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BSI Standards Publication

Wind turbines

Part 2: Small wind turbines

National foreword

This British Standard is the UK implementation of EN 61400-2:2014. It is identical to IEC 61400-2:2013. It supersedes BS EN 61400-2:2006 which is withdrawn.

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Foreword

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This document supersedes EN 61400-2:2006

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The text of the International Standard IEC 61400-2:2013 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 60034 (Series)	NOTE	Harmonized as EN 60034 (Series).
IEC 60364 (Series)	NOTE	Harmonized as HD 60364 (Series).
IEC 60529:1989	NOTE	Harmonized as EN 60529:1991.
IEC 61400-1:2005	NOTE	Harmonized as EN 61400-1:2005.
IEC 61400-4	NOTE	Harmonized as EN 61400-4.
IEC 61400-21:2008	NOTE	Harmonized as EN 61400-21:2008.
IEC 61400-22:2010	NOTE	Harmonized as EN 61400-22:2011.
IEC 61400-24	NOTE	Harmonized as EN 61400-24.
ISO/IEC 17020:2012	NOTE	Harmonized as EN ISO/IEC 17020:2012.
ISO 9000 (Series)	NOTE	Harmonized as EN ISO 9000 (Series).
ISO 9001:2008	NOTE	Harmonized as EN ISO 9001:2008.

Annex ZA
(normative)
Normative references to international publications with their corresponding European publications

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

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu

Publication	Year	Title	EN/HD	Year
IEC 60038 (mod)	2009	IEC standard voltages	EN 60038	2011
IEC 60204-1 (mod)	2005	Safety of machinery - Electrical equipment of machines -- Part 1: General requirements	EN 60204-1	2006
			+prA11	
			+EN 60204-1:2006/corrigendum Feb. 2010	2010
IEC 60364-5-54	-	Low-voltage electrical installations -- Part 5-54: Selection and erection of electrical equipment - Earthing arrangements and protective conductors	HD 60364-5-54	-
			+FprAA	2011
IEC 60721-2-1	-	Classification of environmental conditions -- Part 2-1: Environmental conditions appearing in nature - Temperature and humidity	EN 60721-2-1	-
IEC 61400-1	2005	Wind turbines -- Part 1: Design requirements	EN 61400-1 +prA	2005
IEC 61400-11	-	Wind turbines -- Part 11: Acoustic noise measurement techniques	EN 61400-11	-
IEC 61400-12-1	2005	Wind turbines -- Part 12-1: Power performance measurements of electricity producing wind turbines	EN 61400-12-1	2006
IEC 61643-11 (mod)	2011	Low-voltage surge protective devices -- Part 11: Surge protective devices connected to low-voltage power systems - Requirements and test methods	EN 61643-11	2012
ISO 2394	1998	General principles on reliability for structures	-	-
IEC/TS 61400-13	-	Wind turbine generator systems - Part 13: Measurement of mechanical loads	-	-
IEC/TS 61400-23	2001	Wind turbine generator systems -- Part 23: Full-scale structural testing of rotor blades	-	-
ISO/IEC 17025	-	General requirements for the competence of testing and calibration laboratories	EN ISO/IEC 17025	-

CONTENTS

WIND TURBINES –

Part 2: Small wind turbines

1 Scope

This part of IEC 61400 deals with safety philosophy, quality assurance, and engineering integrity and specifies requirements for the safety of small wind turbines (SWTs) including design, installation, maintenance and operation under specified external conditions. Its purpose is to provide the appropriate level of protection against damage from hazards from these systems during their planned lifetime.

This standard is concerned with all subsystems of SWTs such as protection mechanisms, internal electrical systems, mechanical systems, support structures, foundations and the electrical interconnection with the load. A small wind turbine system includes the wind turbine itself including support structures, the turbine controller, the charge controller / inverter (if required), wiring and disconnects, the installation and operation manual(s) and other documentation.

While this standard is similar to IEC 61400-1, it does simplify and make significant changes in order to be applicable to small wind turbines. Any of the requirements of this standard may be altered if it can be suitably demonstrated that the safety of the turbine system is not compromised. This provision, however, does not apply to the classification and the associated definitions of external conditions in Clause 6. Compliance with this standard does not relieve any person, organisation, or corporation from the responsibility of observing other applicable regulations.

This standard applies to wind turbines with a rotor swept area smaller than or equal to 200 m^2, generating electricity at a voltage below 1 000 V a.c. or 1 500 V d.c. for both on-grid and off-grid applications.

This standard should be used together with the appropriate IEC and ISO standards (see Clause 2).

2 Normative references

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

IEC 60038:2009, *IEC standard voltages*

IEC 60204-1:2005, *Safety of machinery – Electrical equipment of machines – Part 1: General requirements*

IEC 60364-5-54, *Low-voltage electrical installations – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements and protective conductors*

IEC 60721-2-1, *Classification of environmental conditions – Part 2-1: Environmental conditions appearing in nature – Temperature and humidity*

IEC 61400-11, *Wind turbines – Part 11: Acoustic noise measurement techniques*

IEC 61400-12-1:2005, *Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines*

IEC/TS 61400-13, *Wind turbine generator systems – Part 13: Measurement of mechanical loads*

IEC 61400-14:2005, *Wind turbines – Part 14: Declaration of apparent sound power level and tonality values*

IEC/TS 61400-23:2001, *Wind turbine generator systems – Part 23: Full-scale structural testing of rotor blades*

IEC 61643-11:2011, *Low-voltage surge protective devices – Part 11: Surge protective devices connected to low-voltage power distribution systems – Requirements and test methods*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO 2394:1998, *General principles on reliability for structures*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
annual average
mean value of a set of measured data of sufficient size and duration to serve as an estimate of the expected value of the quantity

Note 1 to entry: The averaging time interval shall be an integer number of years to average out non-stationary effects such as seasonality.

3.2
annual average wind speed
V_{ave}
wind speed averaged according to the definition of annual average

3.3
auto-reclosing cycles
event with a time period, varying from approximately 0,01 s to a few seconds, during which a breaker released after a grid fault is automatically reclosed and the line is reconnected to the network

3.4
brake
device capable of reducing the rotor speed or stopping rotation of a wind turbine system

3.5
catastrophic failure
disintegration or collapse of a component or structure, that results in loss of vital function which impairs safety of a wind turbine system

3.6
characteristic value
value (of a material property) having a prescribed probability of not being attained in a hypothetical unlimited test series

3.7
consumer label
a label for the benefit of consumers consisting of two parts: the label itself, and a test summary report made available by a web site

3.8
control system
sub-system that receives information about the condition of the wind turbine system and/or its environment and adjusts the turbine in order to maintain it within its operating limits

3.9
cut-in wind speed
V_{in}
lowest mean hub height wind speed bin value at which the wind turbine system produces a net positive power output

3.10
cut-out wind speed
V_{out}
highest mean wind speed at hub height at which the wind turbine system is designed to produce power

3.11
declared sound power level
the declared apparent sound power level in dB(A) as measured per IEC 61400-11 and as calculated per IEC 61400-14

3.12
design limit
maximum or minimum value used in a design

3.13
design situation
possible mode of wind turbine system operation, e.g. power production, parking, etc.

3.14
design wind speed
wind speed at hub height used as input for the simple design equations (equal to 1,4 V_{ave})

3.15
downwind
in the main direction of wind flow

3.16
emergency shutdown
rapid shutdown of the wind turbine system triggered by a protection system or by manual intervention

3.17
environmental condition
characteristicsof the environment (altitude, temperature, humidity, etc.) which may affect the wind turbine system behaviour

3.18
external condition
factor affecting the operation of a wind turbine system including the environmental conditions (temperature, snow, ice, etc.) and the electrical network conditions that are not part of the wind turbine system

3.19
extreme wind speed
highest average wind speed, averaged over t seconds, that is likely to be experienced within a specified time period (recurrence period): of T years

Note 1 to entry: Recurrence periods of T = 50 years and T = 1 year and averaging time interval of t = 3 s and t = 10 min are used in a number of standards. In popular language the less precise term "survival wind speed" is often used. In practice, however, the wind turbine generator system is designed using the extreme wind speed for design load cases.

3.20
fail-safe
design property of an item which prevents its failures from resulting in critical faults

3.21
furling
a passive control mechanism by means of reducing the projected swept area, which can be used to e.g. control the wind turbine system power or rotational speed, etc.

3.22
gust
sudden and brief increase of the wind speed over its mean value

Note 1 to entry: A gust can be characterized by its rise-time, its amplitude and its duration.

3.23
horizontal axis wind turbine
wind turbine system whose rotor axis is substantially parallel to the wind flow

3.24
hub
fixture for attaching the blades or blade assembly to the rotor shaft of a wind turbine system

3.25
hub height
height of the geometric centre of the swept area of the wind turbine rotor above the terrain surface

3.26
idling
condition of a wind turbine that is rotating slowly and not producing power

3.27
limit state
state of a structure and the loads acting upon it beyond which the structure no longer satisfies the design requirement

Note 1 to entry: The purpose of design calculations (i.e. the design requirement for the limit state) is to keep the probability of a limit state being reached below a certain value prescribed for the type of structure in question (ISO 2394).

[SOURCE: ISO 2394:1998, 2.2.9, modified to be precise to wind turbine systems]

3.28
load case
combination of a design situation and an external condition which results in structural loading

3.29
logarithmic wind shear law
a mathematical law which expresses wind speed variations as a logarithmic function of height above ground

3.30
maximum output current
maximum current (a.c. or d.c.) of the wind turbine system that can be taken from the connection facilities of the wind turbine system and which shall be specified as a 600 s average value, i_{600}, a 60 s average value, i_{60} and as a 0,2 s average value, $i_{0,2}$

Note 1 to entry: The maximum output current is ordinarily the rated current.

Note 2 to entry: The maximum output current is not to be confused with the current at the reference power.

3.31
maximum output power
maximum power (a.c. or d.c.) that can be taken from the connection facilities of the wind turbine system and which 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, $P_{0,2}$

Note 1 to entry: The maximum output power is ordinarily the rated power.

Note 2 to entry: The maximum output power is not to be confused with the reference power.

3.32
maximum output voltage
maximum voltage (a.c. or d.c.) that will be produced at the connection facilities of the wind turbine system and which shall be specified as a 600 s average value, U_{600}, a 60 s average value, U_{60} and as a 0,2 s average value, $U_{0,2}$

Note 1 to entry: The maximum output voltage may be exceeded within the wind turbine system itself.

3.33
mean wind speed
statistical mean of the instantaneous value of the wind speed averaged over a given time period which can vary from a few seconds to many years

3.34
nacelle
housing which contains the drive-train and other elements on top of a horizontal axis wind turbine tower

3.35
noise label
a defined graphical and textual representation of the acoustic noise data pertaining to a small wind turbine system

3.36
normal external conditions
those external conditions which are encountered by the wind turbine system with less than one-year recurrence period

3.37
normal operation
fault free operation complying with the description in the wind turbine manual

3.38
normal shutdown
shutdown in which all stages are under the control of the wind turbine’s control system

3.39
operating limits
set of conditions defined by the SWT designer that govern the activation of the control and protection system

3.40
overspeed control
the action of a control system, or part of such system, which prevents excessive rotor speed

3.41
parked wind turbine
depending on the construction of the wind turbine system, parked refers to the turbine being either in a stand-still or an idling condition

3.42
parking
situation to which a wind turbine system returns after a normal shutdown

3.43
power form
physical characteristics which describe the form in which power produced by the wind turbine system is made deliverable to the load (e.g. 230 V a.c., 50 Hz, 1 ph; or e.g. 48 V d.c.)

3.44
power law for wind shear
a mathematical law which expresses wind speed variations as a power law function of height above ground

3.45
power output
power delivered by a device in a specific form and for a specific purpose

Note 1 to entry: The electric power delivered by a wind turbine system.

3.46
protection system
system which ensures that a wind turbine generator system remains within the design limits

3.47
rated power
maximum continuous electrical output power which a wind turbine system is designed to achieve at the connection facilities under normal operation

Note 1 to entry: The reference power is defined for the purposes of comparing wind turbine systems and is not to be confused with the rated power which may occur at much higher wind speeds. Rated power is an obsolete term that is better replaced by either maximum output power or reference power depending on context.

[SOURCE: IEC 61400-21:2008, 3.14, modified to be precise to wind turbine systems]

3.48
rated current
maximum continuous electrical output current which a wind turbine system is designed to achieve at the connection facilities under normal operation

Note 1 to entry: The reference current is defined for the purposes of comparing wind turbine systems and is not to be confused with the rated current which may occur at much higher wind speeds. Rated current is an obsolete term that is better replaced by maximum output current.

[SOURCE: IEC 61400-21:2008, 3.13, modified to be precise to wind turbine systems]

3.49
rated wind speed
wind speed at which a wind turbine system's rated power is achieved

Note 1 to entry: Rated wind speed is an obsolete term. The reference power & reference annual energy are defined for the purposes of comparing wind turbine systems (see corresponding definitions) and are not to be confused with the maximum power which may occur at much higher wind speeds.

[SOURCE: IEC 61400-21:2008, 3.15, modified to be precise to wind turbine systems]

3.50
Rayleigh distribution
probability distribution function often used for wind speeds

Note 1 to entry: The distribution depends on one adjustable parameter, the scale parameter, which controls the average wind speed.

Note 2 to entry: The Rayleigh distribution is identical to a Weibull distribution (see 3.73) with shape parameter 2.

3.51
reduced speed
rotational speed such that the wind turbine system can be brought to a parked condition manually without any risk to personnel

3.52
reference annual energy
calculated total energy that would be produced during a one-year period at an average wind speed of 5,0 m/s at hub height, assuming a Rayleigh wind speed distribution, 100 % availability, and the power curve derived from IEC 61400-12-1, where it is referred to as "Annual Energy Production" (AEP)

Note 1 to entry: The AEP from IEC 61400-12-1 is either the "AEP-measured" or the "AEP-extrapolated", and is either "sea-level normalised" or "site-specific".

Note 2 to entry: Within this standard reference annual energy is AEP-measured and sea-level normalised.

Note 3 to entry: The reference annual energy is defined for the purposes of comparing wind turbine systems.

3.53
reference power
wind turbine system's power output at 11,0 m/s at hub height per the power curve from IEC 61400-12-1, or the maximum output power of the wind turbine system at a lower wind speed if this is a higher power output (again per the power curve from IEC 61400-12-1)

Note 1 to entry: The reference power is defined for the purposes of comparing wind turbine systems and is not to be confused with the maximum power which may occur at much higher wind speeds.

3.54
reference wind speed
V_{ref}
basic parameter for wind speed used for defining SWT classes

Note 1 to entry: Other design related climatic parameters are derived from the reference wind speed and other basic SWT class parameters.

Note 2 to entry: A turbine designed for a SWT class with a reference wind speed, V_{ref}, is designed to withstand climates for which the extreme 10-min average wind speed with a recurrence period of 50 years at turbine hub height is lower than or equal to V_{ref} (see 3.19).

3.55
resonance
phenomenon appearing in an oscillating system, in which the period of a forced oscillation is very close to that of free oscillation

3.56
rotor centre
geometric centre of the wind turbine rotor

3.57
rotor speed
rotational speed of a wind turbine rotor about its axis

3.58
roughness length
extrapolated height at which the mean wind speed becomes zero if the vertical wind profile is assumed to have a logarithmic variation with height

3.59
safe life
prescribed service life with a declared probability of catastrophic failure

3.60
scheduled maintenance
preventive maintenance carried out in accordance with an established time schedule

3.61
shutdown
transitional state of a wind turbine between power production and standstill or idling

3.62
standstill
condition of a wind turbine generator system that is stopped

3.63
support structure
part of a wind turbine system comprising the tower and foundation

3.64
survival wind speed (deprecated)
popular name for the maximum wind speed that a construction is designed to withstand

Note 1 to entry: This term is not used in the IEC 61400 series; the design conditions instead refer to extreme wind speed (see 3.19), with extreme wind speed being the preferred term.

3.65
small wind turbine
SWT
system of 200 m^2 rotor swept area or less that converts kinetic energy in the wind into electrical energy.

Note 1 to entry: A small wind turbine system includes the wind turbine itself including support structures, the turbine controller, the charge controller / inverter (if required), wiring and disconnects, the installation and operation manual(s) and other documentation.

3.66
swept area
projected area perpendicular to the wind direction that a rotor will describe during one complete rotation

3.67
turbine test class
small wind turbine (SWT) class for which the duration test (13.4) has been completed

3.68
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

3.69
ultimate limit state
limit state which generally corresponds to maximum load carrying capacity (ISO 2394)

3.70
unscheduled maintenance
maintenance carried out, not in accordance with an established time schedule, but after reception of an indication regarding the state of an item

3.71
upwind
in the direction opposite to the main direction of wind flow

3.72
vertical axis wind turbine
wind turbine system whose rotor axis is substantially perpendicular to the wind flow

3.73
Weibull distribution
probability distribution function often used for wind speeds

Note 1 to entry: This distribution function depends on two parameters, the shape parameter, which controls the width of the distribution and the scale parameter, which in turn controls the average wind speed (see wind speed distribution 3.75).

3.74
wind profile
wind shear law
mathematical expression for assumed wind speed variation with height above ground

Note 1 to entry: Commonly used profiles are the logarithmic profile (1) or the power law profile (2).

$$V(z) = V(z_r) \times \frac{\ln(z/z_0)}{\ln(z_r/z_0)} \quad (1)$$

$$V(z) = V(z_r) \times \left(\frac{z}{z_r}\right)^{\alpha} \quad (2)$$

where

$V(z)$ is the wind speed at height z;
z is the height above ground;
z_r is a reference height above ground used for fitting the profile;
z_0 is the roughness length;
α is the wind shear (or power law) exponent.

3.75
wind speed distribution
probability distribution function, used to describe the distribution of wind speeds over an extended period of time

Note 1 to entry: Often used distribution functions are the Rayleigh, $P_R(V_o)$, and the Weibull, $P_W(V_o)$, functions.

$$P_R\{V < V_0\} = 1 - \exp\left[-\pi(V_0 / 2V_{ave})^2\right]$$
$$P_W\{V < V_0\} = 1 - \exp\left[-(V_0 / C)^k\right] \quad (3)$$

$$\text{with } V_{ave} = \left\{ \begin{array}{c} C\,\Gamma(1+\frac{1}{k}) \\ C\sqrt{\pi}/2, \text{ if } k = 2 \end{array} \right\} \quad (4)$$

where

$P(V_0)$	is the cumulative probability function, i.e. the probability that $V<V_0$;
V_0	is the wind speed (limit);
V_{ave}	is the average value of V;
C	is the scale parameter of the Weibull function;
k	is the shape parameter of the Weibull function;
Γ	is the gamma function.

Both C and k can be evaluated from real data. The Rayleigh function is identical to the Weibull function if k = 2 is chosen and C and V_{ave} satisfy the condition stated in Equation (4) for k = 2.

The distribution functions express the cumulative probability that the wind speed is lower than V_0. Thus ($P(V_1)$ – $P(V_2)$), if evaluated between the specified limits V_1 and V_2, will indicate the fraction of time that the wind speed is within these limits. Differentiating the distribution functions yields the corresponding probability density functions.

3.76
wind shear
variation of wind speed across a plane perpendicular to the wind direction

3.77
wind shear exponent
also commonly known as power law exponent (α), see 3.74, wind profile - wind shear law

3.78
wind speed
at a specified point in space, the speed of motion of a minute amount of air surrounding the specified point

Note 1 to entry: The wind speed is also the magnitude of the local wind velocity (vector) (see 3.79, wind velocity).

3.79
wind velocity
vector pointing in the direction of motion of a minute amount of air surrounding the point of consideration, the magnitude of the vector being equal to the speed of motion of this air "parcel" (i.e. the local wind speed)

Note 1 to entry: The vector at any point is thus the time derivative of the position vector of the air "parcel" moving through the point.

