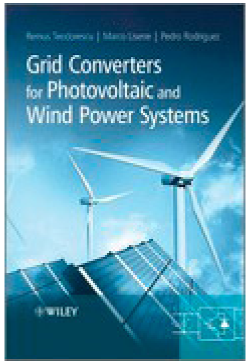

Grid Converters for Photovoltaic and Wind Power Systems

by R. Teodorescu, M. Liserre and P. Rodriguez

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Chapter 7

Grid Requirements for WT Systems

Outline

- Introduction
- Grid Codes for Wind Turbines
  - Grid Code Basics
  - Time Line of Grid Code Developments
  - Recent Grid Codes
  - Grid Code Requirements
- Active Power Control
- Reactive Power Control
- Frequency Control
- Steady-State Operating Range
- Fault Ride-Through Capability
- Future Trends
- Conclusion

Introduction

- Conventional power plants provide
  - Inertia response
  - Synchronizing power
  - Oscillation damping
  - Short-circuit capability
  - Voltage backup during faults

- However, wind turbine technology differs from conventional power plants regarding the converter-based grid interface and asynchronous operation

- Increasing wind power penetration leads Transmission System Operators (TSO) to revise their grid codes

Grid Codes for Wind Turbines

- Grid Code Basics

  Grid Code: set of codes, rules and laws which define the technical requirements for parties connected to public electricity systems, i.e. consumers, generators and other network operators. (EWEA Working Group)

  Grid Code Types:

  - System grid code
  - Planning grid code
  - Operation grid code
  - Connection grid code

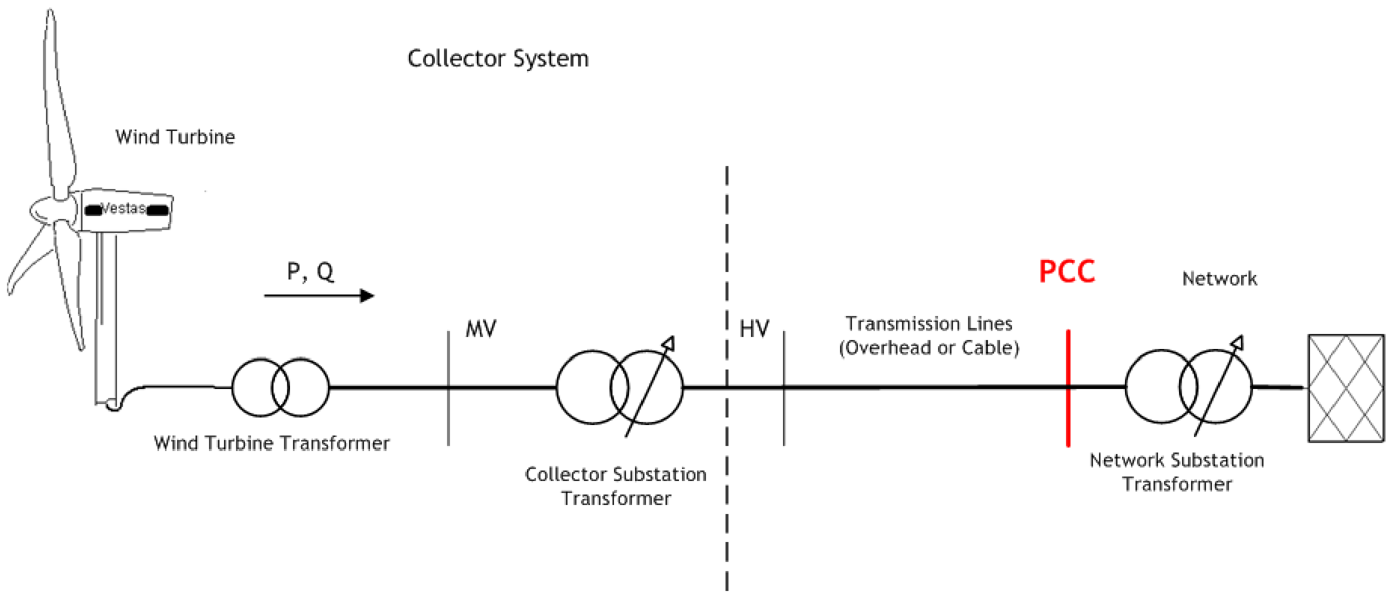
Integration of Wind Power

Grid Codes for Wind Turbines

- Grid Code Basics

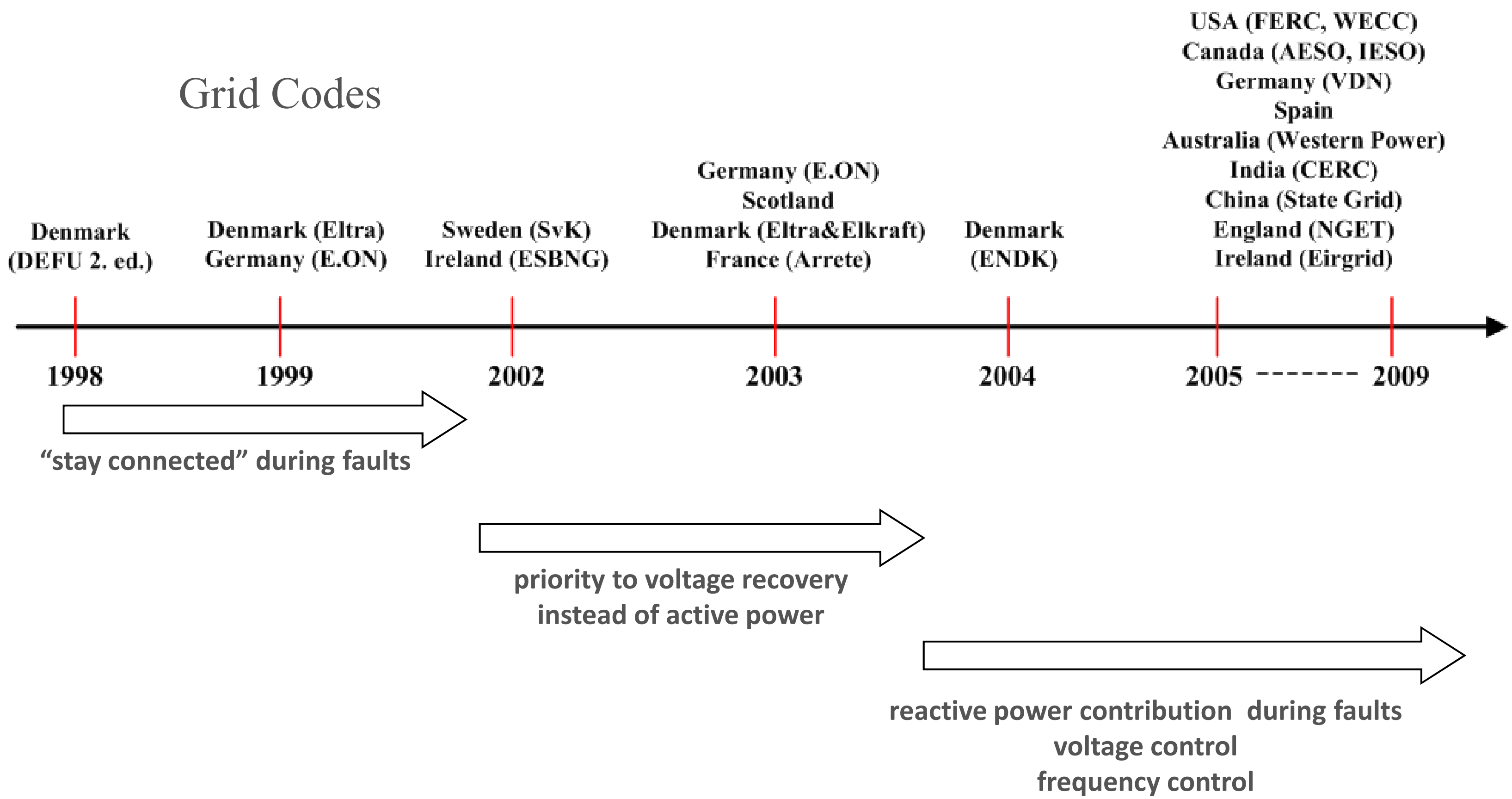
Purpose: to maintain stable, secure and reliable power system operation thus sustain power to the consumers from the generators.

Grid codes are commonly specified for the connection point or point of common connection (PCC) for the generators.



