Draft

World Grid Codes

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Presentation Overview

This is an initial deliverable under IEA Wind TCP Task 41 Work Package 3, "Expand learning and support of the integration of distributed wind into evolving electricity systems".

- This draft PPT is a 'living document' that will be improved and refined over time based on new knowledge gained on global distribution system requirements.
- An attempt has been made to streamline and simplify these requirements so that they may be comparable across different countries, but they are directly impacted by the transmission system design and capabilities, methods of distributing electricity at lower voltages, and types of control available for the varied distribution systems.
- This does not cover technical or legal interconnection requirements such as:
  - Interconnection requirements (there is too much country variation)
  - Flicker
  - All reactive power mode parameters
  - All voltage trip parameters
  - All frequency and frequency droop parameters
- The information is organized alphabetically by country.
- There is quite a variety of voltages and corresponding ride through, disconnect, reactive power and over/under frequency and communication protocols.
- This summary currently reflects distribution network requirements but there is overlap with the transmission system as distributed wind systems can be larger than ~100 kW.
- The draft should be reviewed and modified by Task 41 participants and their country experts who have experience in distributed grid integration.
- We would like to expand this summary to include information from Austria, Belgium, and Canada, among others.

Grid Code Information Collected

Grid Code Categories	Grid Code Details	China	Denmark	Germany	Ireland	Spain	U.S.
General	Reference Standards	X	X	X	X	X	X
	Grid Voltage Ranges	X	X		X	X	X
Ride Through Requirement	Ride through Requirement	X		X	X	X	X
	Over and Under Voltage requirements		X		X	X	X
	Ability to Withstand Voltage Dips					X	X
	Minimum Overvoltage Time					X	
Disconnect	Start-up and reconnection requirements		X	X			X
Reactive Power	Power Factor Adjustment	X		X	X		
	Reactive Power Capacity			X	X	X	
Over and Under Frequency	Operating Frequency Range					X	
	Frequency response and control requirements		X				
	Frequency Power Regulation		X			X	X
	Permitted Active Power Reduction - underfrequency		X		X		X
	Overfrequency Requirements					X	X
Communication Protocols		X	X				X

IEC/IEEE/PAS 63547-2011, Standard for interconnection of distributed power supply and power system

China

Information provided by Inner Mongolia Technology University

China Normative Grid Code Standards

International standard adopted by China in distributed power generation

- IEEE 1547 series standards: http://grouper.ieee.org/groups/scc21/1547/1547_index.html
- IEC/IEEE/PAS 63547-2011, Standard for interconnection of distributed power supply and power system.

Chinese national standards

1) Q/GDW 480-2010 technical provisions on access of distributed power supply to power grid.
https://wenku.baidu.com/view/6aff844ef7ec4afe04a1df3b.html
It is applicable to the distributed power supply in the operation area of state grid corporation of China, which is connected to the power grid of 35 kV or below in the form of synchronous motors, induction motors and converters.

2) Q/GDW 666-2011 technical specification for testing access of distributed power supply to distribution network.
https://max.book118.com/html/2017/0824/129962401.shtm

3) Q/GDW 667-2011 operation control specification for access of distributed power supply to distribution network.
http://www.doc88.com/p-7146282309018.html

4) Q/GDW 677-2011 functional specification for the access of distributed power supply to the monitoring system of distribution network.
https://max.book118.com/html/2017/0820/129095533.shtm

2), 3), 4) the standard is applicable to the distributed power supply in the business area of state grid corporation of China, which is connected to the distribution network of voltage grade 10 kV or below in the form of synchronous motor, induction motor and converter.

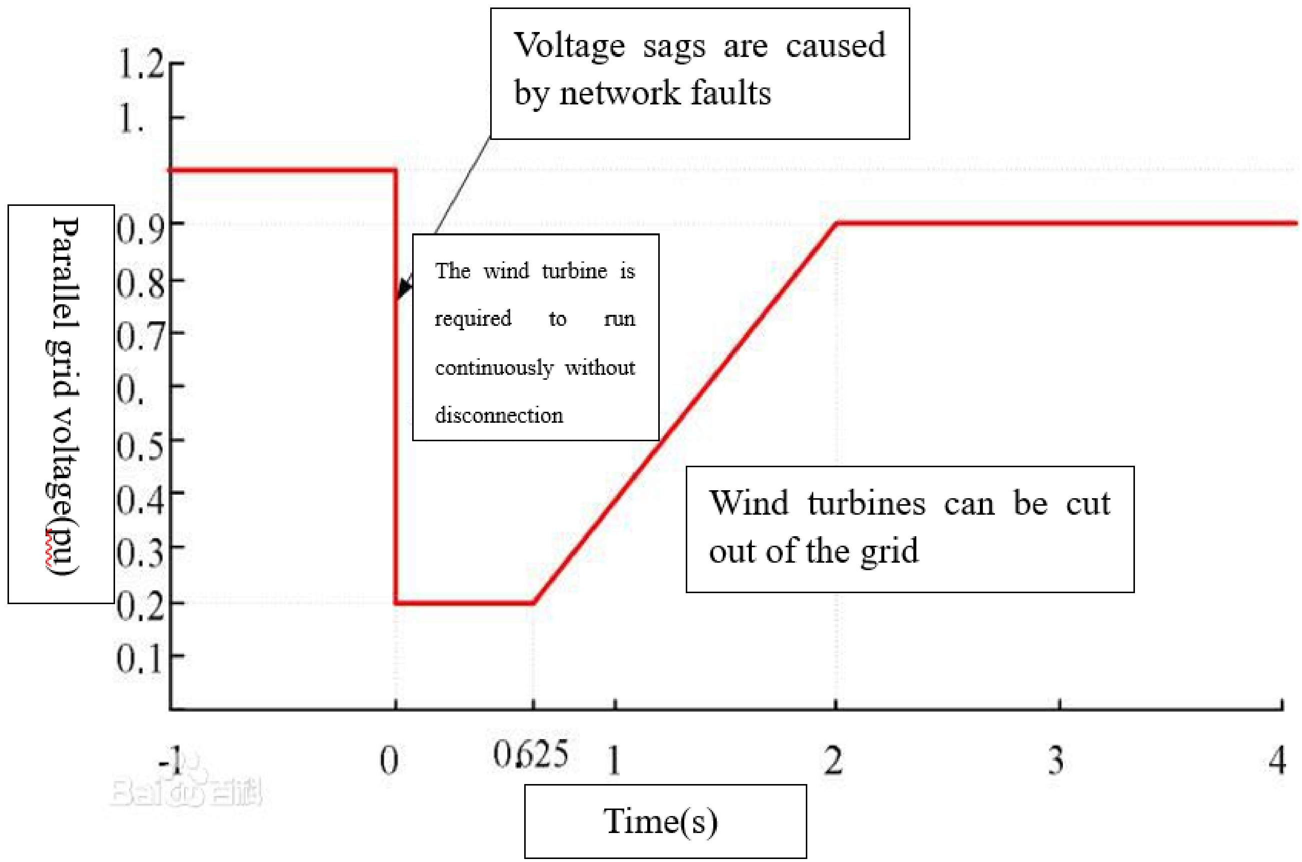
Chinese enterprise standard

Enterprise standard of China southern power grid co., LTD., and technical standard of wind power grid connection: Q/CSG1211005-2016.
https://max.book118.com/html/2018/0827/6120150203001213.shtm

Ride-through Requirements

- Low voltage crossing requirements for wind farms
  - The wind turbine in the wind farm has the ability to ensure continuous operation of 625ms without off-grid when the grid voltage drops to 20% of the rated voltage.
  - When the voltage of the grid connection point in the wind farm can recover to 90% of the rated voltage within 2s after falling, the wind turbine in the wind farm can ensure continuous operation without off-grid.
  - Currently, there are three schemes to achieve low voltage crossing ability:
    1) Use rotor short circuit protection (crowbar circuit);
    2) Apply the new topological structure;
    3) Use reasonable excitation control algorithm.
- Rotor short-circuit protection technology (crowbar circuit)
  - Some wind manufacturers are using this present approach, the method of the generator rotor side with a crowbar circuit
    - provides the bypass for rotor side circuit
    - system failure occurs in the power system of detected voltage sags,
    - atresia doubly-fed induction generator excitation converter, at the same time in the rotor circuit of the bypass (release can resistance) protection device,
    - to limit over-voltage of through the excitation current of current transformer and rotor winding,
    - in order to maintain the generator is not to take off the net running (the doubly-fed induction generator according to the induction motor run).
- New topological structure
  - New bypass system
  - Parallel connection network side converter;
  - Connect the network side converter in series.
- Adopt new excitation control strategy
  - Wind farms must have a low voltage crossing capacity that can maintain 625ms of grid-connected operation when the grid voltage drops to 20% of the rated voltage.
  - When the voltage of the grid connection point of the wind farm can recover to 90% of the rated voltage within 2s after the drop fault, the wind farm must maintain the grid connection operation.

Ride-through Requirements



Power Factor Adjustment

- The value of the power factor can vary from 0 to 1.
- Power factor standard 0.90 is applicable to high-voltage power supply industrial users above 160 kva (including industrial users of the company and team), high-voltage power supply electric users with load adjustment voltage devices and high-voltage power supply irrigation stations above 3200 kva.
- Power factor standard 0.85 is applicable to other industrial users (including industrial users of commune and brigade) with 100 kva (kW) and above, non-industrial users with 100 kva (kW) and above and irrigation stations with 100 kva (kW) and above.
- Power factor standard of 0.80 is applicable to agricultural and wholesale users of 100 kva (kW) and above, but for wholesale users of large industrial users not directly managed by the electricity bureau, the power factor standard shall be 0.85.

Grid Voltage

- Distributed power generation refers to the power generation project located near the user, where the generated power can be used locally and connected to the power grid at a voltage level of 10 kilovolts or less, and the total installed capacity of a single parallel network does not exceed 6 megawatts.

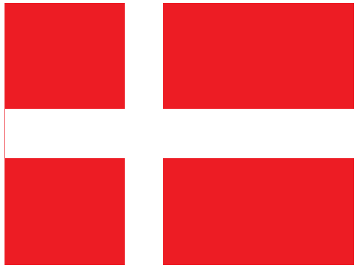
- The network voltage of China's distributed generation system is shown in the following table.

Project size	Access voltage class
≤8kW	220V
8-400kW	380V
400-6000kW	10kV
5000-30000kW	35kV

Communication Protocol

- There are communication protocol requirements, in accordance with
  - IEC 61400-25-1
  - IEC 61400-25-2
  - IEC 61400-25-3
  - IEC 61400-25-4
  - IEC 61400-25-5
- The aim is to realize the free communication between different supplier equipment in wind power plant. Through the abstraction, modeling and standardization of the information of wind power plant, the communication between each equipment can be realized, and the interconnection, interoperability and scalability of each equipment can be achieved.

Technical requirements for connection of power-generating plants to the low-voltage grid (≤1 kV)
Type A and B Version 1.2
New code 27 April 2019
Energinet.dk



Information provided by Nordic Folkecenter

Danish Normative Grid Standards

EU Regulation 2016/631
Joint Regulation 2017 (Fællesregulativet 2017)
The Danish Electricity Supply Act (Elforsyningsloven)
DS/EN 50160: Voltage characteristics of electricity supplied by public distribution net-works.
prEN 50549-1: Requirements for generating plants to be connected in parallel with distri-bution networks – Part 1: Connection to a LV distribution network.
DS/EN 60038: IEC/CENELEC standard voltages.
DS/EN 61000-3-2: Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤16A per phase).
DS/EN 61000-3-3: Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection.
DS/EN 61000-3-11: Electromagnetic compatibility (EMC) – Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤75 A and subject to conditional connection.
DS/EN 61000-3-12: Electromagnetic compatibility (EMC) – Part 3-12: Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤75 A per phase.
DS/EN 61000-4-30: Electromagnetic compatibility (EMC) – Part 4-30: Testing and meas-urement techniques – Power quality measurement methods.
DS/EN 61400-21:2008: Wind turbines – Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines.

Informative Standards

- **IEC/TR 61000-3-14**: Electromagnetic compatibility (EMC) – Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems.

- **IEC/TR 61000-3-15**: Electromagnetic compatibility (EMC) – Part 3-15: Limits – Assess- ment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network.
- **Research Association of the Danish Electric Utilities (DEFU) report RA 557**: 'Maxi- mum emission of voltage disturbances from wind power plants >11 kW', June 2010.
- **Research Association of the Danish Electric Utilities (DEFU) Recommendation no. 16**: Voltage quality in low-voltage grids.

