US Grid Code and Certification Standards

IEEE 1547-2018, IEEE 1547.1-2020 and UL1741-2021

IEEE STANDARDS ASSOCIATION IEEE

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

IEEE Standards Coordinating Committee 21

Sponsored by the
IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

IEEE
3 Park Avenue
New York, NY 10016-5997

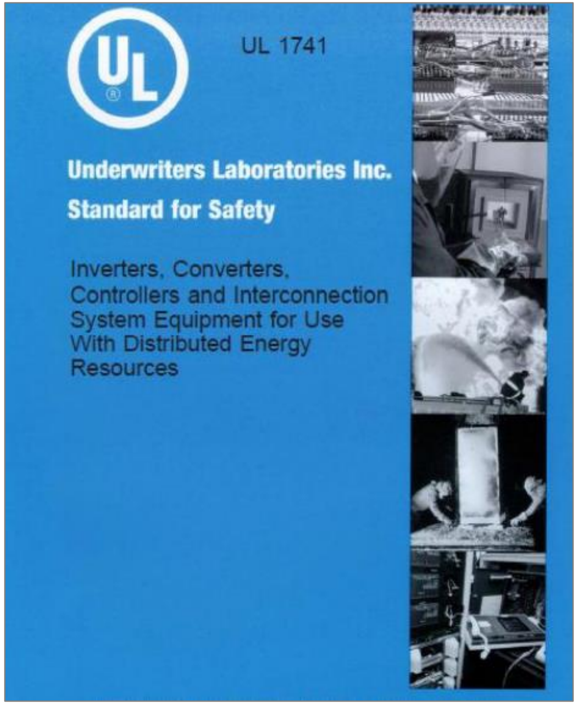
IEEE Std 1547™-2018
(Revision of IEEE Std 1547-2003)

IEEE SA
STANDARDS ASSOCIATION

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

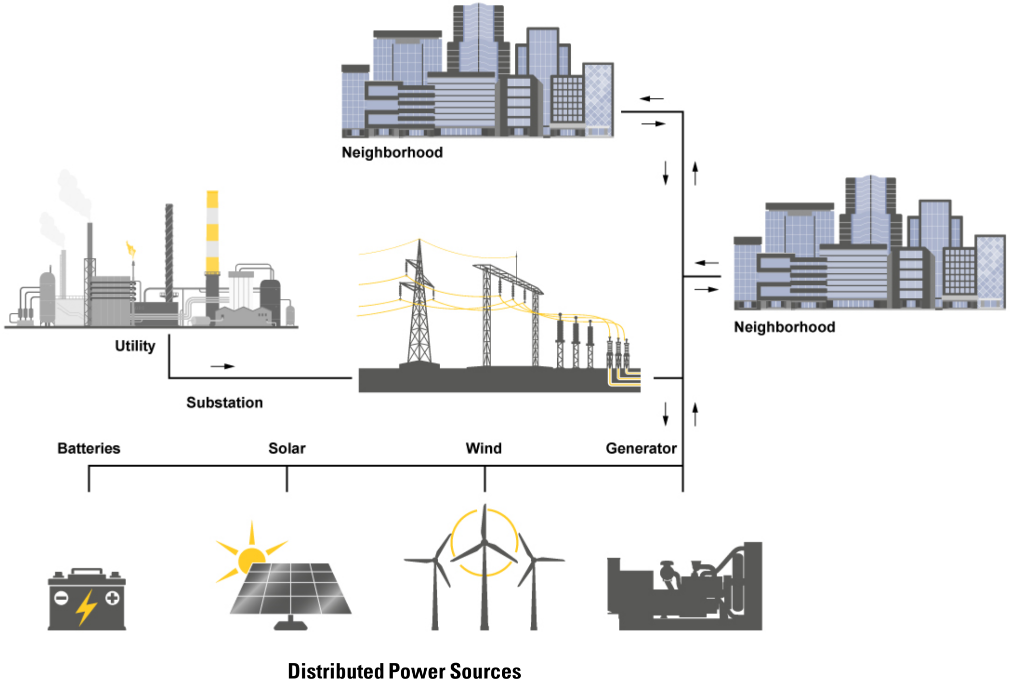
Developed by the

IEEE Standards Coordinating Committee 21
on
Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage



Grid of the Future

- The future Smart Grid is to significantly improve the efficiency of how electricity is delivered and consumed
- High penetration of distributed/green generation resources is expected due to sustainability and environmental constraints
- New grid codes are being introduced to enable integration of distributed generation and maintain / improving reliability



Tackling system stability issues: a prerequisite to the success of the energy transition

- The share of generation produced by rotating machines, providing inertia and other stabilizing features to the system has decreased and will continue to decrease drastically in years to come.

Power System Stability Phenomena

Resonance stability	Converter-driven stability	Rotor angle stability	Voltage stability	Frequency stability

New phenomena
TIMEFRAME OF MILLISECONDS

Growing and changing phenomena
TIMEFRAME OF SECONDS

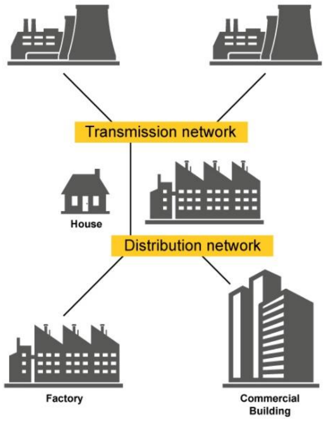
Reference entsoe

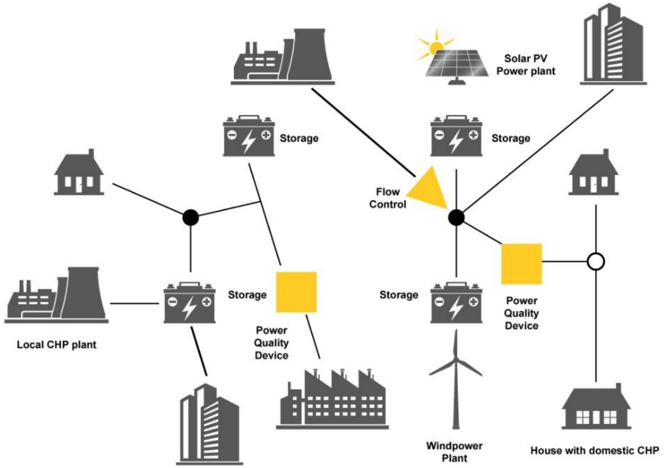
What is a Grid Code?