Grid Codes for Wind Turbines

- Timeline of Grid Code Developments (for wind power)



Grid Codes for Wind Turbines

- Recent Grid Codes

Country	Grid Code Official Name	Release Date
Denmark	Wind turbines connected to the grids with voltages above/below 100kV (Elkraft, Eltra)	2004
Germany	Grid Code, High and extra high voltage (E.ON)	2006
	VDN Transmission Code	2007
Spain	P.O.12.3 – Response requirements against voltage dips in wind installations (Red Electrica)	2006
	Annex of O.P. 12.2 Restricted to the technical requirements of wind power and photovoltaic facilities	2008
UK	The Grid Code, Issue 4 (NGET)	2009
Ireland	Grid Code, Ver.3.1 3 (EIRGRID)	2008
US	Order 661 - Interconnection with Wind Energy, issued by Federal Energy Regulatory Commission (FERC) of United States	2005
	WECC-0060 - PRC-024-WECC-1-CR (WECC)	2009
China	Revised national grid code (draft), report no. WED-QR-C01-E-06 (CEPRI)	2009
Canada	Wind Power Facility – Technical Requirements (AESO)	2004
Australia	National Electricity Amendment Rule 2007 No. 2 (NEEMCO)	2007

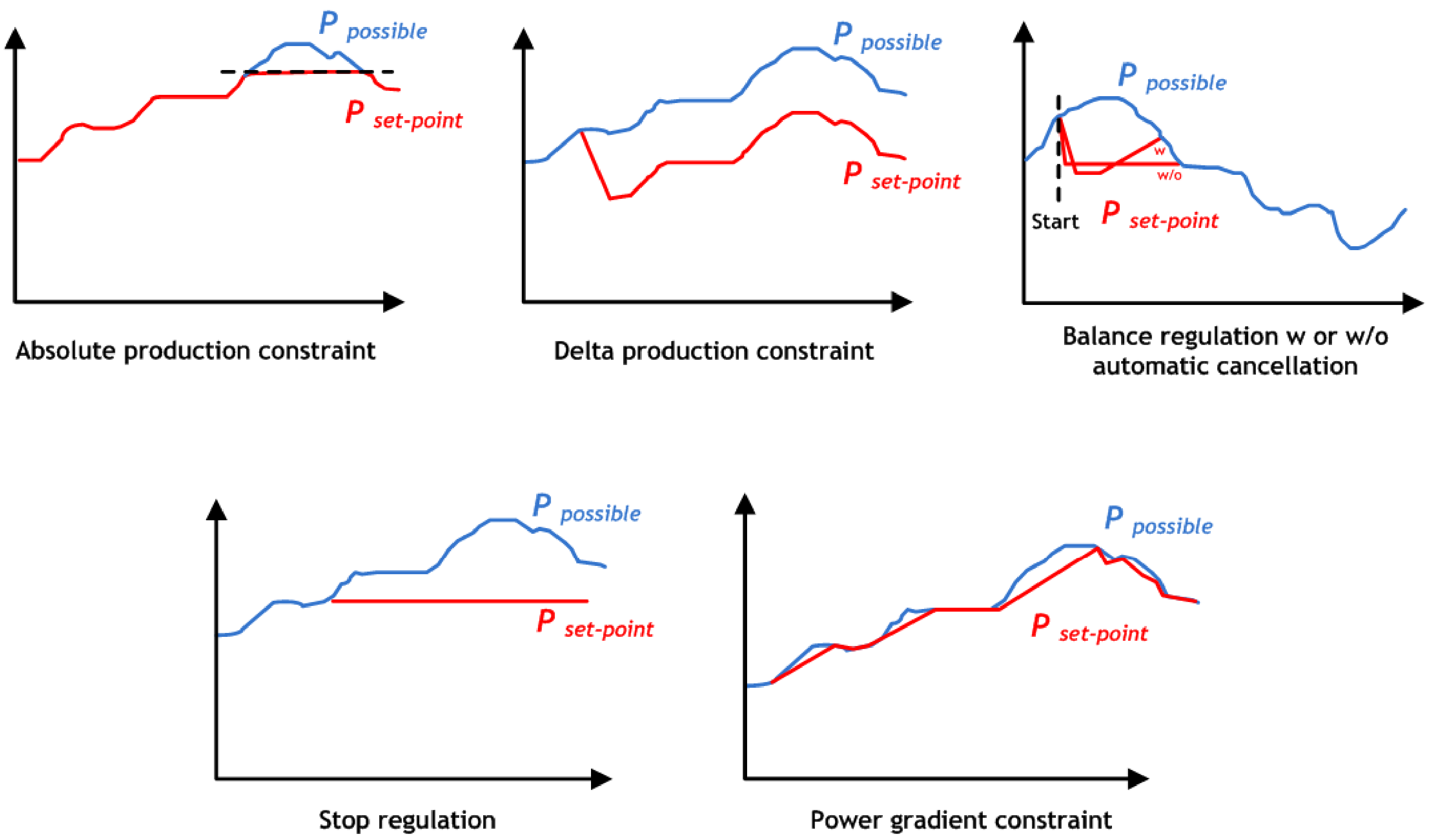
Grid Codes for Wind Turbines

- Grid Code Requirements
  - Active Power Control
    - Active power regulation functions
    - Active power ramp up/down control
    - Active power curtailment
  - Reactive Power Control
    - Reactive power, voltage , and power factor regulation
  - Frequency Control
    - Primary frequency control
    - Secondary frequency control
  - Steady-State Operating Range
    - Nominal frequency and voltage operating limits
  - Fault Ride-Through Capability
    - High and low voltage ride-through
    - Reactive current feed-in

Active Power Control

- The ability of wind farms to regulate the active power output to a value defined by the power system operator
  - Power system operator → active power set point
  - Active power regulation functions (Denmark)
  - Increasing or decreasing of the active output (ramp up/down rates)
  - Active power curtailment during fault
  - Any disconnection demand from the power system operator

Active Power Regulation Functions

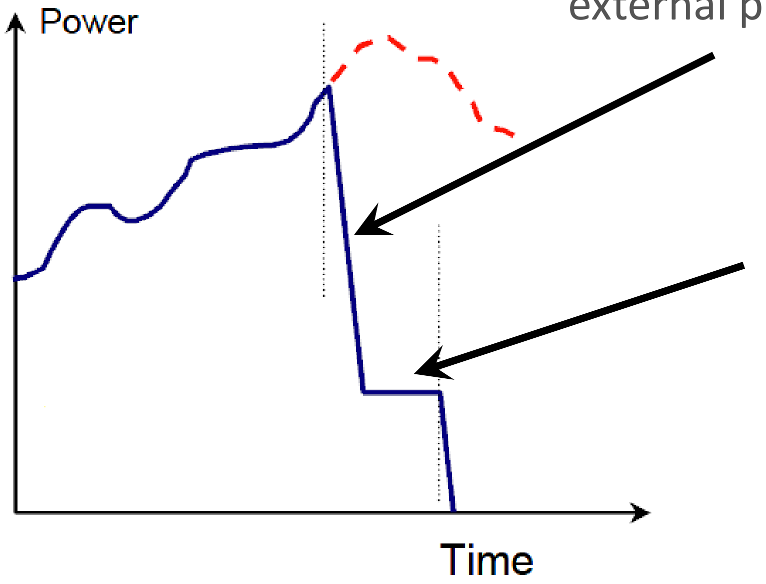


Danish grid code

Active Power Ramp Rates

Country	Active Power Ramp Rate Range		
Denmark	10 – 100% of the rated power per min.		
Germany	At least 10% of grid connection capacity per min.		
Norway	Max. required value 20% of the rated power per min.		
Ireland	over 1 min.: 1–30 MW per min. (activation time less than 10 sec.)	over 10 min.: 1–30 MW per min. (activation time less than 10 sec.)	
China	Inst. capacity <30 MW	Inst. capacity 30-150 MW	Inst. capacity >150 MW
	over 1 min. Max. ramp: 6 MW	over 1 min. Max. ramp: Inst. Cap. / 5	over 1 min. Max. ramp: 30 MW
	over 10 min. Max. ramp: 20 MW	over 10 min. Max. ramp: Inst. Cap./1.5	over 10 min. Max. ramp: 100 MW