Definition of Voltage Levels

Designation of voltage level	Nominal voltage Un [kV]	System operator
Extra high voltage (EHV)	400	
	220	
		Transmission system operator
	150	
	132	
High voltage (HV)		
	60	Distribution system operator
	50	
	33	
	30	
Medium voltage (MV)	20	
	15	
	10	
Low voltage (LV)	0.4	
	0.23	

Default settings for frequency response overfrequency for DK1 and DK2

	DK 1 (Western Den-mark)	DK 2 (Eastern Denmark)
Frequency threshold fRO	50.2 Hz	50.5 Hz
Droop	5%	4%
Delay for islanding detec-tion	500 ms	500 ms

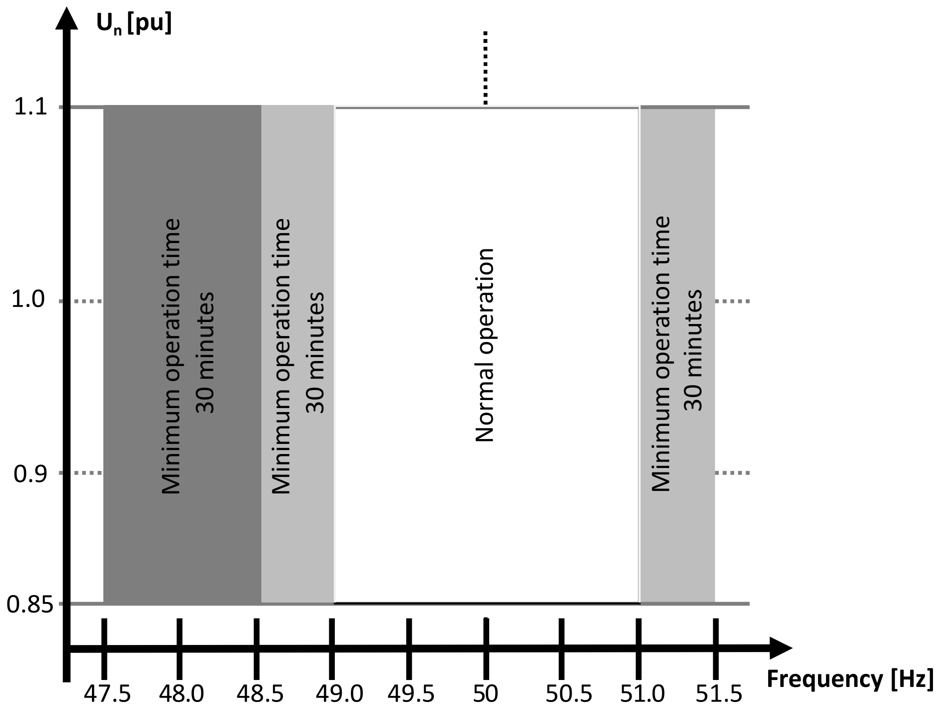
Frequency Control Requirements

Protection function	Symbol	Setting (Range/Resolution)		Trip time (Range/Resolution)	
Undervoltage (step 2)*	U<<	0.2-1/0.01 Default: 0.80	Un	0.1-5/0.05 Default: 0.2	s
Frequency change*	df/dt	0-3.5/0.1 Default: ±2.5	Hz/s	0-5/0.01 Default: 0.08	s
*At least one of the functions must be used.					

Table 4.7 – Requirements for islanding detection for Type A (from 0.8 up to 125 kW).

Ride-through requirements

A power-generating plant must maintain operation at different frequencies for the minimum time periods specified in figure 4.1 without disconnecting from the grid.



Ride-through requirements

Start-up and reconnection of a power-generating plant is only permitted when frequency and voltage are within the following ranges:

	DK 1 (Western Denmark)	DK 2 (Eastern Denmark)
Frequency range	47.5 Hz - 50.2 Hz	47.5 Hz - 50.5 Hz
Voltage range	85% - 110% U_n	85% - 110% U_n
Observation time	Three minutes	Three minutes

Table 4.2 – Criteria for start-up and reconnection of a power-generating plant.

After connecting a power-generating plant, the maximum active power increase per minute is 20% of nominal power.

Criteria for start-up and reconnection of a power-generating plant

	DK 1 (Western Denmark)	DK 2 (Eastern Denmark)
Frequency range	47.5 Hz - 50.2 Hz	47.5 Hz - 50.5 Hz
Voltage range	85% - 110% Un	85% - 110% Un
Observation time	Three minutes	Three minutes

Start-up and reconnection of a power-generating plant is only permitted when frequency and voltage are within the following ranges.

Frequency Response Droop to Overfrequency

When a power-generating plant's lower limit for active power is reached in connection with the downward regulation, the power-generating plant must keep this minimum level of active power until the grid frequency drops again or until the plant is disconnected for other reasons.

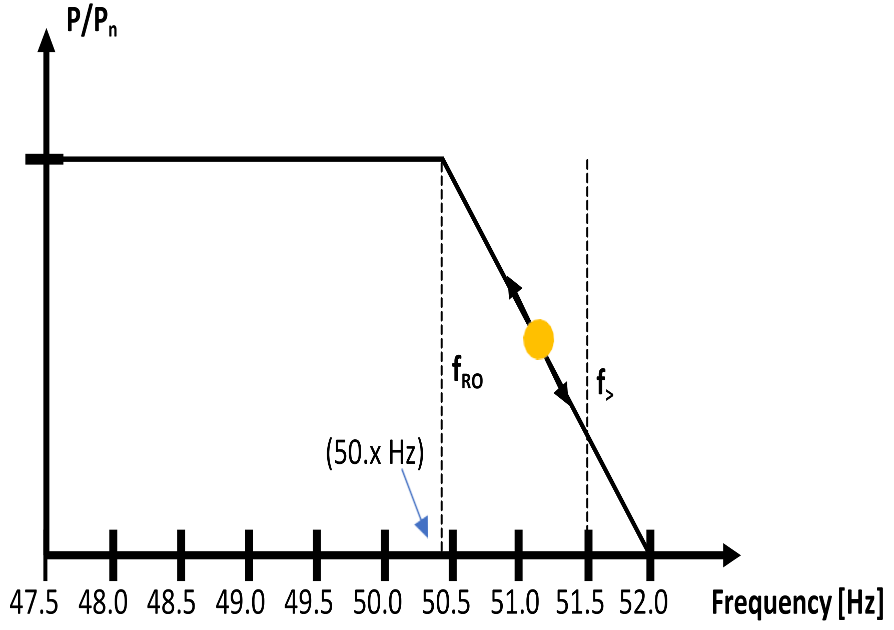


Figure 4.3 – Frequency response droop to overfrequency.

Permitted Active Power Reduction during underfrequency

A power-generating plant is permitted to reduce the active power within the 49 Hz-47.5 Hz frequency range. In this range, it is permitted to reduce the active power by 6% of P_n/Hz as shown in figure 4.2.

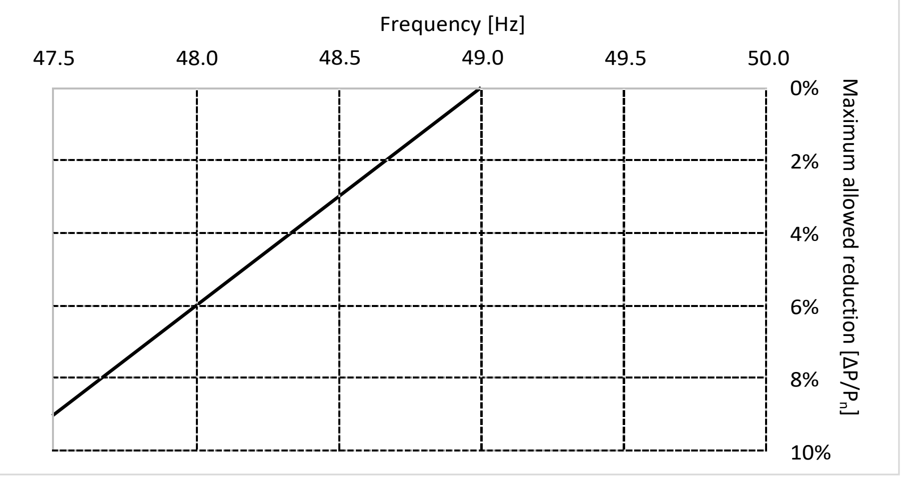


Figure 4.2 – Permitted reduction of active power during underfrequency.

Permitted reduction of active power	
Frequency range	49 Hz - 47.5 Hz
Reduction of P_n/Hz	6%

Table 4.1 – Permitted reduction of active power during underfrequency.

Requirements for all power-generating plants, regardless of type

Protection function	Symbol	Setting (Range/Resolution)		Trip time (Range/Resolution)	
Overvoltage (step 2)	$U_{>>}$	1.0-1.3/0.01 Default: 1.15	U_n	0.1-5/0.05 Default: 0.2	**s**
Overvoltage (step 1)	$U_{>}$	1.0-1.2/0.01 Default: 1.10	U_n	0.1-100/0.1 Default: 60	**s**
Undervoltage (step 1)	$U_{<}$	0.2-1.0/0.01 Default: 0.85	U_n	0.1-100/0.1 Default: 50	**s**
Overfrequency	$f_{>}$	50.0-52.0/0.1 Default: 51.5	Hz	0.1-5/0.05 Default: 0.2	**s**
Underfrequency	$f_{<}$	**47.0-50.0/0.1 Default: 47.5**	**Hz**	**0.1-5/0.05 Default: 0.2**	**s**

Communication Protocols

Power-generating plants which have the same Point of Common Coupling (PCC) and the same owner are deemed to be one plant.

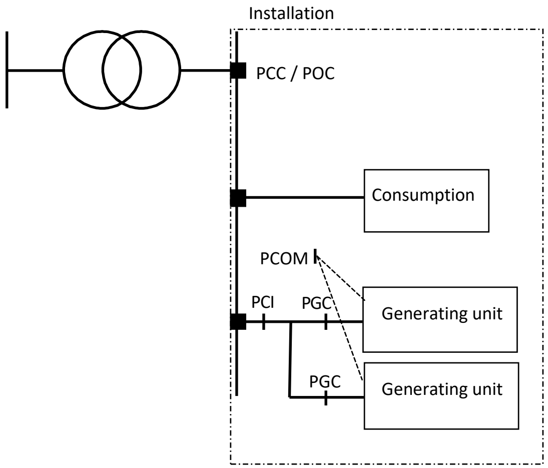


Figure 3.3 – Installation-connected generation with indication of the PGC, PCI, POC and PCC.

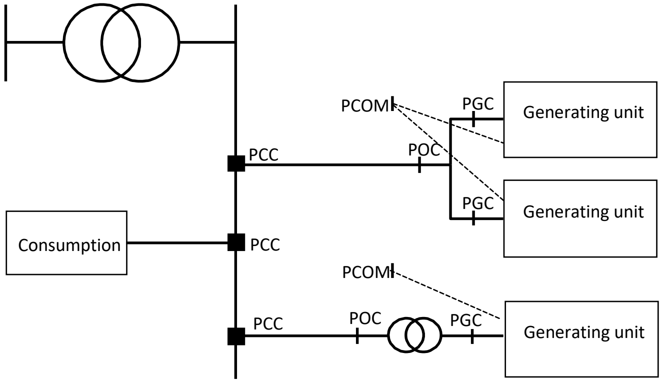


Figure 3.4 – Grid-connected generation with indication of the PGC, POC, PCC and PCOM.

figure 3.3 shows a typical installation connection of one or more power-generating plants with indication of the typical locations of Point of Generator Connection (PGC), Point of Connection (POC), Point of Connection in Installation (PCI) and Point of Common Coupling (PCC). In the illustrated example, the Point of Common Coupling (PCC) coincides with the Point of Connection (POC).

VDE Anwen- dungsregel VDE-AR-N-4105 „Erzeugungsanlagen am Niederspannungsnetz - Technische Mindestanforderungen für Anschluss und Parallelbetrieb von Er- zeugungsanlagen am Niederspannungsnetz"

Germany

Information provided by Enbreeze

General Voltage Definition

- Private customers feed the electricity into the low-voltage grid (0.4 kV)
- Business customers into the medium (10 kV) or high-voltage grid (110 kV)

Germany Normative Grid Standards

- The following link is a summary for the connection of energy-producing-units such as wind or PV to the distribution network in berlin: https://www.stromnetz.berlin/globalassets/dokumente/anschluss/infoblatt-anmeldung-erzeugungsanlage-berlin.pdf

  - VDE Anwen- dungsregel VDE-AR-N-4105 „Erzeugungsanlagen am Niederspannungsnetz - Technische Mindestanforderungen für Anschluss und Parallelbetrieb von Er- zeugungsanlagen am Niederspannungsnetz".

- German Grid-Code for energy-producing-units with an electric power $P < 135$ kW: https://www.vde.com/de/fnn/themen/tar/tar-niederspannung/erzeugungsanlagen-am-niederspannungsnetz-vde-ar-n-4105-2018

- German Grid-Code for energy-producing-units with an electric power $P > 135$ kW: https://www.vde.com/de/fnn/themen/tar/tar-mittelspannung/tar-mittelspannung-vde-ar-n-4110

VDE-AR-N-4105 changes (Standard must be purchased)

