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Official translation of

Wind turbines connected to grids with voltages below 100 kV

Technical regulations for the properties and the control of wind turbines

Approved 19 May 2004

This document is a translation into English of the official Danish technical regulations. In the case of divergences between the English version and the Danish version, the Danish version will overrule the English translation version

Contents

1. Purpose of the regulations

In pursuance of Executive Order No. 444 of 11 June 2002 on system operation and use of the transmission grid etc., Eltra and Elkraft System are required to prepare technical regulations for connection of power generating plants to the public power supply grid and regulations concerning the players' obligations. The regulations must enable the system operators to maintain technical quality and balance within the interconnected power system etc.

Previously, control and stabilisation in the electricity system were taken care of only by large power station units. However, since electricity in Denmark is increasingly produced at small-scale production plants, all generating plants, including wind power plants, must take part in those tasks in future.

These Technical Regulations concern wind power plants connected to grids with voltages below 100 kV.

The Danish Electricity Supply Act and related Executive Orders set out a wide range of factors that have consequences for cost distribution and procedures. Annex 1 gives a description of the legislative basis and rules of importance relating to connection of wind turbines to grids.

The regulations are intended to ensure that the wind turbines have the control and dynamic properties needed for operation of the power system with respect to both short-term and long-term security of supply and voltage quality.. The regulations do not describe how these properties will or may be used in the future electricity supply system.

The regulations are intended to contribute to optimum allocation of resources in the system together with regulations for the rest of the generating plant, the transmission grid, the distribution grid and electricity consumption, This includes balancing the requirements concerning the different types of plants.

The regulations do not deal with the financial aspects of using the control properties.

1. Purpose of the Regulations

The regulations do not deal with metering for accounting purposes or technical requirements concerning this. These requirements are given in Eltra's and Elkraft System's Technical Regulations concerning Metering. The measurements mentioned in these Technical Regulations are online measurements of operating data.

2. Scope of validity

The requirements in these Technical Regulations apply to wind turbines that are connected to grids in Denmark, after 1 July 2004, with voltages equal to or less than 100 kV.

The requirements are divided into general requirements that all wind turbines must meet and some supplementary requirements.

Irrespective of ownership, the supplementary requirements must be met if, after the technical regulations go into effect, wind turbines with a total rated power of 1.5 MW[1] or more are or can be connected in a connection point (see section 3). Wind turbines that can be connected later must thus be included. Wind turbines replacing existing wind turbines are regarded as new installations.

[1] New wind turbines are expected to be erected in an area which in a regional, municipal or local plan is zoned for erection of wind turbines with a total capacity of at least 1.5 MW.

3. Terminology

Electricity system	A system consisting of large and small generating plants interconnected and connected to consumers points via the transmission and distribution grids.
Transmission grid	In these Technical Regulations a transmission grid is defined as a grid with an operating voltage of more than 100 kV.
Distribution grid	In these Technical Regulations a distribution grid is defined as a grid with an operating voltage of less than 100 kV.
Main substation	A substation connected to a grid with voltages of more than 30 kV.
Connection point	The point at which one or more wind turbines is/are connected to a grid company's grid.
Wind farm	A wind farm is a single wind turbine or a group of several wind turbines with associated equipment.
Wind turbine's rated output	The largest active output that a wind turbine is designed to generate continously under standard operating conditions and which appears from the type approval [10].
Wind farm's nominal rated output	In these Technical Regulations, the nominal output of a wind farm is defined as the sum of the rated outputs of the wind turbines in the wind farm.
Rated wind velocity	The specified wind velocity at which a wind turbine can produce its rated output [10].
Stop wind velocity	The maximum wind velocity at shaft height at which a wind turbine is designed to produce energy [10].
General requirements	See Section 2.
Supplementary requirements	See Section 2.

4. *Generally*

The owners of wind turbines are responsible for ensuring that the turbines meet the requirements given in the Technical Regulations and for verifying that the requirements in chapter 11 are met. The System operator (Eltra or Elkraft System) may demand written documentation for this at any time.

The form in Annex 2 must be completed and sent to the grid company before a wind turbine is connected to a distribution grid. Any change made to the notified settings must be approved by the grid company in advance and lead to updating of the form, which the grid company must keep.

The grid company must report the wind turbine's base data to the system operator (to Eltra via http://wim.eltra.dk/wim. For Elkraft System the base data must be reported as specified in Elkraft System's Market Regulations D1, Annex 7, “Reporting to the base data register for wind power plants”. The regulations in question are available on Elkraft System's website: www.elkraft-system.dk). In addition, the turbine owner must enter into agreement with an approved balancing responsible market player before the turbine is connected to the grid. If an agreement is reached on control of the exchange of reactive power with the grid, the grid company must also send a P-Q diagram showing the control range applying in the connection point.

The current and voltage values mentioned in these Technical Regulations are true RMS values.

A wind turbine owner is responsible for safeguarding his wind turbine against damage caused by defects in the turbine or its installation and against external impacts in connection with:

- short circuit and earth currents,
- recovering voltages during clearing of grid short circuits and earth faults,
- increased voltage on fault-free phases in the event of single-phase earth faults in insulated and Petersen coil-grounded grids,
- phase failure,
- out-of-phase reclosing and other impacts that occur during abnormal operating conditions

5. Active power and power control

5.1 Remote control of production

Supplementary requirements

It must be possible to limit a wind turbine's production to any power setpoint in the range 20-100 % of its rated power. The deviation between the power setpoint and a measured 5-minutes' mean value in the connection point must not exceed ±5 % of the wind turbine's rated power.

It must be possible to control the allowed production externally, see chapter 12. It must also be possible to control the regulating speed for both limiting and delimiting production from outside and to select a limit in the range 10…100 % of the rated power per minute.

If a wind farm has wind turbines with passive stall regulation, the regulation of production in the connection point must be agreed with the grid company[2].

5.2 Local frequency-dependent control of production

Supplementary requirements

It must be possible to change a wind turbine's regulation externally between frequency-independent and frequency-dependent control.

In frequency-dependent control mode, a wind turbine's control equipment must change the production depending on the grid frequency as described in the following.

When the frequency changes, the wind turbine's production must be regulated as specified in **Table 1** and shown in **Figure 1**.

The resolution on the setting of the set points in **Table 1** must be at least 10 mHz.

[2] The production from wind turbines with passive stall regulation can be controlled by controlled connection and disconnection of the wind turbines.

