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Guidelines on the calculation of power quality parameters

Technical regulation 3.2.5 for wind power plants with a power output above 11 kW

EXPIRED

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Table of contents

Reading instructions

These guidelines have been prepared as an aid for calculating the power quality parameters required in order to document compliance with the requirements for power quality in accordance with TR 3.2.5.

The document contains examples of the calculation of the power quality parameters that are relevant to *wind power plants*.

References to applicable standards are indicated in TR 3.2.5.

Applicable abbreviations are also indicated in TR 3.2.5.

1. Examples of the calculation of power quality parameters

1.1 Example 1 – calculation of rapid voltage changes

A *wind power plant* with a *rated power* of 1 MW (category B) is connected to the *public electricity supply grid* at 10 kV level.

The *electricity supply undertaking* has calculated a *short-circuit power* of 50 MVA and a short-circuit angle of 84° in the *point of connection*.

It can be seen from the type test for the relevant *wind turbine* that the *voltage change factor* at this angle is 0.5.

The size of the *voltage change* is then calculated as:

$$d(\%) = 100\% \cdot k_u(\psi_k) \cdot \frac{S_n}{S_k} = 100\% \cdot 0.5 \cdot \frac{1}{50} = 1\%$$

The result is lower than the limit value, and the requirement in relation to rapid *voltage changes* can therefore be regarded as having been complied with.

1.2 Example 2 – calculation of flicker during continuous operation

A *wind power plant* with a *rated power* of 1 MW (category B) is connected to the *public electricity supply grid* at 10 kV level.

The *electricity supply undertaking* has calculated a *short-circuit power* of 50 MVA and a short-circuit angle of 84° in the *point of connection*.

The *wind power plant's flicker* coefficient is calculated at 2 for the given values of the average annual wind speed of short-circuit angle Ψ_k.

The *flicker* contribution is then calculated as:

$$\mathrm{P_{st}} = \mathrm{c}(\psi_\mathrm{k}, E_a) \cdot \frac{S_n}{S_k} = 2 \cdot \frac{1}{50} = 0.04$$

As P_{st} can be assumed to be equal to P_{lt} during continuous operation, and the calculated value is below the limit values, the requirement regarding *flicker* during continuous operation can therefore be regarded as having been complied with.

1.3 Example 3 – calculation of flicker when connections are made

A *wind power plant* with a *rated power* of 1 MW (category B) is connected to the *public electricity supply grid* at 10 kV level.

The *electricity supply undertaking* has calculated a *short-circuit power* of 50 MVA and a short-circuit angle of 84° in the *point of connection*. It can be seen from the data sheet for the IEC 61400-21 type test which is included in the type approval for the *wind turbine* that the *flicker* step factor is 0.1.

Assuming that there is a maximum of two connections per hour, the *flicker* contribution can then be calculated as:

$$P_{lt,i} = 8 \cdot P_{lt,i}^{0.31} \cdot k_{f,i}(\psi_k) \cdot \frac{S_{n,i}}{S_k} = 8 \cdot 4^{0.31} \cdot 0.1 \cdot \frac{1}{50} = 0.02$$

As the calculated value is below the limit value, the requirement regarding *flicker* during continuous operation can be considered as having been complied with.

1.4 Example 4 – calculation of harmonic distortions

Two *wind turbines* of 15 kW each (category A) with a *rated current* of 22A and harmonics 5 and 7 of 0.31% and 0.36%, respectively, as well as two *wind turbines* of 12.5 kW each (category A) with a *rated current* of 19A and harmonics 5 and 7 of 0.29% and 0.33%, respectively.

First, calculate $I_{h,i}$ for all harmonic currents for each *wind turbine*:

$$I_{h,i} = \frac{I_{h,i} / I_{n,i}[\%]}{100} \cdot I_{n,i}$$

$$I_{5,15k} = \frac{0.31}{100} \cdot 22A = 0.0682A \;\; ; \;\; I_{7,15k} = 0.0792\,A$$

$$I_{5,12,5k} = 0.0551A \;\; ; \;\; I_{7,12,5k} = 0.0627\,A$$

Then calculate the harmonic currents for the total *wind power plant* using the general summation rule and exponent α=1.4:

$$\mathrm{I}_5 = \sqrt[1.4]{0.0682^{1.4} + 0.0682^{1.4} + 0.0551^{1.4} + 0.0551^{1.4}} = 0.166\,A$$

$$\mathrm{I}_7 = \sqrt[1.4]{0.0792^{1.4} + 0.0792^{1.4} + 0.0627^{1.4} + 0.0627^{1.4}} = 0.192\,A$$

