



Connection Conditions for Wind Generation (Grid Code Aspects)

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Regulatory Requirements – Regulated Markets



- Vertically integrated utilities responsible for generation/transmission/distribution
- Planning activities in one hand
- Only basic Technical References required
- Planning based on internal guidelines



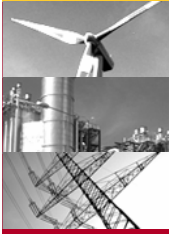
Regulatory Requirements – Deregulated Markets



- Unbundling between Generation, Transmission, Distribution
- Different responsibilities, integrated planning is limited
- Technical framework required for defining the standards with which each party has to comply and to define interfaces.

- Grid Code can include:
 - Transmission Code
 - Distribution Code and Metering Code
 - Operation Code and Scheduling and Dispatch Code
 - Data Registration Code
 - all kinds of other aspects....

- In some countries, the grid code is part of a law (e.g. Australia “National Electricity Law”, some aspects for wind generators in Spain etc.)



Connection Conditions for Generation – Typical Approaches

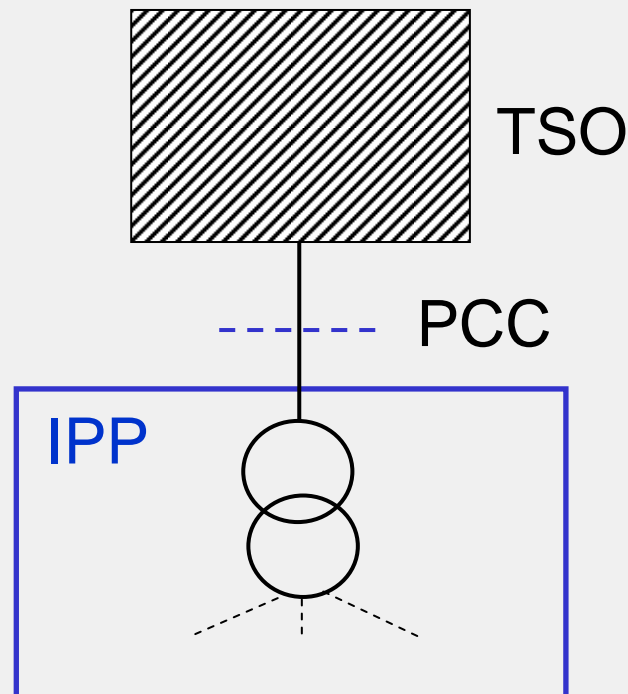


- General Connection Conditions/Black Box Principle
 - Network characterised by properties at the connection point only (e.g. Fault level, max./min. frequencies, max./min. voltages, worst case credible voltage dips to be expected etc.
 - Requirements to the behaviour of the new power plant by its response at the connection point (PCC)
- Individual Requirements/Integrated Planning Approach
 - Interaction between transmission system and power plant taken into account: integrated studies required (likewise vertically integrated planning process)
- Combinations of both approaches are of course possible and widely used.



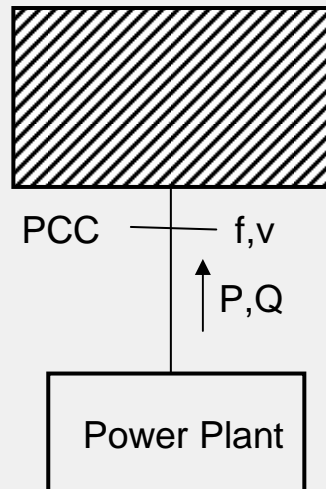
Basic Aspects of Grid Code Definitions - PCC

- Interface between system operator (TSO) and independent power producer (IPP) is the Connection Point or Point of Common Coupling (PCC).



Connection Conditions

- Connection Conditions should treat the Power Plant as “black box”, which means that all conditions should apply to the PCC.
- The TSO shall describe ranges of voltage and frequency at the PCC that comply with actual system behaviour
- The TSO shall define requirements for active and reactive power output of the Power Plant that guarantee secure system operation



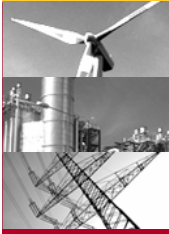


Technical Requirements



Technical Requirements

- Power Quality:
 - Voltage deviations during switch on/switch off operations.
 - Flicker
 - Harmonics/Impact on ripple control system
 - Normal operating conditions
 - Voltage range
 - Frequency range
- > No operational restriction of wind farm for the whole voltage and frequency range required



Active Power – Frequency Control

- Typical requirement:
Limitation of active power production must be possible if system security is at risk, e.g.
 - n-1 conditions not fulfilled
 - risk of losing system stability
 - islanding situation: limitation of over-frequencies
- In some countries (e.g. U.K.):
 - Wind farms must have the technical capability for frequency control (primary and secondary).



Reactive Power – Voltage Control

- Definition of required power factor range in function of voltage at PCC of the power plant and active power.

Converter costs depend on apparent current -> larger power factor range increases converter costs because of larger apparent currents.

- Depending on system requirements:
 - Constant or variable power factor control
 - Voltage control
 - More complex control (definition of dead-bands, droop etc.)

Control strategy is realized by software -> complex control strategy only increases development costs, no hardware costs



