IEEE 1547 DER Interconnection Standard Overview

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Disclaimer and Acknowledgment

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

Outline, IEEE 1547 Module

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

2. **IEEE 1547-2018 Revision Overview,** focusing on new requirements
   - General Requirements
   - Reactive Power (VAR) Capacity and Voltage Regulation Modes
   - Abnormal Condition Response
   - Interoperability Requirements
   - P1547.9 Future Guide for DER-ES Interconnection

3. **Energy Storage(ES), and ES+PV Interconnection Considerations**

4. **IEEE 1547-2018 Adoption,** and early movers, CA Rule 21, HA Rule 14, and UL-1741-SA

IEEE Std 1547-2018 Introduction

IEEE

IEEE 1547-2018 Scope and Purpose

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

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

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

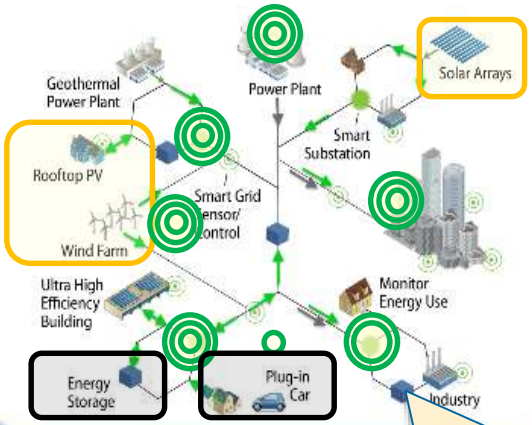
Changes from IEEE 1547-2003 shown in red

Evolution of the Grid

- Large generation systems
- Central control
- Highly regulated

Current Power System

Future Power Systems



New Challenges

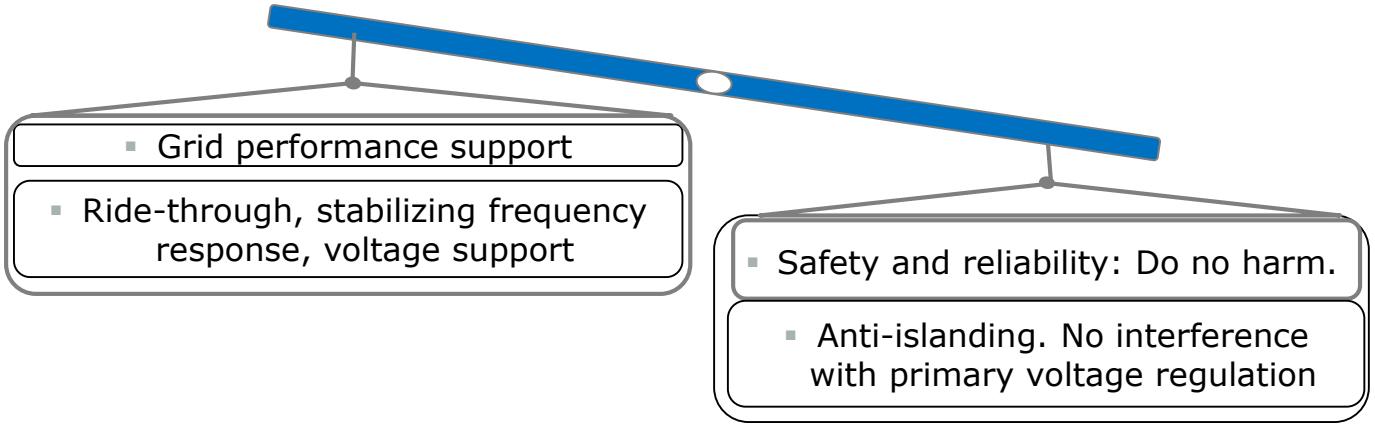
- New energy technologies and services
- Penetration of variable renewables in grid
- New communications and controls (e.g., Smart Grids)
- Electrification of transportation
- Integration of distributed energy storage
- Regulatory advances

DRIVERS

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

Grid Planning and Operation Challenges

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



IEEE 1547 Evolution of Grid Support Functions

IEEE 1547-2003

- **Shall NOT** actively regulate voltage
- **Shall** trip on abnormal voltage/frequency

IEEE 1547a-2014 (Amendment 1)

- **May** actively regulate voltage
- **May** ride through abnormal voltage or frequency
- **May** provide frequency response

IEEE 1547-2018

- **Shall be capable of** actively regulating voltage
- **Shall** ride through abnormal voltage/frequency
- **Shall be capable of** frequency response

IEEE 1547-2018 Document Outline (Clauses)

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

Areas of greatest change in the Standard.

And, areas of greatest challenge for AHJ's & Stakeholders to determine how to reference

1547-2018 General Specifications & Requirements

Clause 4

IEEE

1.4 General remarks and limitations

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

Reactive power, voltage/power control

Clause 5

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.