"A set of rules that must be met by generating units and facility owners to gain permission to access the electricity grid"

From: **Centralized**

To: **Distributed**





Before:

- Disconnect during a fault

Now:

- Stay connected
- Ride-through the fault
- Support the grid

Drive towards high renewable penetration leads to increased risk of instability and black-outs

Stabilizing technologies must be deployed to counterbalance the increase of factors destabilizing the power system

Variable, Renewable Energy Resources
Conventional Power Electronics
Interfaced Resources & Devices
Long Distance Transmission & Weak Connections
Long HVAC cables
Climate Change & Extreme conditions

Advanced Monitoring & Control of Stability
Simulation Techniques & Models
Controllable Resources & Flexibility Grid
Forming Capabilities of Power
Electronics & Interoperability
Synchronous Generation

Reference
entsoe

The “New Wave” of Grid Code Activity

CATERPILLAR®

The “New Wave” of Grid Code Activity

The “New Wave” of Grid Code Activity

CATERPILLAR®

US Grid Code and Certification Standards

IEEE 1547-2018, IEEE 1547.1-2020 and UL1741-2021

IEEE STANDARDS ASSOCIATION ◆IEEE

IEEE 1547-2018

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

IEEE Standards Coordinating Committee 21

Sponsored by the
IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

IEEE
3 Park Avenue
New York, NY 10016-5997

IEEE Std 1547™-2018
(Revision of IEEE Std 1547-2003)

IEEE SA
STANDARDS ASSOCIATION

IEEE 1547.1-2020

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

Developed by the

IEEE Standards Coordinating Committee 21
on
Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

UL 1741

UL 1741-2021

Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources

Top 5 Changes Introduced by IEEE 1547-2018

- Voltage support functions
- Frequency support functions
- Anti-islanding requirements
- Interoperability
- Fault ride through (FRT) capabilities

Different Requirements for Different Generation Technologies

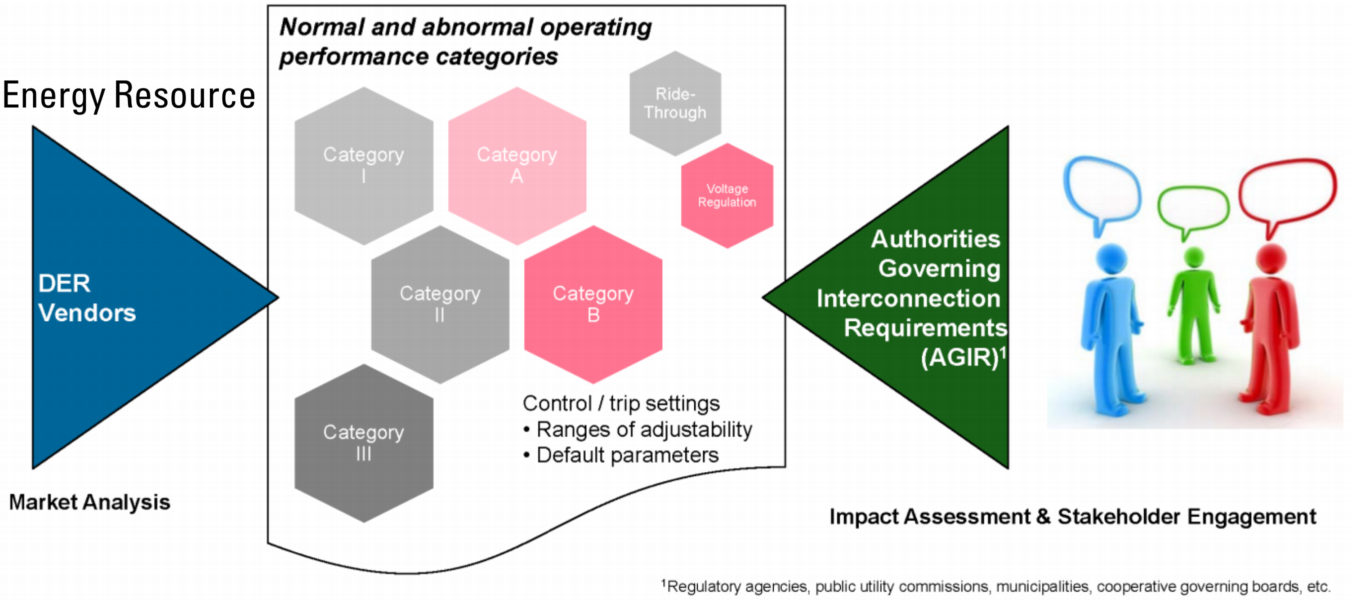
IEEE Std 1547 is technology agnostic … BUT

Several performance categories are defined to accommodate the limitations of some technologies

- Category A … fewer voltage regulation functions
- Category B … more voltage regulation functions
- Category I … lower FRT requirements
- Category II … higher FRT requirements
- Category III … highest FRT requirements

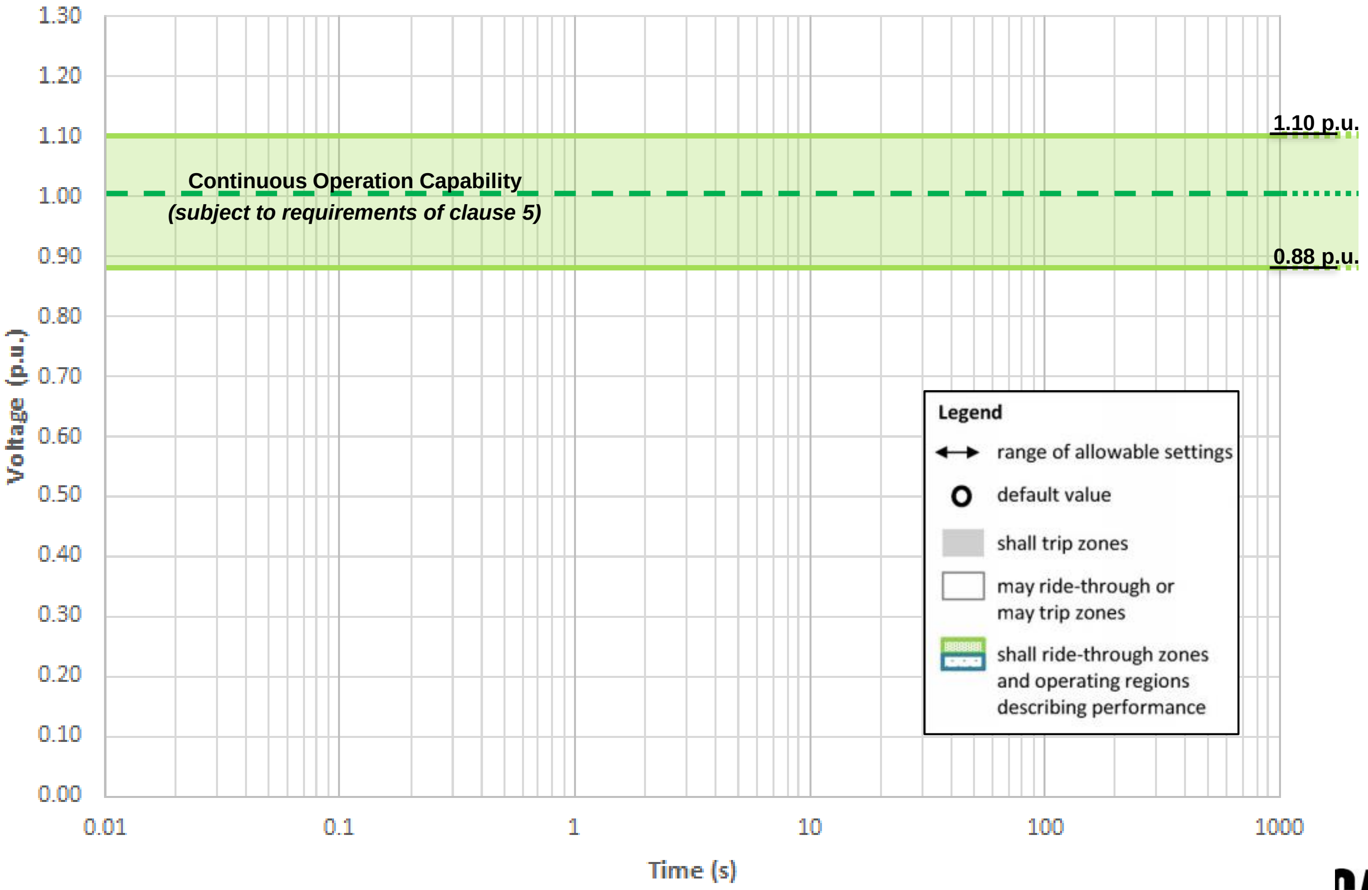
High-level overview of performance-based category approach