Reactive Power – Voltage Control

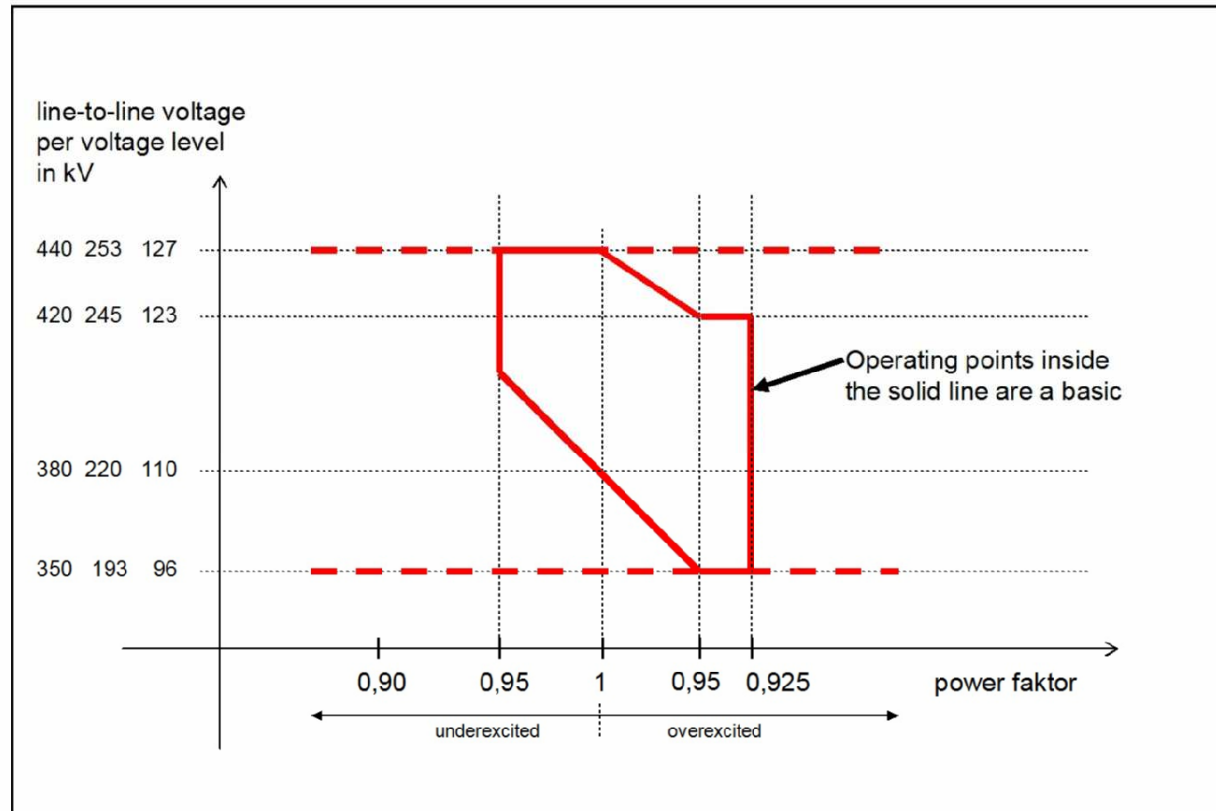
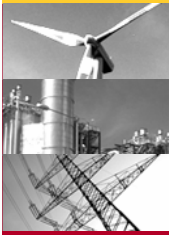
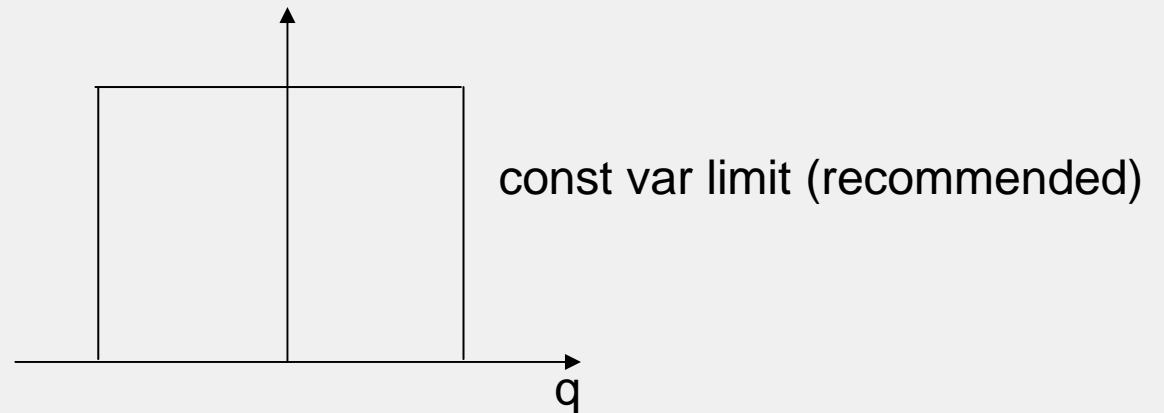
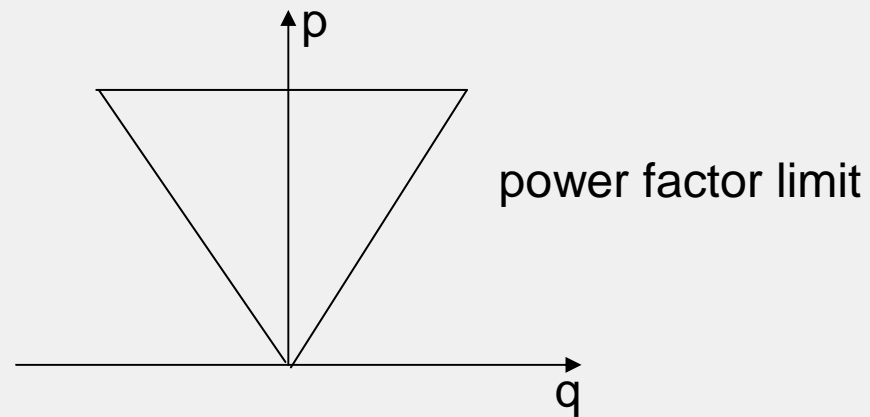


Figure 4 Requirements placed on the reactive power provision of a generating plant at frequencies between 49.5 and 50.5 Hz and without limiting the active power output



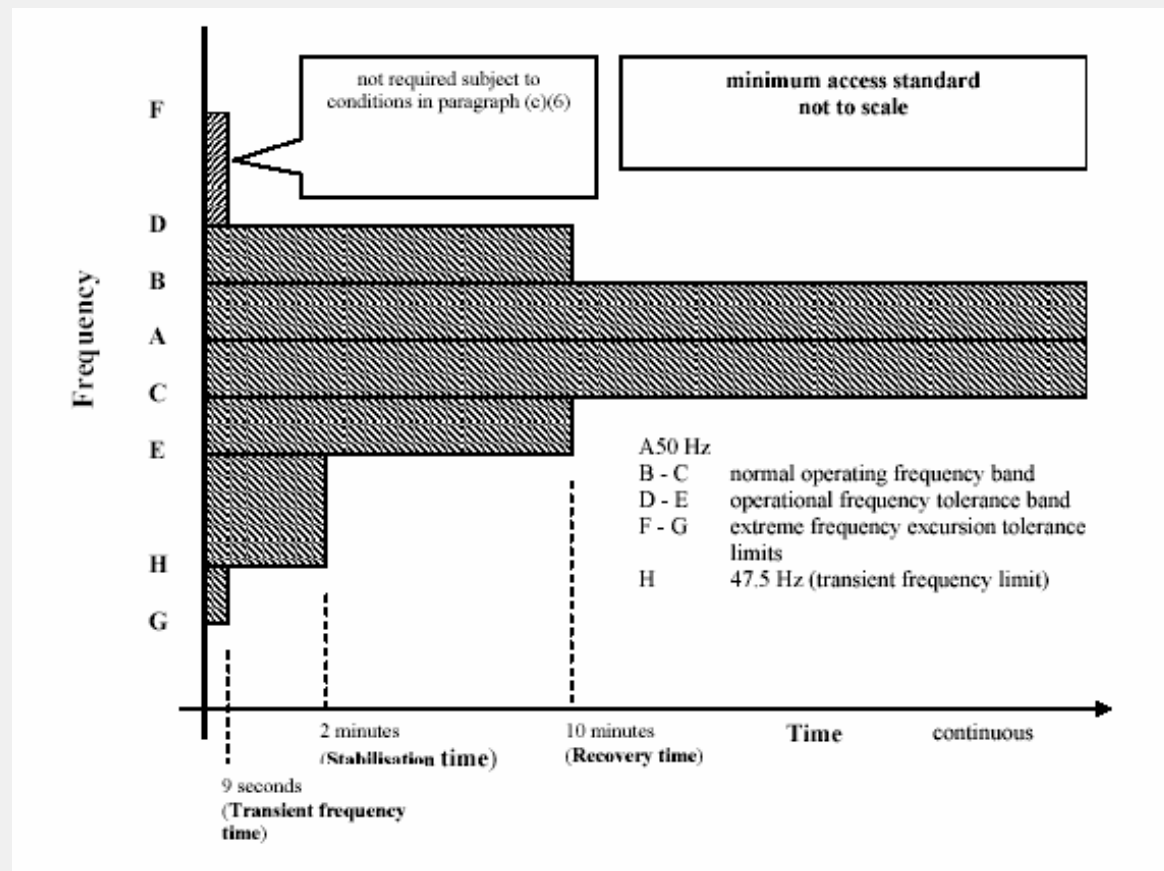
Reactive Power – Voltage Control





Behaviour in case of frequency disturbance

- Definition of frequencies vs. duration for which no disconnection is allowed and full active power production is required.





Behaviour in case of network faults

- Requirement of a minimum voltage profile. For voltages above the profile, no disconnection allowed.
- Voltages below profile: Wind generators must disconnect

Required voltage profile must be derived from actual system properties, e.g. fault clearing times and depth of voltage sags that can possibly cover a wide area.

- Alternatively: Requirement that wind farm stays connected in case of all “credible fault events” (e.g. 3-phase or two phase faults at lines/busbars etc. -> “credible fault events” require definition)
- For voltage support, reactive current contribution during fault may be required.



Behaviour in case of network faults

- Requirement for voltage support by short-circuit current (reactive current) contribution to the network

Reactive current contribution during fault lifts the voltage at the generator terminal and sometimes helps the wind generator to ride through faults.

Reactive current contribution during faults requires total unloading of active currents and therefore increases the torque disturbance at the generator shaft -> costs implied.