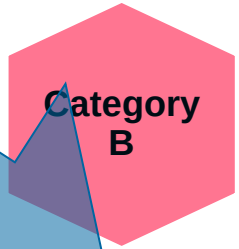
Operation at any active power output above 20% of rated active power shall not constrain the delivery of reactive power injection or absorption, up to the capability specified in Table 7, as required by the active control function at the time, as defined in 5.3. Curtailment of active power to meet apparent 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

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

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



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

Category assignment specified by Area EPS Operator

Active voltage regulation capability requirements

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

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

Constant power factor mode

Constant reactive power mode (“reactive power priority”)

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

“State-of the art” DER – Cat B

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

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

SEE BACK-UP SLIDES FOR EXAMPLE CURVES: DEFAULT SETTINGS AND RANGES OF ADJUSTABILITY

Response to abnormal conditions

Clause 6

Performance Categories – Abnormal Operating Conditions

Ride Through Capabilities

Category I

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

Category II

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

Category III

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

SEE BACK-UP SLIDES FOR EXAMPLE CURVES: DEFAULT SETTINGS AND RANGES OF ADJUSTABILITY

Categories for DER response to abnormal EPS conditions

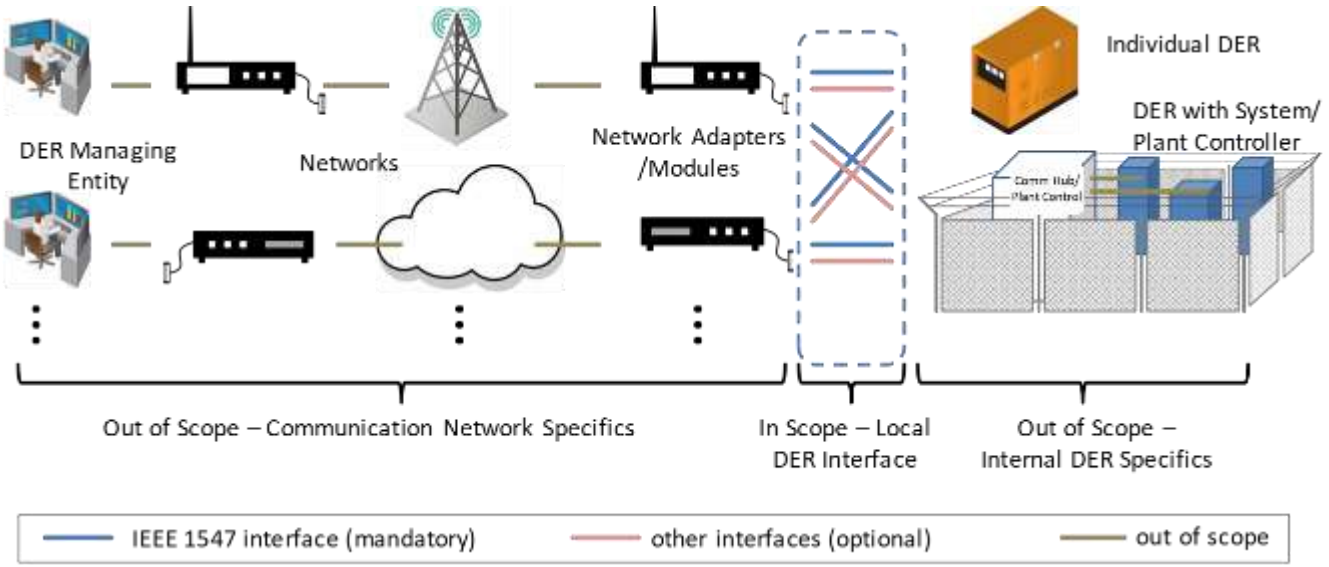
Category	Objective	Foundation
I	Essential bulk system needs and reasonably achievable by all current state-of-art DER technologies	German grid code for synchronous generator DER
II	Full coordination with bulk power system needs	Based on NERC PRC-024, adjusted for distribution voltage differences (delayed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

Category II and III are sufficient for bulk system reliability.

Interoperability

Clause 10

Interoperability Requirements: *New with the -2018 Revision*



IEEE 1547-2018 defines communication interface

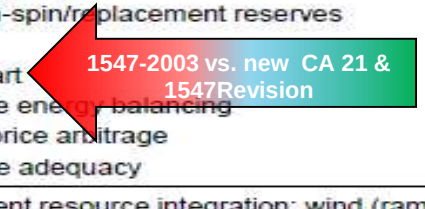
Energy Storage(ES), and ES+PV Interconnection Considerations

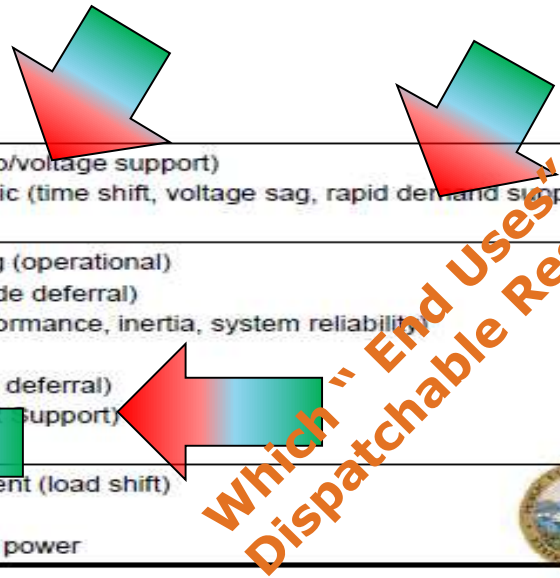
P1547.9 a Future Guide for ES-DER Interconnection

