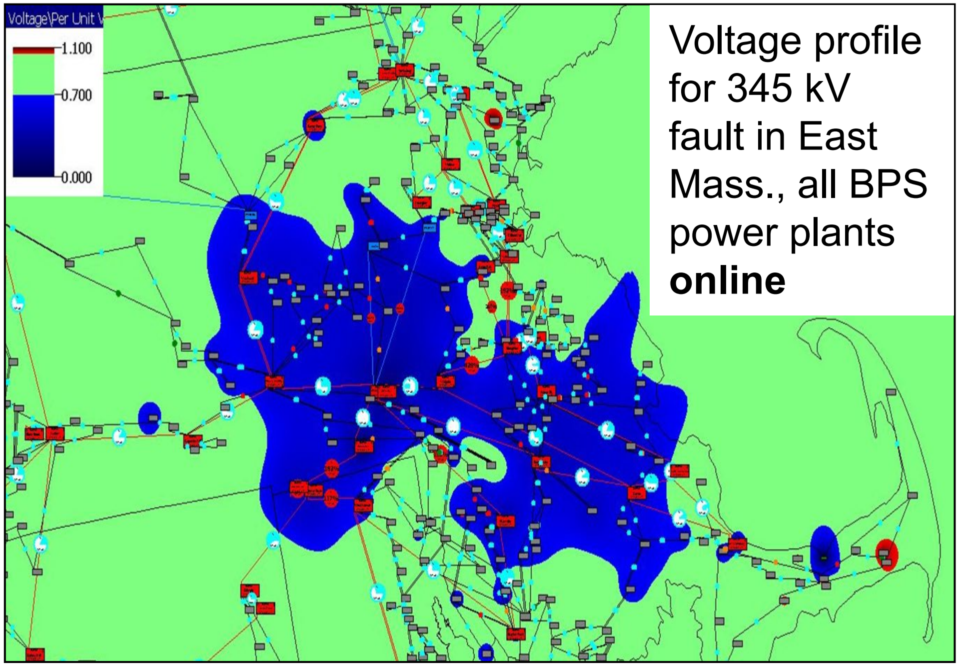

- *We thank Jens Boemer, Reigh Walling, and EPRI for the contribution of slides on the voltage and frequency ride-through requirements.*

# Contents

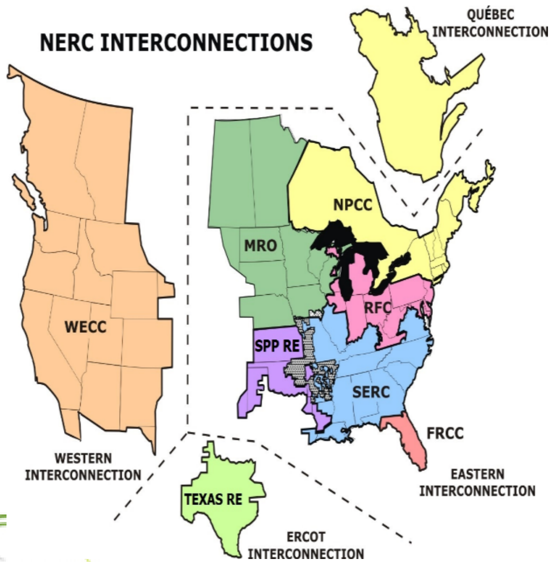
- Normal and abnormal performance categories
- Response to abnormal conditions
  - Voltage and frequency trip
  - Voltage and frequency ride-through capability
    - Dynamic voltage support capability
    - Frequency control capability
- Default values and ranges of allowable settings for the above

# Driver for new ride-through requirements: Potential for widespread DER tripping

- System frequency is defined by balance between load and generation
- Frequency is similar across entire interconnection; all DER can trip simultaneously during disturbance
- Impact the same whether or not DER is on a high-penetration feeder



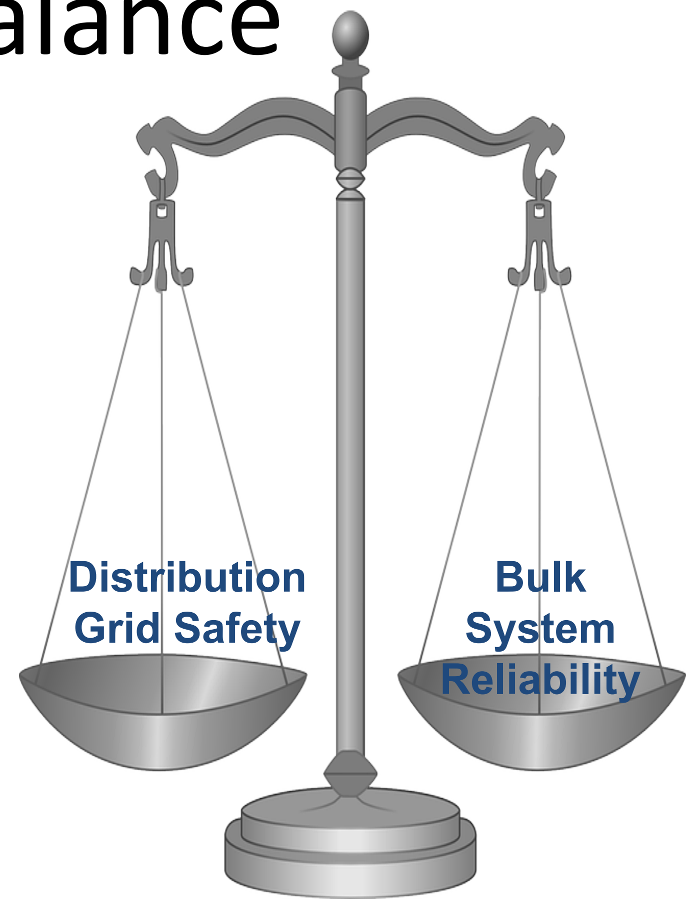

**Source: ISO-New England**




- Transmission faults can depress distribution voltage over very large areas
- Sensitive voltage tripping (i.e., 1547-2003) can cause massive loss of DER generation
- Resulting BPS event may be greatly aggravated

# Striking a new balance

- IEEE 1547-2018 mandates BOTH:
  - Tripping requirements, and
  - Ride-through requirements
- Ride-through is not a "setting", it is a minimum *capability* of the DER
  - *"shall ride through <u>for at least</u> … seconds"*
  - I.e., it is the minimum required DER robustness to withstand voltage and frequency disturbances
  - May or may not be fully utilized, or it may be exceeded
- Trip thresholds and clearing times are maximum operational *settings*
  - *"shall trip <u>at latest by</u> … seconds"*
  - May differ from *default settings* and are adjustable over a 'range of allowable settings'
  - Specified ranges do not allow DER tripping to seriously compromise bulk power system reliability
  - Tripping points specified by the distribution utility may account for utility-specific practices but may also be constrained by the ***regional reliability coordinator***



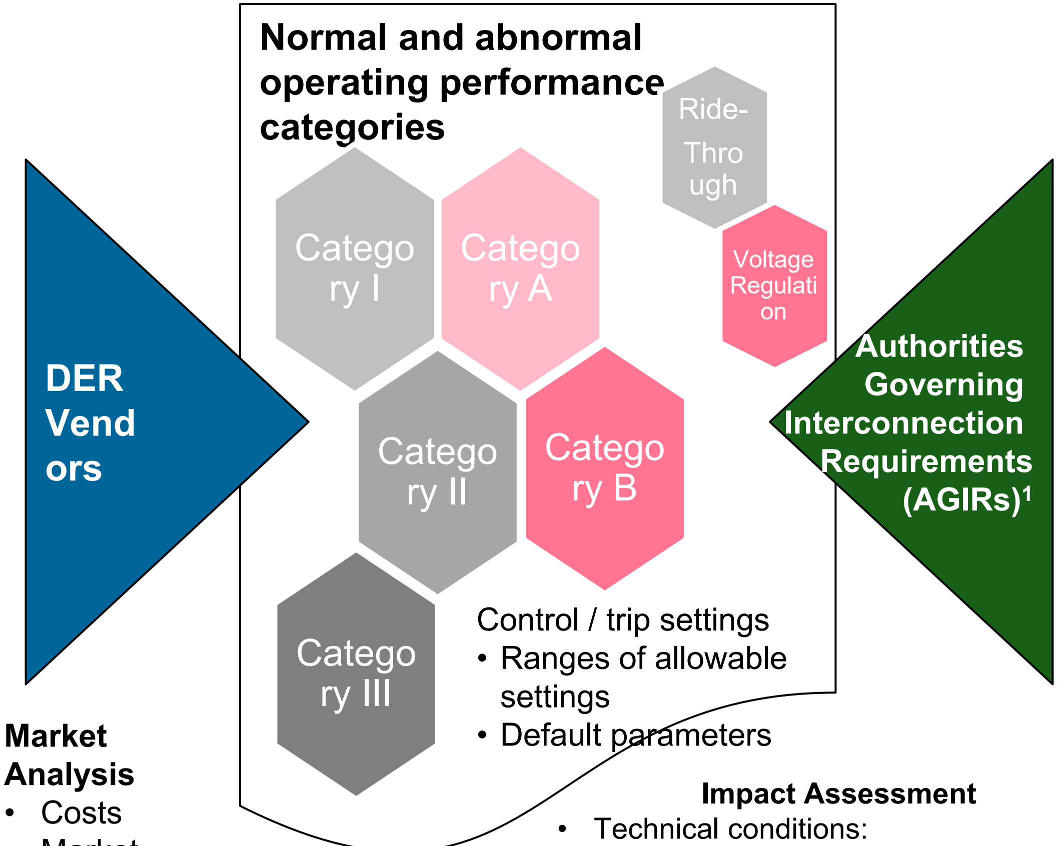
# General tripping and reclose coordination requirements

- DER must trip for any short-circuit faults on the circuit to which it is connected
  - Exception for faults not detectable by Area EPS protections
  - At Area EPS Operator discretion, sequential tripping can be employed
- DER must detect and cease to energize for open phase condition directly at the *reference point of applicability* within two seconds
- DER must implement means such that Area EPS circuit reclosing does not result in unacceptable stress or disturbance. Possible means include:
  - Low DER penetration = no islanding sustained for reclose delay
  - Feeder reclosing “hot-line blocking”
  - Transfer trip
  - Anti-islanding detection proven to be faster than reclose delay

# Disturbance performance categories

- Not all DER technologies can meet the full extent of ride-through compatible with BPS requirements
  - Synchronous generators have stability issues with LVRT
  - Some “prime mover” or “energy source” systems can also have potential issues
  - Example: Engine converting landfill $CH_4$ to energy
- Solution: define “disturbance performance categories”
  - Authority Governing Interconnection Requirements (AGIR) decides which performance category will be met by each DER type and application
  - Technical criteria: type, capacity, future penetration of DER, type of grid configuration, etc.
    - AGIR may also limit cumulative capacity allowed to meet “lower-level” requirements
  - Non-technical criteria: DER use case, impacts on environment, emissions, and sustainability, etc.
    - Making non-technical judgements is outside purview of IEEE standards
- Note: It’s currently hard/unfeasible to retroactively change DER performance in most cases. Think 30 years ahead when choosing performance category and settings!

# Assignment of new IEEE 1547-2018 Performance Categories




**Market Analysis**
- Costs
- Market segment
- Etc.

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

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

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# Abnormal Performance Categories

| 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.

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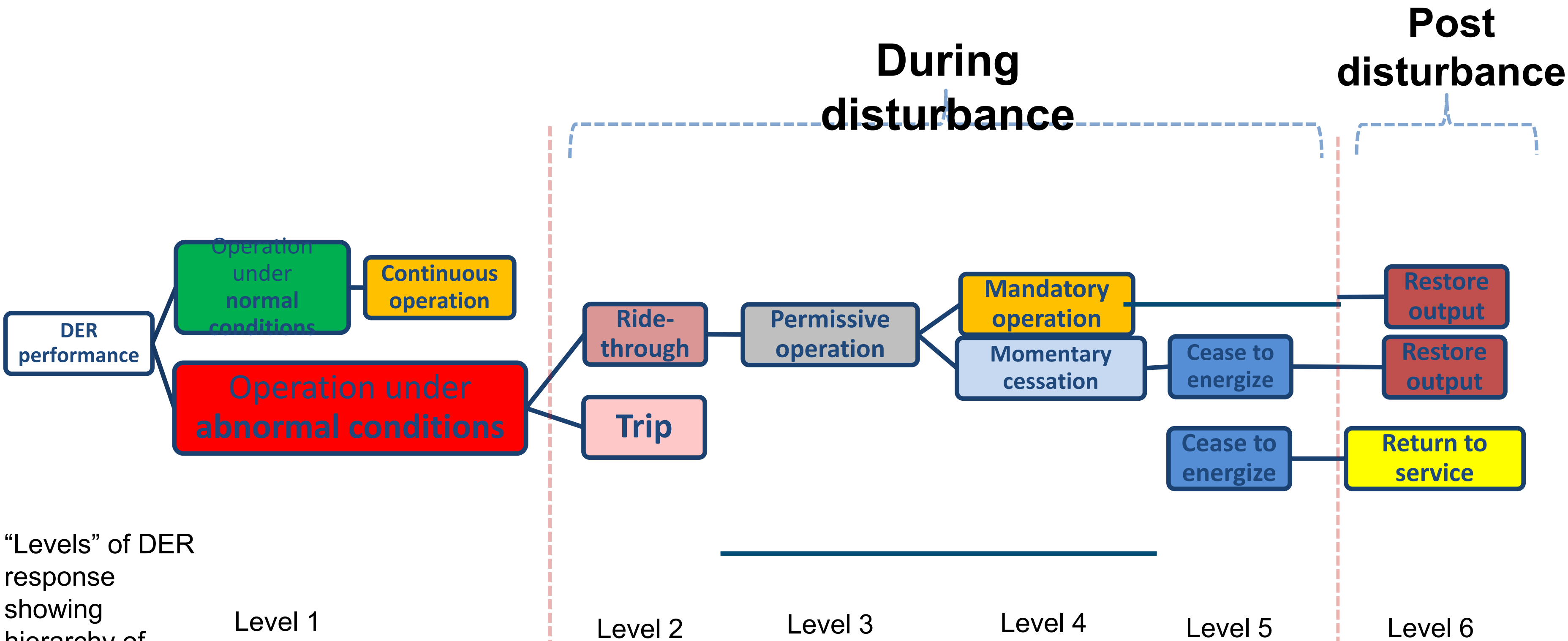
# Disturbance performance terminology



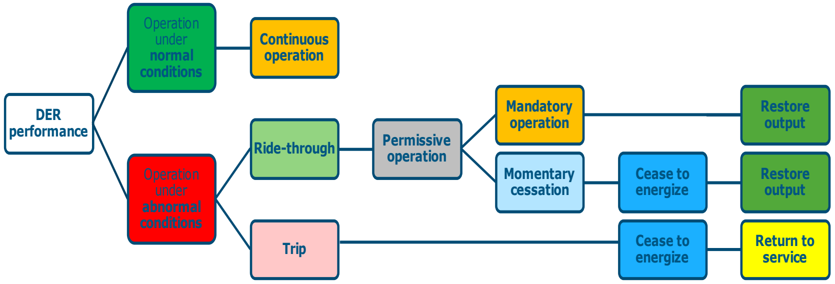

"Levels" of DER response showing hierarchy of terms/requirements:

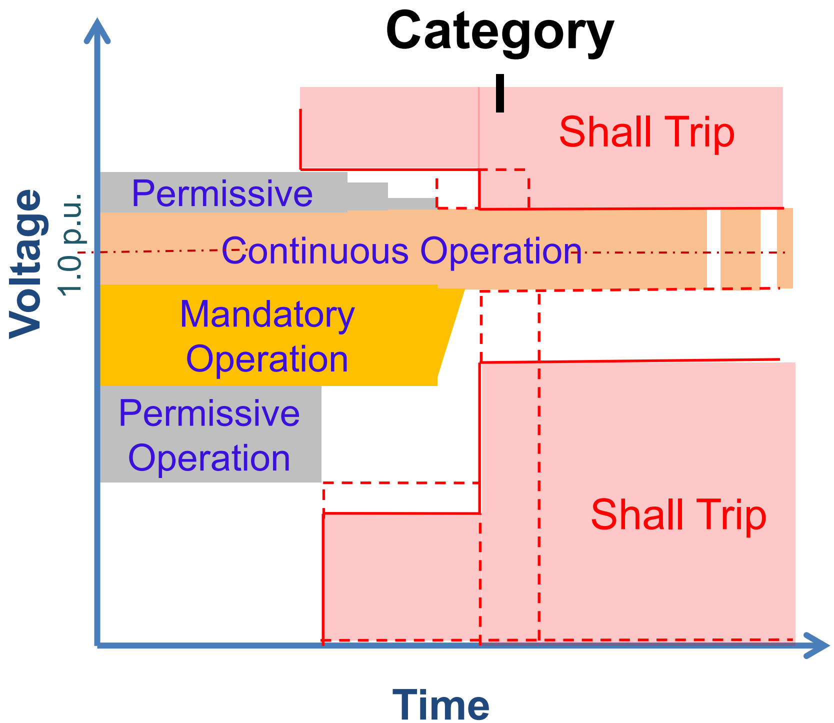
- **Ride-through** – ability to withstand voltage or frequency disturbances
  - **Permissive operation** – DER may either continue operation or may cease to energize, at its discretion
    - **Mandatory operation** – required active and reactive current delivery
    - **Momentary cessation** – cessation of energization for the duration of a disturbance with rapid recovery when voltage or frequency return to defined range
  - **Restore output** – DER recovery to normal output following a disturbance that does not cause a ***trip***.
- **Trip** – cessation of output without immediate return to service; not necessarily disconnection
  - **Return to service** – re-entry of DER to service following a trip; equivalent to start-up of DER

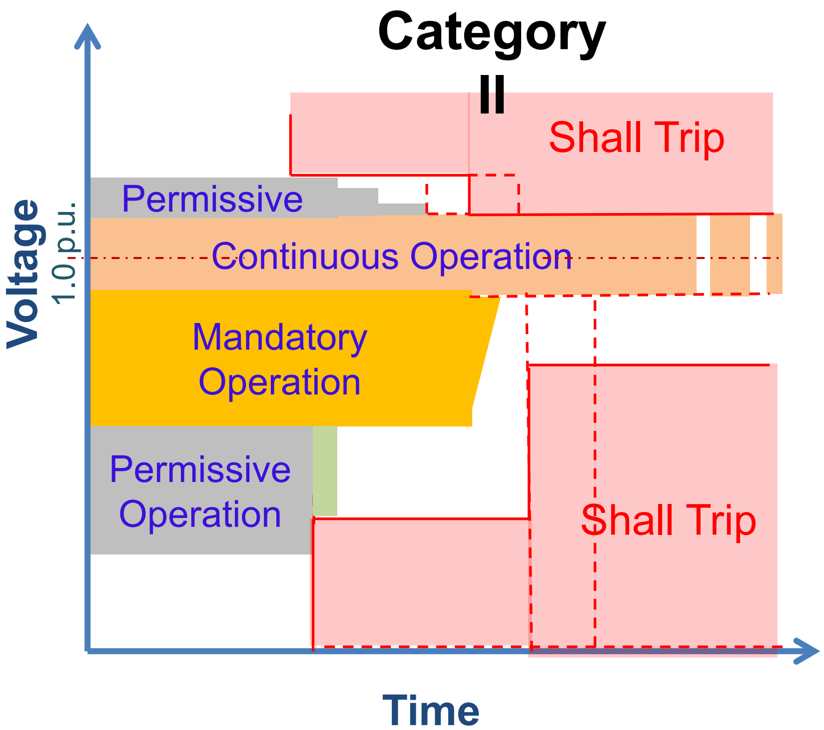
# Clarification of “Cease to Energize”

- **Cease to energize**
  - Refers to Point of DER Connection (PoC) of individual DER unit(s)
  - No active power delivery
  - Limitations to reactive power exchange
  - Does not necessarily mean physical disconnection
  - Used either for *momentary cessation* or *trip*

# Structure of VRT – Cat. I and II

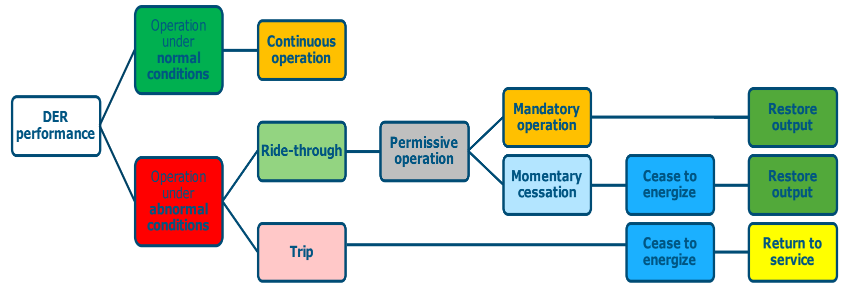


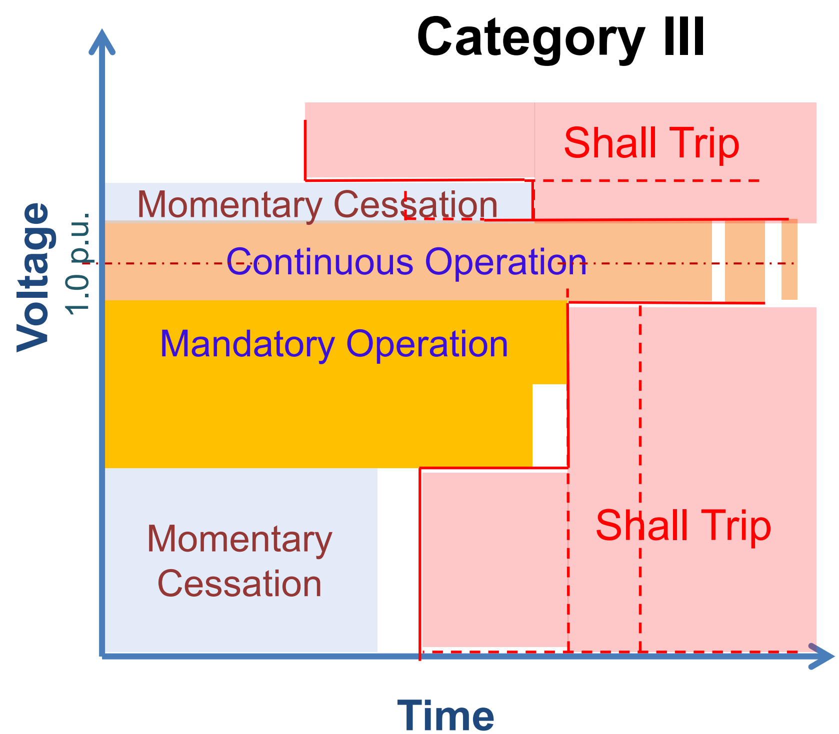




Dashed lines indicate permissible range of trip adjustment, solid lines indicate default settings.
Figure are approximate and solely for illustration. Refer to IEEE 1547-2018 for actual requirements.

