Technical requirements for connection of generating units above 11 kW to the Faroese grid

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1. Introduction

1.1 Administrative provisions

As the main supplier of energy, SEV is the central player in transforming electricity generation from being based on oil to being based on renewable energy sources such as wind power and hydropower. A power system with a large share of fluctuating generation places new demands on generating units connected to the grid.

1.1.1 Purpose

The purpose of this regulation is to set out the necessary technical requirements for generating units above 11 kW, which are connected to the Faroese grid.

1.1.2 Scope

This regulation applies to all generating units above 11 kW connected to the Faroese grid. The requirements in this regulation must be complied with for the service life of the generating unit.

Generating units are divided into the following categories depending on the size of the unit.

1. Power plants above 11 kW and up to and including 50 kW for which SEV has granted an exemption allowing compliance with less strict requirements.
2. Power plants above 50 kW and up to 200 kW for which SEV has granted an exemption allowing compliance with less strict requirements.
3. Power plants above 11 kW which are not subject to any exemption.

Consumer systems not directly related to the generating unit will be considered separately in accordance with ‘Technical requirements for connection of consumer systems to the Faroese grid’.

1.1.3 Delimitation

Generating units connected before 01.08.2017 are not covered by this regulation.

1.1.4 Authority

SEV is responsible for Faroese grid system security, and pursuant to this *Elveitingareftirlitið* has given SEV authority to set out the technical requirements for systems and plants connected to the grid.

1.1.5 Complaints

Any complaints about SEV's management of this regulation may be lodged with *Elveitingareftirlitið*, which will make a final decision based on a specific assessment of the individual case.

1.1.6 Sanctions

The plant owner is responsible for ensuring that the generating unit complies with the requirements of this regulation for the service life of the generating unit.

If the plant owner does not meet its obligations, SEV may, after having notified *Elveitingareftirlitið*, disconnect the generating unit from the grid.

1.1.7 Exemptions and unforeseen events

SEV may grant an exemption from one or more of the requirements of this regulation.

An exemption is granted upon a written request to SEV stating which provisions the exemption concerns and the reason for the exemption.

If events not foreseen in this regulation occur, SEV must consult the parties involved to agree on a course of action. If an agreement cannot be reached, SEV as the transmission system operator must decide on a course of action. The decision must be based on system requirements, and what is reasonable towards the affected parties.

1.2 Definitions/terms

Absolute power constraint
Active power control to a maximum level indicated by a set point. The set point control's +/- tolerance is referred to as the absolute power constraint. For a more detailed description, see section 5.1.3.1.

Plant controller
A plant controller is a set of regulating and control features that make it possible to regulate and control a power plant as a single plant in the point of connection (POC).
The regulating and control features must be part of the power plant communication system, i.e. if communication to the plant fails, the system must be able to continue generation as planned or perform a controlled shutdown.

Plant owner
Plant owner is the entity that legally owns the power plant. The plant owner can transfer the operational responsibility to a plant operator.

Plant operator
The plant operator is the company, which according to the Danish Heavy Current Regulation (*Stærkstrømsbekendtgørelsen*) has the operational responsibility for the power plant, either through ownership or contractual obligations.

Plant categories
Plant categories as determined by the total rated power in the point of connection:

1. Power plants above 11 kW and up to and including 50 kW for which SEV has granted an exemption allowing compliance with less strict requirements.
2. Power plants above 50 kW and up to 200 kW for which SEV has granted an exemption allowing compliance with less strict requirements.
3. Power plants above 11 kW which are not subject to any exemption.

Delta power constraint
Active power control with a set point-defined deviation (delta) between potential and actual power is called delta power constraint. For a more detailed description, see section 5.1.3.2.

Ramp rate constraint
Time interval control of active power with a set point-defined maximum increase/reduction (gradient) of the active power is called ramp rate constraint. For a more detailed description, see section 5.1.3.3.

Electricity-generating unit
An electricity-generating unit is a unit with a total rated power output above 11 kW which is connected to the grid.
An electricity-generating unit comprises all necessary auxiliary supply systems and auxiliary equipment, requiring the entire unit to be designed in compliance with the requirements of this technical regulation.

Point of generator connection (PGC)
The point of generator connection is the point in the plant infrastructure where the terminals/generator terminals for the electricity-generating unit are located.

Flicker

Flicker is the visual perception of light flickering caused by voltage fluctuations. Flicker occurs if the luminance or spectral distribution of light fluctuates with time. At a certain intensity, flicker becomes straining on the eye.
Flicker is measured as described in EN/IEC 61000-4-15.

Frequency control

Frequency control is active power control with the aim of stabilising the grid frequency. The function is called frequency control. For a more detailed description, see section 5.1.2.

Generator convention

The sign for active/reactive power indicates the power flow seen from the generator. Consumption/import of active/reactive power is indicated by a negative sign, while the generation/export of active/reactive power is indicated by a positive sign. In this regulation, the generator convention is used only to describe active and reactive power.

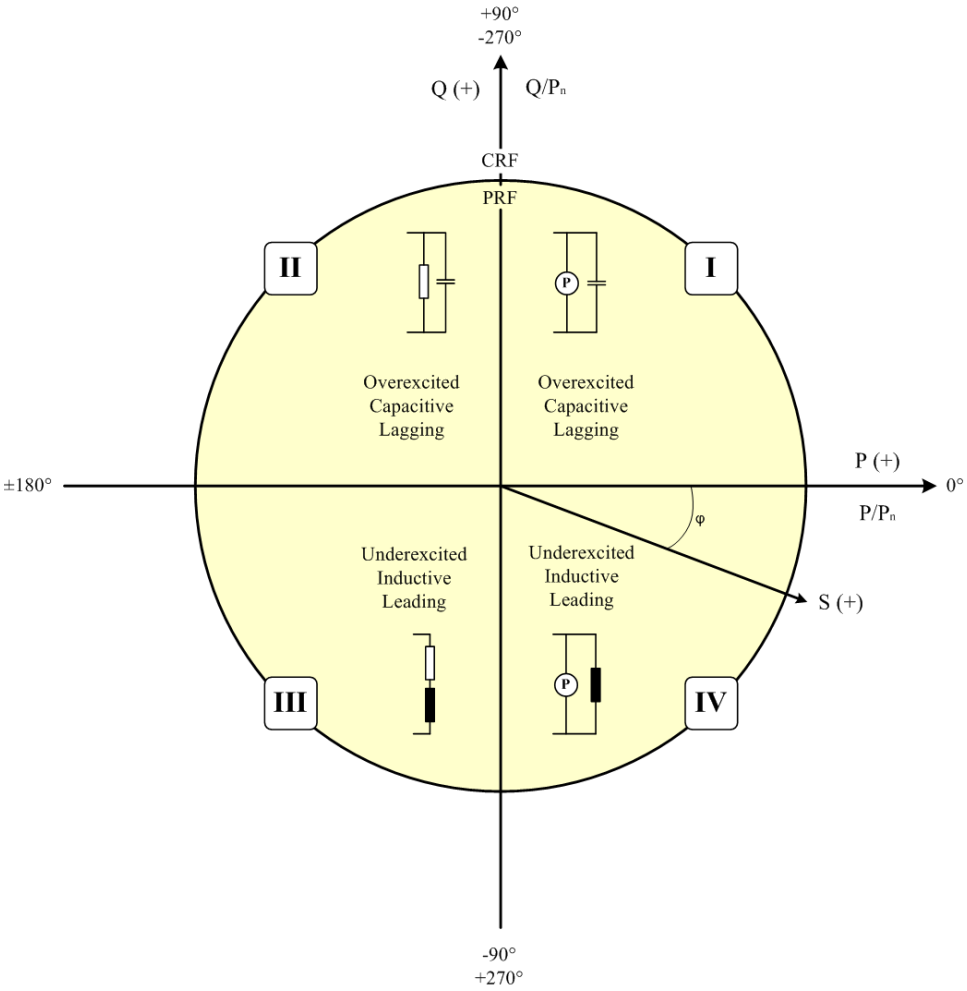


Figure 1: Definition of signs for active and reactive power.

Rapid voltage changes

A brief isolated change of voltage root mean square value from one level to another. Rapid voltage changes are expressed as a percentage of the reference voltage.

Point of connection in installation (PCI)

The point of connection in installation (PCI) is the point in the installation where electricity-generating units are connected or can be connected, see Figure 2for typical location.

Public electricity supply grid

Transmission and distribution grids transporting electricity for an indefinite group of electricity suppliers and consumers on terms laid down by the public authorities.

Point of communication (PCOM)
The point of communication (PCOM) is the point in a plant where the data communication properties specified in section 7 must be made available and verified.

Short-circuit power
The short-circuit power S_k is the level of three-phase short-circuit power in the point of connection. The short-circuit power in the point of connection is provided by SEV.

Short-circuit ratio
The short-circuit ratio R_{sce} is the ratio between the short-circuit power in the point of connection S_k and the power plants nominal apparent power S_n.

The point of common coupling (PCC)
The point of common coupling (PCC) is the point in the public electricity supply grid where consumers are or can be connected.
Electrically, the point of common coupling and the point of connection may coincide. The point of common coupling is always located closest to the public electricity supply grid, see Figure 2 and Figure 3. The point of common coupling is defined by SEV.

Rated power of an electricity-generating unit
The rated power of an electricity-generating unit is the highest active power which an electricity-generating unit is designed to continuously provide and that appears from the type approval.

Rated power of a power plant
The rated power of a power plant P_n is the highest active net power that a power plant is approved to continuously provide in the point of connection under normal operating conditions. The rated power must be stated in the project authorisation.

Rated value of the apparent power of a power plant
Rated value of the apparent power S_n is the highest power consisting of both active and reactive components which a power plant is designed to continuously deliver.

Rated current
Rated current I_n is defined as the maximum continuous current that a power plant is designed to provide under normal operating conditions, see DSF/CLC/FprTS 50549-1.

Rated wind speed

Rated wind speed is the wind speed at which a wind turbine achieves its rated power, see IEC 60050-415-03-04.

Point of connection (POC)

The point of connection (POC) is the point in the public electricity supply grid where the power plant is or can be connected, see Figure 2 and Figure 3 for the typical location.
All requirements specified in this regulation apply to the point of connection. Subject to separate agreement with SEV, reactive compensation at no load can be placed elsewhere in the public electricity supply grid. The point of connection is defined by SEV.
Figure 3 shows a typical grid connection of one or more electricity-generating units with indication of the typical location of the point of generator connection (PGC), the point of connection (POC) and the point of common coupling (PCC).

