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***Wind Turbines Connected to Grids with Voltages
above 100 kV***

*Technical regulation for the properties and the regulation
of wind turbines*

The regulation was approved by Elkraft System and Eltra in November 2004.
Registered with the Danish Energy Authority on December 3, 2004

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Appendix 1: Technical information for the regional grid company

Appendix 2: Elaboration of regulation functions in the farm controller

Version History

This Regulation replaces "Specifications for connecting Wind Farms to the Transmission Network" (Eltra doc. no. 74557 dated April 26, 2000 and Elkraft Transmission Trapla 99-7, first version).

1. Purpose of the Regulation

According to Order No. 444 dated June 11, 2002, on system operation and the use of the transmission grid, etc., Eltra and Elkraft System are responsible for preparing technical regulations for connecting electricity production units to the collective electricity supply grid as well as regulations relating to market player obligations. The regulations are to provide the system operators with a possibility of maintaining the technical quality and balance within the public power grid, etc.

Previously, large power station units undertook the tasks relating to regulation and stabilisation of the power system. As power production in Denmark is increasingly based on wind and on local combined heat and power (CHP) production, all production units, including wind turbines, will have to contribute to solving these tasks in future.

This technical Regulation lays down requirements for connecting wind turbines to the grid. Besides, it is to ensure that the wind farm has the regulation properties and dynamic properties essential for power system operation.

The Regulation does not deal with the economic aspects associated with the use of regulation properties.

2. Scope

The requirements in this technical Regulation shall apply to wind farms connected to the transmission grid in Denmark after December 1, 2004, that is, grids with voltages above 100 kV.

Wind farms shall be regarded as connected to the transmission grid when autoproduction for production and grid facilities is the only form of power consumption between the wind turbines and the transmission grid.

Replacement of and radical changes in existing wind turbines shall be considered as new units. All changes relating to the properties of wind turbines mentioned in this Regulation shall basically be considered as essential. The system operator shall determine whether changes are essential.

3. Terminology

Power system	A system consisting of central and local production units which are interconnected via transmission grids and distribution networks to consumption sites.
Transmission grid	In this technical Regulation transmission grids shall be defined as public grids with an operational voltage exceeding 100 kV.
Regional grid company	The owner of the transmission grid to which the wind farm is connected.
Connection point	The point where one or several wind turbines are connected to the grid of a grid company.
Reference point	Metering point for voltage or Mvar control. The reference point may differ from the connection point.
Wind farm	A wind farm is a collection of one or several wind turbines with equipment (for instance internal network for connection to the connection point).
Rated power of a wind turbine	The maximum active output which a wind farm is constructed to produce continuously under standard operating conditions and which appears from the type approval, cf. IEC 60050-415 [4].
Nominal power of a wind turbine	In this technical Regulation the nominal power of a wind farm is defined as the sum of the rated power for the wind turbines in the farm.
Rated wind speed	Specified wind speed at which a wind turbine can produce the rated power, cf. IEC 60050-415 [4].
Cut-off wind velocity	The maximum wind speed at shaft height at which a wind turbine is constructed to produce energy, cf. IEC 60050-415 [4].
Farm controller	Regulating function and interface for a wind farm, which enables the wind farm to be regulated locally and by remote control.
System operator	Defined in Section 5 of the Danish Electricity Supply Act. At present, the responsibility is borne by Elkraft System and Eltra east and west of the Great Belt, respectively.

4. General

The plant owner shall be responsible for ensuring that the wind farm observes the requirements of the regulation. The regional grid company and the system operator shall be entitled to ask for documentation to this effect at any time.

Besides, wind farms shall observe other applicable regulations, for instance market and system operation regulations. This ensures that wind farms connected to the transmission grid contribute sufficiently to the operational reliability of the power system.

Wind turbines shall be type tested according to the order of the Danish Energy Authority [7].

When a wind farm is connected to the transmission grid, the plant owner shall:

- send a request in writing to the regional grid company concerning grid connection of the plant
- fill in the form in **Appendix 1**, which is attached to the request for grid connection
- forward documentation for the wind turbine test, cf. section 8, at least three months before the commissioning of the wind farm
- forward a complete model for simulation of the wind farm, cf. section 8.3, at least three months before the commissioning of the wind farm
- carry out a commissioning test verifying that the requirements of the regulation have been observed. The detailed conditions shall be arranged jointly by the regional grid company, the system operator and the plant owner.

Upon approval of the supplied documentation the system operator shall grant permission to normal operation of the wind farm.

The current and voltage values mentioned in the regulation are true RMS values. The sign for power values follows the generator convention. Both active power and reactive power are thus calculated positively from the wind farm.

The plant owner shall be responsible for protecting a wind turbine against harmful damage caused by faults in the wind turbine or its installations as well as external impacts concerning:

- short-circuit currents and earth fault currents
 - recurrent voltages at disconnection of grid short circuits and earth faults
 - broken conductor
 - out-of-phase reclosing
- as well as other impacts occurring under extraordinary operating conditions.

5. Active Power and Power Regulation

Deviations from the desired power production caused by lack of wind resources shall not be covered by the requirements in chapter 5.

It shall be possible to limit the production of a wind farm to a random set-point value in the range of 20...100 per cent of rated power. See also chapter 9. The deviation between a set-point value and a metered 5-minute mean in the connection point shall not exceed ± 5 per cent of the rated power of the wind farm.

It shall be possible to set the regulation speed at upward and downward regulation in the interval 10...100 per cent of rated power per minute.

5.1 Total regulation of the power production

For each wind farm a joint function is to ensure remote control of the farm's total active power production. The function is called "farm controller" and is to ensure that regulating orders to the wind farm's total production are met in the connection point. The farm controller shall enable ordering of the various types of regulation as total orders which can be given both locally and via remote control. **Figure 5.1** illustrates the principle.