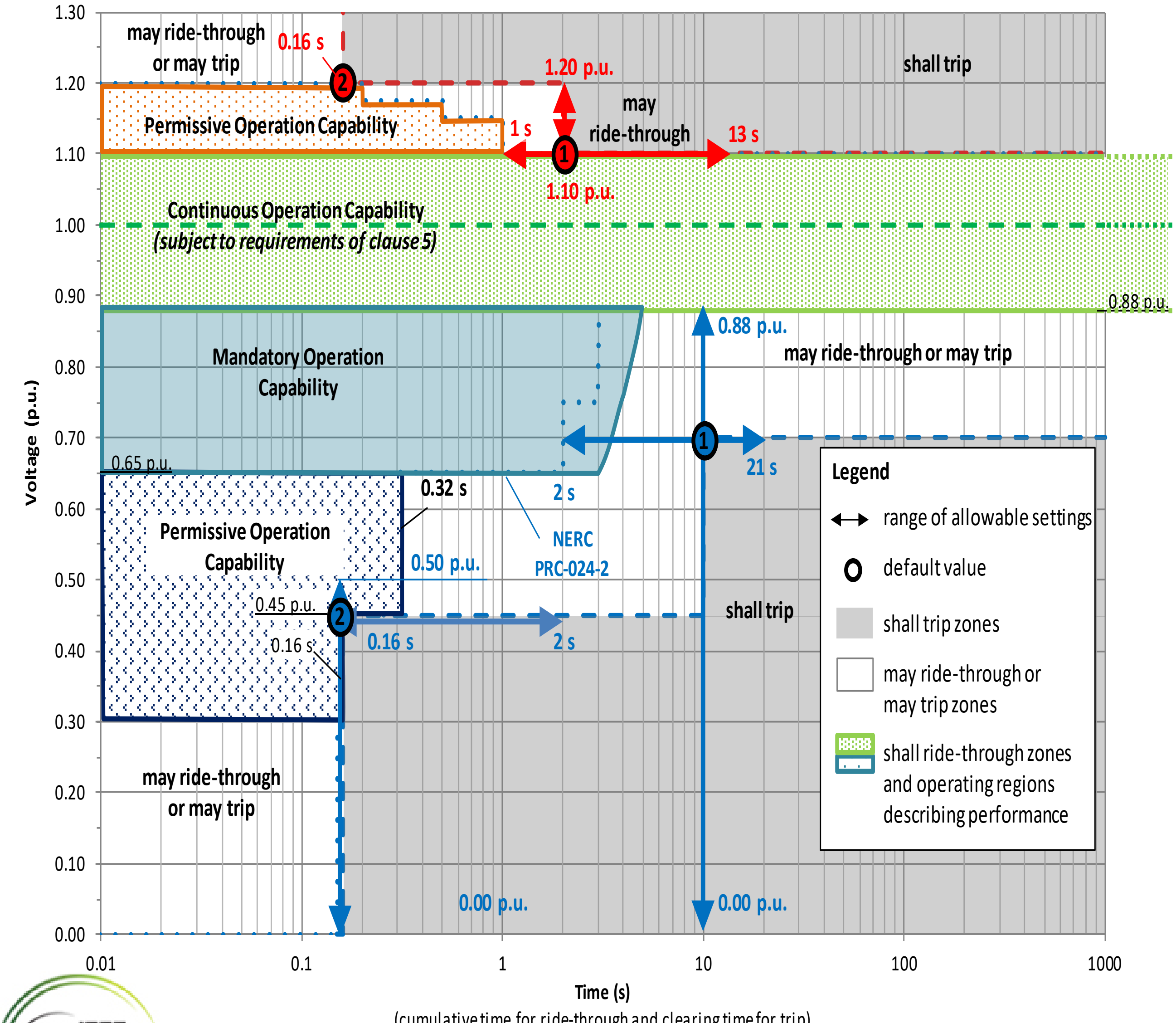
# Structure of VRT – Cat. III




- Category III introduces *momentary cessation* requirement
- Requires a relatively long zero voltage ride-through requirement (in *momentary cessation* mode)
- If feeder is faulted and tripped at the substation, then DER in momentary cessation will not energize the islanded feeder
  - DER will eventually trip off if grid voltage does not return

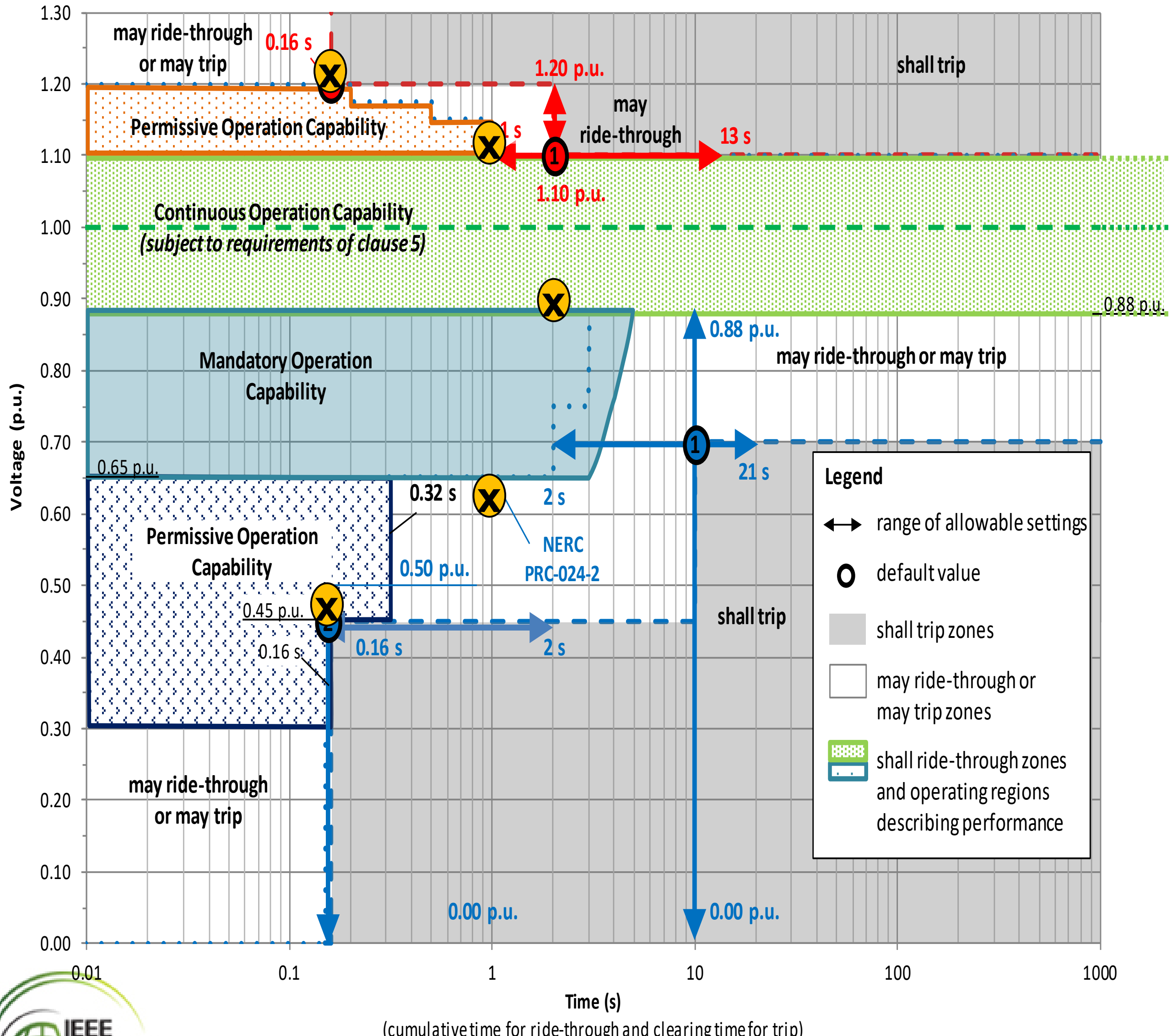


# IEEE Std 1547-2018 Abnormal Performance Category II




- **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.

## Abnormal performance category II – IEEE Std 1547a-2014 default settings.

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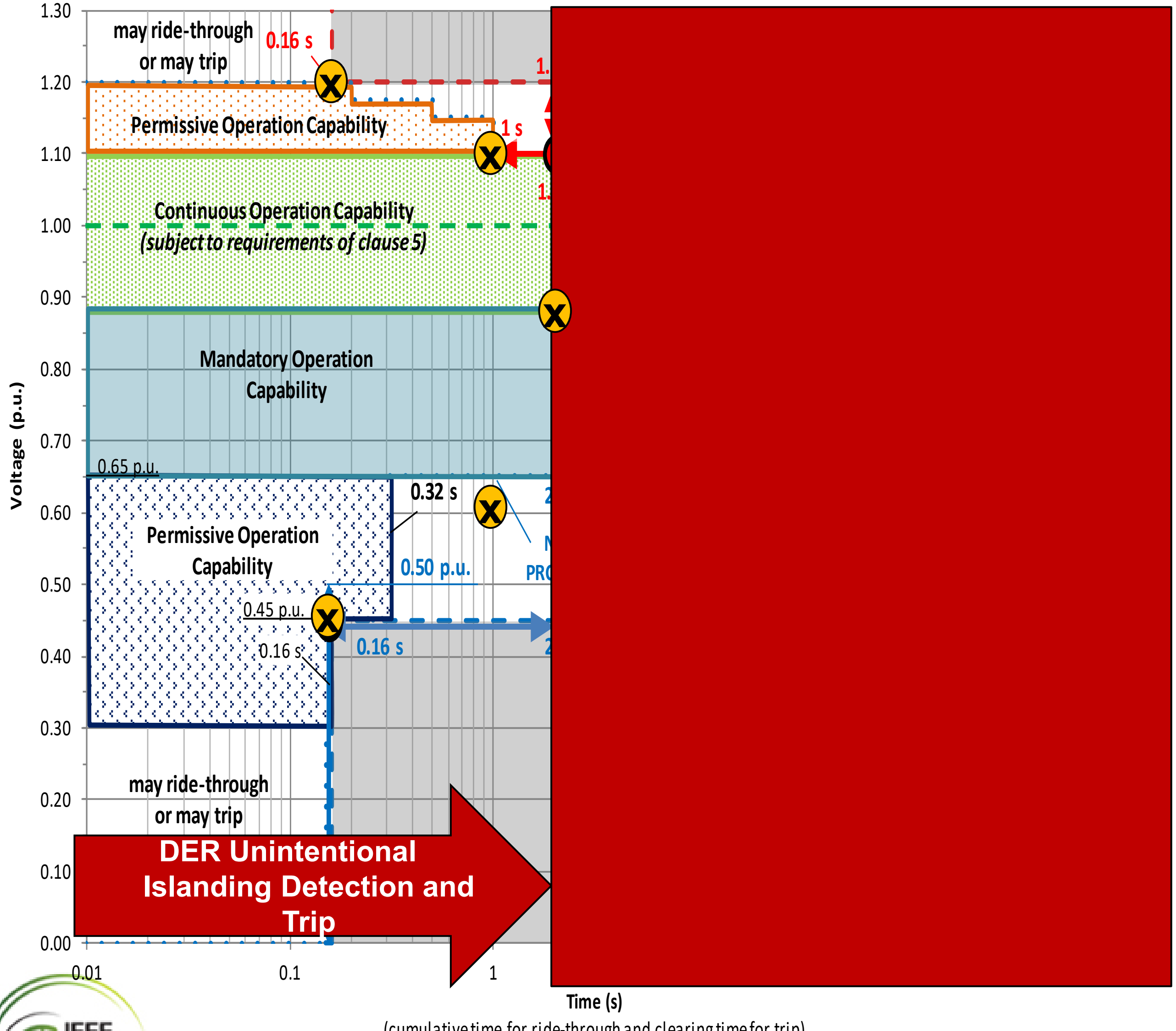


**IEEE Std 1547a-2014 default settings.**

- **Mandatory operation:**
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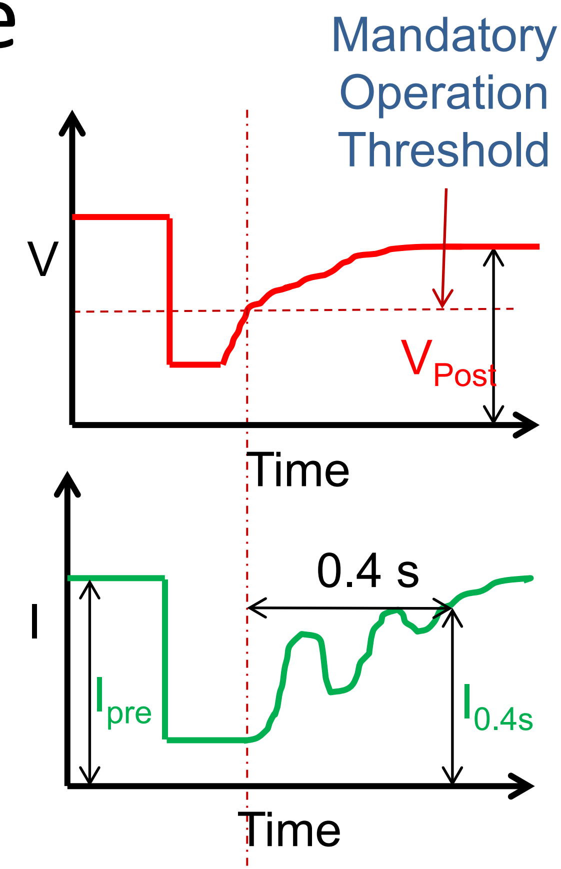
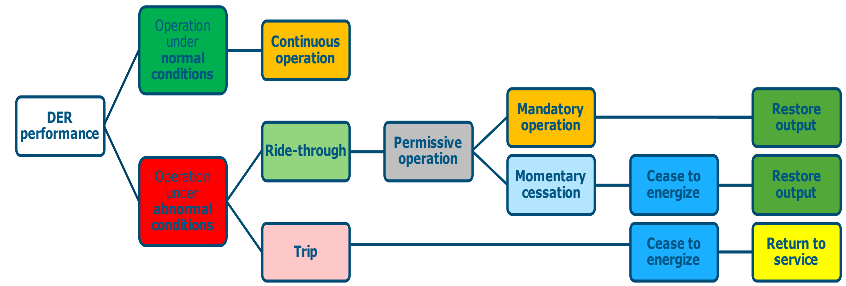
# Restore Output after Ride-through Performance

- DER must *restore output* to 80% of pre-disturbance active current within 0.4 s
- Time begins when applicable voltage returns to mandatory operation or continuous operation ranges
- Oscillatory power output is acceptable if positively damped (accommodates rotor angle swings of synchronous generators and imperfect control of inverters)
- If DER provides dynamic reactive power support (not mandatory), dynamic support must continue for 5 seconds before returning to pre-disturbance reactive control mode.




$$I_{0.4s} \geq 0.8 \times I_{pre}$$

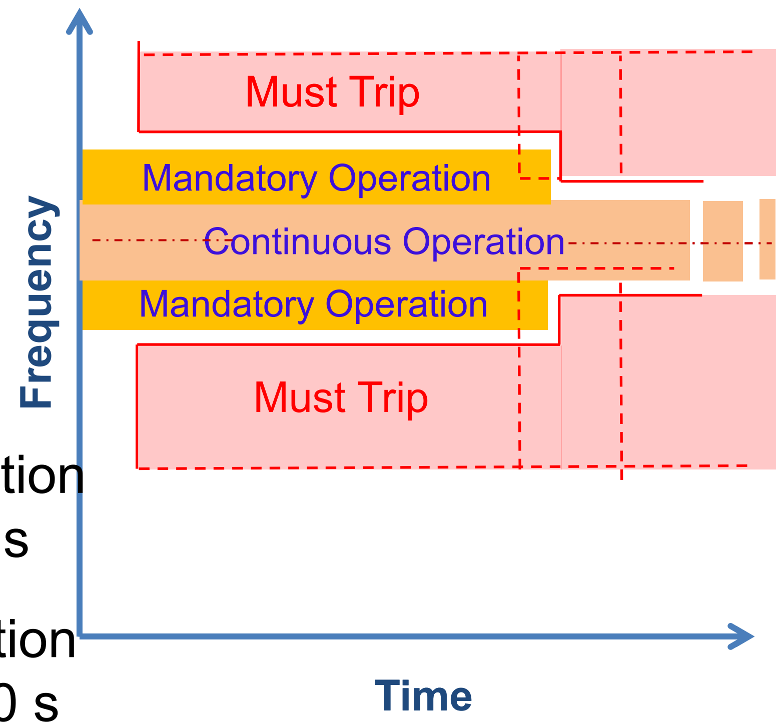
# Frequency trip and ride-through



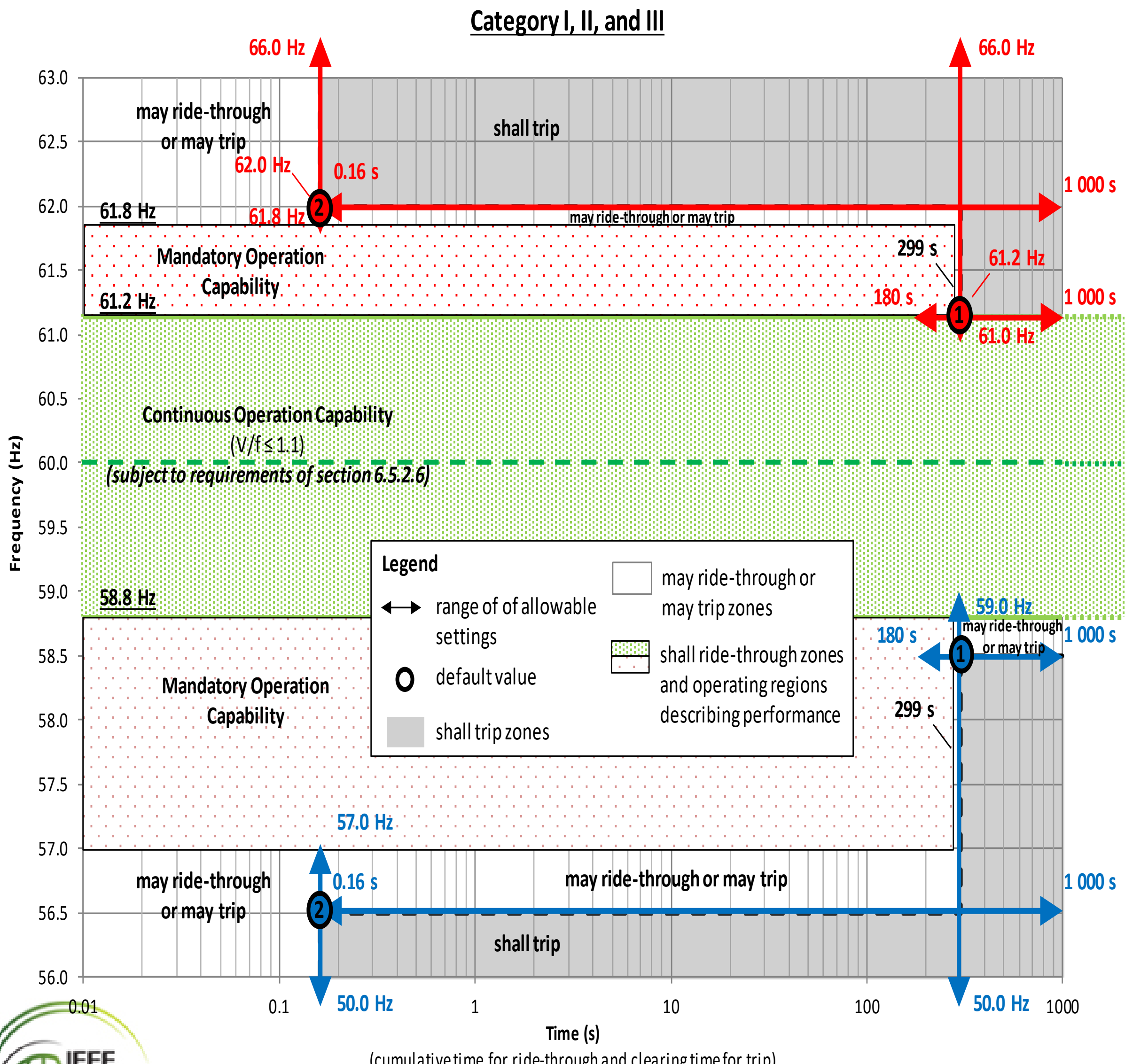

- Frequency is an interconnection-wide parameter
- Underfrequency tripping needs to be coordinated with UFLS
- IEEE 1547-2018 allows wide range of must-trip settings to accommodate small, isolated grids
  - OF: 61.8 – 66.0 Hz
  - UF: 50.0 – 57.0 Hz
  - OF: 61.0 – 66.0 Hz
  - UF: 50.0 – 59.0 Hz

Short duration
0.16 – 1.0 s

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

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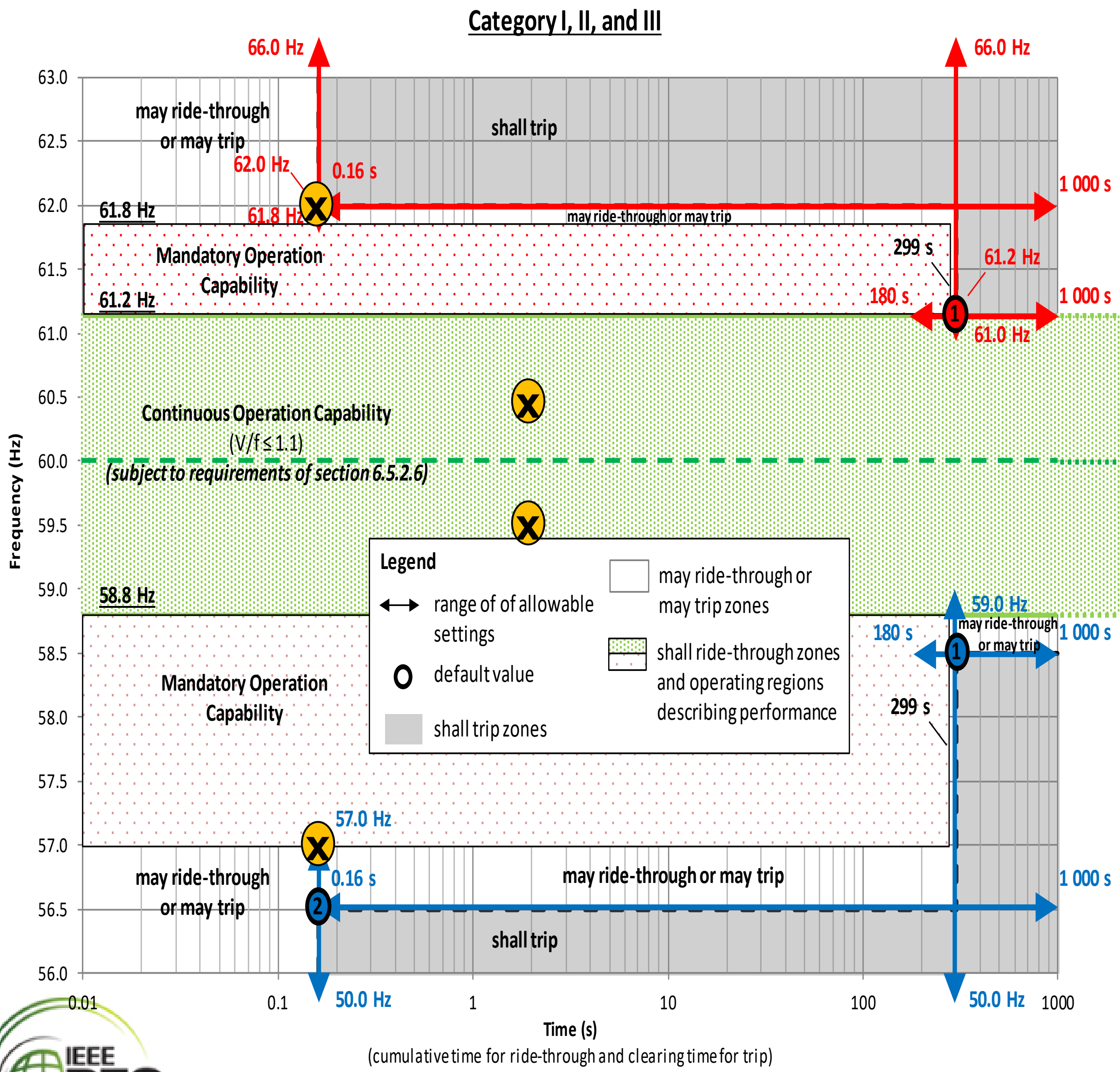
## Frequency disturbance requirements – IEEE Std 1547a-2014 default settings