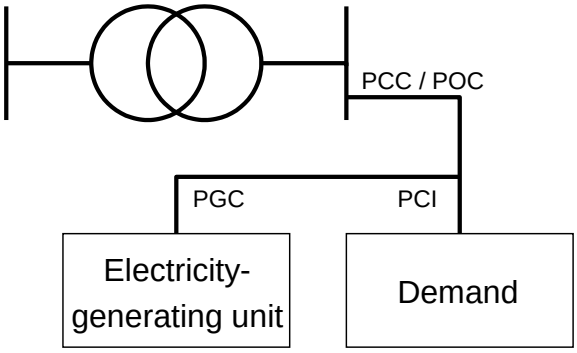


Figure 2: Installation-connected generation with indication of PGC, PCI, POC and PCC.

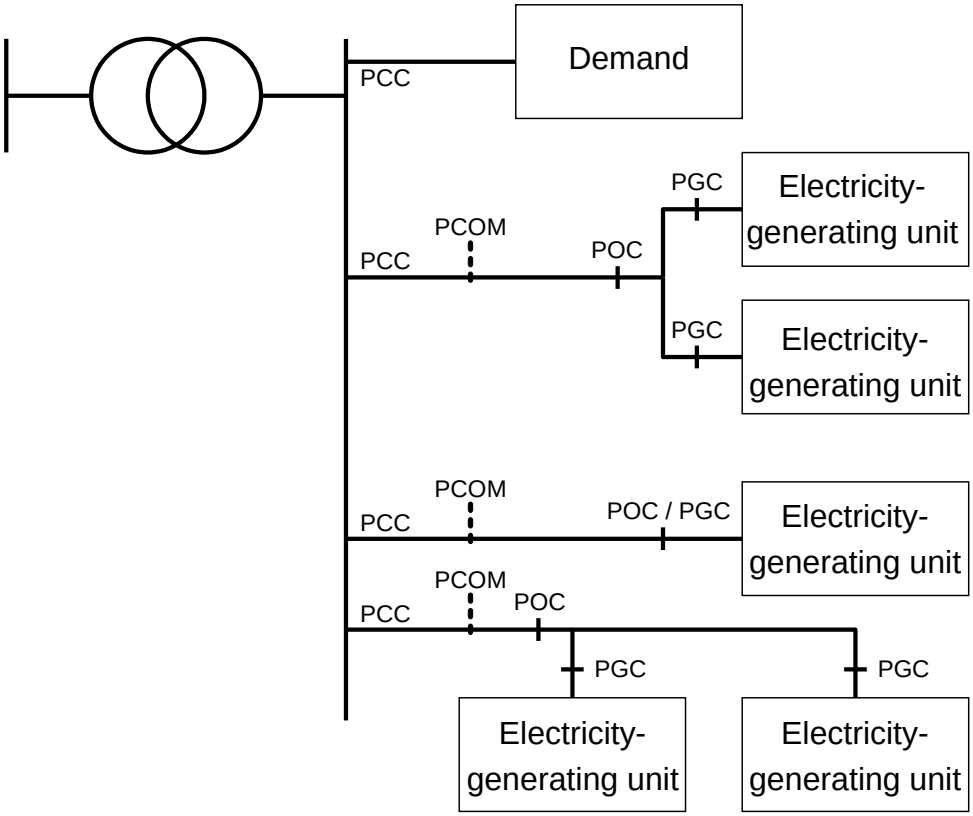


Figure 3: Grid-connected generation with indication of PGC, POC, PCC and PCOM.

Nominal voltage

The voltage level at the POC for which a grid is defined and to which operational characteristics refer. Nominal voltage is denoted by U_n. The internationally standardised voltage levels are shown in Table 1.

Voltage level denominations	Nominal voltage U_n [kV]	Minimum voltage U_{min} [kV]	Maximum voltage U_{max} [kV]
High voltage (HV)	60	54	72.5
Medium voltage (MV)	20	18	24
	10	9	12
	6.6	6	7.2
Low voltage (LV)	0.4	0.36	0.44

Table 1: Standardised voltage levels, including indication of minimum and maximum voltages.

Nominal apparent power
The power denoted by S_n.

Normal production
Normal production indicates the voltage/frequency range where a power plant must be able to continuously generate the specified rated power, see section 2.

Plant infrastructure
The plant infrastructure is the electrical infrastructure between the individual electricity-generating units of a power plant until the point of connection in the public electricity supply grid where the power generated is delivered.

PCC
The point of common coupling (PCC) is further defined under point of common coupling.

PCI
The point of connection in installation (PCI) is further defined under point of connection in installation.

PCOM
The point of communication (PCOM) is further defined under point of communication.

PF
The power factor is denoted by PF. PF is the relationship between the active power P and the apparent power S, i.e. PF can also be expressed as the cosine of the angle between P and S, i.e. PF = cosφ. PF = P/S. PF is a dimensionless value. The angle φ is defined in Figure 1.

PGC
The point of generator connection (PGC) is further defined under point of generator connection.

P_M
P_M denotes the active power which it is possible to produce under specific circumstances.

POC
The point of connection (POC) is further defined under point of connection.

Interconnected electrical power system
The public electricity supply grid and associated systems in a large region which is interconnected for the purposes of joint operation.

Voltage fluctuation
Voltage fluctuation is a series of rapid voltage changes or a periodic variation of the voltage root-mean-square (RMS) value.

Voltage reference point
Measuring point used for voltage control. The voltage reference point is either in the point of connection, in the point of common coupling or a point in between.
The location of the voltage reference point is defined by SEV.

Droop
Droop is the slope of a curve which a control function must follow.

Cut-out wind speed
Cut-out wind speed is the maximum wind speed at hub height at which a wind turbine is designed to generate power, see IEC 60050-415-03-06.

Transmission system operator
Company holding the overall responsibility for maintaining security of supply and ensuring effective utilisation of an interconnected electricity supply system.

Normal operating voltage
The normal operating voltage U_c is defined by SEV. The normal operating voltage is used to determine normal generation range and reduction ratio for the plant transformer.

Wind power plant
A wind power plant is one or more wind turbines with a total rated power above 11 kW connected to the public electricity supply grid in accordance with IEC 61400-1.
A wind power plant comprises all necessary auxiliary supply systems and auxiliary equipment, and it is therefore the entire wind power plant that must be designed in compliance with the requirements of this technical regulation.

Wind turbine
A wind turbine is a system that converts the kinetic energy in the wind to electrical power, see IEC 60050-415-01-02. A wind turbine is an electricity-generating unit.

1.3 References (normative/informative)

1.3.1 Normative references:

1. **Fællesregulativet 2014** 'Connection of electrical equipment and utility products'.
2. **The Danish Heavy Current Regulation (*Stærkstrømsbekendtgørelsen*), section 6** 'Electrical installations'.
3. **The Danish Heavy Current Regulation (*Stærkstrømsbekendtgørelsen*), section 2** 'Design of electrical installations'.
4. **EN 50160:** Voltage characteristics in public distribution systems.
5. **IEC 60038:** IEC standard voltages.
6. **IEC 60044-1:** Instrument transformers – Part 1: Current transformers.
7. **IEC 60044-2:** Instrument transformers – Part 2: Inductive voltage transformers.
8. **IEC 60050-415:** International Electrotechnical Vocabulary – Part 415: Wind turbine generator systems.
9. **IEC 60071-1:** Insulation co-ordination – Part 1: Definitions, principles and rules.
10. **DS/EN 60204-1:** Safety of machinery – Electrical equipment of machines.
11. **DS/EN 60204-11:** Safety of machinery – Electrical equipment of machines – Part 11: Requirements for equipment for voltages above 1000 V AC or 1500 V DC and not exceeding 36 kV.
12. **IEC 60870-5-101:** Telecontrol equipment and systems, part 5-101.
13. **IEC 60870-5-104:** Telecontrol equipment and systems, part 5-104.
14. **EN/IEC 61000-3-2:** Limits – Limits for harmonic current emissions (equipment input current ≤16 A per phase), 2014.
15. **EN/IEC 61000-3-3:** 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, 2013.
16. **IEC/TR 61000-3-6:** EMC limits. Limitation of emission of harmonic currents for equipment connected to medium and high voltage power supply systems.
17. **IEC/TR 61000-3-7:** EMC limits. Limitation of voltage fluctuations and flicker for equipment connected to medium and high voltage power supply systems.
18. **EN/IEC 61000-3-11:** 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, 2000.

19. **EN/IEC 61000-3-12:** Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤75 A per phase, 2011.
20. **IEC/TR 61000-3-13:** Limits – Assessment of emission limits for the connection of unbalanced installation to MV, HV and EHV power systems, 2008.
21. **IEC/TR 61000-3-14:** Assessment of emission limits for the connection of disturbing installation to LV power systems, 2011.
22. **IEC/TR 61000-3-15:** Limits – Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network, 2011.
23. **EN/IEC 61000-4-15:** Testing and measurement techniques – Flickermeter – Functional and design specifications, 2010.
24. **IEC 61400-1:** Wind Turbines – Part 1: Design requirements.
25. **IEC 61400-2:** Wind Turbines – Part 2: Design requirements for small wind turbines.
26. **IEC 61400-12:** Wind turbine generator systems. Power performance measurement techniques.
27. **IEC 61400-21:** Measurement and assessment of power quality characteristics of grid connected wind turbines.
28. **IEC 61400-22:** Conformity testing and certification.
29. **IEC 61400-25-1:** Communications for monitoring and control of wind power plants – overall description of principles and models.
30. **IEC 61400-25-2:** Communications for monitoring and control of wind power plants – information models.
31. **IEC 61400-25-3:** Communications for monitoring and control of wind power plants – information exchange services.
32. **IEC 61400-25-4:** Communications for monitoring and control of wind power plants – mapping to communication protocol stacks.
33. **IEC 62053-21:** Electricity metering equipment (ac) – Particular requirements. Part 21: static meters for active energy.
34. **DSF/CLC/FprTS 50549-1:** Requirements for generating plants larger than 16 A per phase to be connected in parallel with a low-voltage distribution network.
35. **DSF/CLC/FprTS 50549-2:** Requirements for generating plants to be connected in parallel with a medium-voltage distribution network.