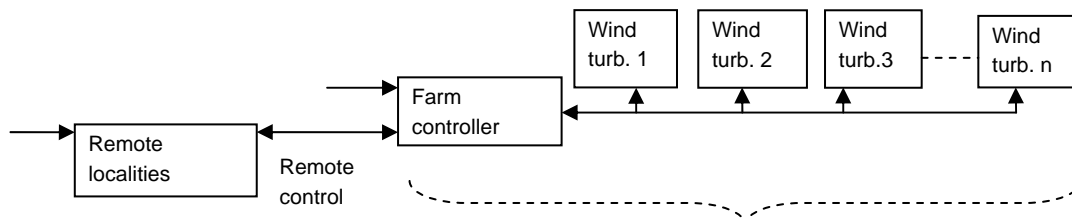


Figure 5.1 Farm controller in wind farm.

Each wind farm shall cover the following regulation functions for active power performed by the farm controller:

Type of regulation	Purpose	Primary regulation aim
Absolute production constraint	Limit the wind farm's current power production in the connection point to a maximum, specifically indicated MW value. Constraints may be necessary to avoid overloading of the power grid.	Limit production to optional MW_{\max}
Delta production constraint	It must be possible to reduce the power production of the wind farm by a desired power value compared to what is possible at present, thereby setting aside regulating reserves for the handling of critical power requirements.	Limit production by MW_{delta}
Balance regulation	The power production of the wind farm must be adjusted to the current power requirement with a view to maintaining the power balance of the balance responsible market player and/or the system operator. Downward/upward regulation of production must be possible.	Change current production by -MW/+MW with the set gradient and maintain the production at this level
Stop regulation	The wind farm must maintain the power production at the current level (if the wind makes it possible). The function results in stop for upward regulation and production constraints if the wind increases.	Maintain current production
Power gradient constrainer	For system operational reasons it may be necessary for wind turbines to limit the maximum speed at which the power output changes in relation to changes in wind speed. The power gradient constrainer is to ensure this.	Power gradients do not exceed the maximum settings
System protection	System protection is a protective function which must be able to automatically downward regulate the power production of the wind farm to a level which is acceptable to the power system. In the case of unforeseen incidents in the power system (for instance forced outage of lines), the power grid may be overloaded at the risk of power system collapse. The system protection regulation must be able to rapidly contribute to avoiding system collapse.	Downward regulate power production automatically on the basis of an external system protection signal

Type of regulation	Purpose	Primary regulation aim
Frequency control	At frequency deviations in the power system all production units connected to the transmission grid must be able to contribute with rapid automatic power control to support the restoration of normal frequency (50 Hz).	Regulate power production on the basis of local frequency metering for re-establishment of normal frequency

The precise regulation functionality and possible setting ranges for regulation parameters shall be arranged in detail with and be approved by the system operator before a plant is connected to the transmission grid. **Appendix 2** further describes the individual power control requirements.

The plant owner shall be responsible for ensuring that power control is done statically and dynamically stable for the farm as a whole. Actual control settings and constraints shall be agreed with the system operator.

5.1.1 Mutual prioritising of regulation functions

To ensure that the various regulating and constraint functions do not interfere with each other in an unintended way, the following priority ranking shall be observed where function 1 has preference over function 2, etc.

1. System protection
2. Frequency control
3. Stop regulation
4. Balance regulation
5. Power gradient constraint
6. Absolute production constraint
7. Delta production constraint.

The active power control functions shall be agreed in detail with the system operator.

5.2 Statement of non-supplied active production caused by power constraint

In the case of actual activation of one or more of the different types of regulation constraints the wind farm will not produce what it could have done without constraints. The wind farm shall:

- estimate the possible production
- meter the actual production
- calculate the "non-supplied production" divided on different types of regulation constraints.

The wind farm shall save the "non-supplied production" as a 5-minute time series. These data shall be transferable to the system operator on demand.

Estimation of the possible production shall take place with due consideration to the current operational conditions for the wind farm and be based on the production possibilities of the individual turbine. Documentation of the estimated potential production of the wind farm shall be stated as aggregation of the potential production of the individual turbines.

The accuracy of the statement of "non-supplied production" shall be documented by the plant owner and approved by the system operator, where it may be a matter of compensating the lost production.

As a minimum, calculations shall be made as 5-minute energy values.

6. Reactive Power Regulation

The wind farm shall be equipped with reactive power compensation ensuring that the reactive power as a mean value over 10 seconds is kept within the control band, as shown in Figure 6.1. This applies in the connection point at all production levels in the stated full-load range for the voltage, cf. section 7.

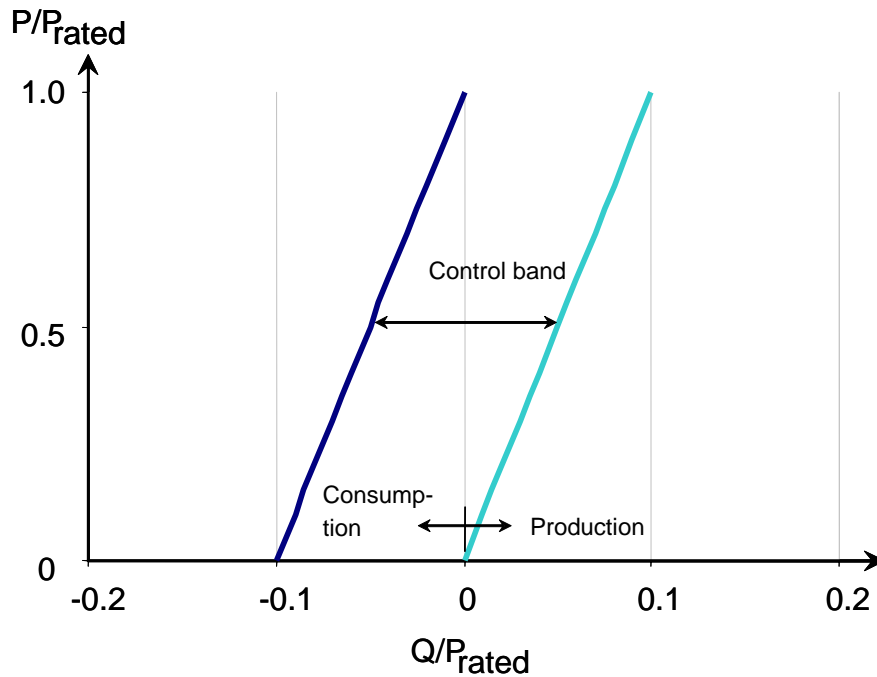


Figure 6.1 Requirements concerning a wind farm's exchange of reactive power in the connection point (P : Active power, Q : Reactive power).