In the frequency range 47.00-52.00 Hz the measuring error must not exceed ±10 mHz. This requirement must be met even if the sinusoidal voltage waveform is distorted. A single instant phase shift of 20° must not initiate any control action.

	Setting range	**Default value**
Lower frequency limit for the control range during under-frequency (f_n)	50.00…47.00 Hz	48.70 Hz
Upper frequency range for the control range during over-frequency (f_u)	50.00…52.00 Hz	51.30 Hz
Lower frequency limit for the deadband during under-frequency (f_{d-})	50.00…47.00 Hz	49.85 Hz
Upper frequency limit for the deadband during over-frequency (f_{d+})	50.00…52.00 Hz	50.15 Hz
Control factor for the production applying to frequencies in the range $f_n \ldots f_{d-}$ and $f_{d+} \ldots f_u$, see **Figure 1**. (Control factor 1 means that the production is the maximum possible – or the power setpoint if this is specified)	$\text{Over-frequency}: (1 - \frac{f - f_{d+}}{f_ø - f_{d+}})$ $\text{Under-frequency}: (1 + \frac{f - f_{d-}}{f_n - f_{d-}})$	
Regulating speed calculated from exceeding a limit value to completed control action	10 % of the rated power per second	

Table 1 *Values applying to frequency control of production*

Figur 1 shows two examples, one without and one with 50% reduction of allowed maximum production setpoint. In the first example, the frequency control can only reduce the output from the wind turbine. In the second example increase of wind turbine output is possible.

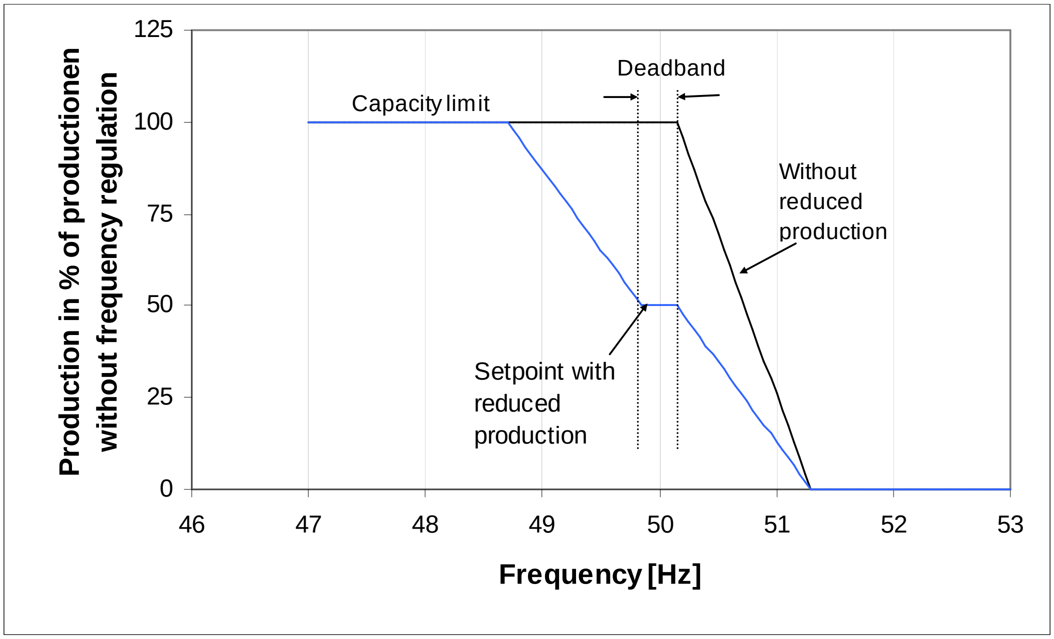

***Figure 1** Frequency control based on the default values in **Table 1**.*

6. Reactive power

General requirements

Averaged over 5 minutes, the reactive power that a wind turbine (including wind turbine transformer) exchanges with a grid must lie within the control band shown in **Figure 2** unless the exchanged power is less than 25 kvar.

The control or compensation can be carried out centrally in a wind farm. In this case, the exchange of reactive power must meet the above requirements at the farm's connection point, P_{rated} is then replaced by the wind farm's nominal power in the relations in **Figure 2**.

By agreement between the wind farm owners and the grid company, the compensation task can be assigned to the grid company.

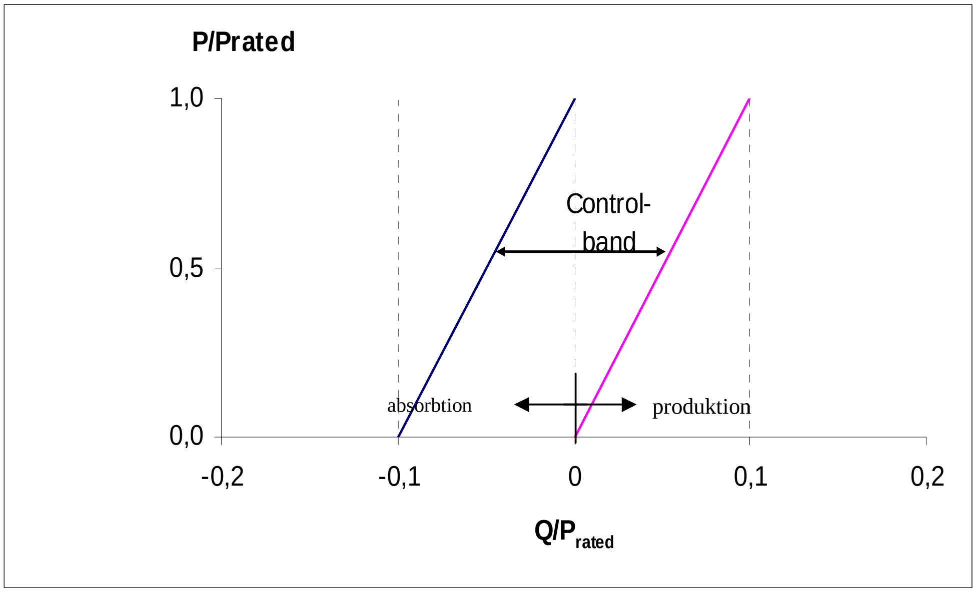

Figure 2 *Requirements concerning a wind turbine's exchange of reactive power with a grid (P: Active power, Q: Reactive power).*

Supplementary requirements

The amount of reactive power that a wind turbine can absorb or deliver outside the control band shown in **Figure 2** must be stated when application is made for connection of a wind turbine, and the ability must be made available to the grid company by agreement for control of the electricity system's need for reactive power. This also applies if central compensation is used in a wind farm[3]. Reporting should be done in accordance with Annex 2.

