

Wind turbine generator systems —

Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines

The European Standard EN 61400-21:2002 has the status of a
British Standard

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National foreword

This British Standard is the official English language version of EN 61400-21:2002. It is identical with IEC 61400-21:2001.

The UK participation in its preparation was entrusted to Technical Committee PEL/88, Wind turbine generator systems, which has the responsibility to:

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- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
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Wind turbine generator systems
Part 21: Measurement and assessment of power quality
characteristics of grid connected wind turbines
(IEC 61400-21:2001)

Aérogénérateurs
Partie 21: Mesurage et évaluation
des caractéristiques de qualité
de puissance des éoliennes
connectées au réseau
(CEI 61400-21:2001)

Windenergieanlagen
Teil 21: Anforderungen an die
Netzverträglichkeit für an ein
Verbundnetz angeschlossene
Windenergieanlagen
(IEC 61400-21:2001)

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Foreword

The text of document 88/144/FDIS, future edition 1 of IEC 61400-21, prepared by IEC TC 88, Wind turbine systems, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61400-21 on 2002-02-01.

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Annexes designated "normative" are part of the body of the standard.
Annexes designated "informative" are given for information only.
In this standard, annex ZA is normative and annexes A and B are informative.
Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61400:2001 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

- | | | |
|---------------|------|---|
| IEC 61000-3-3 | NOTE | Harmonized as EN 61000-3-3:1995 (not modified). |
| IEC 61400-12 | NOTE | Harmonized as EN 61400-12:1998 (not modified). |

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INTRODUCTION

The purpose of this part of IEC 61400 is to provide a uniform methodology that will ensure consistency and accuracy in the measurement and assessment of power quality characteristics of grid connected wind turbines (WTs). In this respect the term power quality includes those electric characteristics of the WT that influence the voltage quality of the grid to which the WT is connected. The standard has been prepared with the anticipation that it would be applied by:

- the WT manufacturer striving to meet well-defined power quality characteristics;
- the WT purchaser in specifying such power quality characteristics;
- the WT operator who may be required to verify that stated, or required power quality characteristics are met;
- the WT planner or regulator who must be able to accurately and fairly determine the impact of a WT on the voltage quality to ensure that the installation is designed so that voltage quality requirements are respected;
- the WT certification authority or component testing organization in evaluating the power quality characteristics of the wind turbine type;
- the planner or regulator of the electric network who must be able to determine the grid connection required for a WT.

This standard provides recommendations for preparing the measurements and assessment of power quality characteristics of grid connected WTs. The standard will benefit those parties involved in the manufacture, installation planning, obtaining of permission, operation, utilization, testing and regulation of WTs. The measurement and analysis techniques recommended in this standard should be applied by all parties to ensure that the continuing development and operation of WTs are carried out in an atmosphere of consistent and accurate communication.

This standard presents measurement and analysis procedures expected to provide consistent results that can be replicated by others.

WIND TURBINE GENERATOR SYSTEMS –

Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines

1 Scope

This part of IEC 61400 includes:

- definition and specification of the quantities to be determined for characterizing the power quality of a grid connected wind turbine;
- measurement procedures for quantifying the characteristics;
- procedures for assessing compliance with power quality requirements, including estimation of the power quality expected from the wind turbine type when deployed at a specific site, possibly in groups.

The measurement procedures are valid for single wind turbines with a three-phase grid connection, and as long as the wind turbine is not operated to actively control the frequency or voltage at any location in the network. The measurement procedures are valid for any size of wind turbine, though this standard only requires wind turbine types intended for PCC at MV or HV to be tested and characterized as specified in this standard.

The measured characteristics are valid for the specific configuration of the assessed wind turbine only. Other configurations, including altered control parameters that cause the wind turbine to behave differently with respect to power quality, require separate assessment.

The measurement procedures are designed to be as non-site-specific as possible, so that power quality characteristics measured at for example a test site can be considered valid also at other sites.

The procedures for assessing compliance with power quality requirements are valid for wind turbines with PCC at MV or HV in power systems with fixed frequency within ± 1 Hz, and sufficient active and reactive power regulation capabilities and sufficient load to absorb the wind power production. In other cases, the principles for assessing compliance with power quality requirements may still be used as a guide.