Behaviour in case of network faults

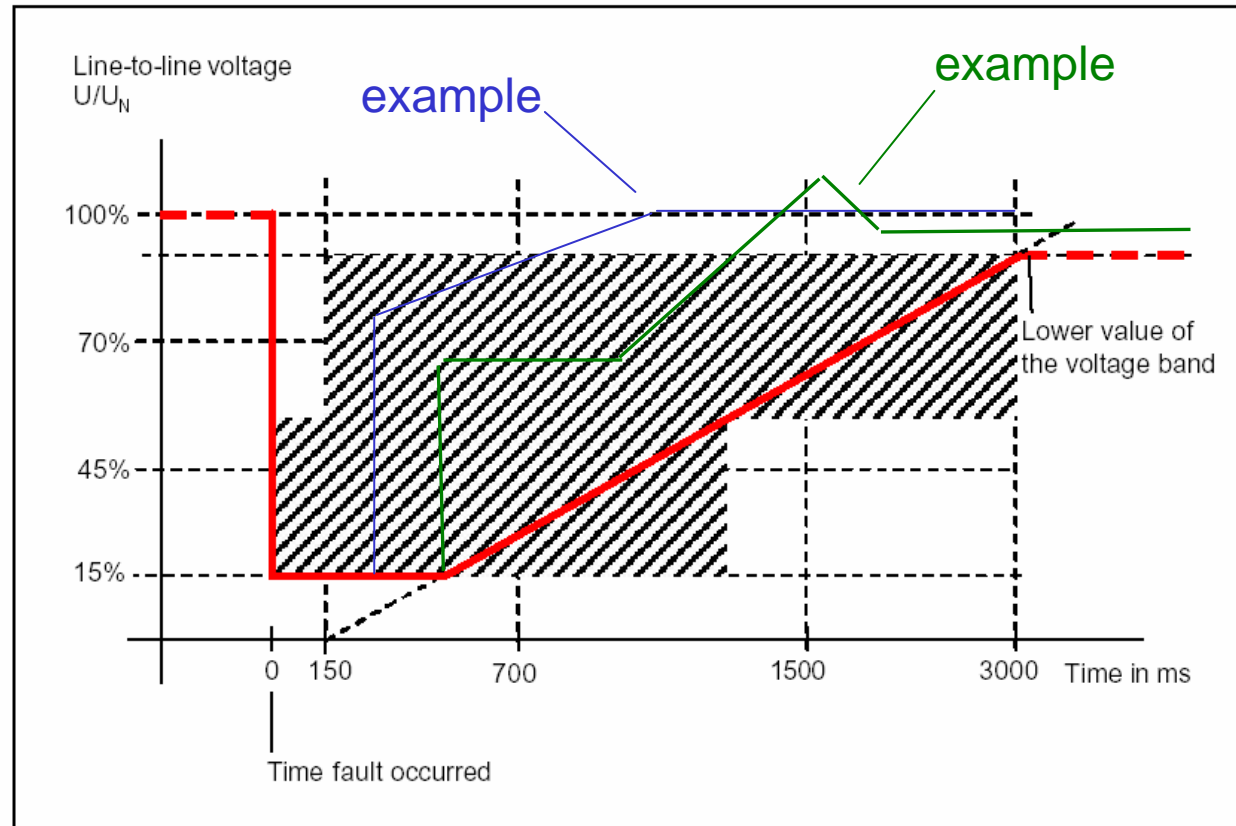


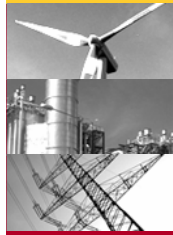
Fig. 5b Voltage limit curve of a network fault



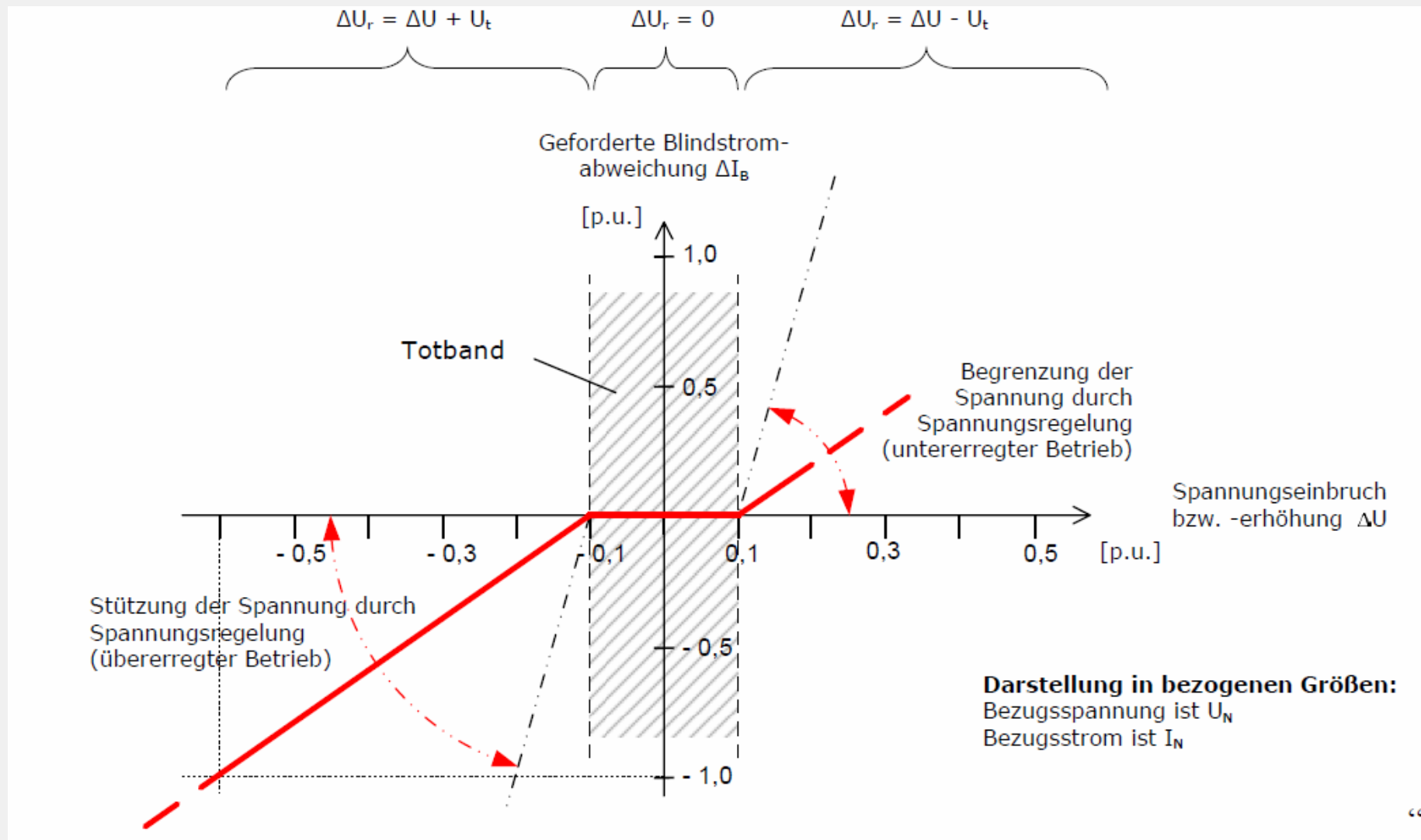
Behaviour subsequent to network faults/voltage recovery **gtz**



- Reactive power contribution during voltage recovery must be defined (e.g. no absorbing reactive power)
- Very important:
Availability of pre-fault active power after voltage recovery must clearly be defined. A wind generator that remains connected is useless if it doesn't produce active power during and after voltage recovery



Reactive Current Support



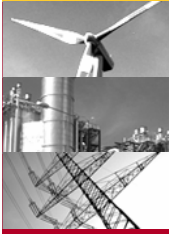
Secondary Equipment

- Definition of protection requirements
- Process information, SCADA support, monitoring requirements
- Metering



Validation of Equipment Characteristics

- Tests for validating wind farm characteristics are required.
- Possible requirements:
 - Site tests: Tests of the entire wind-farm -> *difficult in case of short-circuit tests*
 - Individual wind generator tests
 - Type tests -> *assumption that all generators of the same type behave the same way. Less time consuming than testing of individual generators.*



Validation of Equipment Characteristics – Proposed Procedure



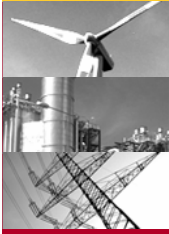
- Type Tests for validating turbine designs against technical Grid Code requirements (e.g. FRT)
- Model development and model validation of wind turbines and other dynamic devices (e.g. reactive power compensation) using results of type tests.
- Validate grid code requirements of the entire wind farm by modelling and simulating the wind farm using certified dynamic models.



