IEEE 1547

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

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

IEEE PES Power & Energy Society®

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- Ride through
- Voltage regulation
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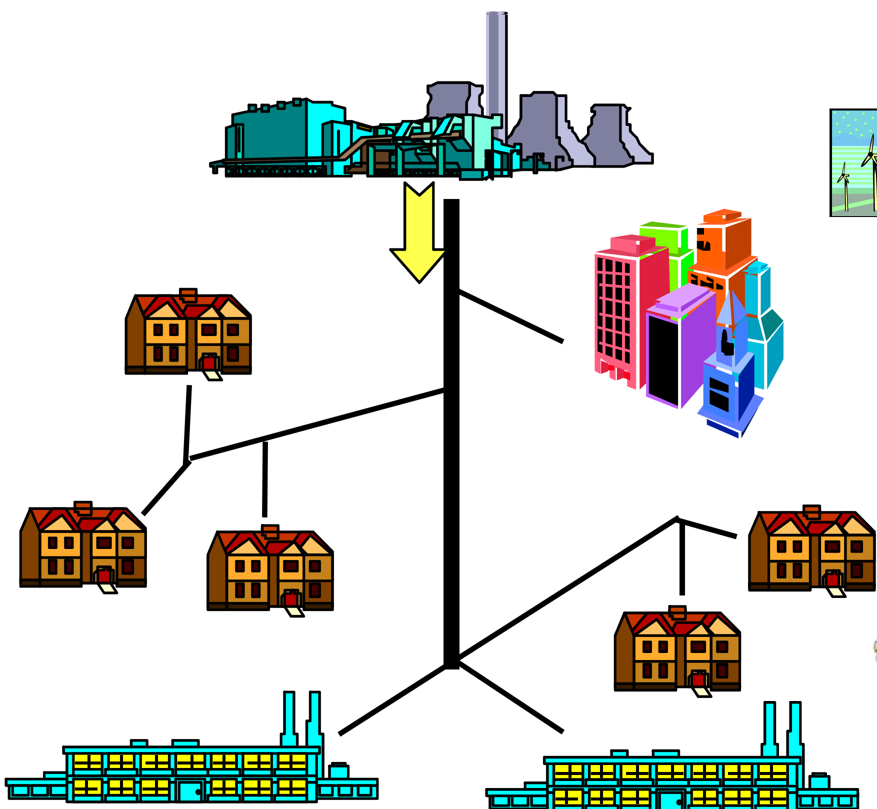
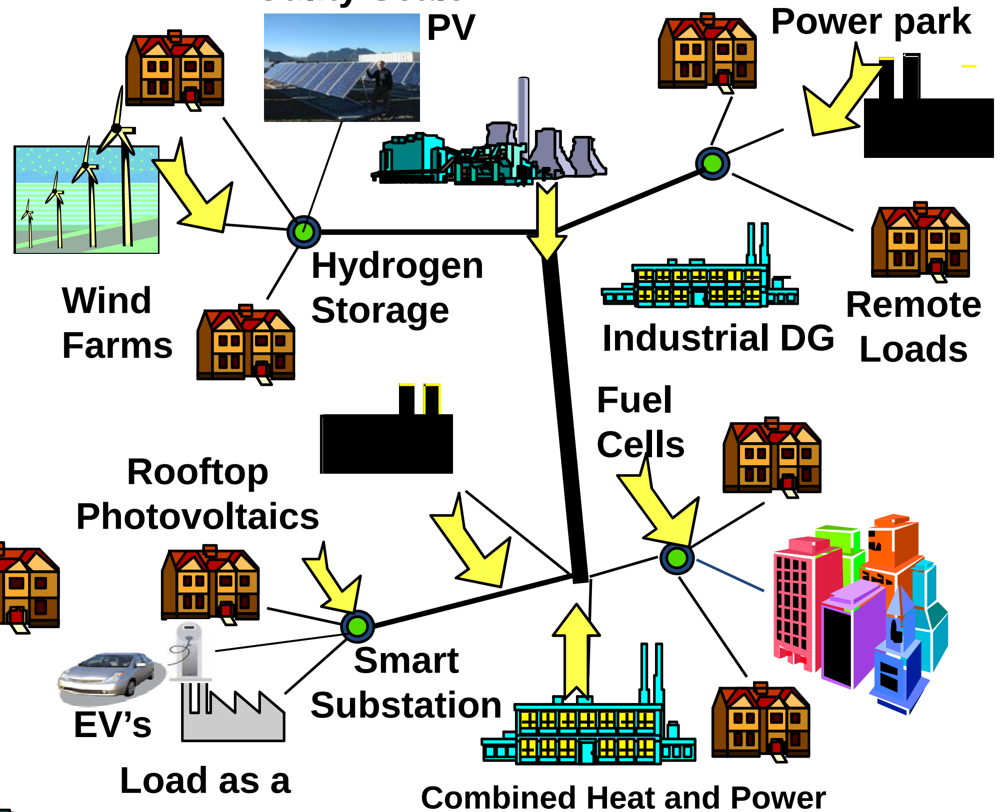
Challenges of Grid Modernization

Traditional Electric Grid… → ***Modern Electricity Choices …***





P1547 Revision: Draft *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**.

Note: Interfaces defined in IEEE 2030: "a logical interconnection from one entity to another that supports one or more data flows implemented with one or more data links.

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**.

IEEE SCC21 1547 Series of Standards*

IEEE Std 1547™(2003 and 2014 Amendment 1) Standard for Interconnecting Distributed Resources with Electric Power Systems

- **IEEE Std P1547™(full revision)** Draft Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces
- **IEEE Std 1547.1™(2005 and 2015 Amendment 1)** Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
  - **IEEE Std P1547.1 (full revision)** Draft Standard for Conformance Tests Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces

IEEE Std 1547.2™(2008) Application Guide for IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems

IEEE Std 1547.3™(2007) Guide for Monitoring Information Exchange, and Control of Distributed Resources with Electric Power Systems

IEEE Std 1547.4™(2011) Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems

IEEE Std 1547.6™(2011) Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Networks

IEEE Std 1547.7™ (2013) Guide to Conducting Distribution Impact Studies for Distributed Resource Interconnection

IEEE Std P1547.8™ Draft Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE Std 1547-2003

* Colored background designates IEEE published standard; clear background is draft standard work in progress.