Finally, calculate the harmonic currents as a percentage of *the rated current*:

$$\mathrm{I}_\mathrm{n} = 22 + 22 + 19 + 19 = 82A$$

$$I_h / I_n = \frac{I_h}{I_n} \cdot 100\%$$

$$I_5 / I_n = \frac{0.166}{82} \cdot 100 = 0.20\% \;\; ; \;\; I_7 / I_n = \frac{0.192}{82} \cdot 100 = 0.23\%$$

2. Examples of the calculation of limit values

This section provides guidelines on how to determine limit values, illustrated by practical examples.

2.1 Determination of flicker limit values.

If the connected *rated power* is lower than 0.4% of the minimum *short-circuit power* in the *point of connection*, the *wind power plant* can be connected without any additional examinations being performed.

If the connected power is greater than 0.4% of the minimum *short-circuit power* in the *point of connection*, the following procedure must be applied:

Category A and B wind power plants

The limit values indicated in TR 3.2.5, section 4, can be applied directly.

Category C and D wind power plants

The limit value $P_{lt,i}$ for the emission from the *wind power plant*, i, is determined as:

$$P_{lt,i} = G_{lt} \cdot \sqrt[3]{\frac{S_i}{S_{prod,tot}}}$$

where:

- G_{lt} is the total permissible *flicker* contribution from fluctuating production facilities connected at the same voltage level under the same substation. G_{lt} is shown in the table below.
- S_i is the power generated by *wind power plant* i.
- $S_{prod,\ tot}$ is the maximum concurrent fluctuating production, including S_i, which is expected to be connected to the *public electricity supply grid* at the same voltage level and under the same substation.

Voltage level	G_{st}	G_{lt}
$U_n \leq 35$ kV	-	0.50
35 kV < $U_n \leq 150$ kV	-	0.35
$U_n > 150$ kV	0.30	0.20

Table 1 G_{st} and G_{lt} for category C and D plants.

2.2 Example 1 – calculation of flicker limit value

A *wind power plant* of 2 MW (category C) (S_i) is to be connected to a 10 kV radial. The current production is 0.5 MW for the same 10 kV radial to which the *plant* is to be connected. Based on this information, the limit value can be calculated on the basis of the planning value in table 1 as follows:

$$P_{lt,i} = 0.5 \cdot \sqrt[3]{\frac{2\ \text{MW}}{2\ \text{MW} + 0.5\ \text{MW}}} = 0.464$$

2.3 Determination of limit values for harmonic distortions

For calculating emission limits for *harmonic distortions* at medium-voltage level, use the expression:

$$E_{(h)} = \sqrt[\alpha]{L_{MV,h}^{\alpha} - T_{HV-MV} \cdot L_{HV,h}^{\alpha}} \cdot \sqrt[\alpha]{\frac{S_i}{S_{last} + S_{prod}}}$$

where:

$E_{h,i}$:	Emission limit for harmonic voltage for *plants* i
α:	Exponent, in accordance with these technical regulations
$L_{MV,h}$:	Planning value for the h order at medium-voltage level
$L_{HV,h}$:	Planning value for the h order at high-voltage level
$T_{HV\text{-}MV}$:	Transmission factor for the h order at high-voltage to medium-voltage level
S_i:	*Apparent power* for connected *plant* i
S_{load}	*Apparent power* for the total load connected under the transformer, incl. expected new load
S_{prod}	*Apparent power* for the total harmonics-generating production connected under the transformer, incl. expected new production

The reason for introducing $T_{HV\text{-}MV}$ is that the harmonic voltages are not transmitted directly between the high-voltage and medium-voltage grids. The $T_{HV\text{-}MV}$ value is normally set at 1, but in case the grid is known, the value may be increased or decreased.

In case of an odd harmonic order (which is not a multiple of 3), it is assumed that all harmonics are transmitted directly from the medium-voltage to the high-voltage grid. This may vary depending on the type of transformer and the short-circuit impedance of the grid in the relevant *point of connection*.

A *wind turbine's* odd *harmonic distortions* which are a multiple of 3 will be reduced if it is connected to a grid that is virtually symmetrically loaded. Therefore, $T_{HV\text{-}MV}$ for odd *harmonic distortions* (multiple of 3) is set at 0.25.