**IEEE Std 1547a-2014 default settings.**

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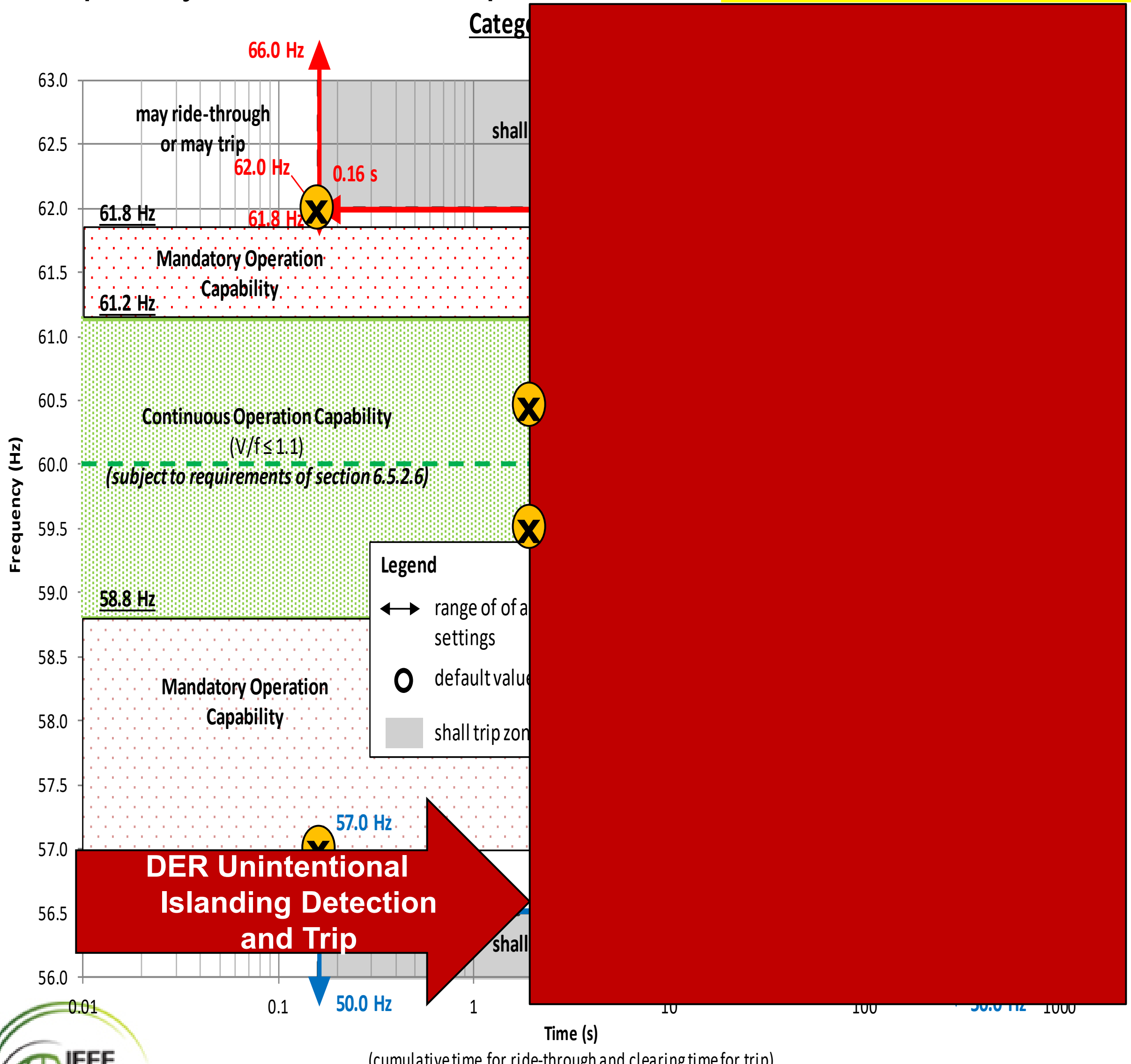


**IEEE Std 1547a-2014 default settings.**

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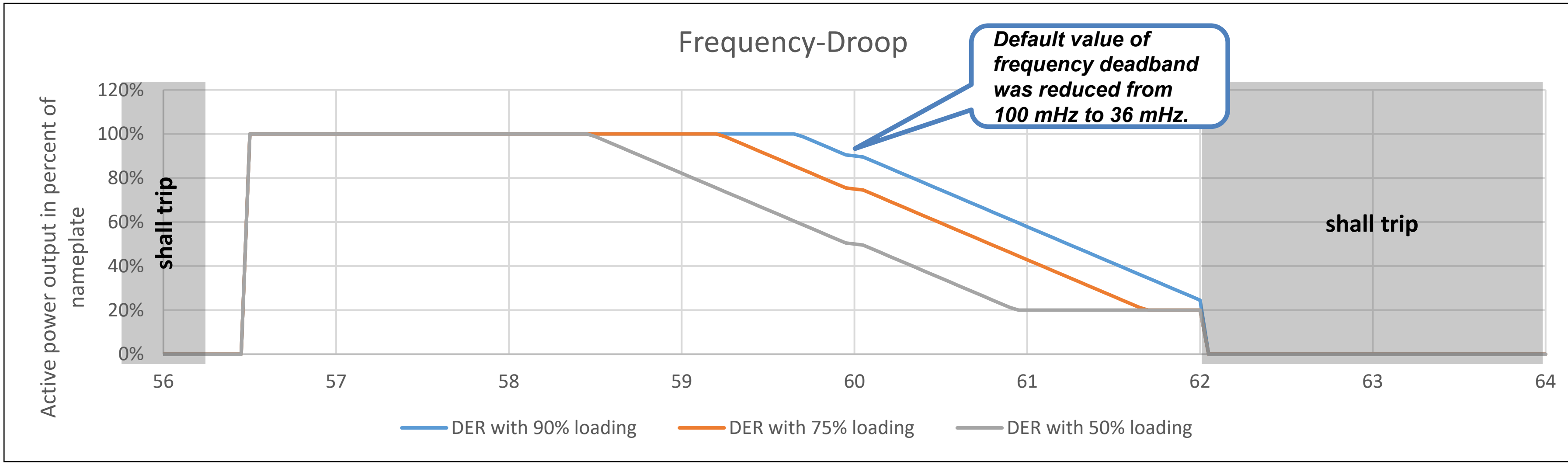
# Frequency Support




- 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")

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# Other conditions DERs must ride through

- If frequency remains in the continuous operation or ride-through frequency range, DER shall not trip for **rate-of-change-of-frequency (ROCOF)** < criterion:
  - Category I: ROCOF $\leq$ 0.5 Hz/s
  - Category II: ROCOF $\leq$ 2.0 Hz/s
  - Category III: ROCOF $\leq$ 3.0 Hz/s
- IEEE 1547-2018 voltage **phase-jump** ride-through requirements:
  - Up to 20° positive-sequence voltage phase angle step
  - Up to 60° individual phase voltage phase angle step
- **Voltage unbalance** ride-through:
  - Negative sequence voltage ($V_2$) $\leq$ 5% for duration $\leq$ 60 s.
  - Negative sequence voltage ($V_2$) $\leq$ 3% for duration $\leq$ 300 s.
- Recurring disturbances: see extra slides and 1547-2018 for details
- See additional notes in extra slides

# Does ride-through compromise island detection?

- Sensitive undervoltage trip does help avoid an island being energized by DER, in most cases
- However, most detectable distribution faults reduce voltage on a substantial portion of a feeder to < 0.5 p.u. on at least one phase
  - At least some DER will trip or momentarily cease in most cases
  - Tripping upsets generation-load balance required for island to sustain
- DERs are required by IEEE 1547-2018 to detect island in less than two seconds even with perfect generation-load balance and for any voltage or frequency trip setting within allowable range
- Duration of island (within 2 second limit) may be slightly lengthened
  - Only an issue if anti-islanding is used to coordinate with feeder reclosing
- In general, there is virtually no material increase of islanding risk due to ride-through requirements specified in IEEE 1547-2018

- NREL report on multi-inverter anti-islanding with ride-through and other grid support functions: NREL/TP--5D00-66732

Interconnection screening may need to address DER integration issues such as *protection coordination*, *reclosing coordination* and *risk of islanding*.

Majority of cases of IEEE 1547-2018-compliant applications

- Voltage and frequency regulation
- Frequency and voltage ride-through
- 2s anti-islanding detection/clearing time
- Trip for faults on the circuit where DER connected
- UV2 close to the 1547a-2014 default value
- “Momentary Cessation” for LVRT < 0.5 p.u.

**Preliminary Screens, Fast Track**

Common cases with DER in distribution areas that use **fast reclosing**

Some cases where DER may **disrupt Area EPS protection coordination** for **high-impedance faults**

Rare cases with reduced effectiveness of **anti-islanding detection**

**Supplemental Screen** for issues, then apply **appropriate means, e.g.:**

- extend automatic reclosing times,
- block hot reclosing,
- direct transfer trip,
- very fast islanding detection

**Supplemental Screen** for issues, then apply means:

- DER overcurrent protection or
- DER voltage-supervised overcurrent protection

**Supplemental Screen** for issues, also consider extending anti-islanding detection/clearing time from 2s to up to 5s

# Conclusions

- IEEE 1547-2018 will help standardize “smart DERs” and accelerate state of the art. It can provide **high value** to the power industry.

- IEEE 1547-2018 Working Group agreed on and specified **safe, reliable,** and **cost-effective** new interconnection and interoperability **requirements** for DERs.

- Specification of **test and verification** requirements is under way in P1547.1.
  - Interim solutions via UL1741-SA exist. ➔ support offered in EPRI project

- IEEE 1547-2018 and P1547.1 will provide a solid and widely-accepted **technical basis for regulatory proceedings**.
  - Action required from state regulators, et al.

# For More Information

General information:
http://grouper.ieee.org/groups/scc21/1547_revision/1547revision_index.html

Working Group meeting notes:
http://grouper.ieee.org/groups/scc21/1547_revision/1547revision_logistics.html

Sign up for the 1547 email listserv:
http://grouper.ieee.org/groups/scc21/1547_revision/1547revision_listserv.html

Contact Info:

Andy Hoke, NREL | andy.hoke@nrel.gov
Jens C. Boemer, EPRI | jboemer@epri.com
Dave Narang, NREL | david.narang@nrel.gov

**Thank You**

# Further Reading


- NERC (2017): Distributed Energy Resources. Connection, Modeling, and Reliability Considerations. North American Electric Reliability Corporation (NERC). [Online]
- Boemer, J.C., et al. (2017): Status of Revision of IEEE Std 1547 and 1547.1. In: 2017 IEEE PES General Meeting. Chicago, IL, 16-20 July. IEEE Power & Energy Society.
- Boemer, J.C., et al. (2016): Status of Revision of IEEE Std 1547 and 1547.1. Informal report based on IEEE P1547/Draft 5.0 (August 2016). In: 6th International Workshop on Integration of Solar Power into Power Systems. Vienna, Austria, November 14-15. [Online]
- van Ruitenbeek, E., et al. (2014): A Proposal for New Requirements for the Fault Behaviour of Distributed Generation Connected to Low Voltage Networks. In: 4th International Workshop on Integration of Solar Power into Power Systems. Berlin, Germany, November 10-11. [Online]
- Hoke, A., et al. (2016): Experimental Evaluation of PV Inverter Anti-Islanding with Grid Support Functions in Multi-Inverter Island Scenarios, National Renewable Energy Laboratory, NREL/TP-5D00-66732. [Online]

IEEE Std 1547-2018

# Clause 6:
# Response to Area EPS abnormal conditions

# Backup slides

# Application of revised IEEE 1547-2018

## What are “ranges of allowable settings”?

- **Definition:** The range within which settings may be adjusted to values other than the specified default settings.

- Used for functional specifications, not for capabilities.

- Default values specify generic settings *that do not harm*.
  - May not be most effective.

**Used throughout the standard**

- Voltage regulation
  - 5.3 Voltage and reactive power control
  - 5.4 Voltage and active power control
- Voltage and frequency trip
  - 6.4.1 Mandatory voltage tripping
  - 6.5.1 Mandatory frequency tripping
- Momentary cessation threshold during ride-through (6.4.2.7.3)
- Frequency regulation
  - 6.5.2.7 Frequency-droop (frequency-power)

# Application of revised IEEE 1547-2018

Required Processes for Transmission and Distribution Utilities Coordination in the Context of IEEE 1547-2018

- Appendix B: Selection of abnormal (and possibly also normal) performance categories.
  - Consideration of bulk system reliability with future penetration of DERs.

- 4.10.3 (Performance during entering service):
  - Approval of non-standard increase of output of active power by DER with a rating of ≥500 kVA that increase output with active power with steps greater than 20% of nameplate active power rating.

- 6.4.1 (Mandatory voltage tripping requirements) and 6.5.1 (Mandatory frequency tripping requirements):
  - Guidance on voltage / frequency trip settings different from default values and within specified ranges of allowable settings.
  - Guidance on occasionally and selectively used trip settings of distribution grid protective equipment that is not a DER and that may be set outside the ranges of allowable settings as specified by the new P1547 to accommodate worker safety practices or to safeguard distribution infrastructure while in an abnormal configuration.

# Application of revised IEEE P1547-2018

Required Processes for Transmission and Distribution Utilities Coordination in the Context of IEEE 1547-2018

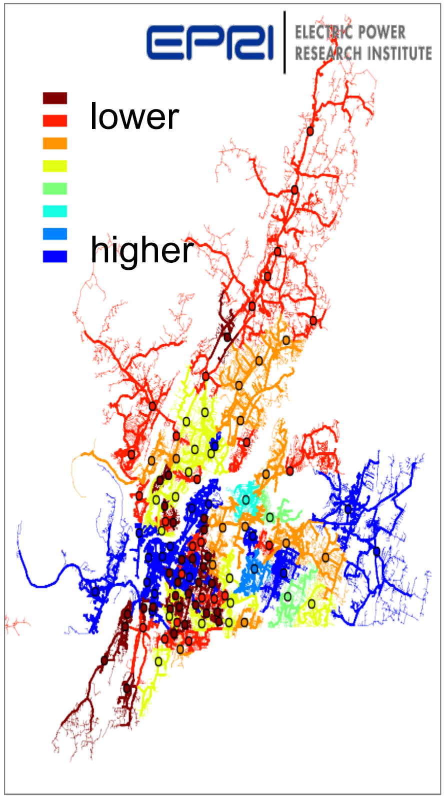
- 6.5.2.7.2 (Frequency-droop (frequency-power) operation):
  - Guidance on adjustments to the frequency-droop (frequency-power) operation settings including parameters for the deadband ($db_{OF}$ , $db_{UF}$), droop ($k_{OF}$ , $k_{UF}$) and small-signal open-loop response time ($T_{response\ (small\text{-}signal)}$).

- 6.4.2.7.3 (Transition between performance operating regions for Category III DER):
  - Guidance on the non-mandatory capability to adjust and the setting of the Momentary Cessation voltage threshold of category III DER.

- 6.5.2.8 (Inertial response):
  - Guidance on the non-mandatory capability and performance requirements for inertial response, in which the DER active power is varied in proportion to the rate of change of frequency.

Example: Specify grid-specific voltage control settings to increase "hosting capacity".

## Hosting Capacity




Factors impacting hosting capacity:

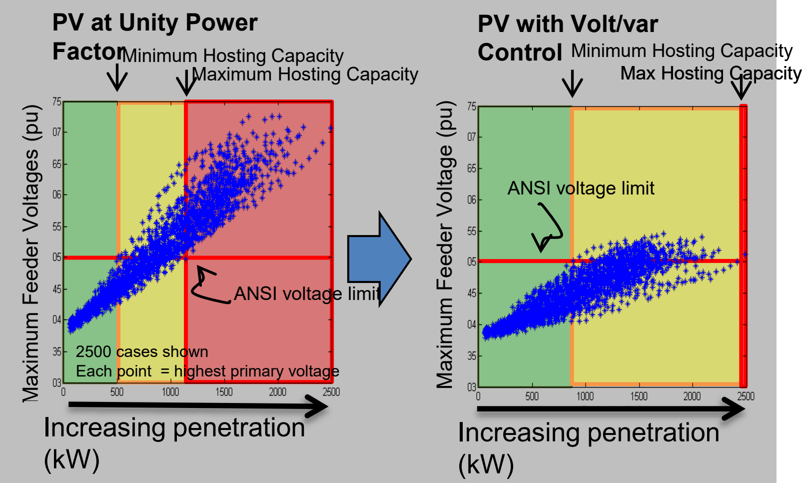
- Feeder Design and Operation
- DER Location
- DER Technology
  - Variable vs. non-variable generation
  - Synchronous vs. inverter-based
  - Traditional vs. advanced inverters

Criteria evaluating hosting capacity:

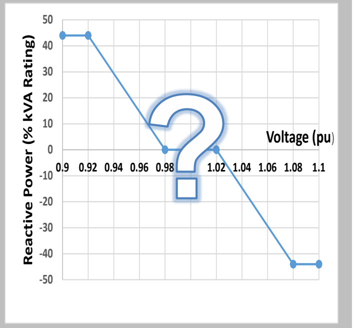
- Power quality/voltage
- Thermal overload
- Protection
- Reliability/Safety

Refer to 3002008848 for more info.

## Voltage-Reactive Power Control



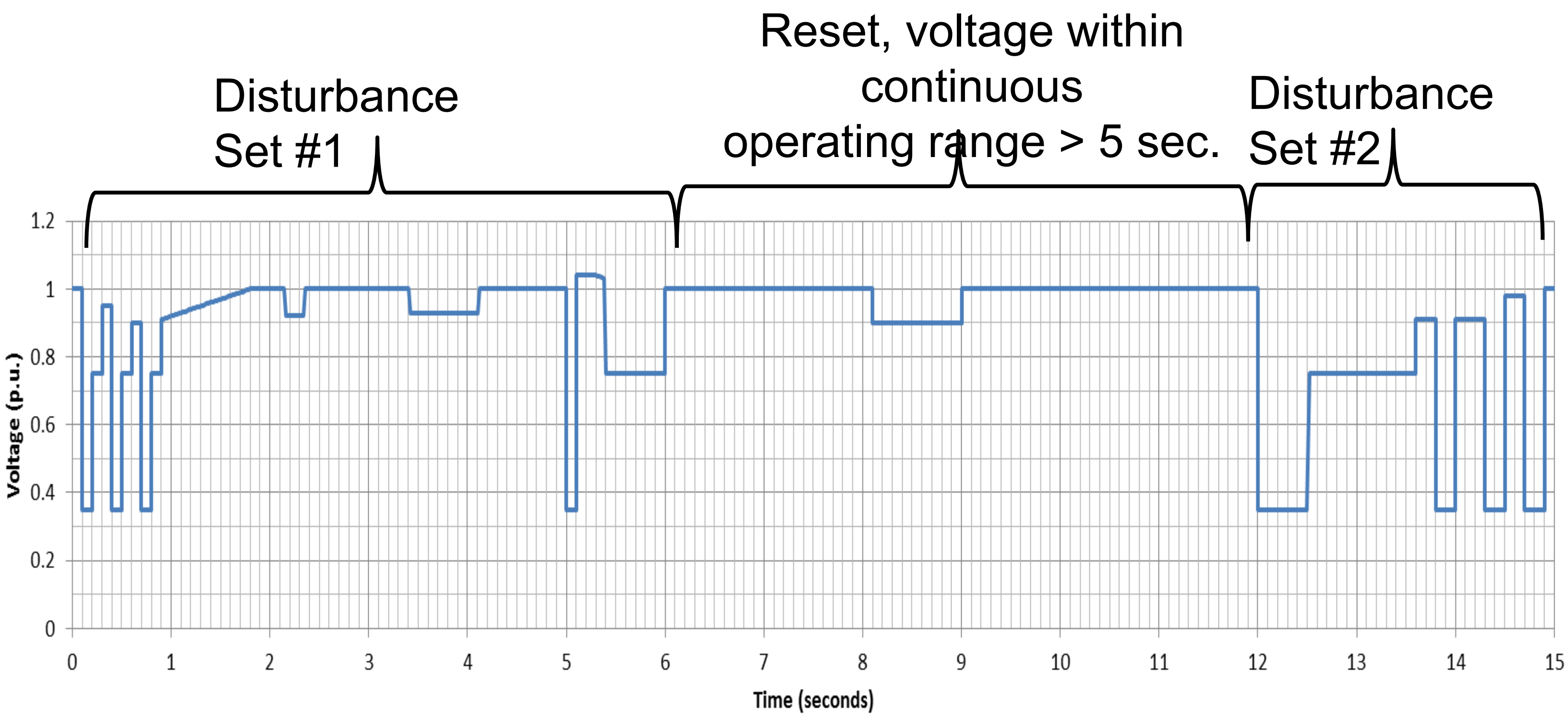

- Increase hosting capacity
  - by addressing voltage issues with exchange of reactive power.
  - may require feeder-specific settings.



