INTERNATIONAL STANDARDS FOR POWER QUALITY OF DISPERSED GENERATION

John Olav Giæver Tande
SINTEF Energy Research
7034 Trondheim, Norway
Phone: +47 73 59 74 94
Fax: +47 73 59 72 50
e-mail: john.tande@energy.sintef.no

Dr. Nick Jenkins
Electrical Energy and Power Systems Group
UMIST, PO Box 88, Manchester M60 1QD, UK
Phone: +44 161 200 4813
Fax: +44 161 200 4820
e-mail: jenkins@umist.ac.uk

SUMMARY

It is suggested that dispersed generation should be characterised by a set of parameters revealing information on maximum continuous power, reactive power, flicker and harmonics, and these should be applied for predicting the impact on voltage quality. The procedures outlined are based on IEC 61400-21 giving power quality requirements for wind turbines. The authors suggest however that similar procedures could usefully be formulated and applied for other dispersed generation technologies.

INTRODUCTION

Dispersed generation is currently being installed in significant quantities posing new challenges for utilities. One of the major issues is to decide how much dispersed generation may be allowed to connect to a certain part of the electric network. This task is complex, as the amount may not only be limited by the thermal rating of the network. Rather, the connection may be limited in order to ensure voltage quality as well as by considerations of how the available network capacity may be shared between potential new users. Presently, different utilities, to a large degree, apply different approaches for dealing with this task. The differences are not only due to differences in policy related to sharing the available network capacity between potential new users, but also to some extent these differences demonstrate a lack of a common basis in relation to aspects of voltage quality .

Within the framework of the IEC, the only standard specifically addressing power quality of dispersed generation is [1]. Although its scope is limited to power quality in relation to wind turbines only, [1] certainly contains information that is relevant also for other dispersed generation technologies.

This paper gives a summary of [1] highlighting the issues considered of general interest in relation to power quality of dispersed generation. The measurement procedures given are thus not presented here as these are considered not of general interest. Rather, the focus of this presentation is on the sections of [1] specifying power quality parameters and how to use these in relation to network planning and design. These two issues are dealt with in the next two main sections of this paper.

POWER QUALITY PARAMETERS

Any load or generation unit affects the voltage quality in the electric network to which it is connected. To ensure that the voltage quality is kept within the required limits, the network must be of a certain minimum strength (short-circuit level), the loads must comply with certain requirements and the generation units must supply a certain power quality. To enable proper planning and operation of a network, it is thus most important to know the power quality of the connected or planned power generation units. To serve this purpose, [1] suggests the power quality of wind turbines should be characterised by the set of parameters specified in the following subsections. For other types of dispersed generation a similar set of parameters may be identified.

Reference values

To enable consistent comparison of the electrical characteristics of different wind turbines, the electrical characteristics must be normalised. For this purpose, a set of reference parameters is introduced. The set includes the parameters listed in Table 1.

Table 1 Reference parameters for normalising the power quality parameters of a wind turbine.

Parameter	Unit	Symbol	Definition
Reference power	W	P_{ref}	The maximum point of the power curve
Reference reactive power	var	Q_{ref}	The reactive power at reference power
Reference apparent power	VA	S_{ref}	$S_{ref} = \sqrt{P_{ref}^2 + Q_{ref}^2}$
Reference current	A	I_{ref}	$I_{ref} = \frac{S_{ref}}{\sqrt{3} \cdot U_n}$

Maximum continuous power

The maximum continuous power from a wind turbine is essential for determining the impact on the steady state voltage level. In general terms, the reference power is not a proper measure for this. This is because the reference power is given for standard conditions. Thus at certain conditions, the output power may be higher. Hence, it is relevant to introduce a separate parameter for specifying the maximum continuous power from a wind turbine. Defining this parameter as the ten-minute-average power that is not exceeded irrespective of weather and electric network conditions, this means that the wind turbine must have a mechanism that controls operation so that the continuous power never exceeds a certain limit.

Reactive power

The reactive power (consumption or production) of a wind turbine is essential for determining the impact on the steady state voltage level. For this purpose, the reactive power must be specified as ten minutes average values as a function of the output power of the wind turbine.

Flicker coefficient

Flicker is defined as an impression of unsteadiness of visual sensation induced by light stimulus whose luminance or spectral distribution fluctuates with time. Variations in the voltage may cause this. Applying a flickermeter, i.e. a particular instrument described in [2], a ten-minute time-series of measured or simulated voltage variations can be transformed to a short-term flicker value, P_{st}.