3 It should be evaluated whether it is necessary to reduce the regulating speed so that the voltage control of the grid can keep pace.

7. Design voltages and frequencies

General requirements

A wind turbine must be designed to produce power at voltages and frequencies that differs from the rated values in the minimum times shown in **Figure 3**. Voltages and frequencies for which the figure specifies time-limited operation will occur less than 10 hours per year. Abnormal voltages and frequencies must not result in a reduction of the production of more than 15%.The requirements in section 8.2 must also be fulfilled.

The requirements to the turbine design are in some cases more restrictive than the settings of voltage and frequency relays (section 8.1), as changes in settings may occur in the lifetime of the wind turbine.

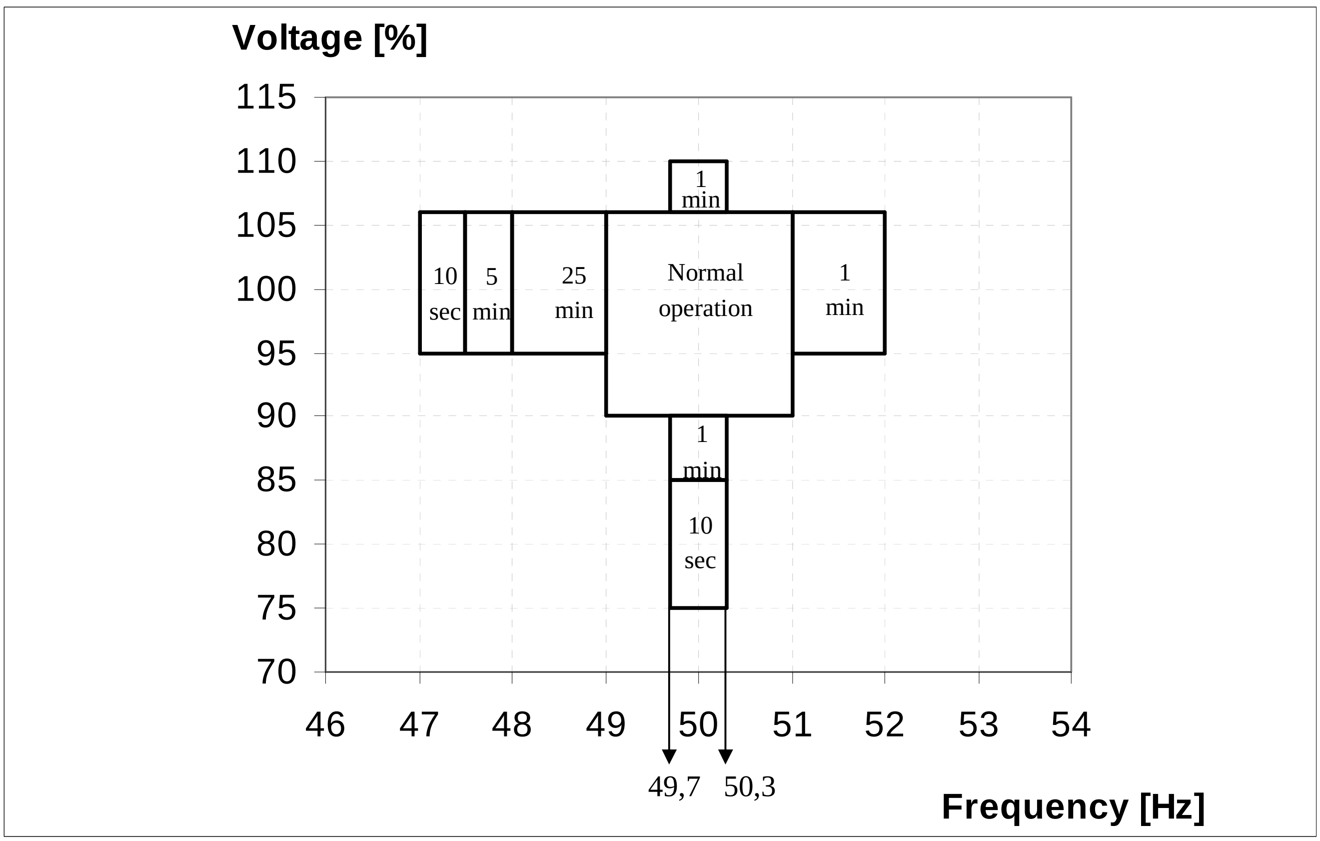

Figure 3 *Design voltages and frequencies*

8. *Interaction between wind turbines and the rest of the electricity system during grid faults*

8.1 Situations in which a wind turbine must be disconnected

General requirements

Unless otherwise agreed with the grid company, wind turbines must disconnect from the grid if the voltage or the frequency deviate from the operating settings given in **Table 2** and shown in **Figure 4**.

The voltage and frequency may be measured on either the high or low voltage side of the turbine transformer. The voltage must be measured in all three phases. On the high voltage side voltages must be measured as phase to phase voltages. Voltage measurements on the low voltage side of the transformer may be measured as phase to neutral voltages.

It is assumed that a wind turbine's rated voltage, $U_{rated,}$ is defined on the low voltage side of the turbine transformer. In the case of three-winding transformers it is the rated voltage of the low voltage winding with the highest rated output that must be used to determine the setting value.

If the voltage is measured at the high voltage side, the setting value shall be determined by converting the rated voltage to the turbine transformer's high voltage side.

The function values must not deviate more than ±1 % from the setting values.

Disconnection criterion	Setting value		Duration of which the setting value must be exceeded	
Under-voltage	$0.9 \cdot U_{rated}$	V	10…60	s
Over-voltage 1	$1.06 \cdot U_{rated}$	V	60	s
Over-voltage 2	$1.1 \cdot U_{rated}$	V	200	ms
Over-frequency	51 If frequency regulation is active: $f_u + 0.5$ (f_u is the upper frequency limit for the control range)	Hz Hz	200	ms
Under-frequency	47	Hz	200	ms

Table 2 *Disconnection criteria*[4]*.*

It is assumed in **Figure 4** that an appropriate turns ratio has been chosen for the turbine transformer. It should be chosen in consultation between the wind turbine supplier and the grid company.

Disconnection of a grid section with wind turbines can cause the voltage in the isolated grid to rise rapidly. The temporary over-voltages between the phases must not exceed $1.2 \cdot U_{rated}$. See section 11.1.