1.3.2 Informative references:

36. **DEFU report RA557:** Maksimal emisson af spændingsforstyrrelser fra vindkraftværker større end 11 kW (Maximum emission of voltage disturbances from wind power plants above 11 kW).

37. **DEFU recommendation 16:** Spændingskvalitet i lavspændingsnet (Voltage quality in low-voltage grids).
38. **DEFU recommendation 21:** Spændingskvalitet i mellemspændingsnet (Voltage quality in medium-voltage grids).

2. Normal operating conditions

This section describes the requirements for power plants under normal operating conditions. What is considered to be normal frequency and voltage is defined below. Under normal operating conditions, a power plant must be able to operate continuously within the normal voltage and frequency range.

2.1 Voltage

A power plant must be able to operate continuously in the voltage range of 90% U_c to 110% U_c. The power plant must be able to deliver its nominal power when the voltage is 100% of U_c or above. At voltages below 100% of U_c, it is allowed to reduce the power output of the power plant to comply with the power plant current limit. The reduction in generation must be as small as technically possible.

2.2 Frequency

The power plant must as a minimum operate in the frequency range 47-52 Hz. Power plants consisting of inverter-based electricity-generating units must be able to operate in the frequency range 45-55 Hz.

The power plant must as a minimum be able to operate continuously and deliver its nominal power in the frequency range 49-51 Hz. A power plant must be able to operate for at least the time period specified in Table 2 in frequency ranges 47-49 Hz and 51-52 Hz.

It is also allowed to reduce the generation by 10% per Hz for frequencies below 49 Hz. The minimum power to be delivered is specified in Table 2.

Frequency	Minimum time	Minimum generation
47.0-47.5	0-20 seconds	80% of normal generation
47.5-49.0	30-90 minutes	90% of normal generation
49.0-51.0	Continuous operation	100% of normal generation
51.0-51.5	30-90 minutes	100% of normal generation
51.5-52.0	0-15 minutes	100% of normal generation

Table 2: Operating requirements at different frequencies.

Inverter-based electricity-generating units must be able to operate continuously in the frequency range 45-55 Hz.

3. Abnormal operating conditions

This section describes the requirements for power plants under abnormal operating conditions such as faults, voltage dips, etc.

The power plant must be designed to remain connected to the grid and continue normal generation in case of:

- Transitory (100 ms) phase angle jumps of up to 20° in the POC.
- Frequency changes of up to 2.5 Hz/s.

The power plant must be able to return to normal production within 5 seconds of voltage and frequency returning to normal range. If the power plant has been disconnected, voltage and frequency must have been in the normal operating range for at least 1 minute before connection, reclosing and automatic reclosing. If the power plant has been disconnected due to a stop signal, it must not be connected before permission for start-up has been given and voltage and frequency have been within the normal range for at least 1 minute.

When connecting the power plant, synchronisation with the grid must be fully automatic, and manual bypass must not be possible.

3.1 Voltage dip

A power plant must be designed to withstand voltage dips down to 10% of operating voltage for at least 0.25 seconds without disconnecting, see Figure 4.

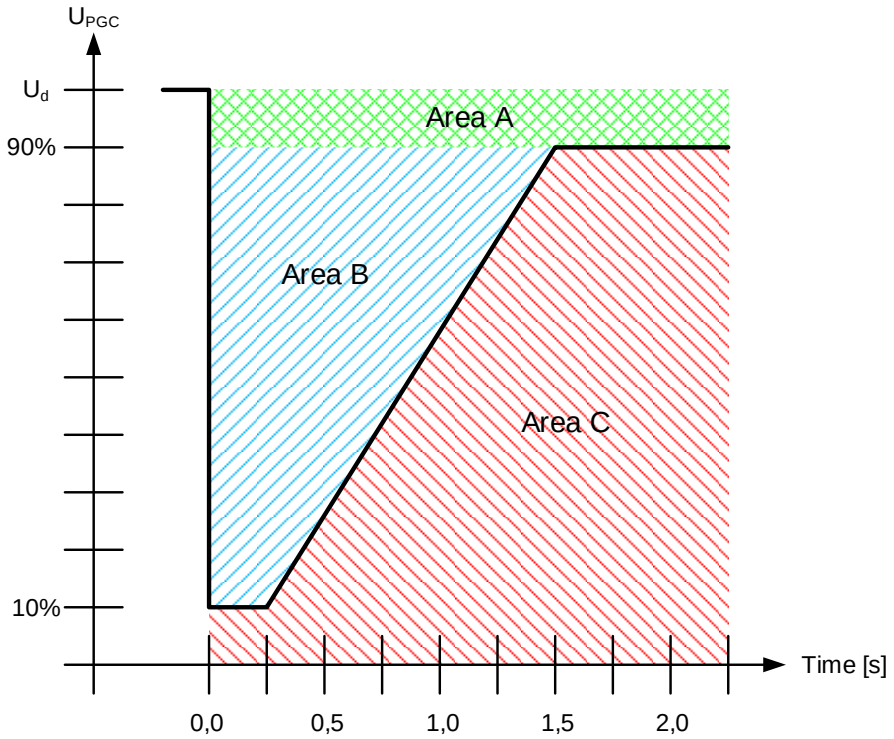


Figure 4: Voltage dip characteristics of category 1, 2 and 3 power plants.

The following requirements apply to all types of faults:

- Area A: Power plant must remain connected and generate as if under normal operating conditions.
- Area B: Power plant must remain connected and provide voltage support with reactive current as specified in Figure 5.
- Area C: Power plant may disconnect.

If, during a fault sequence, voltage returns to area A, subsequent voltage dips will be considered new faults.

If several successive faults result in the voltage remaining in area B and not returning to area A between faults, the event is considered to be a single fault, and the power plant may disconnect when enough time has passed for the voltage to enter area C.

In area B, category 3 power plants provide voltage support by supplying additional reactive current as specified in Figure 5.

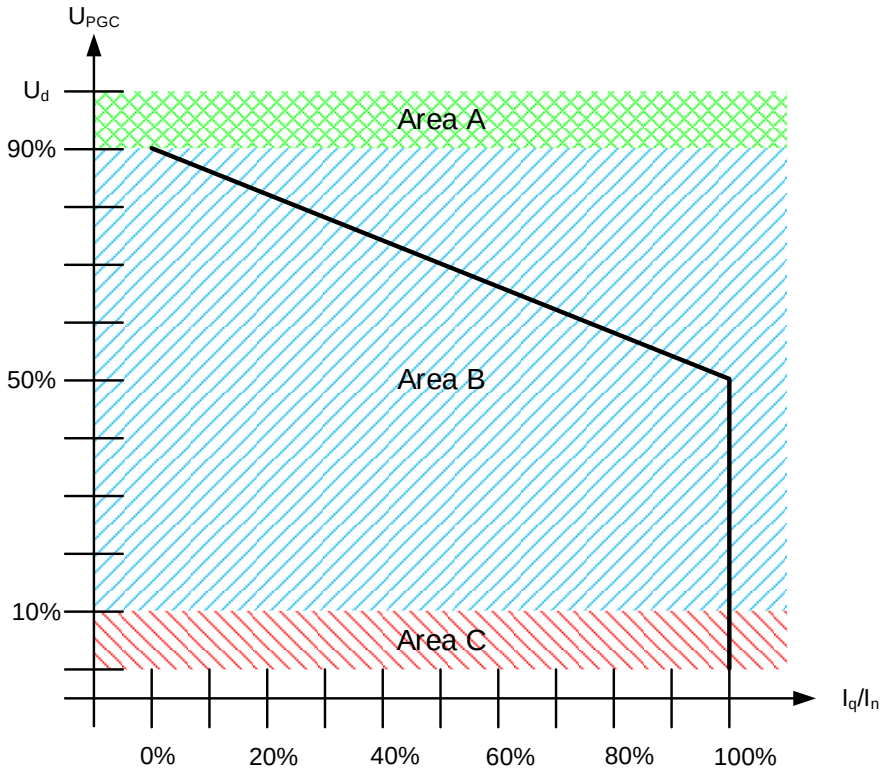


Figure 5: Voltage support for category 3 power plants.

The additional reactive current must be delivered within 100 ms and must follow the characteristics with an accuracy of ±20%. Supply of additional reactive current has first priority, while supply of active power takes second priority. Supply of active power must be maintained during voltage dips within the technical limitations of the power plant.

3.2 Voltage rises

A power plant must be able to handle short-term voltage rises without disconnecting. The requirements are stated in Table 3.

Voltage	Minimum time
115%	1 second
120%	100 ms

Table 3: Tolerance to voltage rises.

4. Power quality (EMC/PQ)

A power plant must not cause unacceptable power quality in the grid. To avoid this, the power plant must comply with the requirements specified in the following sections.

Category 1 power plants must comply with all requirements specified in IEC 61000-3-2, 61000-3-3, 61000-3-11 and 61000-3-12 and section 4.1.

Category 2 power plants must comply with the power quality requirements specified in the following sections.

Category 3 power plants must comply with the power quality requirements provided by SEV for the installation in question.

4.1 Rapid voltage changes

A rapid voltage change is a single, rapid change of the voltage root mean square value from one level to another. Rapid voltage changes from generation are typically caused by connection and disconnection or start-up.

A power plant must comply with the limits for rapid voltage changes specified in Table 4.

Voltage level	d (%)
$U_n \leq 20\ kV$	4%
$U_n > 20\ kV$	3%

Table 4: Limit values for rapid voltage changes.

Inverter-based generating units are considered to meet these requirements as they will typically not cause this type of disruptions.

4.2 Flicker

Flicker is the visual impression of flickering lights caused by changes in the luminance (strength) or the spectral distribution (colour) of light. At a certain intensity, flicker becomes straining on the eye. It is therefore important to keep the flicker level (flicker intensity) low. All units connected to the grid contribute to flicker intensity, and so requirements apply for the flicker contribution of each individual power plant.

Flicker from power plants is caused by fluctuating energy supply to the generator or by electrical switching in the power plant, e.g. star/delta connections. Flicker contributions are divided into short-term contributions (10 min) P_{st} and long-term contributions (120 min) P_{lt}. A power plant's flicker contribution during continuous operation is calculated according to the following formula using data provided by the generator manufacturer:

$$P_{lt,i} = c_i(\Psi_k) \cdot \frac{S_{n,i}}{S_k}$$

Where $P_{lt,i}$ = long-term flicker contribution
Ψ_k = grid impedance angle
$c_i(\Psi_k)$ = flicker coefficient at grid impedance angle Ψ_k
$S_{n,i}$ = nominal apparent power of electricity-generating unit
S_k = short-circuit capacity in the point of connection

The mean wind flicker coefficient is used for wind power plants.