Active Power Curtailment



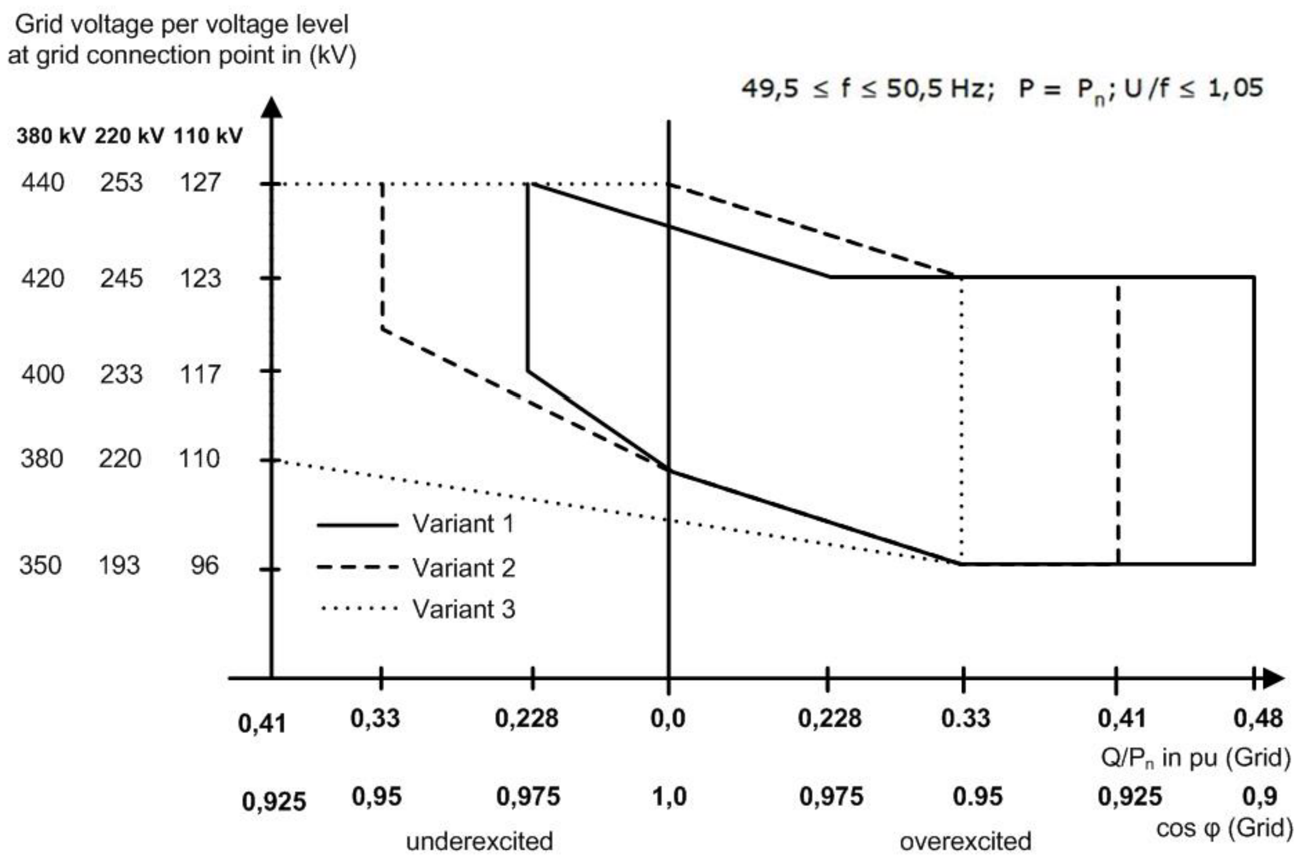
Danish grid code

full load → stop in 30 sec.

Reactive Power Control

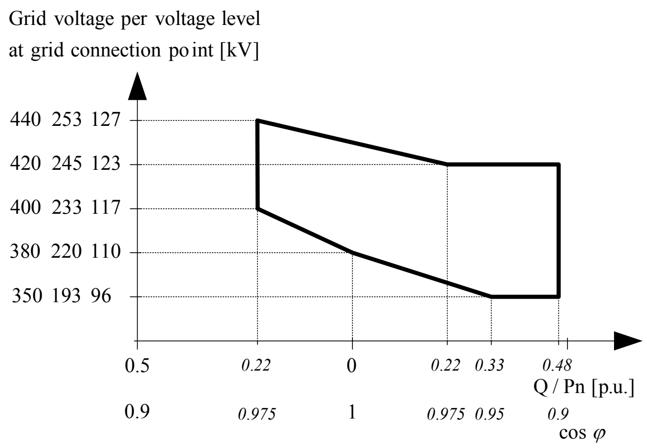
- In steady-state operation, reactive power control is generally reactive power regulation in response to the PCC voltage variations
- Performance of the reactive power control related to
  - Short-circuit power (impedance) of the PCC
  - R/X ratio of the short circuit impedance
  - Reactive power compensation equipments nearby
- Types of the reactive power control
  - Reactive power control
  - Power factor control
  - Voltage control

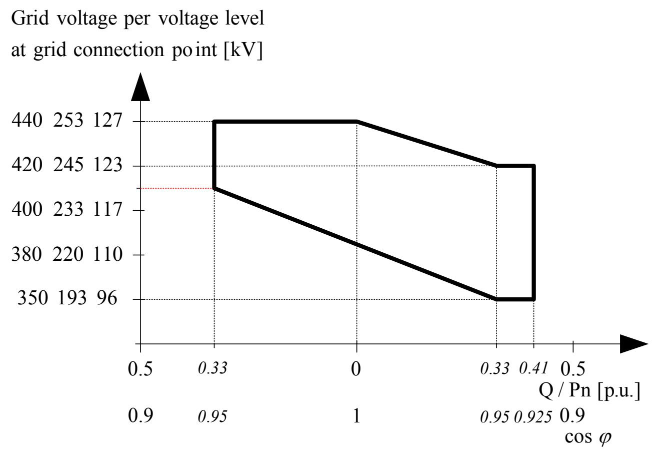
Reactive Power Control (Germany)

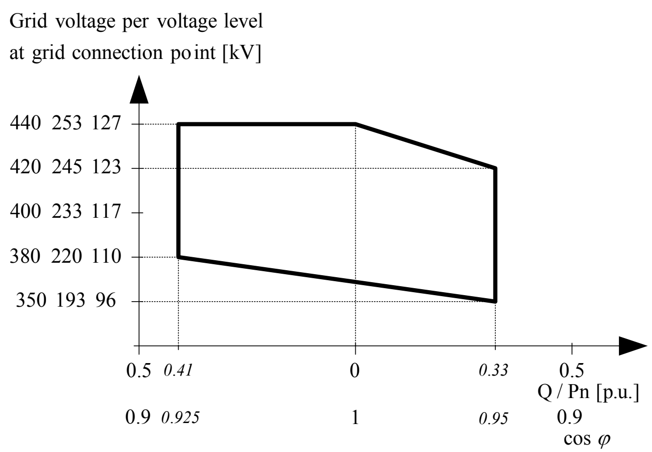


Reactive power depending on voltage
(Q control) at rated active power

Reactive Power Control (Germany)