The wind turbine's other protection functions must have time delays that respect the requirements in section 8.2. However, protection against internal defects in the wind turbine or its installation must have higher priority.

The disconnection conditions from **Table 2** – applying to abnormal voltages– are depicted graphically in **Figure 4**. The figure also shows that a brief voltage drop must not result in definitive disconnection, cf. section 11.3, and that voltages over 1.2 pu must not occur even briefly.

4 The purpose of disconnection is to facilitate restoration of the electricity supply in the event of operating disturbances, to avoid infeed continuing during a fault in the grid and to avoid plant and equipment being exposed to abnormal operating conditions.

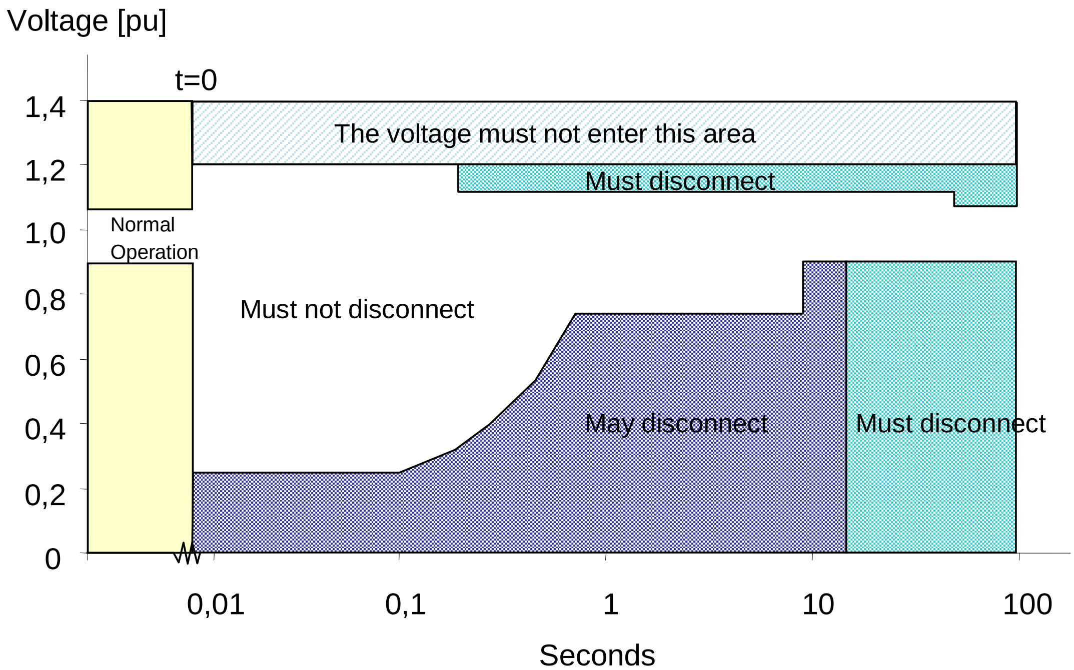

Figure 4 *Requirements concerning disconnection in the event of deviations in voltage. At t=0 an operating disturbance occurs. (With a linear time axis the curve section between 0.1 and 0.75 seconds is a straight line.)*

8.2 Situations in which a wind turbine must not disconnect

Supplementary requirements

A wind turbine must remain connected after the faults in the transmission grid listed below. Compensation equipment must also remain connected.

3-phase short circuit:	Short circuit lasting 100 ms
2-phase short circuit with/without earth fault:	Short circuit lasting 100 ms followed by a new short circuit 300…500 ms later, also lasting 100 ms

A wind turbine must have sufficient capacity to meet the foregoing requirements in the event of the following two independent sequences:

- at least two 2-phase short circuits within 2 minutes
- at least two 3-phase short circuits within 2 minutes

A wind turbine must have sufficient reserves (auxillary power, hydraulic capacity etc.) to withstand the following two independent sequences:

- at least six 2-phase short circuits at 5-minutes' intervals
- at least six 3-phase short circuits at 5-minutes' intervals.

This requirement is considered met if a wind turbine passes the type tests mentioned in sections 11.2 and 11.3.

The short-circuit protection of a wind turbine or a wind farm must not be triggered by the currents that can occur during and after faults in the transmission grid. This requirement is considered met for the individual wind turbines if the short circuit protection is not triggered by the currents occurring in the above-mentioned type tests.

9. Starting and stopping a wind turbine

General requirements

It must be possible to connect and disconnect a wind turbine externally.

If a wind turbine is disconnected definitively by a fault in the grid, the wind turbine may reconnect automatically 5-10 minutes after the operating conditions have returned to normal, cf. **Figure 3**.

A wind turbine that is disconnected because of high wind velocity may reconnect automatically when the velocity has dropped to below the stop wind velocity.

If a wind turbine is disconnected due to an internal failure, the wind turbine may be reconnected when the defect has been corrected without advising the grid company.

Supplementary requirements

If a wind turbine has been disconnected by an external signal prior to a grid fault, the wind turbine must not reconnect automatically when the operating conditions have returned to normal.

The design stop wind velocity must be at least 25 m/s and the setting must not be lower.

10. Voltage quality

The voltage quality must meet the same requirements irrespective of where the first common point of connection between consumers and producers lies.

10.1 Rapid voltage variations

General requirements

A rapid voltage variation is defined as a single, rapid change in the RMS value of the voltage. The following requirements are made concerning the magnitude (d) of rapid voltage variations caused by a wind turbine at the connection point:

10-20 kV grid	$d \leq 4\ \%$ [1]
50-60 kV grid	$d \leq 3\ \%$

The voltage variation factor, $k_u(\psi_K)$, is defined in [5]. The voltage variation factor is determined by type-testing a wind turbine. The relationship between a rapid voltage variation (d) and the voltage variation factor is as follows:

$$d(\%) = 100 \cdot k_u(\psi_k) \cdot \frac{S_n}{S_k}$$

S_k: the short circuit capacity in the connection point

ψ_k: the short circuit angle in the connection point

S_n: the wind turbine's apparent rated power.

Example 1:

From a completed form – like that shown in Annex 2 – it can be seen that the wind turbine's voltage variation factor is 1.1 at the short circuit angle in question. The voltage variation is calculated by inserting the data in the above formula. This gives:

$$d(\%) = 100 \cdot 1.1 \cdot \frac{0.75\,\text{MVA}}{50\,\text{MVA}} = 1.7\%$$

Since the voltage variation may be up to 5%, the requirement is met.