If the power plant consists of several units, the contributions of the individual units are summed up using the following formula:

$$P_{lt} = \sqrt[3]{\sum_i \left(P_{lt,i}\right)^3}$$

The flicker contribution of a power plant during electrical switching operations is calculated according to the following formulas using data provided by the generator manufacturer:

$$P_{st,i} = 18 \cdot N_{10min,i}^{0,31} \cdot k_{f,i}(\Psi_k) \cdot \frac{S_{n,i}}{S_k}$$

$$P_{lt,i} = 8 \cdot N_{120min,i}^{0,31} \cdot k_{f,i}(\Psi_k) \cdot \frac{S_{n,i}}{S_k}$$

Where $P_{st,i}$ = flicker contribution
Ψ_k = grid impedance angle
$N_{10\text{min}}$ = number of switching operations in 10 min

N_{120min} = number of switching operations in 120 min
$k_{f,i}(\Psi_k)$ = highest flicker coefficient at grid impedance angle Ψ_k
$S_{n,i}$ = nominal apparent power of electricity-generating unit
S_k = short-circuit capacity in the point of connection

Inverter-based generating units are considered to meet the requirements for plants during electrical switching operations as they will typically not cause this type of disruptions.

If the power plant consists of several units, the contributions of the individual units are summed up using the following formula:

$$P_{st} = \sqrt[3]{\sum_i \left(P_{st,i}\right)^3}$$

$$P_{lt} = \sqrt[3]{\sum_i \left(P_{lt,i}\right)^3}$$

Category 2:
If the power plant rated power (P_n) is less than 0.4% of the short-circuit power (S_k) in the point of connection (POC), the system can be connected. If a power plant exceeds 0.4% of the short-circuit power in the point of connection, the flicker contribution from the power plant must not exceed the values stated in Table 5.

Voltage level	P_{st}	P_{lt}
$U_n \leq 1\ kV$	0.35/0.45/0.55*	0.25/0.3/0.4*
$U_n > 1\ kV$	0.3	0.2

*) The limit values apply if 4/2/1 power plant(s), respectively, are already connected via the same substation.

Table 5: Limit values for maximum flicker contribution from category 2 power plants.

Inverter-based generating units are considered to comply with the requirement for P_{st} as this requirement is typically met through compliance with the requirement for P_{lt}.

Category 3:
SEV defines the maximum allowable power plant flicker contribution.

4.3 Harmonics

A harmonic current or voltage is a sinusoidal current or voltage at a multiple of the fundamental frequency – i.e. a multiple of the nominal frequency. Harmonics distort the fundamental frequency sinusoidal waveform. Other equipment connected to the grid (including protective equipment) may not work as intended or may become damaged as a result of such distortion. Therefore, it is necessary to limit power plant harmonics emissions.

A power plant must not emit harmonics which exceed the limit values set out in this section.

The harmonics level is provided by the manufacturer of the electricity-generating unit. If the power plant consists of several units, the contributions of the individual units are summed up using the following formula:

$$I_h = \sqrt[\alpha]{\sum_i I_{h,i}^{\alpha}}$$

Where I_h = the total harmonic current of order h
$I_{h,i}$ = harmonic current from unit i
α = summation exponent

Harmonic order	α (alpha)
$h < 5$	1
$5 \leq h \leq 10$	1.4
$h > 10$	2
$h > 40$	3

In addition to the limit values for individual harmonic currents, the power plant must also comply with the limit values for total harmonic distortion (THD_I) and partially weighted harmonic distortion ($PWHD_I$).

THD_I and $PWHD_I$ are determined from the individual harmonics using the formulas in (1) and (2), see IEC 61000.

$$THD_I = \sqrt{\sum_{h=2}^{h=40} \left(\frac{I_h}{I_1}\right)^2}$$

$$PWHD_I = \sqrt{\sum_{h=14}^{h=40} h \cdot \left(\frac{I_h}{I_1}\right)^2}$$

Similar formulas apply to voltage harmonics.

Category 2:
Category 2 power plants must not emit current harmonics exceeding the limit values in Table 6 and Table 7.

Voltage level	R_{sce}	Odd harmonic order h (not a multiple of 3)					Even harmonic order (h)		
		5	7	11	13	$17 \leq h \leq 39$	2	4	$8 \leq h \leq 40$
$U_n \leq 1\ kV$	< 33	3.6	2.5	1.0	0.7	–	–	–	–
	≥ 33	4.1	2.8	1.1	0.8	–	–	–	–
	≥ 66	5.3	3.5	1.7	1.2	–	–	–	–
	≥ 120	7.2	4.6	2.6	1.6	–	–	–	–
	≥ 250	11.7	7.5	4.4	3.0	–	–	–	–
	≥ 350	15.2	9.6	5.9	4.1	–	–	–	–
$U_n > 1\ kV$	–	4.0	4.0	2.0	2.0	$\frac{400}{h^2}$ *)	0.8	0.2	0.1

*) However, not less than 0.1%.

Table 6: Limit values for harmonic current Ih/In (%).

Voltage level	R_{sce}	THD_I	$PWHD_I$
$U_n \leq 1\ kV$	< 33	4.5	7.9
	≥ 33	4.9	8.1
	≥ 66	6.0	9.0
	≥ 120	8.3	10.5
	≥ 250	13.9	14.3
	≥ 350	18.0	17.3

Table 7: Limit values for total harmonic distortion (%).

Interpolation between values for different short-circuit conditions is allowed for voltages lower than 1 kV.

The limit values must be observed at all levels of generation. The level of generation yielding the highest value of a specific harmonic current is used for assessing individual harmonic currents. The level of generation yielding the highest value of THD and PWHD is used for assessing THD and PWHD, respectively.

Category 3:
SEV defines the emission limits for harmonic voltages in the point of connection (POC).

SEV states grid impedance as a function of the frequency in the relevant frequency range.

4.4 Interharmonics

An interharmonic current or voltage is a sinusoidal current or voltage with a frequency that is not at a multiple of the fundamental frequency – i.e. not a multiple of the nominal frequency. Like harmonics, interharmonics distort the fundamental frequency sinusoidal waveform. Interharmonics, like harmonics, may impact equipment connected to the grid negatively, and therefore it is necessary to limit the emission of interharmonic distortions from a power plant.

Category 2:
Emissions of interharmonics from category 2 power plants are not allowed to exceed the limit values in Table 8.

Voltage level	R_{sce}	Frequency (Hz)		
		75	125	>175

$U_n \leq 1\ kV$	< 33	0.4	0.6	$\frac{75}{f}$ *
	≥ 33	0.5	0.7	$\frac{83}{f}$ *
	≥ 66	0.6	0.8	$\frac{104}{f}$ *
	≥ 120	0.7	1.1	$\frac{139}{f}$ *
	≥ 250	1.2	1.8	$\frac{224}{f}$ *
	≥ 350	1.5	2.3	$\frac{289}{f}$ *
$U_n > 1\ kV$	–	0.44	0.66	$\frac{83}{f}$ *

*) However, not less than 0.1%.

Table 8: Limit values for emission of interhamonic currents.

Category 3:
SEV defines emission limits for interharmonic voltages in the point of connection (POC).

SEV states grid impedance as a function of the frequency in the relevant frequency range.

Interharmonic currents are assessed in the same way as harmonic currents. However, α = 3 is used for power plants consisting of several units.

4.5 Harmonics and interharmonics in the 2-9 kHz frequency range

Like harmonics and interharmonics mentioned in sections 4.3 and 4.4, harmonics and inter-harmonics with higher frequencies may also have negative impacts on equipment connected to the grid. In order to avoid negative impacts from harmonics and interharmonics in the 2-9 kHz range, harmonics and interharmonics emission limits are defined for power plants.

Harmonics and interharmonics in the 2-9 kHz frequency range are measured in groups of 200 Hz width as specified in IEC 61000.
Category 2:
Emission of harmonic and interharmonic currents in the 2-9 kHz frequency range must not exceed 0.2% of the rated current (I_n) for any of the measured groups.

Category 3:
SEV defines emission limits for harmonic and interharmonic voltages in the point of connection (POC) in the 2-9 kHz frequency range.

SEV states grid impedance as a function of the frequency in the relevant frequency range.

Harmonics and interharmonics in the 2-9 kHz frequency range are assessed in the same way as harmonics. However, $\alpha = 3$ is used for power plants consisting of several units.

4.6 Other

This section describes additional conditions relating to power quality which are not covered in the previous sections.

4.6.1 Asymmetry

Asymmetry is a condition where the voltages on the 3 phases are not the same in all phases, or where the angles between the phases are not the same. Asymmetry is typically caused by different consumption and generation on the individual phases, and may affect 2- and 3-phase units negatively, reducing grid transmission capacity. It is therefore necessary to limit asymmetry in the grid to avoid these negative effects.

The power plant must not cause grid voltage imbalance. To avoid this, a power plant connected at low voltage must not have a current imbalance exceeding 16 A. Power plants connected at medium voltage must be connected as balanced 3-phase systems.

4.6.2 DC content

Current DC content may cause saturation of distribution substations, leading to worse power quality.

The DC content of the supplied AC current must not exceed 0.5% of power plant nominal current.

5. Control and regulation

It is necessary to control the electricity generation from power plants to safely and efficiently operate the grid. Therefore requirements are defined for power plant control and regulation functions.

For a power plant to be connected to the grid, it must comply with the below control and regulation requirements. Unless otherwise specified, all control functions refer to the POC. It must be possible to activate, deactivate and set all control functions using external signals (see section 7). Control function settings must be agreed with SEV before the power plant can be connected to the grid.

If the power plant consists of several units, the required active and reactive power will be reduced on a pro-rata basis relative to the number of units in operation.

The power plant must have a minimum operating range as stated in Table 9 and be able to supply the functionality specified in Table 10. The required functions can be implemented either in the individual power plant units or in the power plant controller as long as there is only one communication interface as shown in Figure 6.

	Category 1	Category 2	Category 3
Section	5.3.1	5.3.2	5.3.2

Table 9: Required operating range for power plants.