International Practice

Comparison of:

- TC2007/SDLV (Germany)
- The Grid Code (NGT/U.K.)
- Requerimientos para Interconexion e Aerogeneradores al Sistema Electrico Mexicano (CFE/Mexico)



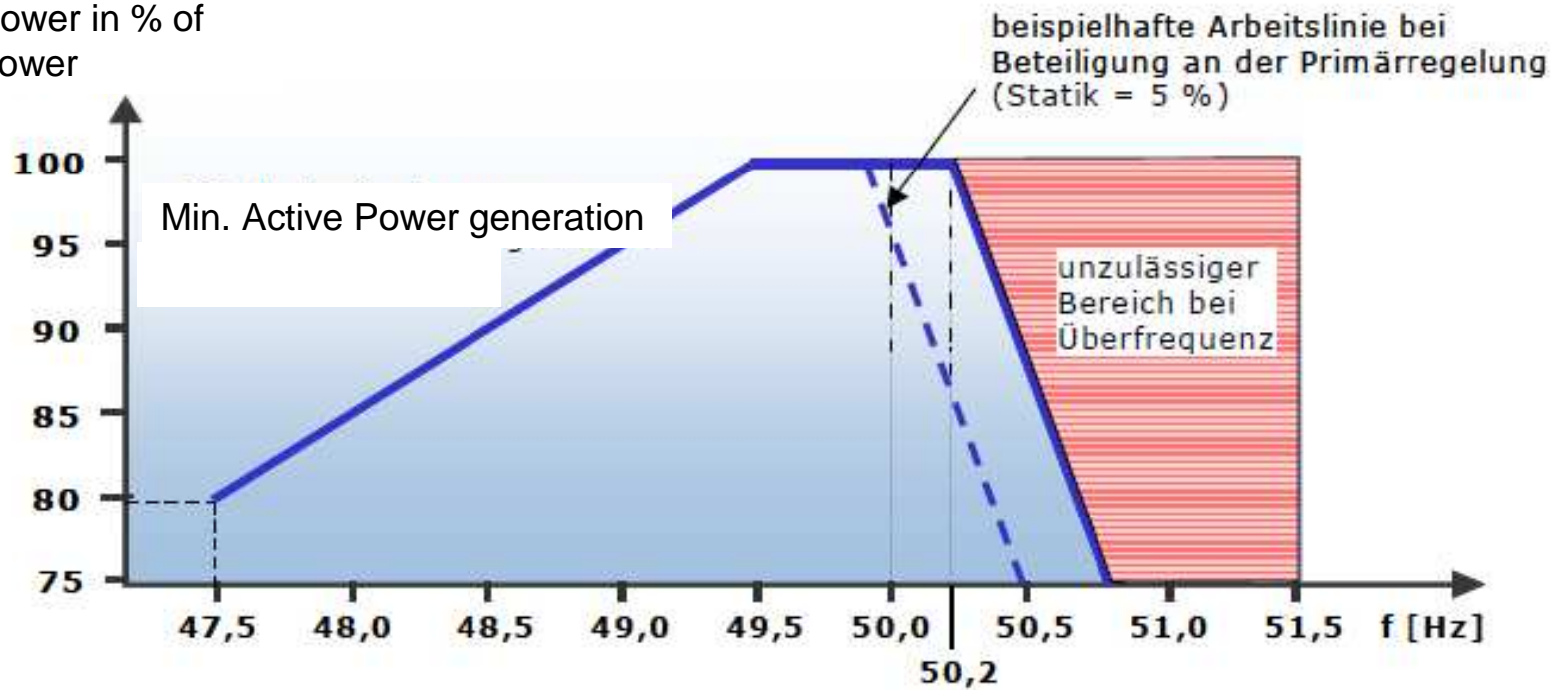
Frequency Range of Operation

- TC2007/SDLV (Germany):
 $47,5\text{Hz} < f < 51,5\text{Hz}$
- The Grid Code (NGT/U.K.):
 $47,5\text{Hz} < f < 52\text{Hz}$ (continuously)
 $47,0\text{Hz} < f < 52\text{Hz}$ (for up to 20s)
- Codigo red (CFE/Mexico):
 $57,5\text{Hz} < f < 62\text{ Hz}$ (continuously)



Active Power vs. Frequency, TC2007/SDLV (Germany)

Active Power in % of Rated Power

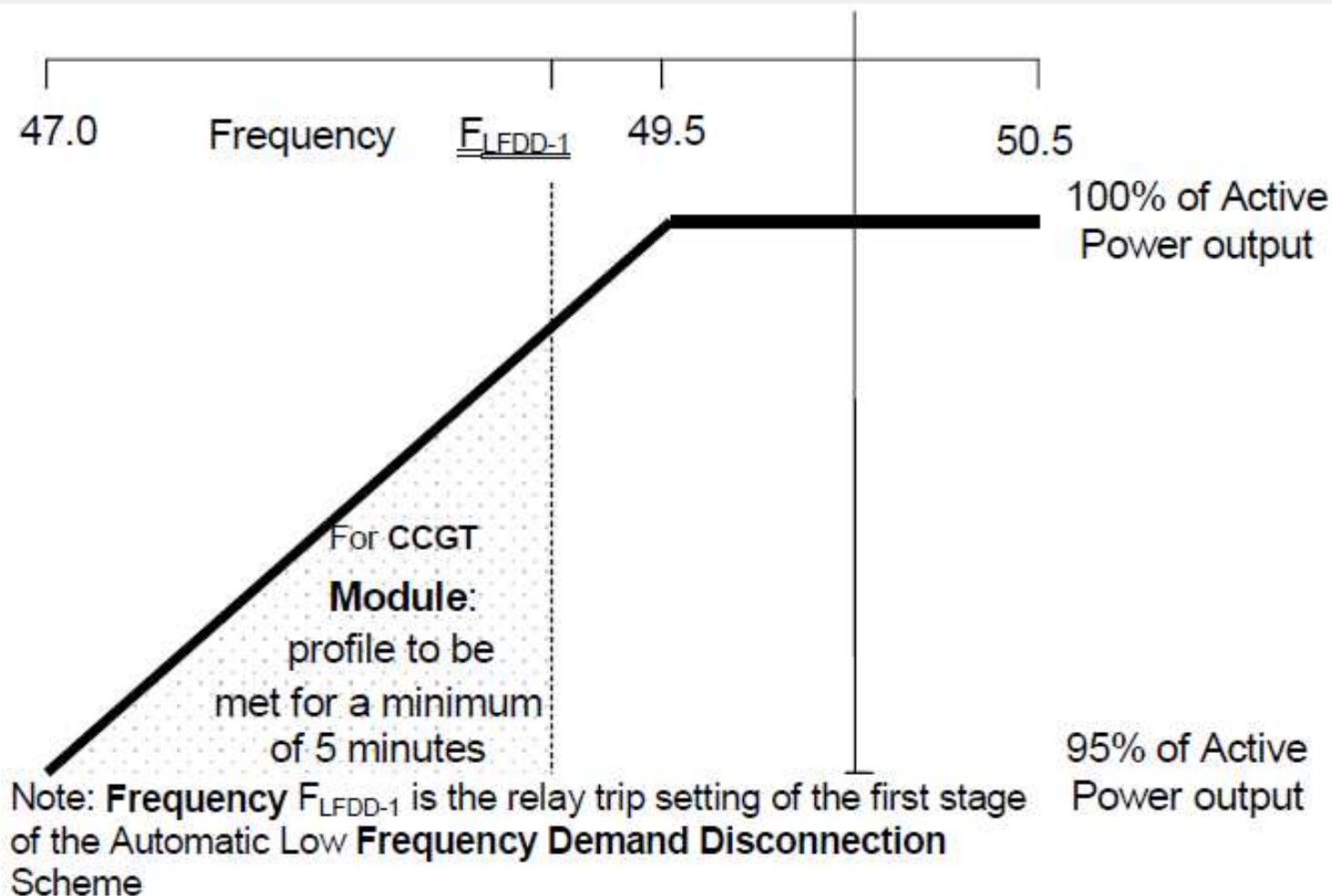




Active Power vs. Frequency, The Grid Code (NGT/U.K.)