# Ride-through of recurring voltage disturbances

- IEEE 1547-2018 mandates ride-through of multiple consecutive disturbances to accommodate:
  - Unsuccessful reclose attempts (transmission or other feeder)
  - Rapidly occurring fault events (e.g., during a severe storm)
  - Dynamic oscillations of bulk system causing voltage to swing in and out of normal range
- Ride-through of multiple events in a *disturbance set* are defined by cumulative undervoltage (or overvoltage) duration – number of events not limited
- Voltage within the continuous operating range for a prescribed period (5 s – 20 s, depending on category) resets cumulative timers; any further disturbance is a new disturbance set.
- Maximum number of sets = 2 to 3, depending on category
- Disturbance set count reset after a period of 20 to 60 minutes

# Consecutive disturbance rule example




Disturbance Set #1: V ≤ 0.75 p.u. for 1 s, V ≤ 0.35 p.u. for 0.4 s

Disturbance Set #2: V ≤ 0.75 p.u. for 2.2 s, V ≤ 0.35 p.u. for 1.1 s

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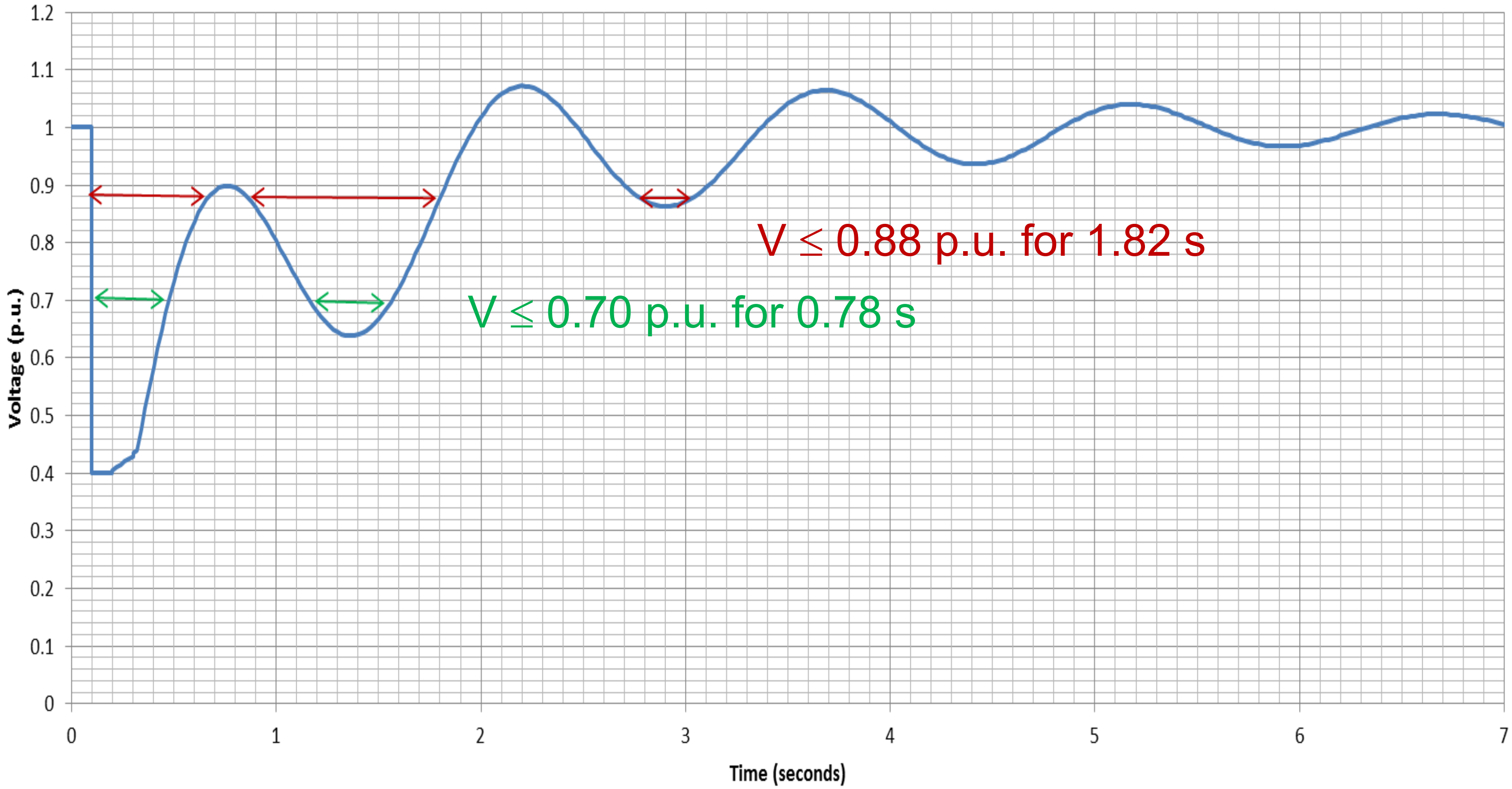
# Bulk system post-fault dynamic swing (example of multiple disturbances)

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# Technical justification for Category II requirements

- Geographic extent of voltage sag
- Voltage sag propagation from T to D
- Typical bulk system fault clearing times
- Fault-induced delayed voltage recovery (FIDVR)

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Recommended Settings for Voltage and Frequency Ride-Through of Distributed Energy Resources

**Minimum and Advanced Requirements and Settings for the Performance of Distributed Energy Resources During and After System Disturbances to Support Bulk Power System Reliability and Their Respective Technical Implications on Industry Stakeholders**

*May 2015*

*Table 3 – Typical Clearing Times of Bulk Power System Faults*

| Clearing | Protection type | High-speed protection[1] all extra-high-voltage elements, >200 kV | Distance protection many high-voltage elements, 100 kV to 200 kV | |
|---|---|---|---|---|
| Normal | Primary | 0.07 s – 0.10 s (4 – 6 cycles) | Zone 1 | 0.10 s – 0.16 s (6 – 10 cycles) |
| Delayed | Backup | 0.16 s – 0.32 s (10 – 20 cycles) | Zone 2 | 0.20 s – 0.42 s (12 – 25 cycles) |
| | | | Zone 3 | 0.50 s – 0.92 s (30 – 55 cycles)[2] |

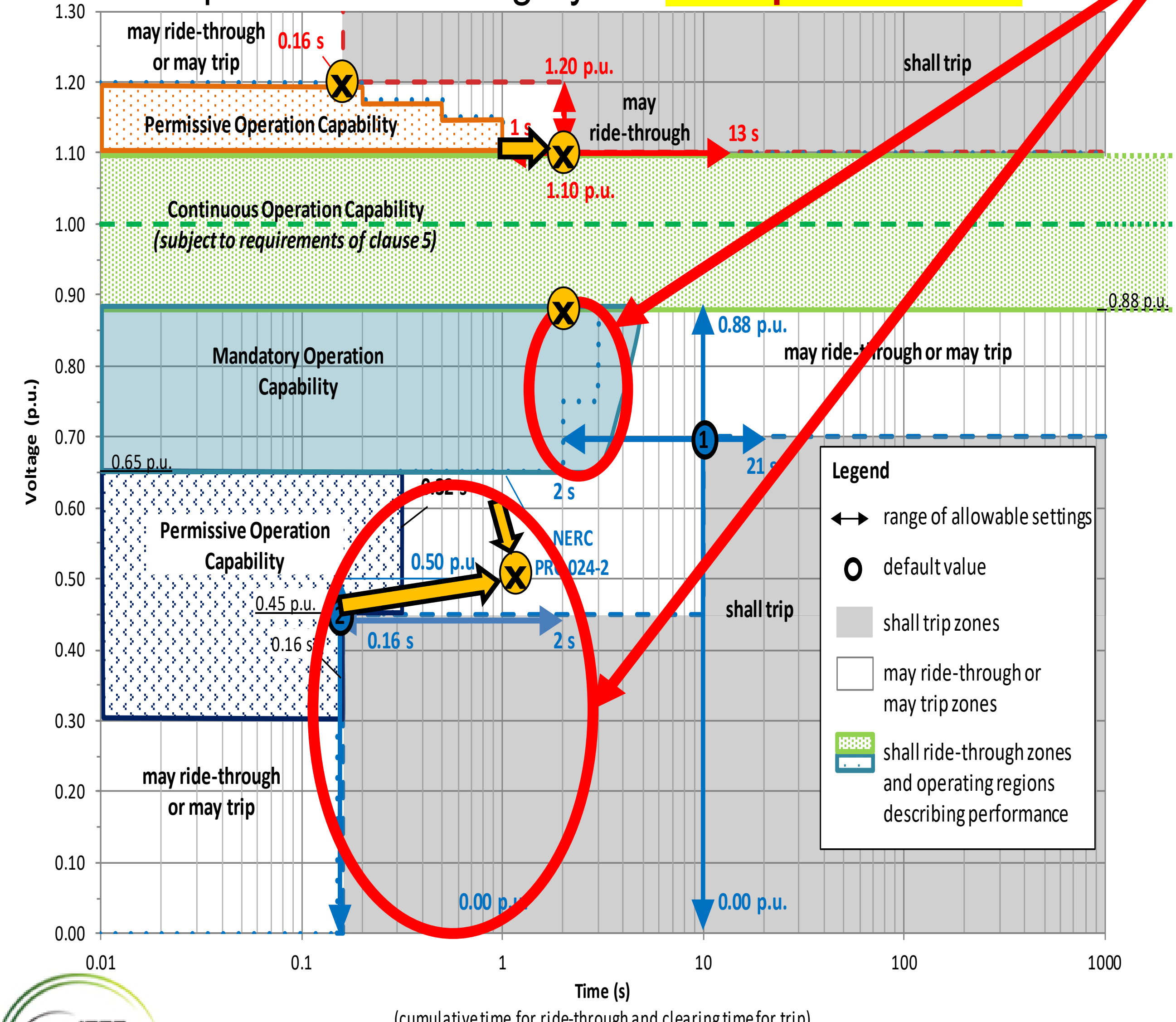
[1] Such as tele-protection or unit/differential protection.
[2] May extend to the order of 1.25 seconds (75 cycles) in some cases.

Source: EPRI White Paper (3002006203), May 2015

# Application of IEEE Std 1547-2018

**Settings of UV1 and UV2 in areas need special attention**

## Abnormal performance category II – Example of ISO NE




- **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**:
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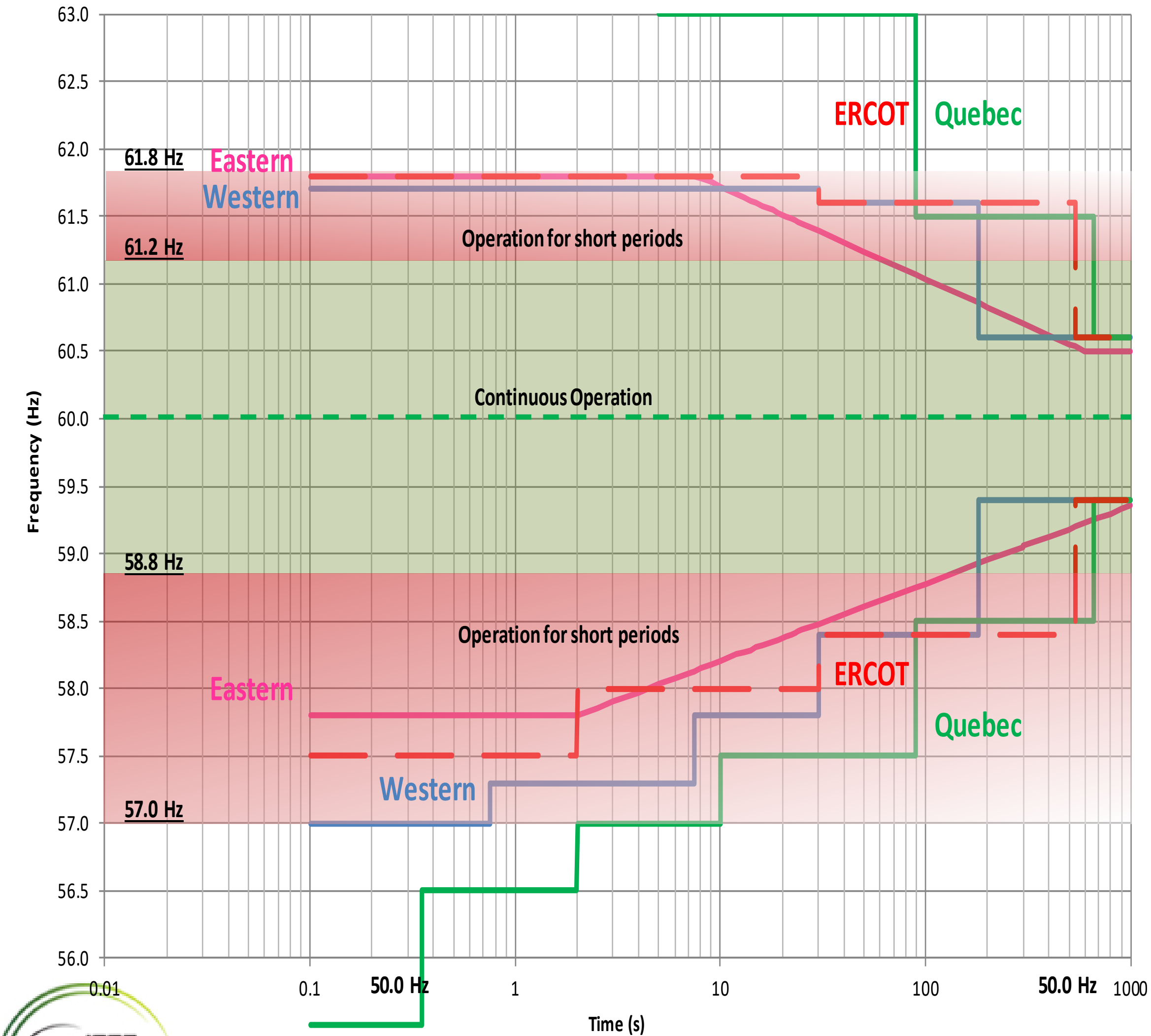
# Comparison with IEEE Std C50.13 and NERC PRC-024-2



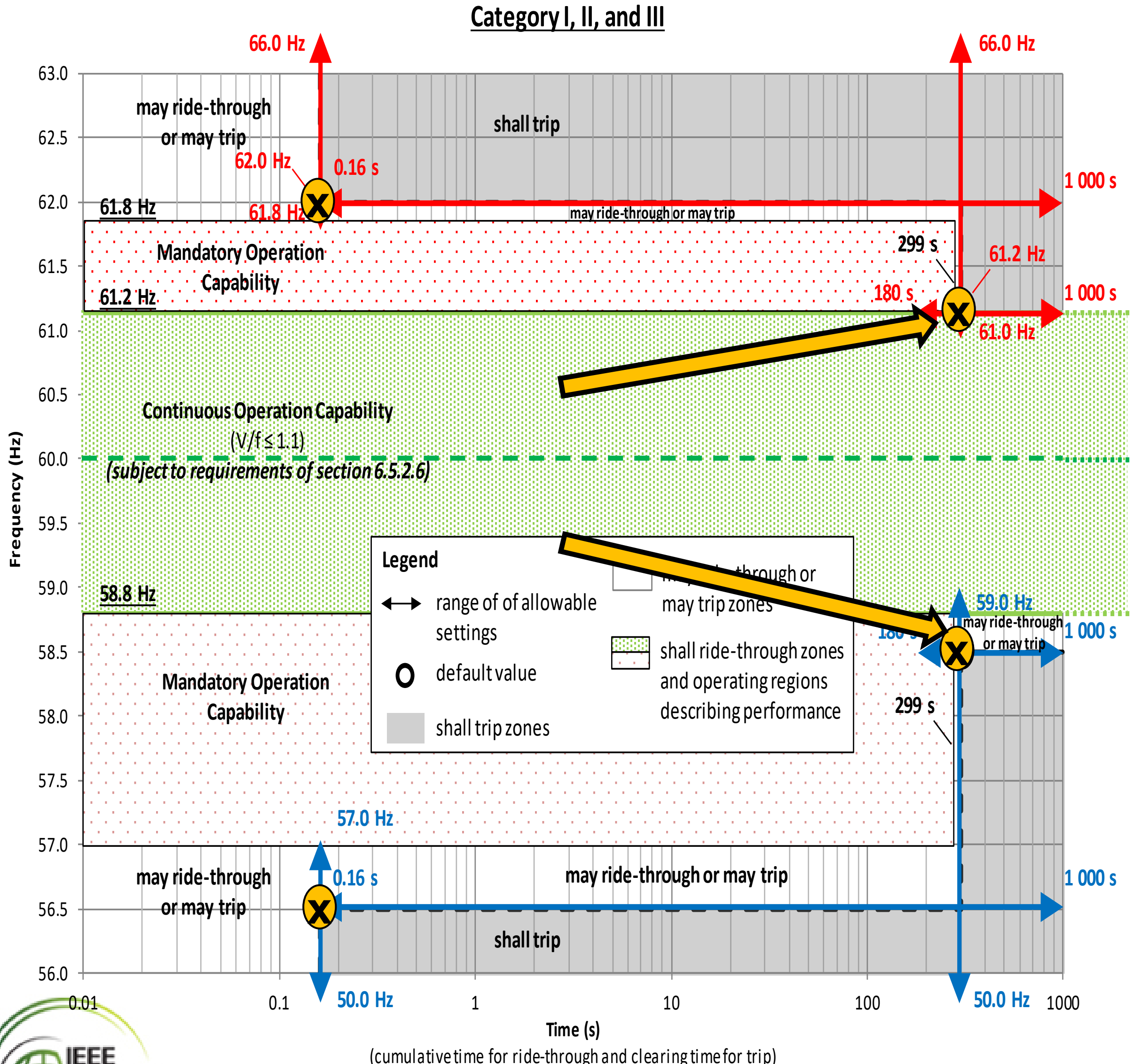

- Shaded areas indicate design specifications of IEEE Std C50.13 for synchronous generators ≥ 10 MVA

- Lines indicate frequency settings envelopes specified by NERC PRC-024-2

# Application of IEEE Std 1547-2018

## Frequency disturbance requirements – Example of ISO NE

ⓧ ISO NE example settings

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  - while the *applicable voltage* and the system frequency is within specified parameters.
- **Mandatory operation:**
  - Continuance of active current and reactive current exchange

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# Voltage disturbances within continuous operating range

- DER must remain in operation for any voltage disturbances in which voltage magnitude remains within C84.1 Range B.
  - E.g., abrupt steps of voltage up or down could be such a disturbance
- Specific requirements for ride-through of recurring disturbances – see extra slides
- DER must deliver available active power as great as the pre-disturbance level prorated by per-unit voltage if voltage is less than nominal
  - Temporary deviations of active power < 0.5 seconds allowed

- Exceptions for unbalance:
  - Negative sequence voltage (V2) > 5% for duration > 60 s.
  - Negative sequence voltage (V2) > 3% for duration > 300 s.

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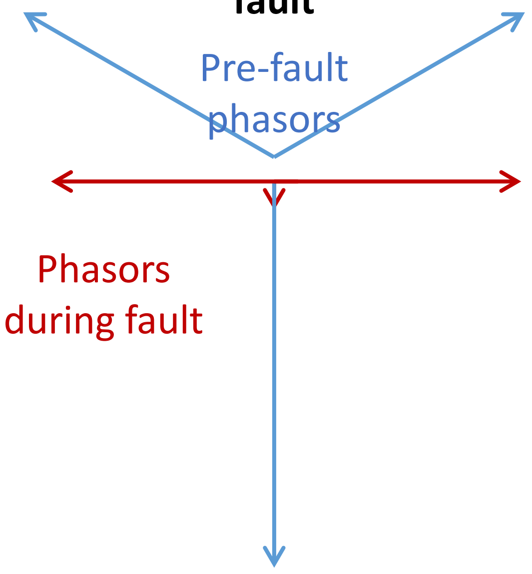
# Frequency rate-of-change ride-through

- During severe grid disturbances, frequency can change rapidly
  - Rate-of-change of frequency (ROCOF) can be greater in low-inertia grids
  - Displacement of synchronous generators by inverter-coupled resources decreases inertia
- If frequency remains in the continuous operation or ride-through frequency range, DER shall not trip for ROCOF < criterion
  - Category I: ROCOF $\leq$ 0.5 Hz/s
  - Category II: ROCOF $\leq$ 2.0 Hz/s
  - Category III: ROCOF $\leq$ 3.0 Hz/s
- Some DER anti-islanding schemes have been based on sensitive ROCOF detection
- ROCOF ride-through requirement places limit on such schemes
  - Manufacturers using this scheme may need to adopt alternative approaches

# Phase jump ride-through

- A phase jump is theoretically an infinite frequency for an infinitesimal period
  - Without a phase-jump ride-through requirement, a phase jump is a loophole
- Positive sequence voltage phase angle jumps occur from:
  - Large abrupt load changes (load tripping)
  - Generator tripping
  - Change in impedance – line tripping
  - Faults – to a relatively small degree
- Individual phase voltage phase angle jumps are caused by unbalanced faults
- IEEE 1547-2018 ride-through requirements:
  - Up to 20° positive-sequence voltage phase angle step
  - Up to 60° individual phase voltage phase angle step
  - Damped power oscillations or momentary cessation < 0.5 seconds allowed

**Distribution voltages for transmission phase-to-phase fault**



# Dynamic Voltage Support (not mandatory)

**Support *during* disturbances?**

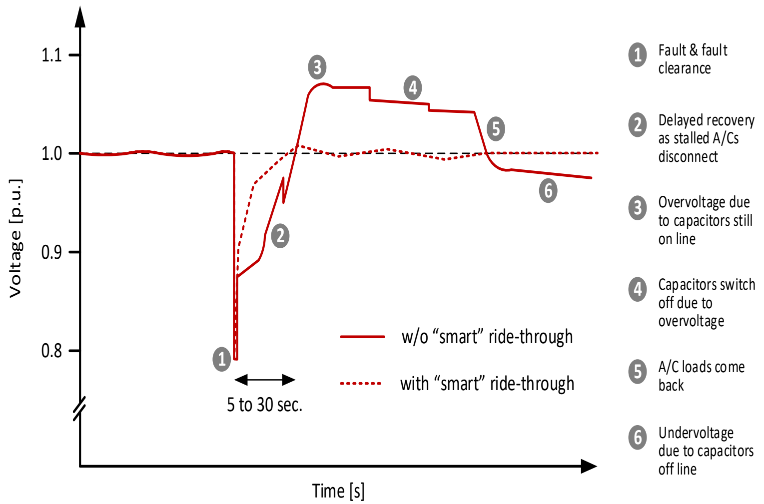
- Very fast response within a few cycles
- Short-circuit contribution
- Keep legacy DER online

**Support *after* disturbances?**

- Fast response within 1 s … 10 s
- Dynamic reactive support
- Mitigate fault-induced delayed voltage recovery (FIDVR)

**Recent EPRI research:**

- Feeder-specific analysis (3002011112)
- System-wide analysis (3002011171)




Source: EPRI White Paper on Ride-Through (3002006203)

**Requirements in new IEEE 1547-2018:**

- Not mandatory but allowed during mandatory or permissive operation
  - Area EPS Operator must agree
- Not specified in detail
  - Shall be designed not to cause overvoltage during unbalanced faults

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# TOP 5 concerns of distribution grid planners, operators, and line workers

- "Cease to energize" with or without galvanic separation?
- Unintentional islanding risk with DERs that ride through disturbances and regulate voltage and/or frequency.
- DER coordination with Area EPS automatic reclosing.
- DER coordination with Area EPS protection.
- DER impact on line workers' safety during hot-line maintenance.

Specify **tests** in IEEE P1547.1

Address in DER interconnection practices via **screening**

➢ ***Feel free to share your own questions and concerns now…***

TOP 5 concerns of distribution grid planners, operators, and line workers

"Cease to energize" with or without galvanic separation?

Distribution **protection** and **operation engineers** may be concerned about performance of DER during **cease to energize**, especially for inverter-based DER.

However, IEEE 1547-2018 explicitly states that DER shall not deliver **active power** and that DER shall limit **reactive power** exchange from **passive devices**.

Hence, the new standard allows solid-state means and does not require disconnection of the DER during cease to energize.

- Therefore, get engaged in IEEE P1547.1 to specify robust cease to energize **test** procedures.

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## TOP 5 concerns of distribution grid planners, operators, and line workers

Unintentional islanding risk with DERs that ride through disturbances and regulate voltage and/or frequency.

Distribution **operations engineers** may be concerned about reduced effectiveness of **anti-islanding detection** when the new voltage and frequency regulation and ride-through requirements enter into effect.

However, on an isolated resistive circuit section, voltage and frequency regulation of DERs tend to not effectively stabilize the island. Furthermore, IEEE 1547-2018 still requires the 2 s anti-islanding detection and clearing time – **without compromise**.

Note that anti-islanding detection **may take longer than 2s** on a **limited number** of distribution circuits with certain combinations of load and DERs.

- Therefore, get engaged in IEEE P1547.1 to specify robust anti-islanding detection **test** procedures and consider extending the AID time from 2s to 5s, if distribution reclosing allows for it.

TOP 5 concerns of distribution grid planners, operators, and line workers

DER coordination with Area EPS automatic reclosing.

Distribution **protection engineers** may be concerned about **out-of-phase reclosing** onto a circuit remaining energized by DERs during low-voltage ride-through (LVRT) operation, especially on circuits with fast reclosing.

However, IEEE 1547-2018 explicitly requires **appropriate means** to ensure that automatic reclosing does not expose the grid to unacceptable stresses or disturbances.

Even though out-of-phase reclosing may not be a big issue for inverter-based DERs themselves, it may cause high TrOV similar to capacitor restrike and severe magnetic inrush that can cause overcurrent protective devices to operate.

- Therefore, **screen for** DER and automatic reclosing coordination issues: **Distribution utilities** may either need to extend automatic reclosing times or deploy measures to block hot reclosing, or **DER owners** may need to deploy means like direct transfer trip or very fast islanding detection.

TOP 5 concerns of distribution grid planners, operators, and line workers

DER coordination with Area EPS protection.

Distribution **protection engineers** may be concerned about adverse impacts of DERs during low-voltage ride-through (LVRT) on **distribution protection schemes**.

However, IEEE 1547-2018 requires a DER to trip for faults on the circuit to which the DER is connected, keeps the under voltage trip value UV2 close to the 1547a-2014 default value and requires “Momentary Cessation” for LVRT below 50% of nominal voltage for Category III (very high penetration) DERs.

Hence, only high-impedance faults, for which the retained voltage remains high, may still be of concern.

- Therefore, **screen for** issues where DER **short-circuit current** for high-impedance faults **may exceed a defined threshold** and may not be out-of-phase with the fault current from other sources, as it may often be the case for inverter-based DERs.

TOP 5 concerns of distribution grid planners, operators, and line workers

DER impact on line workers' safety during hot-line maintenance.

Distribution **line workers** may be concerned about **increased risk** of **shock and burn** and **arc flash** during hot-line maintenance, due to DERs feeding a current during low-voltage ride-through (LVRT).