Control function	Category 1	Category 2	Category 3
Frequency response	X	X	X
Frequency control			X
Absolute power constraint			X
Delta power constraint			X
Ramp rate constraint			X
System protection			X
Q control	X	X	X
Power factor control	X	X	X
Aut. power factor control	X	X	
Voltage control			X

Table 10: Control and regulating functions required for power plants.

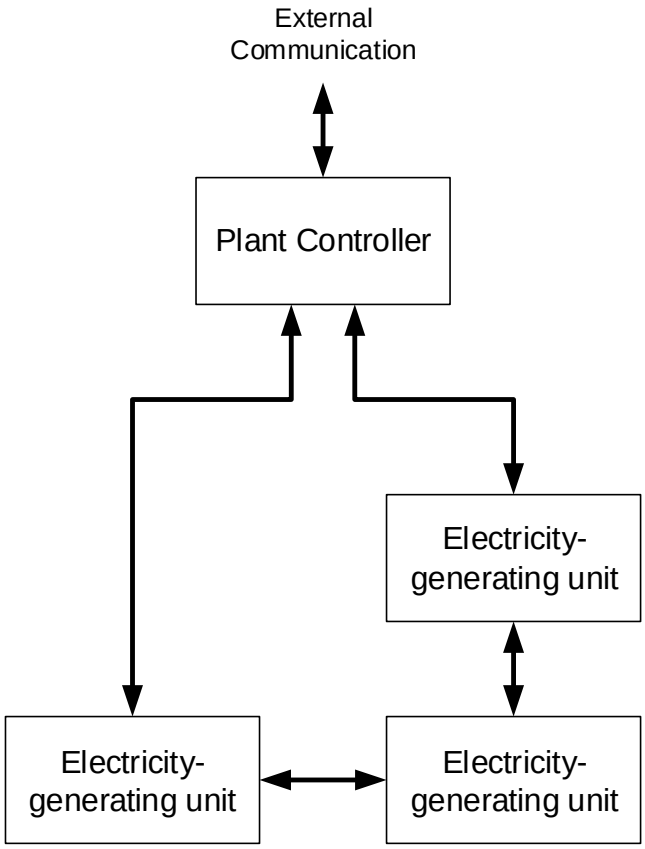


Figure 6: Communication interface.

5.1 Active power control

A power plant must be equipped with active power control functions. These functions must use the POC as reference and perform control using set points and settings defined by SEV.

In addition to fulfilling the general requirements, active power control functions must comply with the requirements provided in the following subsections.

5.1.1 Frequency response

In the event of frequency deviations in the grid, a power plant must contribute to grid stability by reducing active power at grid frequencies above 50 Hz.

Frequency must be measured with an accuracy of ±10 mHz or higher.

The function must have 3 adjustable frequency points: fmax, fmin and f1. It must be possible to set these to any value in the 47-52 Hz range with an accuracy of 10 mHz.

It must be possible to set a time delay for activation of the function of between 0-2 seconds in increments of 50 ms.

The droop, indicating the change in active power as a function of grid frequency, is given in per cent of the power plant's nominal power.

The adjustable frequency points, time delay and droop are defined by SEV. An example is shown in Figure 7.

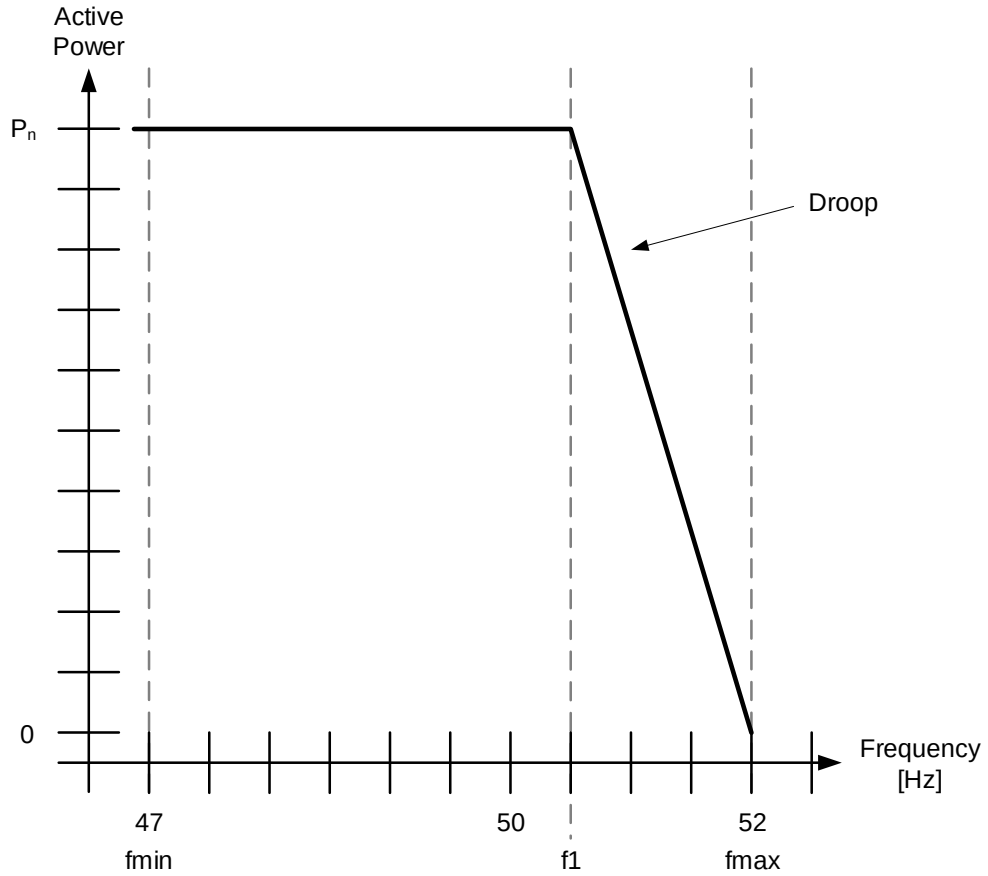


Figure 7: Power plant frequency response.

5.1.2 Frequency control

In case of frequency deviations in the grid, the power plant must contribute to grid stability by being able to control active power to stabilise the grid frequency.

Frequency must be measured with an accuracy of ±10 mHz or higher.

The function must have 6 adjustable frequency points: fmax, fmin and f1-f4. It must be possible to set these to any value in the 47-52 Hz range with an accuracy of 10 mHz.

The droop, indicating the change in active power as a function of grid frequency, is given in per cent of the power plant's nominal power.

Adjustable frequency points and droop are defined by SEV. An example is shown in Figure 8. P_{delta} is the power that the available active power is reduced with in order to provide frequency stabilisation (upward regulation) in the event of falling grid frequency.

Frequency control using a new parameter set must be possible no later than 10 seconds from receipt of the parameter change order.

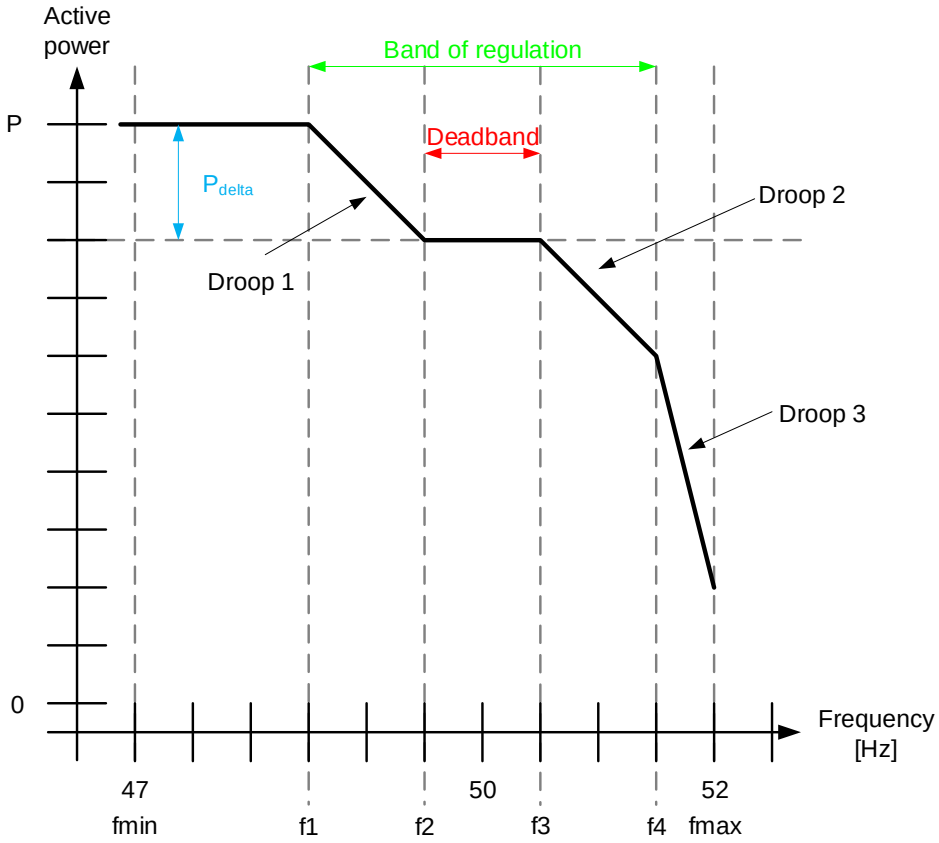
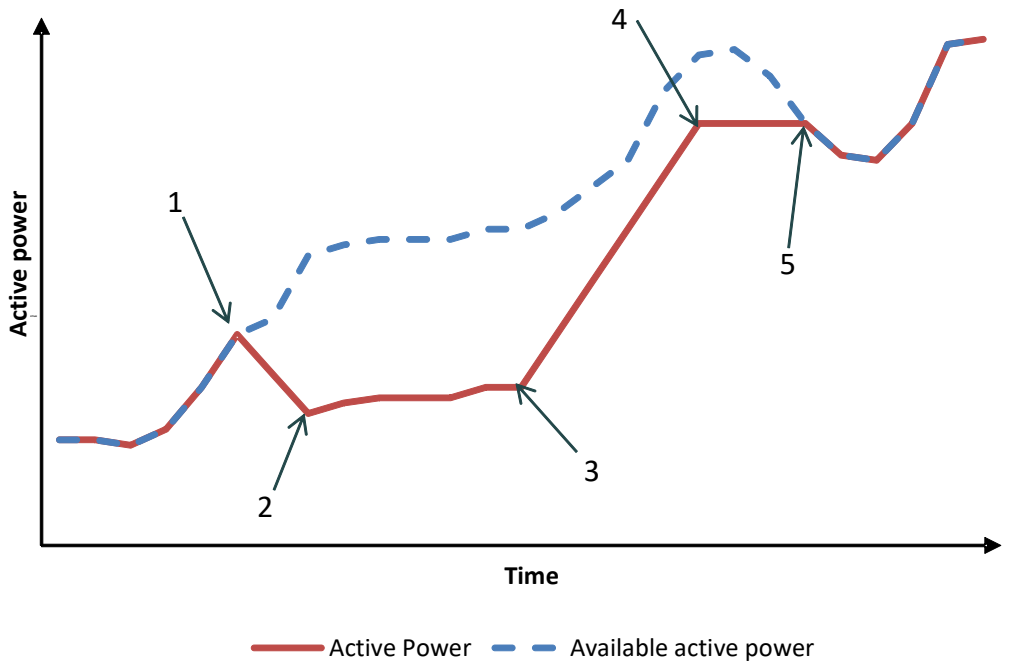


Figure 8: Power plant frequency control.