3.80
yawing
rotation of the rotor axis about a vertical axis (for horizontal axis wind turbines only)

3.81
yaw rate
time rate of change of yaw angle, the rate of yawing

3.82
yaw misalignment
horizontal deviation of the wind turbine rotor axis from the wind direction

4 Symbols and abbreviated terms

4.1 General

NOTE Symbols and abbreviations can vary in some annexes, and if so they are defined internally within the annex.

4.2 Symbols

A	cross section area	[m^2]
A_{proj}	the component area projected on to a plane perpendicular or parallel to the wind direction	[m^2]
a	slope parameter for turbulence standard deviation model	[-]
B	number of blades	[-]
C	scale parameter of the Weibull distribution function	[m/s]
C_d	drag coefficient	[-]
C_f	force coefficient	[-]
C_l	lift coefficient	[-]
C_T	thrust coefficient	[-]
Coh	coherency function	[-]
D	rotor diameter	[m]
e_r	distance from the centre of gravity of the rotor to the rotation axis	[m]
F	force	[N]
F_{zB}	force on the blade at the blade root in the spanwise direction	[N]
$F_{x\text{-shaft}}$	axial shaft load	[N]
f	frequency	[Hz]
f_k	characteristic value for material strength	[-]
G	ratio between rated torque and short circuit torque for a generator	[-]
g	acceleration due to gravity: 9,81	[m/s^2]
i	electrical current	[A]
I_B	mass moment of inertia of the blade about the blade root flap axis	[kgm^2]
I_{15}	characteristic value of hub-height turbulence intensity at a 10-min average wind speed of 15 m/s	[-]
K	modified Bessel function	[-]
k	shape parameter of the Weibull distribution function	[-]
L	isotropic turbulence integral scale parameter	[m]
L_{lt}	distance between the lifting point and the top of the tower	[m]
L_{rt}	distance between the rotor centre and the yaw axis	[m]
L_{rb}	distance between rotor centre and first bearing	[m]
L_c	coherency scale parameter	[m]
L_k	velocity component integral scale parameter	[m]
M_{xB}, M_{yB}	blade root bending moments	[Nm]
M_{brake}	torque on the low speed shaft caused by the brake	[Nm]
$M_{x\text{-shaft}}$	torsion moment on the rotor shaft at the first bearing	[Nm]
M_{shaft}	combined bending moment for the shaft at the first bearing (nearest to rotor)	[Nm]
M_{tower}	the bending moment in the tower at the lifting point attachment	[Nm]

m_B	blade mass	[kg]
$m_{overhang}$	the mass of the tower between the lifting point and the top of the tower	[kg]
m_r	rotor mass being the mass of the blades plus the mass of the hub	[kg]
$m_{towertop}$	the mass of the nacelle and rotor combined	[kg]
$N(.)$	is the number of cycles to failure as a function of the stress (or strain) indicated by the argument (i.e. the characteristic S-N curve)	[-]
N	recurrence period for extreme situations	[yr]
n	rotor speed	[r/min]
n_{design}	design rotational speed	[r/min]
n_i	counted number of fatigue cycles in load bin i	[-]
n_{max}	maximum rotational speed	[r/min]
O	operational time fraction	[%]
P	electrical power	[W]
$P_R(V_0)$	Rayleigh cumulative probability distribution, i.e. the probability that $V<V_0$	[-]
$P_W(V_0)$	Weibull cumulative probability distribution	[-]
P_H	harmonic multiple of fundamental excitation frequency, being rotor speed	[Hz]
p	survival probability	[-]
Q	rotor torque	[Nm]
Q_{design}	design shaft torque	[Nm]
R	radius of the rotor	[m]
R_{cog}	radial distance between the centre of gravity of a blade and the rotor centre	[m]
r	magnitude of separation vector projection	[m]
$S_1(f)$	power spectral density function	[m²/s²]
S_k	single sided velocity component spectrum	[m²/s²]
s_i	the stress (or strain) level associated with the counted number of cycles in bin i	[-]
T	gust characteristic time	[s]
t	time	[s]
T_d	design life	[s]
T_E	excluded time	[h]
T_N	time during which the turbine was not operational	[h]
T_T	total time elapsed in the duration test	[h]
T_U	unknown time	[h]
U	electrical potential difference (voltage)	[V]
V	wind speed	[m/s]
$V(z)$	wind speed at height z	[m/s]
V_{ave}	annual average wind speed at hub height	[m/s]
V_{cg}	extreme coherent gust magnitude over the whole rotor swept area	[m/s]
V_{design}	design wind speed	[m/s]
V_{eN}	expected extreme wind speed (averaged over 3 s), with a recurrence time interval of N years. V_{e1} and V_{e50} for 1 year and 50 years, respectively	[m/s]
V_{gustN}	largest gust magnitude with an expected recurrence period of N years.	[m/s]
V_{hub}	wind speed at hub height averaged over 10 min	[m/s]
V_{in}	cut-in wind speed	[m/s]

V_{maint}	wind speed (10-min average) below which safe shutdown of the SWT for performing inspections, service or maintenance is possible	[m/s]
$V_{max,shutdown}$	the maximum wind speed at which the manufacturer allows a normal shutdown	[m/s]
V_0	limit wind speed in wind speed distribution model	[m/s]
V_{out}	cut-out wind speed	[m/s]
V_{ref}	reference wind speed averaged over 10 min	[m/s]
V_{tip}	speed of the blade tip	[m/s]
$V(t,z)$	longitudinal wind velocity component to describe transient variation for extreme gust and shear conditions	[m/s]
W	section modulus used in stress calculations	[m^3]
x, y, z	co-ordinate system used for the wind field description; along wind (longitudinal), across wind (lateral) and height respectively	[m]
z_{hub}	hub height of the wind turbine	[m]
z_r	reference height above ground	[m]
z_0	roughness length for the logarithmic wind profile	[m]
α	wind shear power law exponent	[-]
β	parameter for extreme direction change model and extreme operating gust model	[-]
Γ	gamma function	[-]
γ_f	partial safety factor for loads	[-]
γ_m	partial safety factor for materials	[-]
Δ	range	[-]
$\theta(t)$	wind direction change transient	[°]
θ_{cg}	angle of maximum deviation from the direction of the average wind speed under gust conditions	[°]
θ_{eN}	extreme direction change with a recurrence period of N years	[°]
η	efficiency of the components between the electric output and the rotor (typically generator, gearbox and conversion system)	[-]
Λ_1	turbulence scale parameter defined as the wave length where the non-dimensional, longitudinal power spectral density, $fS_1(f)/\sigma_1^2$, is equal to 0,05	[m]
λ	tip speed ratio	[-]
ρ	air density, here assumed 1,225	[kg/m^3]
σ_1	hub-height longitudinal wind velocity standard deviation	[m/s]
σ_2	hub-height vertical wind velocity standard deviation	[m/s]
σ_3	hub-height lateral wind velocity standard deviation	[m/s]
σ_d	design stress	[MPa]
σ_k	k^{th} hub-height component wind velocity standard deviation (k = 1, 2, or 3)	[m/s]
ω_n	rotational speed of the rotor	[rad/s]
ω_{yaw}	yaw rate	[rad/s]
$\omega_{yaw,max}$	maximum yaw rate	[rad/s]

Subscripts:

ave	average
B	blade

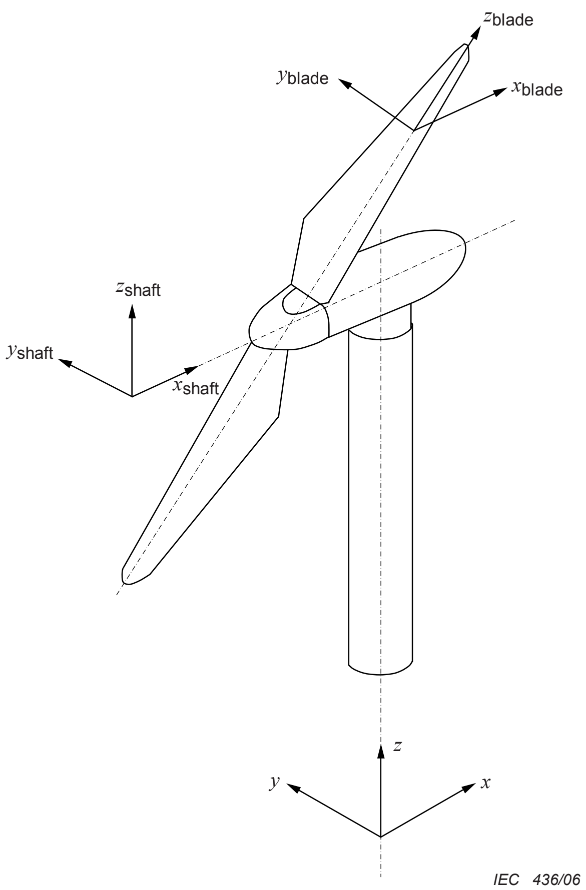
design	input parameter for the simplified design equations
e1	once per year extreme (averaged over 3 s)
e50	once per 50 year extreme (averaged over 3 s)
hub	hub
max	maximum
overhang	description of section of tower between lifting point and tower top
r	rotor
shaft	shaft
x	in the x-direction
y	in the y-direction
z	in the z-direction

Abbreviations:

asl	above sea level
AEP	Annual Energy Production
RAE	Reference Annual Energy
AC	Alternating current
DC	Direct current
CFD	Computational Fluid Dynamics
DLC	Design load case
ECD	Extreme coherent gust with direction change
ECG	Extreme coherent gust
EDC	Extreme wind direction change
EMC	Electromagnetic compatibility
EOG	Extreme operating gust
EWC	Extreme wind conditions
EWM	Extreme wind speed model
F	Fatigue
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode Effects and Criticality Analysis
GFCI	Ground fault circuit interrupter
HAWT	Horizontal axis wind turbine
NTM	Normal turbulence model
NWC	Normal wind conditions
NWP	Normal wind profile model
OWC	Other wind conditions
S	Special IEC wind turbine class
SWC	Standard wind conditions
SWT	Small wind turbine
U	Ultimate
UV	Ultra violet (radiation)
VAWT	Vertical axis wind turbine

4.3 Coordinate system

To define the directions of the loads of a horizontal axis wind turbine (HAWT), the system of axes shown in Figure 1 is used.



The following notes form part of the above figure:

Tower:

x is positive in the downwind direction, z is pointing up, y completes right hand coordinate system

the tower system is fixed

Shaft:

x_{shaft} is such that a positive moment about the x axis acts in the rotational direction

y_{shaft} and z_{shaft} are not used, only the combined moment is used

the shaft axis system rotates with the nacelle

Blade:

x_{blade} is such that a positive moment about the x-axis acts in the rotational direction

y_{blade} is such that a positive moment acts to bend the blade tip downwind

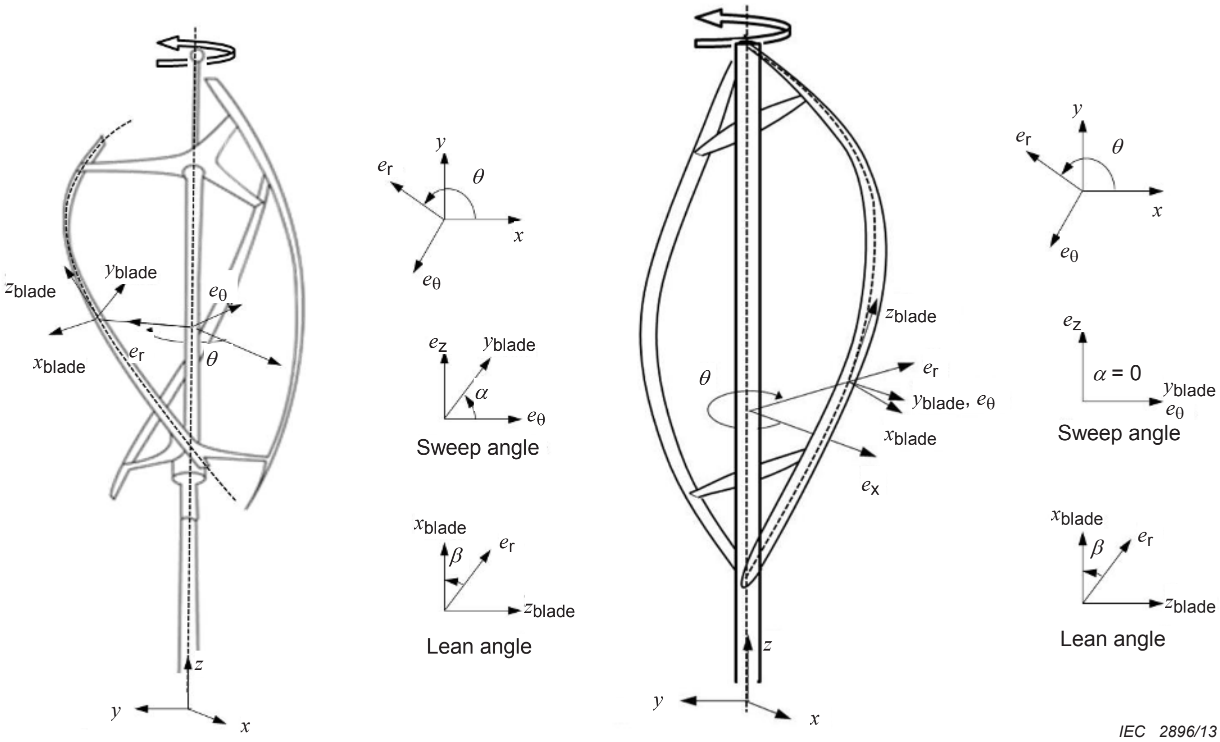
z_{blade} is positive towards blade tip

the blade coordinate system follows the right-hand convention for a rotor that spins clockwise and the left-hand convention for a rotor that spins counter clockwise when viewed from an upwind location.

the blade axis system rotates with the rotor

Figure 1 – Definition of the system of axes for HAWT

To define the directions of the loads of a vertical axis wind turbine (VAWT), the system of axes shown in Figure 2 is used.



Tower:

x is positive in the downwind direction, z pointing up, y completes the right hand coordinate system.

Rotor:

The rotor coordinate system is cylindrical of axis z, the angle $\theta=(e_x,e_r)$ is positive from the downwind axis x. (e_r, e_θ, e_z) is a right hand coordinate system.

Blade:

z_{blade} is tangent to the reference line of the blade, and points upward.

y_{blade} is perpendicular to z_{blade} and to the radial vector e_r; points in the opposite direction to the rotation

x_{blade} completes the right hand coordinate system (and is normal to the blade)

NOTE In the case of a rotor with planar straight blades (lean and sweep angle are both zero) spinning in the negative z direction, the blade coordinate system is coincident with the rotor coordinate system.

Figure 2 – Definition of the system of axes for VAWT

5 Principal elements

5.1 General

The engineering and technical requirements to ensure the safety of the structural, mechanical, electrical and control systems of the wind turbine are given in the following Clauses 5 through 12. This specification of requirements applies to the design, manufacture, installation and maintenance of the wind turbine, and the associated quality management process, together with appropriate and sufficient documentation.

5.2 Design methods

The design method for turbines covered under this standard is depicted in Figure 3. A simplified approach is permitted for a variety of turbine configurations. For turbines with a swept rotor area of 2 m^2 or less only the sample support structure is considered part of the design (however see 11.2.3.2).

The design loads shall be obtained in one or a combination of the following three ways. The design loads shall be verified by measured "design data test" (See 13.2):

It is *recommended* that in-house tests for design data are conducted early in the development.

1) Simplified loads methodology

   For certain turbine configurations a simplified calculation method is given. A limited set of load cases and configurations is given in 7.4 with simple formulas and simplified external conditions. The turbine data assumed within the simplified equations shall be verified by the "Tests to verify design data" (see 13.2).

2) Simulation model

   A model shall be used to determine the loads over a range of wind speeds, using the turbulence conditions and other extreme wind conditions defined in 6.3.3, and design situations defined in 7.5. This approach uses a structural dynamics simulation model in combination with wind turbine and application adequate assumptions. The assumptions shall be verified by the "Tests to verify design data" (see 13.2).

   All relevant combinations of external conditions and design situations shall be analysed. A minimum set of such combinations has been defined as load cases in this standard.

3) Full scale load measurement

   Full scale load measurement with load extrapolation (see 7.6).

Each of these methods has different uncertainties. Therefore, different sets of safety factors shall be applied depending upon the load estimation method used (see 7.8).

For all turbines a static blade test is required (see 13.5.2). To verify the adequacy of other load carrying components, either calculations or testing is required or a combination of both. Test conditions shall reflect the design loads including the relevant safety factors.

Finally, for all turbines a safety and function test (see 13.6) and duration test (see 13.4) are required.

5.3 Quality assurance

Quality assurance shall be an integral part of the design, procurement, manufacture, installation, operation and maintenance of the wind turbine and all its components.

It is recommended that the quality system complies with the requirements of the ISO 9000 series.

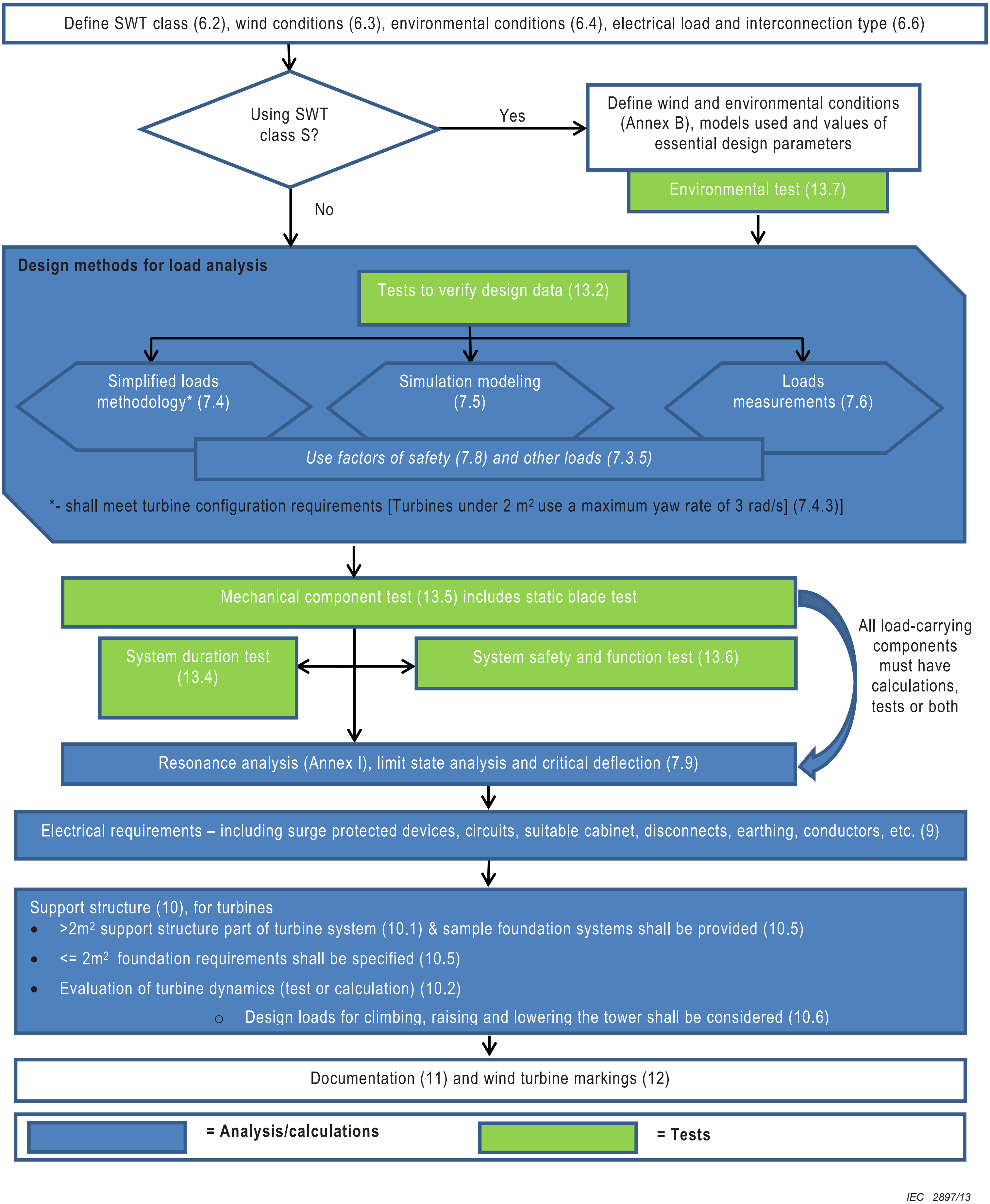


Figure 3 – IEC 61400-2 decision path

I Design evaluation

6 External conditions

6.1 General

SWTs are subjected to environmental and electrical conditions that may affect their loading, durability and operation. To ensure the appropriate level of safety and reliability, the environmental, electrical and soil parameters shall be taken into account in the design and shall be explicitly stated in the design documentation.