10.2 Flicker

General requirements

The following requirements are made concerning the resulting flicker contribution P_{lt} from wind turbines connected at the same voltage level and to the same Main Substation:

10-20 kV grid: $P_{lt} \leq 0.50$

50-60 kV grid: $P_{lt} \leq 0.35$.

The index (lt) refers to an observation period of two hours.

In [5] two factors are defined that can be used to estimate the flicker contribution from a single wind turbine at the connection point, when the grid's short circuit capacity and short circuit angle are known. One of the factors – the flicker coefficient – is used to estimate the flicker contribution from the fluctuations in a wind turbine's production. The other factor – the flicker step factor – is used to estimate the flicker contribution from connections with wind turbines. The two factors can be determined by type-testing a wind turbine.

10.2.1 Flicker contribution during operation

The requirement concerning a wind turbine's flicker coefficient can be determined from the following expression:

$$c(\psi_k) < P_{lt} \cdot \frac{S_k}{\sqrt{S_{park} \cdot S_n}}$$

$c(\psi_k)$: the flicker coefficient

S_k: the short circuit capacity in the connection point

ψ_k: the short circuit angle in the connection point

S_n: the wind turbine's apparent rated power

S_{park}: the wind farm's nominal apparent power.

Example:

The requirement concerning the flicker contribution is calculated by means of the above formula. This gives::

$$c \le 0.5 \cdot \frac{50MVA}{\sqrt{4.5MVA \cdot 0.75MVA}} = 13.6$$

From the completed form – like that shown in Annex 2 – it can be seen that the wind turbines have a flicker coefficient of 10 at the short circuit angle in question. The requirement is thus met.

If, besides the wind turbines in a wind farm, other wind turbines are or will be connected to the same main substation, this must be taken into account when determining the requirement concerning the flicker coefficient of the former wind turbines. The requirement concerning the flicker coefficient is considered met if the entire wind turbine output that will be connected under the main substation is inserted in the expression for S_{farm}.

10.2.2 Flicker contribution in the case of connection with wind turbines

The requirement concerning the flicker factor of a wind turbine can be determined from the following expression:

$$k_f(\psi_k) < \frac{P_{lt}}{8 \cdot \sqrt[3]{N_{kobl}}} \cdot \frac{S_k}{\sqrt[3]{S_{park} \cdot S_n^2}}$$

$k_f(\psi_k)$: flicker step factor
S_k: short circuit capacity in the connection point
ψ_k: short circuit angle in the connection point
S_n: the wind turbine's apparent rated power
S_{farm}: the wind farm's nominal apparent power
N_{kobl} the maximum number of design connections in a 2-hour period.

Example:
The requirement concerning the flicker factor is calculated by means of the above formula. This gives:

$$k_f \le \frac{0.5}{8 \cdot \sqrt[3]{8}} \cdot \frac{50MVA}{\sqrt[3]{4.5MVA \cdot (0.75MVA)^2}} = 1.15$$

From the completed form – like that shown in Annex 2 – it can be seen that the wind turbines have a flicker step factor of 1 at the short circuit angle in question. The requirement is thus met.

If the maximum number of (design) connections and disconnections in a 2-hour period is not limited by a wind turbine's control equipment, the requirement concerning the flicker step factor is as follows:

$$k_f(\psi_k) < \frac{P_{lt}}{16} \cdot \frac{S_k}{\sqrt[3]{S_{park} \cdot S_n^2}}$$

If other wind turbines are or will be connected under the same main substation, this must be taken into account when determining the requirement concerning the flicker step factor of the former wind turbines. The requirement concerning the flicker step factor is considered met if the total wind turbine output that will be connected under the main substation is inserted for S_{farm} in the expression.

10.3 Harmonics

General requirements

If a current's amplitude does not vary according to a sinusoidal wave, it contains a fundamental frequency current and harmonic currents. If the frequency of the harmonics is a whole number times the fundamental frequency, which is normally 50 Hz, the harmonics are designated harmonics of the fundamental frequency. Harmonics whose frequency is not a multiple of the fundamental frequency are called interharmonics.

10.3.1 Harmonics of the fundamental frequency

The magnitude of harmonics in the current from a wind turbine – and generated by this – must meet the following requirements[5]:

[5] By agreement with the grid company, the requirement can be reduced if turbine transformers with different vector groups are used in a wind farm, and if equalisation is thereby achieved between the 5th and the 7th harmonic currents.

$$I_\nu(\%) \le U_\nu(\%) \cdot \sqrt{\frac{1+\mathrm{tg}(\psi_k)^2}{1+(\nu \cdot \mathrm{tg}(\psi_k))^2}} \cdot \frac{|S_k|}{|S_{last}|+|S_{park}|}$$

I_ν: the ratio between a ν. harmonic in the current from a wind turbine and the current's fundamental frequency.

U_ν: the ν. harmonic current from **Table 3.1** (values for grids with voltages over 30 kV are under consideration)

S_k: short circuit capacity in the connection point

ψ_k: short circuit angle in the connection point

S_{last}: main substation's maximum load (without small-scale production)

S_{farm}: the wind farm's nominal apparent power

If the sum of the outputs in the denominator is greater than the rated capacity of the main transformer in front, the transformer's rated capacity is inserted instead.

Example:
The requirement concerning the fifth harmonic in the current is calculated by means of the above formula. This gives:

$$I_5(\%) \le 3(\%) \cdot \sqrt{\frac{1+tg(45)^2}{1+(5 \cdot tg(45))^2}} \cdot \frac{50MVA}{4.5MVA+5MVA} = 4.4\%$$

From a completed form –like that shown in Annex 2 – it can be seen that the 5th harmonic in the current is 3.5%. The requirement is thus met.

If, besides the wind turbines in the wind farm, other wind turbines are or will be connected to the same main substation, this must be taken into account when determining the requirement concerning the current harmonic of the former wind turbines. The requirement is considered met if the total wind turbine rated capacity that will be connected under the main substation is inserted for S_{farm} in the expression.

The above mentioned formula is based on the assumption that current harmonics with the same ordinals add themselves directly. By agreement with the grid company, the requirement can be reduced by inverters that use PWM modulation with switching frequencies in the kHz range.

10.3.2 Interharmonics

The total contribution from wind turbines to the interharmonic voltages in the connection point must meet the requirements in **Table 3.2**.

The requirements in the table are considered met if the interharmonic currents meet the requirements made for neighbouring harmonic currents with equal ordinals.