For dynamic requirements for reactive power, please see section 8.

The plant owner shall supply a P-Q diagram showing the regulation capability for reactive power in the connection point. The amount of reactive power that a wind farm can adopt or supply shall be made available to the system operator for control of the power system's reactive power requirement. In such situations the control band in Figure 6.1 does not have to be observed, but the plant shall contribute as far as possible to maintaining the agreed Mvar exchange in the reference point or to maintaining an agreed voltage level in the reference point. The reference point shall be agreed for the individual wind farm.

Reactive regulation shall be done for the total wind farm by the farm controller function (see section 5.1). It shall be possible to place the desired reactive orders and settings here.

Type of regulation	Purpose	Primary regulation aim
Mvar regulation	Automatically ensure that the wind farm supplies the desired Mvar exchange in the reference point.	Maintain the desired Mvar value in the reference point.
Voltage regulation	Automatically ensure the desired voltage in the reference point by reactive regulation of the wind farm.	Maintain the desired voltage in the reference point.
Reactive regulation according to minimum requirements	The reactive production of the wind farm shall observe the permitted reactive characteristic in the connection point (see Figure 6.1).	Ensure satisfaction of reactive minimum requirements in this Regulation.

It shall be possible to order reactive regulation requirements via remote control and locally. Depending on the operational situation, the system operator changes the desired Mvar or voltage reference.

The reactive power regulation functions shall be agreed in detail with the system operator.

7. Dimensioning Voltages and Frequencies

A wind farm shall be dimensioned to produce at voltages and frequencies that deviate from rated values in the minimum hours indicated in **Figure 7.1**. Voltages and frequencies for which the figure states time-limited operation will occur in less than ten hours per year. Voltages above the upper limit for full-load voltage range (U_{HF}) will be very rare, for instance by reestablishment of the supply after major operational disturbances. Abnormal voltages and frequencies shall not result in a production decrease larger than the one indicated in **Figure 7.1**.

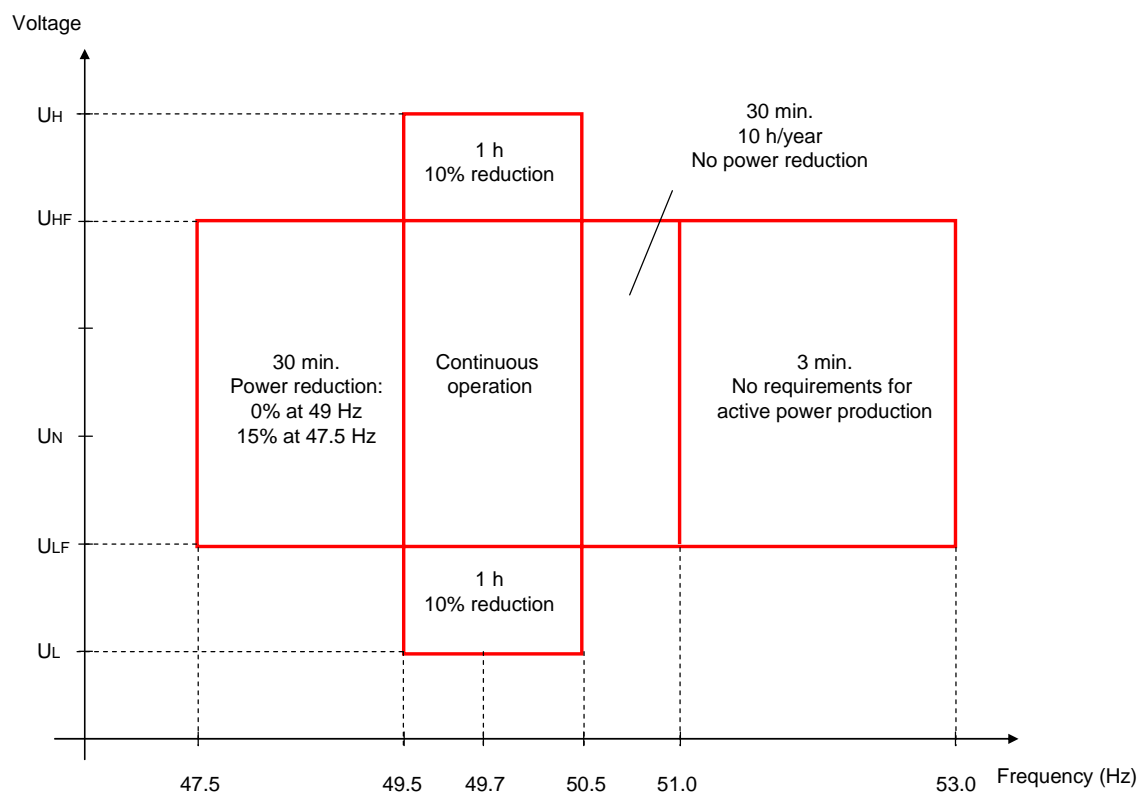


Figure 7.1 Dimensioning voltages and frequencies.

7.1 Voltages in the transmission grid

Nominal voltage, U_N	Lower voltage limit, U_L	Lower voltage limit for full-load range, U_{LF}	Upper voltage limit for full-load range, U_{HF}	Upper voltage limit, U_H
400 kV	320 kV	360 kV	420 kV	440 kV
150 kV	135 kV	146 kV	170 kV	180 kV
132 kV	119 kV	125 kV	145 kV	155 kV

The full-load range indicates the voltage range within which the wind farm shall be able to supply its nominal power.

The transmission grids are effectively earthed, cf. the Danish Heavy Current Regulation [6].

When the connection point is on the secondary side of a transformer belonging to the transmission grid, rated voltages and operational voltages shall be agreed with the regional grid company and the system operator. A full-load range of 90...105 per cent of rated voltage shall be considered.

7.2 Temporary overvoltages

If the wind farm is isolated with part of the power system, the wind farm shall not give rise to overvoltages which may damage the equipment in the power system.