The environmental conditions are divided into wind conditions and other environmental conditions. The electrical conditions refer to either network conditions or local electrical conditions like batteries, hybrid systems or local grid. Soil properties are relevant to the design of SWT foundations.

Wind conditions are the primary external consideration for structural integrity. Other environmental conditions also affect design features such as control system function, durability, corrosion, etc.

Each type of external condition may be subdivided into a normal external condition and an extreme external condition. The normal external conditions generally concern long-term structural loading and operating conditions, while the extreme external conditions represent the rare but potentially critical external design conditions. The design load cases shall consist of a combination of these external conditions with wind turbine operational modes.

6.2 SWT classes

The external conditions to be considered in design are dependent on the intended site or site type for a SWT installation. SWT classes are defined in terms of wind speed and turbulence parameters. The values of wind speed and turbulence parameters are intended to represent the characteristic values of many different sites and do not give a precise representation of any specific site. The goal is to achieve SWT classification with clearly varying robustness governed by the wind. Table 1 specifies the basic parameters, which define the SWT classes.

The intention of the classes is to cover most applications, and reference should be made to Annex L for other wind conditions that may be experienced. In cases where a special design (e.g. special wind conditions, or other wind conditions (per Annex L) or other external conditions or a special safety class) is necessary, a further SWT class, class S, is defined. The design values for the SWT class S shall be chosen by the designer and specified in the design documentation (see Annex B). For such special designs, the values chosen for the design conditions shall reflect a more severe environment than anticipated for the use of the SWT.

The particular external conditions defined for classes I, II, III and IV are neither intended to cover offshore conditions nor wind conditions experienced in tropical storms such as hurricanes, cyclones and typhoons. Such conditions may require wind turbine class S design (see Annex B, Annex K, and Annex L).

Table 1 – Basic parameters for SWT classes

SWT class		I	II	III	IV	S
V_{ref}	(m/s)	50	42,5	37,5	30	Values to be specified by the designer
V_{ave}	(m/s)	10	8,5	7,5	6	
I_{15} (Note 2)	(-)	0,18	0,18	0,18	0,18	
a	(-)	2	2	2	2	

NOTE

1) the values apply at hub height, and;

2) I_{15} is the dimensionless characteristic value of the turbulence intensity at 15 m/s, where 0,18 is the minimum value that shall be used, and noting that Annex M discusses observations regarding turbulence intensity;

3) a is the dimensionless slope parameter to be used in Equation (7).

In addition to these basic parameters, several important further parameters are required to completely specify the external conditions used in SWT design. In the case of the SWT classes I through IV later referred to as standard SWT classes, the values of these additional parameters are specified in 6.3, 6.4 and 6.6.

The abbreviations added in parentheses in the subclause headings in the remainder of Clause 6 are used for describing the wind conditions for the design load cases defined in 7.5, simulation modelling (note that for the simple load calculations, the wind conditions are simplified as well).

For the SWT class S the manufacturer shall in the design documentation describe the models used and values of essential design parameters. Where the models in the present subclause 6.2 are adopted, statement of the values of the parameters will be sufficient. The design documentation of SWT class S shall contain the information listed in Annex B.

The design lifetime shall be clearly specified in the design documentation.

6.3 Wind conditions

6.3.1 General

A SWT shall be designed to safely withstand the wind conditions defined by the selected SWT class. The design values of the wind conditions shall be clearly specified in the design documentation. The wind regime for load and safety considerations is divided into the normal wind conditions (NWC) which will occur frequently during normal operation of a SWT, and the extreme wind conditions (EWC) which are defined as having a 1-year or 50-year recurrence period.

In this standard the combination of the NWC and EWC in conjunction with the four SWT classes I-IV define the standard wind conditions (SWC). In Annex L other wind conditions (OWC) are discussed.

In all cases the influence of an inclination of mean flow with respect to the horizontal plane of up to 8° shall be considered. The flow inclination angle may be assumed to be invariant with height. Note that oblique inflow can have an effect on furling if the furl direction is chosen poorly with respect to the rotational direction of the rotor.

6.3.2 Normal wind conditions

6.3.2.1 Wind speed distribution

The wind speed distribution at the site is significant for the SWT design because it determines the frequency of occurrence of the individual load conditions. In case of the standard SWT classes, the mean value of the wind speed over a time period of 10 min shall be assumed to be Rayleigh distributed for the purposes of design load calculations. In this case, the cumulative probability distribution at hub height is given by:

$$P_R(V_{hub}) = 1 - \exp\left[-\pi(V_{hub} / 2V_{ave})^2\right] \qquad (5)$$

6.3.2.2 Normal wind profile model (NWP)

The wind profile, $V(z)$, denotes the average wind speed as a function of height, z, above the ground. In the case of standard wind turbine classes, the normal wind speed profile shall be assumed to be given by the power law:

$$V(z) = V_{hub}(z/ z_{hub})^{\alpha} \qquad (6)$$

The power law exponent, α, shall be assumed to be 0,2.

The assumed wind profile is used to define the average vertical wind shear across the rotor swept area.

6.3.2.3 Normal turbulence model (NTM)

The normal turbulence model shall include a wind shear as described under NWP, in 6.3.2.2. The expression "wind turbulence" denotes stochastic variations in the wind velocity from the 10-min average. The turbulence model shall include the effects of varying wind speed, varying direction, and rotational sampling. For the standard SWT classes, the power spectral densities of the random wind velocity vector field, whether used explicitly in the model or not, shall satisfy the following requirements:

a) The characteristic value of the standard deviation of the longitudinal wind velocity component shall be given by[1]:

$$\sigma_1 = I_{15}(15 + aV_{hub})/(a+1) \qquad (7)$$

Values for I_{15} and a are given in Table 1. The characteristic values of the standard deviation, σ_1, and of the turbulence intensity, σ_1/V_{hub}, are shown below in Figure 4.

1 To perform the calculations of load cases in addition to those specified in Table 4, it may be appropriate to use different percentile values. Such percentile values shall be determined by adding a value to Equation (7) given by:

$$\Delta\sigma_1 = 2(x-1)I_{15}$$

where x is determined from the normal probability distribution function. For example, x = 1,64 for a 95[th] percentile value.

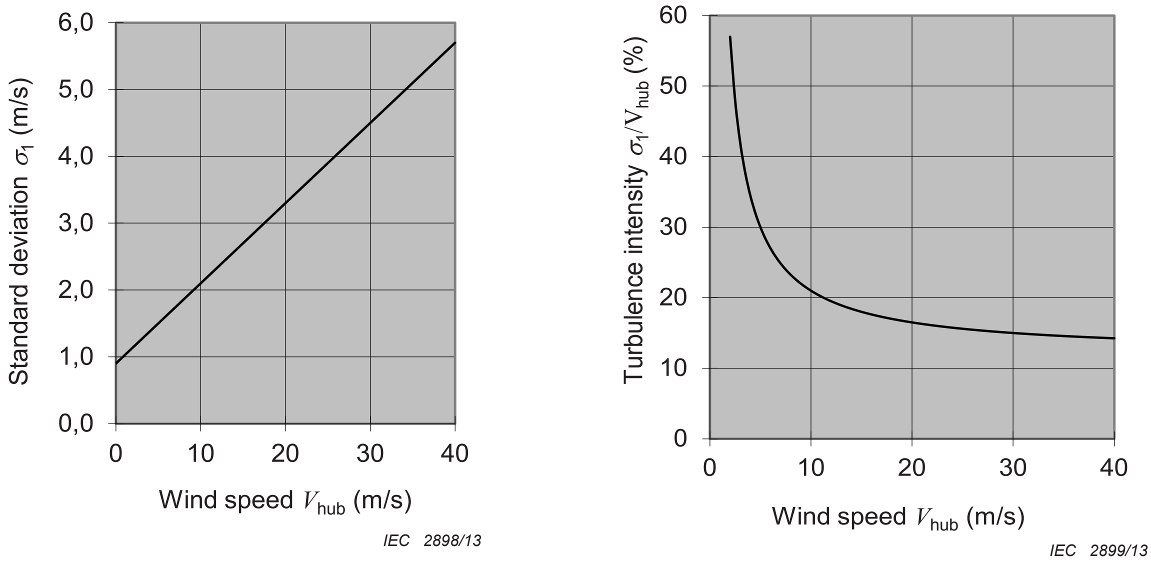


Figure 4 – Characteristic wind turbulence

b) Towards the high frequency end of the inertial subrange the power spectral density of the longitudinal component of the turbulence, $S_1(f)$, shall asymptotically approach the form:

$$S_1(f) = 0{,}05(\sigma_1)^2(\Lambda_1 / V_{hub})^{-2/3} f^{-5/3} \tag{8}$$

c) The turbulence scale parameter, Λ_1,shall be given by:

$$\Lambda_1 = \begin{cases} 0{,}7 z_{hub} & \text{for } z_{hub} < 30\text{ m} \\ 21\text{ m} & \text{for } z_{hub} \geq 30\text{ m} \end{cases} \tag{9}$$

Specifications for stochastic turbulence models, which satisfy these requirements, are given in Annex C. In Annex D a simplified deterministic model, which is based on a stochastic description of the turbulence, is given. This deterministic model may be used when it can be demonstrated that the turbine blade response to rotationally sampled wind velocity is sufficiently well damped. Guidance for this validation is also given in Annex D.

6.3.3 Extreme wind conditions

6.3.3.1 General

The extreme wind conditions are used to determine extreme wind loads on SWTs. These conditions include peak wind speeds due to storms and rapid changes in wind speed and direction. These extreme conditions include the potential effects of wind turbulence so that only the deterministic effects need to be considered in the design calculations.

6.3.3.2 Extreme wind speed model (EWM)

The 50-year extreme wind speed V_{e50} and the one year extreme wind speed V_{e1} shall be based on the reference wind speed V_{ref}. For SWT designs in the standard SWT classes, the 3-s gust V_{e50} and V_{e1} shall be computed using the following equations:

$$V_{e50}(z) = 1{,}4 V_{ref}(z / z_{hub})^{0{,}11} \tag{10}$$

$$V_{e1} = 0{,}75 V_{e50} \tag{11}$$

where z_{hub} is hub height, and 1,4 is the gust factor at hub height.

Short-term deviations from the mean wind direction of ± 15° shall be assumed.

6.3.3.3 Extreme operating gust (EOG)

The hub height gust magnitude V_{gustN} for a recurrence period of N years shall be given for the standard SWT classes by the following relationship:

$$V_{gustN} = \beta\left(\frac{\sigma_1}{1+0{,}1(\frac{D}{\Lambda_1})}\right) \quad (12)$$

where

- σ_1 is the standard deviation, according to Equation (7);
- Λ_1 is the turbulence scale parameter, according to Equation (9);
- D is the rotor diameter;
- β = 4,8 for N = 1; and
- β = 6,4 for N = 50.

The wind speed shall be defined for a recurrence period of N years by the equation:

$$V(t) = \begin{cases} V(z) - 0{,}37 V_{gustN} \sin(3\pi t/T)(1-\cos(2\pi t/T)) & \text{for } 0 \le t \le T \\ V(z) & \text{for } t < 0 \text{ and } t > T \end{cases} \quad (13)$$

where

$V(z)$ is defined in Equation (6);

T = 10,5 s for N = 1; and

T = 14,0 s for N = 50.

As an example, the extreme operating gust with a recurrence period of one year and V_{hub} = 25 m/s is shown in Figure 5:

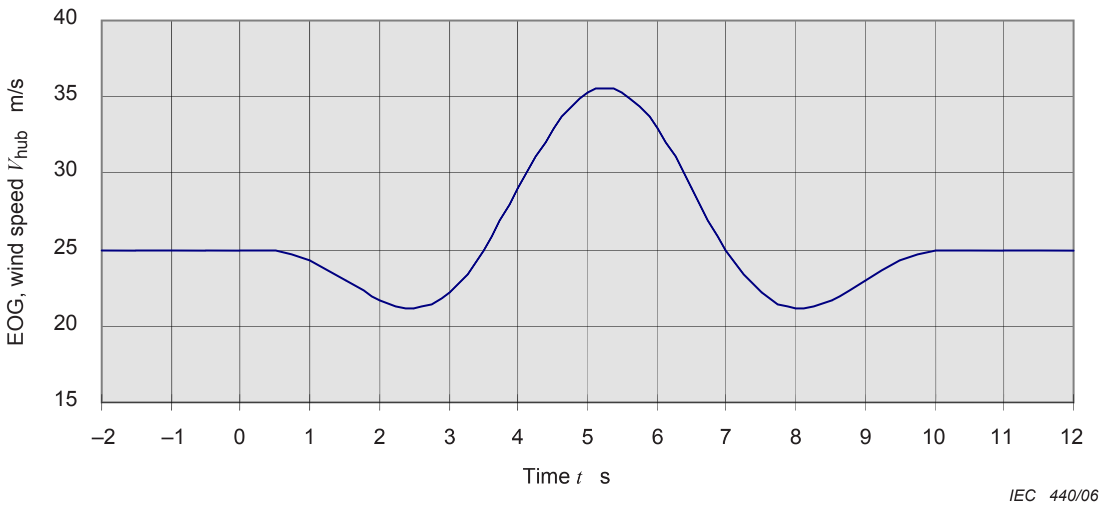


Figure 5 – Example of extreme operating gust (N=1, V_{hub} = 25 m/s)

The parameter values for both recurrence periods were selected to give the same maximum rise rate.

6.3.3.4 Extreme direction change (EDC)

The extreme direction change magnitude, θ_{eN}, for a recurrence period of N years shall be calculated using the following relationship:

$$\theta_{eN}(t) = \pm\beta \arctan\left(\frac{\sigma_1}{V_{hub}\left(1+0{,}1\left(\frac{D}{\Lambda_1}\right)\right)}\right) \tag{14}$$

where

θ_{eN} is limited to the interval ±180°;

Λ_1 is the turbulence scale parameter, according to Equation (9);

D is the rotor diameter;

β = 4,8 for N = 1; and

β = 6,4 for N = 50.

The extreme direction change transient for a recurrence period of N years, $\theta_N(t)$,shall be given by:

$$\theta_N(t) = \begin{cases} 0 & \text{for } t < 0 \\ 0{,}5\theta_{eN}\left(1-\cos(\pi t / T)\right) & \text{for } 0 \le t \le T \\ \theta_{eN} & \text{for } t > T \end{cases} \tag{15}$$

where T = 6 s is the duration of the extreme direction change transient. The sign shall be chosen so that the worst transient loading occurs. At the end of the direction change transient the direction is assumed to remain unchanged.

As an example, the extreme direction change with a recurrence period of 50 years and V_{hub} = 25 m/s is shown in Figure 6 and Figure 7.

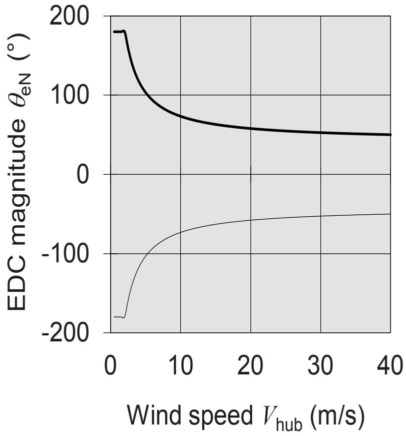


Figure 6 – Example of extreme direction change magnitude (N = 50, D = 5 m, z_{hub} = 20 m)

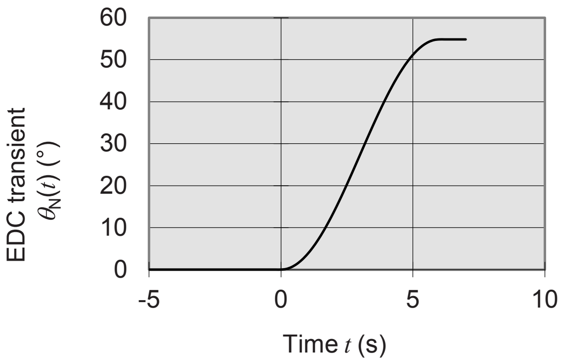


Figure 7 – Example of extreme direction change transient (N = 50, V_{hub} = 25 m/s)

6.3.3.5 Extreme coherent gust (ECG)

For wind turbine designs for the standard SWT classes, an extreme coherent gust with a magnitude of V_{cg} = 15 m/s shall be assumed. The wind speed shall be defined by the relations:

$$V(t,z) = \begin{cases} V(z) & \text{for } t < 0 \\ V(z) + 0{,}5\,V_{cg}(1 - \cos(\pi t/T)) & \text{for } 0 \le t \le T \\ V(z) + V_{cg} & \text{for } t > T \end{cases} \quad (16)$$

where T = 10 s is the rise time. The normal wind profile model of wind speed as specified in Equation (6) shall be used. The extreme coherent gust is illustrated in Figure 8 for V_{hub} = 25 m/s.

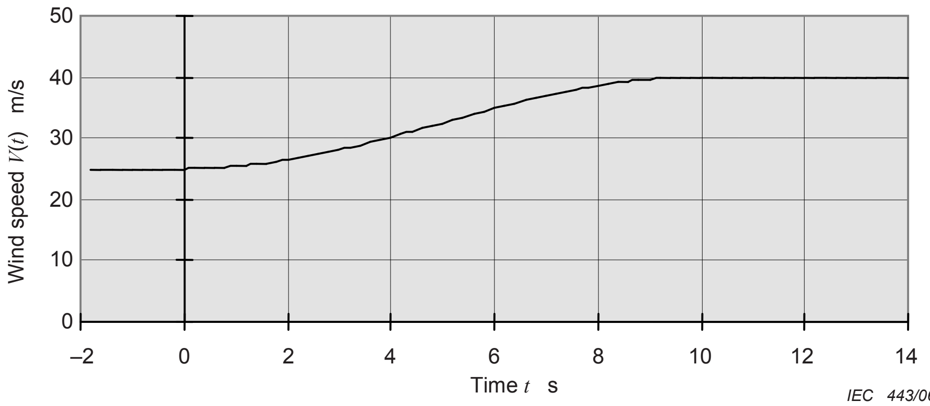


Figure 8 – Extreme coherent gust (V_{hub} = 25 m/s) (ECG)

6.3.3.6 Extreme coherent gust with direction change (ECD)

In this case, the rise in wind speed (described by ECG, see Figure 8) shall be assumed to occur simultaneously with the direction change θ_{cg}, where θ_{cg} is defined by the relations:

$$\theta_{cg}(V_{hub}) = \begin{cases} 180° & \text{for } V_{hub} < 4 \text{ m/s} \\ \dfrac{720°}{V_{hub}} & \text{for } 4 \text{ m/s} \le V_{hub} \le V_{ref} \end{cases} \quad (17)$$

The direction change, θ_{cg}, as a function of V_{hub} and as a function of time for V_{hub} = 25 m/s is shown in Figure 9 and Figure 10, respectively.