IEEE

Without Updated Standards, Plus Adoption by AHJ's, Some Services from ES & PV+ES Won't Be Deliverable

Category	Storage "End Use"
ISO/Market	• Frequency regulation • Spin/non-spin/replacement reserves • Ramp • Black start • Real time energy balancing • Energy price arbitrage • Resource adequacy
VER Generation	• Intermittent resource integration: wind (ramp/voltage support) • Intermittent resource integration: photovoltaic (time shift, voltage sag, rapid demand support) • Supply firming
Transmission/ Distribution	• Peak shaving: off-to-on peak energy shifting (operational) • Transmission peak capacity support (upgrade deferral) • Transmission operation (short duration performance, inertia, system reliability) • Transmission congestion relief • Distribution peak capacity support (upgrade deferral) • Distribution operation (Voltage Support/VAR Support) • Outage mitigation: micro-grid
Customer 7	• Time-of-use /demand charge bill management (load shift) • Power quality • Peak shaving (demand response), Back-up power





IEEE P1547.9 Project

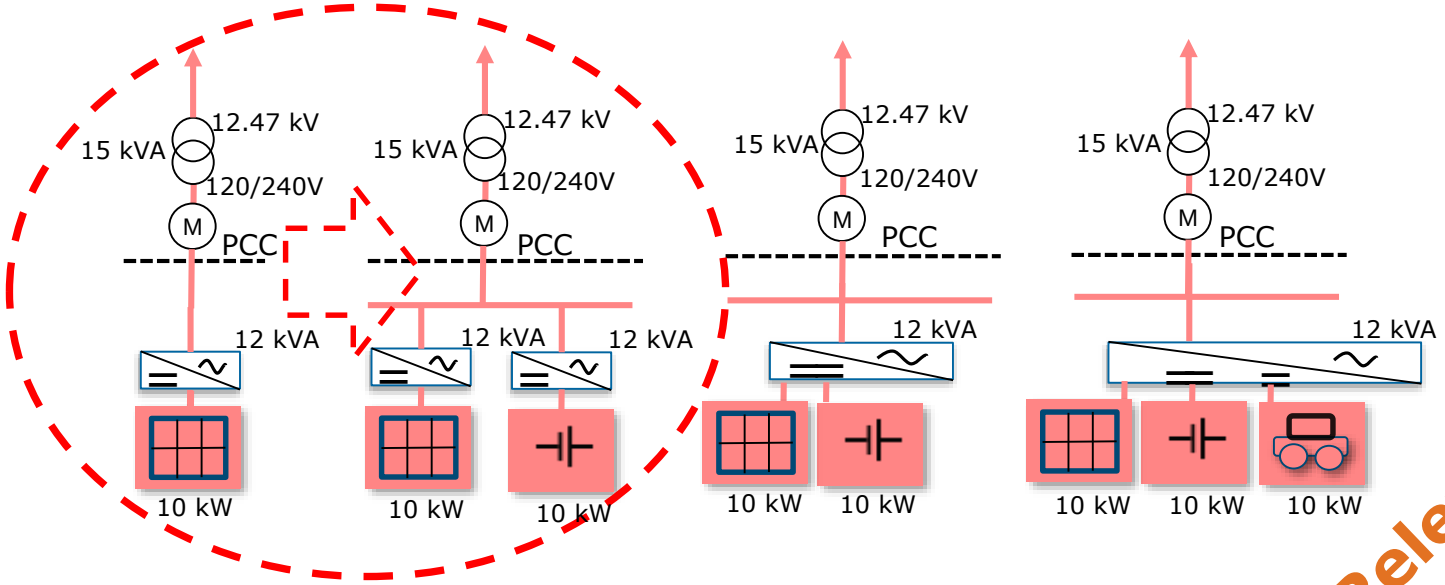
Approved by the IEEE SASB on March 8, 2018

Title: Draft Guide to Using IEEE Standard 1547 for Interconnection of Energy Storage Distributed Energy Resources with Electric Power Systems

Scope: This Guide provides information on and examples of how to apply the IEEE Std 1547, for the interconnection of Energy Storage Distributed Energy Resources (DER ES). Scope includes DER ES connected to area Electric Power Systems (local EPSs) that are capable of bidirectional real and reactive power flow, and are capable of exporting real power to the EPS. Guidance is also provided for non-exporting DER ES, such as Uninterruptible Power Supply (UPS) type systems that support onsite loads, or Electric Vehicle (EV) chargers, with charging attributes that could have power system impacts, e.g. modulating rate of charge proportionally to system frequency.

Purpose: The purpose of this guide is to provide guidance on prudent and technically sound approaches to interconnection of DER ES to power systems. This guideline will also consider ES-related topics not currently addressed or fully covered in the main IEEE 1547 Standard document. For example:
1). Guidance for interconnection of EV charging stations with the ability for exporting (i.e., bidirectional real or reactive power exchange) to the connected power system (i.e., "V2G").
2). Guidance on when ES are or are not within the scope of P1547. For example, 1547.9 would expand on the exceptions for systems that are non-exporting, e.g. UPS that receive energy from the grid, but only use it for premise loads while off-grid.
3). Guidance on charging and generation constraints to minimize negative impacts in the distribution system.