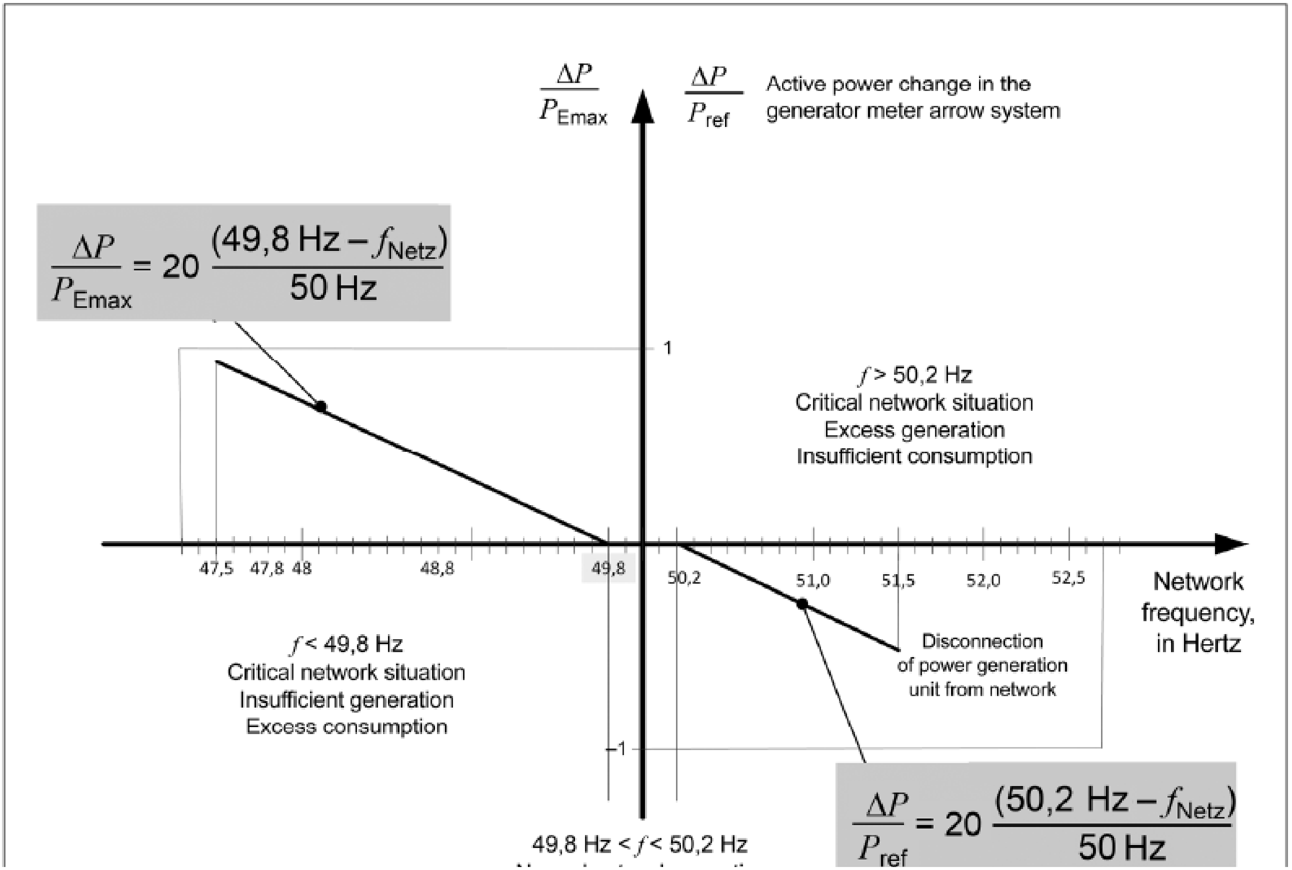
Major innovations include:

- Dynamic grid support: In the future, new generators will have to remain connected to the grid during short-term voltage dips or increases, thus supporting it

- Infeed of reactive power as a function of the voltage (Q (U) control) can be used: depending on local conditions, more generators can be integrated into an existing grid

- Active power output at underfrequency: If power in the system is missing, generating systems and storage systems will increasingly feed in future and thus support the system

Active Power Adjustment for Type 1 and 2



Key

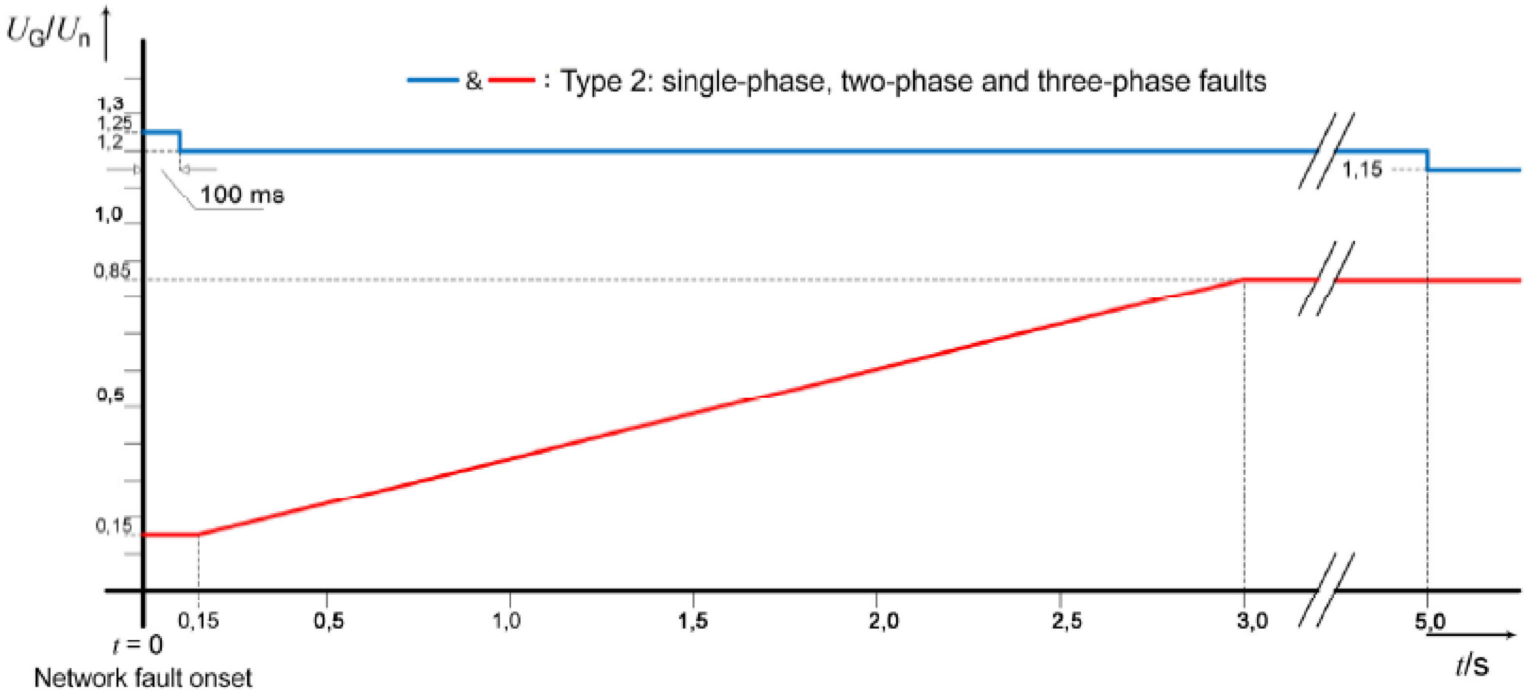
P_{Emax} highest active power of a power generation unit (10 min mean value)

P_{ref} equals P_{Emax} for type 1 power generation units or P_{mom} for type 2 power generation units at the moment when 50,2 Hz is exceeded.

ΔP power change

f network frequency

Type 2 Fault Ride-through Limit Curve



Key

&	FRT curve for single-phase, two-phase and three-phase network faults
UG	r.m.s. value of the actual voltage at the generator terminals

Reactive Power Supply

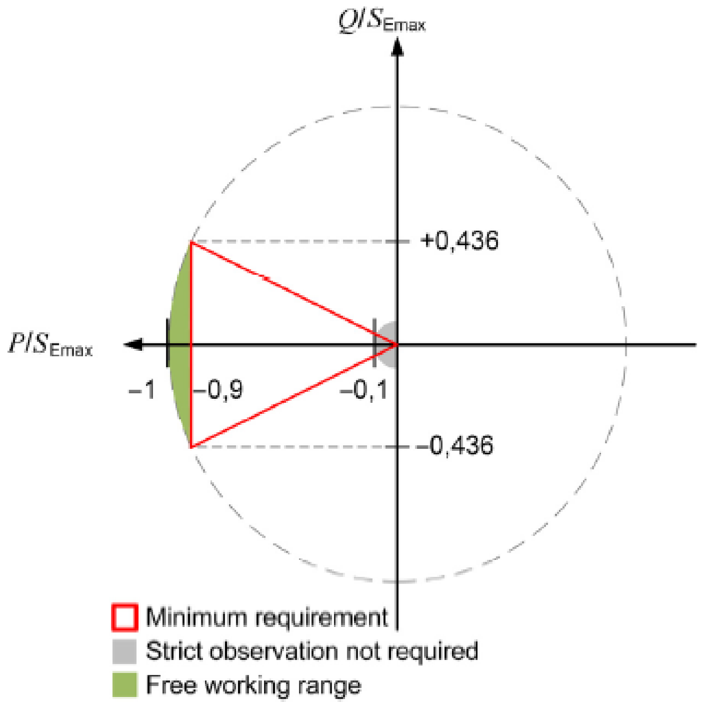


Figure 6 – *P*/*Q* diagram for type 2 (inverters only) $\sum S_{Emax} > 4{,}6$ kVA at the generator terminals in the passive sign convention system

Frequency/Time Range for Operation

Table 1 – Frequency/time ranges for the proper operation of power generation systems

Frequency range	Operating period
47,5 Hz to 49,0 Hz	≥ 30 min
49,0 Hz to 51,0 Hz	unlimited
51,0 Hz to 51,5 Hz	≥ 30 min

Type 2 systems – asynchronous generator

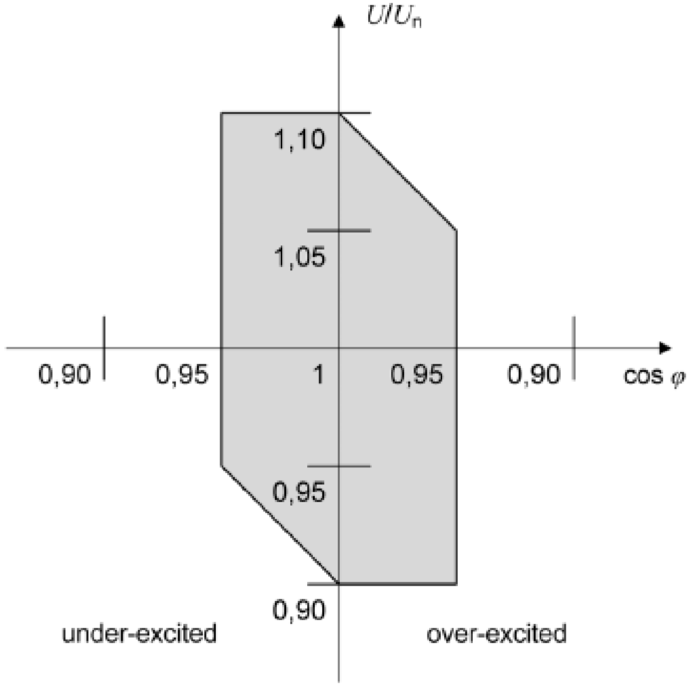


Figure 2 – Requirements for power generation units regarding the reactive power supply at the generator terminals
($\sum S_{Emax} \leq 4{,}6\ \text{kVA}$)

Germany DG Requirement

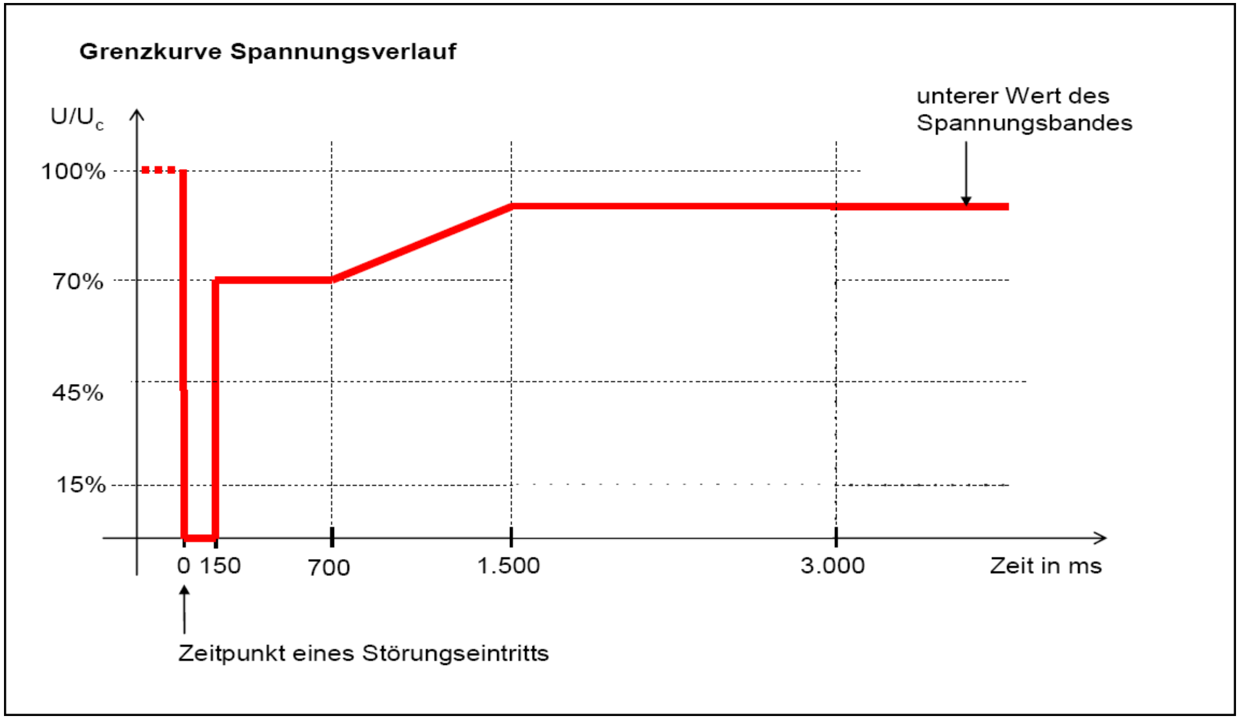
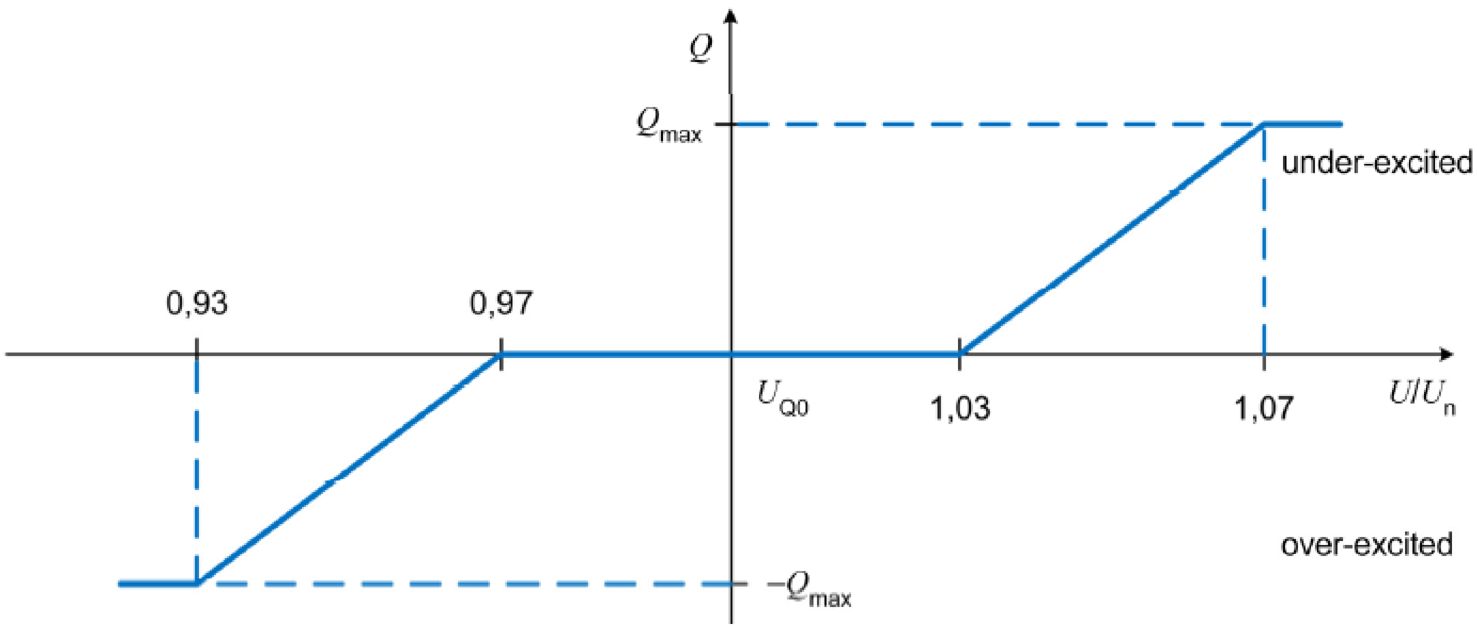