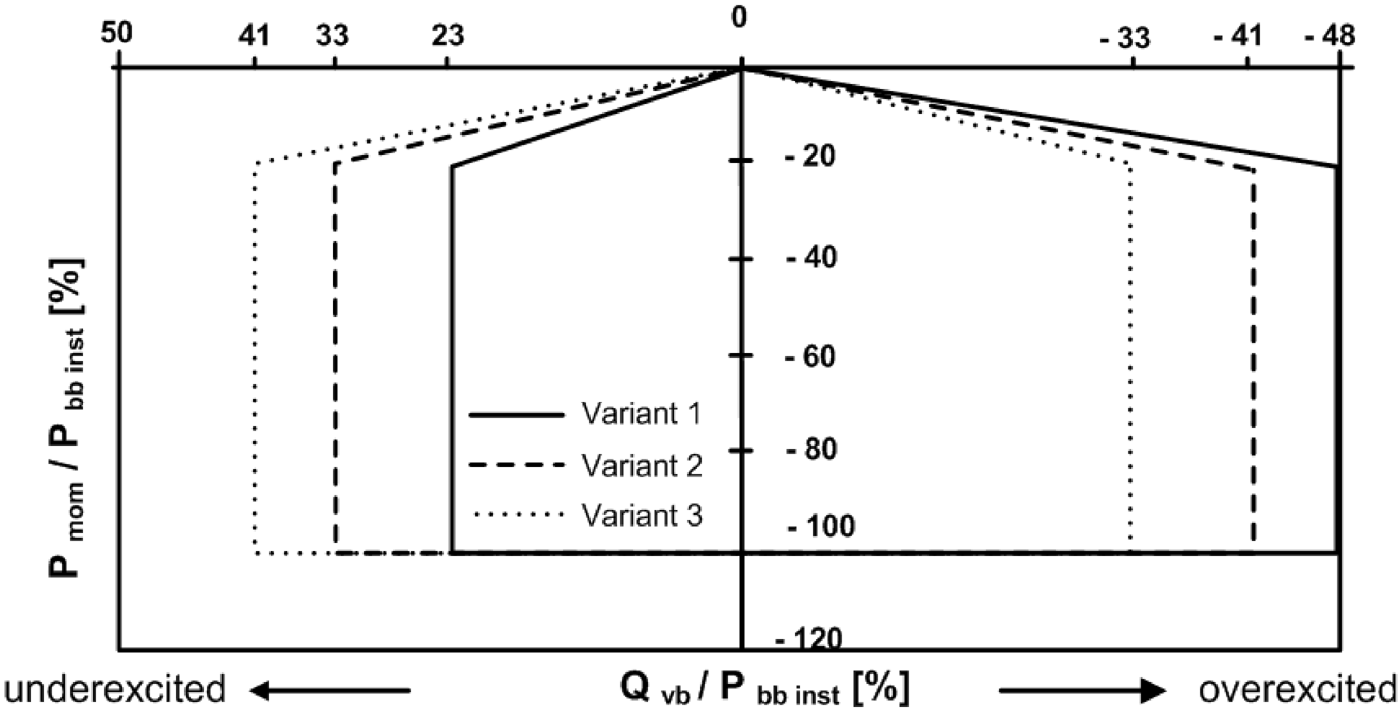






Reactive power depending on voltage
(Q control) at rated active power

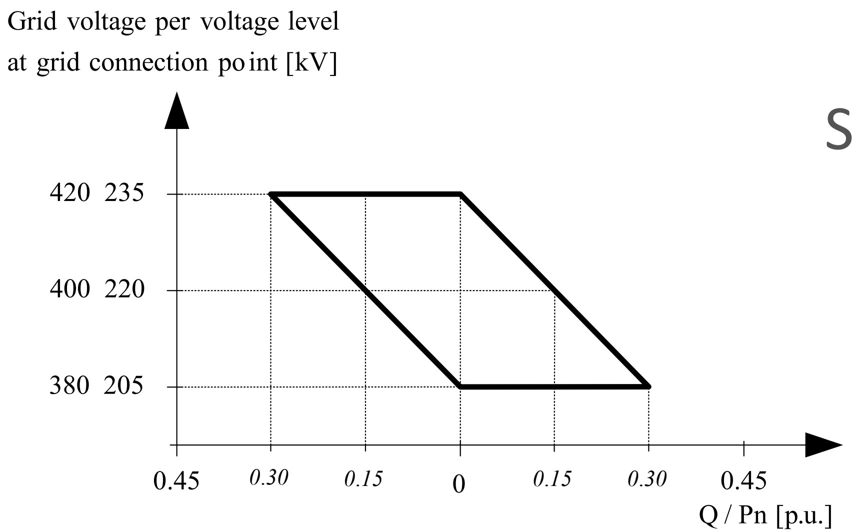
Reactive Power Control (Germany)



Reactive power depending on active power
(pf control) below rated active power

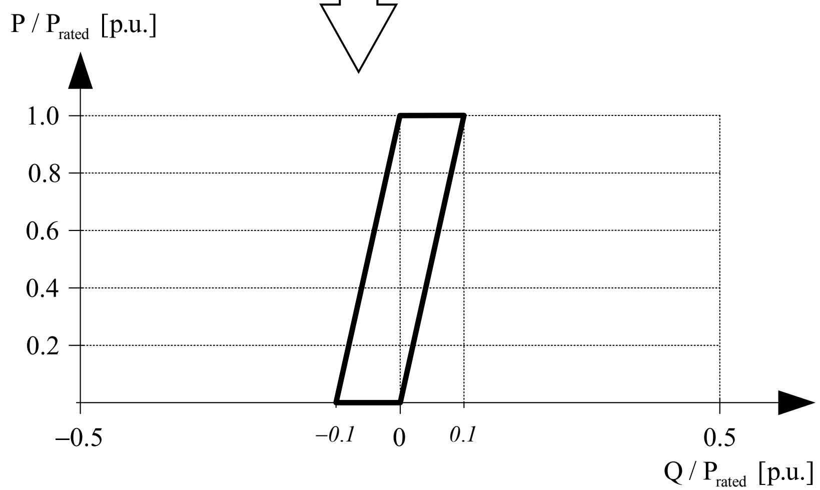
Reactive Power Control (Spain and Denmark)

Spain

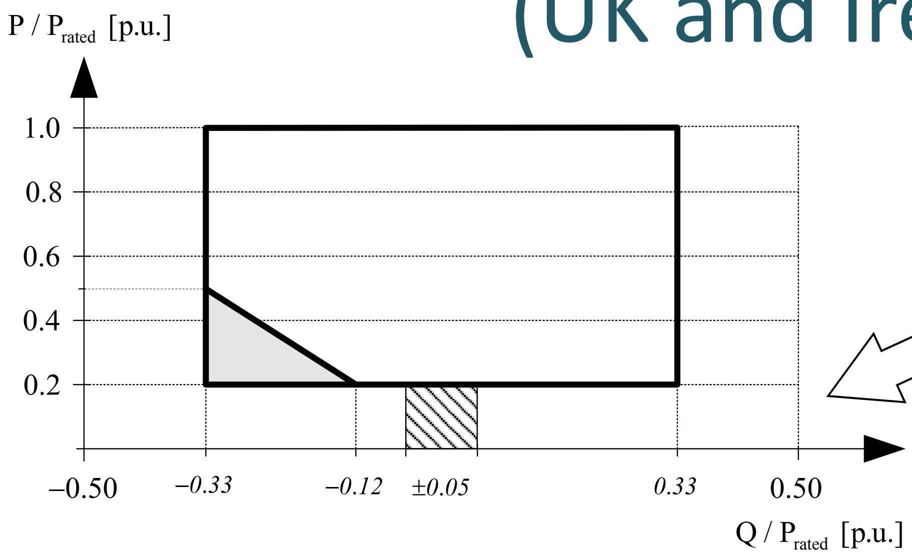


pf control

Denmark



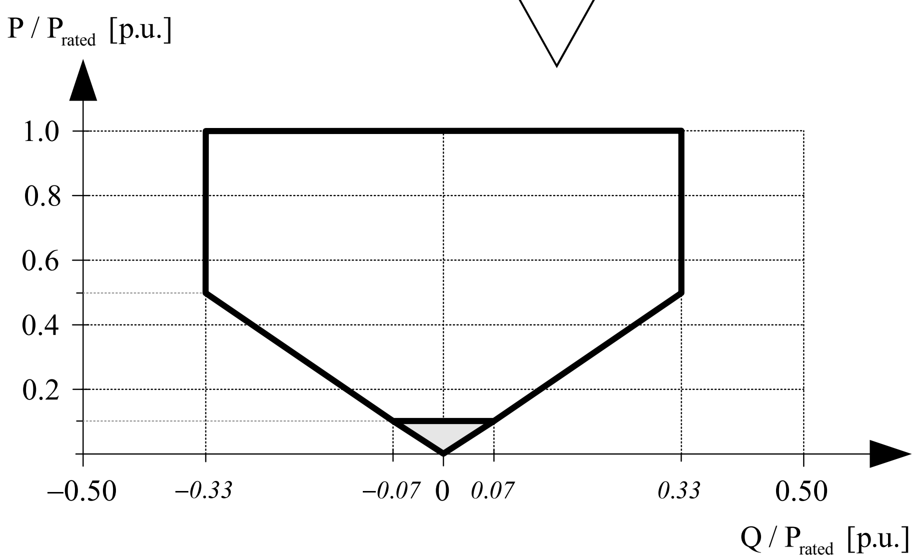
Reactive Power Control (UK and Ireland)