DER – Distributed Energy Resource

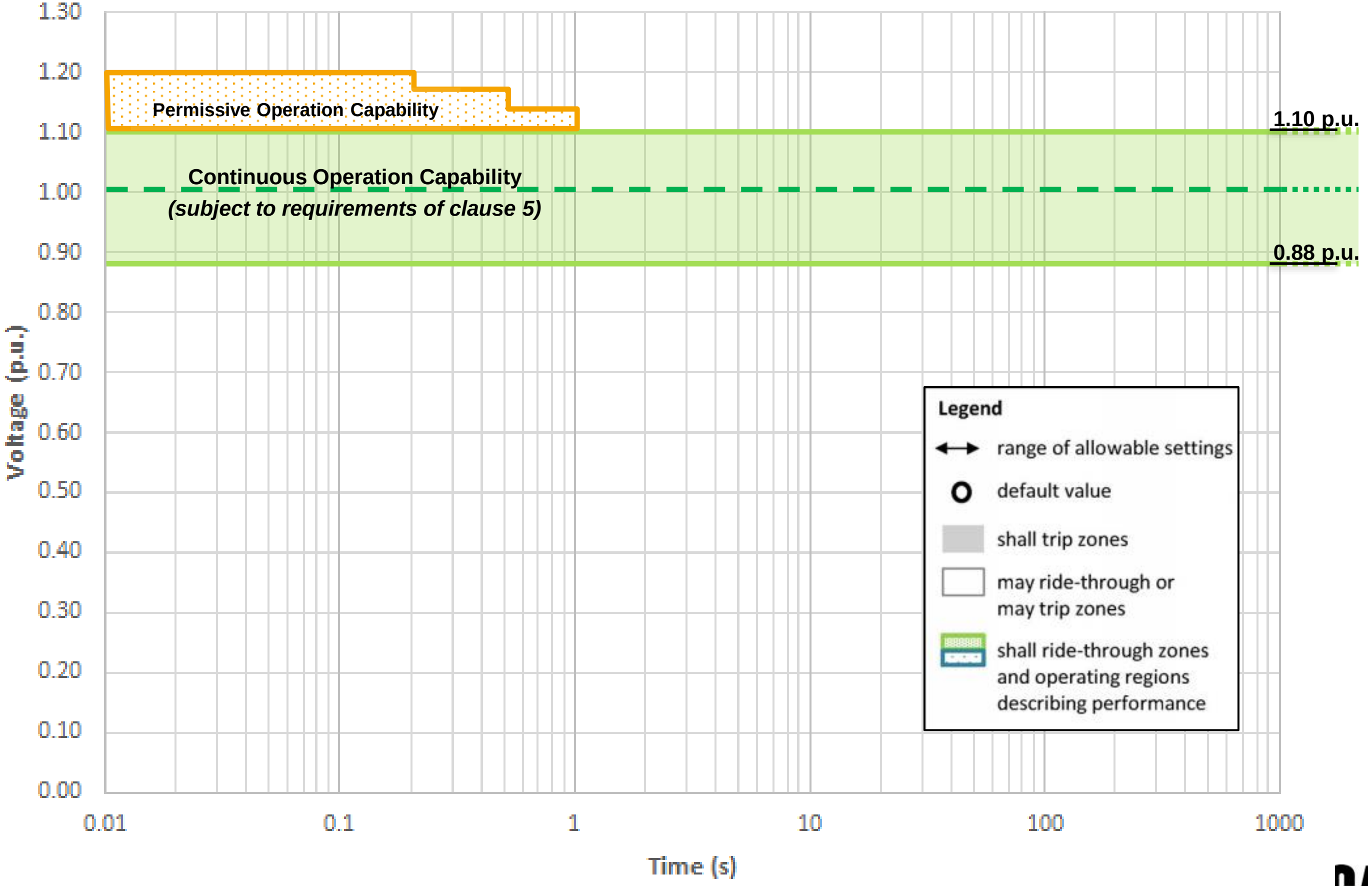


- Category I intended for rotating machinery based generation
- Category II intended for power electronics based generation
- Category III intended for generation with high penetration on distribution feeder

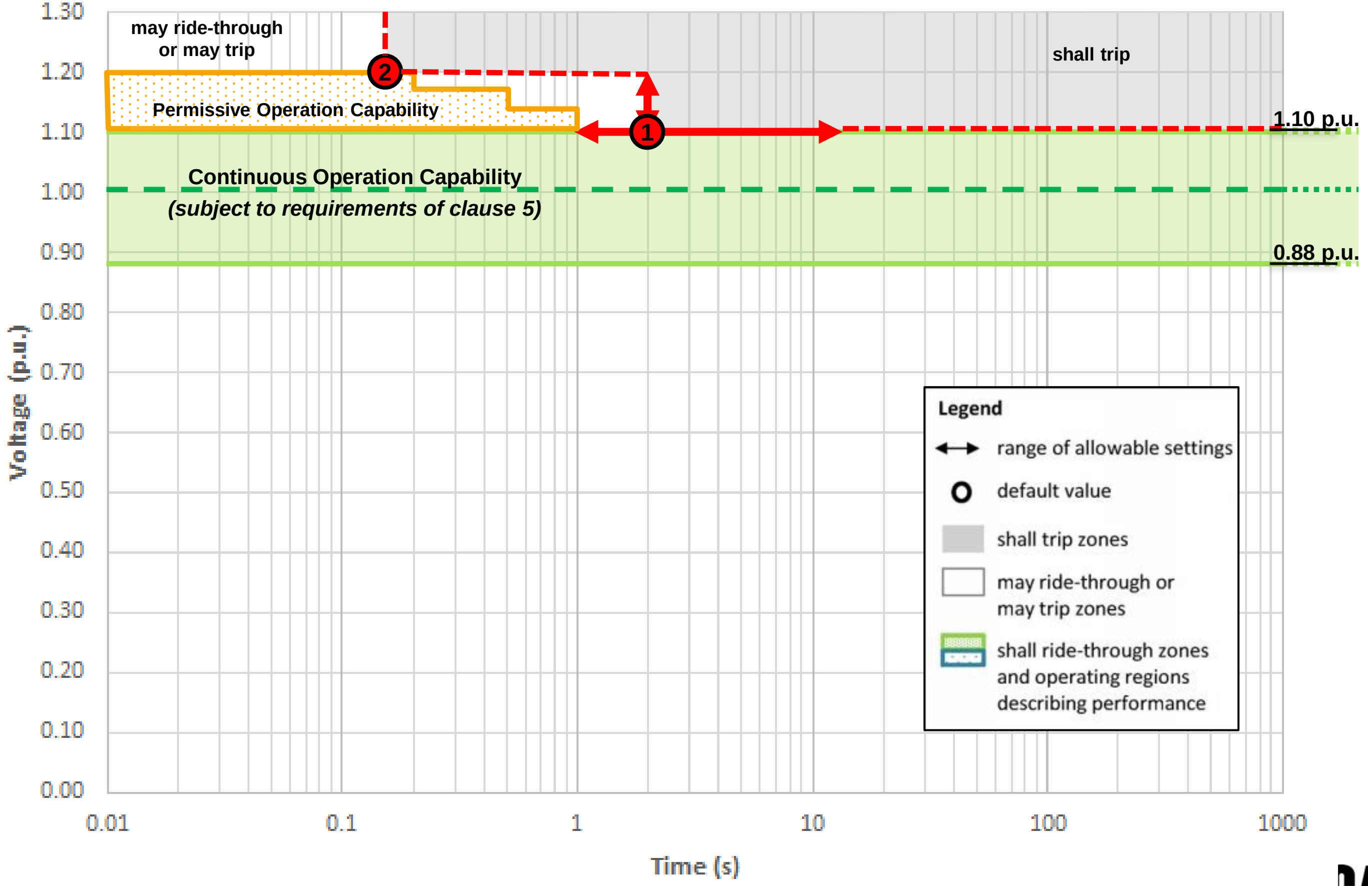
Fault Ride Through IEEE 1547 – Category I