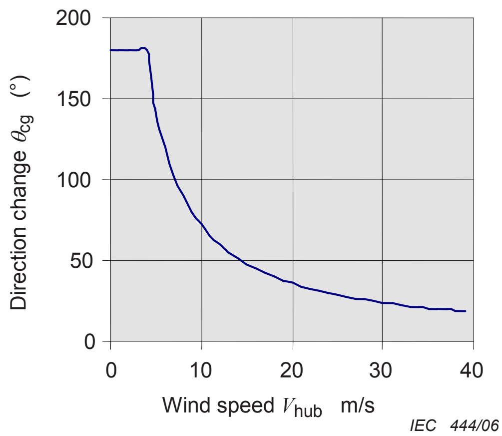


Figure 9 – The direction change for ECD

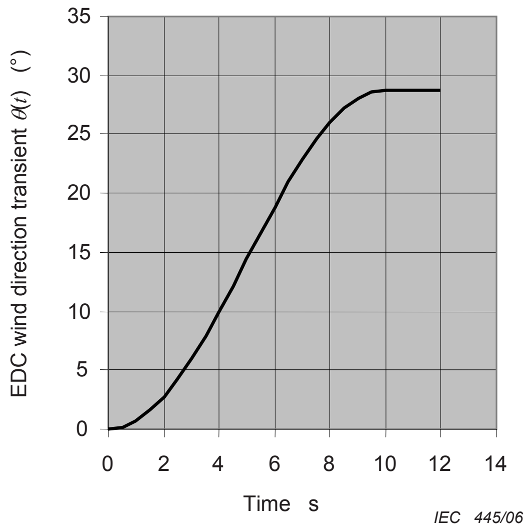


Figure 10 – Time development of direction change for V_{hub} = 25 m/s

The simultaneous direction change is then given by:

$$\theta(t) = \begin{cases} 0° & \text{for } t \le 0 \\ \pm 0{,}5\,\theta_{cg}(1 - \cos(\pi t/T)) & \text{for } 0 \le t \le T \\ \pm\theta_{cg} & \text{for } t \ge T \end{cases} \quad (18)$$

6.4 Other environmental conditions

6.4.1 General

Environmental (climatic) conditions other than wind can affect the integrity and safety of the SWT, by thermal, photochemical, corrosive, mechanical, electrical or other physical action. Moreover, combinations of the climatic parameters given may increase their effect. At least the following other environmental conditions shall be taken into account and the action taken stated in the design documentation (see Annex J for further information):

1) temperature;
2) humidity;
3) air density;
4) solar radiation;
5) rain, hail, snow and ice;
6) chemically active substances;
7) mechanically active particles (e.g. sand and dust particles);
8) lightning;
9) earthquakes; and
10) marine environment - corrosion.

A marine environment requires special additional consideration. The climatic conditions for the design shall be defined in terms of representative values or by the limits of the variable conditions. The probability of simultaneous occurrence of the climatic conditions shall be taken into account when the design values are selected.

Variations in the climatic conditions within the normal limits, which correspond to a one-year recurrence period shall not interfere with the designed normal operation of a SWT. Unless correlation exists, other extreme environmental conditions according to 6.4.3 shall be combined with the normal wind conditions according to 6.3.2.

6.4.2 Other normal environmental conditions

The other normal environmental condition values, which shall be taken into account are:

1) normal system operation ambient temperature range of –10 °C to +40 °C;
2) relative humidity of up to 95 %;
3) atmospheric content equivalent to that of a non-polluted inland atmosphere (see IEC 60721-2-1);
4) solar radiation intensity of 1 000 W/m^2; and,
5) air density of 1,225 kg/m^3.

When the designer specifies additional external condition parameters, these parameters and their values shall be stated in the design documentation and shall conform to the requirements of IEC 60721-2-1.

6.4.3 Other extreme environmental conditions

6.4.3.1 General

Other extreme environmental conditions, which shall be considered for SWT design, are temperature, lightning, ice and earthquakes.

6.4.3.2 Temperature

The design values for the extreme temperature range shall be at least –20 °C to +50 °C for the standard SWT classes.

6.4.3.3 Lightning

The provisions of lightning protection required in 9.5 may be considered as adequate for wind turbines in the standard SWT classes.

6.4.3.4 Ice

No ice requirements are given for the standard SWT classes.

In case the manufacturer wants to include ice loading in their design load estimation, a minimum of 30 mm layer of ice with a density of 900 kg/m^3 on all exposed areas is recommended. This static ice load would then be combined with the drag loads on the parked turbine system at $3 \times V_{ave}$. Ice loads on the support structure including guy wires should be considered in the design loads of the support structure.

6.4.3.5 Earthquakes

No minimum earthquake requirements are given for the standard SWT classes.

6.5 Controlled test conditions

Room temperature is +10 °C to +35 °C. For tests under controlled test conditions the controlled room temperature shall always be in the range of +18 °C to +28 °C (+23 ± 5) °C).

6.6 Electrical load conditions

6.6.1 General

The electrical conditions which need to be considered in the design depend on the application of the turbine.

6.6.2 For turbines connected to the electrical power network

6.6.2.1 Normal electrical conditions

The normal conditions at the wind turbine terminals to be considered in design are listed below. Normal electrical power network conditions apply when the following parameters fall within the ranges stated below:

- Voltage
  Nominal value (according to IEC 60038) ± 10 %;
- Frequency
  Nominal value ± 2 %;
- Voltage imbalance
  The ratio of the negative-sequence component of voltage to the positive-sequence component will not exceed 2 %;
- Auto-reclosing cycles
  Auto-reclosing cycle periods of 0,2 s to 5,0 s for the first reclosure and 10 s to 90 s for a second reclosure; and
- Outages
  Electrical network outages shall be assumed to occur 20 times per year. An outage of up to 24 h shall be considered a normal condition.

6.6.2.2 Extreme electrical conditions

At least the following extreme electrical power network conditions at the wind turbine terminals shall be considered in the design:

- voltage – deviations from nominal value of ± 20 %;
- frequency – nominal value ± 10 %;
- voltage imbalances of 15 %;
- symmetrical and unsymmetrical faults; and
- outages – an outage of up to 1 week shall be considered an extreme condition.

6.6.3 For turbines not connected to the electrical power network

6.6.3.1 Battery-charging turbine

The turbine shall be able to operate over the full range of battery voltages listed below:

- voltage range –15 % or +30 % of nominal voltage (example 12 V, 24 V, 36 V, etc.); or
- 5 % beyond upper and lower settings of charge controller.

6.6.3.2 Local-grid

Turbines connected to a local grid thus not connected to a large electrical network will be expected to encounter larger variations in voltage and frequency. The turbine system shall be able to operate within the following constraints:

- voltage: deviation from nominal values of ± 15 %; and
- frequency: nominal ± 5 Hz.

7 Structural design

7.1 General

Wind turbine system structural design shall be based on verification of the structural integrity of the components in the critical load paths from the rotor blades to the foundation. The ultimate and fatigue strength of all structural members (for example: rotor blade, rotor hub, rotor shaft, nacelle, yaw shaft, tower, connections) shall be verified by calculations or tests, or a combination of both, to determine the structural integrity of a SWT with the appropriate safety level. The scope of verification is the same regardless of the design methodology chosen (7.2).

The structural analysis shall be based on ISO 2394 or equivalent, where applicable.

7.2 Design methodology

It shall be verified that the limit states are not exceeded for the wind turbine design.

There are three ways given to determine the design loads for the turbine which are described in 5.2 as being:

1) simplified loads methodology;
2) simulation model;
3) full scale load measurement.

7.3 Loads and load cases

7.3.1 General

The types of loads described in 7.3.2 to 7.3.6 shall be considered.

7.3.2 Vibration, inertial and gravitational loads

Inertial and gravitational loads are static and dynamic loads acting on the SWT resulting from inertia, gyroscopic, vibration, rotation, gravity and seismic activity or motion of the support structure such as boats, etc.

A resonance analysis, such as provided by a Campbell diagram, shall be provided for the main structural components of the wind turbine system (see Annex I).

7.3.3 Aerodynamic loads

Aerodynamic loads are static and dynamic loads, which are caused by the airflow and its interaction with the stationary and moving parts of the SWT. The airflow shall be considered to be dependent upon the rotational speed of the rotor, the wind speed across the rotor plane, turbulence, the density of the air, and the aerodynamic shapes of the wind turbine components and their interactive effects, including aero-elastic effects.

7.3.4 Operational loads

Operational loads result from the operation and control of the turbine system. Operational loads can be caused by yawing, braking, furling, pitching, grid connection, etc.

7.3.5 Other loads

All loads that may occur due to special operating environments specified by the manufacturer shall also be considered (e.g. wave loads, wake loads, ice loads, transport, assembly, maintenance and repair loads, etc.).

7.3.6 Load cases

For design purposes, the life of a SWT can be represented by a set of design situations covering the most significant conditions which the turbine system may experience.

The load cases shall be determined from the combination of specific assembly, erection, maintenance, and operational modes or design situations with the external conditions. All relevant load cases with a reasonable probability of occurrence shall be considered, together with the behaviour of the control and protection system.

Generally the design load cases used to determine the structural integrity of a SWT may be calculated from the following combinations:

- turbine operation without fault and with normal external conditions;
- turbine operation without fault and with extreme external conditions;
- turbine operation with fault and appropriate external conditions; and
- transportation, installation and maintenance design situations and appropriate external conditions (see also 10.6).

If a significant correlation exists between an extreme external condition and a fault situation, a realistic combination of the two shall be considered as a design load case.

Within each design situation several design load cases shall be considered to verify the structural integrity of SWT components. As a minimum the design load cases in Table 2 or Table 4 shall be considered. In those tables, the design load cases are specified for each design situation by the description of the wind, electrical and other external conditions.

Where the control and protection system does not monitor and limit certain turbine parameters, this shall be taken into account in the load cases. Examples of such parameters are:

- cable twist;
- vibrations;
- rotor speed; and
- flutter.

7.4 Simplified loads methodology

7.4.1 General

For certain turbine configurations the loads can be derived using simple, conservative equations for a limited set of load cases. Annex F provides background information for these equations. If the turbine configuration does not meet those configuration requirements the simplified loads methodology cannot be used, instead the alternative simulation modelling (7.5) or load measurements shall be used (7.6).

The turbine configurations that are able to use the simplified loads methodology shall meet all of the following requirements:

- horizontal axis;
- 2 or more bladed propeller-type rotor;
- cantilever blades;
- coordinated blade movement (not independent and uncoordinated pitching, coning, etc.); and
- rigid hub (not teetering or hinged hub).

The turbine configuration may use an upwind or downwind rotor; it may operate at either variable or constant speed; it may have an active or passive pitch mechanism (provided that the pitch mechanism coordinates all blades simultaneously), as well as fixed pitch; and it may furl about vertical, horizontal, or intermediate axes, as well as not furling.

The simplified load methodology uses input parameters which shall be determined as described in 13.2, noting especially the clause regarding yaw 13.2.3. These parameters are:

- design rotational speed, n_{design};
- design wind speed, V_{design};
- design shaft torque, Q_{design};
- maximum yaw rate, $\omega_{\text{yaw,max}}$; and
- maximum rotational speed, n_{max}.

Further the design tip speed ratio is defined as:

$$\lambda = \frac{V_{\text{tip}}}{V_{\text{hub}}} = \frac{\varpi R}{V_{\text{hub}}} \Rightarrow \lambda_{\text{design}} = \frac{R}{V_{\text{design}}} \frac{\pi n_{\text{design}}}{30} \tag{19}$$

$$\omega_n = \frac{2\pi n}{60} = \frac{\pi n}{30} \tag{20}$$

The load cases for the simplified load methodology are summarised in Table 2. The load components for the simplified load methodology are found in each clause discussing the load case.

For each design situation, the appropriate type of analysis is stated by “F” and “U” in Table 2. F refers to analysis of fatigue loads, to be used in the assessment of fatigue strength. U refers to the analysis of ultimate loads such as analysis of exceeding the maximum material strength, analysis of tip deflection, and stability analysis.

Table 2 – Design load cases for the simplified load calculation method

Design situation	Load cases		Wind inflow	Type of analysis	Remarks
Power production	**A**	Normal operation		F	
	B	Yawing	$V_{hub}=V_{design}$	U	
	C	Yaw error	$V_{hub}=V_{design}$	U	
	D	Maximum thrust	$V_{hub}=2{,}5\ V_{ave}$	U	Rotor spinning but could be furling or fluttering
Power production plus occurrence of fault	**E**	Maximum rotational speed		U	
	F	Short at load connection	$V_{hub}=V_{design}$	U	Maximum short-circuit generator torque
Shutdown	**G**	Shutdown (Braking)	$V_{hub}=V_{design}$	U	
Extreme wind Loading	**H**	Extreme wind loading	$V_{hub}=V_{e50}$	U	The turbine may be parked (idling or standstill) or governing. No manual intervention has occurred.
Parked and fault conditions	**I**	Parked wind loading, maximum exposure	$V_{hub}=V_{ref}$	U	Turbine is loaded with most unfavourable exposure
Transport, assembly, maintenance and repair	**J**	To be stated by manufacturer		U	

Key

F analysis of fatigue loads

U analysis of ultimate loads

Other design load cases relevant for safety shall be considered, if required by the specific SWT design.

7.4.2 Load case A: normal operation

The design load for "normal operation" is a fatigue load. The load case assumes constant range fatigue loading for the blade and shaft, these ranges are given below. The ranges are to be considered in the fatigue assessment as peak-to-peak values. The mean values of the load ranges can be ignored.

NOTE See Clause F.3.

Blade loads:

$$\Delta F_{zB} = 2 m_B R_{cog} \varpi_{n,design}^2 \tag{21}$$

$$\Delta M_{xB} = \frac{Q_{design}}{B} + 2 m_B g R_{cog} \tag{22}$$

$$\Delta M_{yB} = \frac{\lambda_{design} Q_{design}}{B} \tag{23}$$

The fatigue loading on the blade would be considered to occur at the airfoil – root junction or at the root – hub junction, whichever is determined to have the lowest ultimate strength. The calculated stresses are the combination of the centrifugal loading (F_{zB}) and the bending moments (M_{xB} and M_{yB}).

Shaft loads:

$$\Delta F_{x-shaft} = \frac{3}{2}\frac{\lambda_{design} Q_{design}}{R} \tag{24}$$

$$\Delta M_{x-shaft} = Q_{design} + 2 m_r\, g\, e_r \tag{25}$$

$$\Delta M_{shaft} = 2 m_r\, g L_{rb} + \frac{R}{6} \Delta F_{x-shaft} \tag{26}$$

where e_r = 0,005R, unless through design documents it can be proven that a lower value is reasonable.

The fatigue load on the rotor shaft shall be considered at the rotor shaft at the first bearing (nearest to the rotor). The range of the stress shall be calculated from the combination of the thrust loading ($F_{x\text{-shaft}}$), the torsion moment ($M_{x\text{-shaft}}$) and the bending moment (M_{shaft}).

7.4.3 Load case B: yawing

For this load case, the ultimate loads (gyroscopic forces and moments) shall be calculated assuming the maximum yaw speed $\omega_{yaw,max}$ occurring with n_{design}.

For a passive yaw system, the maximum yaw rate is given by the following equation:

$$\omega_{yaw,max} = 3 - 0{,}01 \times (\pi R^2 - 2) \tag{27}$$

For all turbines with a swept rotor area of less than 2 m^2, the maximum yaw rate shall be 3 rad/s.

For an active yaw system the maximum yaw rate shall be determined by measurement in calm winds. If the maximum yaw rate is expected to occur under special conditions such as emergency yawing at higher rate, the active yaw rate shall be measured under those conditions.

The loads due to the bending moment M_{yB} on the blade and the shaft bending moment M_{shaft} shall be calculated using the following equations:

$$M_{yB} = m_B \omega_{yaw,max}^2 L_{rt} R_{cog} + 2\omega_{yaw,max} I_B \omega_{n,design} + \frac{R}{9} \Delta F_{x-shaft} \tag{28}$$

where $\Delta F_{x\text{-shaft}}$ is given by Equation (24).

For the shaft, the loads are dependent on the number of blades.

For a two bladed rotor:

$$M_{shaft} = 4\omega_{yaw,max} \omega_{n,design} I_B + m_r g L_{rb} + \frac{R}{6} \Delta F_{x-shaft} \tag{29}$$

For a three or more bladed rotor:

$$M_{shaft} = B\omega_{yaw,max} \omega_{n,design} I_B + m_r g L_{rb} + \frac{R}{6} \Delta F_{x-shaft} \tag{30}$$

7.4.4 Load case C: yaw error

All turbines operate with a certain yaw error. In this load case a yaw error of 30° is assumed.

The flapwise bending moment caused by the yaw error is given by Equation (31)

$$M_{yB} = \frac{1}{8}\rho\, A_{proj,B} C_{l,max} R^3 \omega_{n,design}^2 \left[1 + \frac{4}{3\lambda_{design}} + \frac{1}{2}\left(\frac{1}{\lambda_{design}}\right)^2\right] \tag{31}$$

If no data is available on the maximum lift coefficient, $C_{l,max}$, a value of 2,0 shall be used.

7.4.5 Load case D: maximum thrust

The SWT can be exposed to high thrust loads on the rotor. The thrust load acts parallel to the rotor shaft and has a maximum value given by:

NOTE See Clause F.3.

$$F_{x-shaft} = C_T 0{,}5\rho(2{,}5 \times V_{ave})^2 \pi R^2 \tag{32}$$

where C_T is the thrust coefficient, equal to 0,5. However, caution should be exercised with wind turbines that operate at high rotational speeds at 2,5 V_{ave}, where a C_T of 8/9 may be more appropriate.

7.4.6 Load case E: maximum rotational speed

The centrifugal load in the blade root s_{zB} and the shaft bending moment M_{shaft} due to centrifugal load and rotor unbalance shall be calculated from equations below. The maximum possible rotor speed $\omega_{n,max}$ = (π/30) n_{max} shall be derived by measurements as described in 13.2.4.

$$F_{zB} = m_B \omega_{n,max}^2 R_{cog} \tag{33}$$

$$M_{shaft} = m_r g L_{rb} + m_r e_r \omega_{n,max}^2 L_{rb} \tag{33'}$$

7.4.7 Load case F: short at load connection

In the case of a direct electrical short at the output of the SWT or internal short in the generator, a high moment is created about the rotor shaft due to the short circuit torque of the alternator. In the absence of any proven more accurate values, two times the Q_{design} is to be taken as the short circuit torque acting on the generator shaft.

$$M_{x-shaft} = G\, Q_{design} \tag{34}$$

In the absence of any proven more accurate values, G shall be 2,0.

$$M_{xB} = \frac{M_{x-shaft}}{B} + m_B g R_{cog} \tag{35}$$

7.4.8 Load case G: shutdown (braking)

In the case of wind turbines with a mechanical or electrical braking system in the drive train, the braking moment can be greater than the maximum driving moment. In these cases, the braking moment M_{brake}, derived from testing or calculations, shall be used in the design calculations of the SWT. The maximum shaft torque is assumed to be equal to the brake plus the design torque (thus assuming that the brake is applied while the generator still delivers design torque).

$$M_{x-\text{shaft}} = M_{\text{brake}} + Q_{\text{design}} \tag{36}$$

The brake torque shall be multiplied by the gearbox ratio to yield M_{brake} if the brake is on the high speed shaft.