A wind turbine produces an output power that may cause voltage variations. Hence, a wind turbine is a source of flicker. In general, flicker may be caused both due to continuous operation of a wind turbine as well as due to switching operations such as cut-in of a wind turbine.

The emission of flicker from a wind turbine during continuous operation is adequately described by a flicker coefficient. The flicker coefficient is a normalised measure of the flicker emission from a wind turbine. Hence, a measured flicker value, P_{st} at the wind turbine terminals operated at an electric network without any other disturbing sources corresponds to a flicker coefficient, $c_c(\psi_k, v_a)$ given by equation (1) below.

$$c_c(\psi_k, v_a) = P_{st} \cdot \frac{S_{k,fic}}{S_{ref}} \qquad (1)$$

Here, ψ_k is the network impedance phase angle, v_a is the annual average wind speed at hub height of the wind turbine, $S_{k,fic}$ is the short-circuit apparent power at the wind turbine terminals and S_{ref} is the reference apparent power of the wind turbine.

As the flicker coefficient, c_c for a wind turbine is a function of the network impedance phase angle and the annual average wind speed as in indicated by equation (1), c_c must be specified for a range of ψ_k and v_a values as illustrated in Table 2.

Table 2 Specification of flicker coefficient for a wind turbine. The numbers are for illustration only.

Network impedance phase angle, ψ_k (deg.)	30	50	70	85
Annual average wind speed, v_a (m/s)	Flicker coefficient, $c_c(\psi_k,v_a)$			
6.0	7.5	3.2	0.8	3.8
7.5	7.7	3.3	1.2	4.0
8.5	7.9	3.4	1.8	4.5
10.0	8.0	3.5	2.0	5.2

Flicker emission due to switching operations may be characterised in a similar manner, though introducing some additional parameters.

Harmonics and interharmonics

Injection of an ac current with a content of higher order harmonics and interharmonics into an electric network may disturb the waveform of the voltage. It is thus a necessity to limit the amount of higher order harmonic and interharmonic currents to a level that does not bring the waveform of the voltage outside the required limits.

A wind turbine with a generator directly connected to the electric network without any power electronic converter will normally not cause significant harmonic or interharmonic distortion during continuous operation. During start-up there may be a short-duration burst of distortion due to the operation of thyristors for soft starting. Such bursts are commonly however not a problem as long as they do not occur too frequently and as long as their duration is less than some tens of seconds.

A wind turbine with a power electronic converter, e.g. for operation at variable speed, will produce a limited amount of harmonic and interharmonic distortion while in operation. This emission of harmonic currents must therefore be specified. These shall be specified for frequencies up to 50 times the fundamental grid frequency, as the individual harmonic currents and the maximum total harmonic current distortion. The individual harmonic currents shall be given as ten-minute-average data for each harmonic order at the output power giving the maximum individual harmonic current.

An example of measured harmonic distortion currents is given in Figure 1. The distortion may be limited to the required level to comply with utility requirements by installation of filters. The size and cost of the required filters depends basically on the switching frequency of the converter. Commonly, converters operating at a higher switching frequency will require less costly filters.

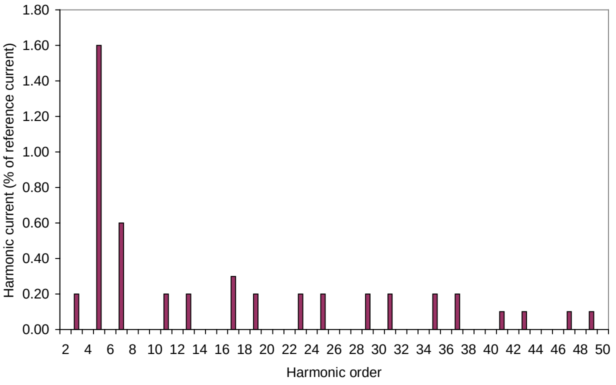

Figure 1 Example of measured emission of harmonic current distortion from a wind turbine with a power electronic converter.

A stringent method for presenting emission of interharmonic currents is under consideration. The issue is only relevant for self-commutated converters.