Ordinal ν	**Harmonic voltage** U_ν **(%)**
Unequal harmonics	
5	3.0
7	2.5
11	1.8
13	1.5
17	1.0
19	0.8
23	0.8
25	0.8
Equal harmonics	
2	1.0
4	0.5
6	0.3
8	0.3
10	0.1
>12	0.1

Table 3.1 *Limit values for harmonic voltages in the 10-20 kV grid*

Frequency [Hz]	**Maximum contribution to overtone voltages [%]**
<100	0.2
100≤ f <2.500	0.5

Table 3.2 *Limit values for interharmonic voltages in the 10-20 kV grid [2]*

11. Type tests

The system operators Elkraft and Eltra must be sent a copy of test reports concerning the following special tests. The grid companies may only connect wind turbines that are included in the system operators' list of tested wind turbines.

11.1 Over-voltages during stand-alone operation

General requirements

The type test must be performed at

- a wind velocity that results in production of the rated power
- full compensation – even when central compensation is used
- a voltage on the generator terminals that does not deviate more than ±5 % from the generator's rated voltage.

The wind turbine's connection to the grid must be disconnected, and the temporary over-voltages between the phases should be recorded in the period immediately prior to the separation until the wind turbine itself has definitively disconnected. The type test is passed if the RMS value of the voltage does not increase more than 1.2 pu in three consecutive tests.

11.2 Reserve capacity

Supplementary requirements

It must be verified that a wind turbine has sufficient auxillary power reserves to function as prescribed in chapter 8 in case of repeated short circuits in the grid.

11.3 Power production during and after a short circuit in the grid

Supplementary requirements

A calculation of the behaviour of a wind turbine during short circuits in the grid must be carried out. It is sufficient to simulate a 3-phased short circuit. The calculation shall be performed at:

- a wind velocity that results in production of the rated power
- nominal rotor speed
- full compensation before the short circuit.

The electricity system shall be represented by a 3-phase Thevenin equivalent. The RMS value of the voltage on the Thevenin generator's terminals must vary as shown in **Figure 5.1** with the wind turbine's rated voltage as the basis.

The series impedance in the Thevenin equivalent must have the following value related to 10 kV:

R + jX = (0.1 + 1.0) ohm

It is assumed that the wind turbine model includes the turbine transformer's impedance, see **Figure 5.2**.

If a supply does not include a turbine transformer, the wind turbine manufacturer must specify the requirements that must be made concerning the transformer's data in order for the combination wind turbine and transformer to pass the type approval test. The requirements concerning the transformer's data must appear from the test report.

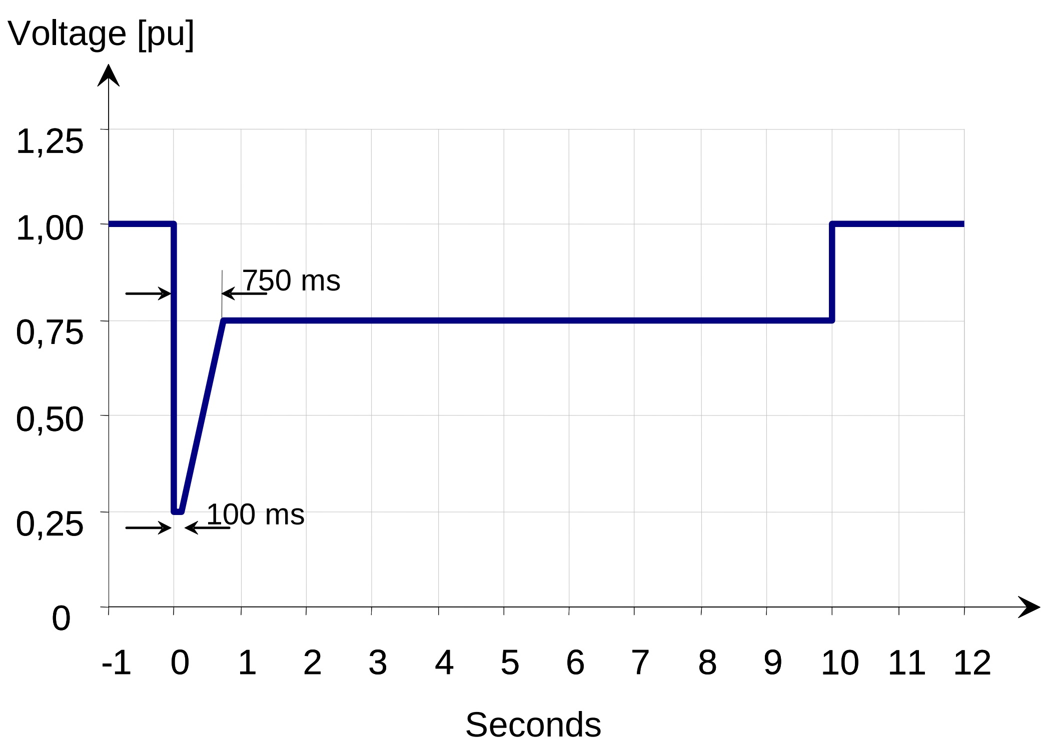

Figure 5.1 *Voltage profile.*

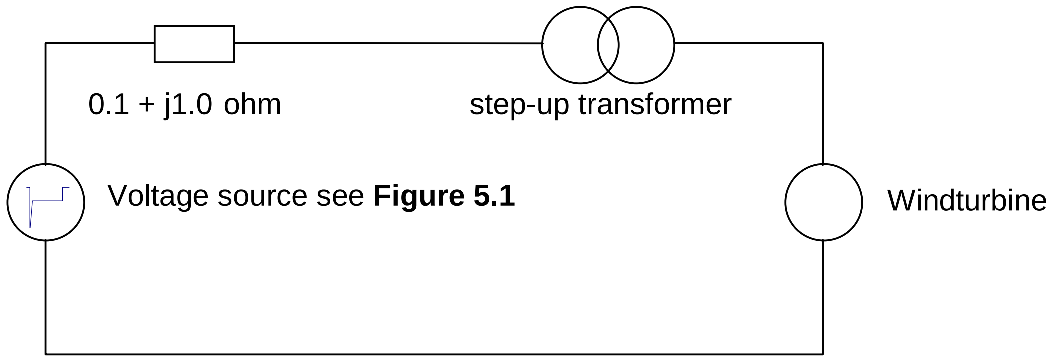

Figure 5.2 *The Thevenin equivalent in 1-phase depiction*

The test report must state which program tool was used in the calculation and include a description of the used model of the wind turbine type in sufficient detail for the calculation to be repeated.

