



BSI Standards Publication

Wind turbines —

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

National foreword

This British Standard is the UK implementation of EN 61400-21:2008. It is identical to IEC 61400-21:2008. It supersedes BS EN 61400-21:2002 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PEL/88, Wind turbines.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 January 2009.

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ISBN 978 0 580 56750 6

ICS 27.180

Amendments issued since publication

Amd. No.	Date	Text affected
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English version

**Wind turbines -
Part 21: Measurement and assessment
of power quality characteristics of grid connected wind turbines
(IEC 61400-21:2008)**

Eoliennes -
Partie 21: Mesurage et évaluation
des caractéristiques de qualité
de puissance des éoliennes
connectées au réseau
(CEI 61400-21:2008)

Windenergieanlagen -
Teil 21: Messung und Bewertung
der Netzverträglichkeit
von netzgekoppelten
Windenergieanlagen
(IEC 61400-21:2008)

This European Standard was approved by CENELEC on 2008-10-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Foreword

The text of document 88/317/FDIS, future edition 2 of IEC 61400-21, prepared by IEC TC 88, Wind turbines, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61400-21 on 2008-10-01.

This European Standard supersedes EN 61400-21:2002.

EN 61400-21:2008 includes the following new items with respect to EN 61400-21:2002:

- interharmonics and current distortions (< 9 kHz),
- response to voltage dips,
- active power ramp rate limitation and set-point control,
- reactive power capabilities and set-point control,
- grid protection and reconnection time after grid faults.

The following dates were fixed:

- latest date by which the EN has to be implemented
at national level by publication of an identical
national standard or by endorsement (dop) 2009-07-01
- latest date by which the national standards conflicting
with the EN have to be withdrawn (dow) 2011-10-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61400-21:2008 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 61000-3-3:2008 (not modified).
IEC 61000-4-30	NOTE Harmonized as EN 61000-4-30:2003 (not modified).
IEC 61400-1	NOTE Harmonized as EN 61400-1:2005 (not modified).

Annex ZA (normative)

Normative references to international publications with their corresponding European publications

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60044-1 (mod)	- ¹⁾	Instrument transformers - Part 1: Current transformers	EN 60044-1	1999 ²⁾
IEC 60044-2 (mod)	- ¹⁾	Instrument transformers - Part 2: Inductive voltage transformers	EN 60044-2	1999 ²⁾
IEC 60050-161	- ¹⁾	International Electrotechnical Vocabulary (IEV) - Chapter 161: Electromagnetic compatibility	-	-
IEC 60050-415	- ¹⁾	International Electrotechnical Vocabulary (IEV) - Part 415: Wind turbine generator systems	-	-
IEC 61000-4-7	2002	Electromagnetic compatibility (EMC) - Part 4-7: Testing and measurement techniques - General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto	EN 61000-4-7	2002
IEC 61000-4-15	- ¹⁾	Electromagnetic compatibility (EMC) - Part 4-15: Testing and measurement techniques - Flickermeter - Functional and design specifications	EN 61000-4-15	1998 ²⁾
IEC 61400-12-1	- ¹⁾	Wind turbines - Part 12-1: Power performance measurements of electricity producing wind turbines	EN 61400-12-1	2006 ²⁾
IEC 61800-3	2004	Adjustable speed electrical power drive systems - Part 3: EMC requirements and specific test methods	EN 61800-3	2004
IEC 62008	- ¹⁾	Performance characteristics and calibration methods for digital data acquisition systems and relevant software	EN 62008	2005 ²⁾

¹⁾ Undated reference.

²⁾ Valid edition at date of issue.

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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 presentation, testing and assessment of power quality characteristics of grid connected wind turbines (WTs). The power quality characteristics here include wind turbine specifications, voltage quality (emissions of flicker and harmonics), voltage drop response, power control (control of active and reactive power), grid protection and reconnection time.

This part of IEC 61400 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 has to 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 has to be able to determine the grid connection required for a WT.