1547: Interconnection Is The Focus

IEEE Std 1547 covers:

- **INTERCONNECTION** TECHNICAL SPECIFICATIONS & REQUIREMENTS
- **INTERCONNECTION TEST** SPECIFICATIONS & REQUIREMENTS

Distributed Energy Resource (DER) unit

Interconnection System

Note: P1547 full revision started in year 2015 is also addressing interoperability and interfaces

Area Electric Power System (EPS)

IEEE 1547
IS:

- A Technical Standard – Functional Requirements For
  - the interconnection itself
  - the interconnection test
- Technology neutral, e.g., does not specify particular equipment nor type
- A single (whole) document of mandatory, uniform, universal, requirements that apply at the PCC or Point of DER Connection.
- Should be sufficient for most installations.

IEEE 1547
Is NOT:

- **a design handbook**
- **an application guide**
- **an interconnection agreement**
- **prescriptive, e.g., does not address DR self-protection, nor planning, designing, operating, or maintaining the Area EPS.**

IEEE 1547.1 is:
Test Procedures for Conformance to1547

IEEE Std 1547a – Amendment 1, May 2014

(Amendment 1: revisions to 4.1.1, 4.2.3, and 4.2.4)

4.1.1 Voltage Regulation

… DER allowed to change its output of active and reactive power.

4.2.3 (Response to abnormal grid …) Voltage

…. DER allowed to “ride through” abnormalities of grid voltage;

… grid and DER operators can mutually agree to other voltage trip and clearing time settings

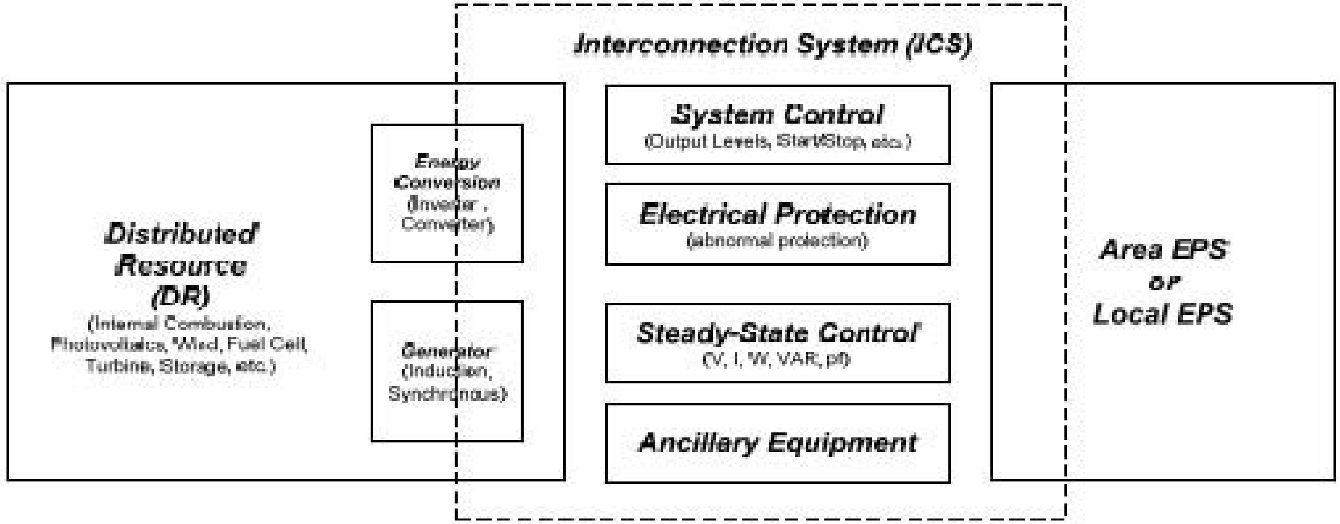
4.2.4 (Response to abnormal grid …) Frequency

… DER allowed to provide modulated power output as a function of frequency

… … grid and DER operators can mutually agree to other frequency trip and clearing time settings

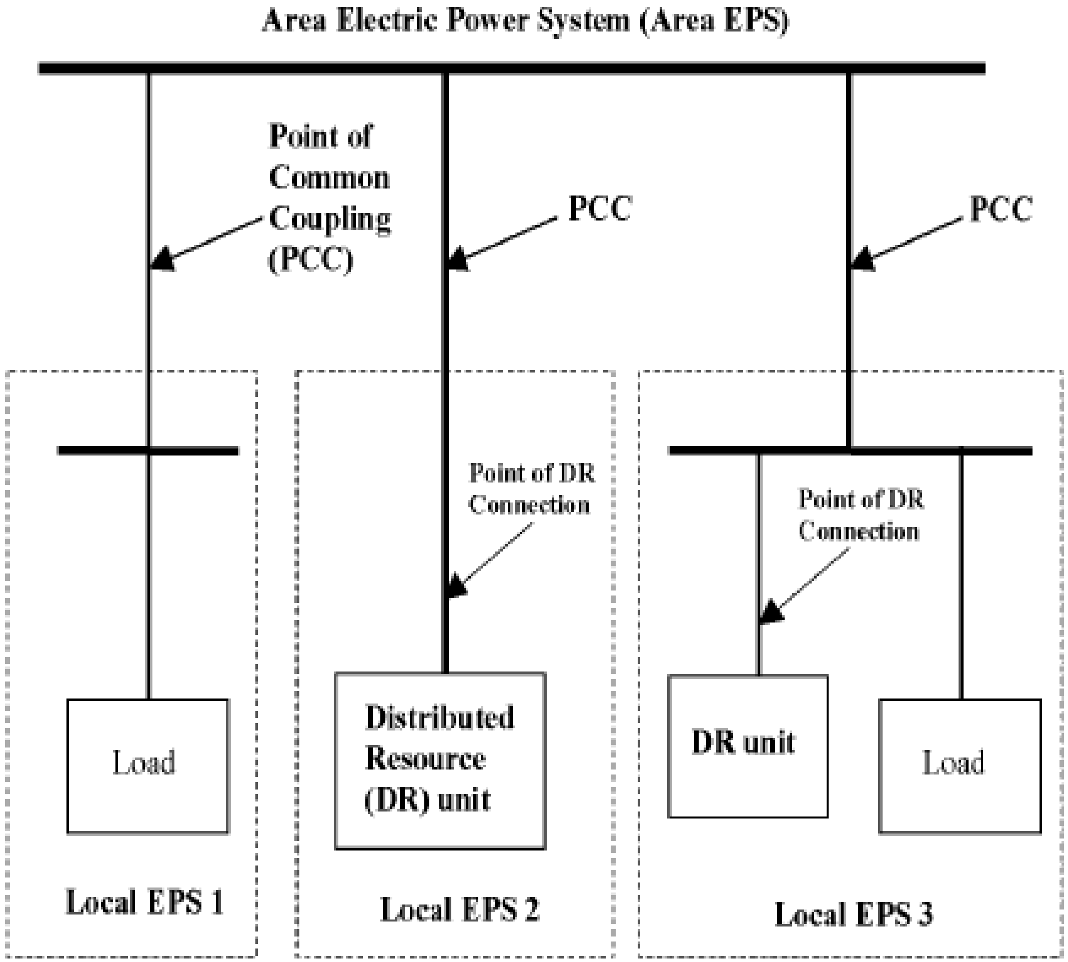
IEEE Std 1547.1 (2005; reaffirmed 2011)