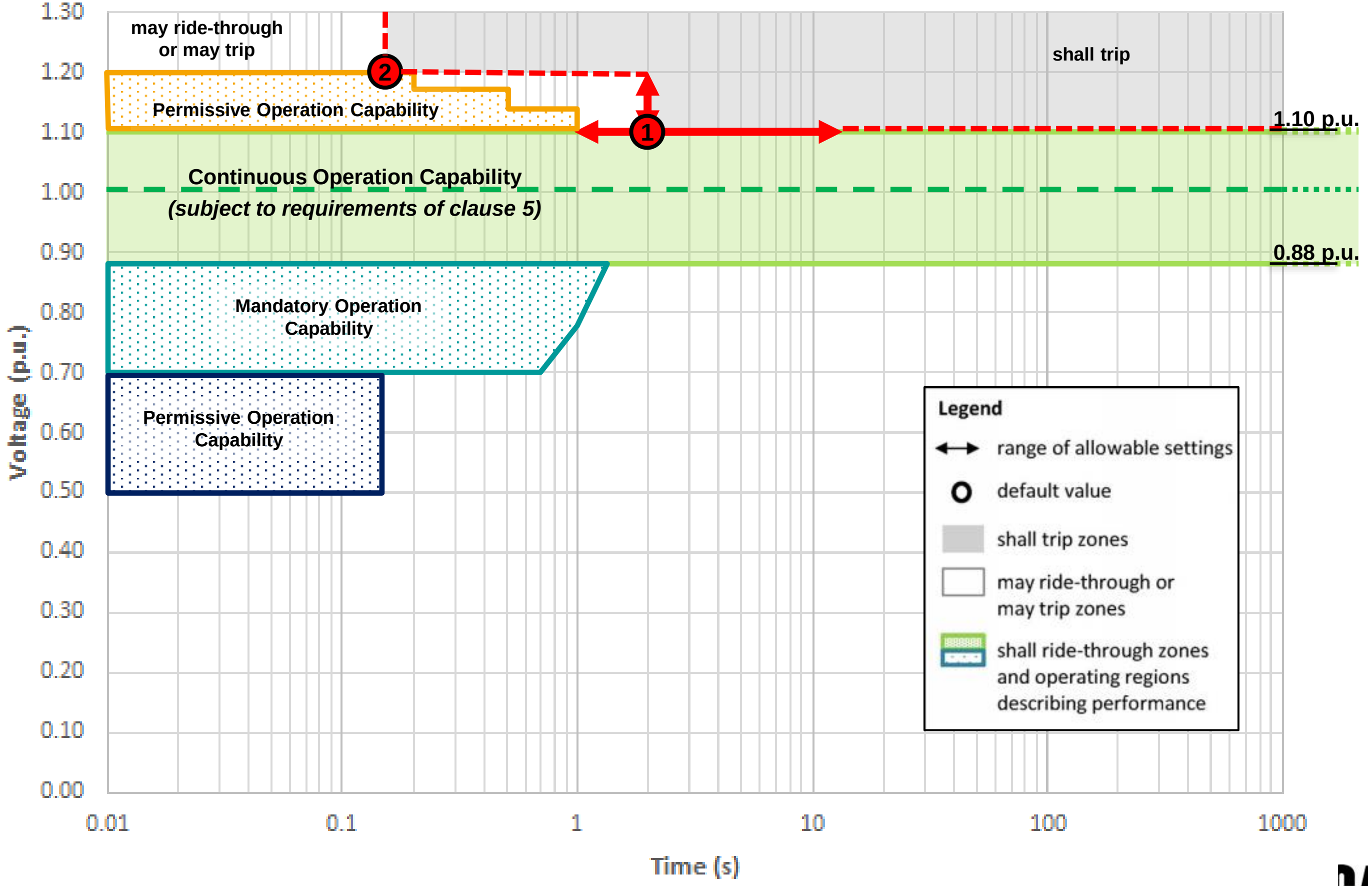
Fault Ride Through IEEE 1547 – Category I