For a wind turbine to pass the type test, the following requirements must be met:

- No later than 10 seconds after the voltage is again 1 pu, the wind turbine must produce the rated power, and the exchange of reactive power with the grid must meet the requirement in section 6.

- It must be documented that the wind turbine tolerates the thermal impacts in two repeated, consecutive (with 2 minutes interval in between) short circuits with the same conditions used in the simulation of a 3-phase short circuit.

The test report must state how the RMS value of the active and reactive current through the wind turbine's connection terminals varies during the simulation.

11.4 Data relating to quality of voltage

The data needed to evaluate the effect wind turbines have on the voltage quality must be determined. The relevant data are mentioned in [ref. 5] and must be determined as prescribed in the standard.

12. External control of wind turbines. Supplementary requirements

12.1 Scope of data

Table 4 specifies the data that it must be possible to transmit between a wind turbine and an external locality, e.g. a control room. The following abbreviations are used:

O:	Command	DO:	Double command
T:	Condition report	DT:	Four-state indication
K:	Possible value*	M:	Measured value
B:	Power setpoint	V:	Number (18 digits)

* theoretical calculated possible production

Data	Number and type
Limitation on production, on/off	DO and DT
Active power [kW]	K, B and M
Speed of regulation [kW/min.]	B
Lost production [kWh]	See the text after the table
Frequency control, on/off	DO and DT
Lower and upper frequency limit for the range of regulation [Hz]	2 B
Deadband at under-frequency and over-frequency [Hz]	2 B
Control of reactive power, on/off	DO and DT
Reactive power [kvar]	2 K, B and M
Connection and disconnection of wind turbine	DO
Wind turbine connected/disconnected	DT
Disconnected due to high wind velocity	T
Disconnected by the grid company	T
Out of operation due to defect, inspection or maintenance	T
Voltage on the low voltage side [V]	M
Wind turbine's identification no. (GSRN No.)	V

Table 4 *Data that it must be possible to transmit between a wind turbine and an external locality.*

The sign for the power values must follow the generator convention. The reactive power must have a negative sign if the wind turbine absorbes reactive power and a positive sign if it produces reactive power.

All metered values must be transmitted with a resolution of at least 11 bit plus sign and be in accuracy class 1.0.

The measuring uncertainty on the metered active power must thus lie within the error limits for class 1.0 meters according to IEC 62053. The measuring transformers used must be at least class 0.5 according to IEC 60044-1 (current transformers) and IEC 60044-2 (voltage transformers).

The possible and metered values mentioned in **Table 4** must be automatically transmitted to an external locality when a new value deviates from the last value transmitted. It must be possible to define a suitable filtration for each measurement. The "Event-Delta" method should be used so that changes in a metered value are accumulated over time, whereby major changes can be transmitted instantaneously and small changes after some time.

It must be possible to transmit the data mentioned in **Table 4** from the wind turbine to an external locality on request. Similarly, it must be possible to transmit power setpoints the other way. When an indication changes value, it must be transmitted automatically.

On the basis of possible and measured values, a wind turbine must be able to calculate the energy production (kWh) that is lost in periods with forced power reduction. The wind turbine must save the calculated value of the lost production in each period with forced power reduction together with the time the period starts and ends (year, date, hour, minute). It must be possible for these data to be transmitted on request. The uncertainty that can be accepted on the possible value will depend on the billing requirements.

Data can also be transmitted to/from a joint control unit for the wind turbines in a wind farm. In this case, the wind farm shall be treated as a single large wind turbine.

12.2 Data transmission

Unless otherwise agreed with the grid company, the communication system must be in accordance with [6].

If the protocol in a wind turbine's control system has not been implemented at the time when these Technical Regulations go into effect, it must be inserted later.

The protocol to be used is under consideration.

References

1 DEFU Recommendation No. 21: *Spændingskvalitet i 10-20 kV-net (Voltage quality in the 10-20 kV grid) (February 1995)*

2 IEC 61000-3-6: *EMC limits. Limitation of emissions of harmonic currents for equipment connected to medium and high voltage power supply systems. (October 1996).*

3 IEC 61000-3-7: *EMC-limits. Limitation of voltage fluctuations and flicker for equipment connected to medium and high voltage power supply systems. (November 1996).*

4 IEC 61400-12: *Wind turbine generator systems. Power performance measurement techniques.*

5 IEC 61400-21: *Power quality requirements for grid connected wind turbines.*

6 IEC 61400-25: *Communications for monitoring and control of wind power plants (only in draft form at present).*

7 IEC 62053-21: *Electricity metering equipment (ac) – Particular requirements. Part 21: Static meters for active energy.*

8 IEC 60044-1. *Instrument transformers – Part 1: Current transformers.*

9 IEC 60044-2. *Instrument transformers – Part 2: Inductive voltage transformers.*

10 IEC 60050-415. *Electrotechnical Vocabulary – Part 415: Wind turbine generator systems.*

11 IEC 61000-4-7: *General guide on harmonics and interharmonics measurements and instrumentation for power supply systems and equipment connected thereto.*

Legislation, rules, regulations and procedures for connection of wind turbines to grids

The following is a guide to legislation, rules, regulations and procedures that must be complied when wind turbines etc. are connected to a grid. The guide covers the following areas:

1. Rules on connection of wind turbines
2. Who does what when application is made for connection?
3. Random sampling
4. Consequence of failure to comply with rules and regulations
5. Supervision and complaints
6. Type approval.

1. The rules

The rules of law on connection of wind turbines are given in Section 68 of the Danish Electricity Supply Act and are amplified in Executive Order No. 331 of 8 May 2003 on connection of wind turbines to a grid (and billing of electricity produced by wind turbines).

The grid companies should check the correctness of meters, cf. Executive Order No. 54 of 23 January 1997.

The system operators are required to issue technical regulations for connection of electricity production plant to the public supply system.

Technical Regulations TF 3.2.6 have been issued on the basis of the above-mentioned rules.

Furthermore, a wind turbine may only be connected to the grid provided that it has been erected in accordance with current provisions in the Electricity Supply Act, Act on use of renewable energy sources, etc., including the rules on type approval, planning and building legislation and rules in pursuance of these Acts.

The energy acts and related executive orders can be accessed under "lovstof" (Legislation) on the Danish Energy Agency's website (www.ens.dk).