The blade load during shutdown is assumed to be determined by the shaft torque and blade mass. Thus being:

$$M_{xB} = \frac{M_{x-\text{shaft}}}{B} + m_B g R_{\text{cog}} \tag{37}$$

where $M_{x\text{-shaft}}$ is the shaft torque as calculated in Equation (36).

In case the turbine has a gearbox and a high-speed shaft brake, the shaft torque calculated in Equation (36) should be increased to account for drive train dynamics. In the absence of any proven more accurate values the shaft torque shall be multiplied by a factor of two.

7.4.9 Load case H: extreme wind loading

In this load case, the wind turbine is functioning as per the design intent during extreme wind speeds. The loads on the exposed parts of the SWT shall be calculated assuming wind speed of V_{e50} found in 6.3.3.2.

NOTE See Clause F.3.

If the spinning rotor is controlled to a very low speed then the higher thrust given by Equation (40) shall be used instead of the lower thrust given by Equation (41).

For turbines which will be parked, the out of plane blade root bending moment is dominated by drag and thus defined as:

$$M_{yB} = C_d \, \tfrac{1}{4} \rho {V_{e50}}^2 A_{\text{proj,B}} R \tag{38}$$

where

C_d is the drag coefficient and shall be taken as 1,5; and

$A_{\text{proj,B}}$ is the planform area of the blade.

For turbines that have their rotor spinning at V_{e50}, it is expected that, at some location on the rotor $C_{l,\max}$ will occur on one of the blades due to variations in wind direction. Thus the blade root bending moment is:

$$M_{yB} = C_{l,\max} \, \tfrac{1}{6} \rho V_{e50}^2 A_{\text{proj,B}} R \tag{39}$$

If no data is available on $C_{l,\max}$ a value of 2,0 shall be used.

For the thrust load:

For a parked rotor the shaft thrust load is calculated as given by Equation (40).

$$F_{x-\text{shaft}} = B \, C_d \, \tfrac{1}{2} \rho V_{e50}^2 A_{\text{proj,B}} \tag{40}$$

For a spinning rotor the thrust force is given by:

$$F_{x-\text{shaft}} = 0{,}17 B A_{\text{proj,B}} \lambda_{\text{e50}}^2 \rho V_{\text{e50}}^2 \quad (41)$$

where λ_{e50} is the tip speed ratio at V_{e50}, which if not known can be estimated by:

$$\lambda_{\text{e50}} = \frac{n_{\max} \pi R}{30\, V_{\text{e50}}} \quad (42)$$

The maximum tower bending moment shall be calculated using the thrust force calculated with either Equation (40) or (41) (depending on the turbine design). The drag or lift force on the tower and nacelle need to be taken into account as well. Equation (43) shall be used to calculate those forces. For free standing towers the maximum bending moment will occur at the tower base. For guyed towers the maximum bending moment will occur at the upper guy wire attachment.

The load for each component is given by:

$$F = C_{\text{f}}\, {}^1\!/_2\, \rho V_{\text{e50}}^2 A_{\text{proj}} \quad (43)$$

where

C_f is the force coefficient (see Table 3); and

A_{proj} is the component area projected on to a plane perpendicular to the wind direction.

From the loads on the individual components the blade, shaft and tower loads need to be calculated.

7.4.10 Load case I: parked wind loading, maximum exposure

In the case of a failure in the yaw mechanism, the SWT can be exposed to the wind from all directions. Thus, for design purposes, the forces on the SWT blades, nacelle, tower, and tail (if applicable) shall be calculated for all possible exposures including winds from the front, side or rear of the rotor.

The load on each component is given by:

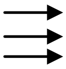
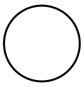
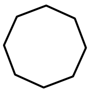
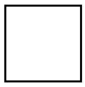
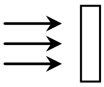
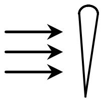
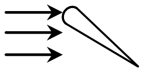
$$F = C_{\text{f}}\, {}^1\!/_2\, \rho V_{\text{ref}}^2 A_{\text{proj}} \quad (44)$$

where

C_f is the force coefficient, which may result from lift or drag; and

A_{proj} is the component area (in its most unfavourable position) that is appropriate for the force coefficient. For blunt (or bluff) bodies (e.g. nacelle covers and tower sections) the area shall be the projected area on a plane perpendicular to the wind direction. For airfoil shapes the area shall be the planform area.

Table 3 – Force coefficients (C_f)

For all cross sections wind direction is from left to right 						
Characteristic length[a] < 0,1 m	1,3	1,3	1,5	1,5	1,5	2,0
Characteristic length [a] > 0,1 m	0,7	1,2	1,5	1,5	1,5	2,0

[a] Characteristic length is the top to bottom dimension (perpendicular to the flow) as illustrated here except in the case of the oblique aerofoil for which an aerofoil data book should be consulted.

7.4.11 Load case J: transportation, assembly, maintenance and repair

The manufacturer shall consider loads on the turbine system caused by the transportation, assembly, installation, and maintenance and repair of the system. Examples of such loads are:

- gravity loads on turbine during transportation in other than upright position;
- loads caused by special installation tools;
- wind loads during installation or maintenance;
- loads introduced by hoisting the turbine onto the foundation;
- loads on a tilt up tower during erection; and
- load on a support structure from climbing it.

As an example the equation to calculate loads during tower tilt up are given below.

$$M_{\text{tower}} = 2(m_{\text{towertop}} + \frac{m_{\text{overhang}}}{2}) \times g L_{\text{lt}} \qquad (45)$$

where

M_{tower}	is the bending moment of the tower at the lifting point attachment [Nm];
$m_{\text{tower top}}$	is the mass of the nacelle and rotor combined [kg];
m_{overhang}	is the mass of the tower between the lifting point and the tower top [kg]; and
L_{lt}	is the distance between the lifting point and the top of the tower [m].

Equation (45) is based on the following assumptions:

- dynamic amplification factor is 2;
- centre of gravity of turbine is along the rotor axis; and
- the rotor is parked; and
- maximum bending moment occurs when tower is horizontal.

7.5 Simulation modelling

7.5.1 General

In case the design loads are determined by simulation (aero-elastic) modelling the load cases in this subclause 7.5 shall be considered. A minimum set of design load cases (DLC) is given in Table 4. In Table 4 the design load cases are specified for each design situation by the description of the wind, electrical and other external conditions. In load cases evaluated where a wind speed range is given, the load case shall be evaluated over the entire wind speed range to ensure the worst load is identified.

Other design load cases relevant for safety shall be considered, if required by the specific wind turbine design.

For each design situation, the appropriate type of analysis is stated by "F" and "U" in Table 4. F refers to analysis of fatigue loads, to be used in the assessment of fatigue strength. U refers to the analysis of ultimate loads such as analysis of exceeding the maximum material strength, analysis of tip deflection, and stability analysis.

Table 4 – Minimum set of design load cases (DLC) for simulation by aero-elastic models

Design situation	DLC	Wind condition		Other conditions	Type of analysis
1) Power production	1.1	NTM	$V_{in} < V_{hub} < V_{out}$ or $3 \times V_{ave}$		F, U
	1.2	ECD	$V_{hub} < V_{design}$		U
	1.3	EOG_{50}	$V_{in} < V_{hub} < V_{out}$ or $3 \times V_{ave}$		U
	1.4	EDC_{50}	$V_{in} < V_{hub} < V_{out}$ or $3 \times V_{ave}$		U
	1.5	ECG	$V_{hub} = V_{design}$		U
2) Power production plus occurrence of fault	2.1	NWP	$V_{hub} = V_{design}$ or V_{out} or $2{,}5 \times V_{ave}$	Control system fault	U
	2.2	NTM	$V_{in} < V_{hub} < V_{out}$	Control or protection system fault	F, U
	2.3	EOG_1	$V_{in} < V_{out}$ or $2{,}5 \times V_{ave}$	Loss of electrical connection	U
3) Normal shutdown	3.1	NTM	$V_{in} < V_{hub} < V_{out}$		F
	3.2	EOG_1	$V_{hub} = V_{out}$ or $V_{max,shutdown}$		U
4) Emergency or manual shutdown	4.1	NTM	To be stated by the manufacturer		U
5) Extreme wind loading (standing still or idling; or spinning)	5.1	EWM	$V_{hub} = V_{e50}$	Possible loss of electrical power network	U
	5.2	NTM	$V_{hub} < 0{,}7\ V_{ref}$		F
6) Parked and fault condition	6.1	EWM	$V_{hub} = V_{e1}$		U
7) Transport, assembly, maintenance and repair	7.1	To be stated by the manufacturer			U

Key

F analysis of fatigue loads

U analysis of ultimate loads

7.5.2 Power production (DLC 1.1 to 1.5)

In these load cases, a wind turbine is running and connected to the electric load. The assumed wind turbine configuration shall take into account rotor imbalance. The maximum mass and aerodynamic imbalances (e.g. blade pitch and twist deviations) specified for manufacturing the rotor shall be used in the design calculations.

In addition, deviations from theoretical optimum operating situations such as yaw misalignment and control system tracking errors shall be taken into account in the analyses of operational loads.

The worst combination of conditions shall be assumed in the calculation, e.g. direction change with characteristic yaw misalignment in DLC 1.4. Design load case 1.1 embodies the requirements for loads resulting from atmospheric turbulence. DLC 1.2 to 1.5 specify transient cases, which have been selected as potentially critical events in the life of a wind turbine.

7.5.3 Power production plus occurrence of fault (DLC 2.1 to 2.3)

Any fault in the control or protection systems, or internal fault in the electrical system significant for wind turbine loading (such as generator short circuit) shall be assumed to occur during power production. For DLC 2.1 the occurrence of a fault in the control system which is considered a normal event shall be analysed. The occurrence of faults in the protection or internal electrical systems, which do not cause an immediate shutdown and thus can lead to significant fatigue damage, shall be evaluated in DLC 2.2.

In DLC 2.3 the one-year extreme operating gust needs to be combined with a loss of electrical connection.

For passively controlled turbines examples of control system faults are:

- faulted furl system (e.g. locked tail) (if the furling system is not demonstrated to be safe life); and
- faulted blade pitch system (if the blade pitch system is not demonstrated to be safe life).

Evaluate the fatigue case for any single fault of the turbine system for a minimum of 24 h/year.

7.5.4 Normal shutdown (DLC 3.1 and 3.2)

This load case includes all the events resulting in loads on a wind turbine during normal transient situations from a power production situation to a stand-still or idling condition. The number of occurrences shall be estimated based on the control system behaviour.

For passively controlled turbines there might not be an automatic shutdown, in those cases the fatigue load case can be ignored. For DLC 3.2, the maximum wind speed is V_{out} or $V_{\text{max,shutdown}}$.

7.5.5 Emergency or manual shutdown (DLC 4.1)

Loads arising from emergency or manual shutdown shall be considered. The wind speed limitations for the procedures shall be prescribed by the manufacturer in the operations manual. Instead of using V_{out} the wind speed value specified by the manufacturer shall be used.

7.5.6 Extreme wind loading (stand-still or idling or spinning) (DLC 5.1 to 5.2)

The rotor of a parked wind turbine, which may be either in a stand-still or idling condition, shall be considered with the extreme wind speed condition. Alternatively this shall be considered for turbines which will have their rotors spinning, like most passively controlled turbines (such as furling). Those conditions shall be either turbulent or quasi-steady with correction for gusts and dynamic response.

If significant fatigue damage can occur to some components (e.g. from weight of idling blades), the expected number of hours of non-power production time at each appropriate wind speed shall also be considered.

The effects of the loss of the electrical power network or other electrical load (e.g. battery, or dump loads such as resistance heaters or water pumps) on a parked wind turbine shall be taken into account.

7.5.7 Parked plus fault conditions (DLC 6.1)

Deviations from the normal behaviour of a parked wind turbine, resulting from faults on the electrical network or in the wind turbine, shall require analysis. If any fault other than a loss of electrical power network produces deviations from the normal behaviour of the wind turbine in parked situations, the possible consequences shall be the subject of analysis. In DLC 6.1, the fault condition shall be combined with the extreme wind speed model (EWM) with a recurrence period of one year. Those conditions shall be either turbulent or quasi-steady with correction for gusts and dynamic response.

7.5.8 Transportation, assembly, maintenance and repair (DLC 7.1)

The manufacturer shall consider loads on the turbine system caused by the transportation, assembly, installation, and maintenance and repair of the system. Examples of such loads are:

- gravity loads on turbine during transportation in other than upright position;
- loads caused by special installation tools;
- wind loads during installation;
- loads introduced by hoisting the turbine onto the foundation;
- loads on a tilt up tower during erection; and
- loads on a support structure from climbing it.

7.5.9 Load calculations

Loads as described in 7.3 shall be taken into account for each design load case. Where relevant, the following shall also be taken into account:

- wind field perturbations due to the wind turbine itself (wake-induced velocities, tower shadow etc.);
- the influence of three dimensional flow on the blade aerodynamic characteristics (e.g., three dimensional stall and aerodynamic tip loss);
- unsteady aerodynamic effects;
- structural dynamics and the coupling of vibration modes;
- aero-elastic effects; and
- the behaviour of the control and protection system of the wind turbine.

7.6 Load measurements

In case the design loads are derived from load measurements, these load measurements should be taken under conditions as close as possible to the load cases described under 7.5. Extrapolation of measured loads shall occur in compliance with IEC/TS 61400-13. Further requirements on load measurements can be found in 13.3 and IEC/TS 61400-13.

For any of the load cases in 7.4 or 7.5, load measurements can be used instead of calculations as long as the measurements were taken under similar conditions as the load case specifies.

7.7 Stress calculation

Stresses shall be calculated on all important load carrying components. The stresses calculated from the individual forces and moments within a load case have to be combined to find equivalent stresses. The resulting equivalent stresses have to be compared with the design values for material stresses.

In the calculation of stresses, account shall be taken of:

- stress variations;
- stress concentrations;
- magnitude and direction of the resulting loads;
- component dimensions and material thickness variations;
- component surface roughness, surface treatment;
- type of loading (bending, tensile, torsion, etc.); and
- welding, casting, machining, end grain construction, etc.

Table 5 gives guidance for the calculation of equivalent stresses from the unidirectional values.

Table 5 – Equivalent stresses

	Circular blade root	Rectangular blade root	Rotor shaft
Axial load	$\sigma_{zB} = \frac{F_{zB}}{A_B}$	$\sigma_{zB} = \frac{F_{zB}}{A_B}$	$\sigma_{x-shaft} = \frac{F_{x-shaft}}{A_{shaft}}$
Bending	$\sigma_{MB} = \frac{\sqrt{M_{xB}^2 + M_{yB}^2}}{W_B}$	$\sigma_{MB} = \frac{M_{xB}}{W_{xB}} + \frac{M_{yB}}{W_{yB}}$	$\sigma_{M-shaft} = \frac{M_{shaft}}{W_{shaft}}$
Shear	Negligible	Negligible	$\tau_{M-shaft} = \frac{M_{x-shaft}}{2W_{shaft}}$
Combined (axial + bending)	$\sigma_{eqB} = \sigma_{zB} + \sigma_{MB}$		$\sigma_{eq} = \sqrt{(\sigma_{x-shaft} + \sigma_{M-shaft})^2 + 3\tau_{M-shaft}^2}$

7.8 Safety factors

7.8.1 Material factors and requirements

The material factors given in this subclause 7.8.1 shall be applied to material properties estimated with a 95 % probability with 95 % confidence limits. If the material properties are derived for other survival probabilities the safety factor for materials shall be adjusted (see Annex E).

For strengths, these can be on either a stress or a strain basis. The following factors shall be considered when determining the material properties:

a) materials and material configurations representative of the full-scale structure;
b) manufacturing method of the test samples that are typical of the full scale structure;
c) static, fatigue, and spectrum loading testing (including rate effects);
d) environmental effects (e.g. UV degradation, humidity, temperature, corrosion etc.); and,
e) geometry effects as they affect material properties (e.g. material orientation for injection moulded blades, ply drops in composites and wood, material orientation from forging of metals, etc.).

Table 6 lists the partial safety factors for materials that shall be used for fatigue and ultimate strength analysis. When the five factors above have been adequately considered the minimum partial safety factors for materials may be used. This situation is termed “full characterisation” and may include those cases where recognised material codes are available (e.g. ISO). If material properties are based solely upon coupon testing and do not consider the above factors, the maximum material factor shall be used. This situation is termed “minimal characterisation”.

In reference to item d) above:

- The environmental effects on the load carrying structure of fibre reinforced plastic materials (e.g. material degradation/aging of due to UV radiation, humidity, embrittlement, etc.) of structural components shall be considered by an additional material factor of 1,35 on static strength analysis only. This factor can be reduced if representative tests show lower degradation effects. Fibre reinforced plastic materials include all fibre-reinforced (e.g. by glass or carbon) plastic materials (e.g. epoxy, polyester, vinylester).
- The strength reduction (both for ultimate and fatigue strength) of fibre reinforced plastics due to material temperatures higher than controlled room temperature (see 6.5) shall be considered by a material factor of 1,1. This factor can be set to 1,0 if the coupon tests are executed at the highest (extreme) temperature the wind turbine is designed for, i.e. 50 °C unless a higher figure is stated in the design conditions.
- The environmental effect of corrosion shall be excluded by adequate means of corrosion protection over the lifetime of the wind turbine.

Annex F provides guidelines for determining the appropriate factors depending upon the amount and type of material testing that has been completed.

Table 6 – Partial safety factors for materials

Material characterisation	Fatigue strength, γ_m	Ultimate strength, γ_m
Full characterisation	1,25[a]	1,1
Minimal characterisation	10,0[b]	3,0

[a] Factor is applied to the measured fatigue strength of the material.

[b] Factor is applied to the measured ultimate strength of the material.

7.8.2 Partial safety factor for loads

The partial safety factor accounts for the uncertainty in the load estimation process and thus is different for each load determination method. Table 7 gives the load factors to be used for each method. A simulation model has been verified with limited full-scale measurements; therefore the partial safety factor for loads is lowest for this load determination method. Lower safety factors for ultimate loads may be applied for well-known loads, such as gravity loads.

Table 7 – Partial safety factors for loads

Load determination method (see 5.2)	Fatigue loads, γ_f	Ultimate loads, γ_f
1. Simplified equations	1,0	3,0
2. Simulation model	1,0	1,35
3. Full scale load measurement	1,0	3,0

7.9 Limit state analysis

7.9.1 Ultimate strength analysis

For ultimate strength, the design requirement to be met is expressed by the equation.

$$\sigma_d \leq \frac{f_k}{\gamma_m \gamma_f} \qquad (46)$$

where

f_k is the characteristic material strength;

γ_m is the partial safety factor for materials (7.8.1); and

γ_f is the partial safety factor for loads.

In general, the yield strength can be used as the characteristic strength.

7.9.2 Fatigue failure

The fatigue damage from all fatigue load cases shall be combined. The fatigue damage shall be estimated using an appropriate fatigue damage calculation. For example, in the case of Miner's rule, the limit state is reached when the accumulated damage exceeds 1. So the accumulated damage within the lifetime of a turbine shall be less than or equal to 1:

$$\text{Damage} = \sum_i \frac{n_i}{N(\gamma_f \gamma_m\, s_i)} \leq 1{,}0 \tag{47}$$

where

- n_i is the counted number of fatigue cycles in bin i of the characteristic load spectrum, including all relevant load cases;
- s_i is the stress (or strain) level associated with the counted cycles in bin i, including the effects of both mean and cyclic range;
- $N(.)$ is the number of cycles to failure as a function of the stress (or strain) indicated by the argument (i.e. the characteristic S-N curve); and
- γ_f, γ_m are the appropriate safety factor for loads and materials respectively.