The temporary overvoltages, which are defined in IEC-60071-1 [5], shall therefore be limited to 1.30 p.u. of the output voltage and be reduced to 1.20 p.u. of the output voltage after 100 ms. These voltages are the 50 Hz component, that is, without deformation due to harmonics from saturation in components.

8. *Interaction between Wind Turbines and the Remaining Power System at Grid Faults*

8.1 Situations in which a wind turbine shall be disconnected

The wind farm shall be equipped with voltage and frequency relays for disconnection of the wind farm at abnormal voltages and/or frequencies. The relays shall be set according to agreement with the regional grid company and the system operator. The protective functions of the wind turbine shall have settings and time delays meeting the requirements in section 8.2.

8.2 Situations in which a wind turbine must not trip

The wind farm shall remain connected after the below faults in the transmission grid. Likewise, compensation plants shall remain connected.

Three-phase short circuit	Short circuit in 100 ms
Two-phase short circuit with/without earth contact	Short circuit in 100 ms followed by a new short circuit 300...500 ms later, also with a duration of 100 ms
Single-phase short circuit to earth	Single-phase earth fault 300...500 ms later, also with a duration of 100 ms

A wind farm shall have sufficient capacity to meet the above-mentioned requirements in case of the following three independent sequences:

- at least two single-phase earth faults within two minutes
- at least two two-phase short circuits within two minutes
- at least two three-phase short circuits within two minutes.

Additionally, there shall be sufficient energy reserves (emergency power, hydraulics and pneumatics) for the following three independent sequences:

- at least six single-phase earth faults with five-minute intervals
- at least six two-phase short circuits with five-minute intervals
- at least six three-phase short circuits with five-minute intervals.

To verify that the basic stability properties are incorporated into the design of the wind farm, a turbine test shall be carried out which covers all types of wind turbines included in the wind farm. If the chosen wind turbine technology implies central installations or the like, this shall be included in the turbine test, which shall be carried out for a model of the specific wind farm. The turbine test is carried out by simulation of the wind farm stability by applying a symmetric three-phase short circuit to the power grid.

Furthermore, the wind farm shall be able to withstand the impacts from asymmetrical faults in the grid where unsuccessful automatic reclosure takes place without necessitating disconnection of wind turbines in the wind farm from the grid.

8.2.1 Turbine test, simulation of stability at symmetric three-phase grid fault

By means of simulation the plant owner shall document the behaviour of the wind farm by application of a fixed voltage profile. The simulation results shall be documented in a report that shall be approved by the system operator.

The report shall indicate how the RMS value of current as well as active and reactive power through the wind farm's connection terminals as well as the voltage vary during the simulation. Measurement data shall be sent which can be used to validate the model.

The report shall state which program was used for the calculation. Besides, it shall include a description of the applied model of the wind farm to a level of detail that makes it possible to repeat the calculation in the analysis tool of the system operator.

The turbine test shall be done with the voltage profile shown in **Figure 8.1** and shall show the behaviour of the wind farm in the case of a three-phase fault with a slowly recovering voltage.

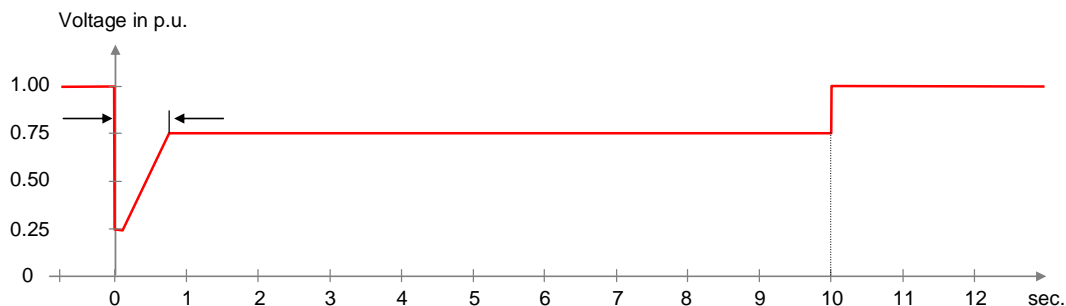


Figure 8.1 Voltage profile for simulation of symmetric three-phase faults.

The power system shall be represented by a Thevenin equivalent as shown in **Figure 8.2**. The power value of the voltage at the clamps of the Thevenin generator shall vary as shown in **Figure 8.1** based on the rated voltage in the connection point.

The short-circuit power (S_k) in the connection point (A) is assumed to be 10 times the rated power (P_n) of the wind farm and the phase angle 84.3° ($R/X = 0.1$), see **Figure 8.2**. The report shall describe how the internal network is included in the model.

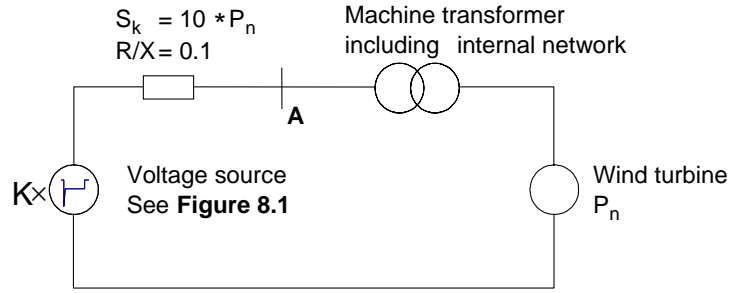


Figure 8.2 Thevenin equivalent in single-phase illustration.

To adjust for the voltage drop over the short-circuit impedance between the voltage source and A, the output voltage of the ideal voltage source is multiplied by a constant factor K so that there is 1.0 p.u. voltage in point A before the fault.

The calculation shall be done under the following starting conditions:

- rated wind speed
- nominal rotor speed
- reactive power compensation corresponding to the wind turbine being neutral in point A.