This part of IEC 61400 provides recommendations for preparing the measurements and assessment of power quality characteristics of grid connected WTs. This part of IEC 61400 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 part of IEC 61400 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 part of IEC 61400 presents measurement and analysis procedures expected to provide consistent results that can be replicated by others.

WIND TURBINES –

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. The measurement procedures are valid for any size of wind turbine, though this part of IEC 61400 only requires wind turbine types intended for PCC (Point of Common Coupling) at MV or HV to be tested and characterized as specified in this part of IEC 61400.

The measured characteristics are valid for the specific configuration and operational mode of the assessed wind turbine type 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. In other cases, the principles for assessing compliance with power quality requirements may still be used as a guidance.

This part of IEC 61400 is for testing of wind turbines, though it contains information that may also be useful for testing of wind farms.

NOTE This part of IEC 61400 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.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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



IEC 60050-161, *International Electrotechnical Vocabulary – Part 161: Electromagnetic compatibility*

IEC 60050-415, *International Electrotechnical Vocabulary – Part 415: Wind turbine generator systems*

IEC 61000-4-7:2002, *Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – 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 61400-12-1, *Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines*

IEC 61800-3:2004, *Adjustable speed electrical power drive systems – Part 3: EMC requirements and specific test methods*

IEC 62008, *Performance characteristics and calibration methods for digital data acquisition systems and relevant software*

3 Terms and definitions

For purposes of this document, the following terms and 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)

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

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

where

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

S_n is the rated apparent power of the wind turbine;

$S_{\text{k, fic}}$ 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:

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

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;

$P_{\text{st, fic}}$ 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 $P_{\text{st, fic}}$ is here evaluated over the time period T_p .

3.5

maximum measured power (for wind turbines)

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

3.6

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

3.7

normal operation (for wind turbines)

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

3.8

operational mode (for wind turbines)

operation according to control setting, for example voltage control mode, frequency control mode, reactive power control mode, active power control mode, etc.

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)

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

$$S_n = \sqrt{3} U_n I_n$$

where

U_n is the nominal voltage;

I_n is the rated current

3.13

rated current (for wind turbines)

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

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

standstill (for wind turbines)

condition of a wind turbine that is stopped

[IEV 415-01-15, modified]

3.17

start-up (for wind turbines)

transitional state of a wind turbine between standstill and power production

3.18

switching operation (for wind turbines)

start-up or switching between generators

3.19

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]

3.20

voltage change factor (for wind turbines)

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

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

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;

$S_{\text{k, fic}}$ 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 .

3.21

wind turbine

WT

system which converts kinetic wind energy into electric energy

3.22

wind turbine terminals

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 part of IEC 61400, the following symbols and units are used.

$\frac{\Delta U_{\text{dyn}}}{U_n}$ maximum permitted voltage change (%)

ψ_k network impedance phase angle (°)

$\alpha_m(t)$ electrical angle of the fundamental of the measured voltage (°)

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 nominal grid frequency (50 Hz or 60 Hz)

$f_{m,i}$ frequency of occurrence of flicker coefficient values within the i 'th wind speed bin

f_{over} over-frequency protection level

f_{under} under-frequency protection level

$f_{y,i}$ 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_{10m}	maximum number of one type of switching operations within a 10 min period
N_{120m}	maximum number of one type of switching operations within a 120 min period
N_{bin}	total number of wind speed bins between v_{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	active power (W)
$P_{0,2}$	maximum measured active power (0,2 s average value) (W)
P_{60}	maximum measured active power (60 s average value) (W)
P_{600}	maximum measured active power (600 s average value) (W)
P_{lt}	long-term flicker disturbance factor
P_n	rated active 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	reactive power (var)
R_{fic}	resistance of fictitious grid (Ω)