The influence of the mean stress shall be considered if it is not already addressed by the analysis method.

In case the simplified load model (7.4) is used, the ranges of load case A normal operation (7.4.2) shall be applied for the number of fatigue cycles given in Equation (48).

$$n = \frac{B\, n_{design} T_d}{60} \tag{48}$$

where

T_d is the design life of the turbine in seconds.

If no S-N curve is available, Equation (46) shall be used with the ultimate strength as the characteristic material strength and the fatigue loads to calculate the design stress. The partial safety factor for fatigue and minimal characterisation from Table 6 (γ_m=10,0) shall then be used.

7.9.3 Critical deflection analysis

It shall be verified that no deflections affecting the wind turbine’s safety occur in the design load cases.

One of the most important considerations is to verify that no mechanical interference between the blade and tower can occur. No part of the blade shall hit the tower under any of the design load cases. The maximum predicted tip deflection multiplied by the appropriate partial load factor shall not exceed the no-load clearance between the blade and the tower.

The tip deflection analysis shall be based on the most severe bending moment distribution assumed for any of the design load cases.

In the case of design loads determined by the simplified load model (7.4), the corresponding distribution of load along the blade span can be obtained by consideration of the equations provided in Annex F.

Partial load safety factors shall be applied.

NOTE For example, if the design loads are based on load case H and the rotor is parked, then Equation (F.34) implies that the out of plane drag loads will vary in proportion to the blade chord. If the design loads are based on load case H and the rotor is spinning for this load case, then Equation (F.35) assumes a linear load distribution that is a maximum at the blade tip and zero at the blade root.

8 Protection and shutdown system

8.1 General

The SWT shall be designed in order to keep all parameters within their design limits under all design load cases. This shall be achieved through an active and/or passive protection system included in the design. In particular, there shall be means to prevent the rotational speed design limit n_{max} from being exceeded.

A safe system or procedure shall be provided that is capable of bringing the turbine to a parked condition in all normal external conditions (i.e. those external conditions which are encountered with less than one-year recurrence period) for the design SWT class, unless the system can be shown to be safer in another condition.

8.2 Functional requirements of the protection system

The protection system shall be designed to be fail-safe. It shall be able to protect the SWT from any single failure or fault in a power source, or in any non-safe-life component within the control and protection system. Testing and/or analysis (such as FMEA/FMECA) shall verify the fail-safe behaviour of the system. A failure of the control, power, or protection system shall not allow the turbine to either exceed the n_{max} rotational speed or go into an unsafe state of operation.

The protection system shall be capable of satisfactory operation at all times, irrespective of whether the turbine is under manual or automatic control.

Measures shall be taken to prevent the accidental or unauthorized adjustment of the protection system.

The service life of safe life components in the protection system shall be well beyond the design lifetime of the wind turbine system, or if they are maintainable components the specified maintenance interval of the component shall not be exceeded. The probability of catastrophic failure of a safe life component in the protection system shall be extremely small during its safe life.

8.3 Manual shutdown

There shall be a manual shutdown button/switch/lever/etc. and shutdown procedures. The manual shutdown button/switch/lever/etc. shall override the automatic control system and result in a parked turbine for all normal external conditions. After shutdown the turbine shall remain parked until manually returned to operation.

NOTE In accordance with Clause 1 “Any of the requirements of this standard may be altered if it can be suitably demonstrated that the safety of the turbine system is not compromised”.

The button/switch/lever/etc. shall be accessible by authorised personnel at floor or ground level. This shall be achievable by an ordinary user, within a reasonable time period.

8.4 Shutdown for maintenance

The manufacturer shall provide a safe method for shutdown of the SWT before performing inspections, service or maintenance. The method shall include specification of the maximum wind and other conditions under which the procedure may be carried out which is termed V_{maint}. This V_{maint} shall not be less than 10 m/s or 1,4 V_{ave} whichever is the greater.

The rotor and yaw motion shall be brought to a standstill prior to performing maintenance. Any other mechanical motions (such as tails or pitch mechanisms) shall also be brought to a standstill or be demonstrated to be safe prior to performing maintenance. Provision shall be made for safe return to service.

For wind turbines of less than 40 m^2 the manufacturer shall provide safe procedures for bringing the turbine to a standstill below V_{maint}. The lowering of a small wind turbine of less than 40 m^2 on a tilt-up tower is an acceptable procedure to bring the turbine to a standstill.

For wind turbines of greater than or equal to 40 m^2 the manufacturer shall provide safe means for bringing the turbine to a standstill below V_{maint} with a procedure for the use of the means (e.g. a procedure for the safe insertion of a locking device). The lowering of a small wind turbine of greater than or equal to 40 m^2 shall not form any part of an acceptable procedure to bring the turbine to a standstill.

Maintenance for small wind turbines on tilt-up towers may be performed on the ground. If the maintenance is performed on top of the upright tower, then there shall be a means to prevent rotor and yaw movement and other mechanical motions (such as tails or pitch mechanisms) before the maintenance is performed.

9 Electrical system

9.1 General

The electrical system of a SWT, and every electrical component used in it such as controllers, generators and the like, shall comply with the applicable portions of Clauses 4 through 15 of IEC 60204-1:2005 and all relevant product standards. When a SWT is connected to an electrical equipment power network, 9.7.3 shall be applied. Every electrical component shall be able to withstand all the design environmental conditions (6.4), as well as the mechanical, chemical and thermal stresses to which the component may be subjected to during operation.

Every electrical component selected on the basis of its power characteristics shall be suitable for the duty demanded of the equipment, taking into account design load cases including fault conditions. However, if an electrical component, by design, does not have the properties corresponding to its end use, it may be used on the condition that adequate additional protection is provided as part of the complete electrical system of the SWT.

9.2 Protective devices

A SWT electrical system shall include suitable devices that ensure protection against malfunctioning of both the SWT and the external electrical system, which may lead to an unsafe condition or state. This shall be done in accordance with 7.1 to 7.5 and 7.8 of IEC 60204-1:2005. (Examples of such devices are fuses for over-current protection, thermistors for temperature, etc.).

Generally the SWT shall be protected against over voltages (e.g. atmospheric or switching) by surge protective devices (SPD). In case of limited space within a SWT such equipment may be installed in separate cabinets outside of the SWT. The cabinets shall be suitable for the environmental conditions.

9.3 Disconnect device

It shall be possible to disconnect a SWT electrical system from all electrical sources of energy as required for maintenance or testing. This shall be done in accordance with Subclauses 5.3.2 and 5.3.3 of IEC 60204-1:2005.

Where lighting or other electrical systems are necessary for safety during maintenance, auxiliary circuits shall be provided with their own disconnect devices, such that these circuits may remain energised while all other circuits are de-energised.

9.4 Earthing (grounding) systems

The design of a SWT shall include a local earthing (grounding) electrode system to meet the requirements of IEC 60364-5-54. The installation, arrangement, and choice of earthing equipment (earth electrodes, conductors, bars, and main terminals) shall match the application of the SWT for lightning protection. The range of soil conditions for which the earth electrode system is designed shall be stated in the installation documentation. For other soil conditions, there shall be recommendations in the installation documentation as to how they shall be managed.

9.5 Lightning protection

Guidance for lightning protection of a SWT can be found in document IEC 61400-24. It is not typically necessary for protective measures to extend to the blades and other aerodynamic devices.

All turbine protection system circuits that could possibly be affected by lightning and other transient overvoltage conditions shall be protected according to IEC 61643-11. All surge protection devices used on SWTs shall be in compliance with the IEC 61643-11.

9.6 Electrical conductors and cables

The conductors of a SWT shall be rated for the particular application with respect to the temperature, voltage, current, environmental conditions and exposure to degraders (oil, UV exposure) in accordance with Clause 13 IEC 60204-1:2005.

Mechanical stresses, including those arising from twisting, to which the conductors may be subjected to during installation and operation, shall be considered. Conductors shall be installed in accordance with Clause 14 of IEC 60204-1:2005.

Where there is a probability of rodents or other animals damaging cables, armoured cables or conduits shall be used. Underground cables shall be buried at a suitable depth so that they are not damaged by service vehicles or farm equipment.

The limits of the protection shall be designed so that any over-voltage transferred to the electrical component will not exceed the limits established by the component insulation levels.

9.7 Electrical loads

9.7.1 General

The electrical loads covered in 9.7.2 through 9.7.5 are suitable loads for SWT systems.

9.7.2 Battery charging

A SWT intended to be used as a battery charging device shall be designed to charge the battery at the current and voltage appropriate for the type recommended in the operation manual. Other considerations are:

- battery temperature;

- battery expansion; and
- conductor size and rating of insulation.

The charging circuit shall be capable of withstanding the maximum voltage during a loss of load or when the batteries are fully charged and the voltage is transferred to another use.

9.7.3 Electrical power network (grid connected systems)

9.7.3.1 General

A SWT, intended to be connected to the electrical power network, shall comply with the requirements in 9.7.3.2 through 9.7.3.3 and relevant interconnect standards.

9.7.3.2 Self-excitation – loss of grid connection

Any electrical system that by itself can self-excite the SWT shall be automatically disconnected from the network and remain safely disconnected in the event of loss of network power.

If a capacitor bank is connected in parallel with a network-connected SWT (i.e. for power factor correction), a suitable switch is required to disconnect the capacitor bank whenever there is a loss of network power, to avoid self-excitation of the SWT electric generator. Alternatively, if capacitors are fitted, it shall be sufficient to show that the capacitors cannot cause self-excitation. Provisions shall be made in order to bleed the capacitors in the event that the capacitor bank cannot be disconnected.

9.7.3.3 Power conditioning equipment, EMC, harmonics and electrical flicker, and reactive power

The electromagnetic compatibility (EMC) of small wind turbine systems is discussed in Annex H.

The power conditioning component, such as inverters, power electronic controllers, and static VAR compensators, shall be designed such that harmonic line currents and voltage waveform distortion do not interfere with electrical network protective relaying. Specifically, for network-connected SWT the current harmonics generated by the SWT shall be such that the overall voltage waveform distortion at the network connecting point will not exceed the acceptable upper limit for the electrical network. Any reactive power correction capacity shall similarly not interfere with electrical network protective relaying.

9.7.4 Direct connect to electric motors (e.g. water pumping)

SWTs that are directly connected to motors can vary in voltage, current and frequency. It shall be demonstrated to operate safely over the whole operating range.

9.7.5 Direct resistive load (e.g. heating)

SWTs that are directly connected to resistive loads can vary in voltage, current and frequency. It shall be demonstrated to operate safely over the whole operating range.

The documentation for a SWT intended for connection to a resistive load, such as a heater, shall specify conductors that are suitable for the current, voltage and temperatures involved.

9.8 Local requirements

Local electrical codes differ around the world, often because of the different technical details of the local electrical distribution and/or transmission systems. In particular earthing and lightning protective system practices can be incompatible and/or in conflict. It is recommended that documentation of the SWT should be sufficient to provide guidance in such situations.

10 Support structure

10.1 General

The support structure is a critical component for the SWT. The support structure carries the loads from the turbine. If the rotor swept area is greater than 2 m^2 then the support structure shall be included as part of the SWT system and designed as described in Clause 7.

It is recommended that any wind turbine and tower that cannot be safely lowered to the ground for maintenance should have a fall arresting system for ascending, descending, and working at the top of the tower.

10.2 Dynamic requirements

An evaluation of the wind turbine system dynamics shall be conducted. By experimentation and/or analysis it shall be shown to be generally free of damaging dynamic or resonant conditions that can affect the structure and/or cause loss of control functions. For further information see Annex I.

10.3 Environmental factors

The SWT support structure should be able to withstand all the external conditions listed in Clause 6. Particular consideration should be given to installation, operation and maintenance of the SWT under extreme environmental conditions. The manufacturer shall identify the design environmental conditions for the SWT in the installation and operation manuals and design documentation.

10.4 Earthing

The SWT support structure (including guy wires) shall be appropriately earthed to reduce damage from lightning (see 9.4 and 9.5).

10.5 Foundation

For turbines with a rotor swept area greater than 2 m^2, the manufacturer shall specify the foundation requirements including layout of the foundation, location of guy wires with minimum and maximum guy location recommendations, and guy wire installation requirements as applicable. For turbines with a rotor swept area greater than 2 m^2 the manufacturer shall design a sample foundation system for normal soil conditions and design loads.

For turbines with a swept area of less than or equal to 2 m^2 refer to 11.2.3.2.

10.6 Turbine access design loads

Consideration shall be given for the design loads arising from normal turbine maintenance including climbing, raising and lowering the tower. These loads shall be consistent with the turbine access procedures specified in the appropriate manuals (for the loads refer to 7.4.11 and/or 7.5.8).

11 Documentation requirements

11.1 General

Clause 11 provides requirements for SWT product manuals and other product literature.

11.2 Product manuals

11.2.1 General

The product manuals shall provide a clear description of assembly, installation, operation and erection requirements for the SWT equipment, including the technical specification of the wind turbine. The documentation shall also provide specific information for the maintenance requirements of the SWT. The information shall be provided in one or more manuals for the installer, owner and service personnel.

All documentation shall inform the user that the contents are important safety instructions and they should be saved. The documentation shall reference the turbine model, serial and revision number. The documentation shall be available to the user and be written in a language that they can read and understand.

11.2.2 Specification

The following information shall be provided by the manufacturer:

a) manufacturer;

b) model;

c) general description of main components;

d) reference power (W or kW) to be provided only following the completion of tests;

e) reference annual energy (kWh/yr);

f) rotor diameter (m) (if applicable);

g) swept area (m^2);

h) number of blades;

i) upwind or downwind rotor (if applicable);

j) VAWT or HAWT or other;

k) tower top weight (kg);

l) description of protection and shutdown system;

m) description of yaw mechanism;

n) direction of rotation;

o) rotor speed and/or tip speed range (r/min and/or m/s) to be provided only following the completion of tests;

p) cut-in wind speed (m/s) to be provided only following the completion of tests;

q) cut-out wind speed (m/s);

r) extreme wind speed (3-s gust with 50-year recurrence period, m/s);

s) SWT class (as designed, and if available as tested)
(if it is an S class a precise explanation of the design parameters is required);

t) power form;

u) maximum output power (per definitions, giving the P_{60} as a minimum);

v) maximum output voltage (per definitions, giving the $U_{0,2}$ as a minimum);

w) maximum output current(s) (per definitions, giving the i_{60} as a minimum);

x) declared sound power level at a wind speed of 8 m/s (dB(A)) to be provided only following the completion of tests;

y) operating temperature range (°C);

z) available support structures;

aa) design life (years).

11.2.3 Installation

11.2.3.1 General

The manufacturer of SWTs shall provide drawings, procedures, specifications, instructions and packing lists for assembly, installation, operation and erection of the SWT. The documentation shall contain details of all loads, weights, lifting tools and procedures necessary for the safe handling and installation of the SWT.

If the manufacturer requires that the SWT be installed by trained personnel, a statement to this effect shall appear on the cover of the installation manual: “TO BE INSTALLED BY TRAINED PERSONNEL ONLY”.

Requirements for cranes, hoists and lifting equipment, including all slings, hooks and other apparatus required for safe lifting shall be included. Specific lifting points shall be clearly marked in the manual and on the component. Reference shall be made to all special tools, jigs and fixtures and other apparatus required for safe installation.

Requirements for pre-service conditioning and proper lubrication of all components shall be clearly stated in the documentation.

An electrical interconnection wiring diagram with international markings for electrical machine terminals shall be included in this clause of the manual with sufficient information to select appropriate conductor sizes if wire is to be supplied by the owner/installer. A system wiring diagram shall be provided in either the installation or service portion of the manual(s).

11.2.3.2 Support structure

For turbines with a swept area of less than or equal to 2 m^2 the manufacturer shall supply all information needed by the user to select a suitable support structure for safe turbine operation. This shall include but is not limited to:

- details on the mechanical turbine/tower connection;
- details on the electrical turbine/tower connection;
- minimum blade/tower clearance;
- maximum allowable tower top deflection; and
- maximum tower top loads (stating whether a safety factor has been included, and its magnitude);
- a sample support structure design.

For turbines with a swept area of more than 2 m^2, it is recommended that the above information be supplied. For these turbines the information required by 10.5 shall be provided including drawings of a sample foundation stating assumed soil conditions, operating loads, and access loads.

11.2.4 Operation

The operation document shall include specific procedures for starting the SWT and stopping it in normal external conditions. The manual shall include all appropriate controller settings such as emergency shutdown control set points. The operation document shall also cover a description of the overall system for normal operation and intended applications.

The manufacturer shall provide a written manual shutdown procedure including a specification of a wind speed limit and other conditions in which the procedure may safely be carried out. Contact information shall be provided for unscheduled maintenance/customer support.

11.2.5 Maintenance and routine inspection

11.2.5.1 General

The manufacturer shall provide documentation for inspection and maintenance of the SWT. This documentation shall provide a clear description of inspection, shutdown procedure, and routine maintenance requirements for the SWT equipment. This documentation shall clearly state and explain V_{maint} per 8.4.

If the manufacturer requires that the SWT be maintained and serviced by trained personnel, a statement to this effect shall appear on the cover of the maintenance and service manual:

“MAINTENANCE AND REPAIRS TO BE PERFORMED BY TRAINED PERSONNEL ONLY”.

11.2.5.2 Safety procedures

The maintenance document shall include specific shutdown procedures, including but not necessarily limited to instructions of how to:

- disengage the load and/or energy sources (see 9.3);
- stop and secure the rotor;
- stop and secure the yaw mechanism;
- stop and secure the furling system if appropriate.

If the SWT is connected to the utility grid, then a procedure to disconnect the turbine from the utility grid shall be provided.

The manufacturer shall provide safety recommendations for climbing towers, including proper climbing equipment and procedures, as applicable.

11.2.5.3 Routine inspections

Manufacturers shall provide an interval for routine inspection of the SWT including tower, drivetrain, controller, and rotor. The manufacturer shall document the components to inspect, that includes but is not limited to:

- rotor blades;
- worn or twisted droop cables;
- guy wire tension;
- lubrication leaks; and
- fasteners.

The manufacturer shall provide a list of equipment and measurements necessary to ensure proper operation and its verification. The manufacturer shall state all values of normal operating ranges, which are critical to the safety of the SWT. (This could include battery voltages, water pump flow rate, inverter voltage, current and frequency, etc.).

Manufacturers shall recommend that a logbook be maintained for each SWT. Data that should be included in the logbook are the date, time, and personnel conducting the inspection, any important events, and any corrective action taken or additional information recorded.

11.2.5.4 Maintenance

The manufacturer shall provide an interval for routine maintenance of the SWT. Routine maintenance is defined as any service or repairs that the manufacturer deems necessary after a period of time to maintain the safe operation of the SWT. Routine maintenance may include but is not limited to:

- lubrication;
- periodic testing of emergency shutdown/overspeed system;
- adjustment/replacement of braking system;
- replacement of bearings, brushes/sliprings; and
- maintenance required on any safe life components that are required for them to meet their design lifetime.

If the manufacturer requires that the SWT be shutdown before routine maintenance, a statement to this affect shall be provided in the documentation.

“CAUTION – PRIOR TO PERFORMING ROUTINE MAINTENANCE, FOLLOW PROCEDURE FOR THE PROPER SHUTDOWN OF THE WIND TURBINE”

Manufacturers shall recommend that all maintenance and repair be recorded in the logbook referenced in 11.2.5.3 and 11.2.5.4.

11.2.5.5 Troubleshooting

The manufacturer shall provide a troubleshooting list of items that can be checked before calling service personnel. Items in the list shall be such that they could be checked by a trained operator but not requiring specialised test equipment or trained service personnel.