NOTE 1 This standard uses the following terms for system voltage:

- low voltage (LV) refers to $U_n \leq 1$ kV;
- medium voltage (MV) refers to $1 \text{ kV} < U_n \leq 35$ kV;
- high voltage (HV) refers to $U_n > 35$ kV.

NOTE 2 The issue of interharmonics is not addressed in this standard, though it is under consideration awaiting proper measurement and assessment procedures to be established by the appropriate IEC committee.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 61400. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 61400 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60034-1, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60044-1, *Instrument transformers – Part 1: Current transformers*

IEC 60050(161), *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electro-magnetic compatibility*

IEC 60050(393), *International Electrotechnical Vocabulary (IEV) – Chapter 393: Nuclear instrumentation: Physical phenomena and basic concepts*

IEC 60050(415), *International Electrotechnical Vocabulary (IEV) – Chapter 415: Wind turbine generator systems*

IEC 60186, *Voltage transformers*
Amendment 1 (1988)
Amendment 2 (1995)

IEC 60688, *Electrical measuring transducers for converting a.c. electrical quantities to analogue or digital signals*

IEC 61000-4-7, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 7: General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*

IEC 61000-4-15, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 15: Flickermeter – Functional and design specifications*

IEC 61800-3, *Adjustable speed electrical power drive systems – Part 3: EMC product standard including specific test methods*

3 Definitions

For the purpose of this part of IEC 61400, the following definitions apply.

3.1

continuous operation (for wind turbines)

normal operation of the wind turbine excluding start-up and shutdown operations

3.2

cut-in wind speed (for wind turbines)

lowest wind speed at hub height at which the wind turbine starts to produce power

[IEV 415-03-05]

3.3**flicker coefficient for continuous operation (for wind turbines)**

a normalized measure of the flicker emission during continuous operation of the wind turbine:

$$c(\psi_k) = P_{st, \text{fic}} \cdot \frac{S_{k, \text{fic}}}{S_n}$$

where

$P_{st, \text{fic}}$ is the flicker emission from the wind turbine on the fictitious grid;

S_n is the rated apparent power of the wind turbine;

$S_{k, \text{fic}}$ is the short-circuit apparent power of the fictitious grid.

NOTE The flicker coefficient for continuous operation is the same for a short-term (10 min) and long-term period (2 h).

3.4**flicker step factor (for wind turbines)**

a normalized measure of the flicker emission due to a single switching operation of the wind turbine:

$$k_f(\psi_k) = \frac{1}{130} \cdot \frac{S_{k, \text{fic}}}{S_n} \cdot P_{st, \text{fic}} \cdot T_p^{0,31}$$

where

T_p is the measurement period, long enough to ensure that the transient of the switching operation has abated, though limited to exclude possible power fluctuations due to turbulence;

$P_{st, \text{fic}}$ is the flicker emission from the wind turbine on the fictitious grid;

S_n is the rated apparent power of the wind turbine;

$S_{k, \text{fic}}$ is the short-circuit apparent power of the fictitious grid.

3.5**maximum permitted power (for wind turbines)**

the 10 min average power from the wind turbine that must not be exceeded irrespective of weather and grid conditions

3.6**maximum measured power (for wind turbines)**

that power (with a specified averaging time) which is observed during continuous operation of the wind turbine

3.7**network impedance phase angle**

phase angle of network short-circuit impedance:

$$\psi_k = \arctan (X_k / R_k)$$

where

X_k is the network short-circuit reactance;

R_k is the network short-circuit resistance.

3.8**normal operation (for wind turbines)**

fault free operation complying with the description in the wind turbine manual

[IEV 393-08-12, modified]

3.9

output power (for wind turbines)

electric active power delivered by the wind turbine at its terminals

[IEV 415-04-02, modified]

3.10

point of common coupling (PCC)

point of a power supply network, electrically nearest to a particular load, at which other loads are, or may be, connected

NOTE 1 These loads can be either devices, equipment or systems, or distinct customer's installations.

NOTE 2 In some applications, the term "point of common coupling" is restricted to public networks.

[IEV 161-07-15, modified]

3.11

power collection system (for wind turbines)

electrical system that collects the power from a wind turbine and feeds it into an electrical supply network

[IEV 415-04-06, modified]

3.12

rated apparent power (for wind turbines)

the apparent power from the wind turbine while operating at rated power and nominal voltage and frequency:

$$S_n = \sqrt{P_n^2 + Q_n^2}$$

where

P_n is the rated power;

Q_n is the corresponding reactive power.