Figure 22: Fault Ride-Through Characteristic for a Synchronous Machine Following Fault Initiation (Point of Failure)

CONSULTANT REPORT - **EUROPEAN RENEWABLE DISTRIBUTED GENERATION INFRASTRUCTURE STUDY – LESSONS LEARNED FROM ELECTRICITY MARKETS IN GERMANY AND SPAIN** Prepared for: **California Energy Commission Prepared by: KEMA, Incorporated,** DECEMBER 2011 CEC-- 400 -- 2011 -- 011

Reactive Power Voltage Characteristic Curve



Distribution Code Approved by CER

Version: 5.0 Date: April 2016

Issued by: Distribution System Operator ESB Networks Limited

Ireland

Information provided by Raymond Byrne

General Requirements

- Distribution Grid Code
- Transfer of Planning Data
  - By user/customer
  - Information to be exchanged
  - Planning studies
- Distribution Connection Conditions
  - Information required for connection
  - Connection arrangements
  - Technical requirements
    - Connection standards
    - Protection requirements
    - Earthing
    - Voltage regulation and control
    - Short circuit levels
    - Insulation levels
    - Capacitive and inductive effects
    - Voltage disturbance
    - Power factor and phase balance
  - Additional requirements for all 110kV connected users
- Generator Requirements

Standards

- All Equipment in an installation connected to the Distribution System shall be designed, manufactured, tested and installed in accordance with all applicable statutory obligations and shall conform to the relevant ETCI, CENELEC or IEC standards current at the time of the connection of the installation to the Distribution System
- *Distribution grid code reference*

Table 1 – Distribution Nominal Voltages (DPC4.2.1)

Low Voltage (LV)	230 volts – phase to neutral 400 volts – phase to phase
Medium Voltage (MV)	10,000 volts (10kV) 20,000 volts (20kV)
High Voltage (HV)	38,000 volts (38kV) 110,000 volts (110kV)

Table 2 – Operating Voltage Range (DPC4.2.2)

Nominal voltage	Highest voltage	Lowest voltage
230V	253V	207
400V	440V	360
10kV	11.1kV	Variable according to operating conditions. Information on particular location on request by the User concerned
20kV	22.1kV	
38kV	43kV	
110kV	120kV	

Maximum Voltage at Connection Point with Generators (DPC10.5.1)

Nominal voltage	Highest voltage
230V	253V
400V	440V
10kV	11.3kV
20kV	22.5kV
38kV	43.8kV
110kV	120kV

Distribution Code Approved by CER, Version: 5.0 Date: April 2016

The following information may be required (DCC4.3)

- **All Types of Demand**
  - Maximum **Active Power** requirements.
  - Maximum and minimum **Reactive Power** requirement.
  - Type of load and control arrangements (e.g. type of motor start, controlled rectifier or large motor drives).
  - Maximum load on each phase.
  - Maximum **Harmonic** currents that may be imposed on the **Distribution System**.
  - Details of cyclic load variations or fluctuating loads (as below).

- **Disturbing Loads**
- **Disturbing Loads** could be non-linear loads, power converters/regulators and loads with a widely fluctuating **Demand**. The type of load information required for motive power loads, welding **Equipment**, etc. These are loads which have the potential to introduce
  - **Harmonics**,
  - **Flicker** or
  - **Unbalance**

- **Fluctuating Loads**
- Details of cyclic variation, and where applicable the duty cycle, of **Active Power** (and
- **Reactive Power** if appropriate), in particular:
  - The rates of change of **Active Power** and **Reactive Power**, both increasing and decreasing;
  - The shortest repetitive time interval between fluctuations in **Active Power** and
- **Reactive Power**; and
  - The magnitude of the largest **Step Changes** in **Active Power** and **Reactive Power**, both increasing and decreasing

Short Circuit Protection (DCC6.5.1 Table 3)

Connection Voltage	Short Circuit Level (RMS Symmetrical) Normally	Short Circuit Level (RMS Symmetrical) Certain Designated Areas
LV (Domestic)	9.0kA	
LV (Ind/Comm)	37.0kA	
10kV	12.5kA	20kA
20kV	12.5kA	20kA
38kV	12.5kA	20kA
110kV	26.0kA	31.5kA

In certain 220kV/110kV substations at 110kV busbars the design short circuit level is 40kA.

Distribution Code Approved by CER, Version: 5.0 Date: April 2016

Voltage Flicker (DCC6.8.3)

- **Frequency** of occurrence
  - 0.22 per min – 600 per min
- Pst - Short term **Flicker** severity
  - an index of visual severity evaluated over a 10 minute period
- Plt - Long term **Flicker** severity
  - an index of visual severity evaluated over a 2 hour period
- **Frequency** of occurrence
  - 0.02 per min – 0.22 per min
  - Magnitude of up to 3% is permitted
- **Frequency** of occurrence
  - =< 0.02 per min
  - Magnitude of up to 5% is permitted.

Voltage Level	Pst	Plt
38kV, MV, LV	0.7	0.5

Distribution Code Approved by CER, Version: 5.0 Date: April 2016

Harmonic Distortion (DCC6.8.3)

% **Harmonic** Voltage Distortion (RMS voltage as a % of RMS value of the fundamental component)

Harmonic Order	LV	MV	38kV
2	0.70	0.50	0.25
3	0.75	0.50	0.25
4	0.70	0.50	0.25
5	2.00	1.00	0.50
6	0.50	0.50	0.30
7	2.00	1.00	0.50
8	0.50	0.50	0.30
9	0.50	0.50	0.25
10	0.50	0.75	0.25
11	1.50	1.50	0.75
12	0.50	0.50	0.30
13	1.50	1.50	0.75
14	0.50	0.50	0.50
15	0.50	0.75	0.25
16	0.75	0.75	0.25
17	0.75	0.75	0.50
18	0.50	0.50	0.25
19	1.00	0.50	0.25

For **Generators** the Total **Harmonic** Voltage Distortion (THVD) limit is given in the table below

Voltage Level	% Harmonic Voltage Distortion
LV	2.5
MV	2.0
38kV	1.5

Fault Ride-through Limit Curve for Controllable WFPSs Connected to the Distribution System (DCC11.2.1)

Phase Voltage vs Time profile at HV Terminals of Grid-Connected Transformer

Additional requirements for 110kV up to 2 MW - Reactive Power

Voltage Range	Connected at:	At 100% Registered Capacity	At 35% of Registered Capacity
99kV ≤ V ≥ 123kV	110kV	0.93 power factor leading to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factor lagging
85kV ≤ V ≥ 99kV		Unity power factor to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factory lagging

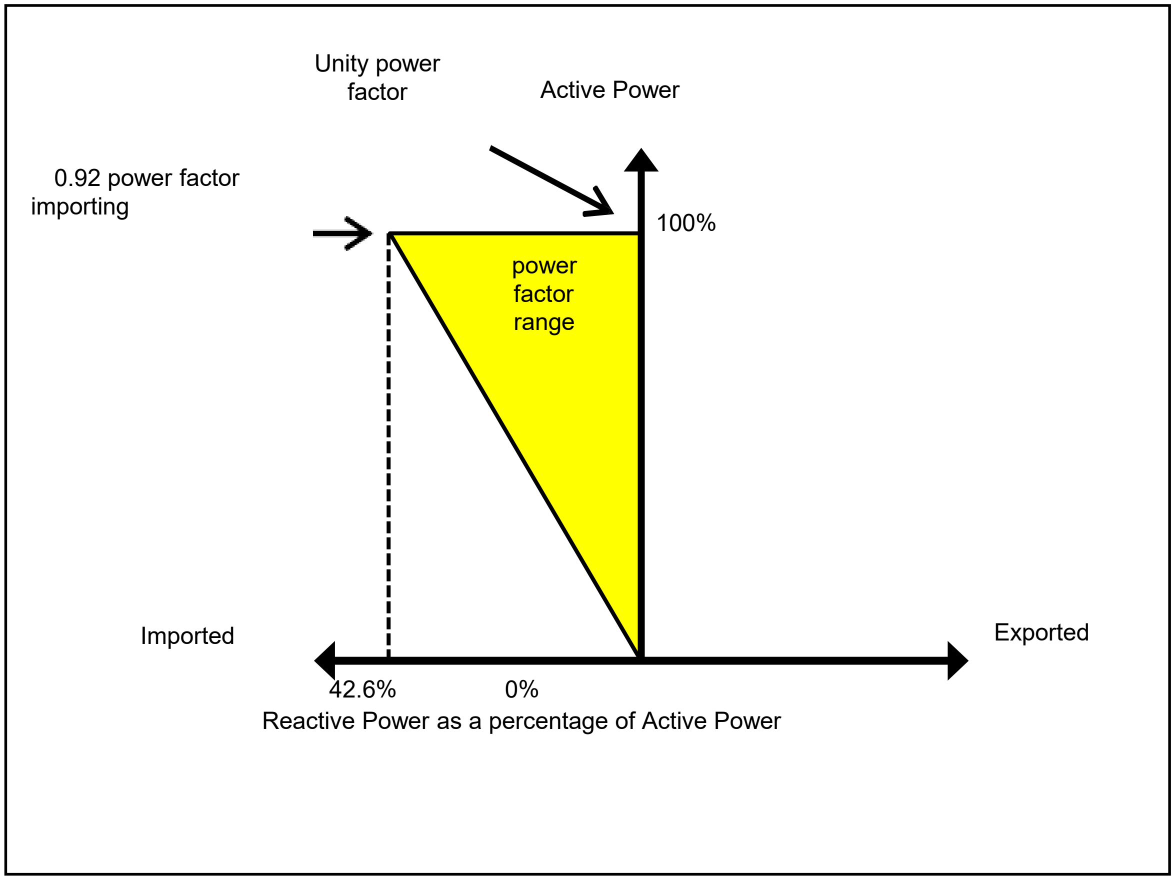
Each **Generation Unit** shall have the following **Reactive Power** capability as measured at their alternator terminals

Reactive Power Capability

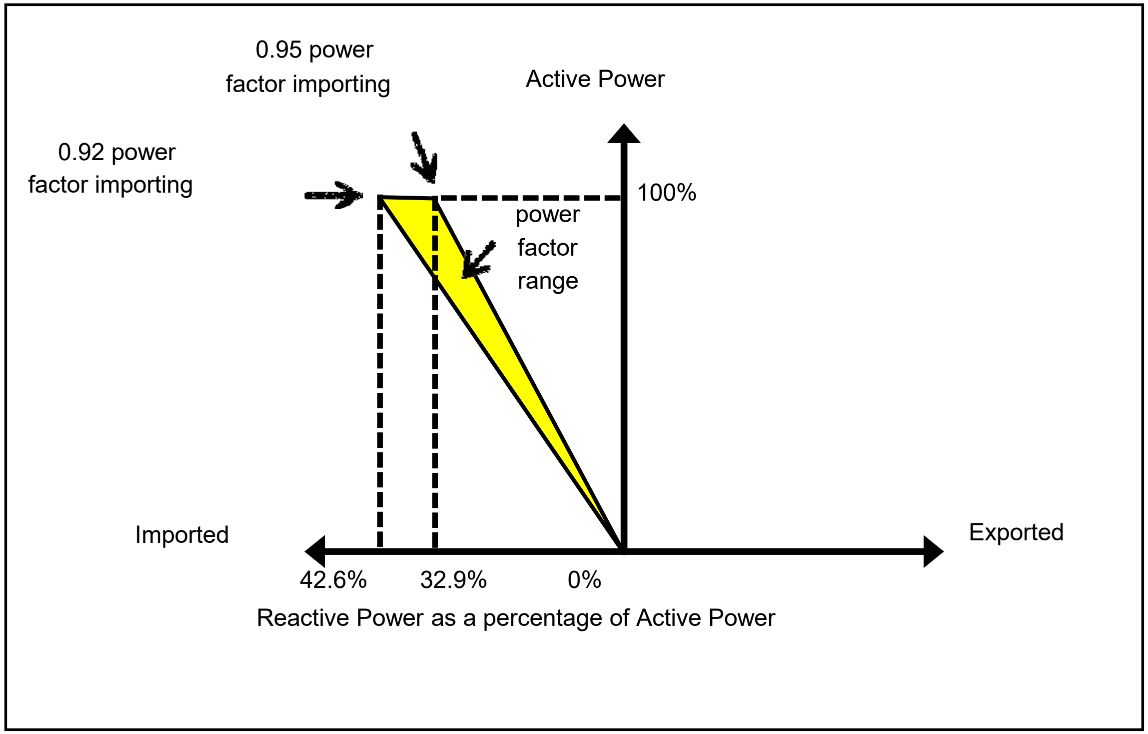
Each **Generation Unit** shall have the following **Reactive Power** capability as measured at their alternator terminals:

Voltage Range	**Connected at:**	**At 100% Registered Capacity**	**At 35% of Registered Capacity**
99kV ≤ V ≥ 123kV	110kV	0.93 power factor leading to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factor lagging
85kV ≤ V ≥ 99kV		Unity power factor to 0.85 power factor lagging	0.7 power factor leading to 0.4 power factory lagging

Reactive Power as a percentage of Active Power (DOC.11.4.3 – Figure 11)



Reactive power as a percentage of Active Power (DOC11.4.3 – Figure 12)



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Octubre de 2018

Spain

Information provided by Ignacio Cruz

Table 6: Overview of Voltage Levels in Spain per IEC Definitions

Source: KEMA, Inc.