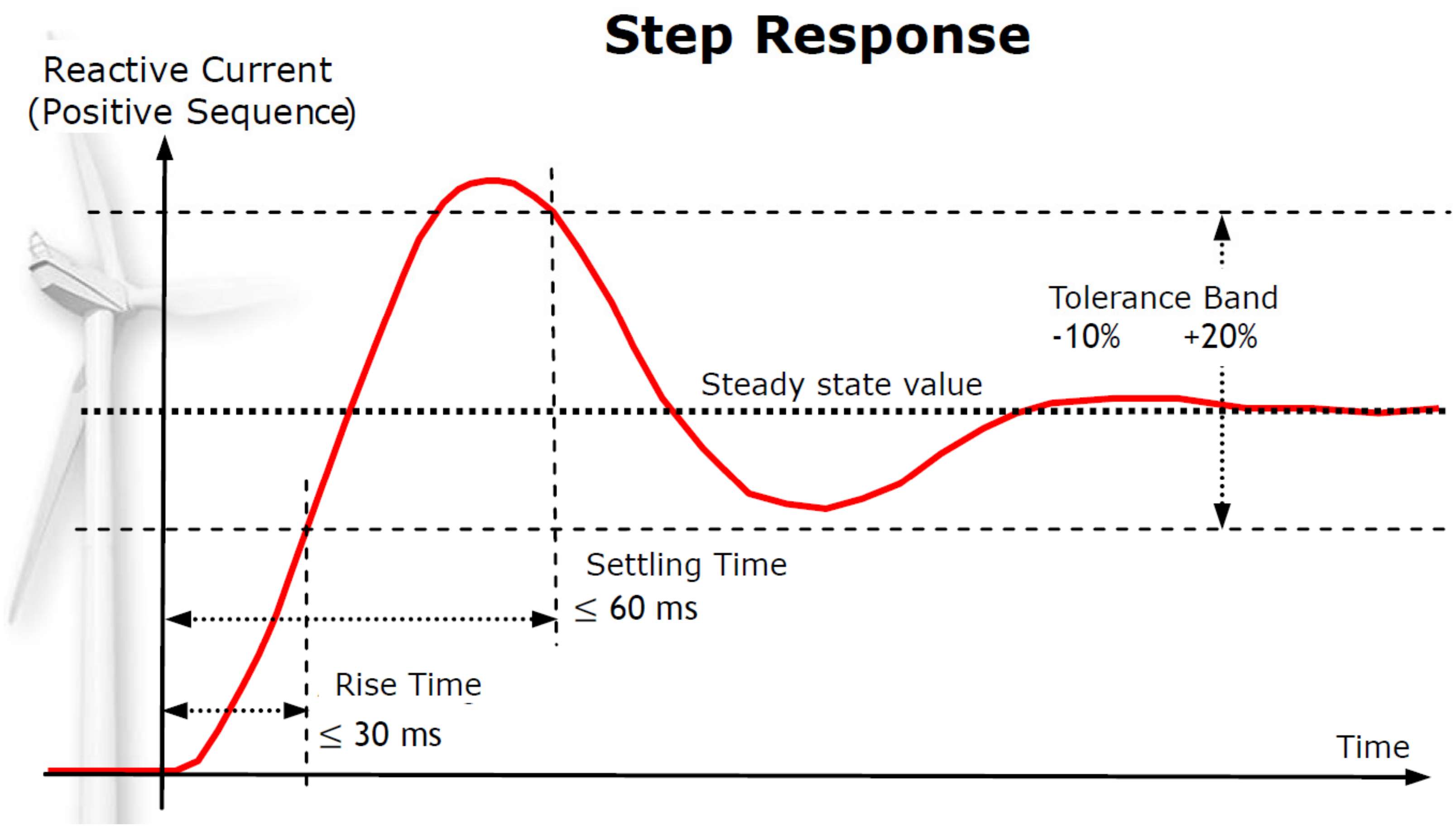
U.K.

pf control

Ireland



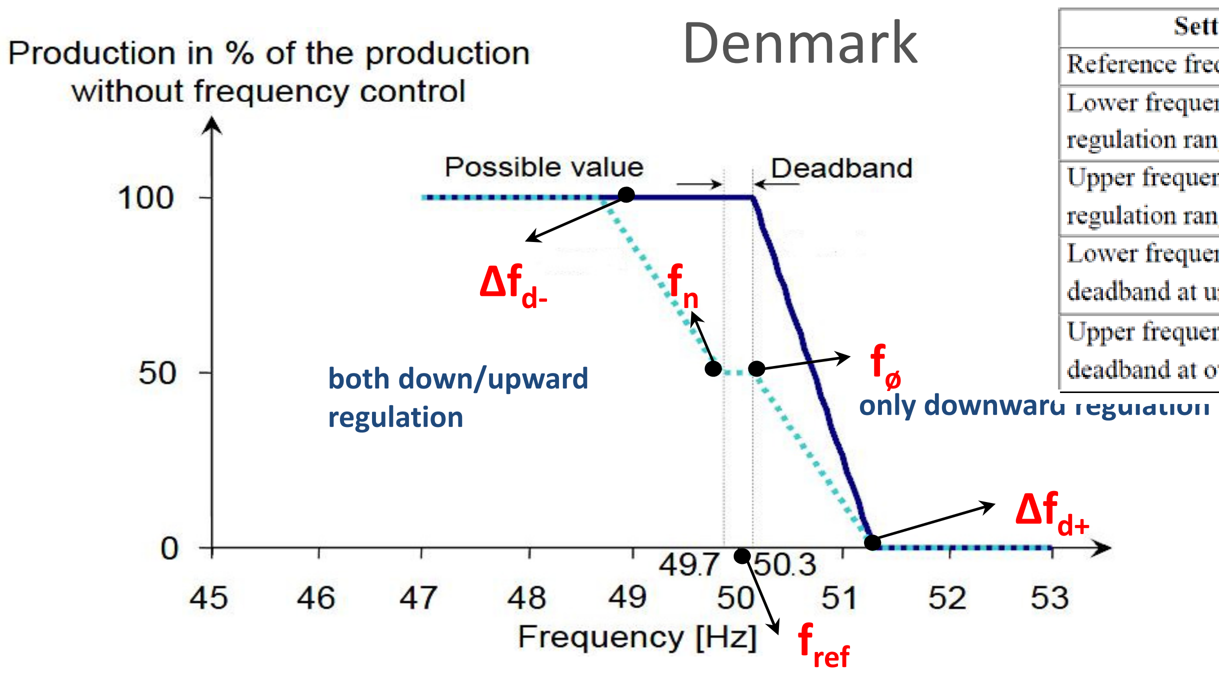
Reactive Power Control Dynamics (Germany)



Frequency Control

- Regulation of the active power with respect to the frequency deviations (load-generation imbalance) in the power system
- Types of the frequency control
  - Primary frequency control maintains a balance to be re-established at a system frequency other than the set-point value (50 or 60 Hz). (up to 30 sec.)
  - Secondary frequency control is to keep the power balance in each control area and, consequently, to restore the system frequency to its set point value of 50 Hz (or 60 Hz). (at least 15 min.)
- For the frequency control, wind farms need power reserve to provide frequency response (delta control or energy storage solutions)

Frequency Control

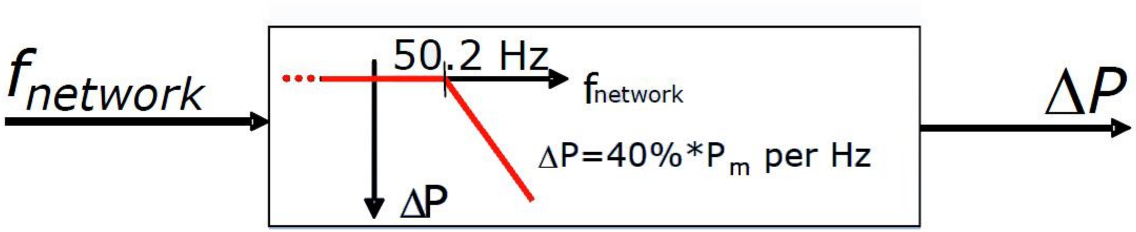


Setting parameter	Setting range
Reference frequency (f_{ref})	49.90…50.10 Hz
Lower frequency limit for the regulation range at underfrequency (f_n)	50.00…47.00 Hz
Upper frequency limit for the regulation range at over frequency ($f_ø$)	50.00…53.00 Hz
Lower frequency limit for the deadband at underfrequency (Δf_{d-})	0…500 mHz
Upper frequency limit for the deadband at overfrequency (Δf_{d+})	0…500 mHz