Fault Ride Through IEEE 1547 – Category I

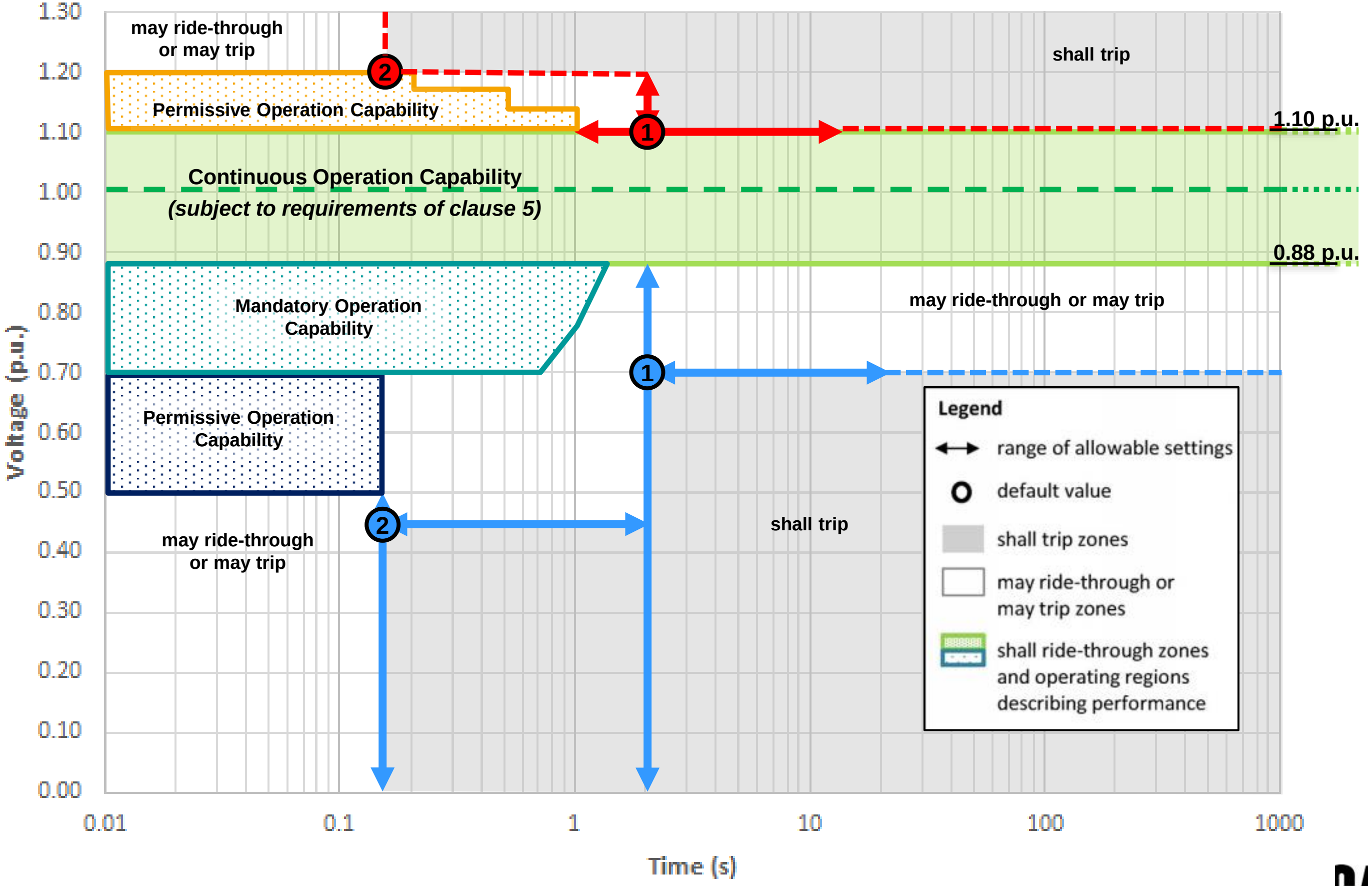


Fault Ride Through IEEE 1547 – Category I



CATERPILLAR®

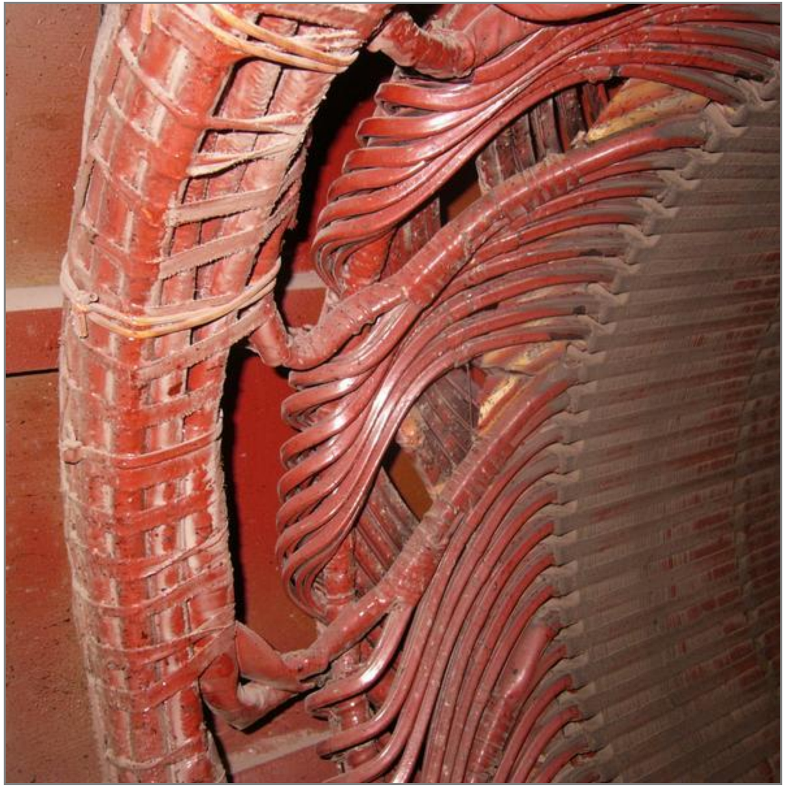
Fault Ride Through IEEE 1547 – Category I