Power Capability vs Controlled Capacity vs Rating at the Point of Common Coupling (PCC)



What's the interconnection rating and/or requirement at the PCC?

Who determines? On what basis?

Does amount of metered demand, and how its connected, have an impact?

P1547.9 TIMELINE

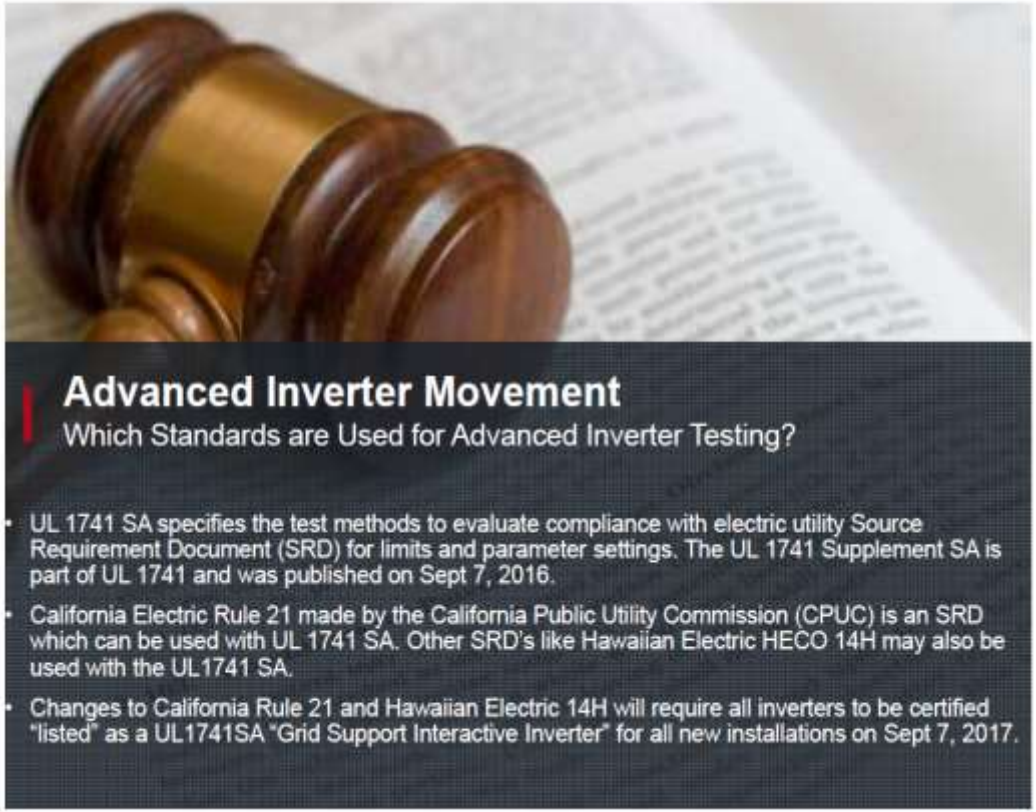
Dates	Activities	Status
February 28, 2019	P1547.9 WG meeting – WG initiated	Done
June 6, 2019	P1547.9 WG Meeting – Draft 1 initiated	Done
October 2019	P1547.9 WG Meeting (online meeting)	Done
February 2020	P1547.9 WG Meeting – Draft 1 complete	Plan
Summer 2020	P1547.9 WG Meeting	Plan
Fall/Winter 2020	P1547.9 WG Meeting	Plan
Spring/Summer 2021	P1547.9 WG Meeting	Plan
Q2 2021	P1547.9 Ballot draft approved by WG	
QX 2021	P1547.9 To IEEE-SA for ballot	
QX2021	IEEE Std 1547.9-20XX Published	