The wind farm meets the requirements when the following is observed:

- a) The wind farm shall produce the rated power no later than 10 seconds after the voltage is above 0.9 p.u. again. During the voltage dip the active power in the connection point shall meet the following condition:

$$P_{current} \geq k_p \cdot P_{t=0} \left(\frac{U_{current}}{U_{t=0}} \right)^2$$

where

- P_{current} : Current active power measured in the connection point
 - $P_{t=0}$: Power measured in the connection point immediately before the voltage dip
 - $U_{t=0}$: The voltage in the connection point immediately before the voltage dip
 - U_{current} : Current voltage measured in the connection point
 - $k_p = 0,4$: Reduction factor considering any voltage dips to the generator terminals.
- b) Exchange of reactive power with the grid shall meet the requirement in section 6 no later than 10 seconds after the voltage is above 0.9 p.u. again. During the voltage dip the wind farm must as a maximum take a reactive current measured in point A corresponding to 1.0 times the nominal current of the wind farm.
- c) During the voltage dip the wind farm's regulation of the reactive power shall change from normal regulation to maximum voltage support. This control mode shall contribute to re-establishing normal voltage as soon as possible. The regulation shall also be ensured against overshoot, so that dangerous overvoltages are avoided.

8.2.2 The wind farm's stability at asymmetric grid faults and unsuccessful reclosure

The wind farm shall be able to withstand the impacts from the following asymmetric faults in the grid without requiring disconnection of wind turbines in the wind farm:

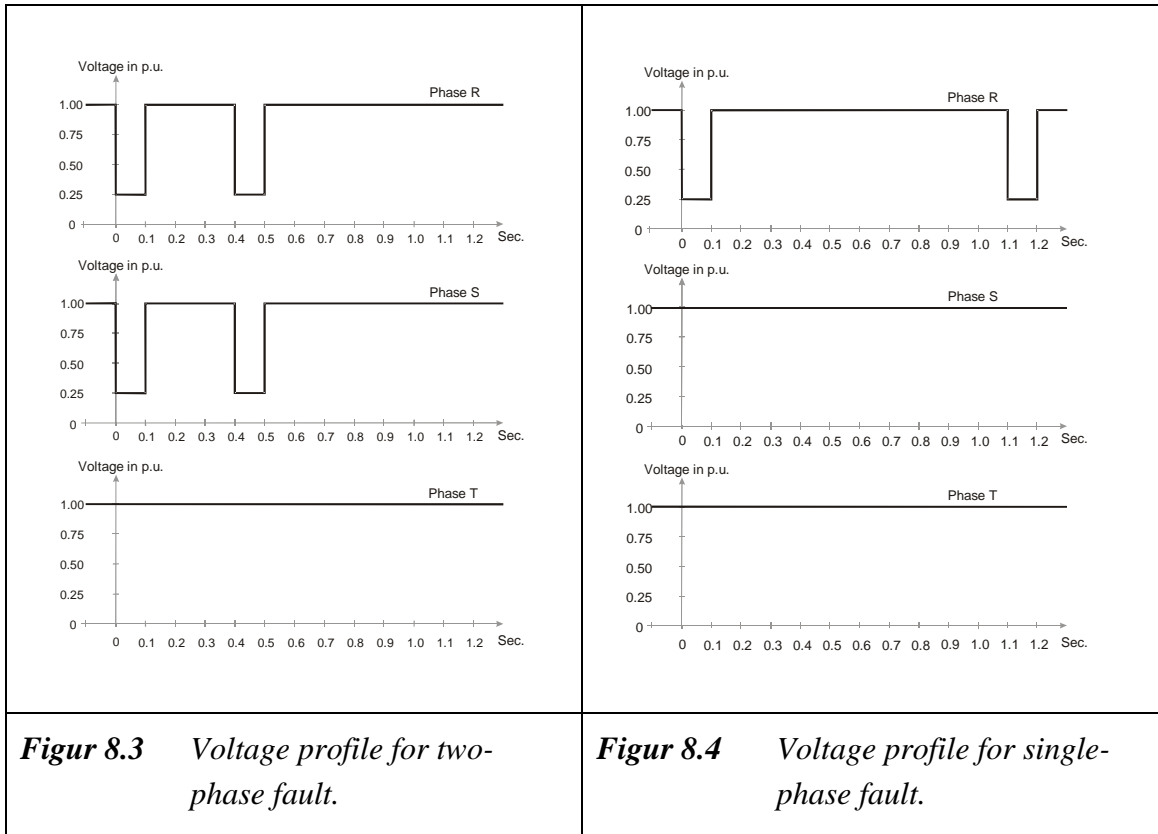
- Two-phase fault on a line in the transmission grid with unsuccessful reclosure. See **Figure 8.3**.
- Single-phase fault on a line in the transmission grid with unsuccessful reclosure. See **Figure 8.4**.

If the connection point is on the secondary side of a transformer belonging to the transmission grid, vector group and phase shift in this transformer shall be taken into consideration at examination of asymmetric faults. Unless otherwise agreed, it shall be assumed that the transformer is YNd11-connected.

Besides, the plant owner shall guarantee that:

- The wind turbines in the wind farm can withstand the thermal impacts at repetition of the turbine test after two minutes.

- The wind turbines in the wind farm can withstand the thermal impacts at repetition of the asymmetric faults described above after two minutes.
- There are sufficient energy reserves (emergency power, hydraulics and pneumatics) for six repetitions of the turbine test at five-minute intervals.
- There are sufficient energy reserves (emergency power, hydraulics and pneumatics) for six repetitions of asymmetric faults described above at five-minute intervals.



8.3 Simulation model

The plant owner shall forward documentation for a complete model (network and generator constants, simplified diagram and parameters for control of turbine and farm controller as well as protection) of the wind farm, which can be used by the system operator for analyses of the dynamic stability of the transmission grid. The model shall be suitable for simulation of RMS values (not EMT model). Measurements shall be forwarded which can be used to validate the model. The system operator shall approve the model.

9. *Start-up and Stop of a Wind Turbine*

A wind turbine which has been disconnected due to high wind speed shall automatically reclose when the speed has decreased to below the cut-off wind velocity.

The cut-off wind velocity measured as a ten-minute mean value shall be at least 25 m/s.

10. Voltage Quality

The assessment of the impact of the wind farm on the voltage quality shall be based on the following concepts:

- rapid voltage changes or voltage jumps
- voltage fluctuations and flicker
- harmonics.