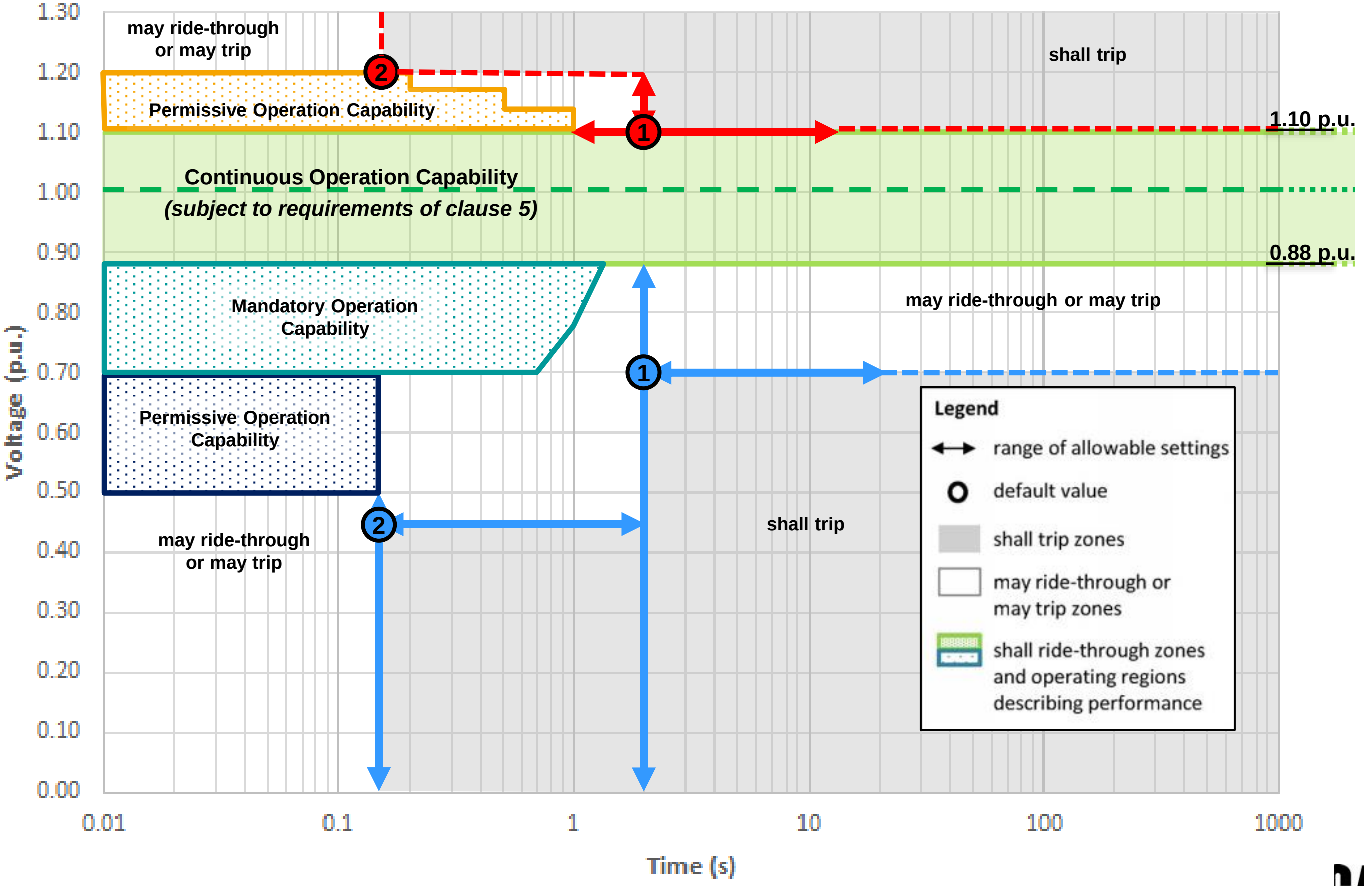
Impact of Voltage Sags on Generators

- Operational Risk
  - Loss of synchronization … pole slip
  - Re-synchronization out of phase
- Equipment Damage Risk
  - Stator windings deformation
  - Magnetic core
  - Rotor

Drives generator oversizing to increase inertia for longer ride-through capabilities



Fault Ride Through IEEE 1547 – Category I



Category I intended for Rotating Machine based generation

Voltage ride-through requirements for DER of abnormal operating performance CATEGORY I

VOLTAGE RANGE (pu)	**OPERATING MODE / RESPONSE**	**MIN. RIDE-THROUGH TIME (s)** (DESIGN CRITERIA)	**MAX. RESPONSE TIME (s)** (DESIGN CRITERIA)
$V > 1.2$	Cease to Energize	N/A	0.16
$1.175 < V \leq 1.2$	Permissive Operation	0.2	N/A
$1.15 < V \leq 1.175$	Permissive Operation	0.5	N/A
$1.10 < V \leq 1.15$	Permissive Operation	1	N/A
$0.88 \leq V \leq 1.10$	Continuous Operation	Indefinite	N/A
$0.70 \leq V < 0.88$	Mandatory Operation	Linear slope from 0.7 s @ 0.7 pu to 1.42 s @ 0.88 pu	N/A
$0.50 \leq V < 0.70$	Permissive Operation	0.16	N/A
$V < 0.50$	Cease to Energize	N/A	0.16

Category II intended for Power Electronics based generation

Voltage ride-through requirements for DER of abnormal operating performance CATEGORY II

VOLTAGE RANGE (pu)	OPERATING MODE / RESPONSE	MIN. RIDE-THROUGH TIME (s) (DESIGN CRITERIA)	MAX. RESPONSE TIME (s) (DESIGN CRITERIA)
$V > 1.2$	Cease to Energize	N/A	0.16
$1.175 < V \leq 1.2$	Permissive Operation	0.2	N/A
$1.15 < V \leq 1.175$	Permissive Operation	0.5	N/A
$1.10 < V \leq 1.15$	Permissive Operation	1	N/A
$0.88 \leq V \leq 1.10$	Continuous Operation	Indefinite	N/A
$0.65 \leq V < 0.88$	Mandatory Operation	Linear slope from 3 s @ 0.65 pu to 5 s @ 0.88 pu	N/A
$0.45 \leq V < 0.65$	Permissive Operation	0.32	N/A
$0.30 \leq V < 0.45$	Permissive Operation	0.16	N/A

Category III intended for Power Electronics based generation

Voltage ride-through requirements for DER of abnormal operating performance CATEGORY III

VOLTAGE RANGE (pu)	**OPERATING MODE / RESPONSE**	**MIN. RIDE-THROUGH TIME (s)** (DESIGN CRITERIA)	**MAX. RESPONSE TIME (s)** (DESIGN CRITERIA)
$V > 1.2$	Cease to Energize	N/A	0.16
$1.10 < V \leq 1.2$	Momentary Cessation	12	0.083
$0.88 \leq V \leq 1.10$	Continuous Operation	Indefinite	N/A
$0.70 \leq V < 0.88$	Mandatory Operation	20	N/A
$0.50 \leq V < 0.70$	Mandatory Operation	10	N/A
$V < 0.50$	Momentary Cessation	1	0.083

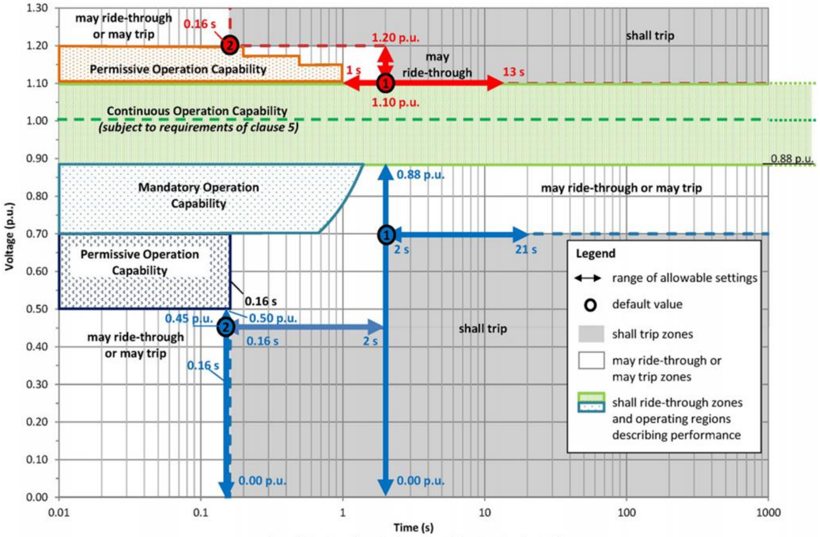
Frequency ride-through requirements (All categories)

FREQUENCY RANGE (Hz)	OPERATING MODE	MIN. RESPONSE TIME (s)
f > 62.0	Not required	
61.2 < f ≤ 61.8	Mandatory Operation	299
58.8 < f ≤ 61.2	Continuous Operation	Indefinite
57.0 ≤ f ≤ 58.8	Mandatory Operation	299
f < 57.0	Not required	

Additional Requirements

In addition to grid support during abnormal conditions, there are requirements for grid support within the normal operating range:

- Frequency support
- Voltage support
- Interoperability
- Islanding / partial grid operation



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 (within ANSI C84.1 range A)	44	44

Voltage and reactive/active power control function requirements for DER normal operating performance categories

DER Category	Category A	Category B
Voltage regulation by reactive power control		
Constant power factor mode	Mandatory	Mandatory
Voltage – reactive power mode (volt-var)	Mandatory	Mandatory
Active power – reactive power mode	Not required	Mandatory
Constant reactive power mode	Mandatory	Mandatory
Voltage and active power control		
Voltage – active power (volt-watt) mode	Not required	Mandatory