IEEE 1547-2018 Adoption,

and early movers, CA Rule 21, HI Rule 14, and UL-1741-SA

IEEE

UL-1741-SA, an interim solution



Source, UL Presentation, T. Zgonena, 11/1/2017

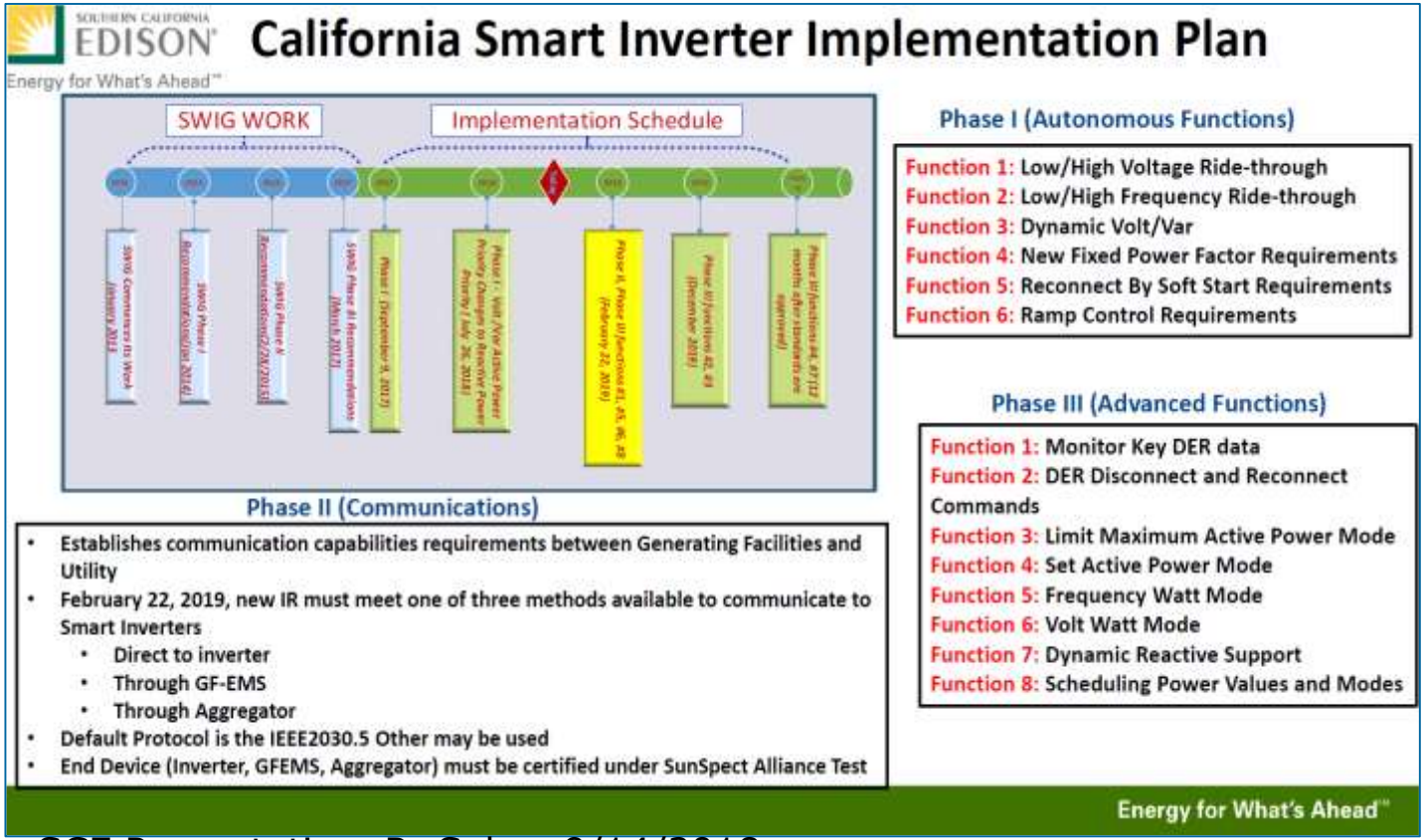
UL-1741-SA, an interim solution

Use of UL1741 SA with IEEE 1547, 2nd Ed. Until IEEE 1547.1 2nd Ed. Publication

- There is some utility interest to make use of IEEE 1547 2nd edition ASAP.
- It is difficult to implement 1547 edition 2 without a test protocol.
- Even with using UL1741 SA as a seed document and fast track task group efforts 1547.1 edition 2 is still ~1.5yrs away from publication.
- There is growing support / agreement to use the published 1547 edition 2 to develop a Source Requirements Document (SRD) such that we can use the existing published UL1741 SA standard and test protocols to provide a certification that addresses a majority of the 2nd edition 1547 requirements.
- This hybrid certification will quickly address a majority of our needs ASAP!
- Once both the 2nd editions of 1547 and 1547.1 are published UL1741 will be revised to replace the Supplement SA with the 2nd edition references and… All will be right with the world.

Source, UL Presentation, T. Zgonena, 11/1/2017

CA Rule 21



Source, SCE Presentation, R. Salas, 9/14/2018

HI Rule 14

Rule 14H Functions Matrix

		Interconnection Standards			Rule 14H		Listing/ Certification		
Function Set	Advanced Functions Capability	IEEE 1547-2003	IEEE 1547a-2014	IEEE 1547-2018	2015	2018 SRD V1.1	UL 1741	UL 1741(SA) 2016	IEEE 1547.1-2017*
All	Adjustability in Ranges of Allowable Settings		√	‡					Δ
Monitoring & Control	Ramp Rate Control			‡ ?	‡	‡ ?		Δ	Δ ?
	Communication Interface			‡		‡			Δ
	Disable Permit Service (Remote Shut-Off)			‡					Δ
	Limit Active Power			‡		‡ CSS,NEM+			Δ
	Monitor Key DER Data			‡					Δ
Scheduling	Set Active Power								
	Scheduling Power Values and Models					‡ CGS+, smart CSS			
Reactive Power & Voltage Support	Constant Power Factor	√	√	‡	‡	‡	√	Δ	Δ
	Voltage-Reactive Power (Volt-Var)	X	√	‡		‡		Δ	Δ
	Autonomously Adjustable Voltage Reference			‡					Δ
	Active Power-Reactive Power (Watt-Var)	X		‡					Δ
	Constant Reactive Power	√	√	‡	‡	‡	√		Δ
	Voltage-Active Power (Volt-Watt)	X	√	‡		‡ Opt		Δ	Δ
	Dynamic Voltage Support during VRT			√					
Bulk System Reliability & Frequency Support	Frequency Ride-Through (FRT)			‡	‡	‡		Δ	Δ
	Rate-of-Change-of-Freq. Ride-Through			‡					Δ
	Voltage Ride-Through (VRT)			‡	‡	‡		Δ	Δ
	Voltage Phase Angle Jump Ride-Through			‡					Δ
	Frequency-Watt	X	√	‡		‡		Δ	Δ

Legend: X Prohibited, √ Allowed by Mutual Agreement, ‡ Capability Required, Δ Test and Verification Defined
[…] Subject to clarification of the technical requirements and use cases, !!! Important Gap

Source: EPRI.