NETWORK PLANNING AND DESIGN

The power quality parameters given in the previous section may be quantified for any wind turbine by measurements at a test installation. Knowing the value of the parameters, these may be applied to plan and design the grid connection of the turbine. This is further described in the following sub-sections. The description is divided into the three issues of concern. These are the magnitude of the voltage, the emission of flicker and the emission of currents with a content of higher order harmonics and interharmonics.

Voltage magnitude

The injection of wind power into an electric network affects the magnitude of the voltage. The impact depends on the strength of the network and the active and reactive power of the wind power installation. Figure 2 illustrates this.

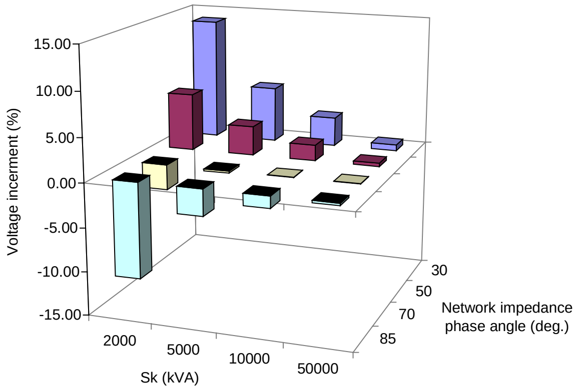

Figure 2 Voltage increment due to an injection of 500 kW wind power with a power factor of 0.95.

It is seen from the figure that the wind power gives less voltage deviations the higher the short-circuit power. Further, the figure shows that for the same short-circuit power, the same injection of wind power may give an increment or a decrement in the voltage magnitude depending on the network impedance phase angle.

The impact of wind turbines on the voltage magnitude is commonly most critical if wind turbines and consumers share the same medium voltage feeder. Hence, in such cases the concern is that the wind power may bring the magnitude of the supply voltage at the consumers outside its acceptable limits. These are commonly either + 6/–10 % or +/- 10 % of its the nominal value. The magnitude of the voltage may be assessed by conducting load flow analyses. Commonly, the maximum voltage magnitude is found by assuming minimum load and maximum production, and the minimum by assuming zero production and maximum load.

Flicker

The emission of flicker from any installation must be limited to comply with the flicker emission limits as specified in equation (2) and (3) below.

$$P_{st} \le E_{Psti} \tag{2}$$

$$P_{lt} \le E_{Plti} \tag{3}$$

Here, P_{st} and P_{lt} are the short and long-term flicker emissions from the installation, and E_{Psti} and E_{Plti} are the short and long-term flicker emission limits.

Recommended methods for assessing the flicker emission limits for installations at medium and high voltage levels are given in [3]. The emission limits will always be less than one, i.e. the limit for acceptable voltage quality. Actually, utilities in Germany apply emission limits as low as P_{lt} = 0.46 when considering grid connection of wind turbines. Assessment would probably show that this is rather conservative in many cases.

The flicker emission from a single wind turbine during continuous operation may be estimated applying equation (4) below.

$$P_{st} = P_{lt} = c_c(\psi_k, v_a) \cdot \frac{S_{ref}}{S_k} \tag{4}$$

Here, $c_c(\psi_k, v_a)$ is the flicker coefficient of the wind turbine for the given network impedance phase angle, ψ_k at the point of common coupling (PCC), and for the given annual average wind speed, v_a at hub-height of the wind turbine at the site. S_{ref} is the reference apparent power of the wind turbine, and S_k is the short-circuit apparent power at the PCC.

P_{lt} is equal to P_{st} in equation (4) because wind conditions giving critical flicker emission during a ten-minute period may often persist for a two-hour period, i.e. the relevant period for P_{lt}.

The flicker coefficient of the wind turbine for the actual ψ_k and v_a at the site, may be found from a table of data similar to Table 2.

In case more wind turbines are connected to the PCC, the flicker emission from the sum of them can be determined according to equation (5) below.

$$P_{st\Sigma} = P_{lt\Sigma} = \frac{1}{S_k} \cdot \sqrt{\sum_{i=1}^{N_{wt}} \left(c_{c,i}(\psi_k, v_a) \cdot S_{ref,i}\right)^2} \tag{5}$$

Here, $c_{c,i}(\psi_k, v_a)$ is the flicker coefficient of the individual wind turbine, $S_{ref,i}$ is the reference apparent power of the individual wind turbine and N_{wt} is the number of wind turbines connected to the PCC.