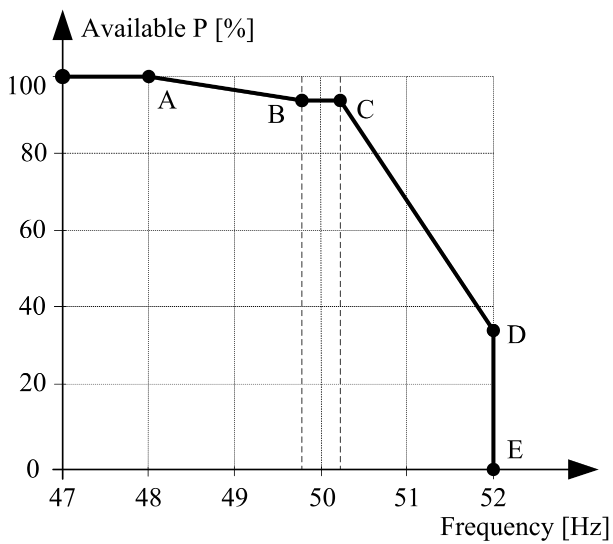
Regulation factor for the production applying to frequencies in the range f_n …(f_{ref} - Δf_{d-}) samt (f_{ref} + Δf_{d+}) … $f_ø$. (Regulation factor 1 means that the production is the maximum possible – or the set-point value if this is specified)	Overfrequency : $(1-\frac{f-(f_{ref}+\Delta f_{d+})}{f_ø-(f_{ref}+\Delta f_{d+})})\cdot 100\%$ Underfrequency : $(1+\frac{f-(f_{ref}-\Delta f_{d-})}{f_n-(f_{ref}-\Delta f_{d-})})\cdot 100\%$	
Regulation speed calculated from exceeding of a limit value to completed regulation	1...10 % of rated power per second	10 % of rated power per second

Frequency Control

Germany



Ireland

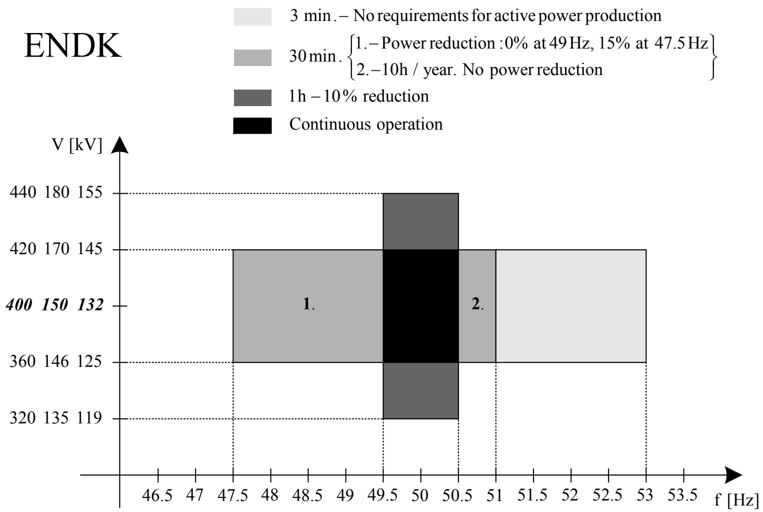


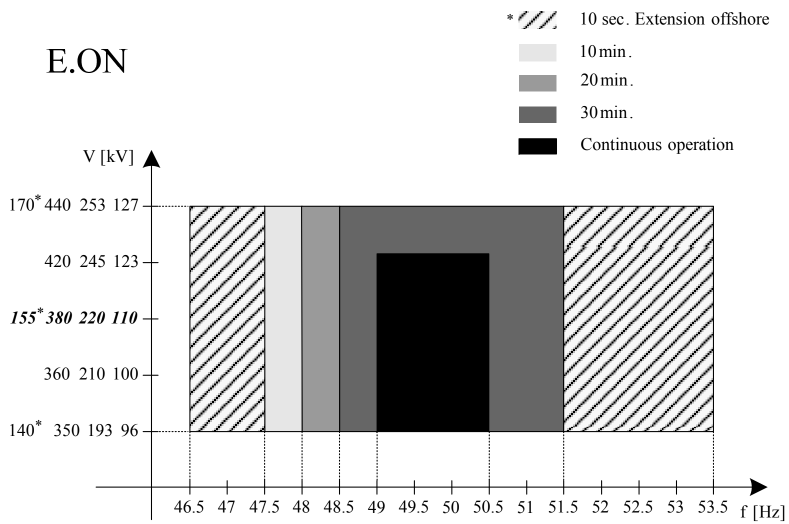
	Transmission System Frequency (Hz)		Available Active Power [%]
F_A	$47.0-51.0$	P_A	$50-100$
F_B	$49.5-51.0$	P_B	$50-100$
F_C	$49.5-51.0$	P_C	
F_D	$50.5-52.0$	P_D	$20-100$
F_E		P_E	0

Steady-State Operating Range

- According to grid codes, wind farms are required to operate within a range around the rated voltage and frequency at the PCC
- Typically this requirement can be described as the following frequency/voltage operation zones:
  - Continuous operation in a limited range below and above the nominal point
  - Time limited operation with possible reduced output in extended ranges
  - Immediate disconnection

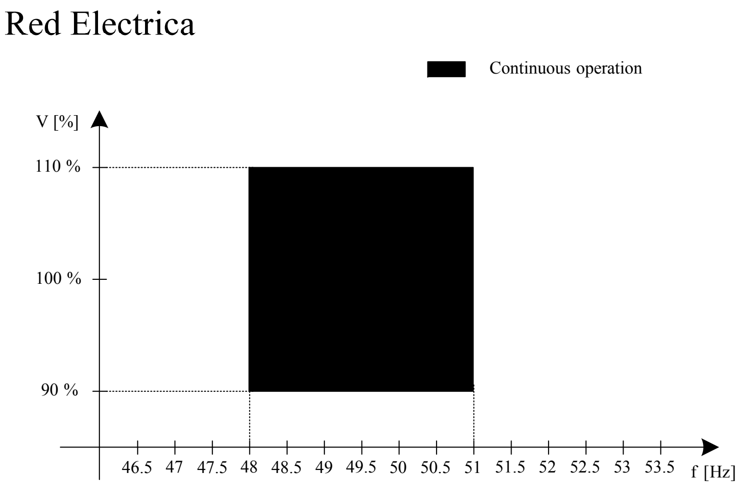
Steady-State Operating Range (Denmark and Germany)

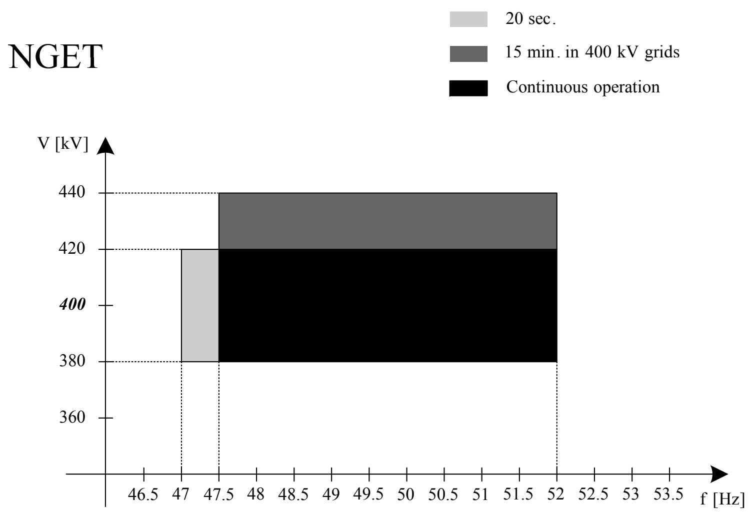




Extreme frequency limits 46.5 Hz and 53.5 Hz are in EON offshore

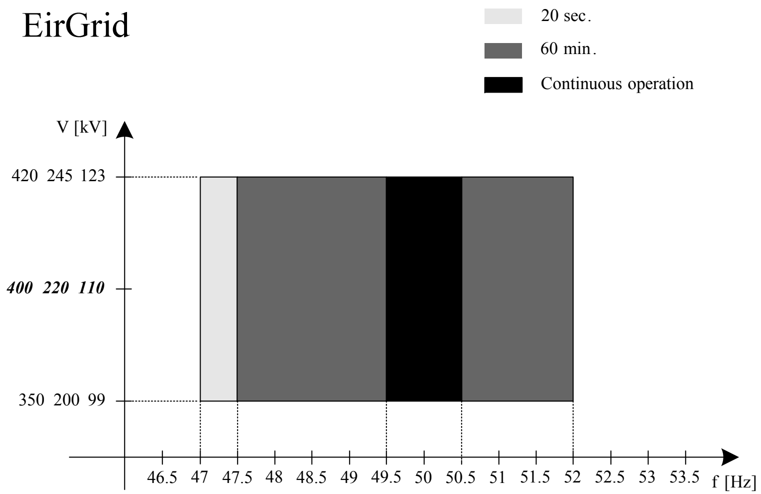
Steady-State Operating Range (Spain and UK)