System Name (IEC Definition)	Abbreviation	Rated Voltage	Role
Extra-high voltage	EHV	400 kV, 220 kV[30]	Transmission grid
High voltage	HV	132 kV, 110 kV 66 kV, 45 kV	Distribution grid
Medium voltage	MV	30 kV, 20 kV, 15 kV, 13.2 kV, 11 kV	Distribution grid
Low voltage	LV	400 V	Distribution grid

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General and Technical Interconnection Requirements for Spain

3) For producers without storage capabilities or not able to directly manage their output, such as wind power and PV producers, it is also established that the MW capacity of the producer or group of producers sharing a connection point (the PCC), will not exceed 5 percent of the grid short---circuit duty (at that point on the system) expressed in MVA. For dispatchable generators (biomass, solar thermal), the MW capacity shall not exceed 10 percent of the grid short---circuit duty (at that point) expressed in MVA. This is intended to limit the maximum voltage deviation due to DG operation to the range of 5--- 10 percent of the local grid's nominal voltage.

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Remaining Barriers to Development of DG in Spain

The main stakeholders (renewable developers and DSOs) have identified several barriers to full development of renewable technologies in Spain:

- Technical requirements:
  - Connection standards (particularly short circuit limits) are viewed as conservative by promoters and, in many cases, require them to connect at a higher voltage than originally planned.
  - Monitoring and communication devices may represent a barrier in case of trying to access the market.
  - In the case of wind generator, its ability to cope with voltage/frequency dips without tripping may become essential.
  - Network capacity for delivery of renewable energy: Renewable resources, especially wind parks, are not always situated near the electrical network and may require construction of high voltage lines. The approval process for line construction can be slow due to environmental issues, and delays in construction may be as long as five years.
  - The DSOs perceive DG as an added complexity in their networks that do not provide any economic benefits and bring additional operational and planning problems such as: grid operation and maintenance personnel safety; impact on grid operation regarding short circuit levels, voltage control, and interruptions due to failures; impact on network reinforcements to accommodate new DG connections; unpredictable energy deviations with respect the scheduled program; and the difficulty to maintain certain power factors at consumption points on the transmission grid.
  - A major revision of distribution system regulations is expected in Spain. Under these changes stakeholders expect that DG expansion will need to be considered as a more integrated component of the overall grid planning process. The revised regulation should provide DSOs with option(s) to recover the cost of network reinforcements due to the connection of DG. Significant connection charges are imposed on DG projects in Spain, which creates issues for renewable expansion.
  - A distribution congestion management procedure to dispatch DG in case of network congestion should be designed and implemented.
  - The definition of DSOs with associated functions should be clarified in Spain, in line with the Directive 2003/54/EC. Operational procedures for DSOs should be clearly stated, as it was done for the TSO.
  - Administrative processes: A developer has to negotiate with the state ministry, the regional authority, the municipality, the electrical company, and, in case of accessing the market, with the market operator and system operator as well. Due to the complexity of this process, experience shows that building a wind park may take five years.
  - Economic support: As the premium is calculated ex---ante and decided by the regulator, not by the market, the fixed amount may be insufficient to recover renewable project costs. Conversely, in the case of wind power, the premium may be too high, which could become a barrier to renewable development in the future if all the economic resources have been dedicated to the first wind parks.

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Main points addressed by the grid operator in DG interconnection planning

- To ensure a secure operation of the grid under all conditions, the are as follows:
- All components used for the interconnection shall be properly dimensioned for the size of the renewable project.
- The range of operating voltages that occur at the point of connection shall be within the acceptable range.
- The use (such as loading) of all electrical grid components shall not exceed the rated current of the respective component(s), as defined per industry norms.

Spain Normative Grid Standards

In this regard, object of this procedure is the establishment of the technical requirements and procedures laid down in the Regulation (EU) 2016/631 of the Commission on the 14 April 2016, which establishes a code of network requirements of connection of generators to the grid, in the rule - mento (EU) 2016 / 1388 of the Commission on the 17 of August of 2016 whereby establishing a network code of connection of the demand; and complete the development of those requirements required by the regulations; as well as technical aspects which, a priori, for their local influence (not "cross-border") are beyond the scope of the European regulations but have total relevance in the works - operation and security of the electricity system.

INSTALACIONES DE GENERACIÓN Y DE DEMANDA:
REQUISITOS MINIMOS DE DISEÑO, EQUIPAMIENTO, FUNCIONAMIENTO, PUESTA EN SERVICIO Y SEGURIDAD

P.O. 12.2
Octubre de 2018

Frequency Ranges

Zona	Rango de frecuencias	Periodo de tiempo de funcionamiento
España peninsular	47,5 Hz – 48,5 Hz	30 minutos
	48,5 Hz – 49,0 Hz	Ilimitado
	49,0 Hz – 51,0 Hz	Ilimitado
	51,0 Hz – 51,5 Hz	30 minutos

1.Rangos de frecuencia

2.A module of generation of electricity of the type A, B, C or D should be able to stay connected to the network and work within the ranges of frequency and time periods specified in table 7;

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Ride Through Requirements

Voltage Range	Operating Time Period
0,90 pu – 1,118 pu	Ilimitado
1,118 pu – 1,15 pu	60 minutos

Minimum periods of time during which a demand installation connected to the transport network, a distribution installation connected to the transport network, or a distribution network connected to the transport network must be able to operate at diverted voltages of the reference value 1 pu, without disconnecting from the mains, when the base voltage for the pu values is 110 kV or more and up to a value less than 300 kV.

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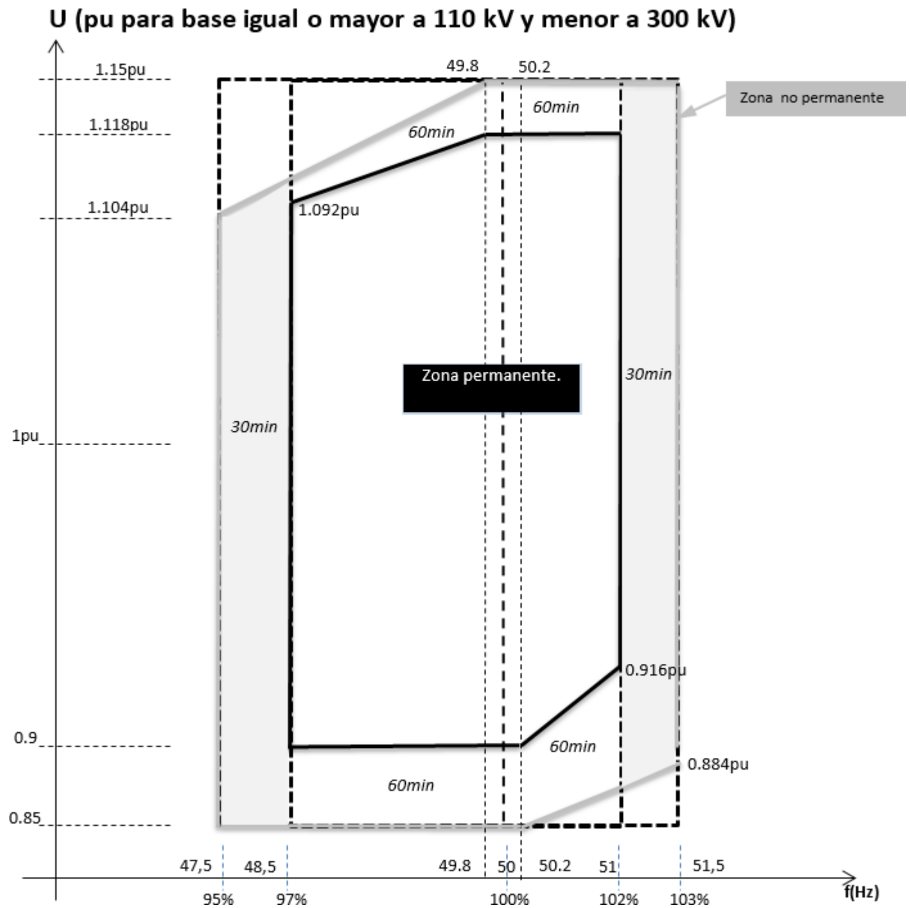
Ride Through Requirements



Minimum periods of time during which a generation of electricity Conn-tado module must be able to operate at different combined values of frequency and voltage, desco - nectarse of the network in the event that the rated voltage of the connection point is equal or greater than 110 kV and lower to 300 kV.

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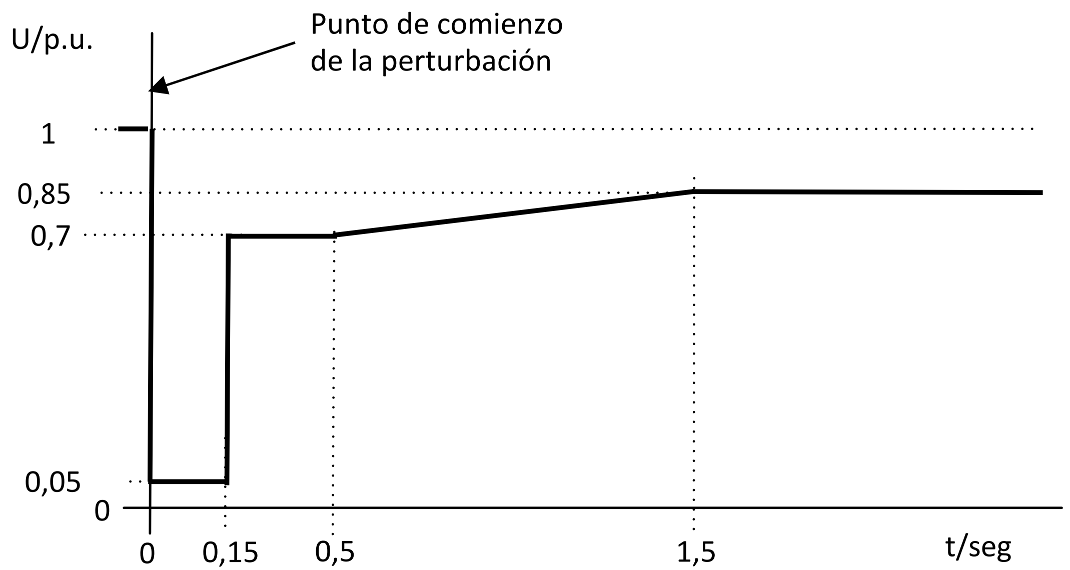
Ride Through Requirements



Profile of the ability to support a synchronous type B electricity generation module Voltage dips, C, or D below 110 kV voltage level. The diagram represents the lower limit of a profile of voltage against time at the point of connection, expressing their real value with respect to its reference value 1 pu before, during and after a failure.

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Overfrequency Requirements

Figura 6 se representa un ejemplo de respuesta.