gtz

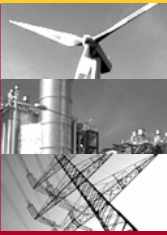
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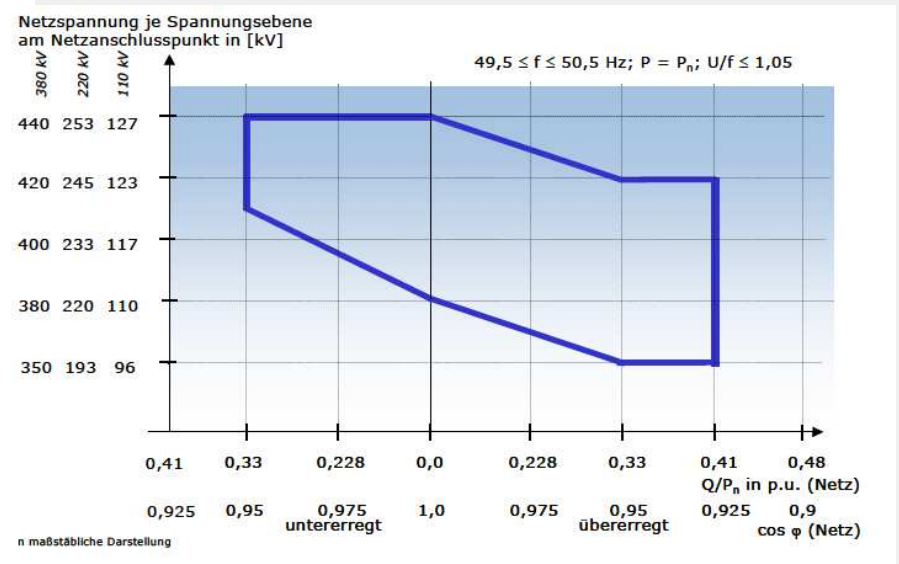
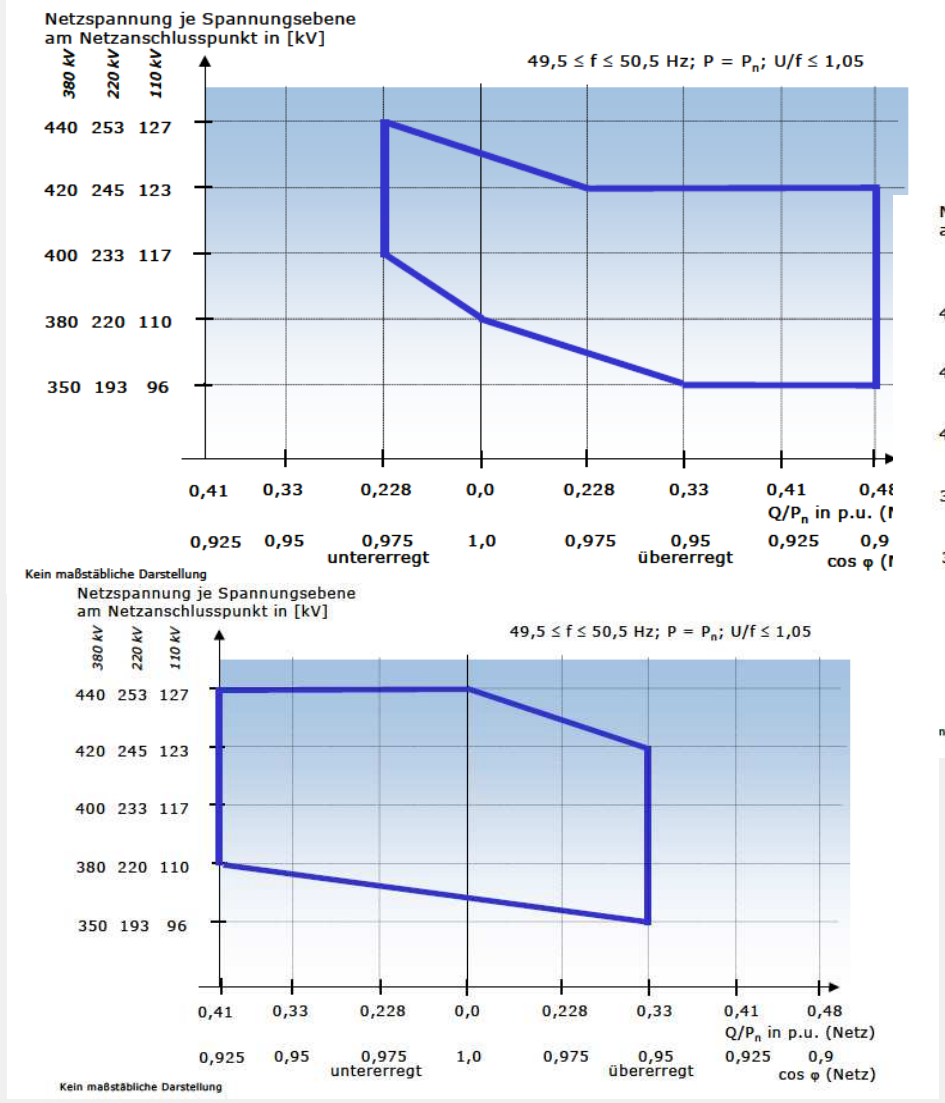


Voltage Range of Operation

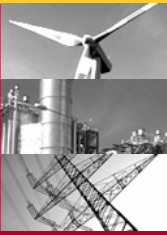
- TC2007/SDLV (380kV, Germany):
 - 5,3% < du < 10,5% (continuously)
 - 10,5% < du < 15,7% (up to 30 minutes)
 - 7,9% < du < -5,3% (up to 2 hours)
- The Grid Code (NGT/U.K.):
 - 10% < du < 10%
- Codigo red (CFE/Mexico):
 - 5% < du < 5% (normal)
 - 10% < du < 10% (emergency)