… ***Standard for Conformance Test Procedures*** …specifies the type, production, and commissioning tests that shall be performed to demonstrate that interconnection functions and equipment of a distributed resource (DR) conform to IEEE Std 1547.



1547.1 Figure 1 - Boundaries between the interconnection system, EPS and DR.

PCC vs Point of DER Connection



Note: Dashed lines are EPS boundaries. There can be any number of Local EPSs.

Point of Evaluation

Requirements shall be met at the Point of Common Coupling (PCC) for all Local EPS

- having an aggregate DER nameplate rating of 500 kW or greater, <u>and</u>
- having an average load demand of equal or less than 10% of the DER nameplate rating.

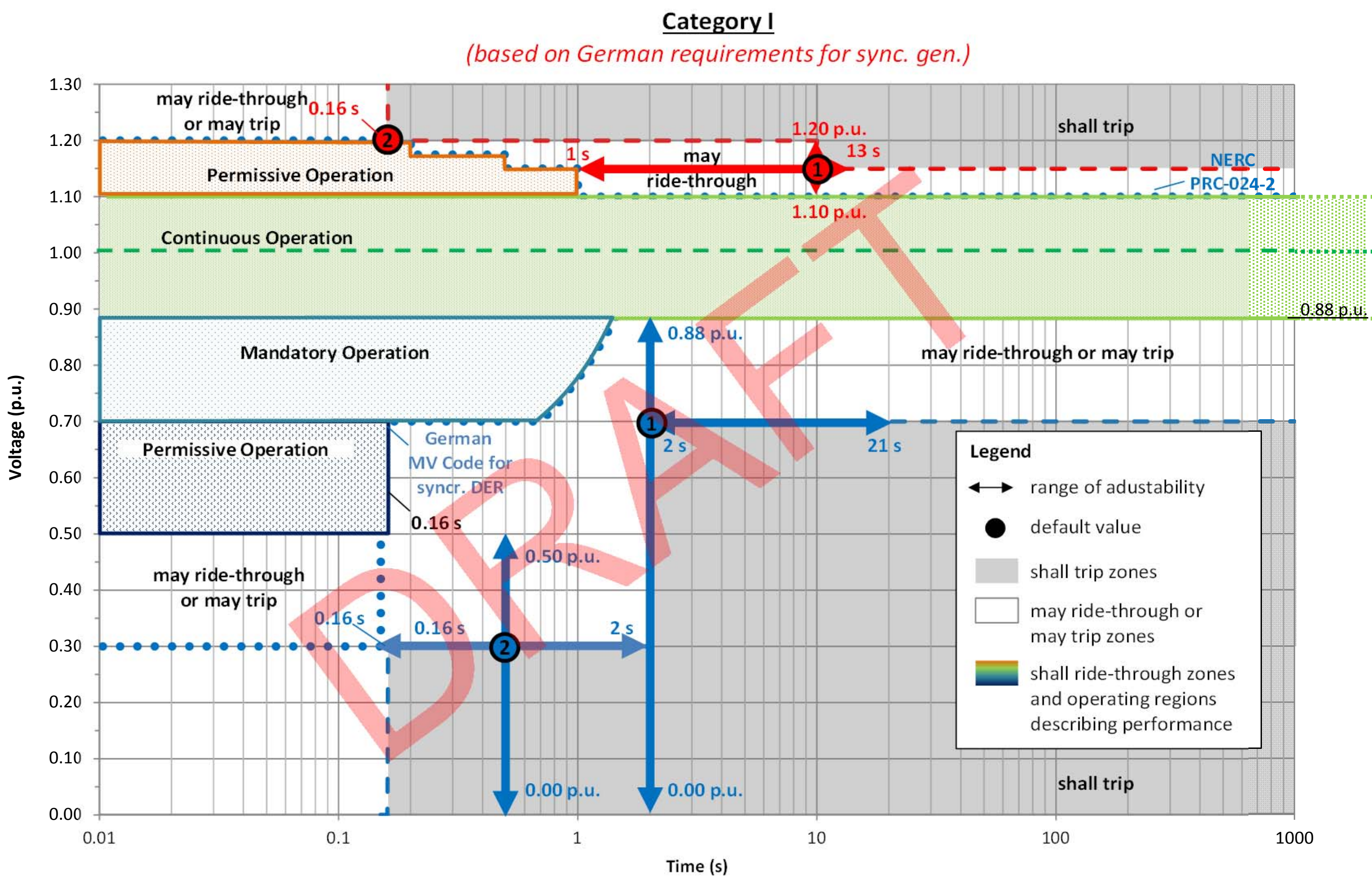
In all other situations, the applicable point for meeting performance requirements shall be the Point of DER connection

P1547 New Requirements for Ride Through (Work In Progress)