3.13

rated current (for wind turbines)

the current from the wind turbine while operating at rated power and nominal voltage and frequency

3.14

rated power (for wind turbines)

maximum continuous electric output power which a wind turbine is designed to achieve under normal operating conditions

[IEV 415-04-03, modified]

3.15

rated wind speed (for wind turbines)

wind speed at which a wind turbine's rated power is achieved

[IEV 415-03-04, modified]

3.16

rated reactive power (for wind turbines)

the reactive power from the wind turbine while operating at rated power and nominal voltage and frequency

3.17**standstill (for wind turbines)**

condition of a wind turbine that is stopped

[IEV 415-01-15, modified]

3.18**start-up (for wind turbines)**

transitional state of a wind turbine between standstill and power production

3.19**switching operation (for wind turbines)**

start-up or switching between generators

3.20**turbulence intensity**

ratio of the wind speed standard deviation to the mean wind speed, determined from the same set of measured data samples of wind speed, and taken over a specified period of time

[IEV 415-03-25]

3.21**voltage change factor (for wind turbines)**

a normalized measure of the voltage change due to a switching operation of the wind turbine:

$$k_u(\psi_k) = \sqrt{3} \cdot \frac{U_{\text{fic,max}} - U_{\text{fic,min}}}{U_n} \cdot \frac{S_{k,\text{fic}}}{S_n}$$

where

$U_{\text{fic,min}}$ and $U_{\text{fic,max}}$ are the minimum and maximum one period RMS value of the phase-to-neutral voltage on the fictitious grid during the switching operation;

U_n is the nominal phase-to-phase voltage;

S_n is the rated apparent power of the wind turbine;

$S_{k,\text{fic}}$ is the short-circuit apparent power of the fictitious grid.

NOTE The voltage change factor k_u is similar to k_i being the ratio between the maximum inrush current and the rated current, though k_u is a function of the network impedance phase angle. The highest value of k_u will be numerically close to k_i .

3.22**wind turbine (WT)**

system which converts kinetic wind energy into electric energy

3.23**wind turbine terminals**

a point being a part of the WT and identified by the WT supplier at which the WT may be connected to the power collection system

4 Symbols and units

In this standard, the following symbols and units are used.

$\frac{\Delta U_{\text{dyn}}}{U_n}$	maximum permitted voltage change (%)
ψ_k	network impedance phase angle (degrees)
$\alpha_m(t)$	electrical angle of the fundamental of the measured voltage (degrees)
β	exponent associated with summation of harmonics
$c(\psi_k)$	flicker coefficient for continuous operation
d	relative voltage change (%)
E_{Plti}	long-term flicker emission limit
E_{Psti}	short-term flicker emission limit
f_g	fundamental grid frequency (Hz)
$f_{m,i}$	frequency of occurrence of flicker coefficient values within the i'th wind speed bin
$f_{y,i}$	frequency of occurrence of wind speeds within the i'th wind speed bin
h	harmonic order
$I_{h,i}$	h'th order harmonic current distortion of i'th wind turbine (A)
$i_m(t)$	measured instantaneous current (A)
I_n	rated current (A)
$k_f(\psi_k)$	flicker step factor
k_i	ratio of maximum inrush current and rated current
$k_u(\psi_k)$	voltage change factor
L_{fic}	inductance of fictitious grid (H)
N_{10}	maximum number of one type of switching operations within a 10 min period
N_{120}	maximum number of one type of switching operations within a 120 min period
N_{bin}	total number of wind speed bins between $v_{\text{cut-in}}$ and 15 m/s
n_i	ratio of the transformer at the i'th wind turbine
N_m	total number of measured flicker coefficient values
$N_{m,i}$	number of measured flicker coefficient values within the i'th wind speed bin
$N_{m,i,c < x}$	number of flicker coefficient values less than x within the i'th wind speed bin
N_{wt}	number of wind turbines
$P_{0,2}$	maximum measured power (0,2-second-average value) (W)
P_{60}	maximum measured power (60-second-average value) (W)
P_{lt}	long-term flicker disturbance factor
P_{mc}	maximum permitted power (W)