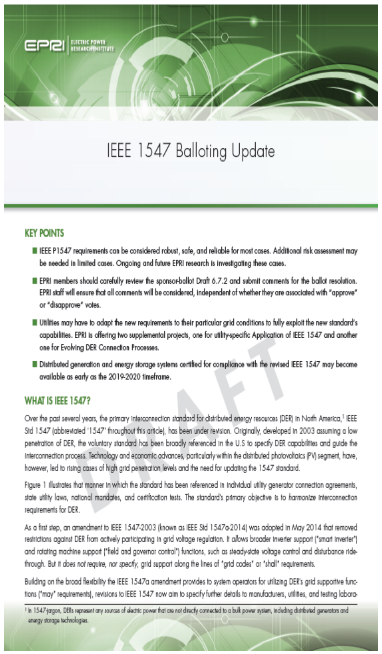
However, in addition to the previously mentioned requirements, IEEE 1547-2018 allows the utility to require and operate an isolation device or shut off the DER via SCADA prior to the maintenance.

Note that **shock and burn** hazard is not uniquely related to fault ride-through of DERs. For **arc flash**, high-impedance faults during hot-line maintenance may still be perceived as a concern, unless DERs are preventively tripped by the **distribution operators**.

- Therefore, **screen for** conditions where arc power may exceed a defined threshold for high-impedance faults and the current contribution from inverter-based DERs may be in the same order of magnitude as the grid contribution. For synchronous generator-based DERs, overcurrent protection or direct transfer trip can minimize DER fault contribution.

# Application of revised IEEE Std 1547

## NRECA articles and EPRI white papers give further insights




**Fact Sheet**
*available on epri.com*

| NRECA *Revision of IEEE Standard 1547™* Articles | Availability |
|---|---|
| 1. The Background for Change, November 2016 | NRECA + EPRI |
| 2. New Reactive Power and Voltage Regulation Capability Requirements, December 2016. | NRECA + EPRI |
| 3. New Disturbance Response Requirements, February 2017. | NRECA + EPRI |
| 4. New Power Quality and Islanding Issues, April 2017. | NRECA + EPRI |

| EPRI white papers | Availability |
|---|---|
| 5. Minimum Requirements for DERs Ride-Through | Published |
| 6. Communications interface and interoperability | Published |
| 7. Power quality considerations for DERs | Published |
| 6. Impacts of DER ride-through on anti-islanding and distribution protection | Draft |

**+ IEEE PES plans to publish white papers in Q1 or Q2 of 2018**

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# TUT-04:
# IEEE Standard 1547-2018
# Clause 8: Islanding (& Energy Storage)

**Leo Casey, ScD**

IEEE T&D Conference Tutorial

April 16, 2018

# Disclaimer & Acknowledgements

- *This presentation and discussion here on IEEE 1547-2018 are the author's views and are not the formal explanation or position of the IEEE.*

- *Note that all information in the proposed standard is the output of IEEE's balloting process and subject to editorial changes during publication of the standard.*

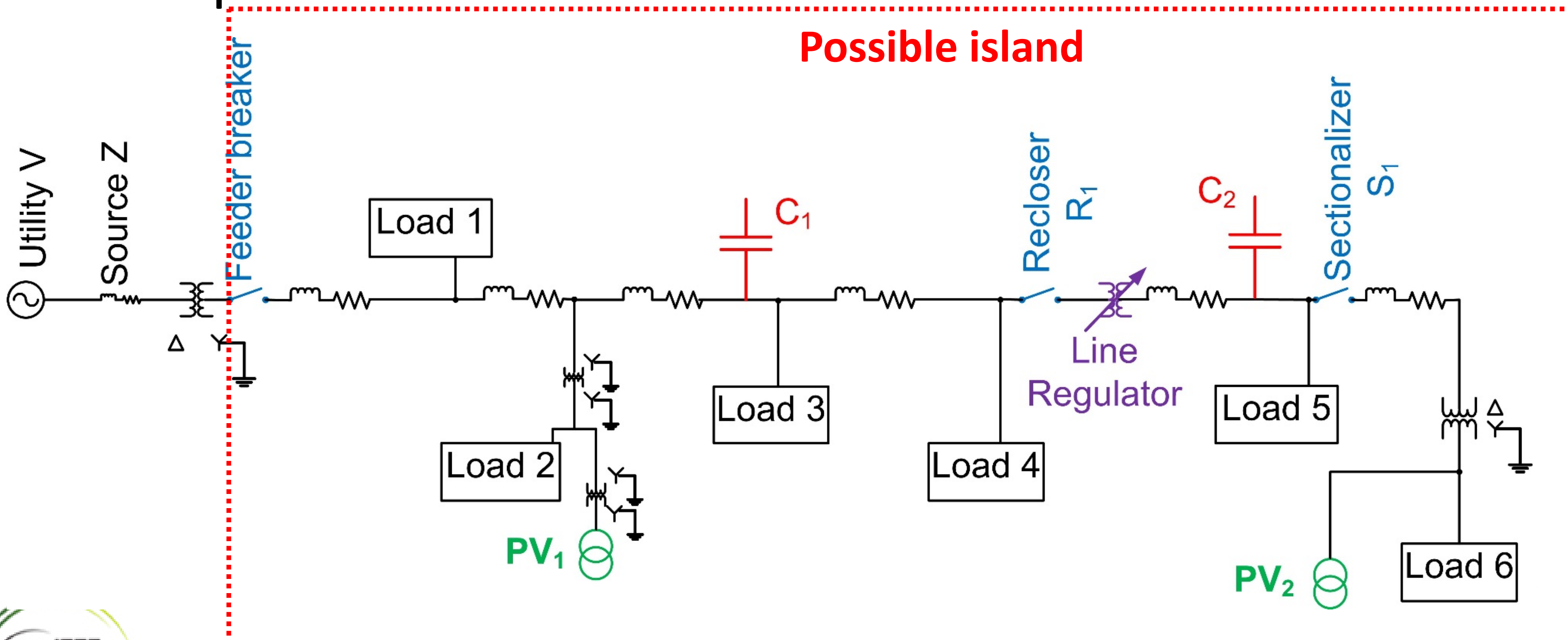
- *Thanks to Dr. Michael Ropp for his work on this section of the Standard*

# Contents

- Islanding Background
- IEEE 1547-2003 on Islanding
- Major changes in IEEE 1547-2018 on Islanding
  - High DER Penetration Challenges
  - Intentional Islanding
  - Impact on Area EPS

# What is an island?

- An electric power island is a section of a power system with its own sources and loads, so that it can self-power or "self-excite".



# Island terminology

- Intentional island: one that is planned, has a defined boundary, and has V/f regulation controls. Types:
  - Microgrid
  - Emergency/standby power supply
  - Island power system (as in, on an actual island)
  - Remote community grid
  - Military bases
  - Remote resource extraction operations
- Unintentional island: one that isn't planned and doesn't have V/f regulation control.

# How can an unintentional island form?

- Two key things have to happen at once.
  - You have to have a close source-sink balance in the island in both real and reactive power.
  - You have to have a breaker, recloser etc. open, without a fault in the island. (If there is a fault, there's almost no way to get a source-sink balance in the island.)
- The likelihood of either one of these events is low; the likelihood of both happening in sequence is *very* low. So, an unintentional island is a very low-likelihood event.

# Risks

- Unintentional islands pose the following risks:
  - Damage to equipment via asynchronous reclosure
  - Impediment to service restoration
  - Damage to equipment via uncontrolled voltage and frequency
  - Potential risk to human health and safety—people may be unaware that a line is energized from the customer side (line worker performing maintenance, “downed wire on a car” scenario)

# Starting point: what IEEE 1547-2003 said

- On the subject of unintentional islanding:
  - Clause 4.1.5, “Inadvertent energization”: the DR shall not energize the Area EPS when the Area EPS is de-energized.
  - Clause 4.4.1, “Unintentional islanding”: it’s the responsibility of the DR to detect an unintentional island and trip offline within 2 s.
  - Clause 4.2.2, “Area EPS reclosing coordination”: the DR shall cease to energize the Area EPS prior to reclosure by the Area EPS, even if that reclosure is in less than 2 s.

# Starting point: what IEEE 1547-2003 said

- On the subject of intentional islanding:
  - Clause 4.4.2, “Intentional islanding”: punted to a future revision.

**4.4.2 Intentional islanding**

This topic is under consideration for future revisions of this standard.

# Major changes in the new revision: unintentional islanding

- Now Clause 8.1.
- The main change: There is a new, optional 5-s clearing time limit that can be used upon mutual agreement between the DER operator and the Area EPS operator.
  - Allows the use of novel islanding detection that may work better in high-pen cases but may need a bit more time to achieve sensitivity *and* selectivity.
- The default clearing time is still 2 s as it was in 1547-2003, so the default case is no change from the previous version.
- There is new *emphasis* placed on the recloser coordination clause, but not a new *requirement*.

# New high-pen challenges

- Mixtures of different inverters—will they interact in such a way that degrades islanding detection? *(Initial indications: yes, they can.)*
- Ride-throughs—will requiring LVRT and L/HFRT degrade islanding detection? *(Initial indications: yes, a little bit, but not much.)*
- Mixtures of inverters and rotating machines—do these mess each other up? *(Initial indications: definitely yes.)*

# Islanding detection methods

- Passive inverter-resident
- Active inverter-resident
- Non-inverter-resident
  - Communication-based
    - DTT
    - Synchrophasors
    - PLCP
  - System configuration changes
    - Capacitor toggling
    - Shorting switches

# Intentional islands: what's in-scope?

**An intentional island that contains any part of the Area EPS is in-scope.**

**Intentional island behavior at the PCC, and impacts on the Area EPS, are in-scope.**

**What happens "behind the meter" within a microgrid that does *not* include any Area EPS elements is out-of-scope.**

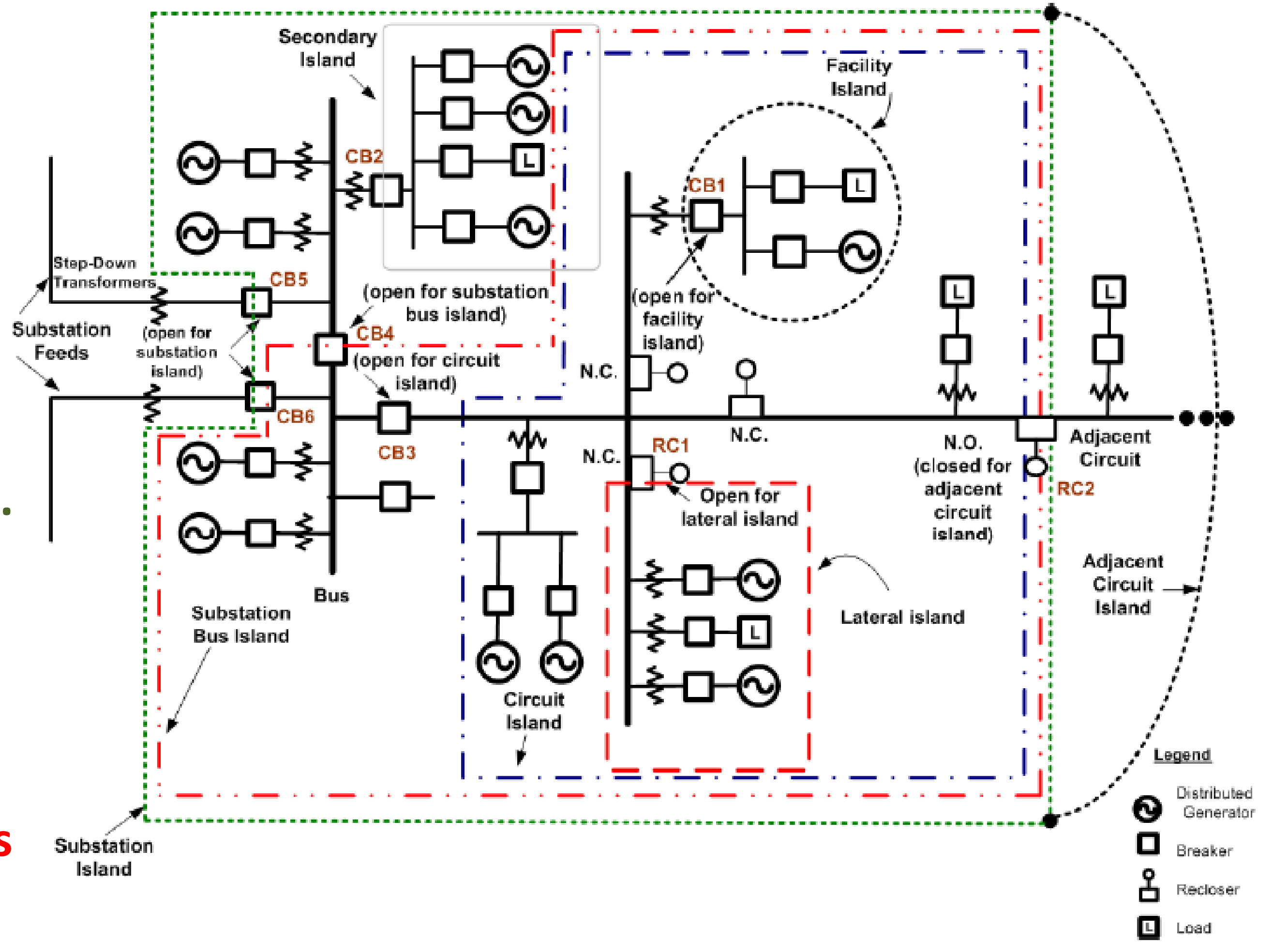



Figure C-1—Examples of DR island systems from IEEE Std 1547.4-2011

# 1547-2018 and intentional islands

- In this presentation, Intentional Island = II
- Two types of transitions into II mode (on-grid to off-grid): scheduled and unscheduled.
  - Scheduled: initiated by manual action or dispatch.
  - Unscheduled: automatically initiated due to abnormal Area EPS conditions.
- Power systems designated by the AHJ as Emergency, Legally Required, or Critical Operations are exempted.

# When can an II leave the grid?

- When conditions are met that are mutually agreed-to by the Area EPS and DER operators;
- If any of the abnormal voltage or frequency trip conditions is met; or
- If an unintentional island is detected.

**For these latter two cases, one may substitute entry into intentional island mode for tripping.**

# Limits on Area EPS impact when leaving the Area EPS

- If an II disconnects from the Area EPS for any of the reasons listed on the previous slide, it shall do so without causing a voltage fluctuation greater than ±5% of the nominal voltage at any PCC between the Area EPS and the intentional island.
- There are two exceptions to this requirement:
  - If the II "takes its load with it"—i.e., when the II leaves the grid, it causes an amount of load equal to 90% to 110% of its rating to leave the grid also;
  - The II is an emergency or standby generator that is on-grid for testing purposes only.

# Limits on an II coming back onto the Area EPS

- An II can reconnect when the "return-to-service" requirements of Clause 4.10 are met (basically, the voltage and frequency are within defined limits).
- When the II reconnects, the requirements of Clause 4.10.4 ("synchronization", which defines how well synched to the grid the II must be in both voltage and frequency).

# Changes to relay settings in II mode

- You're allowed to reduce the threshold and lengthen the time for OV2.
- You're allowed to greatly lengthen the time limits on frequency trips OF1 and UF1 (range of adjustability goes up to 1000 s).
- The ranges of adjustability for the frequency droop gain are made wider.

# DER categories for II use

- The standard defines four categories of DER for II use:
  - Uncategorized = not designed for off-grid operation at all. These are not allowed to energize an II.
  - II Capable: can disable anti-islanding, and meet all the settings adjustments requirements on the previous slide.
  - Black Start Capable: can energize an EPS that contains no other energy sources.
  - Isochronous Capable: Black Start Capable, *and* can regulate V and f in an EPS that does contain other sources.

# Your Input and Participation is Needed

- P1547.1 Test Procedures, Revision

  Andy Hoke, Chair

- P1547.2 User's Guide, Revision

  Wayne Stec, Chair

- P1547.9 Guide to ES-DER Interconnection, *New*

  Mike Ropp, Chair

Leo Casey, Google x | leo.casey@google.com

# THANK YOU

# TUT-04: IEEE Standard 1547-2018 Clause 10: Interoperability, information exchange, information models, and protocols

**Mark Siira** (ComRent)
On behalf of Bob Fox (SunSpec Alliance)

IEEE T&D Conference Tutorial
April 16, 2018

# Interoperability Requirements

- Communication requirements
- Identified functions to communicate
- Scope of interoperability
- Protocols

# Communication Requirements

- A DER shall have provisions for an interface capable of communicating (local DER communication interface) to support the information exchange requirements specified in this standard for all applicable functions that are supported in the DER.
- Under mutual agreement between the Area EPS Operator and DER Operator additional communication capabilities are allowed.
- The decision to use the *local DER communication interface* or to deploy a communication system shall be determined by the Area EPS operator.

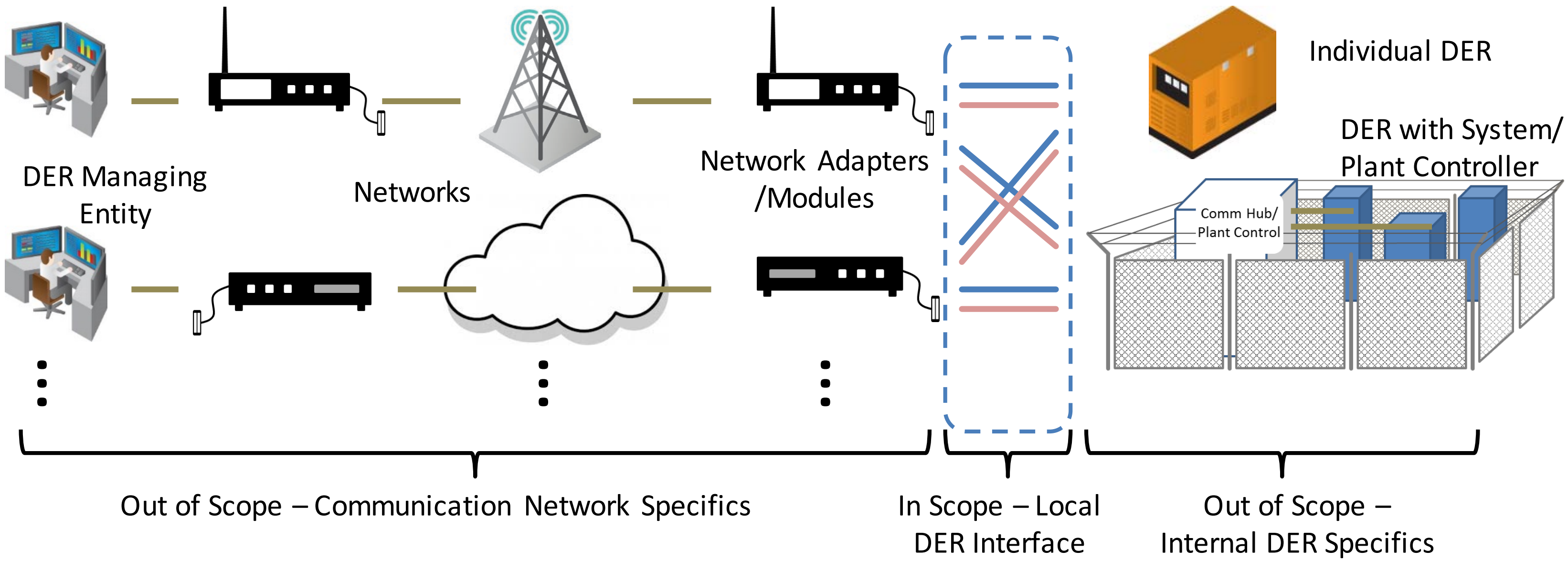
# Information Categories

- Information to be exchanged:
  - Nameplate Data – As-built characteristics of the DER.
  - Configuration Information – Each rating in Nameplate Data may have a configuration setting.
  - Monitoring Information – Latest value measured.
  - Management information – This information is used to update functional and mode settings for the DER.

# Management Information

- Constant power factor mode parameters
- Voltage-Reactive power mode parameters
- Active power-reactive power mode parameters
- Constant reactive power mode parameters
- Voltage-active power mode parameters
- Voltage trip and momentary cessation parameters
- Frequency trip parameters
- Frequency droop parameters
- Enter service parameters
- Cease to energize and trip
- Limit Maximum active power

# Scope of Interoperability Requirements




IEEE 1547 interface (mandatory) — other interfaces (optional) — out of scope

# List of Eligible Protocols

| Protocol | Transport | Physical Layer |
|---|---|---|
| IEEE Std 2030.5™ (SEP2) | TCP/IP | Ethernet |
| IEEE Std 1815™ (DNP3) | TCP/IP | Ethernet |
| SunSpec Modbus | TCP/IP | Ethernet |
| | N/A | RS-485 |

# Logical Combinations of Protocols

| | | | |
|---|---|---|---|
| Application | DNP3 | IEEE 2030.5 | SunSpec Modbus |
| Transport | TCP | TCP | N/A |
| IP Layer | IP | IPV6 | |
| Network Access | Ethernet | Ethernet | RS-485 |
| | Twisted Pair/RJ-45 | Twisted Pair/RJ-45 | Twisted Pair/ RJ-45/CTA-2045 |

- Allowing for a couple of well-defined options gives vendors more flexibility and is still achievable for aggregators/integrators.

# Communication Performance Requirements

| Parameter | Requirement | Description |
|---|---|---|
| **Availability of communication** | When DER is operational | The **local DER communication interface shall be active and responsive whenever the DER is operating** and in a continuous operation region or mandatory operation region. |
| **Information read response time** | ≤ 30 s | The maximum amount of time to respond to read requests. |

# IEEE Std 1547-2018

## Clause 11:
## Verification and Testing

Mark Siira

# Disclaimer

This presentation and discussion on IEEE 1547 are views of the individuals and are not the formal position, explanation, or position of the IEEE.

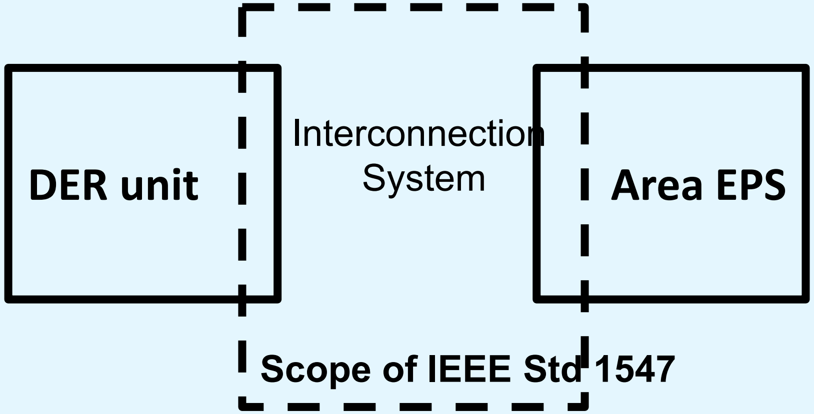
# Index

- General Remarks and Limitations
- Key Decisions
  - Determination of the Reference Point of Applicability
  - DER versus Composite Compliance
- Type Testing
- Production Testing
- Design Evaluation
- As-Built Installation Evaluation
- Commissioning
- Periodic Testing
- Application of IEEE 1547-2018 prior to revision of P1547.1
- Summary and Conclusion

# General remarks and limitations

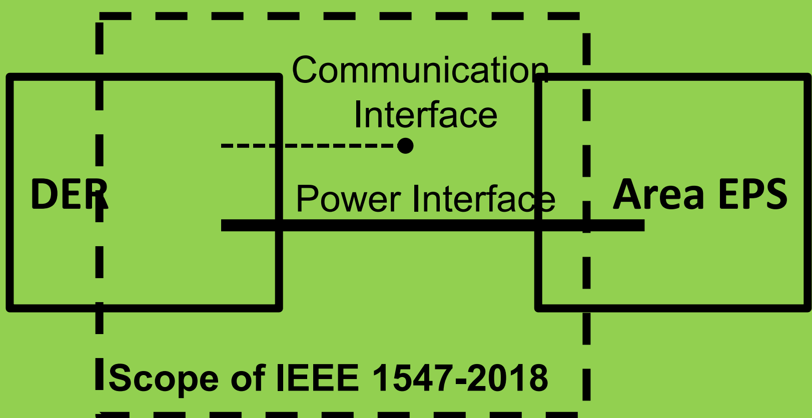
- Applicable to all DERs connected at typical primary or secondary distribution voltage levels.
  - Not applicable for transmission or networked sub-transmission connected resources.
- Specifies <u>performance</u> and <u>not design</u> of DER.
- Specifies <u>capabilities and functions</u>

# Important changes




**IEEE Std 1547-2003**

- Distribution system aspects.
- Specifications for the "interconnection system" sufficiently achieve the standard's objective.
- Meant as DER interconnection standard but mainly used for equipment listing.
- Limited to electrical requirements.