ENPHASE.

Questions?

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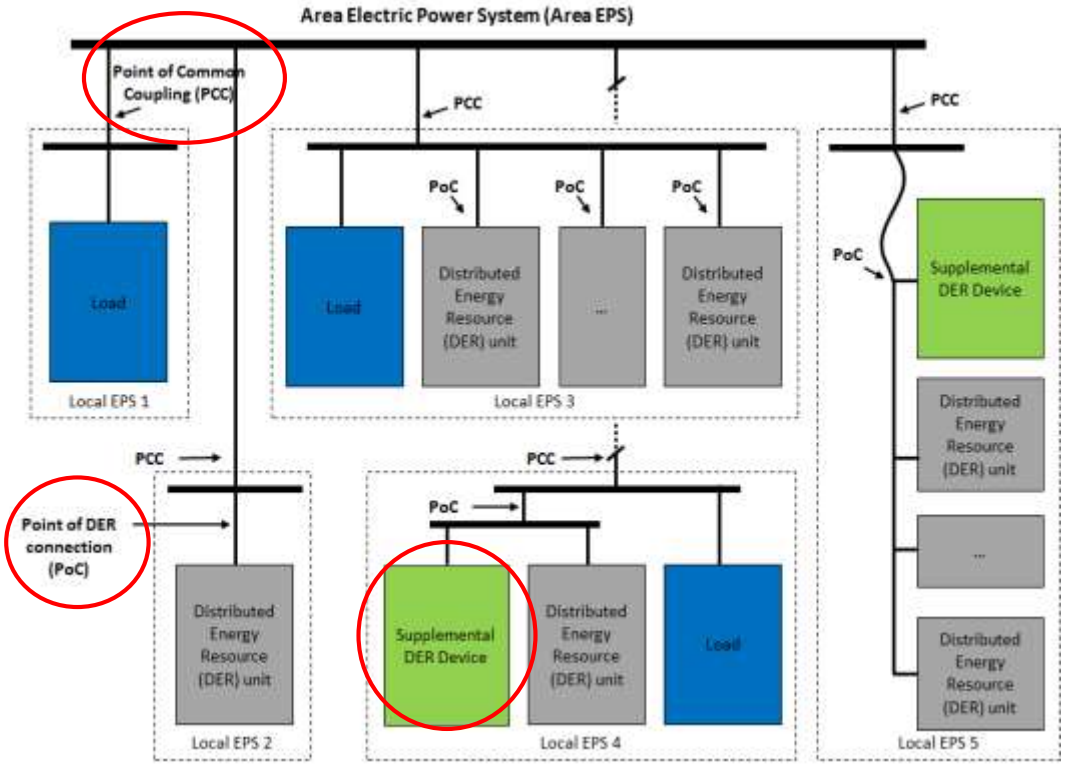
Backup Slides

Reference Point of Applicability



- **RPA is where performance requirements apply**
- IEEE 1547 specifies RPA depending on three criteria:
  - Aggregate DER rating
  - Average load demand
  - Zero sequence continuity
- Generally:
  - PoC (DER terminals) for small and load-immersed DER
  - PCC for large exporting installations