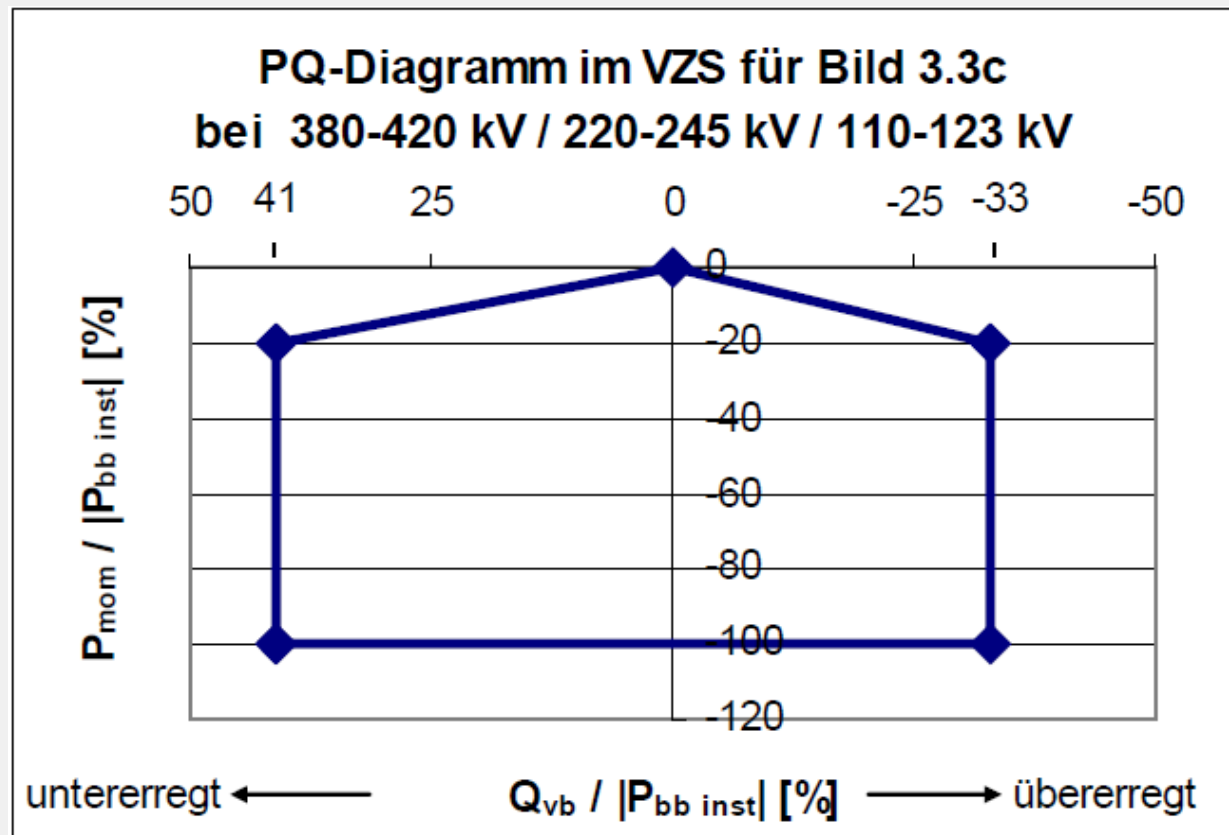
Reactive Power Range, TC2007/SDLV (Germany)



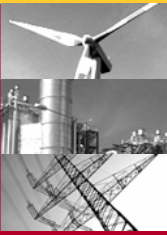
Full Load



Reactive Power Range, TC2007/SDLV (Germany)

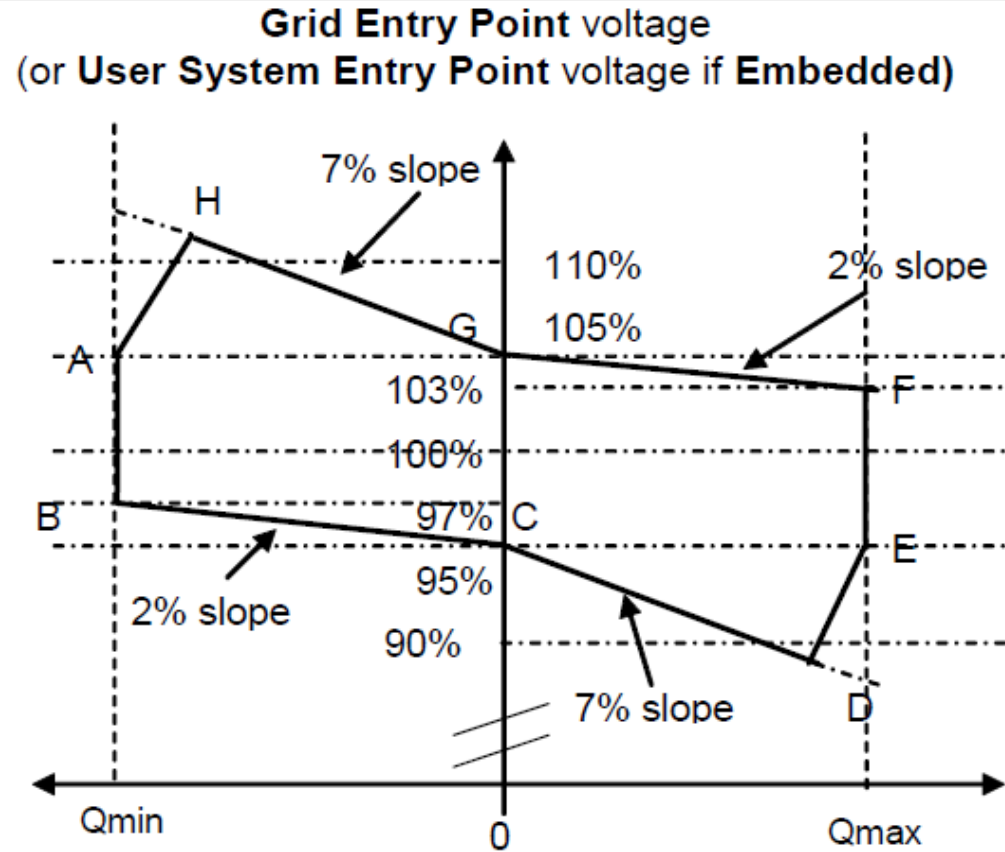


Partial Load (Variant 3)



Reactive Power Range, The Grid Code (NGT/U.K.)

Full Load



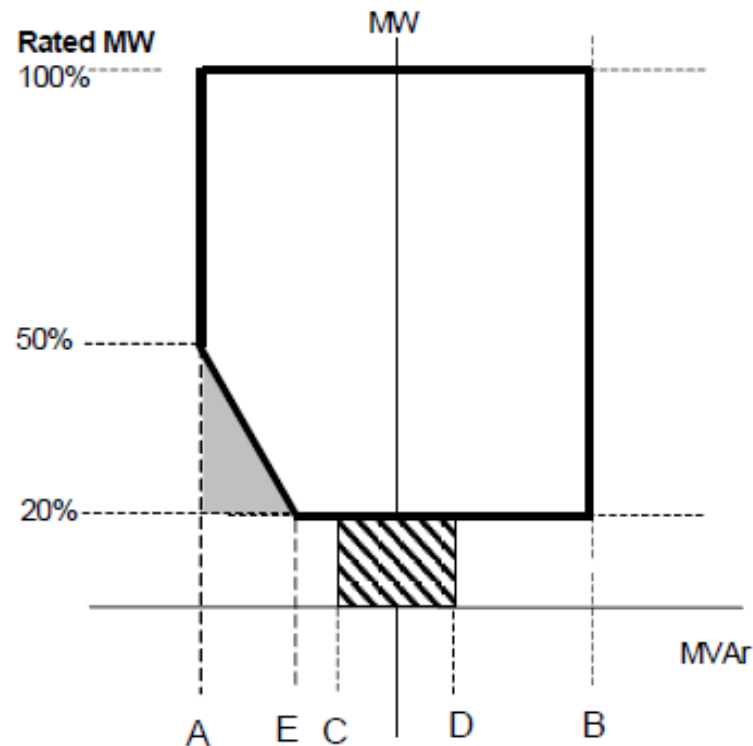
Reactive capability corresponding to 0.95 leading Power Factor at Rated MW

Reactive capability corresponding to 0.95 lagging Power Factor at Rated MW



Reactive Power Range, The Grid Code (NGT/U.K.)