**IEEE 1547-2018**

- Focused on distribution and bulk system aspects.
- Specifications encompass the whole DER.
- Can be used for equipment listing as well as system-level verification.
- Includes both electrical as well as interoperability/communications requirements.



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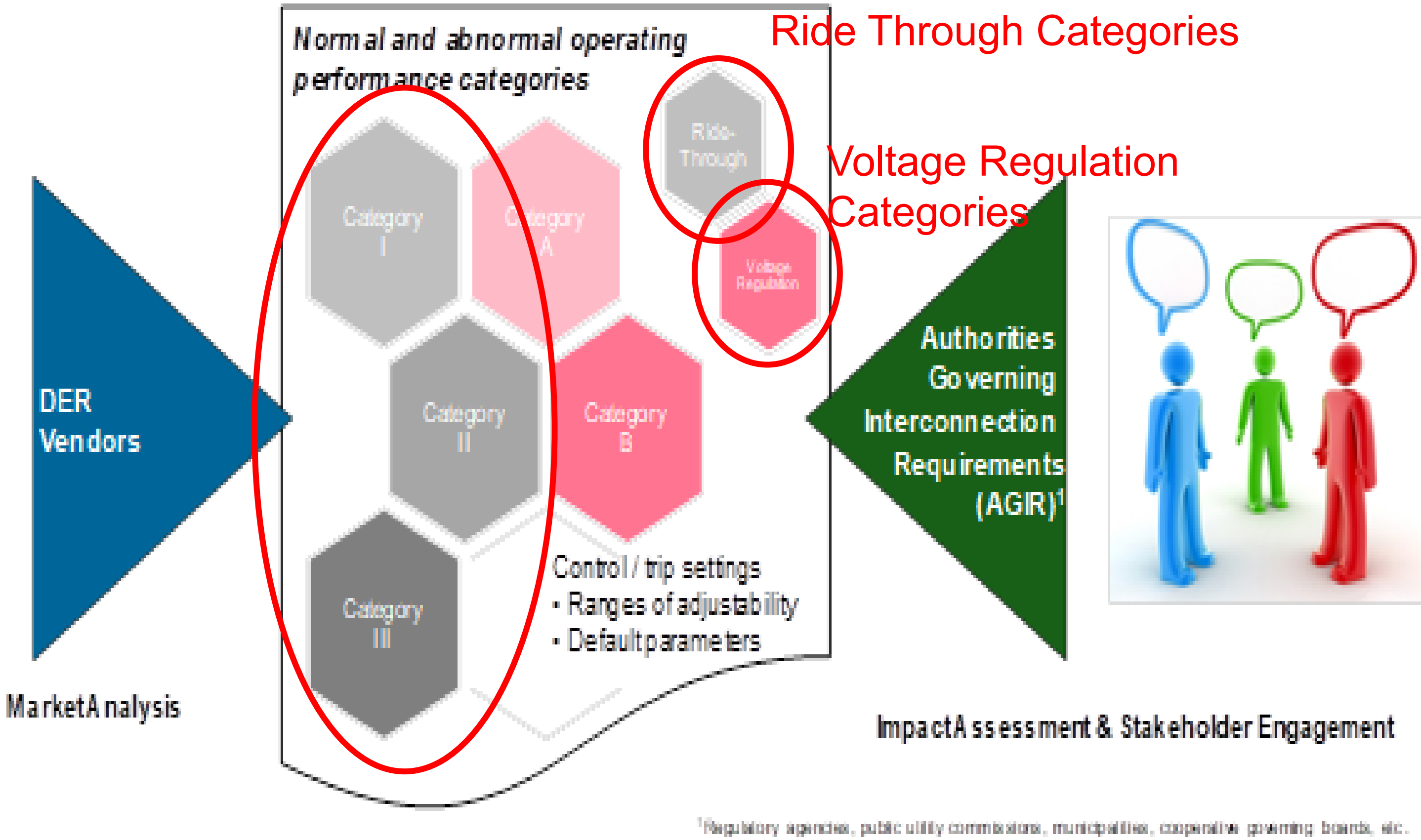
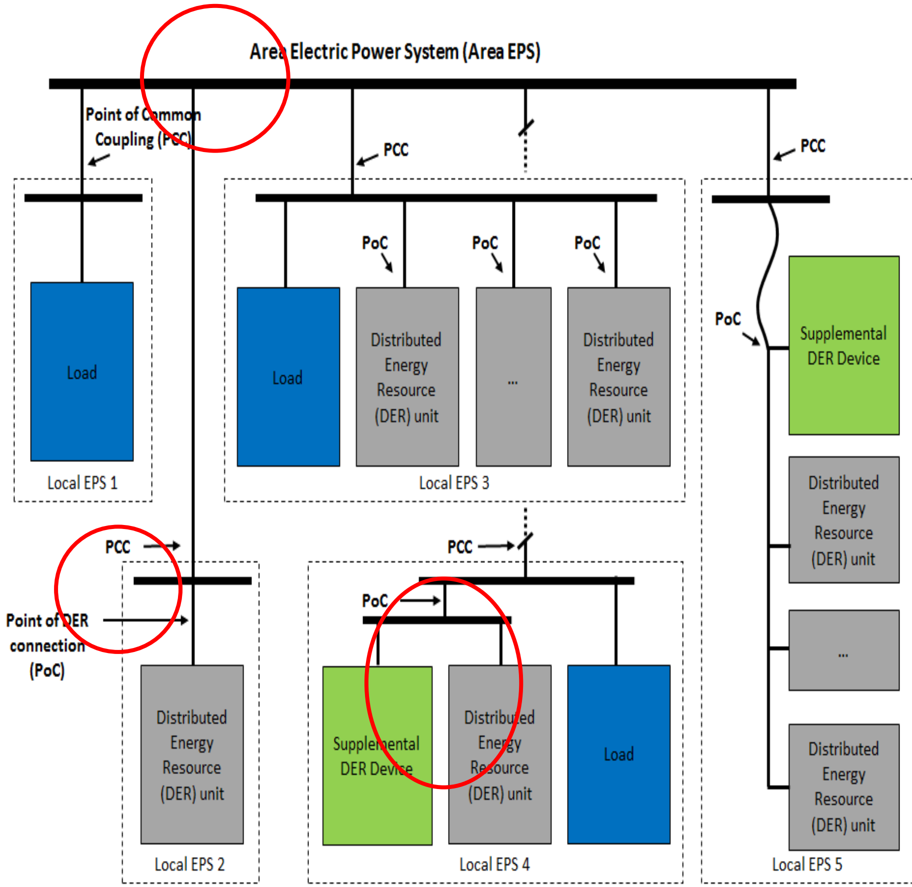
# IEEE 1547-2018 Performance Category



# Determination of Reference Point of Applicability

- Reference Point of Applicability (RPA) and Compliance with or without supplemental DER device determines the verification requirements
- RPA is determined by:
  - The characteristics of the Local EPS and DER
  - Default reference point is Point of Common Coupling (PCC)
  - Point of DER Connection (PoC) is Allowed in Certain Cases

# Reference Point of Applicability and Related Normative Definitions




**reference point of applicability (RPA):** The location where the interconnection and interoperability performance requirements specified in this standard apply.

*Source: 1547-2018Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*

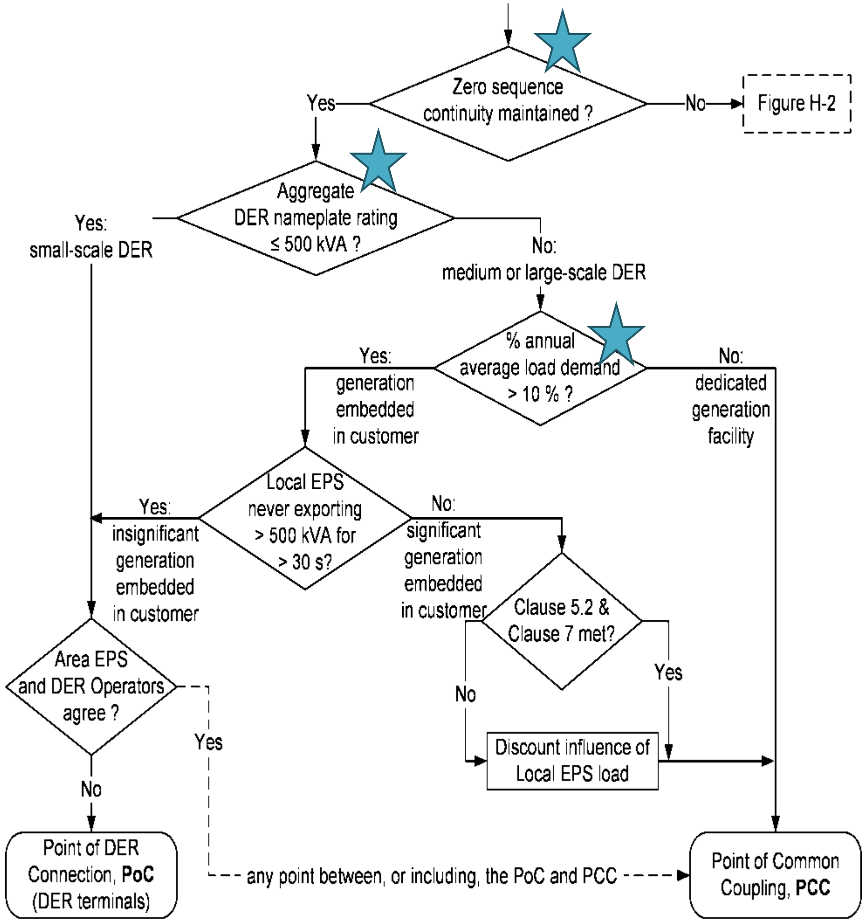
- **Point of common coupling (PCC):** The point of connection between the Area EPS and the Local EPS.

- **Point of DER connection (PoC):** The point where a DER unit is electrically connected in a Local EPS and meets the requirements of this standard exclusive of any load present in the respective part of the Local EPS.

- **Supplemental DER Device**
  - capacitor banks
  - STATCOMs
  - harmonic filters not part of a DER unit
  - protection devices
  - plant controllers

# Determination of Reference Point of Applicability (RPA)

The reference point of applicability (RPA) has implications for testing & conformance requirements in IEEE 1547-2018 & P1547.1 !




## RPA depends on

- Zero-sequence continuity (or not)
- Aggregate DER nameplate rating (500kVA)
- Annual average load demand (10%)

**zero-sequence continuity**: Circuit topology providing continuity between two defined points in the zero sequence network representation.

NOTE—A transformer having a delta or ungrounded-wye winding in the topological path between the defined points produces discontinuity of the zero-sequence network.

# DER versus Composite Compliance

- For DER system that shall meet requirements at PCC
  - DER System – DER system is fully compliant at PCC
    - *No supplemental DER device needed*
  - Composite – Composite of partially compliant DER that is fully compliant at PCC
    - May need one or more supplemental DER devices

- Examples for supplemental DER devices: capacitor banks, STATCOMs, harmonic filters that are not part of a DER unit, protection devices, plant controllers, etc.

# High-level test and verification

The test requirements give guidance, yet are flexible enough to consider the large variety of actual DER setups in the field:

| IEEE 1547-2018 Requirement XYZ | | Applicability of Requirements | |
|---|---|---|---|
| | | Point of DER Connection (PoC) | Point of Common Coupling (PCC) |
| DER Capability & Conformance achieved by | **DER** no Supplemental DER Device needed | Type Test of DER unit + Basic Commissioning Test[1)] | Type Test of DER system + Basic DER Evaluation + Basic Commissioning Test[1)] |
| DER Capability & Conformance achieved by | **Composite** one or more Supplemental DER Device(s) needed | Type Test of DER unit + Detailed DER Evaluation + Detailed Commissioning Test[1)] | Type Test(s) of DER unit(s) + Detailed DER Evaluation + Detailed Commissioning Test[1)] |

[1)] As applicable, may depend on DER Design Evaluation.

# High-Level Test and Verification Process

## Maintenance

**Periodic**
- Scheduled or other criteria
- **Reverification** needed on important system changes

## Post-installation review

**Commissioning Tests**
- Performed **on site** at the time of commissioning
- **Basic**: visual check equipment, isolation device
- **Detailed**: check functionality and interoperability as a system

**As-Built Installation Evaluation**
- Performed **on site** at the time of commissioning
- **Basic**: check components and connections
- **Detailed**: engineering verification of components, may do modeling and simulation

## Interconnection review

**Design Evaluation**
- **Desk study**
- Check equipment together meet requirements
- Typically done off-site before equipment is delivered and installed, may include analysis and modeling/simulation

## Equipment conformance testing

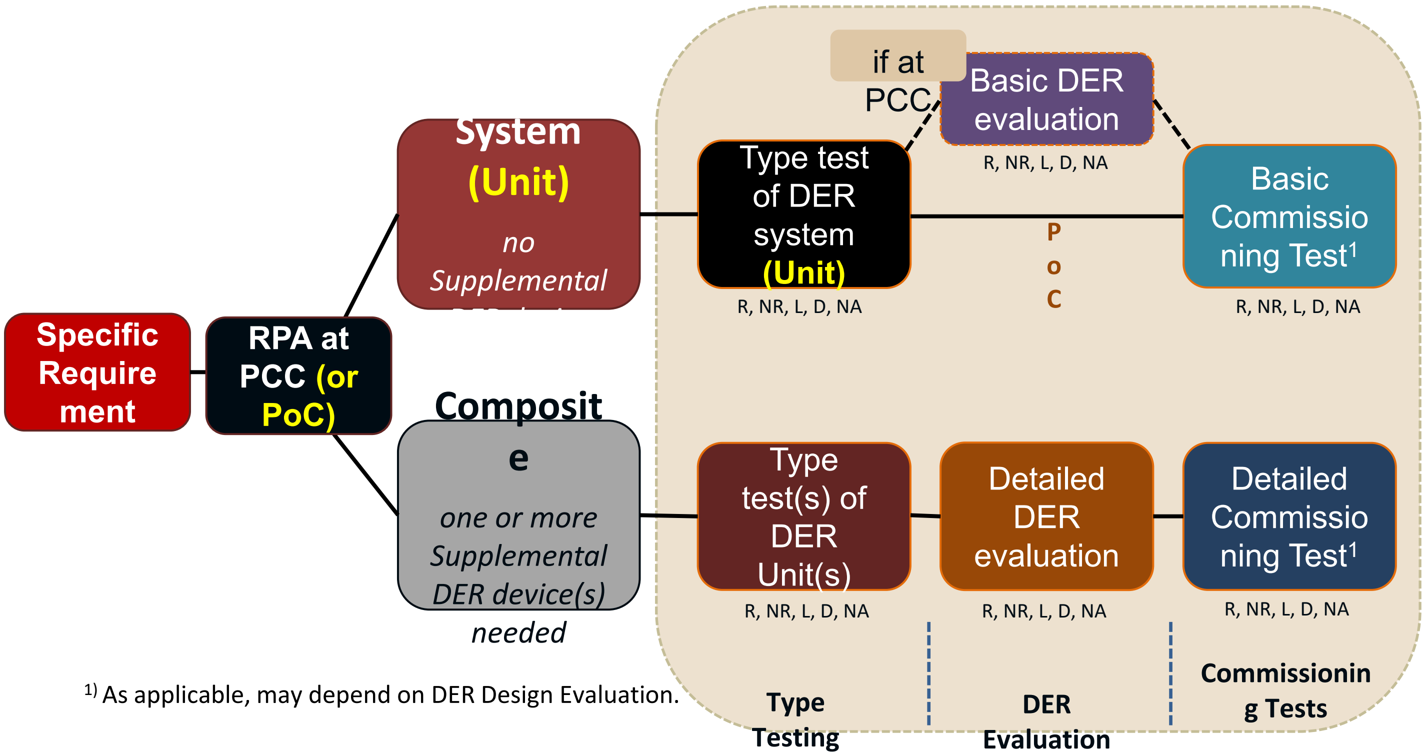
**Production Tests**
- Done in **factory**, or on equipment in **field**
- Tests on **every unit** of DER and interconnection
- **Verify** operability and **document** default function settings

**Type Tests**
- typically done in **test lab** or **factory**
- Tests on **representative** DER Unit or DER system
- Type test from a DER within a product family of the same design

# Determination of Requirements Verification and Testing

**What's the requirement?** → **Where's the reference point of applicability?** → **Are supplemental DER device(s) needed?** → **Category of test and verification needed**

- **R:** Required
- **NR:** Not required
- **L:** Limited
- **D:** Depends on DER design evaluation.
- **NA:** Not applicable




1) As applicable, may depend on DER Design Evaluation.

The type of evaluation or testing needed for each requirement depends on the reference point of applicability and whether there are any supplemental DER devices

-help in Annex F (informative) Discussion of Testing and Verification Requirements at PCC or PoC

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# High-level test and verification process

| Verification Requirement | Description |
|---|---|
| Type Test of DER Unit | A distributed energy resource (DER) unit that is type tested and compliant with the standard. |
| Type Test of DER System | A distributed energy resource (DER) system that is composed of DER units that are type tested and supplemental DER devices. |
| Basic DER Evaluation | A basic DER evaluation shall be limited to verify that the DER has been designed and installed with the proper components and connections. |
| Detailed DER Evaluation | A detailed DER evaluation shall include an engineering verification of the chosen components and may require modeling and simulation of the composite of the individual partially compliant DERs forming a system. |
| Basic Commissioning Test[1)] | A basic functional commissioning test includes visual inspection and an operability test on the isolation device.[1)] |
| Detailed Commissioning Test[1)] | A detailed functional commissioning test shall include a basic functional test and functional tests to verify interoperability of a combination of devices forming a system to verify that the devices are able to operate together as a system.[1)] |

[1)] As applicable, may depend on DER Design Evaluation.

# Test and verification requirements

- **Component Verification**
  - Type Tests
  - Production Tests
- **DER System Verification**
  - DER design evaluation (desk study)
  - DER as-built installation evaluation (on-site)
  - Commissioning tests and verifications
    - DER versus Composite Compliance and related type testing limited to partial compliance of individual DER
    - Requirements met at PCC or PoC

# Type Testing

- Tests on representative DER Unit or DER system
- Done in test lab, factory, or on equipment in field
- Type test from a DER within a product family of the same design
  - Representative for power ratings between 50% to 200% of the tested DER
- For systems in field – allows replacement of DER equipment with substitutive components compliant and tested with this standard
  - Does not invalidate previous type tests
  - Field demonstration of performance agreed upon by EPS and DER operator.

# Production Testing

- Tests on every unit of DER and interconnection prior to customer delivery
- Verify the operability
- Summary report provide
  - List of normal and abnormal performance category capability
  - Final function settings
  - Final operating mode setttings

# DER Evaluation

Verify that a system meet the interconnection and interoperability requirements of this standard

- DER Design Evaluation
  - Performed during the interconnection review process
- DER As-Built Evaluation
  - Performed on site at the time of commissioning

# DER Design Evaluation (desk study)

- Evaluation during interconnection review process
- Verifies the composite of the individually partially compliant DERs forming a system as **designed**:
  - Meets the interconnection and interoperability requirements
- Usually done off-site before equipment is delivered and installed

# DER As-Built Installation Evaluation (on-site)

- At time of commissioning
- Verifies the composite of the individually partially compliant DERs forming a system as **delivered and installed:**
  - Meets the interconnection and interoperability requirements
- This evaluation does not require testing

# Commissioning Tests and Verifications

- Tests and verifications on one device or combinations forming a system:
  - To confirm the system designed, delivered, and installed meets interconnection and interoperability requirements
- Include visual inspections
- May include operability and functional performance test
- Written procedures required
  - Provided by equipment manufacturer or system designer
  - Approved by equipment owner and Area EPS operator

# Commissioning Tests and Verifications

- Basic functional commissioning test
  - Visual inspection
  - Operability test on isolation device
- Detailed functional commissioning test
  - Basic functional commissioning test
  - Functional tests verifying interconnection and interoperability of a combination of devices forming a system – **Verifies devices are able to operate together as a system**

# Periodic Tests and Verifications

- According to scheduled time period or other criteria:
  - Confirm already interconnected device or combination of devices meet interconnection and interoperability requirements
- Provided by interconnection equipment manufacturers and system integrators.
- Approved by AGIR or Area EPS operator
- Periodic test  reports or log for inspection
- Area EPS operator may require commissioning test at any time to verify adherence to this standard

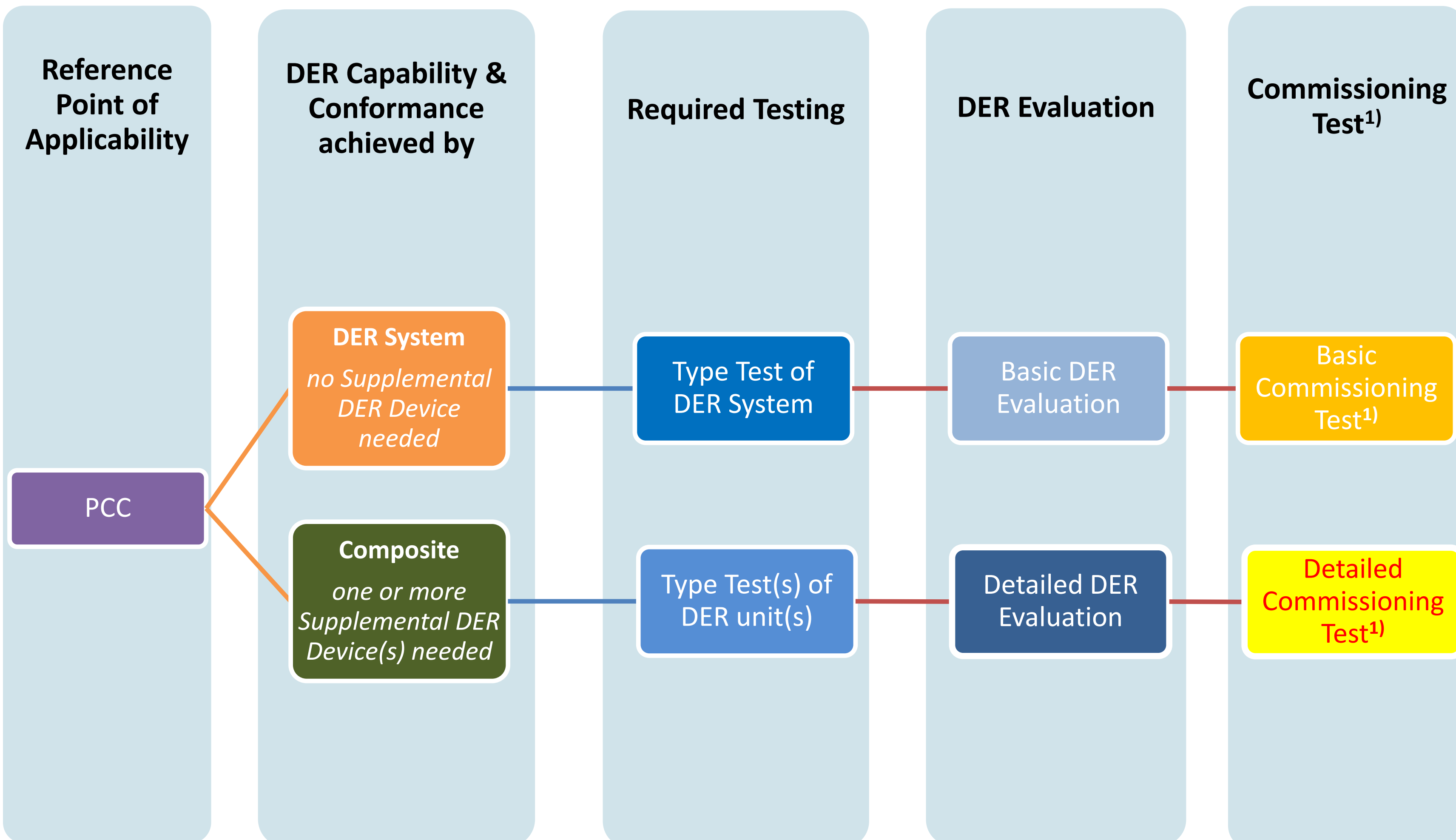
# Periodic Tests and Verifications

- **Reverification of interoperability requirements** of this standard may be required when any of the following events occur:
  - *Functional software or firmware c*hanges have been made on the DER.
  - Any *hardware component* of the DER has been *modified* in the field or has been *replaced or repaired with parts that are not substitutive components* compliant with this standard.
  - *Protection settings have been changed* after factory testing.
  - *Protection functions have been adjusted* after the initial commissioning process.