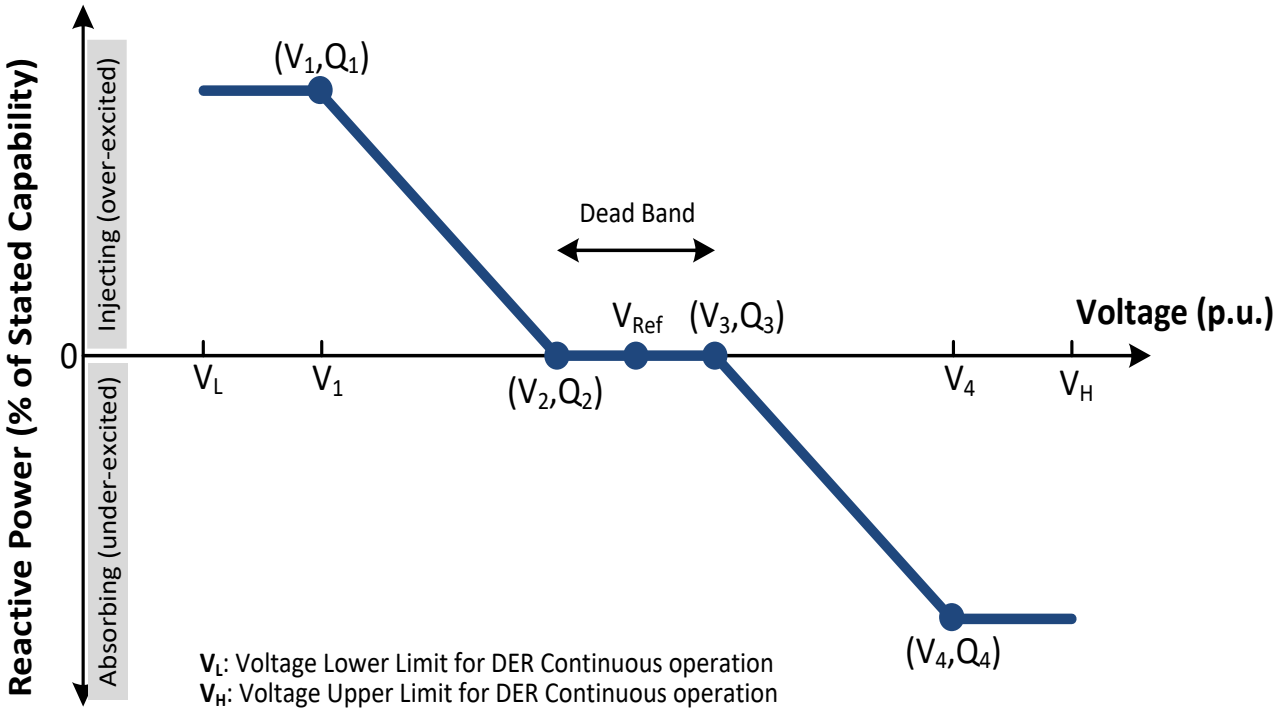
Enter Service criteria

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

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.

Voltage-Reactive Power mode



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} 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} 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

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 .

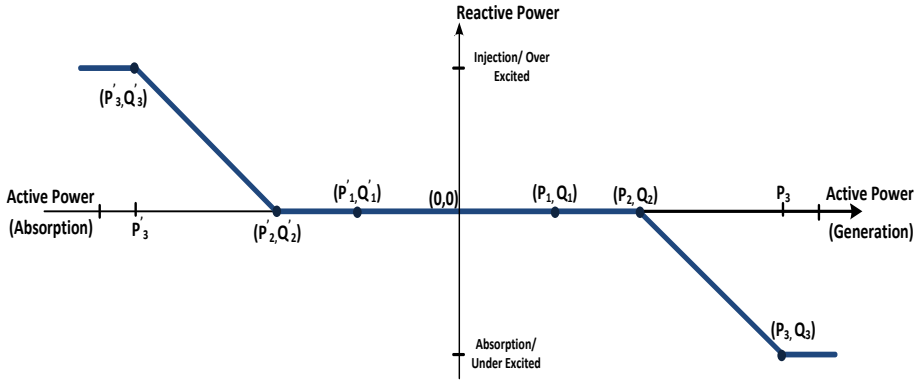


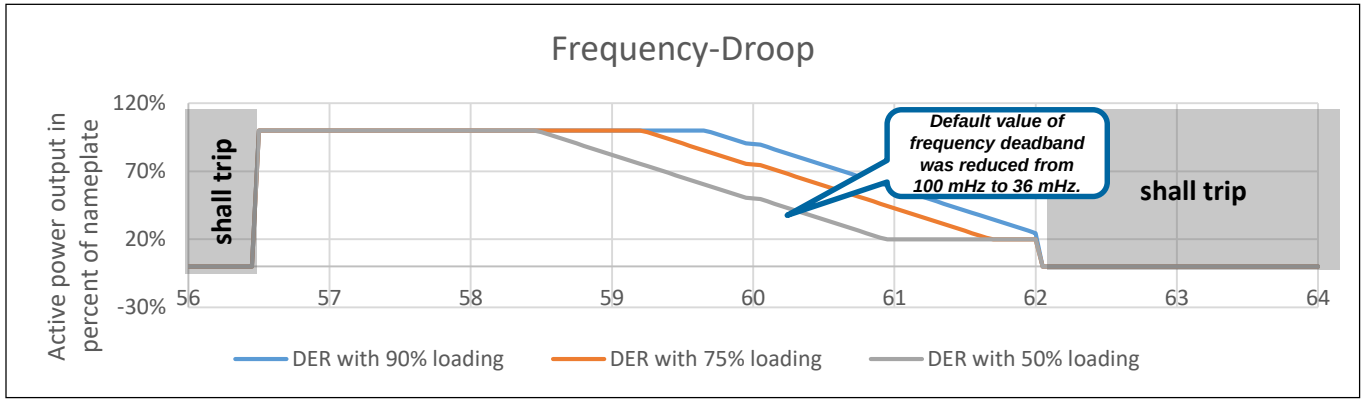
Figure 6—Example active power-reactive power characteristic