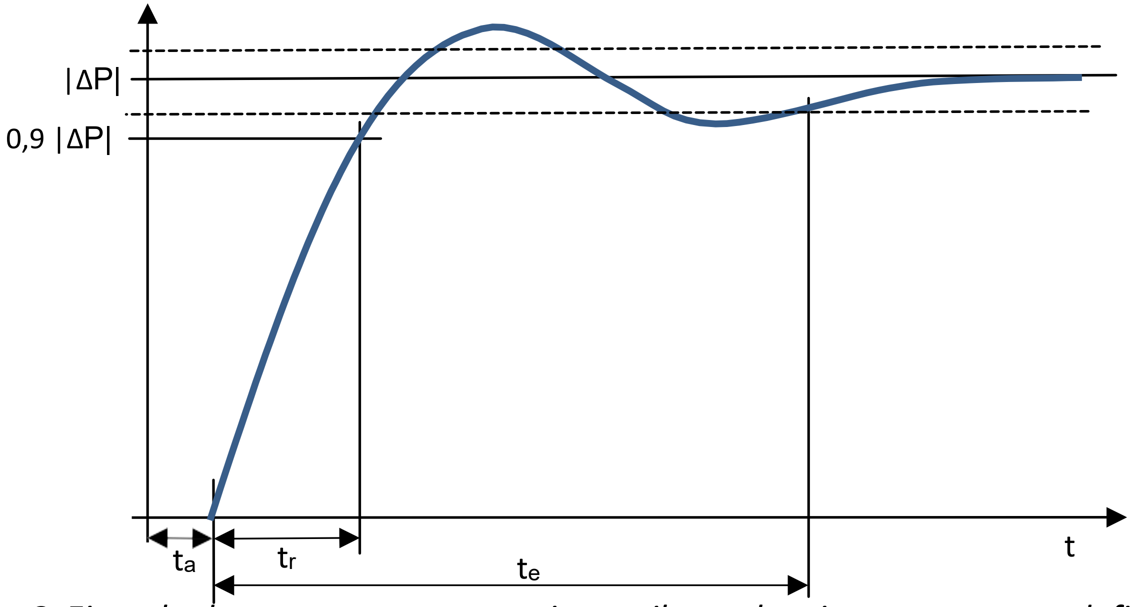

Figura 6. Ejemplo de respuesta en potencia que ilustra los tiempos t_a, t_r, y t_e definidos más arriba.

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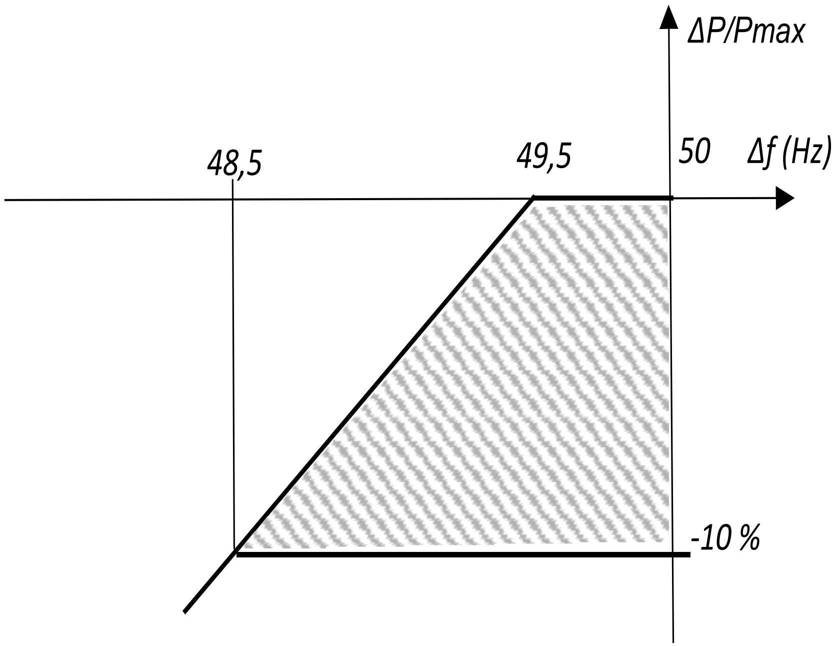
Maximum Capacity with Frequency Drop



Maximum allowable reduction characteristic of the maximum capacity (%) of the synchronous electricity generation module as a function of frequency (Hz)

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Frequency power regulation mode

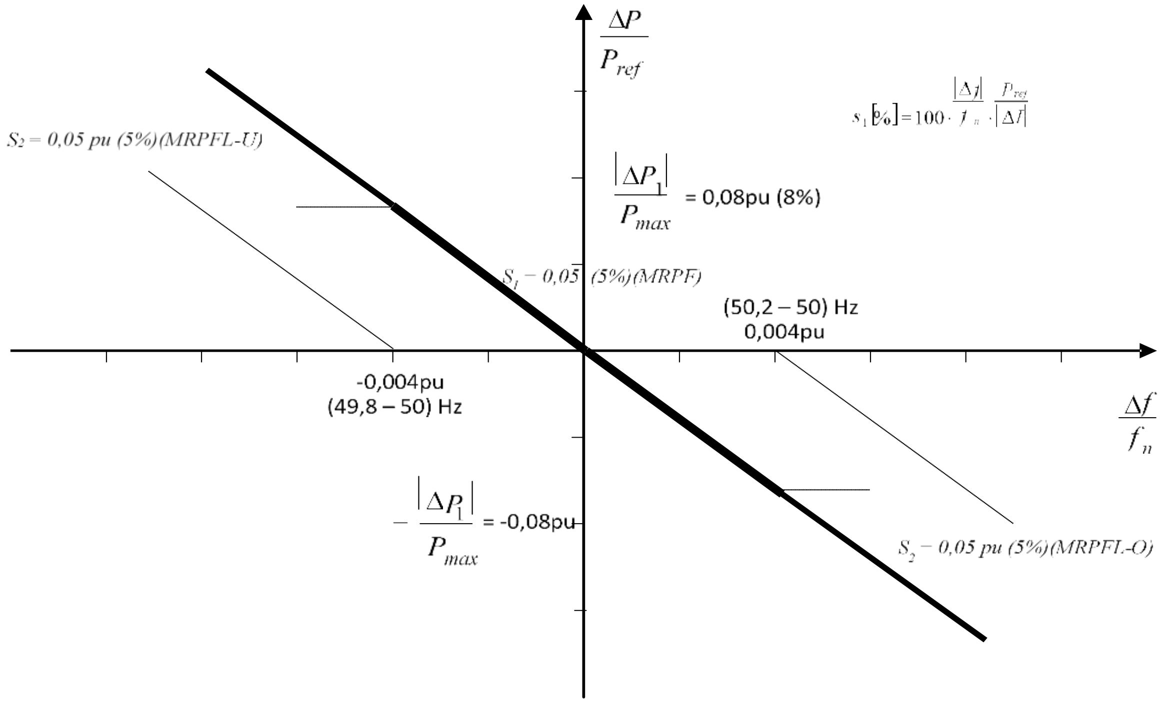

Figura 8. Característica estática potencia-frecuencia continua resultado de acumular las características estáticas de los modos MRPFL-O, MRPFl-U y MRPF.

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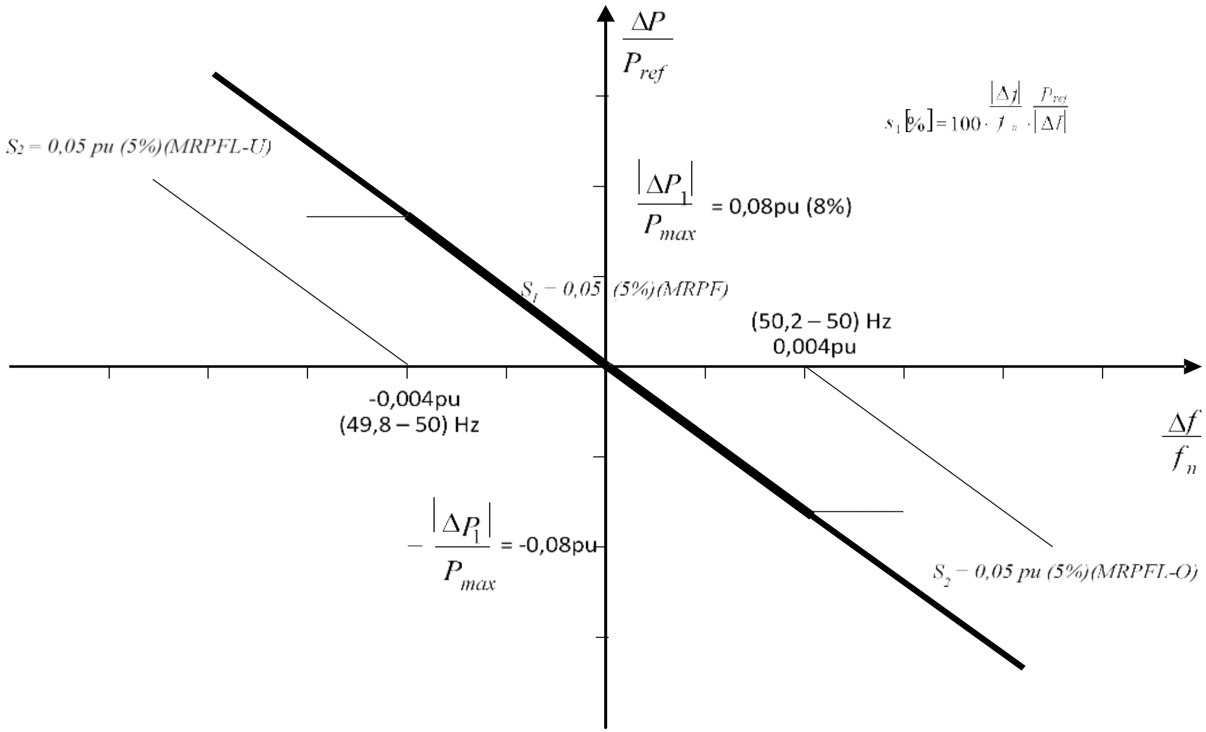
Static Characteristic Power-Frequency Continuous Result



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Voltage Ranges

Voltage Ranges	Operating Time Period
0,85 pu – 0,90 pu	60 minutes
0,90 pu – 1,118 pu	Ilimitado
1,118 pu – 1,15 pu	60 minutes

Minimum periods of time during which the electricity generation module must be capable of operating for voltages that deviate from the reference value 1 pu at the connection point without disconnecting from the network at which the voltage base for the pu values are between 110 kV and 300 kV.

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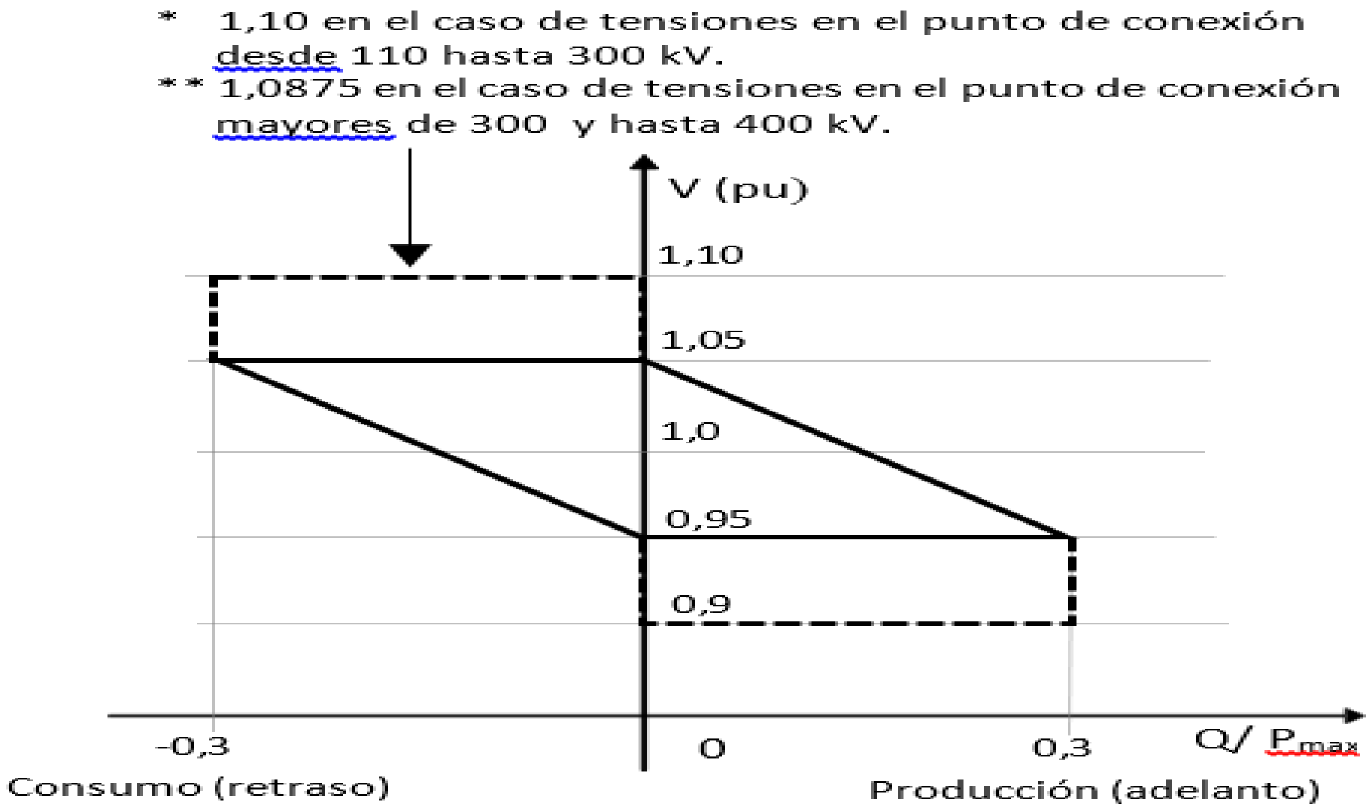
Reactive Power Capacity



U-Q / Pmax diagram of a synchronous electricity generation module

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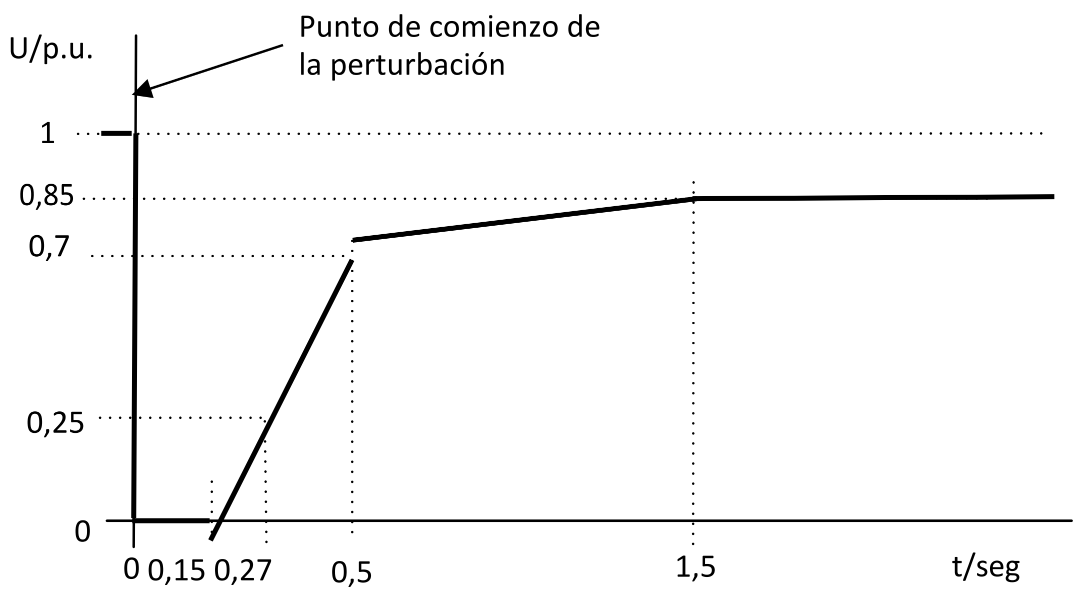
Profile of Capacity to Withstand Voltage Dips for a Type D generator



Profile of the capacity to withstand voltage dips of a type D synchronous electricity generation module connected at 110 kV or above this level. The diagram represents the lower limit of a voltage profile versus time at the connection point, expressing its actual value with respect to its reference value 1 pu before, during and after a fault.