P_n	rated power of wind turbine (W)
$Pr(c < x)$	accumulated distribution of c
P_{st}	short-term flicker disturbance factor
$P_{st, fic}$	short-term flicker disturbance factor at fictitious grid
$Q_{0,2}$	reactive power (0,2-second-average value) at $P_{0,2}$ (var)
Q_{60}	reactive power (60-second-average value) at P_{60} (var)
Q_{mc}	reactive power at P_{mc} (var)
Q_n	rated reactive power of wind turbine (var)
R_{fic}	resistance of fictitious grid (Ω)
$S_{0,2}$	apparent power (0,2-second-average value) at $P_{0,2}$ (VA)
S_{60}	apparent power (60-second-average value) at P_{60} (VA)
S_k	short-circuit apparent power of grid (VA)
$S_{k, fic}$	short-circuit apparent power of the fictitious grid (VA)
S_{mc}	apparent power at P_{mc} (VA)
S_n	rated apparent power of wind turbine (VA)
T_p	transient time period of a switching operation (s)
$u_0(t)$	instantaneous phase-to-neutral voltage of an ideal voltage source (V)
$u_{fic}(t)$	instantaneous phase-to-neutral voltage simulated at fictitious grid (V)
$U_{fic, max}$	maximum phase-to-neutral voltage at fictitious grid (V)
$U_{fic, min}$	minimum phase-to-neutral voltage at fictitious grid (V)
U_n	nominal phase-to-phase voltage (V)
v_a	annual average wind speed (m/s)
v_{cut-in}	cut-in wind speed (m/s)
v_i	mid-point of the i 'th wind speed bin
w_i	weighting factor for the i 'th wind speed bin
X_{fic}	reactance of fictitious grid (Ω)

5 Abbreviations

The following abbreviations are used in this standard.

A/D converter	analogue to digital converter
HV	high voltage
LV	low voltage
MV	medium voltage
PCC	point of common coupling
RMS	root mean square
WT	wind turbine

6 Wind turbine power quality characteristic parameters

6.1 General

This clause gives the quantities that shall be stated for characterizing the power quality of a wind turbine. A sample report format is given in annex A.

Generator sign convention shall be used, i.e. the positive direction of the power flow is assumed to be from the wind turbine and to the grid.

6.2 Rated data

The rated data of the wind turbine shall be specified, including P_n , Q_n , S_n , U_n and I_n .

NOTE The rated data are used only for normalizing purposes in this standard.

6.3 Maximum permitted power

The maximum permitted power P_{mc} of the wind turbine (permitted by the control system) shall be specified.

6.4 Maximum measured power

The maximum measured power of the wind turbine shall be specified both as a 60 s average value, P_{60} and as a 0,2 s average value, $P_{0,2}$.

6.5 Reactive power

The reactive power of the wind turbine shall be specified in a table as 10 min average values as a function of the 10 min average output power for 0, 10, ... 90, 100 % of the rated power. Also the reactive power at P_{mc} , P_{60} and $P_{0,2}$ shall be specified.

6.6 Voltage fluctuations

The voltage fluctuations (flicker and voltage changes) imposed by the wind turbine shall be characterized as described in 6.6.1 and 6.6.2.

6.6.1 Continuous operation

The wind turbine flicker coefficient for continuous operation, $c(\psi_k, v_a)$ shall be stated as the 99th percentile for the network impedance phase angles $\psi_k = 30^\circ, 50^\circ, 70^\circ$ and 85° in a table for four different wind speed distributions with annual average wind speed $v_a = 6$ m/s, 7,5 m/s, 8,5 m/s and 10 m/s respectively. The 10 min average values of the wind speed shall be assumed to be Rayleigh distributed (see note). The annual average wind speed refers to the hub height of the wind turbine.

NOTE The Rayleigh distribution is a probability distribution that commonly fits the annual wind speed distribution. The Rayleigh distribution may be described by:

$$F(v) = 1 - \exp\left(-\frac{\pi}{4}\left(\frac{v}{v_a}\right)^2\right)$$

where

$F(v)$ is the Rayleigh cumulative probability distribution function for the wind speed;

v_a is the annual average wind speed at hub height;

v is the wind speed.