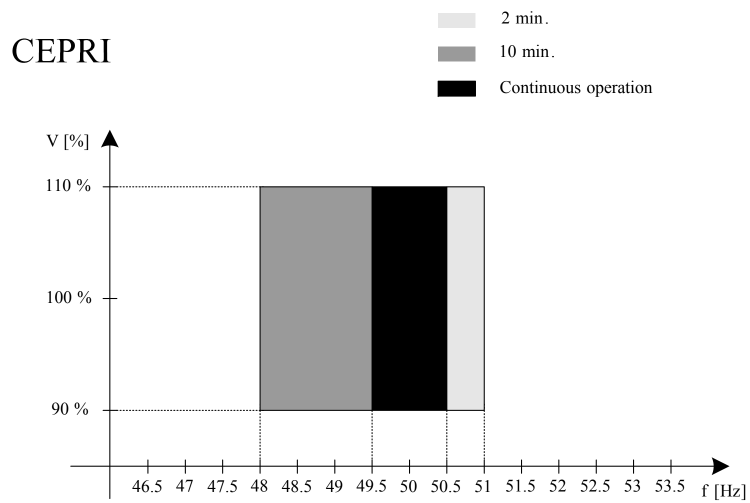




Strictest continuous operation limits for frequency appear in UK (47.5-52 Hz)

Steady-State Operating Range (Ireland and China)



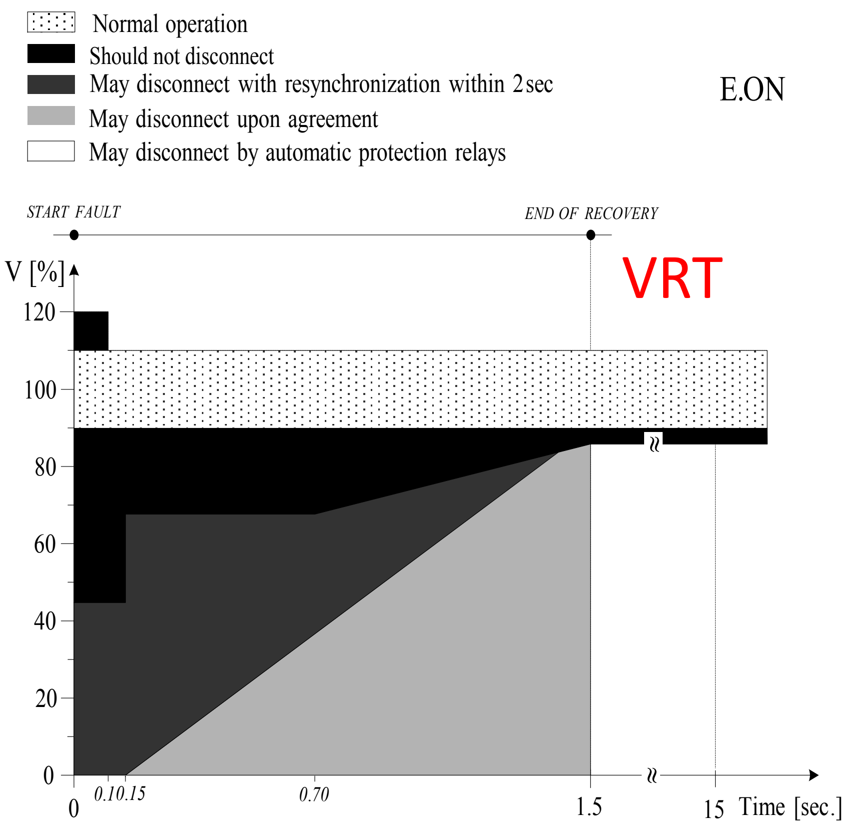


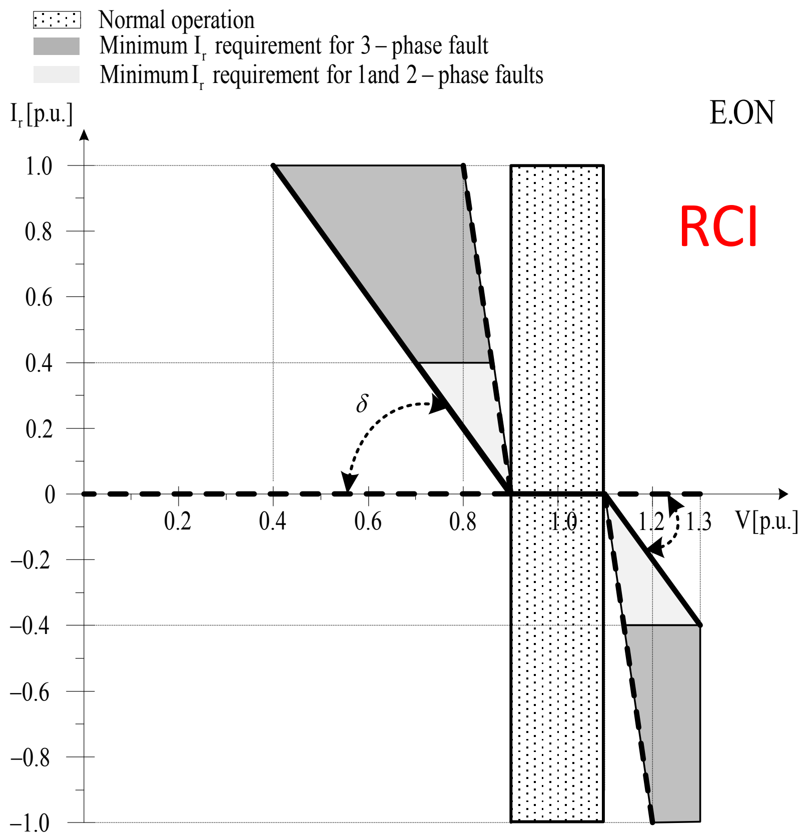
Strictest continuous operation limits for voltage appear in China (90-110% nominal voltage)

Fault Ride-Through Capability

- To avoid WPP disconnections during voltage sags or swells, grid codes require continuous operation even if the voltage dip reaches very low levels
  - VRT in terms of low (LVRT) and high (HVRT) voltage ride through and recovery of the PCC voltage during symmetrical and asymmetrical faults
  - Active power and reactive power limitation during faults and recovery period
  - Restoration active power with limited ramp after fault clearance
  - After the faults, supporting the PCC voltage by injecting/absorbing reactive current
  - For unbalanced fault, specifications for negative and positive sequence currents

Voltage Ride-Through Capability (Germany)