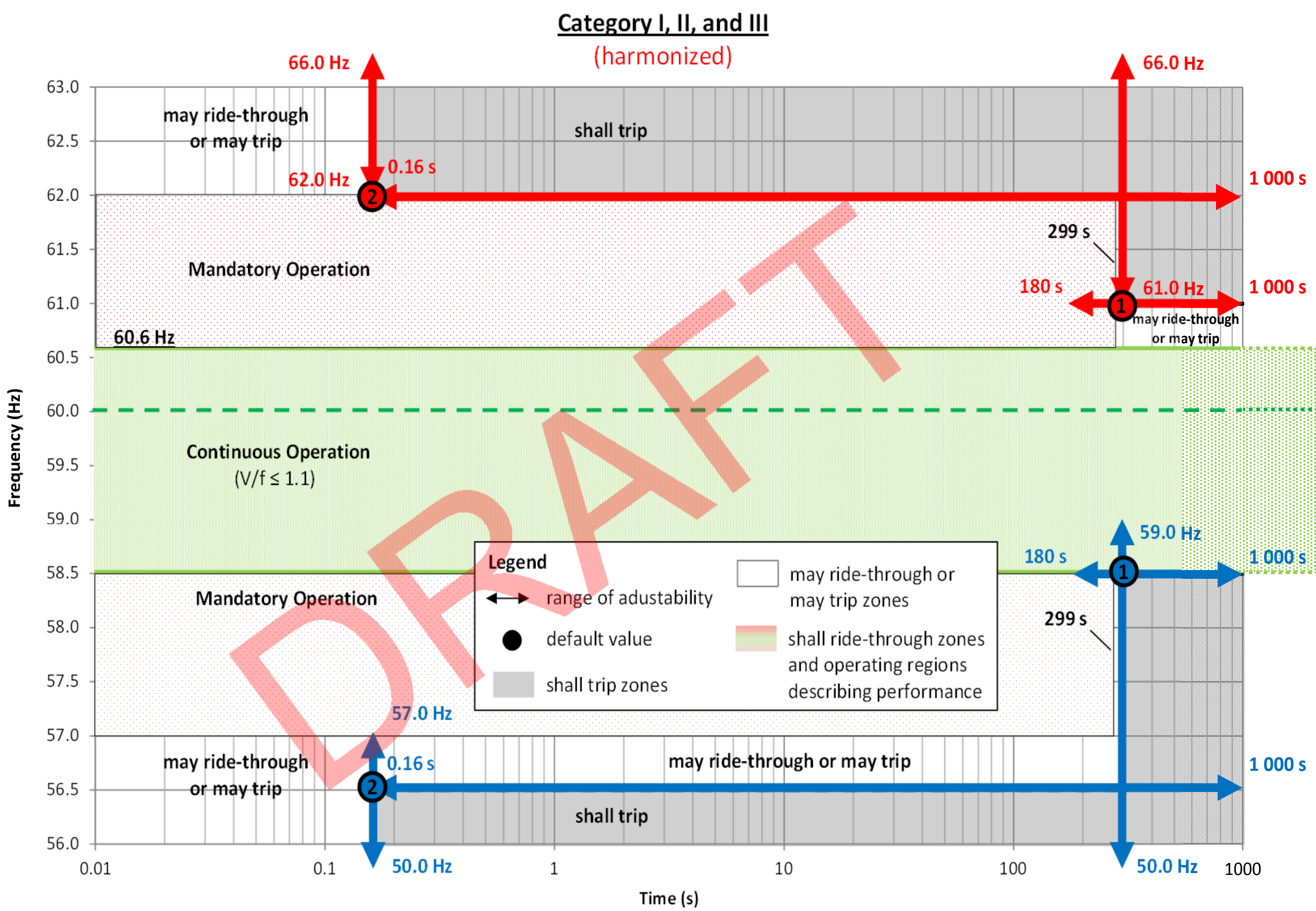
- Three Categories of DER Operational Responses to Support the Grid -- Based on Local and Farther Reaching Grid Requirements and DER

Requirement	Category	Foundation	Justification
Voltage Ride-Through	Category I	German grid code for medium voltage-connected synchronous generator-based DER	• *Essential* bulk system needs. • Attainable by all state-of-the-art DER technologies.
	Category II	NERC PRC-024-2 but w/o stability exception, extended LVRT duration for 65-88% V_{nom} ➢ based on EPRI White Paper (May 2015)	• *All* bulk system needs. • Coordinated with existing reliability standards. • Considering fault-induced delayed voltage recovery.
	Category III	CA Rule 21 and Hawaii, minor modifications	• All bulk system needs. • Considering fault-induced delayed voltage recovery. • Distribution system operation.
Frequency Ride-Through	All Categories (harmonized)	CA Rule 21 and Hawaii, exceeds PRC-024-2 ➢ based on EPRI White Paper (May 2015)	• All bulk system needs. • Low inertia grids.

P1547 Example New Requirements for voltage Ride Through (work in progress)



P1547 Example New Requirements for frequency Ride Through (work in progress)



Distribution grid impacts that need to be carefully reviewed by the utility protection engineer !!

- Distribution Feeder Fault Detection

- Anti-islanding protection

P1547 voltage regulation

(Work In Progress)

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 state-of-the-art DER technologies

b) Category B covers all requirements within Category A and specifies additional requirements to mitigate voltage variations due to resource variability

P1547 Example New Reactive Power Requirements (Work In Progress)

The DER shall be capable of injecting reactive power (over-excited) and absorbing reactive power (under-excited) equal to the minimum reactive power (kvar) corresponding to the value given in Table TBD at all active power output greater than or equal to 20% of nameplate active power rating (kW) or the minimum steady-state power capability of the DER, whichever is greater. As an additional requirement, Category B DER shall provide said capability at all active power levels subject to the restriction that the ratio of the average of absolute value of DER reactive power over the preceding 24 hour period divided by the average of absolute value of DER apparent power over the preceding 24 hour period is less than 0.44.