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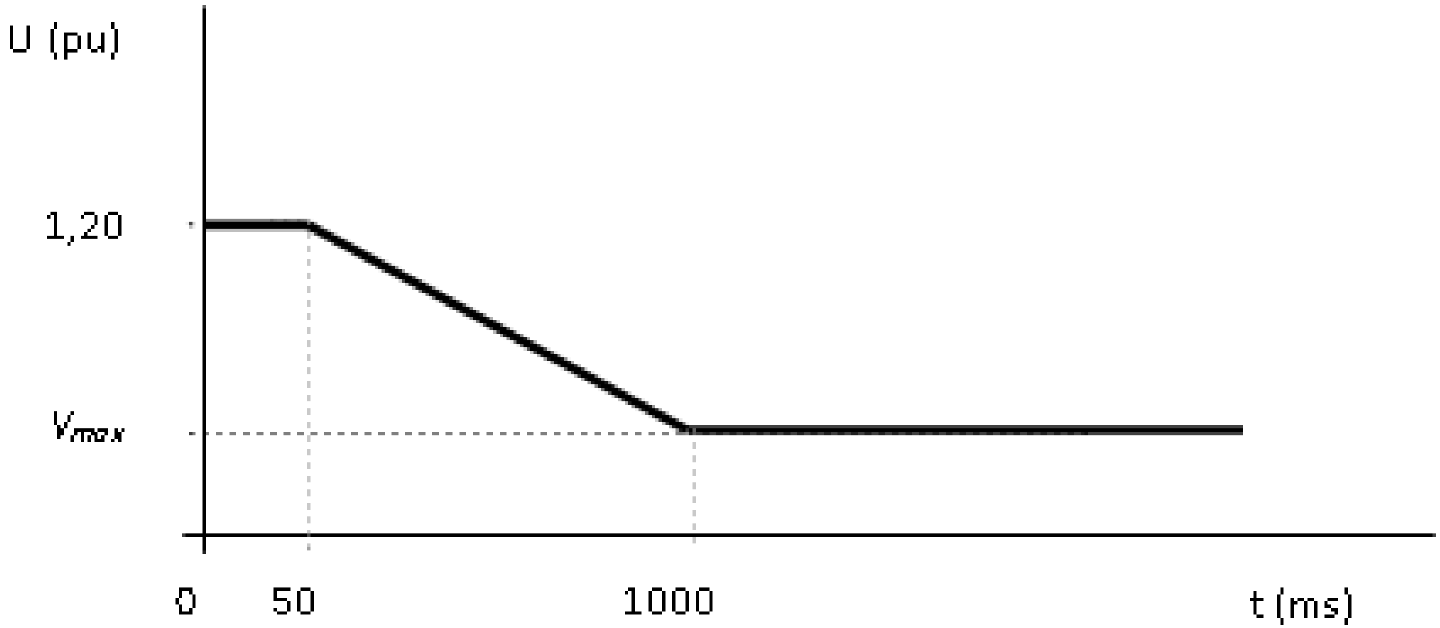
Minimum Overvoltage Time



Minimum overvoltage times at the connection point (effective ground voltage in one or all phases at unit value of the voltage base of the connection point) that the synchronous electricity generation module must be able to withstand without disconnecting where The voltage Vmax corresponds to the highest permissible voltage considered in the voltage ranges and minimum times that it must withstand without disconnecting as set out in section 5.2.1.

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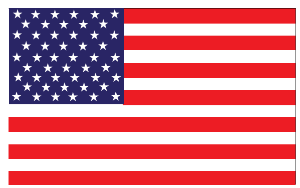
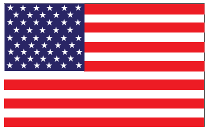
IEEE 1547 - Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces



Information provided by NREL

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



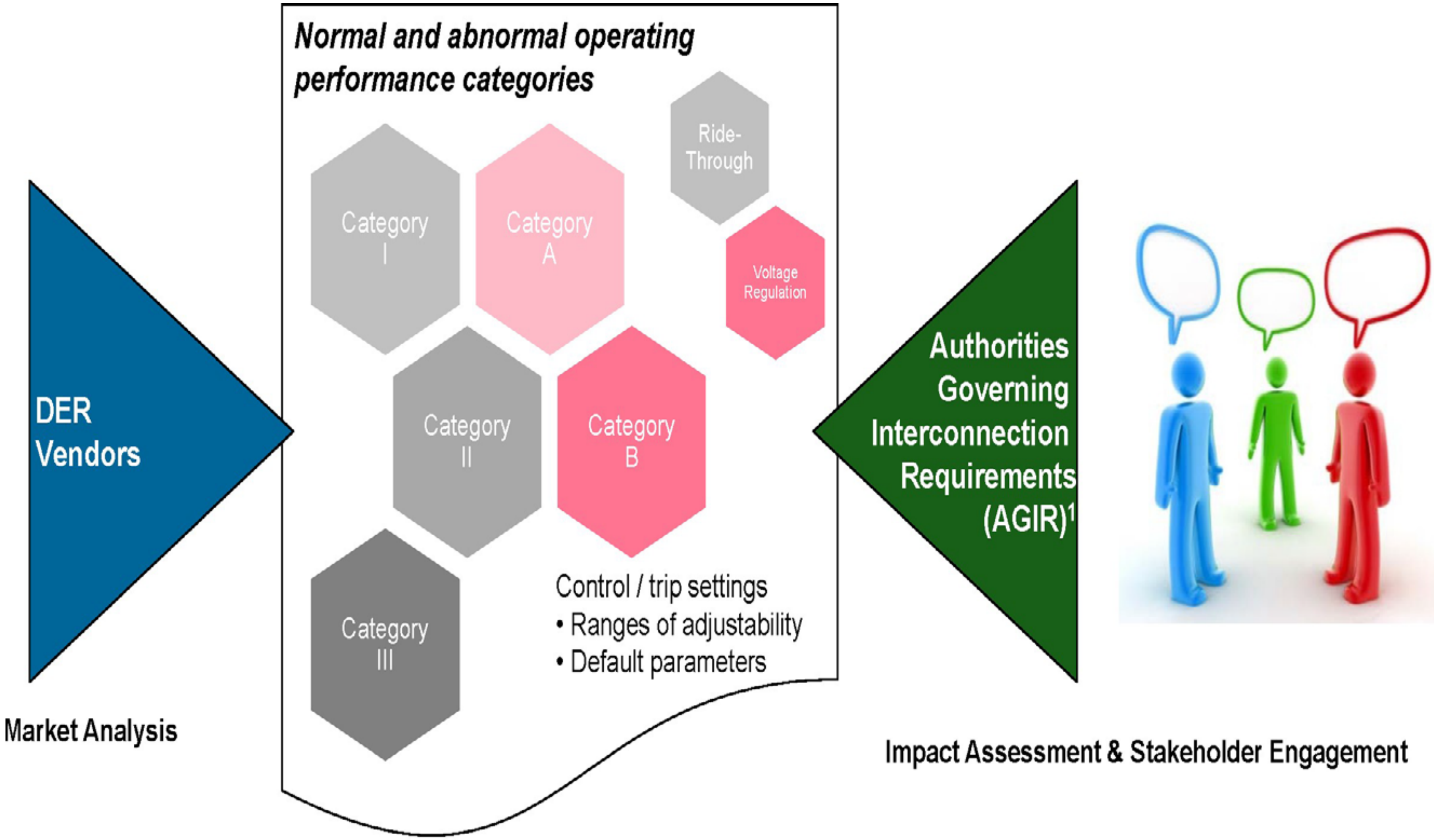
Voltage Definitions

Low Voltage

Medium voltage: A class of nominal system voltages equal to or greater than 1 kV and less than or equal to 35 kV.

NOTE—IEEE standards are not unanimous in establishing the range for "medium voltage".

High-level Overview of Performance-based Category Approach



[1]Regulatory agencies, public utility commissions, municipalities, cooperative governing boards, etc.

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Applicable Voltages When Point of Common Coupling is Located at Low Voltage

Low-voltage winding configuration of Area EPS transformer(s)[a]	Applicable voltages
Grounded Wye, Tee, or Zig-Zag[b]	Phase-to-phase and phase-to-neutral, or Phase-to-phase and phase-to-ground
Ungrounded Wye, Tee, or Zig-Zag	Phase-to-phase or phase-to-neutral
Delta[c]	Phase-to-phase
Single-Phase 120/240 V (split-phase or Edison connection)	Line-to-neutral—for 120 V DER units Line-to-line—for 240 V DER units[d]

a A three-phase transformer or a bank of single-phase transformers may be used for three-phase systems.
b For 120/208 V two-phase services, line-to-line voltages shall be sufficient.
c Including delta with mid tap connection (grounded or ungrounded).
d Sensing line-to-neutral on both legs of a 120/240 V split-phase or Edison connection effectively senses the line-to- line and is therefore compliant with this requirement. Sensing line-to-ground may also be used; however, the ground connection should only be used for voltage sensing purposes.

Categories A and B for Voltage regulation performance and reactive power capability requirements (Clause 5)

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

- Category B covers all requirements within Category A and specifies supplemental capabilities needed to adequately integrate the DER in local Area EPS where the DER penetration is higher or where the DER power output is subject to frequent large variations.
  - To deal with power quality issues caused by increasing DER penetration, especially of variable-generation DER, the majority of the DER should have Category B performance. (B.4.3.1)

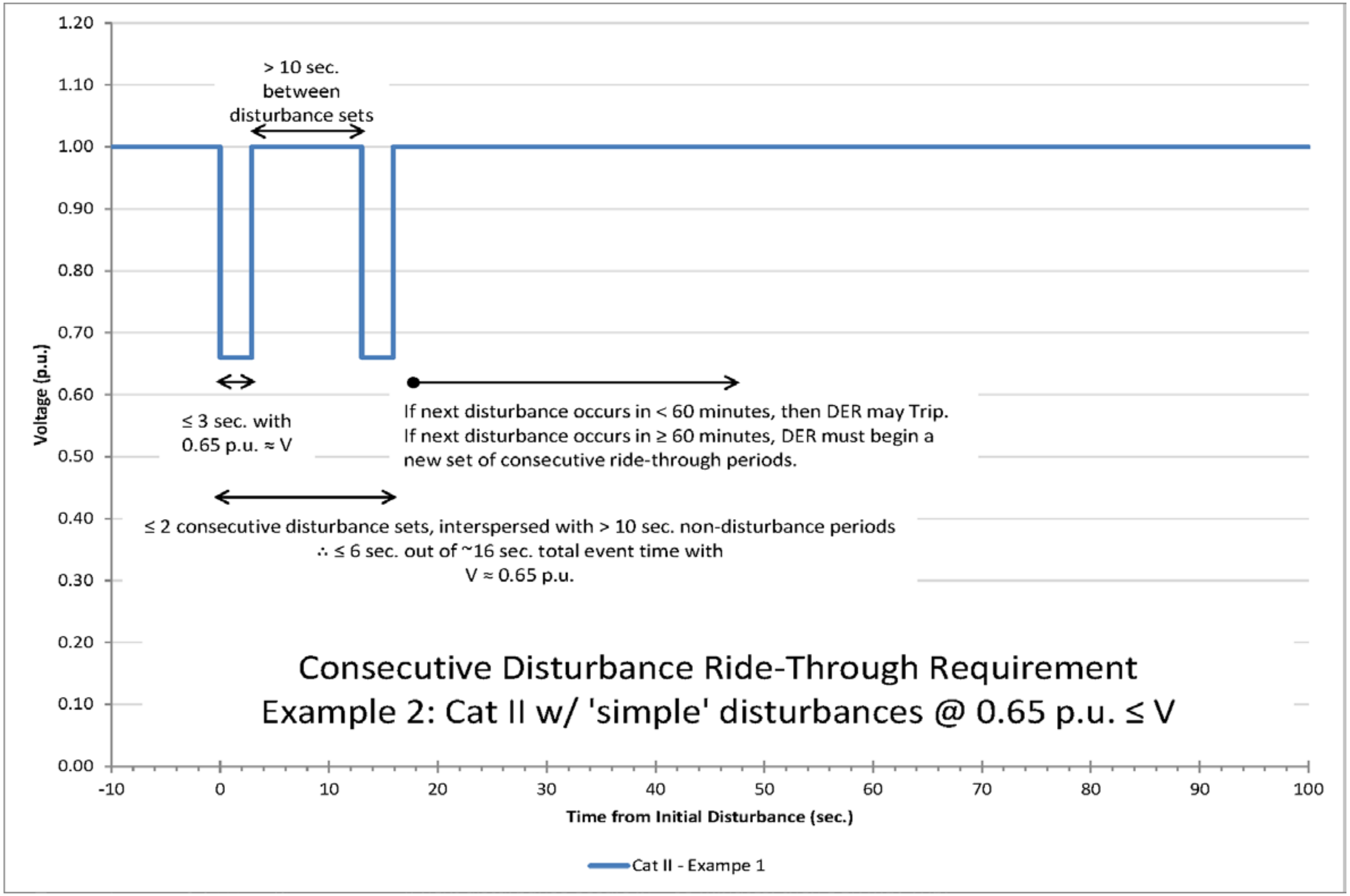
Categories I, II, and III for Disturbance Ride-through Requirements (Clause 6)

- Category I is based on minimal *bulk power system* (BPS) reliability needs and is reasonably attainable by all DER technologies that are in common usage today.
  - The disturbance ride-through requirements for Category I are derived from the German Association of Energy and Water Industries (BDEW [B2]) standard for medium voltage synchronous generators and is one of the most widely applied standards in Europe.