For the relevant connection point, requirements for harmonic voltages shall be converted to requirements for harmonic currents according to agreement with the system operator.

10.1 Rapid voltage changes

Rapid voltage changes shall be defined as a single rapid change of the RMS value of the voltage and where the voltage change has a certain duration. This may e.g. occur at breaker switching within the wind farm. Maximum permissible values for rapid voltage changes from the wind farm in the connection point are:

General constraint	<3.0%
Until a frequency of 10 per hour	<2.5%
Until a frequency of 100 per hour	<1.5%

Requirements based on IEC 61000-3-7 [1].

10.2 Voltage variations and flicker

The flicker contribution from the wind farm in the connection point shall be limited so that:

$P_{st} < 0.30$, determined as a weighted average of the flicker contribution over ten minutes.

$P_{lt} < 0.20$, determined as a weighted average of the flicker contribution over two hours.

The flicker contributions P_{st} and P_{lt} are defined in IEC 61000-3-7 [1].

10.3 Harmonic voltages

The harmonic disturbance D_n for each individual harmonic shall be defined as:

$$D_n = \frac{U_n}{U_1} \times 100\%$$

The total harmonic effective distortion THD shall be defined as:

$$THD = 100 \sqrt{\sum_{n=2}^{50} \left(\frac{U_n}{U_1}\right)^2} \quad \%$$

D_n shall be lower than 1 per cent for $1 < n < 51$ in the connection point.

THD shall be smaller than 1.5 per cent.

11. External Control and Metering of Wind Turbines

11.1 Data extent

The following table specifies which data shall be transferable between a wind farm and external localities such as the production balance responsible player and/or the system operator. The overview is indicative, and details shall be agreed for the individual farm with the relevant external parties. As a minimum, the data extent to the system operator shall be in accordance with the applicable Metering Regulations.

Summary data overview for the wind farm
Setting, activating and displaying the farm controller's functions and data Active power measurement [MW] in the connection point Reactive power measurement [MW] in the connection point Voltage measurement in the connection point Possible production [MW, +Mvar, -Mvar] Lost production [MWh/5 minutes] as time series
Number of turbines stopped due to low wind Number of turbines stopped due to high wind Number of turbines stopped due to maintenance Number of turbines stopped due to forced outage Total number of turbines out of operation Number of turbines with limited capacity
Relevant topology information of the internal network Relevant plant alarms
Wind speed Wind direction Temperature Atmospheric pressure

Requirements for metering accuracy are further defined in the Regulation on Measurements for System Operation Purposes (Måleforskrift til systemdriftsformål).

11.2 Data transfer

The protocol for data communication between the wind farm and the system operator shall be IEC-60870-5-101 [3] and IEC-60870-5-104 [8]. Which of these protocols is to be used shall be determined by the system operator.

In the case of insufficient or lacking remote control, the system operator shall be entitled to demand that the wind farm be disconnected.

11.3 Fault recorder

To control the response of the wind farm to faults in the power system, recording equipment shall be installed which is triggered in the case of faults. The recording shall also be used to verify the model of the wind farm.

For a selected wind turbine of each type of turbine in the farm the plant owner shall install a fault recorder which as a minimum records:

- number of shaft revolutions (rpm)
- active power
- reactive power
- voltage.

The metering can be done on the low-voltage side of any wind turbine's power transformer. The metering points shall be agreed with the system operator.

The system operator shall install a fault recorder in the connection point which records:

- voltage
- active power
- reactive power
- frequency
- current
- harmonics.

Recording of correlated time series of metering shall be able to take place from ten seconds before triggering until 60 seconds after triggering. The fault recorder shall include the necessary number of metering channels to be able to register the above values.

Trigger signals and their settings as well as data exchange format shall be agreed with the system operator.

The plant owner, the regional transmission company and the system operator shall have full access to data from the installed fault recorders on demand.

References

- 1 IEC 61000-3-7: *Electromagnetic compatibility (EMC — Part 3: Limits – Section 7: Assessment of emission limits for fluctuating loads in MV and HV power systems – Basic EMC publication.*
- 2 IEC 61400-21: *Measurement and assessment of power quality characteristics of grid connected wind turbines.*
- 3 IEC-60870-5-101: *Telecontrol equipment and systems, part 5-101.*
- 4 IEC 60050-415. *International Electrotechnical Vocabulary – Part 415: Wind turbine generator systems.*
- 5 IEC 60071-1: *Insulation co-ordination – Part 1: Definitions, principles and rules.*
- 6 The Danish Heavy Current Regulation.
- 7 Order No. 270 af 02/05/1991 *Order on type testing and certification of wind turbines (Bekendtgørelse om typegodkendelse og certificering af vindmøller).*
- 8 IEC-60870-5-104: *Telecontrol equipment and systems, part 5-104.*

Technical Information for the Regional Grid Company

The information in the tables shall be based on the definitions and metering procedures in IEC 61400-21 [2]. Deviations shall be stated. If the regional grid company wishes so, it shall receive a test report. Any change of the stated settings in the table shall be pre-approved by the regional grid company and shall result in an updating of the table.

Wind turbine type/technical data

Wind turbine manufacturer	
Wind turbine type designation	
Type approval	
Name of test organisation	
Rated wind speed, $v_{\text{rated power}}$ [m/s]	
Rated power, P_n [kW]	
Rated apparent power, $S_{\text{rated power}}$ [kVA]	
Maximum permitted power, P_{mc} [kW]	
Maximum measured power:	
- 60 seconds mean value, P_{60} [kW]	
- 0.2 seconds mean value, $P_{0.2}$ [kW]	
Rated voltage [V]	
Rated current, I_n [A]	

Flicker coefficient with the wind turbine in operation, $c(\psi_k, v_a)$

Average wind speed, v_a [m/s]	Network impedance phase angle, ψ_k [degrees]			
	30	50	70	85
6				
7.5				
8.5				
10.0				

Voltage changes and flicker caused by switching operations

Case of switching operation	Start-up at cut-in wind speed			
Max. number of switching operations for two hours, N_{120}				
	Network impedance phase angle, ψ_k [degrees]			
	30	50	70	85
Flicker step factor, $k_f(\psi_k)$				
Voltage change factor, $k_u(\psi_k)$				

Case of switching operation	Start-up at rated wind speed			
Max. number of switching operations for two hours, N_{120}				
	Network impedance phase angle, ψ_k [degrees]			
	30	50	70	85
Flicker step factor, $k_f(\psi_k)$				
Voltage change factor, $k_u(\psi_k)$				

Case of switching operation	Worst case switching between generators or windings			
Max. number of switching operations for two hours, N_{120}				
	Network impedance phase angle, ψ_k [degrees]			
	30	50	70	85
Flicker step factor, $k_f(\psi_k)$				
Voltage change factor, $k_u(\psi_k)$				

Harmonics

This table shall only be filled in for wind turbines equipped with an electronic power inverter.