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		

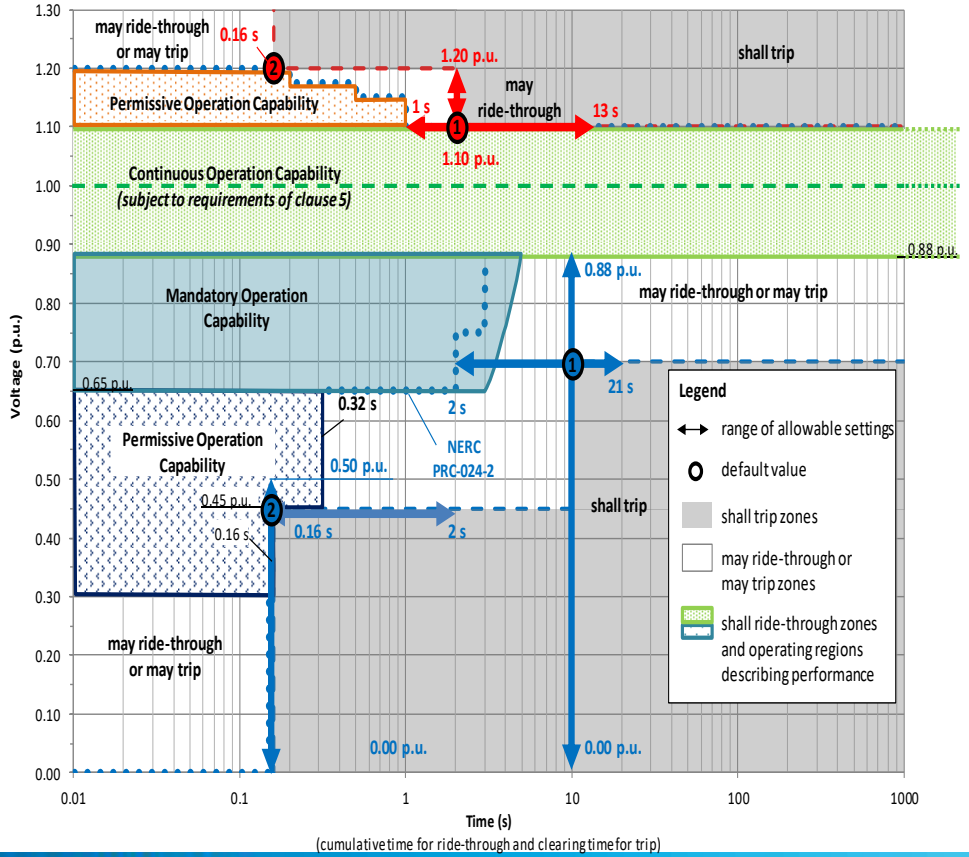
Note: P_{max} is the maximum active power that the DER can deliver.

Frequency Support



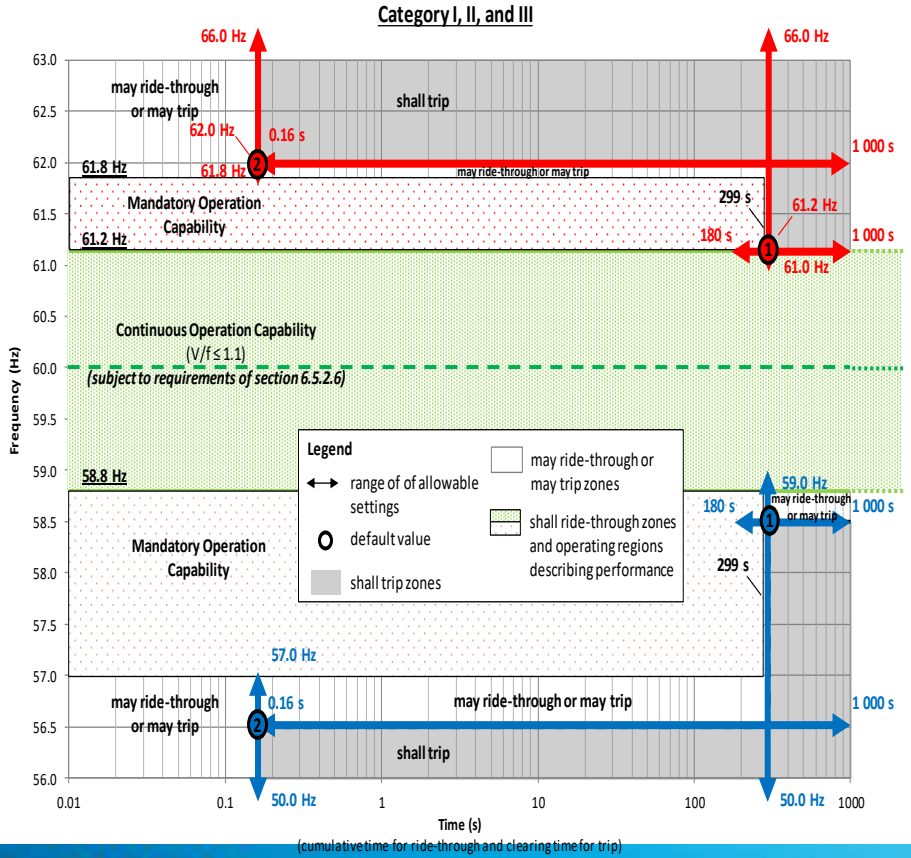
- Overfrequency: all DERs required to provide droop response
- Underfrequency: Cat II and III DERs required to provide droop response *if power is available*
- Only a functional capability requirement
  - Utilization remains outside the scope of IEEE 1547-2018
- Adjustable dead bands and droop
- Response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

IEEE Std 1547-2018 Voltage Ride Through, 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.

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