5.1.3 Constraint functions

A power plant must be equipped with constraint functions. Constraint functions are used to avoid instability or overloading of the grid.

The required constraint functions are specified in the following subsections. An example of use of constraint functions is shown in Figure 9.



1	Delta power constraint activated. Ramp rate constraint activated.
2	Ramp rate constraint deactivated.
3	Delta power constraint deactivated. Ramp rate constraint activated.
4	Absolute power constraint activates. Ramp rate constraint deactivates
5	Absolute power constraint deactivates

Figure 9: Example of use of constraint functions.

5.1.3.1 Absolute power constraint

Absolute power constraint is used to limit the maximum power from the power plant in the POC. Absolute power constraints are mainly used to protect the grid against overload.

Regulation to a new set point must be commenced within 2 seconds and completed no later than 30 seconds after receipt of set point change order. Control accuracy must be ±0.5% of the rated power.

5.1.3.2 Delta power constraint

Delta power constraint is used to constrain the active power to a constant value in proportion to the potential generation. Delta power constraints are mainly used to establish a regulating reserve for frequency control at variable energy source power plants (solar, wind, etc.).

Regulation to a new set point must be commenced within 2 seconds and completed no later than 30 seconds after receipt of set point change order. Control accuracy must be ±0.5% of the rated power.

5.1.3.3 Ramp rate constraint

Ramp rate constraint is used to limit the maximum speed by which the active power can change. Ramp rate constraints are mainly used to ensure grid stability in the event of active power set point changes or automatic reclosing of the power plant after a fault.

Regulation to a new set point must be commenced within 2 seconds and completed no later than 30 seconds after receipt of set point change order. Control accuracy must be ±0.5% of the rated power.

5.1.4 System protection

System protection is a control function which ensures a power plant's capability to very quickly perform downward regulation of active power to one or more predefined set points. There must be a minimum of 5 different regulation steps, which are defined by SEV. Unless otherwise instructed by SEV, the below 5 regulation steps are recommended as default values.

1. 70% of rated power
2. 50% of rated power
3. 40% of rated power
4. 10% of rated power
5. 0% of rated power, i.e. the plant is shut down, but not disconnected from the grid.

Regulation to a new set point must be commenced within 1 second, and completed no later than 10 seconds after receipt of set point change order. Control accuracy must be ±0.5% of the rated power.

5.1.5 Downward regulation of wind power plants at high wind speeds

In order to avoid grid instability, large wind power plants must be equipped with automatic downward regulation at high wind speeds, so as to avoid temporary interruption of the active power generation at wind speeds above the wind turbine cut-out wind speed.

Downward regulation must start at a wind speed lower than the wind turbine cut-out wind speed and be completed at the cut-out wind speed at the latest. The downward regulation must

stay within a specified band and must as far as possible be linear as shown in Figure 10. Downward regulation can be performed as continuous or discrete regulation. Discrete downward regulation must have a step size of maximum 25% of wind power plant rated power.

Settings for downward regulation at high wind speeds is to be agreed with SEV prior to commissioning.

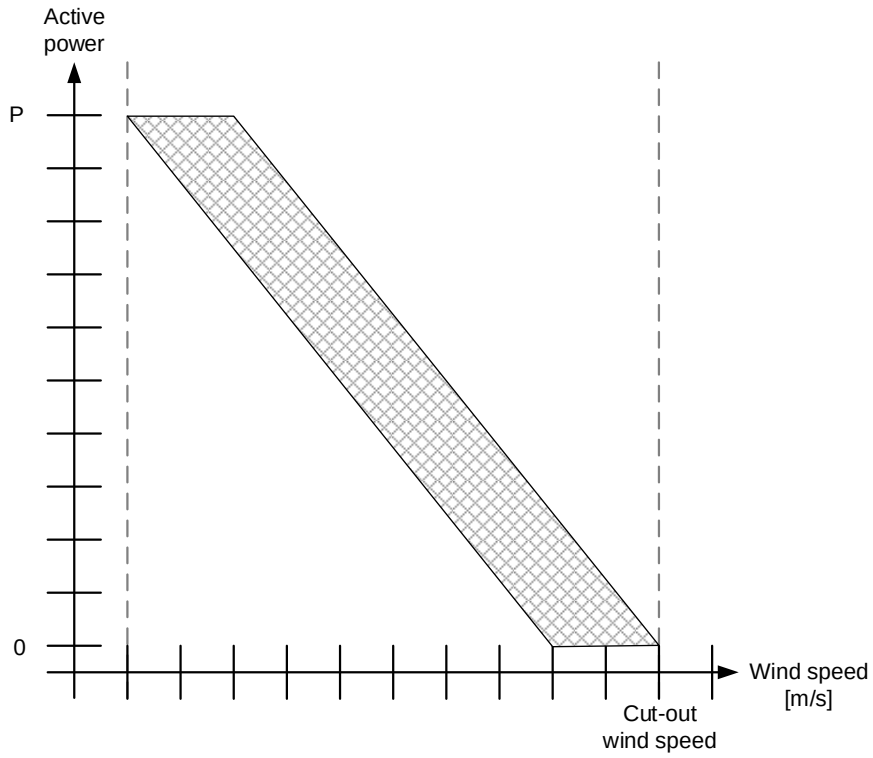


Figure 10: Downward regulation of wind power plants at high wind speeds. Downward regulation begins at a wind speed lower than the cut-out wind speed and ends no later than at the cut-out wind speed and must be within a band defined by SEV.

5.2 Reactive power and voltage control functions

A power plant must be equipped with reactive power control functions. The various control functions are mutually exclusive, meaning that only one function can be activated at a time. These functions perform control based on set points and settings defined by SEV.

All power plants must have a minimum power factor of between 0.9 and 1 when generating more than 10% of the rated power. Small power plants aim to generate power at a power

factor of 1, unless otherwise agreed with SEV. Control functions and settings for large power plants are agreed with SEV before commissioning.

In addition to fulfilling the general requirements, active power control functions must comply with the requirements provided in the following subsections.

5.2.1 Q control

The Q control function controls reactive power independently of active power. The reactive power is constant and follows the set point provided by SEV. An example is shown in Figure 11.

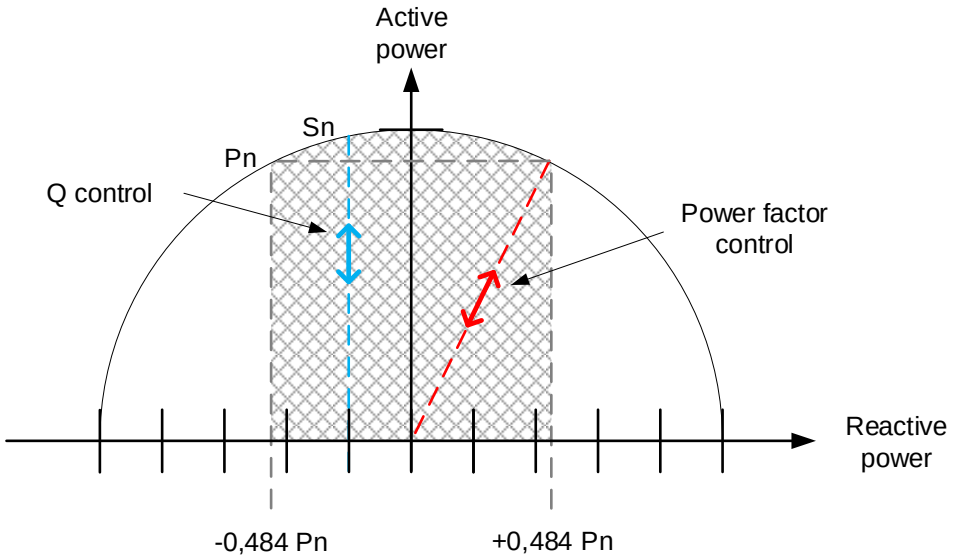


Figure 11: Q control (blue) and power factor control (red). The hatched area is the power plant operating range.

Regulation to a new set point must be commenced within 2 seconds and completed no later than 30 seconds after receipt of set point change order. Control accuracy must be ±0.5% of the rated power.

5.2.2 Power factor control

Power factor control is a control function, which ensures a constant power factor through reactive power control. The power factor must follow the set point defined by SEV. The power factor

must be within the range of 0.9 to 1. An example is shown in

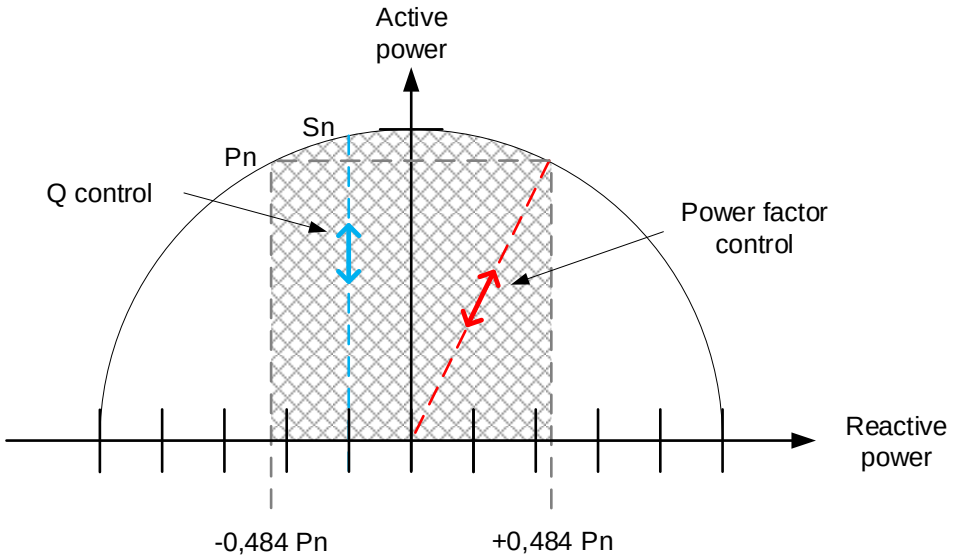


Figure 12.