Voltage level	**Odd harmonic order *h* (not a multiple of 3)**					**Odd harmonic order *h* (not a multiple of 3)**			
	5	7	11	13	17≤*h*≤49	3	9	15	21≤*h*≤45
$U_n \leq 35$ kV	5.0	4.0	3.0	2.5	$1.9 \cdot \frac{17}{h} - 0.2$ *)	4.0	1.2	0.3	0.2
$U_n > 35$ kV	2.0	2.0	1.5	1.5	$1.2 \cdot \frac{17}{h}$ *)	2.0	1.0	0.3	0.2

*) But not less than 0.1%

Table 2 Planning limits for harmonic distortions U_h/U_n (%) for odd harmonic orders h.

Voltage level	**Even harmonic order *h***				
	2	4	6	8	$10 \le h \le 50$
$U_n \le 35$ kV	1.8	1.0	0.5	0.5	$0.25 \cdot \frac{10}{h} + 0.22$
$U_n > 35$ kV	1.4	0.8	0.4	0.4	$0.19 \cdot \frac{10}{h} + 0.16$

Table 3 Planning limits for harmonic distortions U_h/U_n (%) for even harmonic orders h.

Voltage level	***THD_U***
$U_n \le 35$ kV	6.5
$U_n > 35$ kV	3.0

Table 4 Limit values for total harmonic voltage distortion THD_U (% of U_n) for even harmonic distortions h.

For *wind power plants* that are electrically connected far from other consumers, emission limits may be changed to values that are higher than the standard permissible noise level.

However, this calls for a thorough analysis of current and future system characteristics.

For information on limit values for *harmonic distortions* from *wind power plants* connected to the transmission grid, please contact *the electricity supply undertaking*.

2.4 Example 2 – calculation of limit value for harmonics 5

The example shows the calculation of harmonics 5 when connecting a *wind power plant* of 2 MW (category C) (S_i) to a 10 kV radial in the distribution grid. Furthermore, there is an additional production (S_{prod}) of 0.5 MW and a load (S_{load}) of 0.5 MW. Based on this information, the limit value can be calculated on the basis of the planning values specified in table 2. Harmonics 5 is used as a starting point:

$$E_5 = \sqrt[1.4]{5^{1.4} - 1 \cdot 2^{1.4}} \cdot \sqrt[1.4]{\frac{2\ \text{MW}}{0.5\ \text{MW} + 2\ \text{MW} + 0.5\ \text{MW}}} = 2.9687$$

2.5 Determination of limit values for interharmonic distortions

Planning values for interharmonic distortions from category C and D *plants* are specified in the table below.

Frequency (Hz)	Maximum interharmonic voltage (%)
f < 100 Hz	0.2%
100 Hz < f < 2,000 Hz	0.5%

Table 5 Planning limits for interharmonic distortions – category C and D.

For information on limit values for interharmonic distortions from *wind power plants* connected to the transmission grid, please contact *the electricity supply undertaking*.

2.6 Determination of limit values for distortions above 2 kHz

For distortions above 2 kHz, 1% can be used as the planning limit for each frequency group.

For information on limit values for distortions above 2 kHz from *wind power plants* connected to the transmission grid, please contact the *electricity supply undertaking*.

3. Approximate model for the frequency dependence of the grid impedance

For category C and D *wind power plants*, requirements for *harmonic distortions* are specified in the technical regulations as voltage values. Category C and D *wind power plants* are verified by calculating harmonic currents I_h on the basis of the formula in section 4.6.3.

Then calculate the harmonic voltages using the following formula:

$$U_h = \left|Z_{grid,h}\right| \cdot I_h ,$$

where $Z_{grid,h}$ = grid impedance at the current frequency.

NOTE: This calculation must be performed for all relevant *harmonic distortions*, interharmonic distortions and distortions greater than 2 kHz.

Unless otherwise specified by the grid company, the grid impedance is:

$$\left|Z_{grid,h}\right| = \sqrt{R_{50}^2 + \left(2\pi f \cdot L_{50}\right)^2} \text{, for f = [50:1,950] Hz}$$

$$\left|Z_{grid,h}\right| = \sqrt{R_{50}^2 + \left(2\pi \cdot 2000 \cdot L_{50}\right)^2} \text{, for f = [2,000:9,000] Hz}$$