- Category II performance covers all BPS reliability needs and coordinates with the existing BPS reliability standard, NERC PRC-024-2 [B26], developed to avoid adverse tripping of bulk system generators during system disturbances.
  - Additional voltage ride-through capability is specified for DERs, beyond mandatory voltage ride-through defined by NERC PRC-024-2 [B26], to account for the potential for fault-induced delayed voltage recovery on the distribution system, due to distribution load characteristics.
  - To preserve the security of the *bulk power system*, all wind turbines should have Category II disturbance ride-through performance. B.4.3.3

- Category III provides the highest disturbance ride-through capabilities, intended to address integration issues such as power quality and system overloads caused by DER tripping in local Area EPS that have very high levels of DER penetration. This category also provides increased *bulk power system* security by further reducing the potential loss of DER during bulk system events.
  - These requirements are based on the California Rule 21 [B4] Smart Inverter requirements.

Consecutive Disturbance Ride-through Requirement, Example 2 for Category II – Figure E.2 IEEE 1547



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Voltage Ride-through Requirements for abnormal operating Category II (see Figure H.8)

Voltage range (p.u.)	Operating mode/response	Minimum ride-through time (s) (design criteria)	Maximum response time (s) (design criteria)
V > 1.20	Cease to Energize[a]	N/A	0.16
1.175 < V ≤ 1.20	Permissive Operation	0.2	N/A
1.15 < V ≤ 1.175	Permissive Operation	0.5	N/A
1.10 < V ≤ 1.15	Permissive Operation	1	N/A
0.88 ≤ V ≤ 1.10	Continuous Operation	Infinite	N/A
0.65 ≤ V < 0.88	Mandatory Operation	Linear slope of 8.7 s/1 p.u. voltage starting at 3 s @ 0.65 p.u.: $T_{VRT} = 3\text{ s} + \frac{8.7\text{ s}}{1\text{ p.u.}}(V - 0.65\text{ p.u.})$	N/A
0.45 ≤ V < 0.65	Permissive Operation	0.32	N/A
0.30 ≤ V < 0.45	Permissive Operation	0.16	N/A
V < 0.30	Cease to Energize[a]	N/A	0.16

a Cessation of current exchange of DER with *Area EPS in not more than* the maximum specified time and with no intentional delay. This does not necessarily imply disconnection, isolation, or a trip of the DER. This may include momentary cessation or trip.

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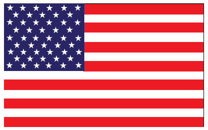
Voltage-active Power Settings for Category A and Category B DER

Voltage-active power parameters	Default settings	Ranges of allowable settings	
		Minimum	Maximum
V1	1.06 VN	1.05 VN	1.09 VN
P1	Prated	N/A	N/A
V2	1.1 VN	V1 + 0.01 VN	1.10 VN
P2 (applicable to DER that can only generate active power)	The lesser of 0.2 Prated or P_{min} [a]	Pmin	Prated
P'2 (applicable to DER that can generate and absorb active power)	0 [b]	0	P'rated
Open Loop Response Time	10 s [c]	0.5 s	60 s

[a] *P*min is the minimum active power output in p.u. of the DER rating (i.e., 1.0 p.u.).

[b] *P*'rated is the maximum amount of active power that can be absorbed by the DER. ESS operating in the negative real power half plane, through charging, shall follow this curve as long as available energy storage capacity permits this operation.

[c] Any settings for the open loop response time of less than 3 s shall be approved by the Area EPS operator with due consideration of system dynamic oscillatory behavior.



DER response (shall trip) to Abnormal Voltages and Operating Performance Category II (see Figure H.8)

Shall trip—Category II				
Shall trip function	Default settings[a]		Ranges of allowable settings[b]	
	Voltage (p.u. of nominal voltage)	Clearing time (s)	Voltage (p.u. of nominal voltage)	Clearing time (s)
OV2	1.20	0.16	fixed at 1.20	fixed at 0.16
OV1	1.10	2.0	1.10–1.20	1.0–13.0
UV1	0.70	10.0	0.0–0.88	2.0–21.0
UV2	0.45	0.16	0.0–0.50	0.16–2.0

aThe Area EPS operator may specify other voltage and *clearing time* trip settings within the *range of allowable settings*, e,g., to consider Area EPS protection coordination.

bNominal system voltages stated in ANSI C84.1, Table 1 or as otherwise defined by the Area EPS operator. The *ranges of allowable settings* do not mandate a requirement for the DER to ride through this magnitude and duration of abnormal voltage condition, etc.

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DER Response (shall trip) to Abnormal Frequencies for DER of Abnormal Operating Performance Category I, II, & III (see Figure H.10)

Shall trip function	Default settings[a]		Ranges of allowable settings[b]	
	Frequency (Hz)	Clearing time (s)	Frequency (Hz)	Clearing time (s)
OF2	62.0	0.16	61.8–66.0	**0.16–1 000.0**
OF1	61.2	300.0	61.0–66.0	**180.0–1 000.0**
UF1	58.5	300.0[c]	50.0–59.0	**180.0–1 000**
UF2	**56.5**	**0.16**	**50.0–57.0**	**0.16–1 000**

aThe frequency and *clearing time* set points shall be field adjustable. The actual applied underfrequency (UF) and overfrequency (OF) trip settings shall be specified by the Area EPS operator in coordination with the requirements of the *regional reliability coordinator*. If the Area EPS operator does not specify any settings, the default settings shall be used.

bThe *ranges of allowable settings* do not mandate a requirement for the DER to ride through this magnitude and duration of abnormal frequency condition. The Area EPS operator may specify the frequency thresholds and maximum *clearing times* within the *ranges of allowable settings*; settings outside of these ranges shall only be allowed as necessary for DER equipment protection and shall not conflict with the frequency disturbance ride through requirements specified in 6.5.2. For the overfrequency (OF) and underfrequency (UF) trip functions *clearing time* ranges and for the OF trip functions frequency ranges, the lower value is a limiting requirement (the setting shall not be set to lower values) and the upper value is a minimum requirement (the setting may be set above this value). For the UF trip functions frequency ranges, the upper value is a limiting requirement (the setting shall not be set to greater values) and the lower value is a minimum requirement (the setting may be set to lower values).

cThis time shall be chosen to coordinate with typical regional underfrequency load shedding programs and expected frequency restoration time.

Voltage Ride-through Requirements for Consecutive Temporary Voltage Disturbances Caused by Unsuccessful Reclosing for DER of Abnormal Operating Performance Category I, II, & III

Col. 1	Col. 2	Col. 3	Col. 4
Category	Maximum number of ride- through disturbance sets	Minimum time between successive disturbance sets (s)	**Time window for new count of disturbance sets (min)**
I	2	20.0	**60**
II	2	10.0	**60**
III	**3**	**5.0**	**20**

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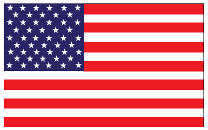

for DER of abnormal operating performance Category I, II, and III

Parameter	Default settings[a]			Ranges of allowable settings[b]		
	Category I	Category II	Category III	Category I	Category II	Category III
dbOF, dbUF (Hz)	0.036	0.036	0.036	0.017[c]–1.0	0.017[c]–1.0	**0.017[c]–1.0**
kOF, kUF	0.05	0.05	0.05	0.03–0.05	0.03–0.05	**0.02–0.05**
Tresponse (small-signal) (s)	**5**	**5**	**5**	**1–10**	**1–10**	**0.2–10**

[a]Adjustments shall be permitted in coordination with the Area EPS operator.
[b]For the single-sided deadband values (*db*OF, *db*UF) ranges, both the lower value and the upper value is a minimum requirement (wider settings shall be allowed). For the frequency droop values (*k*OF, *k*UF) ranges, the lower value is a limiting requirement (the setting shall not be set to lower values) and the upper value is a minimum requirement (the setting may be set to greater values). For the open-loop response time, *T*response (small-signal), the upper value is a limiting requirement (the setting shall not be set to greater values) and the lower value is a minimum requirement (the setting may be set to lower values). Any settings different from the default settings in Table 24 shall be approved by the *regional reliability coordinator* with due consideration of system dynamic oscillatory behavior.
[c]A deadband of less than 0.017 Hz shall be permitted.

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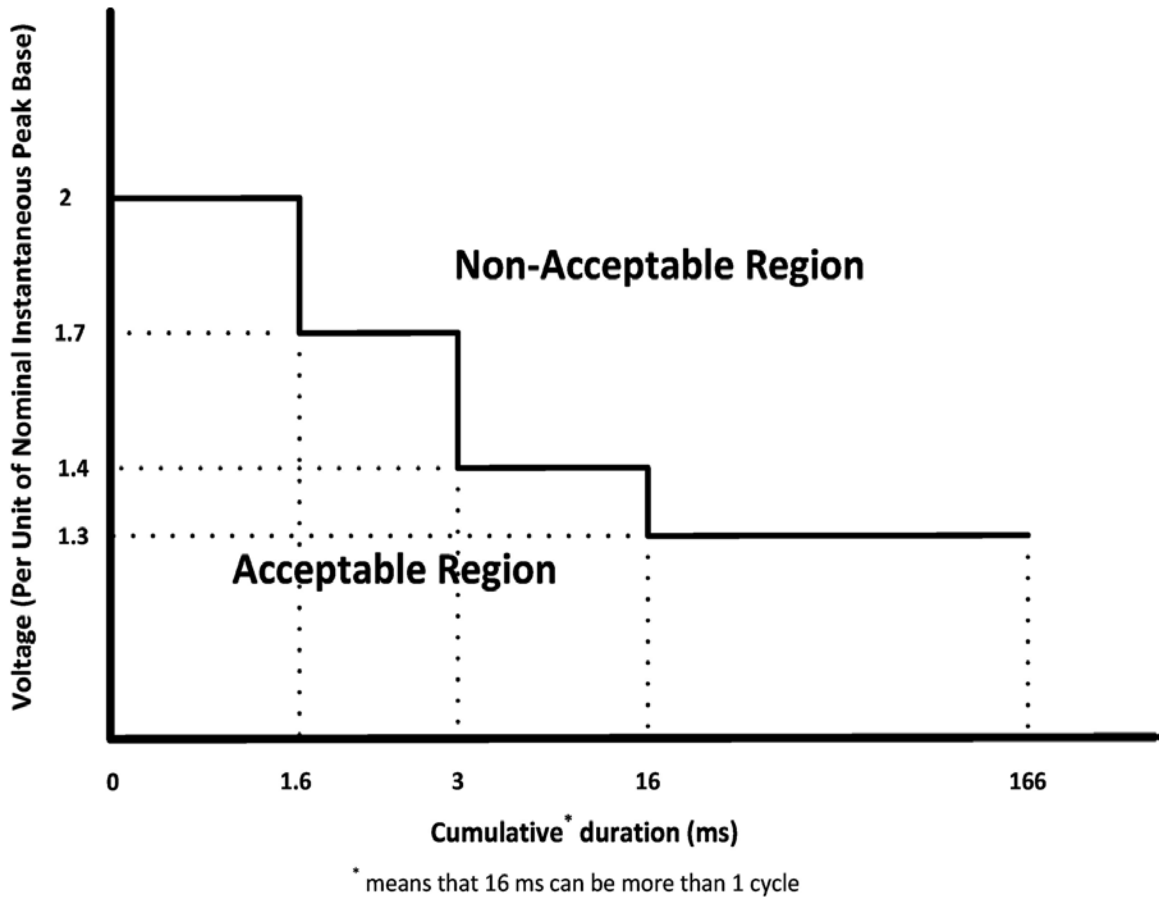
Transient overvoltage limits



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Communication Monitoring information

Parameter	Description
Active Power	Active power in watts
Reactive Power	Reactive power in vars
Voltage	Voltage(s) in volts. (One parameter for single-phase systems and three parameters for three-phase systems).
Frequency	Frequency in Hertz
Operational State	Operational state of the DER. The operational state should represent the current state of the DER. The minimum supported states are on and off but additional states may also be supported.
Connection Status	Power-connected status of the DER
Alarm Status	Active alarm status
Operational State of Charge	0% to 100% of operational energy storage capacity

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Other Relevant Information

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