It is unnecessary to state values lower than 0.1 per cent of rated current.

Order	Output power [kW]	Harmonic current [% of I_{rated} power]	Order	Output power [kW]	Harmonic current [% of I_{rated} power]
2			3		
4			5		
6			7		
8			9		
10			11		
12			13		
14			15		
16			17		
18			19		
20			21		
22			23		
24			25		
26			27		
28			29		
30			31		
32			33		
34			35		
36			37		
38			39		
40			41		
42			43		
44			45		
46			47		
48			49		
50					
Max. total harmonic current distortion [% af I_n]					
Output power at max. total harmonic current distortion [kW]					

Elaboration of Regulation Functions in the Farm Controller

1. Absolute production constraint

An adjustable absolute production constraint function shall be implemented.

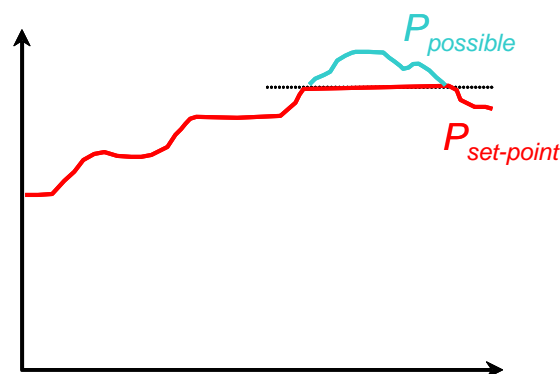


Figure 1 Absolute production constraint.

It shall be possible to limit the production of a wind farm to a random set-point value in the 20...100 % range of rated power. The deviation between a set-point value and a measured 5-minute mean value in the connection point shall not exceed ± 5 % of the rated power of the wind farm. It shall be possible to set the regulation speed at upward and downward regulation in the interval 10...100 % of rated power per minute.

2. Delta production constraint

It shall be possible to limit current production compared to possible production. The power production is always limited to a set delta power value below possible production. It shall be possible to set the delta change as a MW value.

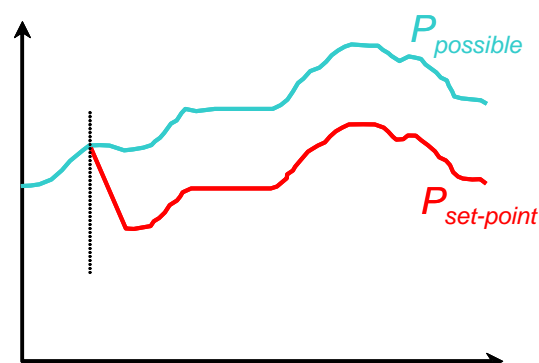


Figure 2 Delta production constraint.

3. Balance Regulation

The balance regulation shall be implemented as a rapid power regulation ensuring upward/downward regulation of the farm production when required.

A power change shall be set optionally with balance regulation orders, partly as a desired change (\pm MW change) to current production, partly as a desired power gradient (MW/min).

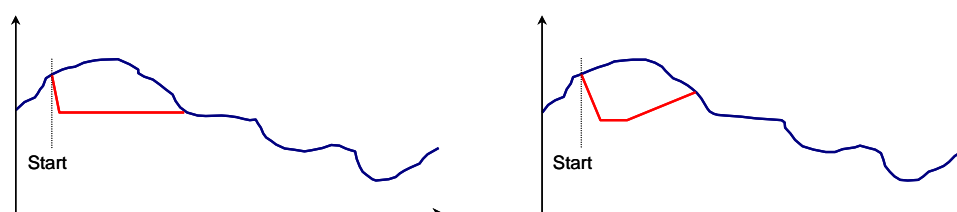


Figure 3 Balance regulation without and with automatic cancellation.

It shall be possible to choose that the balance power is reset automatically after a set time and that return to the applicable power order settings is made with adjustable gradient.

In connection with balance regulation it may be permitted that the production exceeds the limit from the absolute production constraint. How large an exceeding is allowed shall be set separately.

It shall be possible to enable/disable balance regulation separately.

4. Stop Regulation

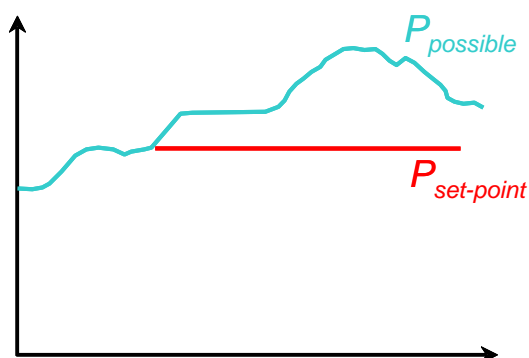


Figure 4 Stop regulation.

Activation of "Stop regulation" is to ensure that the wind farm maintains current power in so far as possible (at falling wind this will, however, be impossible). At cancellation of "Stop regulation" return to the applicable power order settings shall be made with an adjustable gradient.

5. Power Gradient Constraint

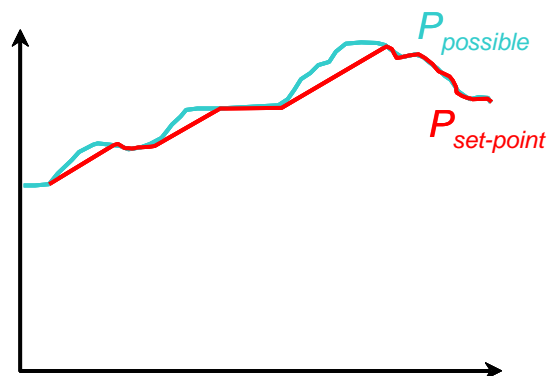


Figure 5 Power gradient constraint.