# DER System and Composite

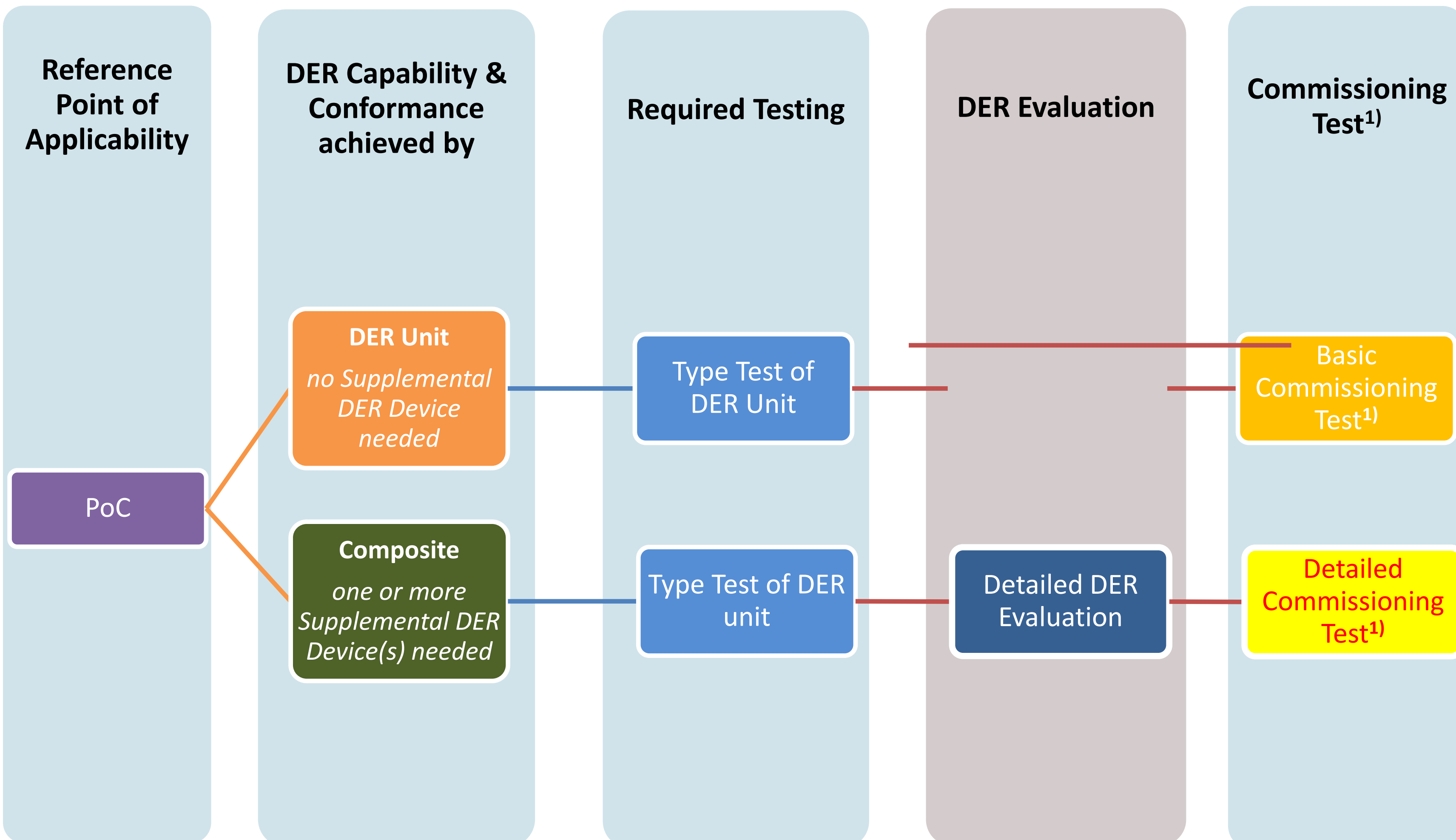
- For DER system that shall meet requirements at PCC
  - DER System – DER system is fully compliant at PCC – *no supplemental DER device needed*
  - Composite – Composite of partially compliant DER that is, as a whole, fully compliant at PCC – may need one or more supplemental DER devices

# High-level test and verification process - PCC




[1)] As applicable, may depend on DER Design Evaluation.

# High-level test and verification process - PoC




[1)] As applicable, may depend on DER Design Evaluation.

# High-level test and verification

| Verification Requirement | Description |
|---|---|
| Type Test of DER Unit | A distributed energy resource (DER) unit that is type tested and compliant with the standard. |
| Type Test of DER System | A distributed energy resource (DER) system that is composed of DER units that are type tested and supplemental DER devices. |
| Basic DER Evaluation | A basic DER evaluation shall be limited to verify that the DER has been designed and installed with the proper components and connections. |
| Detailed DER Evaluation | A detailed DER evaluation shall include an engineering verification of the chosen components and may require modeling and simulation of the composite of the individual partially compliant DERs forming a system. |
| Basic Commissioning Test[1)] | A basic functional commissioning test includes visual inspection and an operability test on the isolation device.[1)] |
| Detailed Commissioning Test[1)] | A detailed functional commissioning test shall include a basic functional test and functional tests to verify interoperability of a combination of devices forming a system to verify that the devices are able to operate together as a system.[1)] |

[1)] As applicable, may depend on DER Design Evaluation.

# 4. General interconnection technical specifications and performance requirements (PCC)

PCC

| Requirement | Compliance at PCC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| | | | | |
| 4.2 Reference points of applicability | DER System | NR | R | NR |
| | Composite | NR | R | NR |
| 4.3 Applicable voltages | DER System | NR | R | NR |
| | Composite | NR | R | NR |
| 4.4 Measurement accuracy | DER System | R | R | NR |
| | Composite | L | R | NR |
| 4.5 Cease to energize performance requirement | DER System | R | R | D |
| | Composite | L | R | D |

R – Required, NR – Not Required, L- Limited type testing,
D – Dependent on DER Design Evaluation

*Excerpt from Table 43 IEEE 1547-2018*

# 4. General interconnection technical specifications and performance requirements (PoC)

PoC

| Requirement | Compliance at PoC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| | | | | |
| 4.2 Reference points of applicability | DER Unit | NR | R | NR |
| | Composite | NR | R | NR |
| 4.3 Applicable voltages | DER Unit | NR | R | NR |
| | Composite | NR | R | NR |
| 4.4 Measurement accuracy | DER Unit | R | **NR** | NR |
| | Composite | L | R | NR |
| 4.5 Cease to energize performance requirement | DER Unit | R | **NR** | **NR** |
| | Composite | L | R | D |

**Highlighted text indicates requirements that differ for DER that shall meet requirements at the PoC**

R – Required, NR – Not Required, L- Limited type testing,
D – Dependent on DER Design Evaluation

*Excerpt from Table 44 IEEE 1547-2018*

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# 4.6 Control, Prioritization, Isolation and Inadvertent Energization (PCC)

PCC

| Requirement | Compliance at PCC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 4.6 Control Capability Requirements | DER System | R | R | D |
| | Composite | L | R | D |
| 4.7 Prioritization of DER responses and execution of mode or parameter changes | DER System | R | R | D |
| | Composite | L | R | D |
| 4.8 Isolation device | DER System | R | Design: NR<br>Installation: R | NR |
| | Composite | L | Design: NR<br>Installation: R | D |
| 4.9 Inadvertent energization of the Area EPS | DER System | R | Design: NR<br>Installation: R | D |
| | Composite | L | R | D |

*Excerpt from Table 43 IEEE 1547-2018*

# 4.6-4.9 Control, Prioritization, Isolation and Inadvertent Energization (PoC)

PoC

| Requirement | Compliance at PoC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 4.6 Control Capability Requirements | DER Unit | R | **NR** | **NR** |
| | Composite | L | R | D |
| 4.7 Prioritization of DER responses and execution of mode or parameter changes | DER Unit | R | **NR** | **NR** |
| | Composite | L | R | D |
| 4.8 Isolation device | DER Unit | R | **NR** | NR |
| | Composite | L | Design: NR Installation: R | D |
| 4.9 Inadvertent energization of the Area EPS | DER Unit | R | Design: NR Installation: R | D |
| | Composite | L | R | **R** |

*Excerpt from Table 44 IEEE 1547-2018*

# 4.10 Enter Service (PCC)

| PCC Requirement | Compliance at PCC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 4.10.2 Enter service criteria | DER System | R | NR | NR |
| | Composite | L | R | D |
| 4.10.3 Performance during entering service | DER System | R | R | D |
| | Composite | L | R | D |
| 4.10.4 Synchronization | DER System | R | R | D |
| | Composite | L | R | D |

*Excerpt from Table 43 IEEE 1547-2018*

# 4.10 Enter Service (PoC)

| PoC Requirement | Compliance at PoC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 4.10.2 Enter service criteria | DER Unit | R | NR | NR |
| | Composite | L | R | D |
| 4.10.3 Performance during entering service | DER Unit | R | R | D |
| | Composite | L | R | D |
| 4.10.4 Synchronization | DER Unit | R | R | D |
| | Composite | L | R | D |

Same as PCC

*Excerpt from Table 44 IEEE 1547-2018*

# 4.11 Interconnect Integrity (PCC)

PCC

| Requirement | Compliance at PCC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 4.11.1 Protection from electromagnetic interference | DER System | R | NR | NR |
| | Composite | L | NR | NR |
| 4.11.2 Surge withstand performance | DER System | R | NR | NR |
| | Composite | L | NR | NR |
| 4.11.3 Paralleling device | DER System | R | NR | NR |
| | Composite | L | NR | NR |
| 4.12 Integration with Area EPS grounding | DER System | NR | R | NR |
| | Composite | NR | R | NR |

*Excerpt from Table 43 IEEE 1547-2018*

# 4.11 Interconnect Integrity (PoC)

PoC

| Requirement | Compliance at PoC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 4.11.1 Protection from electromagnetic interference | DER Unit | R | NR | NR |
| | Composite | L | NR | NR |
| 4.11.2 Surge withstand performance | DER Unit | R | NR | NR |
| | Composite | L | NR | NR |
| 4.11.3 Paralleling device | DER Unit | R | NR | NR |
| | Composite | L | NR | NR |
| 4.12 Integration with Area EPS grounding | DER Unit | NR | R | NR |
| | Composite | NR | R | NR |

Same as PCC

*Excerpt from Table 44 IEEE 1547-2018*

# 5.2 – 5.3 Reactive Power Capability and Voltage/Power Requirements (PCC)

PCC

| Requirement | Compliance at PCC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 5.2 Reactive power capability of the DER | DER System | R | R | D |
| | Composite | L | R | D |
| 5.3 Voltage and reactive power control | DER System | R | Design: NR<br>Installation: R | NR |
| | Composite | L | R | D |
| 5.4.2 Voltage-active power mode | DER System | R | Design: NR<br>Installation: R | NR |
| | Composite | L | R | R |

*Excerpt from Table 43 IEEE 1547-2018*



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# 5.2 – 5.4 Reactive Power Capability and Voltage/Power Requirements (PoC)

PoC

| Requirement | Compliance at PoC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 5.2 Reactive power capability of the DER | DER Unit | R | **NR** | **NR** |
| | Composite | L | R | **NR** |
| 5.3 Voltage and reactive power control | DER Unit | R | **NR** | NR |
| | Composite | L | R | **R** |
| 5.4.2 Voltage-active power mode | DER Unit | R | **R** | NR |
| | Composite | L | R | R |

*Excerpt from Table 44 IEEE 1547-2018*

# 6.2-6.3 Response to Area EPS abnormal conditions (PCC)

PCC

| Requirement | Compliance at PCC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 6.2 Area EPS faults and open phase conditions | DER System | R | Design: R<br>Installation: NR | D |
| | Composite | L | R | D |
| 6.3 Area EPS reclosing coordination | DER System | NR | Design: R<br>Installation: NR | NR |
| | Composite | NR | Design: R<br>Installation: NR | R |

*Excerpt from Table 43 IEEE 1547-2018*

# 6.2-6.3 Response to Area EPS abnormal conditions (PoC)

PoC

| Requirement | Compliance at PoC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 6.2 Area EPS faults and open phase conditions | DER Unit | R | Design: R<br>Installation: NR | **NR** |
| | Composite | L | R | **NR** |
| 6.3 Area EPS reclosing coordination | DER Unit | NR | Design: R<br>Installation: NR | NR |
| | Composite | NR | Design: R<br>Installation: NR | **D** |

*Excerpt from Table 44 IEEE 1547-2018*



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# 6.4.1-6.4.2 Voltage and Voltage Ride Through (PCC)

PCC

| Requirement | Compliance at PCC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 6.4.1, 6.4.2 – Voltage requirement | DER System | R | R | D |
| | Composite | L | R | D |
| 6.4.2.3 Low-voltage ride-through | DER System | R | R | NR |
| | Composite | L | R | D |
| 6.4.2.4 High-voltage ride-through | DER System | R | NR | NR |
| | Composite | L | R | D |
| 6.4.2.5 Ride-through of consecutive voltage disturbances | DER System | R | NR | NR |
| | Composite | L | R | D |

*Excerpt from Table 43 IEEE 1547-2018*

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# 6.4.1-6.4.2 Voltage and Voltage Ride Through (PoC)

PoC

| Requirement | Compliance at PCC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 6.4.1, 6.4.2 – Voltage requirement | DER Unit | R | R / **NR** | **NR** / D |
| | Composite | L | R | D |
| 6.4.2.3 Low-voltage ride-through | DER Unit | R | R | NR / **D** |
| | Composite | L | R | D |
| 6.4.2.4 High-voltage ride-through | DER Unit | R | NR | NR |
| | Composite | L | R / **NR** | D |
| 6.4.2.5 Ride-through of consecutive voltage disturbances | DER Unit | R | NR | NR |
| | Composite | L | R / **NR** | D |

*Excerpt from Table 44 IEEE 1547-2018*

# 6.4.2.6 – 6.4.2.7 Dynamic Voltage Support & Restore Output with Voltage Ride-Through (PCC)

PCC

| Requirement | Compliance at PCC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 6.4.2.6 Dynamic voltage support | DER System | R | R | NR |
| | Composite | L | R | D |
| 6.4.2.7 Restore output with voltage ride-through | DER System | R | R | NR |
| | Composite | L | R | D |

*Excerpt from Table 43 IEEE 1547-2018*

# 6.4.2.6 – 6.4.2.7 Dynamic Voltage Support & Restore Output with Voltage Ride-Through (PoC)

PoC

| Requirement | Compliance at PoC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 6.4.2.6 Dynamic voltage support | DER Unit | R | **NR** | NR |
| | Composite | L | R | D |
| 6.4.2.7 Restore output with voltage ride-through | DER Unit | R | **NR** | NR |
| | Composite | L | R | D |

*Excerpt from Table 44 IEEE 1547-2018*

# 6.5 Frequency (PCC)

PCC

| Requirement | Compliance at PCC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 6.5.1 Mandatory frequency tripping requirements | DER System | R | R | D |
| | Composite | L | R | D |
| 6.5.2 Frequency disturbance ride-through requirements | DER System | R | NR | NR |
| | Composite | L | R | R |
| 6.5.2.3.1 Low-frequency ride-through capability | DER System | R | NR | NR |
| | Composite | NR | NR | NR |
| 6.5.2.3.2 Low-frequency ride-through performance | DER System | R | NR | NR |
| | Composite | L | R | R |
| 6.5.2.4 High-frequency ride-through | DER System | R | NR | NR |
| | Composite | L | R | R |
| 6.5.2.5 Rate of change of frequency (ROCOF) ride-through | DER System | R | NR | NR |
| | Composite | L | R | R |
| 6.5.2.6 Voltage phase angle changes ride-through | DER System | R | NR | NR |
| | Composite | L | Design: R<br>Installation: NR | D |

*Excerpt from Table 43 IEEE 1547-2018*



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# 6.5 Frequency (PoC)

PoC

| Requirement | Compliance at PoC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 6.5.1 Mandatory frequency tripping requirements | DER Unit | R | R | D |
| | Composite | L | R | D |
| 6.5.2 Frequency disturbance ride-through requirements | DER Unit | R | NR | NR |
| | Composite | L | **NR** | **NR** |
| 6.5.2.3.1 Low-frequency ride-through capability | DER Unit | R | NR | NR |
| | Composite | NR | NR | NR |
| 6.5.2.3.2 Low-frequency ride-through performance | DER Unit | R | NR | NR |
| | Composite | L | **NR** | **NR** |
| 6.5.2.4 High-frequency ride-through | DER Unit | R | NR | NR |
| | Composite | L | **NR** | **NR** |
| 6.5.2.5 Rate of change of frequency (ROCOF) ride-through | DER Unit | R | NR | NR |
| | Composite | L | **NR** | **NR** |
| 6.5.2.6 Voltage phase angle changes ride-through | DER Unit | R | NR | NR |
| | Composite | L | **NR** | **NR** |

*Excerpt from Table 44 IEEE 1547-2018*



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# 7. Power Quality (PCC)

PCC

| Requirement | Compliance at PCC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 7.1 Limitation of dc injection | DER System | R | NR | NR |
| | Composite | NR | R | NR |
| 7.2 Limitation of voltage fluctuation induced by the DER | DER System | NR | Design: R Installation: NR | D |
| | Composite | NR | Design: R Installation: NR | D |
| 7.3 Limitation of current distortion | DER System | R | NR | NR |
| | Composite | L | R | D |
| 7.4 Limitation of overvoltage contribution | DER System | R | R | D |
| | Composite | L | R | D |

*Excerpt from Table 43 IEEE 1547-2018*

# 7. Power Quality (PoC)

PoC

| Requirement | Compliance at PoC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 7.1 Limitation of dc injection | DER Unit | R | NR | NR |
| | Composite | NR | R | NR |
| 7.2 Limitation of voltage fluctuation induced by the DER | DER Unit | NR | Design: R Installation: NR | D |
| | Composite | NR | Design: R Installation: NR | D |
| 7.3 Limitation of current distortion | DER Unit | R | NR | NR |
| | Composite | L | R | D |
| 7.4 Limitation of overvoltage contribution | DER Unit | R | R | D |
| | Composite | L | R | D |

Same as PCC

*Excerpt from Table 44 IEEE 1547-2018*

# Islanding

## *Categories*

- **Unintentional islanding**
  - Requirements also in clauses related to response to Area EPS abnormal conditions
  - Coordination with Area EPS automatic reclosing
  - Conditional extended clearing times

- **Intentional islanding:** An intentional island that includes any portion of the area EPS—an intentional area EPS island—while islanded shall be designed and operated in coordination with the area EPS operator.
  - **Scheduled:** Formed through DER operator or area EPS operator manual action or other operating dispatch means (e.g., EMS, automatic generation control) that triggers the transition from being in parallel and synchronized with the area EPS to operation as an islanded system.
  - **Unscheduled:** Unscheduled intentional islands are formed autonomously from local detection of abnormal conditions at the interface(s) with the area EPS and then automatic relay action that triggers switching to rapidly isolate the intentional island from the area EPS.

- Conditions and requirements for transition, voltage fluctuation limits, reconnection are coherent to those for DER.