Table TBD – Minimum Reactive Power Injection and Absorption Capability

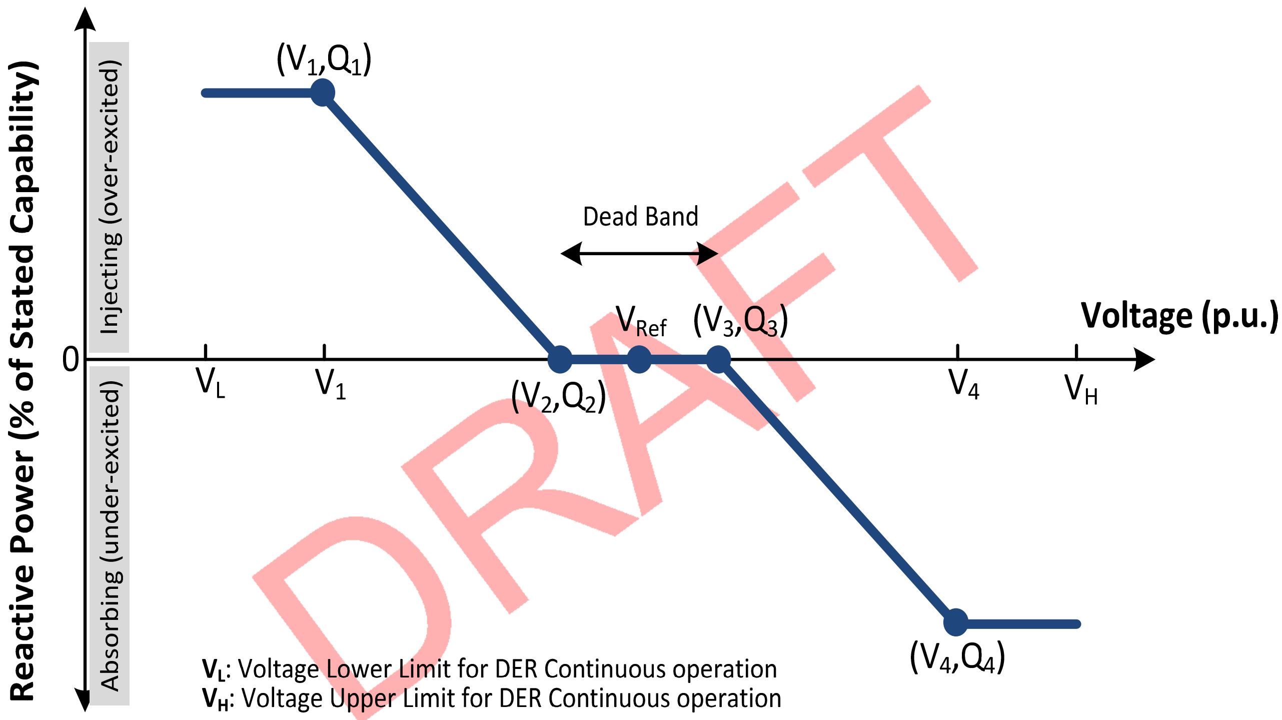
Category	**Injection Capability as % of Nameplate Apparent Power (kVA) Rating $Qmin_{inj}$**	**Absorption Capability as % of Nameplate Apparent Power (kVA) Rating $Qmin_{abs}$**
A (at DER rated voltage)	44 Full load PF=0.9	25 Full load PF=0.97
B (at ANSI range A)	44 Full load PF=0.9	44 Full load PF=0.9

Voltage and Reactive Power Control

The DER shall provide the capabilities of the following modes of reactive power control functions:

1. Adjustable Constant Power factor mode – The capability is mandatory for categories A and B
2. Voltage-reactive power (Volt-var) mode – The capability is mandatory for categories A and B
3. Active power-reactive power mode (watt-var) – The capability is optional for category A and mandatory for categories B
4. Reactive power mode – The capability is mandatory for categories A and B

P1547 Example New Reactive Power Requirements (Work In Progress)

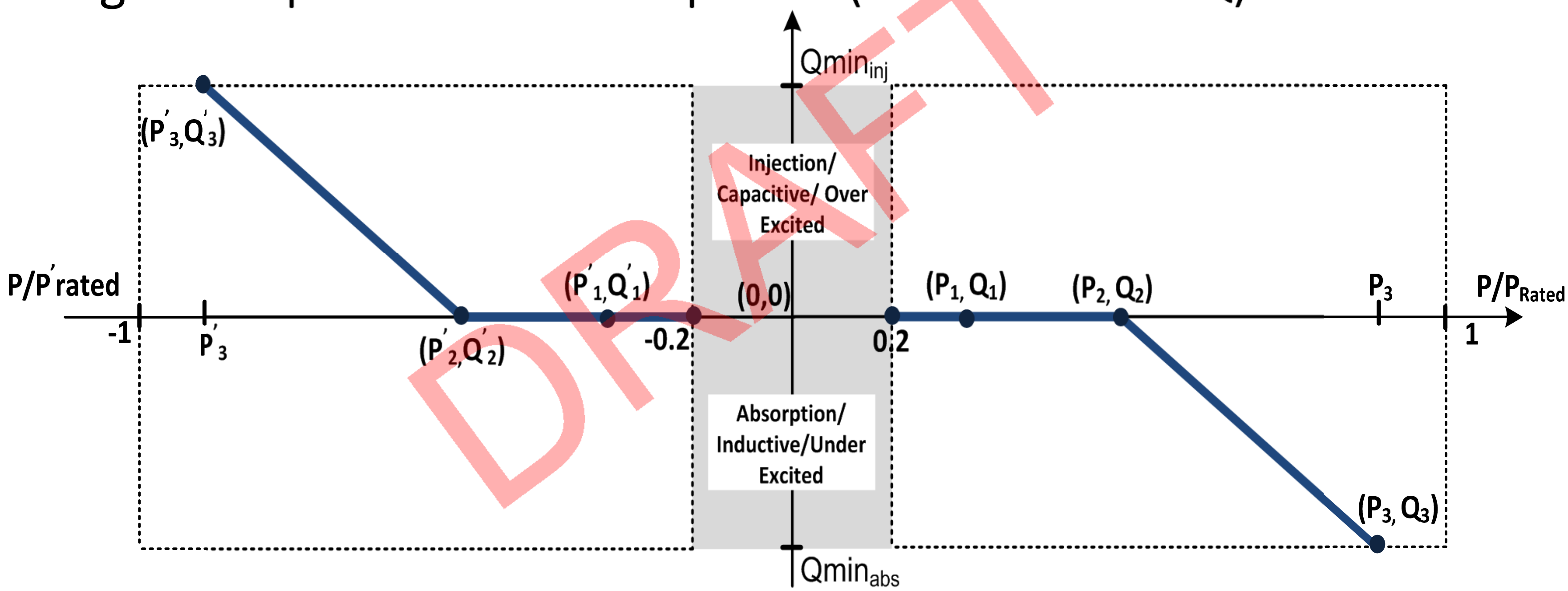


The Volt/VAR characteristics curve is adjustable

Volt-var Parameters	Definitions	Default Values for Cat A DER	Default Values for Cat B DER	Adjustable Range	
				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}
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	0.82 of V_N	$V_2{}^{c}$-0.02 V_N
Q_1	Reactive power injection at voltage V_1	25% of Nameplate kVA	100% of stated reactive capability	0	100% of stated reactive capability
V_4	Voltage at which DER shall absorb Q_4 reactive power	1.1 pu	V_{Ref} + 0.08 V_N	$V_3{}^{c}$+0.02 V_N	1.18 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 95% of the reactive power change in response to the change in voltage	10 sec	5 sec	1s	90s
Mode/setting time	Maximum Time by which mode or setting changes are to be made effective	60s	60s	5s	5 min