S_k	short-circuit apparent power of grid (VA)
$S_{k, \text{fic}}$	short-circuit apparent power of the fictitious grid (VA)
S_n	rated apparent power of wind turbine (VA)
THC	total harmonic current distortion (% of I_n)
T_p	transient time period of a switching operation (s)
U	phase-to-phase voltage (V)
$u_0(t)$	instantaneous phase-to-neutral voltage of an ideal voltage source (V)
$u_{\text{fic}}(t)$	instantaneous phase-to-neutral voltage simulated at fictitious grid (V)
$U_{\text{fic, max}}$	maximum phase-to-neutral voltage at fictitious grid (V)
$U_{\text{fic, min}}$	minimum phase-to-neutral voltage at fictitious grid (V)
U_n	nominal phase-to-phase voltage (V)
U_{under}	under-voltage protection level
U_{over}	over-voltage protection level
v_a	annual average wind speed (m/s)
$v_{\text{cut-in}}$	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)
Z_1	impedance for limiting the effect of the short-circuit on the upstream grid (Ω)
Z_2	impedance between phases or to ground during short-circuit (Ω)

5 Abbreviations

The following abbreviations are used in this part of IEC 61400.

A/D converter	analogue to digital converter
DFT	discrete Fourier transform
HV	high voltage
LV	low voltage

MV	medium voltage
PCC	point of common coupling
RMS	root mean square
SCADA	supervisory control and data acquisition
THC	total harmonic current distortion
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, i.e. wind turbine specifications (6.2), voltage quality (6.3 to 6.4), voltage drop response (6.5), power control (6.6 to 6.7), grid protection and reconnection (6.8 to 6.9). 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 defined to be from the generator to the grid. If the wind turbine is replaced with a resistor and an inductor, both active and reactive power will be negative.

6.2 Wind turbine specification

The rated data of the wind turbine (referred to the wind turbine terminals) shall be specified, including P_n , S_n , U_n and I_n .

NOTE The rated data are used only for normalizing purposes in this part of IEC 61400.

6.3 Voltage fluctuations

6.3.1 General

The voltage fluctuations (flicker and voltage changes) imposed by the wind turbine shall be characterized as described in 6.3.2 and 6.3.3.

6.3.2 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 $v_a = 6 \text{ m/s}, 7,5 \text{ m/s}, 8,5 \text{ m/s}$ 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.

The characteristics shall be stated for the wind turbine operating with reactive power as close as possible to zero, i.e. if applicable, the reactive set-point control shall be set to $Q=0$. If any other operational mode is used, this shall be clearly stated.

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.

6.3.3 Switching operations

The characteristics shall be stated for the following types of switching operations:

- Wind turbine start-up at cut-in wind speed.
- Wind turbine start-up at rated wind speed or higher wind speed.
- The worst case of switching between generators (applicable only to wind turbines with more than one generator or a generator with multiple windings). See also Note 1.

For each of the above types of switching operations, the values of the parameters below shall be stated (see also Notes 2 and 3):

- The maximum number N_{10m} of the switching operation within a 10 min period.
- The maximum number N_{120m} of the switching operation within a 2 h period.
- The flicker step factor $k_f(\psi_k)$ for the network impedance phase angles $\psi_k = 30^\circ, 50^\circ, 70^\circ$ and 85° .
- The voltage change factor $k_u(\psi_k)$ for the network impedance phase angles $\psi_k = 30^\circ, 50^\circ, 70^\circ$ and 85° .

The characteristics shall be stated for the wind turbine operating with reactive power as close as possible to zero, i.e. if applicable the reactive set-point control shall be set to $Q=0$. If other operational mode is used, this shall be clearly stated.

NOTE 1 The worst case of switching between generators is in the context of flicker step factor defined as the switching operation that gives the highest flicker step factor, and in the context of voltage change factor defined as the switching operation that gives the highest voltage change factor.

NOTE 2 The parameters N_{10m} and N_{120m} may be based on manufacturers information, whereas $k_f(\psi_k)$ and $k_u(\psi_k)$ should be measured and computed.