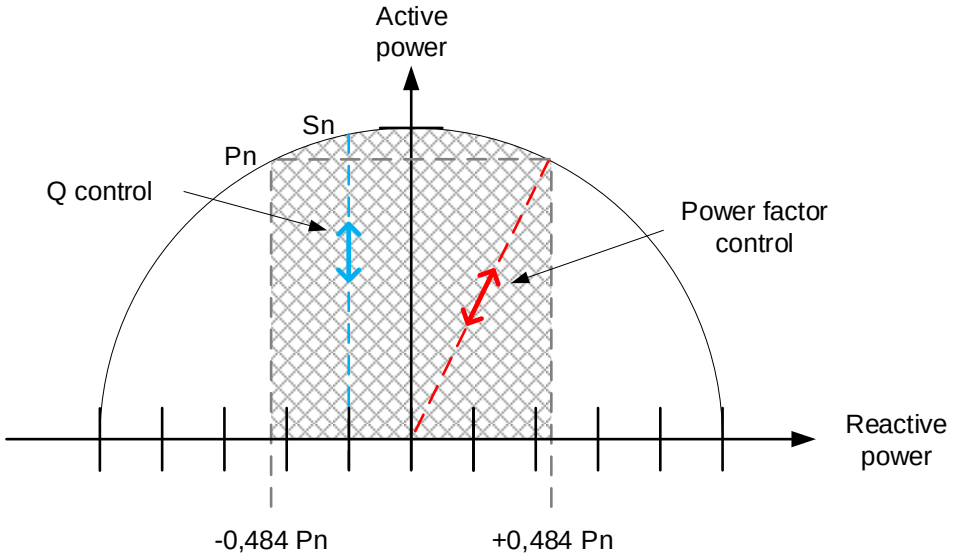


Figure 12: Q control (blue) and power factor control (red). The hatched area is the power plant operating range.

Regulation to a new set point must be commenced within 2 seconds and completed no later than 30 seconds after receipt of set point change order. Control accuracy must be ±0.5% of the rated power.

5.2.3 Automatic power factor control

Automatic power factor control is a control function which controls the reactive power to produce an inductive power factor in the event of high active generation. The control follows a curve, which is predefined by SEV, and is activated/deactivated automatically when the voltage in the voltage reference point reaches a certain level. The level of activation and deactivation can be controlled by means of set points. The normal values for activation and deactivation are 105% and 100% U_n, respectively.

An example of a curve for automatic power factor control is shown in Figure 13.

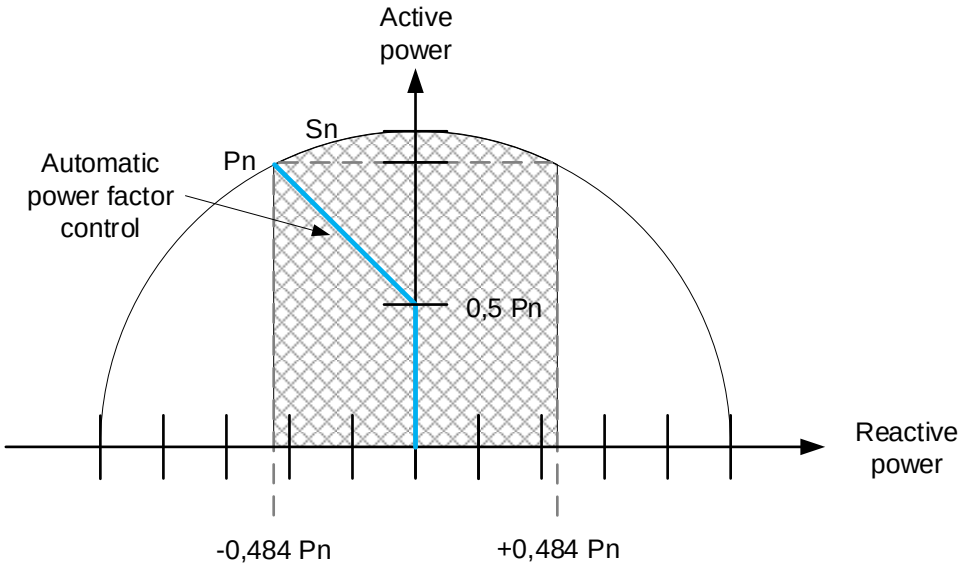


Figure 13: Automatic power factor control (blue). The power factor is controlled as a function of active power. The hatched area is the power plant operating range.

5.2.4 Voltage control

Voltage control is a control function that stabilises the voltage in the voltage reference point based on a set point defined by SEV. The reactive power from the power plant will be adjusted based on the voltage in the voltage reference point using a predefined droop provided by SEV. The droop is the relationship between voltage and reactive power, and is stated in % of the nominal reactive power. An example is shown in Figure 14.

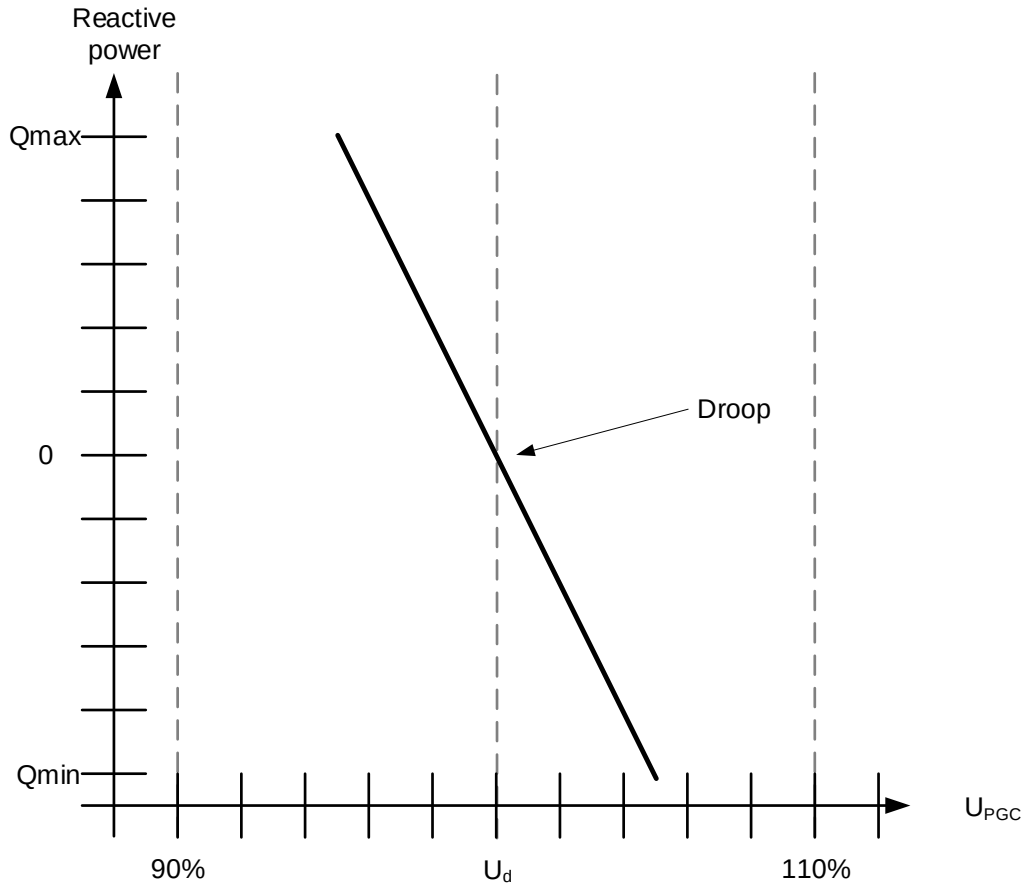


Figure 14: Voltage control. Reactive power as a function of voltage.

Regulation to a new set point must be commenced within 2 seconds, and completed no later than 10 seconds after receipt of set point change order. Control accuracy must be ±0.5% of the rated power.

5.3 Operating range

This section specifies the requirements for a power plant's operating range. A power plant must be able to operate continuously within the specified range under normal operation.

5.3.1 Category 1

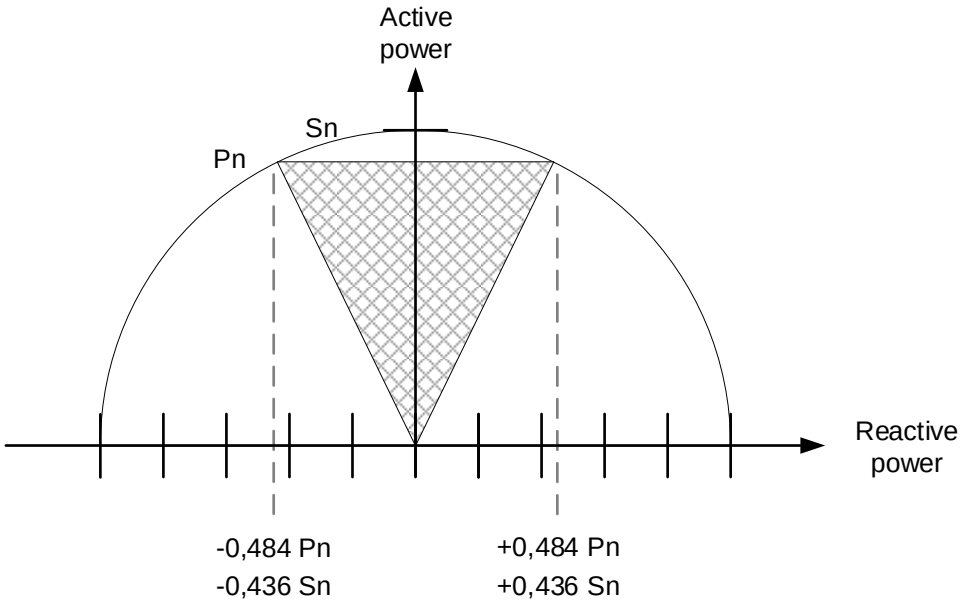


Figure 15: The hatched area is the required operating range for category 1 power plants.