Voltage Support … Volt-VAR

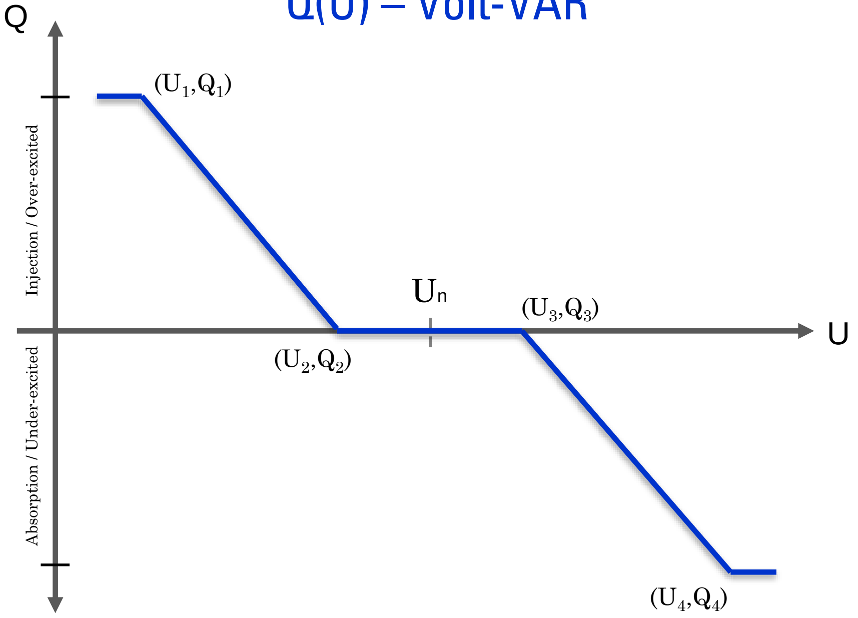
Many different reactive power or power factor control functions are specified in grid codes.

Common control modes include:

- Fixed Q
- Fixed cos θ
- Q(P) – Watt-VAR / cos θ (P)
- **Q(U) – Volt-VAR**

Requirements may define control modes to be enabled/disabled manually by the plant operator, or in some cases remotely by the grid operator.

Q(U) – Volt-VAR



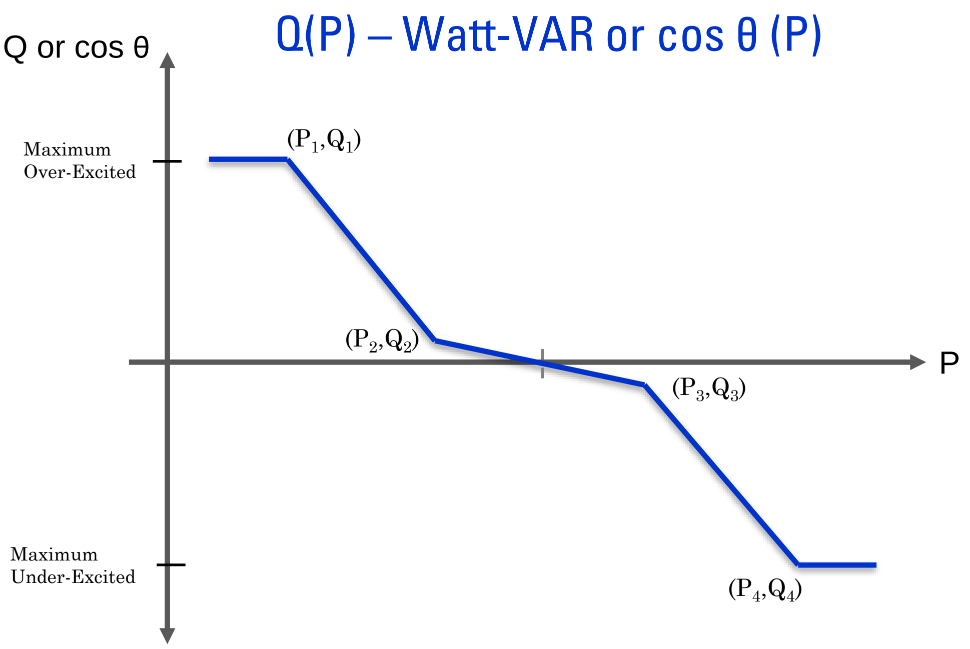
Voltage Support … Watt-VAR

Many different reactive power or power factor control functions are specified in grid codes.

Common control modes include:

- Fixed Q
- Fixed cos θ
- **Q(P) – Watt-VAR / cos θ (P)**
- Q(U) – Volt-VAR

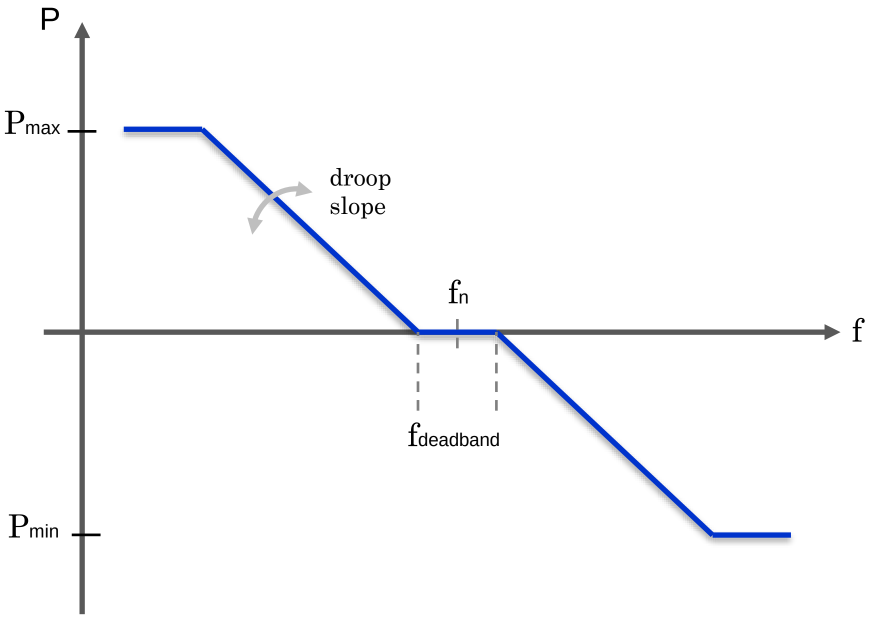
Requirements may define control modes to be enabled/disabled manually by the plant operator, or in some cases remotely by the grid operator.