Active Power – Reactive Power (Watt-Var or P - Q) Mode

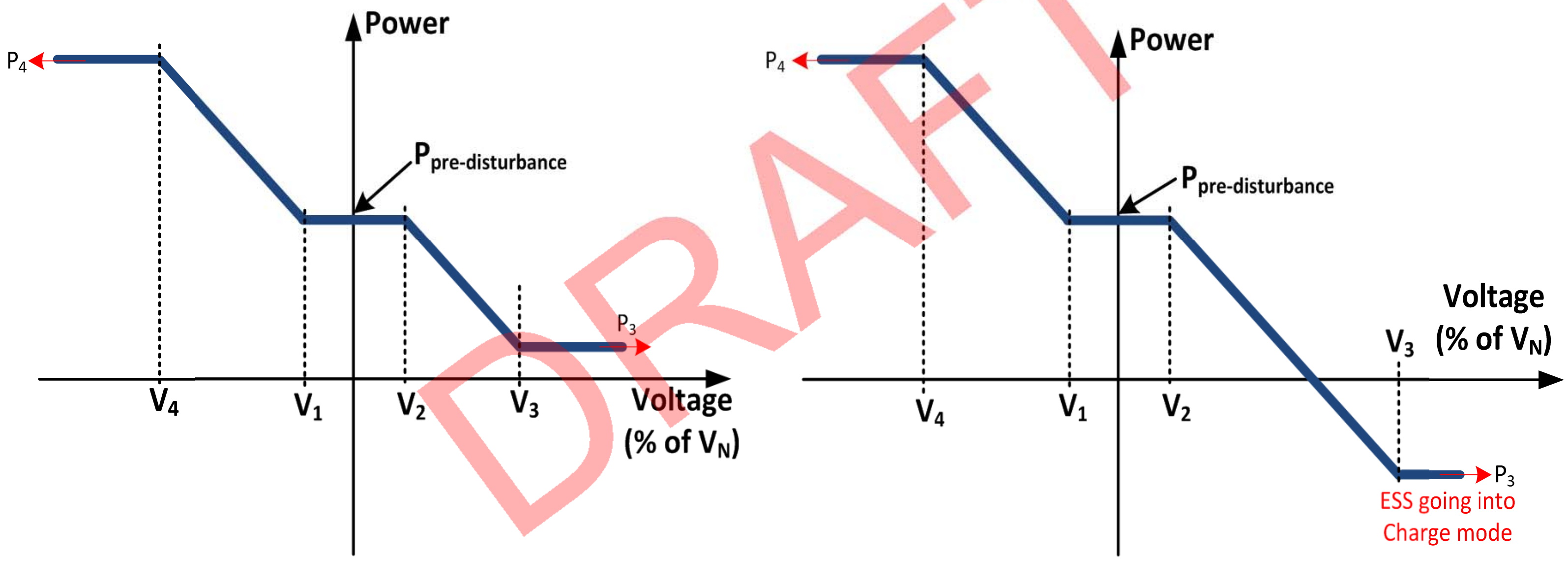
When in this mode, the DER shall actively control the reactive power output as a function of the real power output following a target real power – reactive power (Watt-Var or P-Q) characteristic.



P1547 Example New Voltage Regulation Requirements (Work In Progress)

Voltage-Real Power (Volt-Watt) Mode

When in this mode, the DER shall actively control the real output power as a function of the system voltage following a target voltage – active power (volt-watt) characteristic curve.



Transition from abnormal to normal voltage conditions

The requirements of the voltage regulation clause (4.1) apply to normal voltage range when the voltage is between 0.88 and 1.1 times the nominal voltage (V_N). The voltage conditions outside of this range are defined to be abnormal. The DER shall return to its pre-disturbance operating mode after the system voltage returns to its normal range.

Grid impacts that need to be carefully reviewed by the utility engineer !!

- Anti-islanding protection
- Reactive Power coordination amongst existing DERs and utility assets i. e. capacitor banks, etc.
- Prioritizing the voltage regulation schemes

Are voltage regulation and ride-through requirements proposed to be mandatory?

- The ride-through capability and performance is proposed to be mandatory.
- The voltage regulation capability is proposed to be 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).

Rapid voltage changes (RVC)

- Rapid voltage changes are considered to be changes in fundamental frequency voltage less than one second . The DER shall not cause the ΔV/V voltage variations to go outside the limits specified in table X. (Ref. IEEE 1453)

Number of Changes (moving window)	ΔV/V %
n ≤ 4 per day	6
n ≤ 2 per hour and > 4 per day	4
2 < n ≤ 10 per hour	3

For the one-day moving window of Table X, each new RVC event shall be assessed separately using a sliding one-day window. The new RVC event and all RVC events that occurred in the preceding 24 hours shall be counted together to determine if the new RVC event exceeds the maximum number of rapid voltage changes allowed in one day. For the one-hour moving window of Table X, each new RVC event shall be assessed separately using a sliding one-hour window.

The new RVC event and all RVC events that occurred in the preceding 60 minutes shall be counted together to determine if the new RVC event exceeds the maximum number of rapid voltage changes allowed in one hour.

Flicker

Flicker- Flicker is the subjective impression of fluctuating luminance caused by voltage fluctuations. Assessment methods for flicker are defined in IEC 61000-3-7.

- $P_{st99\%}$ (99th percentile value) shall not be greater than 0.9. If not specified differently, the Pst evaluation time is 10 minutes.
- $P_{lt99\%}$ (99th percentile value) shall not be greater than 0.7. If not specified differently, the P_{lt} evaluation time is 2 hours.