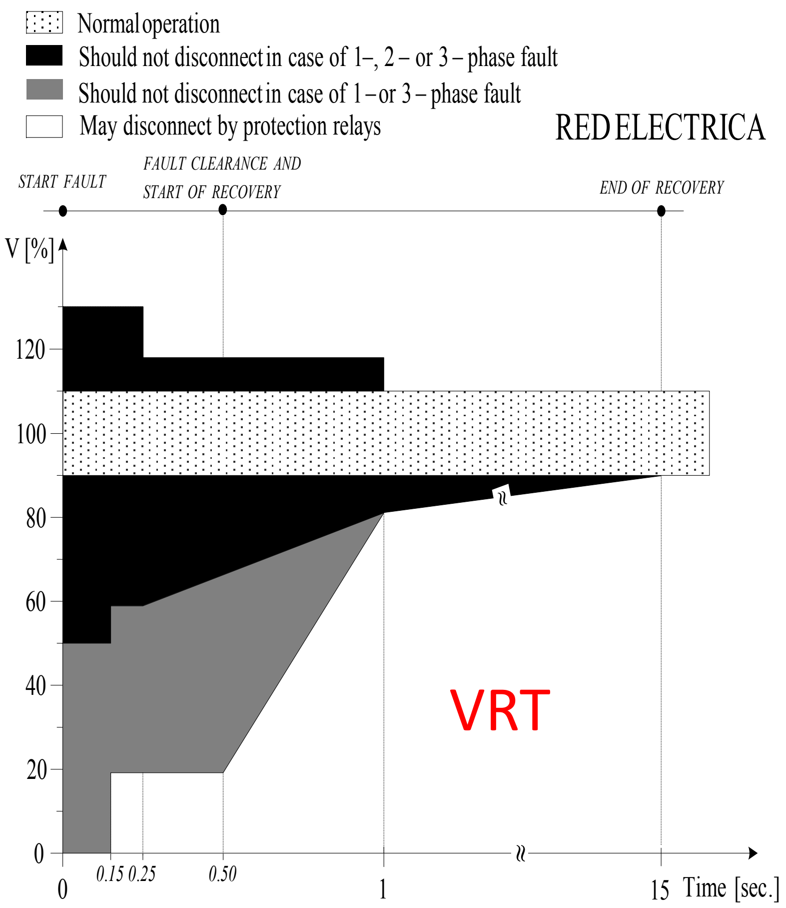




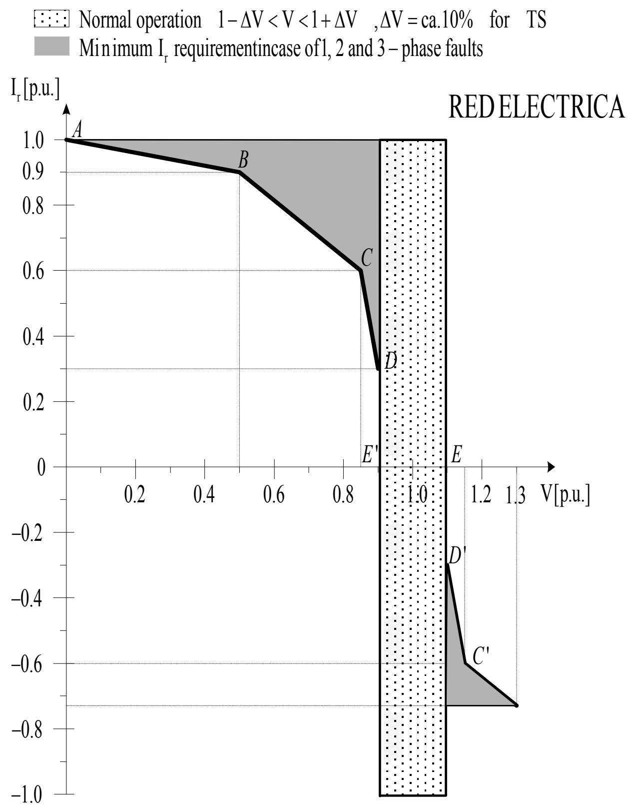
0.4 p.u. positive sequence reactive current must be always available even in the presence of negative sequence

voltage support by injecting reactive current
$K = tg(\delta) = \Delta I_B(pu) / \Delta U(pu)$, $0 < K < 10$
Response time = 30 sec.

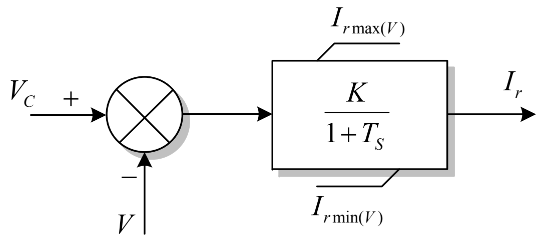
Voltage Ride-Through Capability (Spain)



RCI

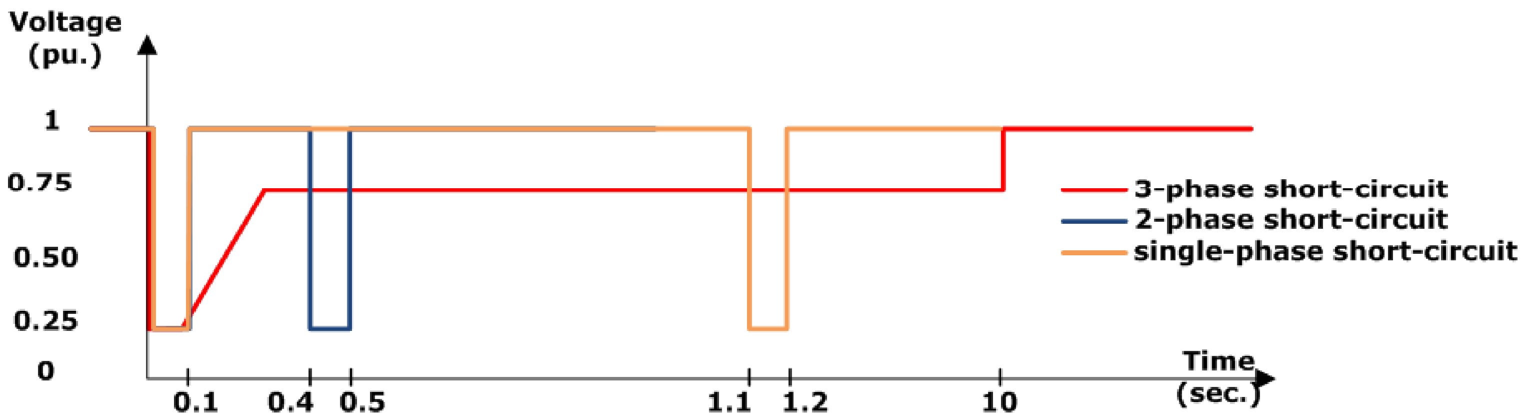


Voltage support by injecting reactive current
In form of saturable controller



Fault Ride-Through Capability (Denmark)

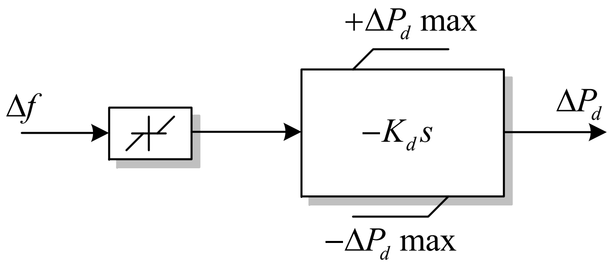
Fault Type	Fault Duration
Three-phase short-circuit	100 msec.
Two-phase short-circuit (with or without earth contact)	100 msec. followed by a new fault 300-500 msec. later
Two-phase short-circuit (with unsuccessful re-closure)	100 msec. followed by a new fault 300 msec. later
Single-phase short-circuit to earth	100 msec. followed by a new fault 300-500 msec. later
Single-phase short-circuit (with unsuccessful re-closure)	100 msec. followed by a new fault 1 sec. later



Future Trends

- Wind Farm Control Functions
  - Inertia Emulation:

    Active power output might be regulated proportional to the derivative of the frequency at the PCC as similar to the synchronous machines natural responses



  - Voltage Control:

    Some of the grid codes grid codes have increased the complexity of the reactive current injection during fault and recovery and a continuous local voltage control may prove to be necessary, particularly for offshore wind farms

Future Trends

- Wind Farm Control Functions
  - Power Oscillation Damping:

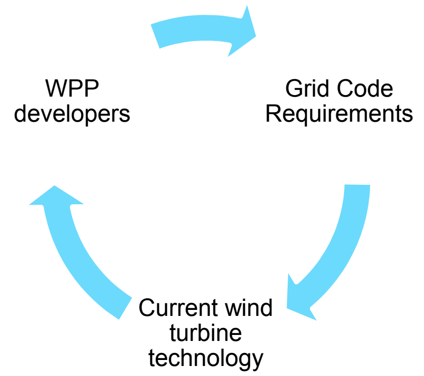
    The generation facilities might possess the ability to reduce power oscillations of electromechanical nature in the system (know as Power System Stabilizer)

    In the wind farm case, the damping control will increase or decrease power output such that its magnitude and angle with regard to the external oscillation help to reduce the power oscillations in frequencies between 0.15 and 2.0 Hz

- Harmonization of the Grid Codes
  - The structural harmonization is to establish a generic grid code format where the structure, designations, figures, method of specification, definitions and units are fixed and agreed upon (EWEA Working Group)

Conclusion

- The objective of grid code requirements → to provide WPPs with control and regulation capabilities of conventional power plants for the safe, reliable and economic operation of the power system
- Harmonization of GC – ENTSOE (European GC) www.entsoe.eu
- Iterative process



- Modern variable speed wind turbines with converter based interface (DFIG & FSC) are required to satisfy GC and the trend is to use FSC