Partial Load

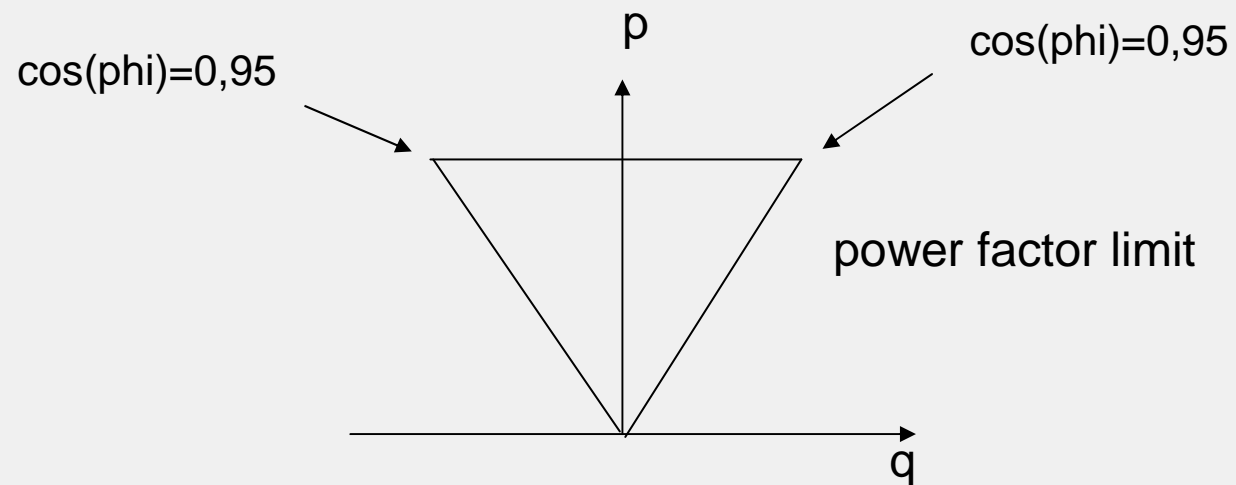


- Point A is equivalent (in MVar) to: 0.95 leading **Power Factor** at **Rated MW** output
- Point B is equivalent (in MVar) to: 0.95 lagging **Power Factor** at **Rated MW** output
- Point C is equivalent (in MVar) to: -5% of **Rated MW** output
- Point D is equivalent (in MVar) to: +5% of **Rated MW** output
- Point E is equivalent (in MVar) to: -12% of **Rated MW** output



Reactive Power Range, Partial Load, Codgo red (CFE/Mexico)

- Power factory range 0,95 (capacitive/inductive)





Reactive Power: Dynamic Requirements

TC2007/SDLV (Germany):

- Slow reactive power control (within minutes) is sufficient.

The Grid Code (NGT/U.K.):

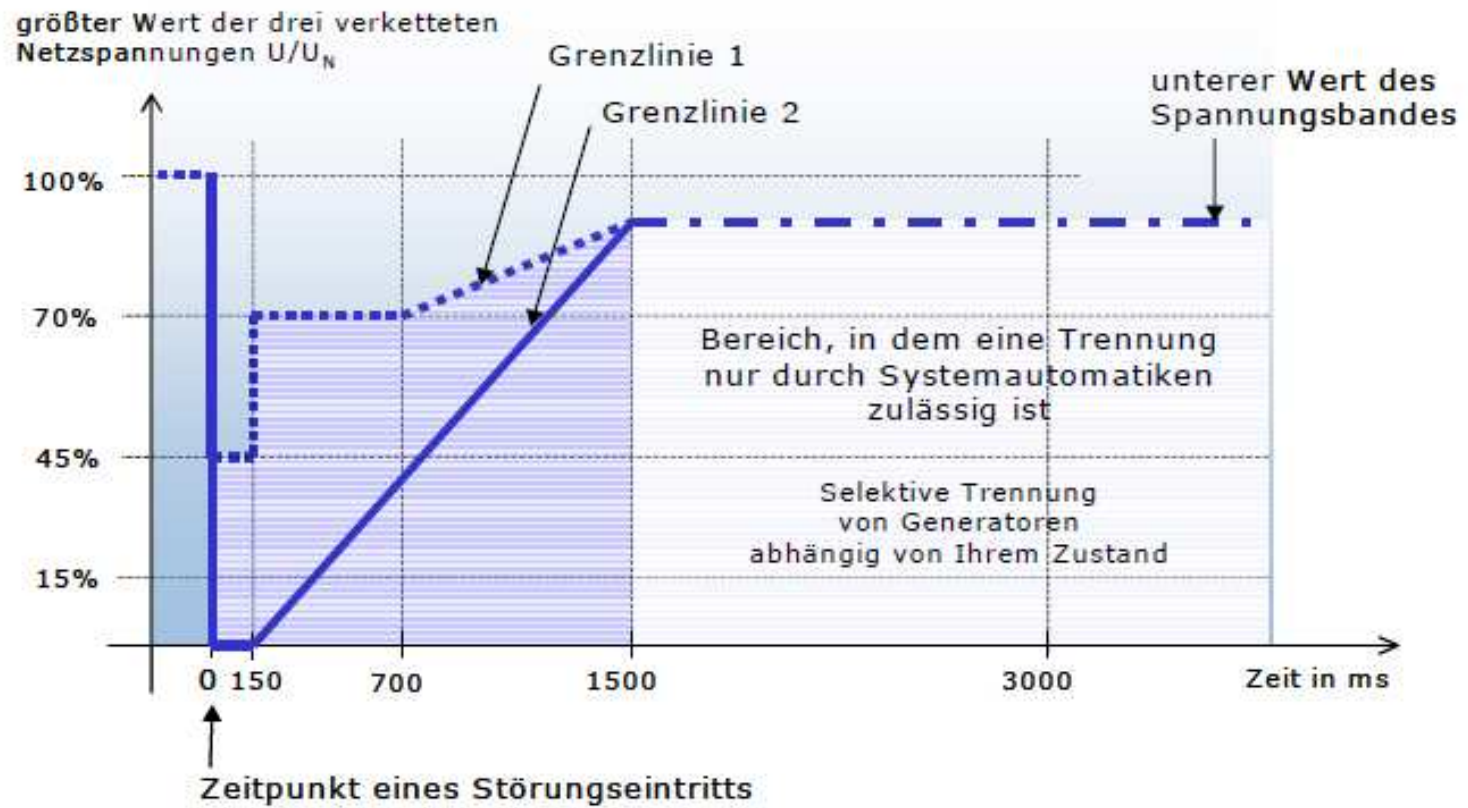
- Fast reactive power control with droop characteristic at the grid connection point required (90% within 1 s).

Codigo red (CFE/Mexico):