P1547 Example New Power Quality Requirements (Work in progress)

Harmonics:

- When the DER is serving balanced linear loads, harmonic current injection into the Area EPS at the Point of DER interconnection shall not exceed the limits stated below.
- 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 3—Maximum odd harmonic current distortion in percent of rated current (I)[a]

Individual odd harmonic order h	$h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h$	Total demand distortion up to the h=50 harmonic (TDD)
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

Table 4—Maximum even harmonic current distortion in percent of rated current (I)[a]

Individual even harmonic order h	h=2	h=4	h=6	$8 \le h$
Percent (%)	1.0	2.0	3.0	Associated range specified in Table 3

P1547 Example New Power Quality Requirements (Work in progress)

Any aggregated interharmonic current distortion between h+/-5Hz shall be limited to the associated harmonic order h limit in Tables 3 and 4. Any aggregated interharmonics current distortion between h+5Hz and (h+1)-5Hz shall be limited to the lesser magnitude limit of h and h+ 1 harmonic order.

P1547 Example New Power Quality Requirements (Work in progress)

As an alternative, a self-excited DER, e.g., synchronous generator, shall be tested to meet the requirements of 4.3.3; either after installation or while powering a balanced resistive load and isolated from any other sources. The voltage harmonics while powering a resistive load at 100% of the machine kVA rating shall not exceed the levels in Tables 5 and 6 for odd and even harmonics, respectively. Voltage harmonics shall be measured line to line for 3-phase/3 wire systems, and line to neutral for 3-phase/4-wire systems.

Table 5—Maximum odd harmonic voltage distortion in percent of rated voltage

Individual odd harmonic order h	h < 11	11≤ h < 17	17 ≤h < 23	23 ≤h < 35	35 ≤h	Total rated distortion up to the h=50 harmonic (TRD)
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

Table 6- Maximum even harmonic voltage distortion in percent of rated voltage

Individual even harmonic order h	h=2	h=4	h=6	8≤h
Percent (%)	1.0	2.0	3.0	Associated range specified on the previous slide

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

Limitation of over-voltage over one fundamental frequency period

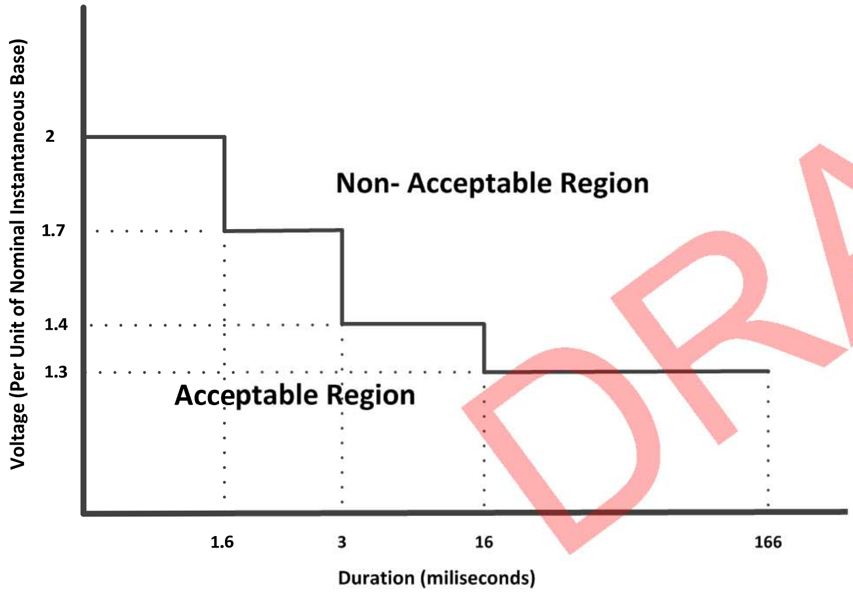
- The DER shall not contribute to instantaneous or RMS over voltages with the following limits:
- The DER shall not cause the RMS Line-Ground voltage on any portion of the Area EPS that is designed to operate effectively grounded, as defined by IEEE C62.92.1, to exceed 138% of its nominal line-ground RMS voltage for duration of exceeding one fundamental frequency period.
- The DER shall not cause the L-L RMS voltage to exceed 138% of its nominal L-L RMS voltage at any location on the Area EPS distribution system for duration of exceeding one fundamental frequency period.
- The RMS voltage measurements of this sub-clause shall be based on one fundamental frequency period.

Limitation of cumulative instantaneous over-voltage

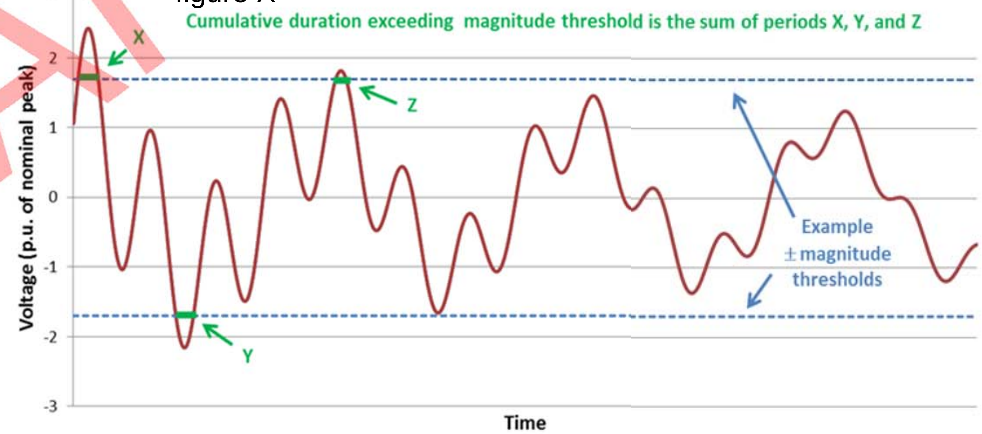
- The DER shall not cause the instantaneous voltage at the point of common coupling (PCC) to exceed the magnitudes and cumulative durations shown in figure TBD. The cumulative duration shall only include the sum of periods for which the instantaneous voltage exceeds the respective threshold over a one minute time window.
- An example of the cumulative duration is provided in figure X (next slide)

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

- The DER shall not cause the instantaneous voltage at the point of common coupling (PCC) to exceed the magnitudes and cumulative durations shown in figure TBD. The cumulative duration shall only include the sum of periods for which the instantaneous voltage exceeds the respective threshold.