2. Who does what when application is made for connection?

The grid company in the licence area in which the wind turbine is to be connected decides whether the conditions for connection have been fulfilled (cf. Section 22 (1) of Executive Order on Wind Turbines). The grid company also decides how costs are to be shared between the turbine owner and the grid company.

2.1. The connection point and requirements concerning the connection

The owner of the wind turbine should:

- send in an application for grid connection of his wind turbine to the grid company in whose area the wind turbine is to be erected;

complete and send in together with the application:

- the form "Technical information for the grid companies", see Annex 2 to these Technical Regulations and
- a copy of the wind turbine's type approval

and have:

- his own meter, which must be in compliance with the system operator's metering regulations, cf. the system operator's metering regulations under Technical Regulations at the system operator's website

and must keep the grid company and the system operator informed. The turbine owner should thus:

- provide information needed for a decision on grid connection of the wind turbine;
- inform the grid company in the event of a change of ownership;
- report earlier grid connections;
- inform the grid company about other changed conditions of importance for compliance with the conditions for connection.

The grid company shall:

- indicate a connection point at the nearest place in the grid where electricity from the new wind turbine can be received with the existing grid conditions;

- if the wind turbine is to be erected in an area specifically zoned for wind turbines according to a regional plan (Ministry of Environment Circular No. 100 of 10 June 1999), extend the grid to a connection point on the boundary of the wind turbine zone when it is certain that a turbine with a total installed capacity (stated in the type approval) of at least 1.5 MW is to be erected;

- set the voltage level and inform the owner of the wind turbine and the system operator of this.

2.2. Connection costs

The owner of the wind turbine shall bear the cost of the grid connection up to the grid connection point indicated by the grid company, i.e.

- installation of the wind turbine
- low-voltage connection
- establishment of a local wind turbine transformer, including a meter, for billing purposes
- service line to the grid
- connection to the grid, including phase compensation (although not for reactive power consumed by the wind turbine),

and the following costs:

- the grid company's costs for dealing with the application for grid connection
- maintenance of the grid company's meter, reading of the meter and billing of electricity
- calibration and replacement of the grid company's meter
- the owner's own meter with associated telecommunication.

The grid company shall bear the cost of:

- enlargement and strengthening of the grid
- grid losses from the meter on the grid to which consumers or other producers than wind turbines are not connected
- phase compensation for reactive power not consumed by the wind turbine.

3. Random sampling

The grid company is responsible for checking the correctness of the meters.

4. Consequence of failure to comply with rules and regulations

Penalty of fining will be imposed if the owner of the wind turbine:

- gives incorrect information in connection with a request for grid connection,
- fails to notify the grid company about changes in conditions of importance for grid connection, or
- gives incorrect information when notifying the grid company about changes.

5. Supervision and complaints

The Danish Energy Regulatory Authority supervises the conditions set by the grid company for connection to the grid.

The owner of the wind turbine may complain to the Danish Energy Agency about the grid company's decision. The owner shall send the complaint in writing to the grid company within four weeks of having been informed of the decision, and the grid company shall send the complaint on to the Energy Regulatory Authority within four weeks of receiving it.

The Danish Energy Agency has been notified about Technical Regulations TF 3.2.6.

Complaints about the Technical Regulations can be made to the Danish Energy Agency and must be sent to the Agency no later than four weeks after the regulations have been made available to users and potential users of the public electricity supply grid.

6. Type approval

The rules for type approval are given in Danish Energy Agency Order No. 270 of 2 May 1991.

Wind turbines that are erected shall be type-approved. Type approvals are issued by the Test Station for Wind Turbines at Risø National Laboratory or others authorised by the Danish Energy Agency.

A certified quality management system for production and installation of a wind turbine should be built up and used to ensure the quality of the turbine.

For type approval and certification, readers are referred to the Danish Energy Agency because the rules are at present under revision.

Technical information to the grid companies

A web solution is being developed in which reporting is combined with reporting of base data!

The information in the forms should be based on the definitions and measuring procedures in IEC 61400-21. Deviations from these definitions and procedures shall be notified. The grid company will be sent a test report if so desired. Any change in the settings given in the form must be approved by the grid company in advance and the form must be updated accordingly.

Wind turbine type/technical data

Manufacturer	
Type designation	
Type approval	
Approval body	
Rated wind velocity, v_{rated} [m/s]	
Rated power, P_n [kW]	
Apparent rated power, S_{rated} [kVA]	
Maximum permissible power, P_{mc} [kW]	
Maximum measured power:	
- 60-second mean value, P_{60} [kW]	
- 0.2-second mean value, $P_{0,2}$ [kW]	
Rated voltage [V]	
Rated current, I_n [A]	
Largest stationary short circuit current during a 3-phase short circuit in the connection point [MVA]	

Flicker coefficient with the wind turbine in operation, c(ψ_k, v_a)

Mean wind velocity, v_a [m/s]	Impedance angle of the grid, ψ_k [degrees]			
	30	50	70	85
6				
7.5				
8.5				
10.0				

Voltage changes and flicker caused by connections

Connection situation	Connection at start wind velocity			
Max. number of connections in 2 hours, N_{120}				
	Impedance angle of the grid, ψ_k [degrees]			
	30	50	70	85
Flicker step factor, $k_f(\psi_k)$				
Voltage variation factor, $k_{\underline{u}}(\psi_k)$				

Connection situation	Connection at rated wind velocity			
Max. number of connections in two hours, N_{120}				
	Impedance angle of the grid, ψ_k [degrees]			
	30	50	70	85
Flicker step factor, $k_f(\psi_k)$				
Voltage variation factor, $k_{\underline{u}}(\psi_k)$				

Connection situation	Worst case during coupling between generators or windings			
Max. number of connections in 2 hours, N_{120}				
	Impedance angle of the grid, ψ_k [degrees]			
	30	50	70	85
Flicker step factor, $k_f(\psi_k)$				
Voltage variation factor, $k_{\underline{u}}(\psi_k)$				

Harmonics

This form need only be completed for wind turbines with an electronic power converter.

It is not necessary to state values that are lower than 0.1 % of the rated current.

Ordinal	Power [kW]	Harmonic current [% of I_{rated}]	Ordinal	Power [kW]	Harmonic current [% of I_{rated}]
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 distortion [% of I_n]					
Power produced at max. total harmonic distortion [kW]					

The reactive power that the wind turbine can deliver/absorb outside the regulating band shown in **Figure 2** shall appear from a P-Q diagram, which shall be attached to the completed Annex 2.