- No specific requirement

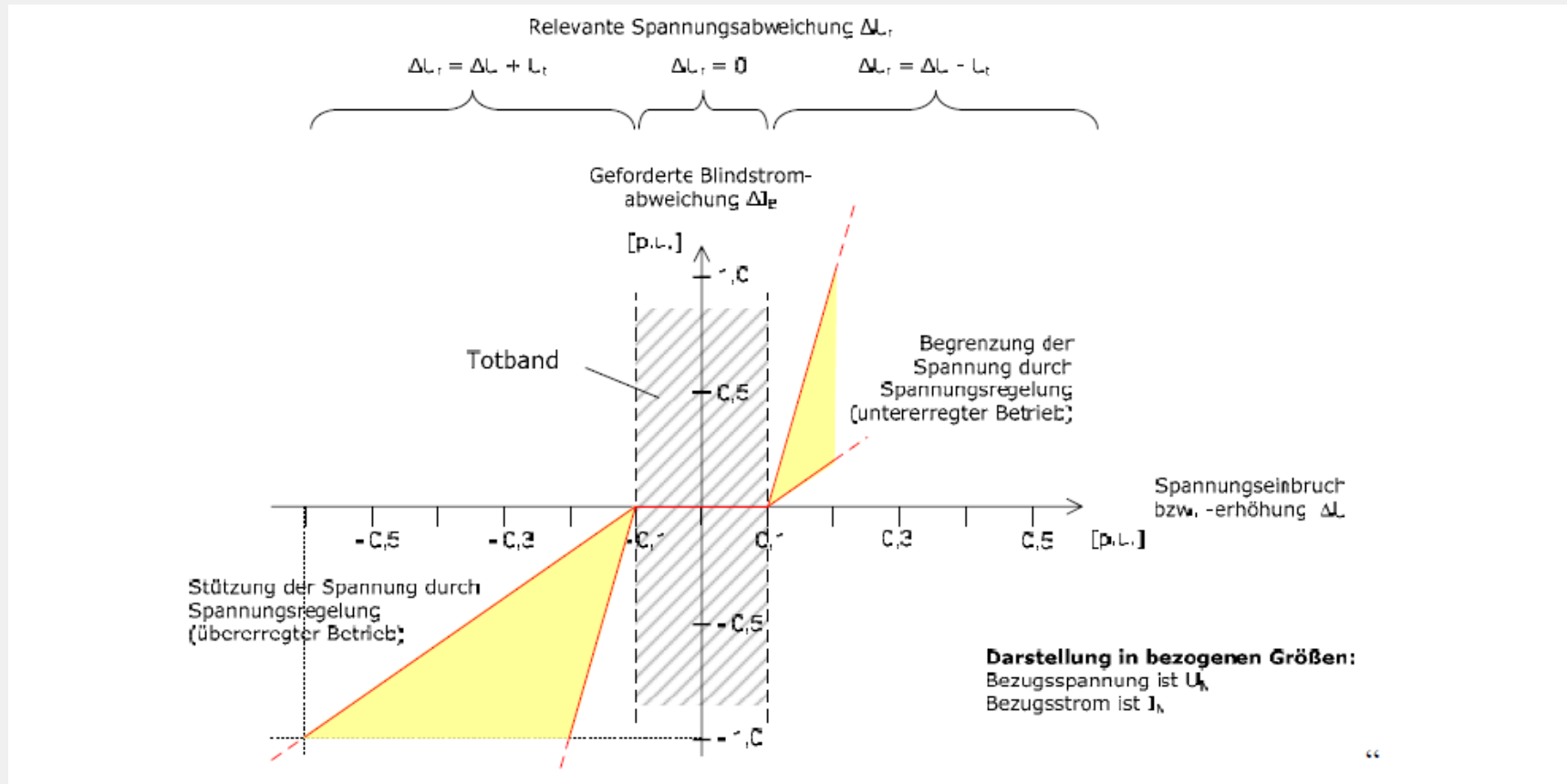


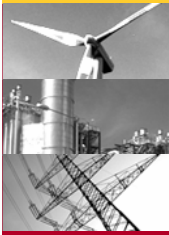
FRT – TC2007/SDLV (Germany)



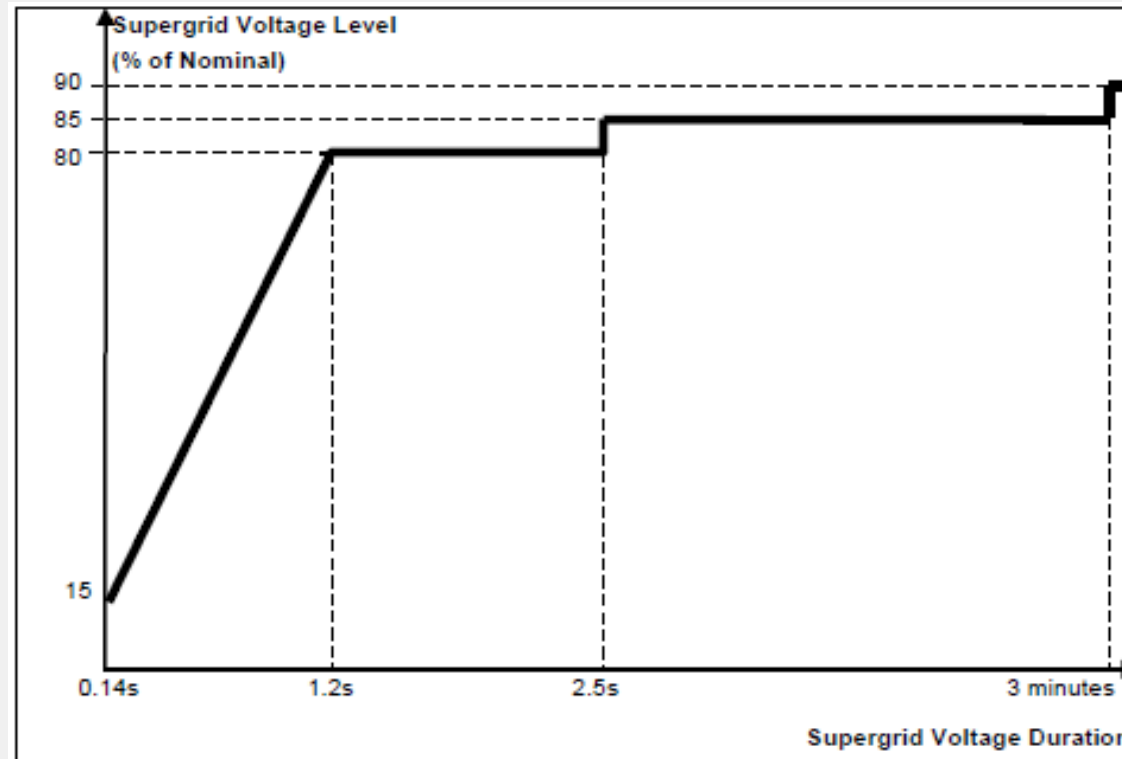


FRT – Reactive Current Support – TC2007/SDLV (Germany)





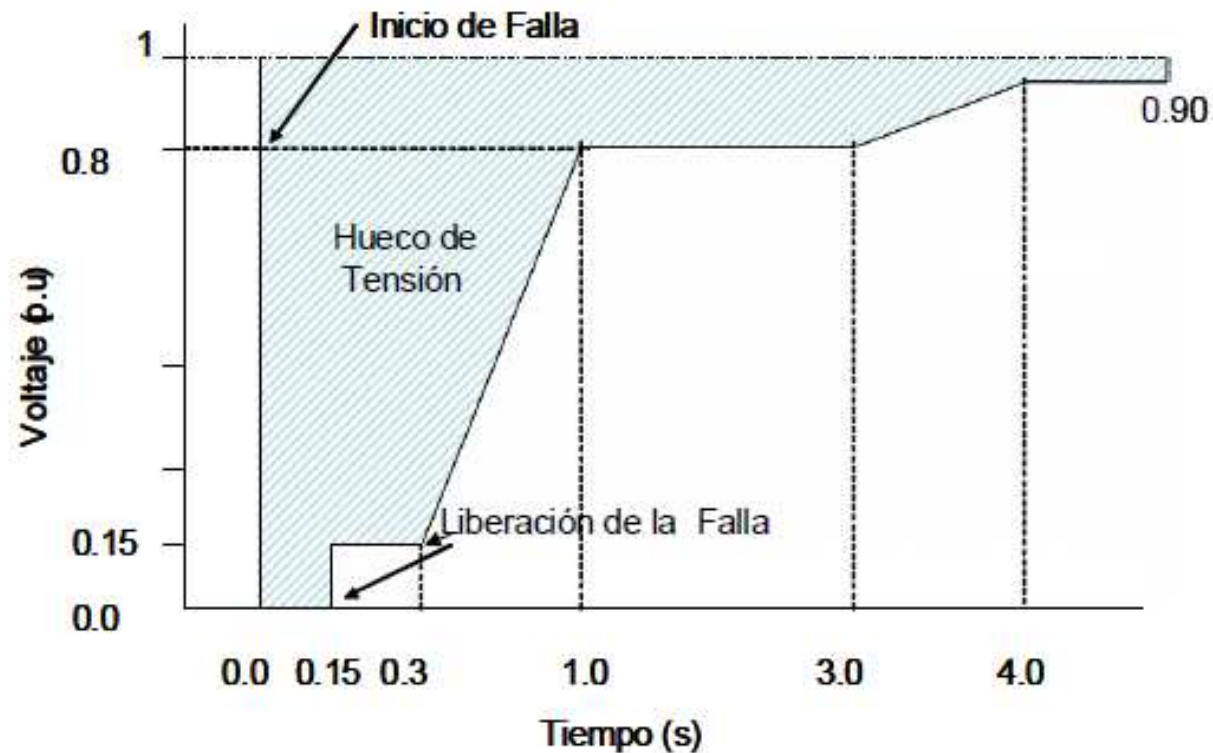
FRT– The Grid Code (NGT/U.K.)



No reactive current support required



FRT, Código red (CFE/México)



No reactive current support required

Frequency Control

- TC2007/SDLV (Germany):
 - No contribution to primary control.
 - Only active power reduction in case of high frequencies ($df > 200\text{mHz}$)
- The Grid Code (NGT/U.K.):
 - Full frequency control capability required, likewise conventional power plants
- Codigo Red (CFE/Mexico):
 - No requirement



Thank You



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