An example of the cumulative duration is provided in figure X



Interoperability and interfaces

Significant New Additions to IEEE 1547

- Interoperability requirements will be included
- Additional interfaces addressed – not only the PCC
- Informative material to be included

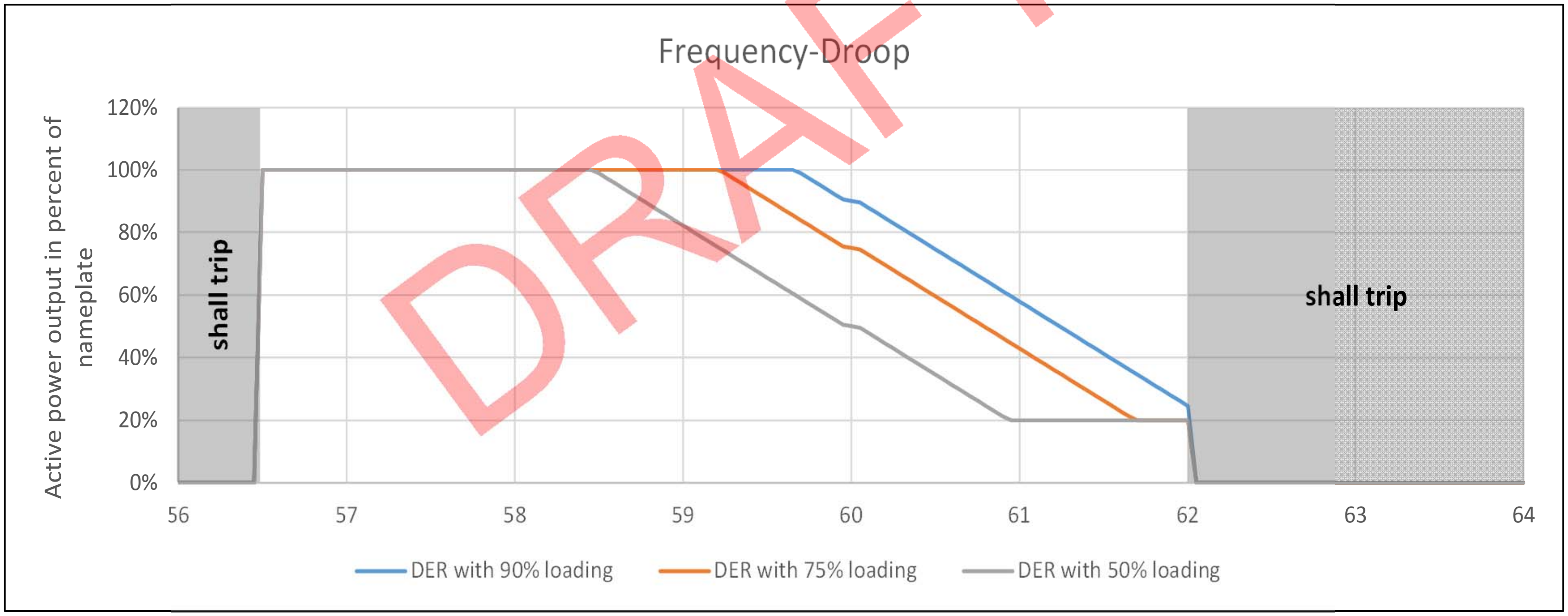
Frequency Droop

During temporary frequency disturbances, for which the system frequency is outside the adjustable deadband db_{OF} and db_{UF} , but still between the trip settings, the DER shall adjust its active power output from the pre-disturbance levels, according to the formulas in Table below:

Formula for frequency-droop (frequency/power) operation	
Operation for Low-Frequency Ride-Through	**Operation for High-Frequency Ride-Through**
$p = \min_{f<60-\mathrm{db_{UF}}} \left\{ p_{\mathrm{pre}} + p_{\mathrm{rated}} \cdot \frac{(60-\mathrm{db_{UF}})-f}{60 \cdot \mathrm{k_{UF}}}, p_{\mathrm{avl}} \right\}$	$p = \max_{f>60+\mathrm{db}_{OF}} \left\{ p_{\mathrm{pre}} - p_{\mathrm{rated}} \cdot \frac{f-(60+\mathrm{db_{OF}})}{60 \cdot \mathrm{k_{OF}}}, p_{\mathrm{min}} \right\}$

Frequency Droop Example

Example of a frequency-droop function with a 5% droop, 36 mHz deadband, and 20% minimum active power output



Other areas being discussed in P1547

- Voltage Ride-Through requirements for consecutive temporary voltage disturbances
- Voltage regulation during ride through
- Island systems
- Interoperability
- Testing
- ……..

CIGRÉ U.S. National Committee NEXT GENERATION NETWORK (USNC NGN)

What is the Next Generation Network (USNC NGN)?

The CIGRÉ U.S. NGN was established for young engineers who have begun to progress their career within the power industry.

- US NGN Membership

  - Any full-time experience of 10 years or less beyond the last degree received in the power field

  - Students (FREE) or professionals (50% Reduction Young member)

  - Become a CIGRÉ US NGN member

  - http://cigre.wpengine.com/membership/

- Provide opportunities for technical and personal development

  - Networking opportunities

  - Advance Technical Skills

  - Collaborate with peers across US and abroad

Ways to get involved

- Participate in webinars and tutorials
- Attend the NGN invited-only events in Grid of the Future Symposium
- Join the NGN Executive Committee
- Expand Technical knowledge through CIGRÉ Working Groups
- Participate in the Paper Competition

UPCOMING EVENT

2017 Next Generation Network Paper Competition.

Win a trip to next year's CIGRÉ General Session

in Paris

with travel expenses and registration fees included!

- 5/1/17 — Participants submit abstract
- 6/30/17 — Top ten partcipants submit technical paper
- 8/4/17 — Top five participants selected
- 10/22 - 10/24/17 — Top five participants present at the Grid of the Future Symposium

Need more information?
http://cigre-usnc.tamu.edu/ngn/

Questions?
Contact usnc-ngn@cigre.org.

CIGRÉ-USNC
Next Generation Network (NGN)

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Thank you!

Questions?