Guidelines on the calculation of power quality parameters

Technical regulation 3.2.2 for PV power plants with a power output above 11 kW

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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 TR 3.2.2.

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

References to applicable standards are indicated in TR 3.2.2.

Applicable abbreviations are also indicated in TR 3.2.2.

1. Example – flicker during continuous operation

A 1 MW *PV power plant* 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 *PV power plant's flicker* coefficient is calculated at 2 for the given values of short-circuit angle Ψ_k.

The *flicker* contribution is then calculated as:

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

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.

2. Example – harmonic currents

Two inverters of 15 kW each with a *rated current* of 22A and harmonics 5 and 7 of 0.31% and 0.36%, respectively, as well as two inverters of 12.5 kW each 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 unit:

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

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

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

Then calculate the harmonic currents for the entire *electricity-generating plant* using the general summation rule and exponent α=1.4:

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

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

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

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

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

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

3. Examples of the calculation of limit values

3.1 Calculation of flicker limit values

For category C and D *PV power plants*, the limit value is calculated as follows:

The limit value $P_{lt,i}$ for the emission from the *PV 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 *PV 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	$\mathbf{G_{lt}}$
$U_n \leq 35$ kV	0.50
35 kV < $U_n \leq 150$ kV	0.35
$U_n > 150$ kV	0.20

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

3.2 Sample calculation of flicker limit value

A *PV power plant* of 2 MW (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:

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

3.3 Calculation of limit values for harmonic distortions

For calculating emission limits for category C and D *PV power plants* harmonics, use the expression:

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

where:

E_h: Emission limit for *harmonic distortions* from the *plant*

α: Exponent, in accordance with this technical regulation

$L_{MV,h}$: 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, including expected new load

S_{prod} Apparent power for the total harmonics-generating production connected under the transformer, including 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, the combination of transformer types and the short-circuit impedance of the grid in the relevant *point of connection*.

The odd *harmonic distortions* of a *PV power plant* which are a multiple of 3 will be reduced if the *plant* is connected to a grid that is virtually symmetrically loaded. Therefore, $T_{HV\text{-}MV}$ for odd harmonics (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≤*h*≤50
$U_n \leq 35$ 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 harmonics U_h/U_n (%) for even harmonic orders h.

Voltage level	THD_U
$U_n \leq 35$ 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 harmonics h.

For *PV power plants* which are connected far from other consumers, the emission limits may, however, be changed to values above the normal emission limits following acceptance from *the electricity supply undertaking*.

3.4 Sample calculation of limit value for the medium-voltage grid

Sample calculation of harmonics 5 when connecting a *PV power plant* of 2 MW (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:

$$E_5 = \sqrt[1.4]{5^{1.4} - 1 \cdot 2^{1.4}} \cdot \sqrt[1.4]{\frac{2\text{ MW}}{0.5\text{ MW} + 2\text{ MW} + 0.5\text{ MW}}} = 2.96867$$

3.5 Calculation of limit values for interharmonic distortions

Planning values for interharmonic distortions from category C and D *PV power 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.

3.6 Calculation 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.

4. Approx. model for the frequency dependence of the grid impedance

For category C and D *PV power plants*, requirements for *harmonic distortions* are specified in the technical regulations as voltage values.

Then calculate the harmonic voltages using the following formula:

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

where:

$Z_{grid,h}$: grid impedance at the current harmonic frequency h.

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

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

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

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