# 8. Islanding (PCC)

PCC

| Requirement | Compliance at PCC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 8.1.1 Unintentional islanding | DER System | R | NR | NR |
| | Composite | L | R | R |
| 8.1.2 Conditional extended clearing time | DER System | R | R | NR |
| | Composite | L | R | R |
| 8.1.3 Area EPS with automatic reclosing | DER System | R | R | NR |
| | Composite | L | R | R |
| 8.2 Intentional islanding | DER System | NA | NA | NA |
| | Composite | L | R | R |

*Excerpt from Table 43 IEEE 1547-2018*

# 8. Islanding (PoC)

PoC

| Requirement | Compliance at PoC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 8.1.1 Unintentional islanding | DER Unit | R | NR | NR |
| | Composite | L | R | R |
| 8.1.2 Conditional extended clearing time | DER Unit | R | **NR** | NR |
| | Composite | L | R | R |
| 8.1.3 Area EPS with automatic reclosing | DER Unit | R | **NR** | NR |
| | Composite | L | R | R |
| 8.2 Intentional islanding | DER Unit | **NR** | **NR** | **NR** |
| | Composite | L | R | R |

*Excerpt from Table 44 IEEE 1547-2018*

# 9. DER on distribution secondary grid (PCC)

PCC

| Requirement | Compliance at PCC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 9.2 Distribution secondary grid networks | DER System | NR | R | D |
| | Composite | NR | R | D |
| 9.3 Distribution secondary spot networks | DER System | NR | R | D |
| | Composite | NR | R | D |

*Excerpt from Table 43 IEEE 1547-2018*

# 9. DER on distribution secondary grid (PoC)

PoC

| Requirement | Compliance at PoC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 9.2 Distribution secondary grid networks | DER Uni | NR | R | D |
| | Composite | NR | R | D |
| 9.3 Distribution secondary spot networks | DER Unit | NR | R | D |
| | Composite | NR | R | D |

Same as PCC

*Excerpt from Table 44 IEEE 1547-2018*

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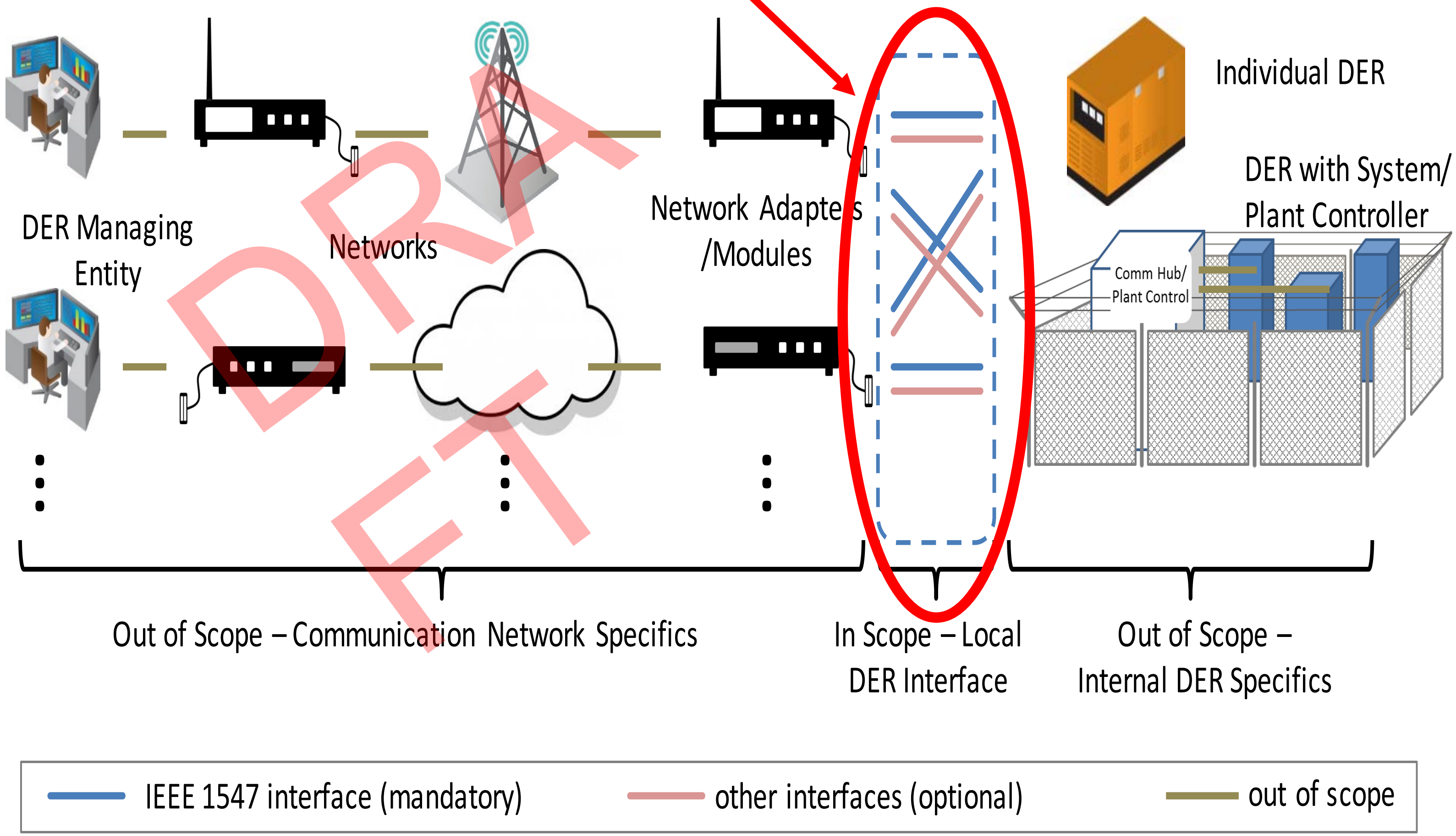
# Interoperability

***Limited Scope of Interoperability Requirements***






*Source: 1547-2018 Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*

# 10. Interoperability (PCC)

PCC

| Requirement | Compliance at PCC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 10.1 Interoperability requirements | DER System | R | R | NR |
| | Composite | L | R | D |
| 10.2 Monitoring, control, and information exchange requirements | DER System | R | R | NR |
| | Composite | L | R | D |
| 10.3 – 10.8 Nameplate Information, Configuration Information, Monitoring Information, Management Information, Communication Protocol and Performance Requirements | DER System | R | NR | NR |
| | Composite | L | R | D |

*Excerpt from Table 43 IEEE 1547-2018*

# 10. Interoperability (PoC)

PoC

| Requirement | Compliance at PoC achieved by: | Type Tests | DER Evaluation | Commissioning Tests |
|---|---|---|---|---|
| 10.1 Interoperability requirements | DER Unit | R | **NR** | NR |
| | Composite | L | R | D |
| 10.2 Monitoring, control, and information exchange requirements | DER Unit | R | **NR** | NR |
| | Composite | L | R | D |
| 10.3 – 10.8 Nameplate Information, Configuration Information, Monitoring Information, Management Information, Communication Protocol and Performance Requirements | DER Unit | R | NR | NR |
| | Composite | L | R | D |

*Excerpt from Table 44 IEEE 1547-2018*

# Application of IEEE 1547-2018 prior to IEEE P1547.1 Revision

## Stakeholder Challenges

**FERC**
Requirements for Small Generating Facilities

Orders for Transmission Providers
No. 827 (reactive power)
No 828 (ride-through)

**Authorities Governing Interconnection Requirements**

Assignment of
Categories A, B (reactive power)
Categories I, II, III (ride-through)

Coordination between new IEEE P1547.1 verification requirements and DER interconnection procedures

**Utilities**
Update of boilerplate interconnection agreements with new capabilities

Grid-specific tuning of DER settings (e.g., determination of volt/var parameters for increased hosting capacity[1])

Specification of local DER interface communication protocols

**DER Developers**

Interconnection requests,
DER design

**DER Vendors**

Testing of DER capabilities (type tests)

[1] for example with EPRI's Distribution Resource Integration and Value Estimation (DRIVE) Tool (3002008293)

# Application of IEEE 1547-2018 prior to IEEE P1547.1 Revision

## UL Certification of Inverters

**Utility Interactive**

- Traditional UL1741
- IEEE 1547 & 1547.1 (1st ed.) Interconnection Requirements

**Grid Support Utility Interactive**

- UL 1741 SA Grid Support Functions
- Source Requirements Documents like CA Rule 21, Hawai'ian Rule 14H, IEEE Std 1547-2018 (2nd ed.)

**Special Purpose Utility Interactive**

- Specific Manufacturer / Utility Defined UL Verified Compliance
- Custom Source Requirements Documents

**UL Certification:**

- Grid Support, Utility Interactive Product

**Scope:**

- Safety & Electric Shock Certification to UL1741 including UL 1741 SA for grid support and general grid interconnection per IEEE 1547

**Includes Testing to Verify:**

- 1.UL 1741 electric shock/fire tests
- 2.UL 1741 SA grid support tests
- 3.Unique tests of IEEE 1547 for general grid interconnection not covered by UL 1741 SA tests

**Deliverable:**

- UL Certification as a Grid Support Utility Interactive product

# Application of IEEE 1547-2018 prior to IEEE P1547.1 Revision

## Selected tests and verification

## - Certification of interconnection requirements for inverter-coupled DER units[1)]

- Inverter-coupled DER applications shall be compliant with all utility-specific settings but only with parts of IEEE Std 1547-2018 (Revision)
  - An informative annex to UL1741-SA is being prepared to specify a majority of capability requirements and settings of IEEE Std 1547-2018 (Revision) as the Source Requirements Document (SRD) that can be tested and verified per type test requirements of UL1741 Supplement-SA (September 2016).
  - **Re-certification** of UL1741-SA (September 2016) certified equipment may become necessary for any IEEE Std 1547-2018 (Revision) "ranges of allowable settings" that are outside the CA Rule 21 and/or HI R 15H ranges.
- Utility-specific custom Source Requirements Document (SRD) should specify appropriate IEEE Std 1547-2018 (Revision) performance categories, and
  - Refer to UL1741 and the above-mentioned annex in UL1741-SA without any modifications (re-certification may become necessary), **or**
  - Specify a subset of the IEEE Std 1547-2018 (Revision) capability requirements such that existing Grid Support Utility Interactive inverters that were already UL1741-SA (September 2016) certified per the requirements of CA Rule 21 and/or Hawai'ian Rule 14H as the SRDs can be used
  - Specify utility-specific settings, e.g., for voltage and frequency trip, within the applicable "ranges of allowable settings".

[1)] not the whole DER facility/system

# Application of IEEE 1547-2018 After IEEE P1547.1 Revision

All tests and verifications, after publication of the revised standard

- Certification of interconnection requirements for inverter-coupled DER units[1)]

- Inverter-coupled DER applications shall be compliant with all utility-specific settings and with all applicable parts of IEEE Std 1547-2018 (Revision)
  - UL1741 Standards Technical Panel (STP) will **replace** UL1741-SA with a reference to IEEE Std 1547.1-20xx (Revision). **IEEE Std 1547-2018 (Revision) is new Source Requirements Document (SRD).**
  - **Re-certificaton** of UL1741-SA (September 2016) certified equipment per IEEE Std 1547.1-20xx (Revision) test and verification procedures and certification via UL1741 will become necessary, based on the applicable IEEE Std 1547-2018 (Revision) performance category.
  - Effective after transition period of [XX] months after IEEE Std 1547.1-20xx (Revision) is published.
- Utility-specific custom Source Requirements Document (SRD) should specify appropriate IEEE Std 1547-2018 (Revision) performance categories, and
  - Refer to UL1741 and the revised IEEE Std 1547.1-20xx (Revision), and
  - Specify utility-specific settings, e.g., for voltage and frequency trip, within the “ranges of allowable settings” specified in IEEE Std 1547-2018 (Revision).

[1)] not the whole DER facility/system

# Summary and Takeaway

- Reference Point of Applicability (RPA) and Compliance with or without supplemental DER device(s) determines the verification requirements
- Detailed Verification Requirements are specified in Table 43 and Table 44 of IEEE 1547-2018
- Type testing can be performed on a DER unit or a DER system
- A composite of DER unit(s) and supplemental DER device(s) requires a detailed DER evaluation
- DER Evaluation and Commissioning Test may be either basic or detailed

# Summary and Takeaway (Continued)

- Test and Verification **Procedures** are being developed by the IEEE P1547.1 - *Standard Conformance Test Procedures for Equipment Interconnecting DER with EPS* Working Group
  - Will be complete in late 2018
  - Stay tuned to IEEE for upcoming working group meetings to assist in developing solutions in the interim.
- Stakeholders will drive specific requirements based on DER system complexity, Area EPS Conditions and location

# More Information on IEEE 1547-2018

Go to IEEE SCC21's 1547-2018 Revision Grouper Website,

http://grouper.ieee.org/groups/scc21/1547_revision/1547revision_index.html

# IEEE P1547.1 DER Interconnection Test Procedures: Revision Status

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**Senior Engineer, National Renewable Energy Laboratory (NREL)**

**Chair, IEEE P1547.1 Working Group**

# DISCLAIMER

*This presentation and discussion here on IEEE P1547 and P1547.1 are individual's views and are not the formal explanation or position of the IEEE.*

# Motivation for IEEE P1547.1

- In many locations the power system **depends on DER support** for proper operation during normal and abnormal conditions
    - True for both **distribution systems** and **bulk power systems**
    - Number of DER-dependent locations is expected to **continue to grow**
- Major paradigm shift from “just get out of the way” to “stay connected (within limits) and support voltage and frequency”
- Now that the grid depends on DERs to perform a certain way, **DER performance must be validated through testing** to ensure the power system continues to be safe and reliable
- Some power systems failed to recognize this in time, sometimes at great cost.
    - North America has a chance to get it right the first time!

# IEEE 1547 Standards Example Use in U.S.

**IEEE 1547**
**Interconnection System and Test Requirements**

- Voltage Regulation
- Grounding
- Disconnects
- Monitoring
- Islanding
- etc.

**IEEE 1547.1**
**Interconnection System Testing**

- O/U Voltage and Frequency
- Synchronization
- EMI
- Surge Withstand
- DC injection
- Harmonics
- Islanding
- Reconnection

**UL 1741***
**Interconnection Equipment**

- 1547.1 Tests
- Construction
- Protection against risks of injury to persons
- Rating, Marking
- Specific DR Tests for various technologies

**NEC ****

Article 690 PV Systems;

Article 705: interconnection systems (shall be suitable per intended use per UL1741)

- Content list is for 1547-2003. Same relationship will exist for 1547-2018 and future revisions of 1547.1, 1741, and NEC.
- 1547-2018 cannot be fully applied until after revised P1547.1 is published!
- Note: 1547-2018 contains many new requirements that are not fully verified through lab testing

  → DER evaluations and commissioning tests become more important

# IEEE 1547 Content Growth

| | 1st Edition | | 2nd Edition |
|---|---|---|---|
| **1547 technical content:** | 13 pages | → | 127 pages |
| **1547.1 technical content:** | 54 pages | → | ??? pages (currently ~200) |

## New/significantly modified 1547-2018 content in red:

**4. General interconnection technical specifications and requirements**
- 4.2 Reference points of applicability
- 4.3 Applicable voltages
- 4.4 Measurement accuracy
- 4.5 Cease to energize performance requirement
- 4.6 Control capability requirements
- 4.7 Prioritization of DER responses
- 4.8 Isolation device
- 4.9 Inadvertent energization of the Area EPS
- 4.10 Enter service
- 4.11 Interconnect integrity
- 4.12 Integration with Area EPS grounding
- 4.13 Exemptions for Emergency Systems and Standby DER

**5. Reactive power capability and voltage/power control requirements**
- 5.2 Reactive power capability of the DER
- 5.3 Voltage and reactive power control
- 5.4 Voltage and active power control

**6. Response to Area EPS abnormal conditions**
- 6.2 Area EPS faults and open phase conditions
- 6.3 Area EPS reclosing coordination
- 6.4 Voltage
- 6.5 Frequency
- 6.6 Return to service after trip

**7. Power quality**
- 7.1 Limitation of dc injection
- 7.2 Limitation of voltage fluctuations induced by the DER
- 7.3 Limitation of current distortion
- 7.4 Limitation of overvoltage contribution

**8. Islanding**
- 8.1 Unintentional islanding
- 8.2 Intentional islanding

**9. DER on distribution secondary grid/area/street (grid) networks and spot networks**
- 9.1 Network protectors and automatic transfer scheme requirements
- 9.1 Distribution secondary grid networks
- 9.2 Distribution secondary spot networks

**10. Interoperability, information exchange, information models, and protocols**
- 10.1 Interoperability requirements
- 10.2 Monitoring, control, and information exchange requirements
- 10.3 Nameplate information
- 10.4 Configuration information
- 10.5 Monitoring information
- 10.6 Management information
- 10.7 Communication protocol requirements
- 10.8 Communication performance requirements
- 10.9 Cyber security requirements

**11. Test and verification requirements**
- 11.2 Definition of test and verification methods
- 11.3 Full and partial conformance testing and verification
- 11.4 Fault current characterization

# P1547.1: Full Revision

***Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces.***

Scope: This standard specifies the type, production, commissioning and periodic tests, and evaluations that shall be performed to confirm that the interconnection and interoperation functions of equipment and systems interconnecting distributed energy resources with the electric power system conform to IEEE Standard 1547.

Purpose: Standardized test and evaluation procedures are necessary to establish and verify compliance with those requirements. These test procedures shall provide both repeatable results, independent of test location, and flexibility to accommodate a variety of DER technologies and functions.

# P1547.1: Full Revision

- What needs to be revised?
- What needs to be added?
- What needs to be external to P1547.1?

- ***Goal**: to come up with P1547.1 contents that fulfill the PAR scope and purpose: addressing revised requirements in IEEE 1547*

**IEEE 1547.1-2005 CONTENTS**





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# P1547.1: Overview

- IEEE P1547.1 provides conformance test procedures to establish and verify compliance with the requirements of revised IEEE 1547
- IEEE P1547.1 is not just for type testing; conformance may be established through combination of type (aka "design" tests), production tests, design evaluation, installation evaluation, commissioning tests, and periodic tests
- Like 1547, applies to all DERs (not just PV, and not just inverter-based)
- Does not cover testing for safety
- Although this standard does not define a certification process, these P1547.1 tests can be used as part of such a process – e.g. UL 1741
- Need to keep objectives technically precise for P1547.1 – this is not a design guide, recommended practice, business, tariff, contractual, regulatory, or policy document

# P1547.1: Types of Verification Methods

Test and evaluations in 1547-2018 show how to achieve compliance at PoC and PCC through various verification methods

- **Type test** – Test of one or more devices made to a certain design to demonstrate that the design meets certain specifications
- **Production test** – A test conducted on every unit of equipment prior to shipment

Majority of 1547.1 content

- **Design evaluation** – A “paper study” evaluating a proposed DER installation
- **Installation evaluation** – An inspection of the field-installed DER to verify correct installation
- **Commissioning test** – A test conducted in the field when the equipment is installed to verify correct operation

Significant new material

- **Periodic test** – A field test conducted periodically or as needed after the DER is installed and operating

# P1547.1: General Requirements

- The test results shall verify that the equipment under test (EUT) meets the requirements of IEEE Std 1547 within the manufacturer's specified accuracy
  - How to derive test result accuracy from manufacturer's specified accuracy and test uncertainty

**Table 3—Minimum measurement and calculation accuracy requirements for manufacturers[a]**

| Time Frame | Steady-State Measurements | | | Transient Measurements | | |
|---|---|---|---|---|---|---|
| Parameter | Minimum Measurement Accuracy | Measurement Window | Range | Minimum Measurement Accuracy | Measurement Window | Range |
| Voltage, RMS | (± 1% $V_{nom}$) | 10 cycles | 0.5 p.u. to 1.2 p.u. | (± 2% $V_{nom}$) | 5 cycles | 0.5 p.u. to 1.2 p.u. |
| Frequency[b] | 10 mHz | 60 cycles | 50 to 66 Hz | 100 mHz | 5 cycles | 50 to 66 Hz |
| Active Power | (± 5% $S_{rated}$) | 10 cycles | 0.2 p.u. < P < 1.0 p.u. | not required | N/A | N/A |
| Reactive Power | (± 5% $S_{rated}$) | 10 cycles | 0.2 p.u. < Q < 1.0 p.u. | not required | N/A | N/A |
| Time | 1% of measured duration | N/A | 5 s to 600 s | 2 cycles | N/A | 100 ms < 5 s |

[a] Measurement accuracy requirements specified in this table are applicable for voltage THD < 2.5% and individual voltage harmonics <1.5%.

[b] Accuracy requirements for frequency are applicable only when the fundamental voltage is greater than 30% of the nominal voltage.

# General Requirements

- Simulated area EPS (utility) source requirements for testing
- Measurement system requirements
- Will need to look into grid simulator specs in terms of new ride-through requirements, ramp rates etc.
- Other equipment requirements? DC supply, prime mover etc.
- May provide guidance on how type tests, evaluations, and commissioning tests fit together to result in a fully compliant DER

# Type Tests

- These are the tests we typically think of as being run by a NRTL as part of UL 1741 testing
- Some test from IEEE 1547.1/1547.1a (2005/2015) are largely valid
  - e.g. temp. stability, synchronization, interconnection integrity etc.
- Some tests can be adopted from UL 1741 SA and revised to make suitable for testing 1547-2018 requirements
  - e.g. ride-through, voltage regulation, islanding detection etc.
- Some tests need to be added
  - e. g. temporary overvoltage, transient overvoltage, interoperability, fault current characterization, “watt-var” control, etc.
- Current UL 1741 SA takes 6-8 weeks if fully automated. Will take longer when P1547.1 is incorporated.

# Type Testing of Communications

- 1547-2018 requires all DERs to be *capable* of communications using at least one of three communications methods:

**Table 41—List of eligible protocols**

| Protocol | Transport | Physical Layer |
|---|---|---|
| IEEE Std 2030.5™ (SEP2) | TCP/IP | Ethernet |
| IEEE Std 1815™ (DNP3) | TCP/IP | Ethernet |
| SunSpec Modbus | TCP/IP | Ethernet |
| | N/A | RS-485 |

- P1547.1 WG reached consensus that **at least a subset of type tests shall be run using at least one of the three protocols**
  - I.e. communications tests must be linked to power tests!
  - Can run all tests using protocol, if desired (automate?)
  - Full certification of each protocol is outside the scope of P1547.1
- Hopefully this will result in progress towards communications interoperability!

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# Production Tests

- Production tests verify the operability of every unit of interconnect equipment manufactured for customer use. These tests assume that the equipment has passed the type tests and may be conducted as a factory test or performed as part of a commissioning test

- Historically very limited:

  Response to abnormal voltage

  Response to abnormal frequency

  Synchronization

  ….

# DER Design Evaluation and Commissioning Tests

- **DER design evaluation** (desk study) is an evaluation during the interconnection review process to verify that the composite of the individual partially-compliant DERs forming a system as designed meets the interconnection and interoperability requirements of 1547-2018
- **DER installation evaluation** is an evaluation performed in the field to confirm that the DER was installed in a manner compliant with 1547-2018 requirements
- **Commissioning tests** are tests and verifications on one device or a combination of devices forming a system to confirm that the system as designed, delivered and installed meets the interconnection and interoperability requirements of 1547-2018

Due to wide variations in DERs, distribution feeders, and utility practices, P1547.1 content on these installation-specific procedures will be **much less detailed than type-test content**.

If interested, please come contribute!

# P1547.1 Subgroups (As of April 2018)

- A large number of new requirements are included in the revised IEEE 1547 – requires a number of writing subgroups in P1547.1

| | | | |
|---|---|---|---|
| General requirements | Overall document | Abnormal voltage and frequency conditions tests | Voltage and frequency regulation tests |
| Unintentional islanding tests | Power quality tests | DER microgrid capabilities | Synchronization tests |
| Modeling and simulation | Hardware-in-the-loop tests | Interoperability tests | Installation, commissioning, and periodic testing |
| Results Reporting | Prioritization of DER Responses | | |

**Chair:** Andy Hoke (emeritus: Sudipta Chakraborty)

**Secretary:** Jeannie Amber

**Treasurer:** Charlie Vartanian

**Vice Chairs:** Tim Zgonena, Babak Enayati, Karl Schoder

# P1547.1 Subgroup Leaders (As of April 2018)

| Subgroup | General requirements | Overall Document | Abnormal voltage and frequency conditions tests (ride-through and trip) | Prioritization of DER Responses | Reporting of test results | Voltage and frequency regulation tests | Unintentional islanding tests | Power quality tests | Synchronization tests | Fault current characterization tests | Hardware-in-the-loop for 1547.1 applications | Interoperability (communications) tests | Installation, commissioning, and periodic testing | DER microgrid capabilities and microgrid interconnection devices |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subgroup Chair(s) | Andy Hoke | Andy Hoke | John Berdner | Bob White | John Berdner | Jon Ehlmann | Sig Gonzalez | Marcelo Algrain | Marcelo Algrain | Mike Ropp | Karl Schoder | Brian Seal | Mark Siira | Babak Enayati |
| | | Mark Siira | Marcelo Algrain | Haile Gashaw | | Aminul Huque | Greg Kern | | | Jeannie Amber | Jesse Leonard | Bob Fox | Wayne Stec | |
| | | | Jens Boemer | | | | John Berdner | | | | | | | |

To join any of the subgroups, please contact a subgroup chair directly, or contact andy.hoke@nrel.gov

# P1547.1 Tentative Timeline to Ballot (As of April 2018)

| Dates | Activities | Status |
|---|---|---|
| June 16, 2016 | P1547.1 WG meeting – Draft 1 initiated | Done |
| October 27-28, 2016 | P1547.1 WG meeting – Draft 1 discussed | Done |
| March 2, 2017 | P1547.1 WG meeting – Draft 2 discussed | Done |
| June 20-21, 2017 | P1547.1 WG meeting – Draft 3 discussed | Done |
| November 14-16, 2017 | P1547.1 WG meeting – Draft 4 discussed | Done |
| February 2018 | P1547.1 Draft 5 posted for WG meeting | Done |
| March 6-8, 2018 | P1547.1 WG meeting – Draft 5 discussed | Done |
| May 25, 2018 | Subgroups deliver Draft 6 content | |
| June 1, 2018 | Draft 6 posted for WG review | |
| June 12-14, 2018 | P1547.1 WG meeting – Draft 6 discussed | |
| June - August 2018 | Subgroups finalize pre-ballot draft content (D7) | |
| September 2018 | Pre-ballot draft to WG for review | |
| October 1, 2018 | WG comments on D7 to subgroups | |
| October 9-11, 2018 | P1547.1 WG meeting – Finalize and approve D7 | |
| November 2018 | IEEE MEC review, IEEE-SA ballot pool formation | |
| Dec 2018 - Jan 2019 | P1547.1 IEEE-SA ballot | |
| Feb - June 2019 | Ballot resolution | |
| Q3 2019 | IEEE RevCom review | |
| Q4 2019 – Q1 2020 | 1547.1 Publication | |

**National Grid, Waltham MA, June 12-14, 2.5 days**

# Further Information

**For further information, see**
**http://grouper.ieee.org/groups/scc21/1547.1_revision/1547.1_revision_index.html**

**Sign up for the ListServ to receive occasional communications, including meeting information.  Instructions are at the website above.**

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