NOTE 3 Depending on the control system of the wind turbine, the maximum number of the switching operation within a 2 h period may be less than twelve times the maximum number of the switching operation within a 10 min period.

6.4 Current harmonics, interharmonics and higher frequency components

The emission of current harmonics, interharmonics and higher frequency components during continuous operation shall be stated (see Note).

The values of the individual current components (harmonics, interharmonics and higher frequency components) and the total harmonic current distortion shall be given in tables in percentage of I_n and for operation of the wind turbine within the active power bins 0, 10, 20, ... , 100 % of P_n . 0, 10, 20, ... , 100 % are the bin midpoints.

The individual harmonic current components shall be specified as subgrouped values for frequencies up to 50 times the fundamental grid frequency, and the total harmonic current distortion shall be stated as derived from these.

The interharmonic current components shall be specified as subgrouped values for frequencies up to 2 kHz in accordance to Annex A of IEC 61000-4-7:2002.

The higher frequency current components shall be specified as subgrouped values for frequencies between 2 kHz and 9 kHz in accordance to Annex B of IEC 61000-4-7:2002.

The current harmonics, interharmonics and higher frequency components shall be stated for the wind turbine operating with reactive power as close as possible to zero, i.e. if applicable the reactive set-point control shall be set to $Q=0$. If other operational mode is used, this shall be clearly stated.

NOTE Harmonics are considered harmless as long as the duration is limited to a short period of time. Hence, this part of IEC 61400 does not require specification of short-duration harmonics caused by wind turbine start-up or other switching operations.

6.5 Response to voltage drops

The response of the wind turbine to the voltage drops specified in Table 1 shall be stated for the wind turbine operating at a) between $0,1 P_n$ and $0,3 P_n$ and b) above $0,9 P_n$. The stated response shall include results from 2 consecutive tests of each case (VD1-VD6) by time-series of active power, reactive power, active current, reactive current and voltage at the wind turbine terminals for the time shortly prior to the voltage drop and until the effect of the voltage drop has abated, but also the wind turbine operational mode shall be specified.

The test is basically for verifying wind turbine response to voltage drops (due to grid faults) and providing a basis for wind turbine numerical simulation model validation. Optional tests and measurements (for example pitch angle and rotational speed) may be carried out and reported for more detailed assessment of simulation models and compliance with specific grid code requirements.

Table 1 – Specification of voltage drops. The specified magnitudes, duration and shape are for the voltage drop occurring when the wind turbine under test is not connected

Case	Magnitude of voltage phase to phase (fraction of voltage immediately before the drop occurs)	Magnitude of positive sequence voltage (fraction of voltage immediately before the drop occurs)	Duration (s)	Shape
VD1 – symmetrical three-phase voltage drop	$0,90 \pm 0,05$	$0,90 \pm 0,05$	$0,5 \pm 0,02$	
VD2 – symmetrical three-phase voltage drop	$0,50 \pm 0,05$	$0,50 \pm 0,05$	$0,5 \pm 0,02$	
VD3 – symmetrical three-phase voltage drop	$0,20 \pm 0,05$	$0,20 \pm 0,05$	$0,2 \pm 0,02$	
VD4 – two-phase voltage drop	$0,90 \pm 0,05$	$0,95 \pm 0,05$	$0,5 \pm 0,02$	
VD5 – two-phase voltage drop	$0,50 \pm 0,05$	$0,75 \pm 0,05$	$0,5 \pm 0,02$	
VD6 – two-phase voltage drop	$0,20 \pm 0,05$	$0,60 \pm 0,05$	$0,2 \pm 0,02$	

NOTE 1 A voltage drop may cause a wind turbine to cut-out for many reasons, not only related to the electrical drive train but also due to mechanical vibrations or ancillary system low voltage capabilities. It is therefore necessary to do the test on the complete wind turbine rather than relying on drive train testing only.