5.3.2 Categories 2 and 3

Category 2 power plants must be able to operate within the operating range specified in Figure 16. The operating range for category 3 power plants is defined by SEV. Unless otherwise instructed by SEV, the operating range for category 3 power plants is the same as for category 2 power plants.

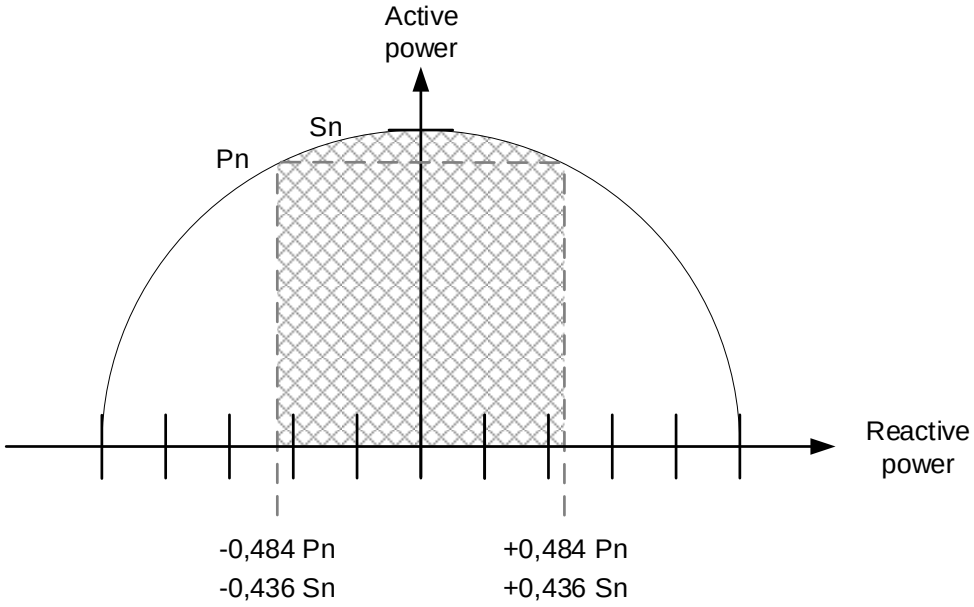


Figure 16: The hatched area is the required operating range for category 2 power plants.

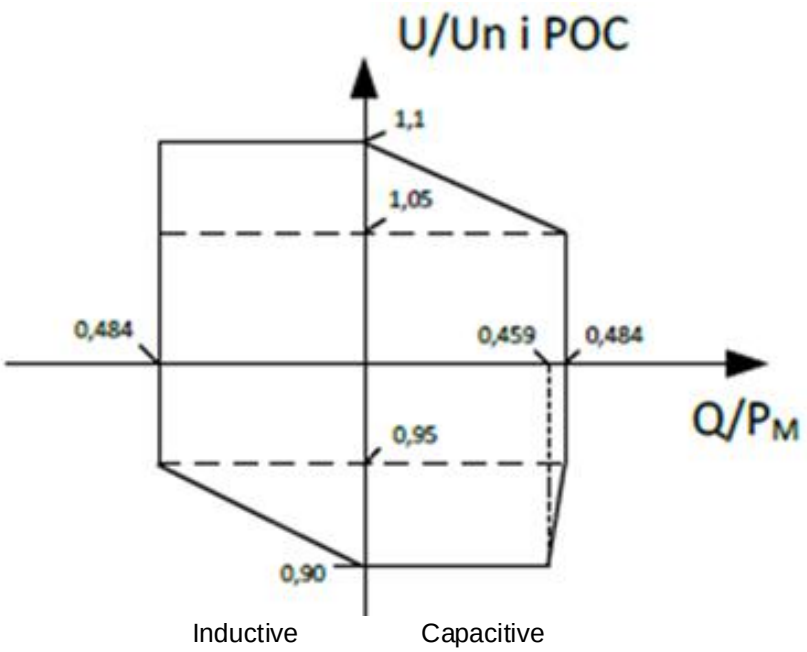


Figure 17: Requirements for reactive power as a function of voltage for category 2 and 3 power plants.

6. Protection

The purpose of the power plant's protective functions is to protect the power plant and ensure grid stability. The plant owner is responsible for ensuring that the power plant is dimensioned and equipped with the necessary protective functions so that the power plant:

- is protected against damage due to faults and incidents in the grid.
- Protects the grid against undesirable impact from the power plant to the widest extent possible.

SEV may require that the setting values for protective functions be changed following commissioning of the power plant. However, the change must not expose the power plant to impact from the grid outside of the design requirements specified in sections 2 and 3 (normal and abnormal operating conditions).

All voltage settings are stated as RMS values. The trip time stated is the measuring period during which the trip condition must constantly be fulfilled for the protective function to release a trip signal. The power plant must be disconnected if a measuring signal deviates more from its set value than the setting.

The voltage must be measured on all 3 phases as line voltage. Alternatively, when measuring on the low-voltage side of the plant transformer, it is possible to measure phase voltages.

Frequency must be measured simultaneously on all 3 phases.

6.1 Categories 1 and 2

The required protective functions as well as their settings and trip times are stated in Table 11.

Protective function	Symbol	Setting		Trip time	
Overvoltage (step 2)	U>>	$1{,}15 \cdot U_n$	V	200	ms
Overvoltage (step 1)	U>	$1{,}10 \cdot U_n$	V	60	s
Undervoltage (step 1)	U<	$0{,}9 \cdot U_n$	V	10	s
Undervoltage (step 2) *)	U<<	$0{,}8 \cdot U_n$	V	200	ms
Overfrequency	f>	52	Hz	200	ms
Underfrequency	f<	47	Hz	200	ms
Change of frequency *)	df/dt	±2.5	Hz/s	200	ms

Table 11: Protective settings for category 1 and 2 power plants.

*) One of the specified protective functions must be implemented.

6.2 Category 3

The required protective functions as well as their settings and trip times are stated in Table 12.

Protective function	Symbol	Setting		Trip time	
Overvoltage (step 3)	U>>>	$1{,}20 \cdot U_n$	V	50	ms
Overvoltage (step 2)	U>>	$1{,}15 \cdot U_n$	V	200	ms
Overvoltage (step 1)	U>	$1{,}10 \cdot U_n$	V	60	s
Undervoltage (step 1)	U<	$0{,}9 \cdot U_n$	V	10	s
Overfrequency	f>	52	Hz	200	ms
Underfrequency	f<	47	Hz	200	ms
Change of frequency	df/dt	±2.5	Hz/s	200	ms

Table 12: Protective settings for category 3 power plants.

6.3 Anti-islanding detection

Detection of islanding is performed by measuring frequency and voltage. As protection against islanding, either ROCOF or undervoltage (step 2) must be applied, see sections 6.1 and 6.2.

7. Communication

To ensure the operation of the grid, the power plant must be prepared for communication with SEV pursuant to this regulation.

For category 3 power plants, it must be possible to obtain measurements and maintain communication in all situations, including when the power plant is shut down and when the grid is dead. Local back-up supply must as a minimum ensure the logging of relevant measurements and data and ensure a controlled shutdown of the power plant's control and monitoring system.

7.1 Commands

A power plant must be capable of receiving a series of commands from SEV. These commands are used to set active control functions and to determine whether the power plant must or may start or shut down.

A list of commands is given in Appendix 1.

7.2 Set points

A power plant must be capable of receiving a number of set points from SEV. These set points are used to set the various control functions which a power plant must be able to use to ensure maintenance of grid stability and optimisation of grid operation.

A list of set points is given in Appendix 1.

7.3 Measurements

A power plant must be capable of sending a series of measurements to SEV. The measurements are used to monitor the condition of the power plant to ensure maintenance of grid stability and optimisation of grid operation.

A list of measurements is given in Appendix 1.

7.4 Status

A power plant must be capable of sending status information to SEV. The status information is used to monitor the power plant's condition to ensure maintenance of grid stability. It must be possible to send the following status messages (these are also listed in Appendix 1):

- Switchgear status in the POC
- Connected (in operation and on the grid)
- Standby (ready for operation, but not in operation)
- Fault (Disconnection alarm due to fault. In addition to the alarm signal, supplementary information about the cause of the fault must be provided)

8. Documentation

8.1 Category 1

The following documentation is required for category 1 power plants:

a. Settings of protective functions according to section 6.1.
b. Calculation of voltage dips in accordance with section 4.1.

8.2 Category 2

The following documentation is required for category 2 power plants:

a. Settings of protective functions according to section 6.1.
b. Single-line diagram showing the main components, electrical connections and the location of protective functions and metering points.
c. Documentation that the plant meets the requirements for power quality in accordance with section 4.

8.3 Category 3

The following documentation is required for category 3 power plants:

a. Settings of protective functions according to section 6.2.
b. Single-line diagram showing the main components, electrical connections and the location of protective functions and metering points.
c. Documentation that the plant meets the requirements for power quality in accordance with section 4.
d. PQ diagram illustrating the plant's ability to deliver reactive power as a function of the active power, i.e. the power plant's operating range.
e. Signal list describing available signals in accordance with section 7.
f. A dynamic simulation model is a model of the power plant's electrical properties and constraints. This model is used in SEV's control system.
g. Documentation that the plant meets the requirements for abnormal operation in accordance with section 3.
h. A verification report in which the individual requirements in this grid code are verified by means of testing, simulation or calculation. Mentioned in order of priority.

9. Other

9.1 Additional services to the grid

Subject to agreement with SEV, a power plant is allowed to supply additional services to the grid. Such additional services may for example be:

- PSS (Power System Stabiliser): Stabilisation of the grid and damping of electromagnetic oscillations.
- Synthetic inertia: Emulating inertia in the inverter-connected generation. This is often implemented according to the formula $dP = -k \cdot \frac{df}{dt}$.