[1] also gives recommendations for estimation of flicker emission due to switching operations.

Harmonic distortion

The emission of harmonic and interharmonic currents from any installation must be limited to the degree needed to avoid unacceptable harmonic and interharmonic voltages at the PCC.

The applicable limits for emission of harmonics and interharmonics may be found by applying the guidance given in [4]. Otherwise, [1] recommends that the emission of harmonic currents is limited according to the specification in [5] on the assumption that the short-circuit apparent power at the PCC is less than 20 times the reference apparent power of the wind turbine installation.

The relevant emission limits according to [5] are given in Figure 3. [5] further recommends the total harmonic current distortion to be less than 5 % of the reference current.

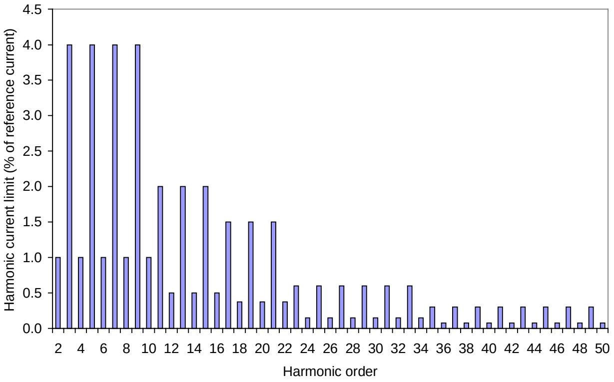

Figure 3 Emission limits for harmonic currents according to [5].

[4] gives guidance for summation of harmonic current distortion from loads. Applying this, the harmonic current distortion at the PCC due to a wind turbine installation with a number of wind turbines may be estimated applying equation (6) below:

$$I_{h\Sigma} = \sqrt[\alpha]{\sum_{i=1}^{N_{wt}} \left(\frac{I_{h,i}}{n_i} \right)^{\alpha}} \tag{6}$$

Here, N_{wt} is the number of wind turbines connected to the PCC, $I_{h\Sigma}$ is the h'th order harmonic current distortion at the PCC, n_i is the ratio of the transformer at the i'th wind turbine, $I_{h,i}$ is the h'th order harmonic current distortion of the i'th wind turbine and α is the exponent given in Table 3. If the wind turbines are equal and their converters operate at the same switching frequency, the harmonics are likely to be in phase and α = 1 shall be used for all harmonic orders.

Table 3 Specification of exponents according to [4].

Harmonic order	α
h < 5	1.0
5 ≤ h ≤ 10	1.4
h > 10	2.0

CONCLUSION

In order to ensure proper voltage quality and still allow fair access of dispersed generation to the distribution network, simplified assessment e.g. characterising dispersed generation only by rated power is unlikely to be appropriate. Rather, the dispersed generation should be characterised by a set of parameters revealing information on maximum continuous power, reactive power, flicker and harmonics, and these should be applied for predicting the impact on voltage quality.

The procedures outlined in this paper are basically aimed at wind power. The authors suggest however that similar procedures could usefully be formulated and applied for other dispersed generation technologies. There is considerable interest worldwide in large-scale grid-connection of photovoltaic systems. Photovoltaic systems share a number of the attributes of wind power with a fluctuating power source and the use of power electronic converters for their connection to the network. It would appear that the approach developed for wind power might be adapted for this technology.

ACKNOWLEDGEMENTS

The authors gratefully acknowledges the members of WG10 of IEC TC88 for their work producing [1] that has formed the basis of this paper.

REFERENCES

[1] IEC 61400-21 (1998) Wind Turbine Generator Systems. Part 21: Power quality requirements for grid connected wind turbines. (Committee draft).

[2] IEC 60868 (1986) Flickermeter. Functional and design specifications.

[3] IEC 61000-3-7 (1996) Electromagnetic compatibility (EMC). Part 3: Limits. Section 7: Assessment of emission limits for fluctuating loads in MV and HV power systems. Basic EMC publication.

[4] IEC 61000-3-6 (1996) Electromagnetic compatibility (EMC). Part 3: Limits. Section 6: Assessment of emission limits for distorting loads in MV and HV power systems. Basic EMC publication.

[5] IEC 61800-3 (1996) Adjustable speed electrical drive systems. Part 3: EMC product standard including specific test methods.