NOTE 2 The purpose of VD1 and VD4 is basically for testing of wind turbines that have no capabilities to ride-through any deep voltage drops, and the tests are generally relevant as basis for validation of numerical simulation models.

6.6 Active power

6.6.1 Maximum measured power

The maximum measured power of the wind turbine shall be specified as a 600 s average value, P_{600} , a 60 s average value, P_{60} and as a 0,2 s average value, $P_{0,2}$.

6.6.2 Ramp rate limitation

The ability of the wind turbine to operate in ramp rate limitation control mode shall be characterized by test results presented in a graph. The graph shall show available and

measured active power output during operation at a ramp rate value of 10 % of rated power per minute for a test period of 10 min.

The test results shall be reported as 0,2 s average data.

6.6.3 Set-point control

The ability of the wind turbine to operate in active power set-point control mode shall be characterized by test results presented in a graph. The graph shall show available and measured active power output during operation at set point values being adjusted from 100 % down to 20 % of rated power in steps of 20 % with 2 min operation at each set-point value, i.e. according to Figure 1.

The test results shall be reported as 0,2 s average data.

NOTE The ability of a wind turbine to participate in an automatic frequency control scheme is closely linked to its ability to operate in active power set-point control mode. Participation in automatic frequency control can for instance be achieved through the SCADA system of a modern wind farm that may continuously update the active power set-point of the individual wind turbines to achieve a requested frequency response.

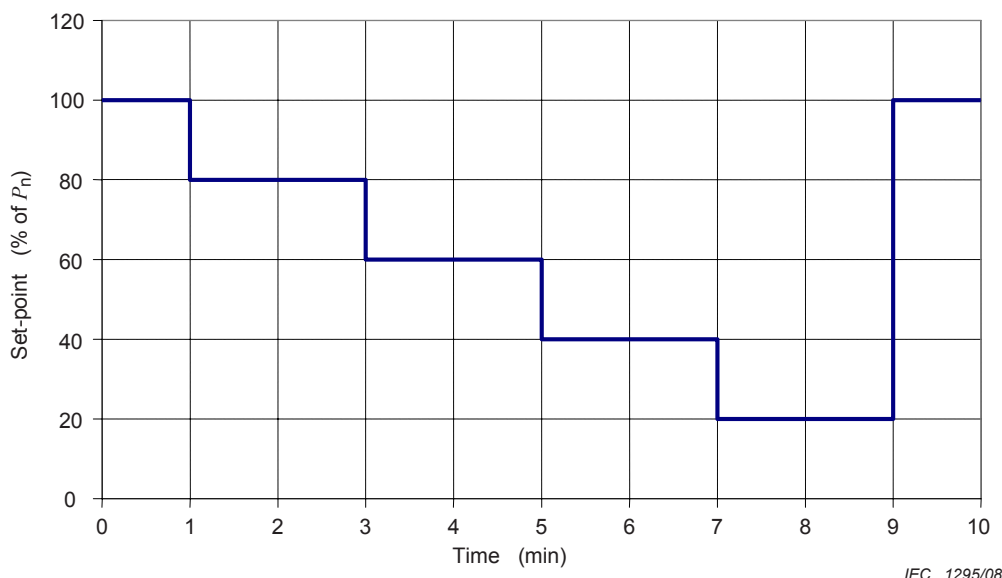


Figure 1 – Adjustment of active power set-point

6.7 Reactive power

6.7.1 Reactive power capability

The capability of the WT concerning the maximum inductive reactive power and the maximum capacitive reactive power of the WT shall be specified in a Table as 1 min average values as a function of the 1 min average output power for 0, 10, ..., 90, 100 % of the rated power.

6.7.2 Set-point control

The reactive power set-point control shall be described by a table and a graph as follows.

- The table shall show measured reactive power at reactive set point value = 0 for operation at 0, 10, 20, ... 100 % active power output.
- The active and reactive power shall be 1 min average values.