11.2.5.6 Personnel safety

In the installation, operating and maintenance manuals, the manufacturer shall supply all necessary information on personnel safety. Such information may include topics such as: climbing procedures, ladders, anchor points, and the use of personnel safety equipment. The manufacturer shall also specify any wind speed limit for climbing and/or lowering the tower.

11.3 Consumer label

It is recommended that a consumer label be provided in accordance with Annex M. If this is done the measurement reports used to complete the consumer label shall meet the requirements of ISO/IEC 17025 and relevant standards used to define the test requirements (e.g. IEC 61400-12-1).

12 Wind turbine markings

The following information shall be as a minimum, prominently and legibly displayed on the indelibly marked turbine nameplate:

- wind turbine manufacturer and country of manufacture;
- model, revision, and serial number;
- SWT class;
- power form;
- maximum output power (per definitions, giving the P_{60} as a minimum);
- maximum output voltage (per definitions, giving the $U_{0,2}$ as a minimum);

Additional information may include:

- production date;
- tower top mass;
- design extreme (survival) wind speed (i.e. V_{e50});
- maximum output current(s) (per definitions, giving the i_{60} as a minimum);

- swept area.

II Type testing

13 Testing

13.1 General

Clause 13 describes the available tests for small wind turbines. In 5.2 an overview is given on which tests are mandatory. The test specimens shall be representative of the design of the wind turbine type/component. Properly calibrated instruments and appropriate sample rates shall be used.

For all measurements where wind speed is required, the location of the anemometer and the measurement sector shall be in accordance with the latest edition of the power performance measurement standard, IEC 61400-12-1.

The tests shall be documented in a report containing a full description of the test methods used, the test conditions, the specifications of the tested machine and the test results. The description of the test method shall include a detailed description of the measuring procedures, instrumentation, data acquisition, and data analysis. Deviations from the methods as described in this clause shall be documented.

The measurement reports shall meet the requirements of ISO/IEC 17025 and relevant standards used to define the test requirements (e.g. IEC 61400-12-1, and IEC/TS 61400-13, and IEC 61400-11).

13.2 Tests to verify design data

13.2.1 General

To determine the data required for the simplified load analysis or verify the simulation (aero-elastic model) a test shall be performed to verify or determine the following design data:

- design power, P_{design};
- design rotational speed, n_{design};
- design shaft torque, Q_{design}; and
- maximum rotational speed, n_{max}.

13.2.2 P_{design}, n_{design}, V_{design} and Q_{design}

The design wind speed is defined as 1,4 V_{ave}. The design power P_{design} and design rotational speed n_{design} are then the power level and rotational speed at that wind speed. To determine these parameters wind speed, power production and rotational speed shall be measured at the nominal electrical load.

The measured data shall be binned into 0,5 m/s wind speed bins. Each wind speed bin from 1 m/s below V_{in} up to 2 V_{ave} shall contain at least 10 data points. A data point is based on a 1-min average of samples recorded at a sample rate of at least 0,5 Hz.

The design torque shall either be derived from P_{design} and n_{design} or may be measured directly. Drive train efficiency, η, shall be assumed to be given by Equation (49) in the absence of any proven, more precise values.

$$\eta = 0{,}6 + 0{,}005 P_{design} \quad \text{for} \quad P_{design} \leq 20\ \text{kW} \qquad (49)$$

$$\eta = 0{,}7 \text{ for } P_{\text{design}} > 20 \text{ kW}$$

$$Q_{\text{design}} = \frac{30 P_{\text{design}}}{\eta \pi n_{\text{design}}} \qquad (50)$$

13.2.3 Maximum yaw rate

The maximum yaw rate is defined as the maximum speed of yaw movement of the rotor around the yaw axis.

1) In case of passive yaw turbines with free movement of the rotor around the yaw and/or furl axis this yaw speed can consist of a nacelle frame yaw speed and a component of the furl speed around an axis parallel to the yaw axis. In the case of passive yawing turbines measured values cannot be used in the simple load calculations. Instead the values given by Equation (27) in 7.4.3 shall be used.
2) In the case of active yaw turbines with controlled movement of the rotor around the yaw axis under all conditions measured values should be used in the simple load calculations.
3) In the case of semi-active yaw or damped yaw turbines with partially restrained movement of the rotor around the yaw axis (e.g. through the use of devices to limit rotational velocity or acceleration, such as dampers) then measured values may be used provided that it can be shown that there is an upper limit to the measured values in all operating wind conditions. If this cannot be shown then the values given by Equation (27) in 7.4.3 shall be used.

In case the manufacturer wants to measure yaw rate for model validation per points 2 and 3 above the following considerations should be taken into account:

- yaw rates are highly influenced by the external conditions;
- interpolation or extrapolation could be necessary to derive the maximum yaw rate; and
- deriving yaw rates from yaw positions can lead to ambiguous results.

13.2.4 Maximum rotational speed

The rotor speed shall be measured during the turbine condition most likely to give the highest rotor speed (e.g. loss of load or wind gust) at wind speeds between 10 m/s and 20 m/s. At least 2 h of data are required of which at least 30 minutes shall be below 15 m/s and 30 minutes shall be above 15 m/s. From these data the maximum rotor speed shall be determined by interpolation or extrapolation to V_{ref}, taking into account any visible slope changes.

13.3 Mechanical loads testing

The purpose of load measurements can be twofold: to verify design calculations or determine the design loads.

The load measurement program shall be based on and consist of measurement load cases that are as close as practically possible to the design load cases defined in 7.5. The measurement load cases shall include all normal and critical operating and fault conditions, braking performance and yaw behaviour. Testing shall be sufficient to characterise typical operational behaviour throughout the design wind speed range. A statistically significant amount of data for relevant wind speeds, allowing extrapolation, shall be collected.

Measured data shall at least include loads, meteorological parameters and wind turbine operational data. Loads at critical load path locations in the structure shall be measured. These loads may include blade root bending moments, shaft loads and loads acting on the support structure. Meteorological parameters shall include hub height wind speed and wind direction. Relevant wind turbine operational data including rotor speed, electrical power, yaw position and turbine status shall be measured.

In case load measurements are performed to verify the design loads the data shall be analysed in such way that valid comparison with calculated loads is possible. As a minimum the mean, minimum and maximum values, standard deviation of the appropriate load data shall be evaluated and included over the recorded wind speed and turbulence ranges and the relevant data included in the test report.

Guidance for test procedures and evaluation of tests may be found in IEC/TS 61400-13.

13.4 Duration testing

13.4.1 General

The purpose of the duration test is to investigate:

- structural integrity and material degradation (corrosion, cracks, deformations);
- quality of environmental protection of the wind turbine; and
- the dynamic behaviour of the turbine.

During the duration test, test procedures shall be implemented to determine if and when the test turbine successfully meets the following test criteria. The wind turbine will have passed the duration test when it has achieved:

1) reliable operation during the test period;
2) at least 6 months of operation;
3) at least 2 500 h of power production in winds of any velocity;
4) at least 250 h of power production in winds of 1,2 V_{ave} and above;
5) at least 25 h of power production in winds of 1,8 V_{ave} and above; and
6) at least 10 min in winds of 2,2 V_{ave} and above but not less than 15,0 m/s during which the turbine shall be in normal operation.

Regarding items 5) and 6) above:

- if the turbine is designed to be shut down at 1,8 V_{ave} then this can be relaxed from power production to normal operation;
- if the turbine is designed to shut down at this wind speed it shall shut down, if the turbine is designed to produce power it shall produce power.

If the turbine is an S class turbine, it shall comply with the full criteria expressed above including the minimum 15 m/s requirement.

The average turbulence intensity at 15 m/s shall be reported. This turbulence intensity is the average turbulence intensity of all data points with 10-min average wind speeds between 14,5 m/s and 15,5 m/s.

The highest instantaneous (3-s gust) wind speed during the test shall be stated in the test report.

The turbine behaviour during the duration test shall resemble normal turbine use as much as possible, e.g. battery voltage levels should change to reflect normal charging and discharging of the battery bank for battery charging systems.

Small repairs are allowed but shall be reported as described in 13.4.4.

Wind speed is defined as the 10-min average of wind speed samples as measured at hub height (10-min periods derived from contiguous measured data as defined in IEC 61400-12-1) with a sampling rate of at least 0,5 Hz.

NOTE To convert 1-min data to 10-min data:

If there is a need to convert 1-min data to 10-min data. The 10-min average is simply the average of the 1-min averages. The 10-min minimum and maximum are simply the minimum and maximum of the 1-min measurements respectively.

The 10-min standard deviation can be calculated from the 1-min standard deviation with the equation below:

$$\sigma_{10\text{min}} = \sqrt{\frac{1}{10}\sum_{i=1}^{10}\left(\sigma_{1\text{min}i}{}^2 + \mu_{1\text{min}i}{}^2\right) - \left(\frac{1}{10}\sum_{i=1}^{10}\left(\mu_{1\text{min}i}\right)\right)^2}$$

Simplified:

$$\sigma_{10\text{min}} = \sqrt{\frac{1}{10}\sum_{i=1}^{10}\left(\sigma_{1\text{min}i}{}^2 + \mu_{1\text{min}i}{}^2\right) - \left(\mu_{10\text{min}}\right)^2}$$

where

σ is the standard deviation; and

μ is the mean value for the given set of data.

Power production means that the turbine is producing positive power as measured by the power transducer at the connection to the electrical load. If the 10-min average power is positive (after accounting for any offset value on the power signal) the whole 10-min period shall be counted towards the 2 500 h.

10-min periods shall be counted toward the 250 h and 25 h of power production if the 10-min average wind speed is equal to or above 1,2 V_{ave} or 1,8 V_{ave} respectively.

For duration testing winds from all directions can be used towards the hours of power production. The terrain does not have to meet the requirements used for power performance testing (Annex B or IEC 61400-12-1). The anemometer should be located and mounted such that the wind speed it measures is representative of the wind speed at the wind turbine hub height. Caution should be taken to not locate the anemometer in such location that it reads a significantly ($>$ 5 %) higher wind speed than the turbine sees.

13.4.2 Reliable operation

13.4.2.1 General

Reliable operation means:

- operational time fraction of at least 90 %;
- no major failure of the turbine or components in the turbine system;
- no significant wear, corrosion, or damage to turbine components; and
- no significant degradation of produced power at comparable wind speeds.

13.4.2.2 Major failure

If the turbine is altered in any way during the test other than to perform scheduled maintenance or for inspections, the test organisation will determine if such an alteration has resulted from a major failure. The test organisation’s judgement shall be noted in the test report. A major failure of the wind turbine system includes any significant failure of the system components which affect the turbine safety and function such as blades, main shaft, alternator, yaw bearings, support structure, controller or inverter.

13.4.2.3 Significant wear

Significant wear is any wear which, extrapolated to the lifetime of the turbine, would result in unacceptable loss of strength or clearance. Wear, corrosion and damage to components shall be assessed by conducting a detailed inspection of the turbine system shortly after installation and commissioning, documenting any wear, corrosion and damage that was present before the test started and a second detailed inspection at the conclusion of the test. Such a detailed inspection shall be no more intrusive than the size of the turbine, the consequences of failure, and the status of the component warrant.

13.4.2.4 Operational time fraction

For purposes of this test, operational time fraction is defined as the ratio of time a wind turbine shows its normal designed behaviour to the test time in any evaluation period expressed as a percentage. Normal designed behaviour includes the following (where applicable):

- turbine producing power;
- automatic start-up and shut-down due to wind speed transitioning across low wind cut-in and high wind cut-out;
- idling or parked states at wind speeds under V_{in} or above V_{out}; and
- extended time between a normal shutdown (not caused by a failure) and a restart of the turbine (e.g. brake cool cycle, retraction of tip brakes).

The operational time fraction, O, is given by the following equation:

$$O = \frac{T_T - T_N - T_U - T_E}{T_T - T_U - T_E} \times 100\ \% \qquad (51)$$

where

T_T is the total time period under consideration;
T_N is the time during which the turbine is known to be non-operational;
T_U is the time during which the turbine status is unknown; and
T_E is the time that is excluded in the analysis.

Note that neither the time during which the turbine status is unknown nor the time that is excluded from the analysis count against or in favour of the operational time fraction.

The following conditions shall be considered as turbine faults and shall be part of T_N:

- any turbine fault condition indicated by the turbine controller that prevent the turbine from operating;
- any automatic shutdown of the turbine by its controller due to an indicated fault;
- manual selection of pause, stop, or test mode that prevents the turbine from operating normally for the purpose of routine maintenance or a perceived fault condition;
- turbine inspections conducted in accordance with manufacturer's recommendations; and
- downtime due to unwrapping of the droop cable.

The following conditions shall be considered as time during which the turbine status is unknown (T_U in the equation above):

- failure or maintenance of the test institute’s data acquisition system; and

- lost or unresolvable records of turbine condition.

The following conditions shall be excluded from the test time period and be part of T_E:

- turbine inspections conducted as part of this test that are not recommended by the manufacturer (e.g. inspection of data acquisition system);
- any non-operational time that is caused by something other than the turbine or manufacturer;
- manual selection of a pause, stop, or test mode that prevents the turbine from operating normally for any purpose other than routine maintenance or a perceived fault condition;
- failure of the grid, battery system, inverter or any component external to the turbine system being tested (see below). If these components are considered part of the system this time shall count as T_N; and
- reduced or no power production due to the turbine control system sensing external conditions outside the designed external conditions.

If a turbine fault is present during one of the above situations, caused during normal external conditions, this time shall count as T_N.

The duration test report shall clearly state which components were considered part of the turbine system and which components were considered as external to the turbine. This statement shall consider:

- mechanical interface between the turbine and the ground;
- electrical interface between the turbine and the load; and
- control interface between the turbine and local and/or remote control devices.

In cases where conditions may exist that are not clearly attributable to a turbine fault or an external condition, the test plan shall define to which category such conditions will be attributed. Examples of such conditions are:

- inadvertent actuation of tip brakes or furling; and
- confusion of the controller due to voltage transients.

The test report shall describe instrumentation and data logging arrangements that allowed for determination and recording of turbine operation status at all times during the duration test.

13.4.2.5 Power production degradation

To check any hidden degradation in the power performance of the turbine the following procedure is part of the duration test.

For each month in the duration test the power levels shall be binned by wind speed. For each wind speed a plot shall be made with the binned power levels as a function of time. If there is a trend visible, then investigation shall take place to determine the cause. For battery charging systems, points with comparable state of charge should be plotted. Only data points that are considered normal operation should be used in this analysis. Only data taken within the measurement sector should be used to eliminate potential effects of terrain or obstacles on wind speed readings on the analysis.

13.4.3 Dynamic behaviour

The dynamic behaviour of the turbine shall be assessed to verify that the system does not exhibit excessive vibration. The dynamic behaviour of the turbine shall be observed under all operating conditions (e.g. loaded, unloaded, furled); and for at least 1 h in total; and in winds from cut-in wind speed up to 1,8 V_{ave}. Special attention should be paid to tower vibrations and resonances, turbine noise, tail movement and yaw behaviour. Observations should be written down in the logbook and be reported in the test report. Assessment by instrumentation is also allowed.

13.4.4 Reporting of duration test

The duration test report shall contain the following information:

a) An identification and description of the specific wind turbine design configuration under test, including:
   - turbine manufacturer, model name, serial number, production year;
   - SWT class stated by the manufacturer for the design;
   - swept area;
   - rotor diameter (if applicable);
   - hub height and tower type;
   - description of load (e.g. grid connected, battery charging) including voltage;
   - control system software versions and set points;
   - a clear description of the boundaries of the turbine system (both mechanical electrical and control).
b) A description of the test site, including:
   - a map of the test site showing the surrounding area covering a radial distance of 20 wind turbine rotor diameters and indicating the topography, location of the wind turbine, meteorological tower, significant obstacles and other wind turbines. The map shall include an indication of scale;
   - photographs taken towards all four cardinal positions (North, East, South and West);
   - a photograph showing the turbine and meteorological tower taken towards the predominant wind direction;
   - description of site elevation and indication of typical air density;
   - a plot showing the air temperature during the test period.
c) A description of the test equipment:
   - make, model, serial number of all instruments used;
   - location of instruments on the meteorological tower;
   - a copy of the calibration certificate for each instrument;
   - description of method used to determine the turbine operation status;
   - description of sample rate.
d) Description of data reduction techniques
e) A description of the test results:
   - a description of the start and end date of the test;
   - a table listing the hours of power production above each wind speed and operation time fraction time components broken down by month (see Annex G);
   - the average turbulence intensity at 15 m/s;
   - the highest instantaneous wind speed during the test (maximum observed 3-s gust);
   - a table listing the hours in each time category used in the calculation of the operational time fraction for each month and the reasons for classification of any time other than T_T;
   - a plot of the power degradation analysis and if applicable reason(s) for found degradation;
   - transcripts of observations of dynamic behaviour;

- the SWT class for which the duration test has been completed (turbine test class).

f) Maintenance/ repairs/modification:

- records of any maintenance that was performed to the turbine;
- records of any repairs or changes that were made to the turbine.

g) Post-test inspection:

- any findings of the post-test inspection including photographs.

h) Deviations from the standard

- any deviations from the requirement in this clause shall be clearly documented in a separate clause. Each deviation shall be supported with the technical rationale and an estimate of its effect on the test results.

13.5 Mechanical component testing

13.5.1 General

A static blade test is required for all turbines. For all other load carrying components, in case no calculations of a component have been performed in accordance with 7.9, one shall subject that component to a component test. In general the worst combination of design loads including safety factors shall be applied to the component. No damage that may interfere with the safe operation of the turbine may occur (e.g. significant loss of stiffness, plastic deformation, buckling or cracking).

In case of purchased components it shall be sufficient to show that the design loads are within the specifications of the component.

13.5.2 Blade test

The applied load for the static blade test shall be the worst combination of the flap-wise bending moment and the centrifugal force. The blade shall be tested including the blade hub connection. No damage may occur at a test load up to the maximum operating load as predicted by simplified load model, simulation modelling or measurements, including load safety factors.

In the case of design loads determined by the simplified load model (7.4), the assumed distribution of load along the blade span can be obtained by consideration of the equations provided in Annex F.

A representative number of loading points should be used to distribute loads along the length of the blade during the test. The location of the loading points and the magnitude of the loads shall be selected to provide the required blade root bending moment and also provide a bending moment distribution along the blade span that is as close as practicable (equal to or greater than) to the bending moment distribution for the design load case being represented by the test.

The blade tip deflection shall not exceed the no-load clearance between the blade and tower or other support structure. Either sufficient deflection margin shall be provided to cover variations in material properties or geometry, or sufficient tests shall be conducted to ascertain the quality of the manufactured blades.

NOTE In some cases it can be appropriate to perform tests for more than one load case. For example, a test can be required to represent the bending moments for a parked rotor and second test required to represent the centrifugal loads during maximum rotational speed.

It is recommended that the blade be tested to failure to determine the strength margin between the design load and actual blade failure load.

In case a blade fatigue test is performed, the test shall meet the requirements of IEC/TS 61400-23.

13.5.3 Hub test

In case a hub test is performed, the hub shall be tested statically by simulating centrifugal force and flap-wise bending on all connection points of the blades. The hub shall be tested including the hub shaft connection. No damage may occur at the design test load (including factors of safety) based on the maximum calculated load.

13.5.4 Nacelle frame test

In case a nacelle frame test is performed the nacelle frame shall be statically tested by subjecting it to a shaft tilt bending moment, axial rotor force and its own weight. No damage may occur at the design test load (including factors of safety) based on the maximum calculated load.

13.5.5 Yaw mechanism test

In case a yaw mechanism test is performed, the yaw mechanism shall be tested by applying the loads as described under the nacelle frame test. It shall be shown that the yaw mechanism still works properly.