The power gradient constrainer shall prevent farm production from increasing too fast when the wind speed is increasing or when the farm is to be started in high wind. If the wind speed is decreasing, the constraint does not have any function, of course, unless the delta production constraint is in function. It shall be possible to set the maximum permissible speed at production increase and decrease individually. It shall be possible to enable/disable the function.

The system operator shall determine the current maximum permissible values for gradient constraints.

6. System Protection

Via an external signal to the farm controller it shall be possible to make a rapid downward regulation of the wind farm in the form of system protection regulation.

Downward regulation shall take place at a pre-set speed. It shall be possible to set the maximum amount of power that system protection regulation shall be able to downward regulate. As long as the external system protection signal is active and maximum power change has not been reached, the downward regulation shall continue. When the external signal ceases,

system protection regulation shall terminate and current power production shall be maintained.

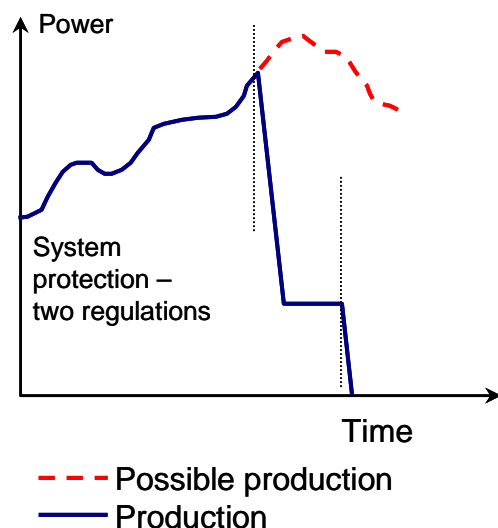


Figure 6 System protection.

The system protection function shall be reset manually. When this takes place, regulation shall be done to return to the current regulation conditions. The speed at which this happens shall be set separately. If the external system protection signal is still active when the function is reset, a new power limit is calculated on the basis of the current production, and the farm may be regulated further downwards.

In the case of system protection intervention it shall be possible to downward regulate the production from full load to stop in a maximum of 30 seconds. It shall be possible to connect/disconnect the system protection function separately.

7. Frequency-controlled Regulation of the Power Production

By automatic frequency regulation the control equipment of the individual turbine shall change the production depending on the grid frequency. Via the farm controller it shall be possible to set the total regulation characteristics of the wind farm.

The figure below shows two examples of frequency control. In one case (full-drawn line) the frequency control can only make downward regulation of the production, whereas in the other case (dotted line) it can also make an upward regulation due to the previous downward regulation.

Production in % of the production
without frequency control

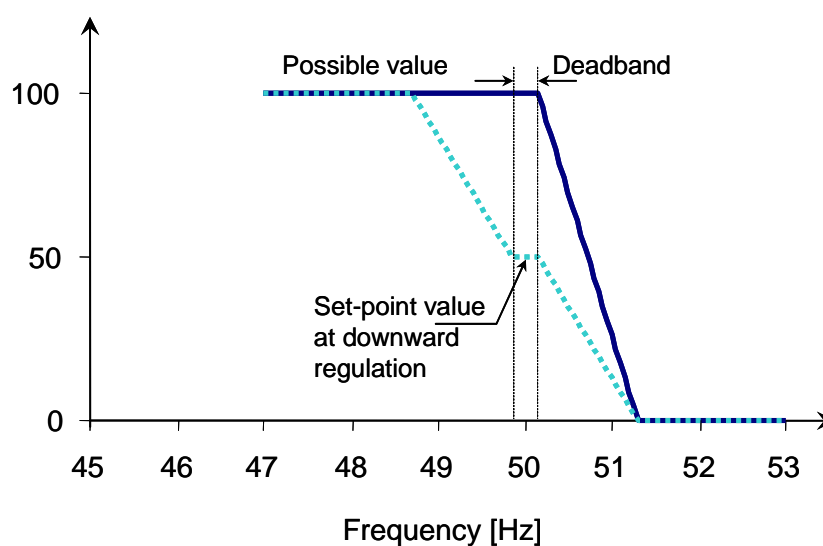


Figure 7 Frequency regulation with and without previous downward regulation.

At production below 20 % of the wind turbine's rated power the turbine shall trip if it cannot downward regulate any further at a continued high frequency.

Setting of the farm's frequency control characteristics shall be done collectively.

The setting parameters are shown in the table below.

Setting parameter	Setting range	Default value
Reference frequency (f_{ref})	49.90...50.10 Hz	50,000 Hz
Lower frequency limit for the regulation range at underfrequency (f_n)	50.00...47.00 Hz	49.00 Hz
Upper frequency limit for the regulation range at over frequency (f_ϕ)	50.00...53.00 Hz	51.00 Hz
Lower frequency limit for the deadband at underfrequency (Δf_{d-})	0...500 mHz	150 mHz
Upper frequency limit for the deadband at overfrequency (Δf_{d+})	0...500 mHz	150 mHz
Regulation factor for the production applying to frequencies in the range $f_n \dots (f_{ref} - \Delta f_{d-})$ samt $(f_{ref} + \Delta f_{d+}) \dots f_\phi$. (Regulation factor 1 means that the production is the maximum possible – or the set-point value if this is specified)	Overfrequency : $(1 - \frac{f - (f_{ref} + \Delta f_{d+})}{f_\phi - (f_{ref} + \Delta f_{d+})}) \cdot 100\%$ 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

It shall be possible to set the above frequency parameters at a resolution of at least 10 mHz.

In the frequency range 47.00...53.00 Hz the frequency measuring error shall not exceed ± 10 mHz. The requirement shall be met even though the curve of the voltage may be distorted. A phase jump of 20° shall not influence the regulation.

It shall be possible to connect/disconnect frequency regulation separately for the wind farm and for the individual wind turbine.