Frequency Support … Frequency-Droop

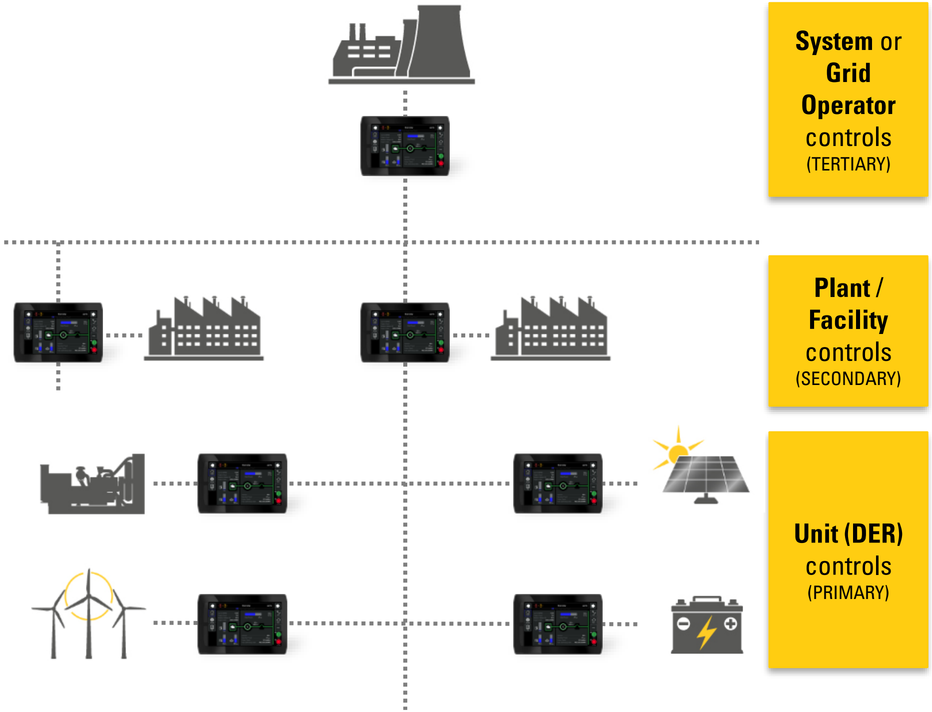
Capability to maintain active power at reduced frequency and to increase or decrease active power output at a defined rate when frequency exceeds a defined threshold.

Requirements may define control modes to be enabled/disabled manually by the plant operator, or in some cases remotely by the grid operator.



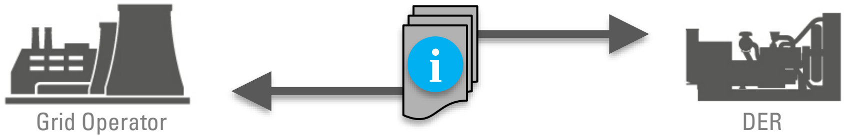
Importance of Controls

- Controls are a key component of grid code compliance
- Unit (DER) controls perform synchronizing, grid support control functions, and protection
- Communication with other devices in the network such as plant level SCADA and grid operator (remote) control systems



DER – Distributed Energy Resource

Interoperability – Information Exchange



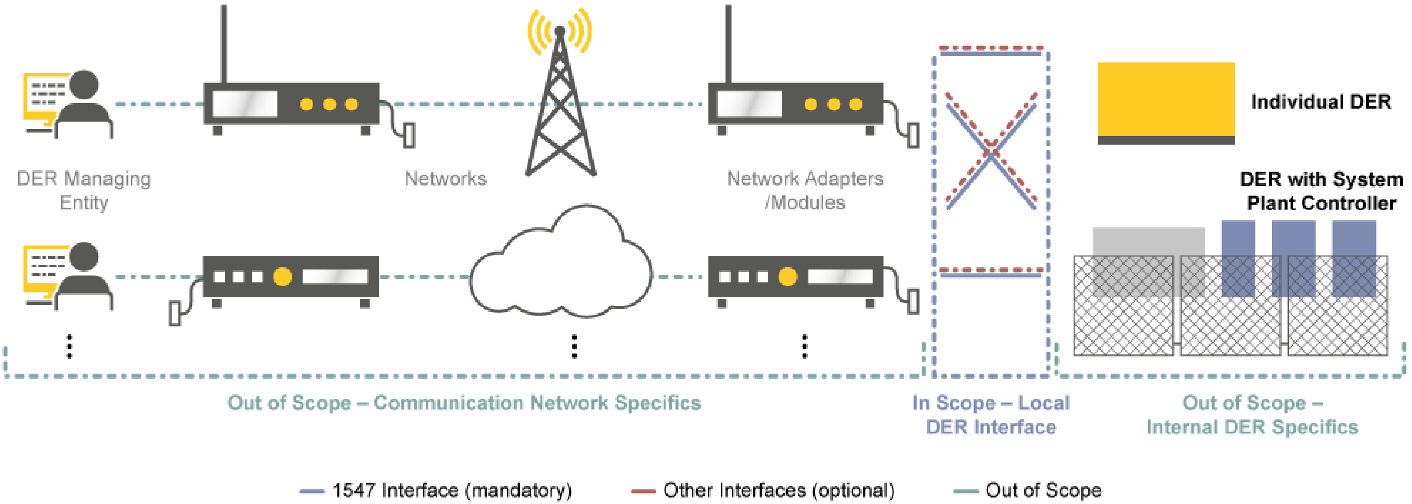
Type	Examples
Nameplate	Rated voltage, rated active power, rated reactive power
Configuration	Derated values from nameplate data due to site conditions
Monitoring	Connection status, voltage, power levels, alarms
Management	Control mode, trip settings, active power limits

DER – Distributed Energy Resource

Interoperability – Communication Protocol Requirements

Control protocol in/out of scope matching

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



US – Islanding Detection Requirements

- IEEE Std 1547 requires generation to stop energizing the area EPS (electric power system) upon the formation of an island
- Power electronics-based generation have the capability of implementing autonomous islanding detection methods
- Rotating machine-based generation are not capable of autonomous islanding detection requiring external means
  - Direct Transfer Trip (DTT)
  - Power Line Carrier
  - Combination of protective relay functions

Germany – Mandatory Partial Grid Operation

- VDE 4110 requires generation to remain connected and sustain the local area EPS upon separation from a larger area EPS
- German approach is not to disrupt electrical service locally and coordinate the reconnection of the local area EPS to the larger area EPS after the separation cause is resolved
- US approach is to remove local area EPS generation, reconnect the local area EPS to the larger area EPS eliminating the island, and then allow the automatic return of local generation into the reconnected local area EPS

Top 5 Changes Introduced by IEEE 1547-2018

- Voltage support functions
- Frequency support functions
- Anti-islanding requirements
- Interoperability
- Fault ride through (FRT) capabilities

Exemptions for Emergency and Standby DER

- DERs with automatic transfer schemes in which load is transferred between the DER and the EPS in a momentary make-before-break operation provided the duration of paralleling the sources is less than 100 ms
- DERs designated by authority having jurisdiction as emergency systems, or standby DERs that only operate in parallel to area EPS for testing purposes or during load transferring periods of less than 5 minutes are exempt from:
  - Voltage disturbance ride-through requirements
  - Frequency disturbance ride-through requirements
  - Interoperability, information exchange, and information models
  - Intentional islanding requirements (may separate from EPS without limitations)

Expected Enforcement Dates in the U.S. for IEEE1547-2018

- Base standard IEEE 1547 published in 2018
- Compliance test standard IEEE 1547.1 published in 2020
- Certification standard UL1741 ed 3 published September 30, 2021
- Hawaii announced enforcement by 2nd quarter 2022 → 1 Oct 22
- California to adopt in 3rd quarter 2022 → March 28, 2023
- Northeastern states likely to follow after California
- Other states are expected to lag in their adoption

Questions