13.5.6 Gearbox test

A gearbox test is not required but testing and designing according to the IEC 61400-4 standard is recommended.

13.6 Safety and function

The purpose of safety and function testing is to verify that the turbine under test displays the behaviour predicted in the design and that provisions relating to personnel safety are properly implemented.

The safety and function tests shall include the critical functions of the control and protection system that require test verification, as described in the design documentation. These critical functions shall include:

1) power and speed control;
2) yaw system control (wind alignment);
3) loss of load;
4) over speed protection at design wind speed or above; and
5) start-up and shut down above design wind speed.

Other items that might be applicable are:

6) excessive vibration protection;
7) battery over- and under-voltage protection;
8) emergency shutdown under normal operation;
9) cable twist; and
10) anti-islanding (for grid connections).

Any additional protection system function that may be activated by component failure or other critical events or operational conditions shall also be tested. This testing may include simulation of the critical event or operational condition. For example, SWTs with droop cables designed to automatically disconnect under excessive cable twisting shall be demonstrated to function properly.

13.7 Environmental testing

In case the turbine is designed for external conditions outside the normal external conditions (as given in clause 6), the turbine shall be subjected to tests simulating those conditions. These tests are preferably performed on the whole turbine. In case this is not feasible, these tests shall be conducted on all portions of the system that are affected by this external condition.

13.8 Electrical

All safety critical electrical subsystems (e.g. generators, control panel, motors, transformers, GFCIs, heaters) of a SWT shall be evaluated and tested to their relevant IEC standards. For example, for generators, the testing should be in compliance with IEC 60034-1, IEC 60034-2 series, IEC 60034-5, and IEC 60034-8.

Annex A
(informative)

Variants of small wind turbine systems

A.1 General

Modifications to a turbine system might be for the purpose of creating variants of the original turbine system, or for the purpose of improving the original turbine system. In principle, modifications include any aspect of the turbine system. Modifications that may affect a Type Certificate are addressed in IEC 61400-22:2010 (see especially but not exclusively 6.5.1).

The concepts in Annex A are relevant to both design evaluation and type testing.

In cases where several variations of a turbine system are available, a full design evaluation shall be performed on a representative configuration. Other variations need only be evaluated or tested in the ways in which they are different from the representative configuration. The decision as to whether to perform a design evaluation of the variants, or type testing, or limited testing, or no testing, or some combination will depend on the details of the deviation(s) from the representative configuration. In making this decision it is essential to have a good understanding of the design and knowledge of the weaknesses of the design.

The examples below are intended as illustrative examples:

A.2 Example 1: power forms

A wind turbine system available in a variety of power forms (such as d.c. or a.c., or different output voltages, or 50 Hz or 60 Hz, but all of the same power) would not ordinarily require separate structural design evaluations unless the performance of a configuration were to stress the system more than, or in a different way than, that of the representative configuration.

However, a wind turbine system available in a variety of power forms would ordinarily need separate performance tests (power and acoustics). Limited performance testing might be sufficient if it can be demonstrated that the configurations have similar performance characteristics to the representative configuration.

For wind turbine systems available with different inverters, limited performance and limited duration testing may be appropriate if it can be demonstrated that the configurations have similar load, performance and functional characteristics to the representative configuration.

A.3 Example 2: blades

A wind turbine system available with blades designed for higher and lower wind conditions (which is an example of a variation in structural configuration) would ordinarily require separate design evaluation, duration testing and static blade testing. If the initial design evaluation and duration testing was carried out on the most highly stressed configuration, then additional duration testing might not be required. Furthermore, these configurations would ordinarily need separate performance tests (power and acoustics).

A.4 Example 3: support structures

For a wind turbine system available with a variety of tower or support structure configurations, a duration test is not required for each tower or support structure if it can be adequately demonstrated by calculation and/or limited testing that the dynamic and static behaviour of an alternate tower or support structure do not lead to exceedance of the design limits of the system.

Note that apparently minor modifications to a wind turbine system can have serious impacts. For example, increasing a wire size may overload a turbine. Similarly, changing a paint colour may lead to overheating. For this reason, it is again emphasized that it is essential to have a good understanding of the system design and the consequences of the modifications.

Annex B
(normative)

Design parameters for describing SWT class S

For SWT class S turbines, the following information shall be given in the design documentation:

- Machine parameters:
  - design power [W]
  - hub height operating wind speed range $V_{in} – V_{out}$ [m/s]
  - design lifetime [yr]
- Wind conditions:
  - characteristic turbulence intensity as a function of mean wind speed
  - annual average wind speed [m/s]
  - average inclined flow [°]
  - wind speed distribution (Weibull, Rayleigh, measured, other)
  - turbulence model and parameters
  - hub height extreme wind speeds V_{e1} and V_{e50} [m/s]
  - extreme gust model and parameters for 1- and 50-year recurrence periods
  - extreme direction change model and parameters for 1- and 50-year recurrence periods
  - extreme coherent gust model and parameters
  - extreme coherent gust with direction change model and parameters
- Electrical network conditions:
  - normal supply voltage and range [V]
  - normal supply frequency and range [Hz]
  - voltage imbalance [V]
  - maximum duration of electrical power network outages [days]
  - number of electrical network outages [1/yr]
  - auto-reclosing cycles (description)
  - behaviour during symmetric and asymmetric external faults (description)
- Other environmental conditions (where taken into account):
  - design conditions in case of offshore SWT (water depth, wave conditions, etc.)
  - normal and extreme temperature ranges [°C]
  - relative humidity of the air [%]
  - air density [kg/m^3]
  - solar radiation [W/m^2]
  - rain, hail, snow and icing
  - chemically active substances
  - mechanically active particles
  - description of lightning protection system
  - earthquake model and parameters
  - salinity [g/m^3]

Annex C
(informative)

Stochastic turbulence models

C.1 General

The following stochastic turbulence models may be used for design load calculations. They satisfy the requirements given in 6.3.2. The turbulent velocity fluctuations are assumed to be a random vector field whose components have zero-mean Gaussian statistics. The power spectral densities describing the components are given in terms of the Kaimal spectral and exponential coherency model or by the Von Karman isotropic model.

Kaimal spectral model

The component power spectral densities are given in non-dimensional form by the equation:

$$\frac{fS_k(f)}{\sigma_k^2} = \frac{4f\,L_k/V_{hub}}{(1+6f\,L_k/V_{hub})^{5/3}} \qquad \text{(C.1)}$$

where

- f is the frequency in Hertz;
- k is the index referring to the velocity component direction (i.e. 1 = longitudinal, 2 = lateral, and 3 = vertical);
- S_k is the single-sided velocity component spectrum;
- σ_k is the velocity component standard deviation (see Equation (C.2)); and
- L_k is the velocity component integral scale parameter.

and with

$$\sigma_k^2 = \int_0^\infty S_k(f)df \qquad \text{(C.2)}$$

The turbulence spectral parameters are given in the following Table C.1.

Table C.1 – Turbulence spectral parameters for Kaimal model

	Velocity component index (k)		
	1	2	3
Standard deviation σ_k	σ_1	0,8 σ_1	0,5 σ_1
Integral scale, L_k	8,1 Λ_1	2,7 Λ_1	0,66 Λ_1

Key

σ_1 and Λ_1 are the standard deviation and scale parameters of turbulence, respectively, specified in the standard.

C.2 Exponential coherency model

The following exponential coherency model may be used in conjunction with the Kaimal autospectrum model to account for the spatial correlation structure of the longitudinal velocity component:

$$Coh(r,f) = \exp\left[-8{,}8((f \times r / V_{\text{hub}})^2 + (0{,}12 r / L_{\text{c}})^2)^{0{,}5}\right] \tag{C.3}$$

where

$Coh(r,f)$	is the coherency function defined by the complex magnitude of the cross-spectral density of the longitudinal wind velocity components at two spatially separated points divided by the autospectrum function;
r	is the magnitude of the projection of the separation vector between the two points on to a plane normal to the average wind direction;
f	is the frequency in Hertz; and
L_{c}	= 3,5Λ_1 is the coherency scale parameter.

C.3 Von Karman isotropic turbulence model

The longitudinal velocity component spectrum is given in this case by the non-dimensional equation:

$$\frac{fS_1(f)}{\sigma_1^2} = \frac{4fL/V_{\text{hub}}}{(1+71\times fL/V_{\text{hub}})^2)^{5/6}} \tag{C.4}$$

where

f	is the frequency in Hertz;
L	= 3,5 Λ_1 is the isotropic integral scale parameter; and
σ_1	is the longitudinal standard deviation at hub height.

The lateral and vertical spectra are equal and given in non-dimensional form by:

$$\frac{fS_2(f)}{\sigma_2^2} = \frac{fS_3(f)}{\sigma_3^2} = 2fL/V_{\text{hub}} \times \frac{1+189\times(fL/V_{\text{hub}})^2}{(1+71\times fL/V_{\text{hub}})^2)^{11/6}} \tag{C.5}$$

where

L	is the same isotropic scale parameter as used in Equation (C.4); and
$\sigma_2 = \sigma_3 = \sigma_1$,	are the wind speed standard deviation components.

The coherency is given by:

$$Coh(r,f) = \frac{2^{1/6}}{\Gamma(5/6)}\left(x^{5/6} K_{5/6}(x) - 0{,}5x^{11/6} K_{1/6}(x)\right) \tag{C.6}$$

where

x	is $2\pi((f\times r/V_{\text{hub}})^2 + (0{,}12r/L)^2)^{0{,}5}$;
r	is the separation between the fixed points;

L is the isotropic turbulence integral scale;

$\Gamma(.)$ is the gamma function; and

$K(.)(.)$ is the fractional-order, modified Bessel function.

Equation (C.6) can be approximated by the exponential model given in Equation (C.3), with L_c replaced by the isotropic scale parameter L.

Annex D
(informative)

Deterministic turbulence description

If the wind turbine modes, and specifically the rotor modes of vibration, are sufficiently damped, the following deterministic model may be used for the turbulence in normal wind conditions. The damping sufficiency may be verified using a simple stochastic model for the rotationally sampled wind velocity. In this simple verification model, an independent, sequentially uncorrelated random increment with a standard deviation of 5 % of the mean is added to the mean wind speed for each blade at each time step in a dynamic simulation model of the wind turbine. Each blade is assumed to be fully immersed in its respective instantaneous velocity field. The time histories of the simulated blade response variables of tip deflection and root bending moment (flap- and edge-wise) are then analysed. This analysis consists of determining the ratio of the higher harmonic amplitudes to the fundamental amplitude at the rotational frequency. If these ratios are all less than 1,5, then the following deterministic model can be used:

Longitudinal velocity component:

$$\begin{aligned} v_1(y,z,t) &= V(z) + A_1 \sin(2\pi f_1 t) \\ &+ A_2\, y \sin(2\pi(f_2 t + 1/4 \sin(2\pi f_3 t))) \\ &+ A_2\, z \sin(2\pi(f_2 t + 1/4 \cos(2\pi f_3 t))) \end{aligned} \quad \text{(D.1)}$$

where

(y,z) are the lateral and vertical co-ordinates of points on the swept surface of the wind turbine rotor with origin at the rotor centre.

Lateral velocity component:

$$v_2(t) = A_3 \sin(2\pi(f_4 t + 1/4 \sin(2\pi f_5 t))) \quad \text{(D.2)}$$

The lateral velocity component may be assumed to be uniform over the rotor swept area.

For the previous wind velocity model, the amplitude and frequency parameters are given by the following relations:

Amplitude parameters:

$A_1 = 2{,}0\ \sigma_1$

$A_2 = A_1 / D$

$A_3 = 0{,}8\ A_1$

Frequency parameters:

$f_1 = 0{,}019\,4\ V_{hub} / \Lambda_1$

$f_2 = 4{,}0\ f_1$

$f_3 = f_1/10{,}0$

$f_4 = 0{,}6\ f_1$

$f_5 = f_4/10{,}0$

where

σ_1 is the hub-height wind speed standard deviation;

Λ_1 is the turbulence scale parameter;

V_{hub} is the 10-min average, hub-height wind speed; and

D is the turbine rotor diameter.

Note, that the lateral and longitudinal velocity components together define the instantaneous hub-height wind speed and direction using the relationships:

$$V_{hub}(t) = ((v_1(0,0,t))^2 + (v_2(t))^2)^{0,5}$$
$$\theta_{hub}(t) = \arctan\frac{v_2(t)}{v_1(0,0,t)} \tag{D.3}$$

Annex E
(informative)

Partial safety factors for materials

E.1 General

This annex provides guidelines for selection of partial safety factors for fatigue of materials when comprehensive material test results are not available.

E.2 Symbols

F	material factor accounting for geometrical effects in composites	[-]
N	cycles to fatigue failure at a given stress level	[-]
P	survival probability	[-]
R	ratio of minimum stress to maximum stress in a fatigue cycle	[-]
S	stress	[MPa]
V_f	fibre volume fraction	[-]
γ_m	partial safety factor for materials	[-]
δ	coefficient of variation	[-]

E.3 Characteristic value versus design values

Definitions of these two concepts are as follows:

- Characteristic value – Mechanical properties of materials or elements that have a specified level of statistical probability and confidence associated with them; used to design a part or structure. In this standard the safety factors for materials are based on a 95 % probability that the material will exceed the characteristic value with 95 % confidence limits.
- Design Value – A value used in the analysis of designs that accounts for criteria used to design a given part, the analysis methods used, and the characteristic value for the material used.

The partial safety factor for materials is defined as:

$$f_d = \frac{1}{\gamma_m} f_k \tag{E.1}$$

where

f_d is the design value for the material;

γ_m is the partial safety factor for materials; and

f_k is the characteristic value of the material property.

For establishing a characteristic value, Figure E.1 shows the appropriate distributions that should be used. Most designers are familiar with the normal distribution, or bell curve. Experience has shown, however, that a better fit for composites is the Weibull distribution.

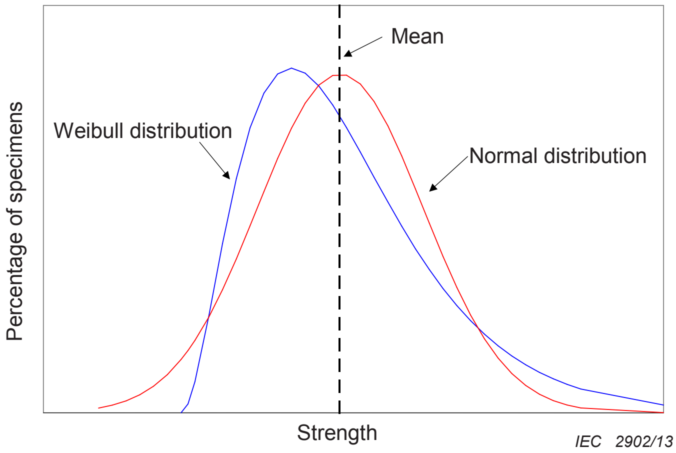


Figure E.1 – Normal and Weibull distribution

The normal distribution is symmetric, which means that for every weak sample there is a corresponding strong sample. The Weibull distribution, however, is skewed towards one side. In the above case it implies that for any set of tests, there will be more weak samples than strong samples. If it is skewed to the right, it means that there are more strong samples in the population than weak ones.

For metals and other homogeneous materials, the best fits are typically normal, or log-normal.

For composite materials, a Weibull distribution is often appropriate. This is especially true for fibre-dominated strength properties where the curve is skewed to the right, indicating more strong than weak samples.

The material factors given in this standard are based on the assumption that the material properties are based on a 95 % probability with 95 % confidence limits.

If the characteristic material properties are derived for other survival probabilities p (but with 95 % confidence limit) and/or coefficients of variation, δ, of 10 % or higher, the relevant materials factors shall be multiplied with the factors found in Table E.1. These factors are based on a normal distribution.

Table E.1 – Factors for different survival probabilities and variabilities

p %	δ =10 %	δ =15 %	δ =20 %	δ = 25%	δ = 30 %
99	0,93	0,95	0,97	1,02	1,06
98	0,96	0,99	1,03	1,09	1,15
95	1,00	1,05	1,11	1,2	1,3
90	1,04	1,11	1,20	1,32	1,45
80	1,08	1,18	1,31	1,47	1,65

E.4 Material factors and requirements

E.4.1 General

Five major factors influence the fatigue and ultimate strength of a material. Material testing should consider these effects. They are:

a) materials and material configurations representative of the full-scale structure;

b) manufacturing method of the test samples that is typical of the full-scale structure;

c) fatigue and spectrum loading testing;

d) environmental effects; and

e) geometry effects as they affect material properties (e.g. material orientation for injection moulded blades, ply drops in composites and wood, material orientation from forging of metals, etc.).

The best test data are derived from full scale testing that includes items a) to e) above. Sufficient test samples should be used to yield results with 95 % probability and 95 % confidence limits.

Note also that these effects do not include conventional stress concentration factors. These factors are considered during the stress analysis, not in the material characterization.

If the material database does not include all factors a) to e) above, then the partial safety factors shall be adjusted accordingly. Separate factors can be estimated for each of the five effects. These factors are multiplicative for all conditions that apply. The characteristic value of the material is divided by the resulting factor.

For example, if the characteristic value does not include environmental effects, or fatigue effects, the following additional safety factor shall be applied to the characteristic value.

Safety factor (environmental effects) × safety factor (fatigue) × nominal safety factor = corrected safety factor

If criteria a) through e) above are not met for the materials database, the following guidelines apply as material safety factors for SWT design.

E.4.2 Composites

Material safety factor composites - glass fibre, γ_m = 7,4

Material safety factor composites - carbon fibre, γ_m = 3,7

These are the material factors as called out in reference [E.1][2] and include conversion from ultimate tensile strength to fatigue strength.

These are the total factors that are applied to the static ultimate material strength to account for fatigue, environmental, reliability, size effects, etc. Additional factors for geometry effects as they apply to local material properties may be needed as discussed in Clause E.5 below. The geometry factors may be determined empirically, or through analysis. It is appropriate to include the stress concentration in the stress analysis. These factors are not included here.

It is noted that the above are not overly-conservative. These factors are consistent with reference [E.4]. Typical data are shown in Figures E.2 to E.4. In particular, note that the slope of the S-N curve in Figure E.4 is approximately half that of Figure E.2. This is one of the sources of the lower material factor of safety for carbon fibre composites compared to glass fibre composites.

2 References in square brackets refer to references listed in Clause E.6.

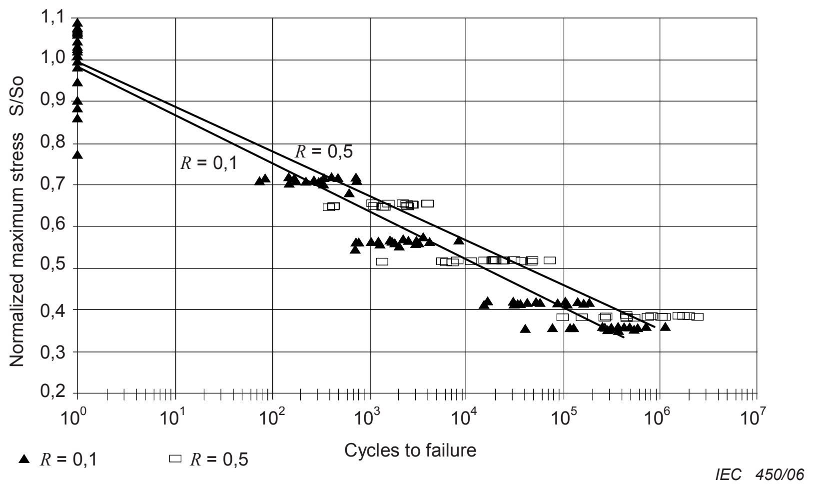


Figure E.2 – Typical S-N diagram for fatigue of glass fibre composites (Figure 41 from reference [E.2])

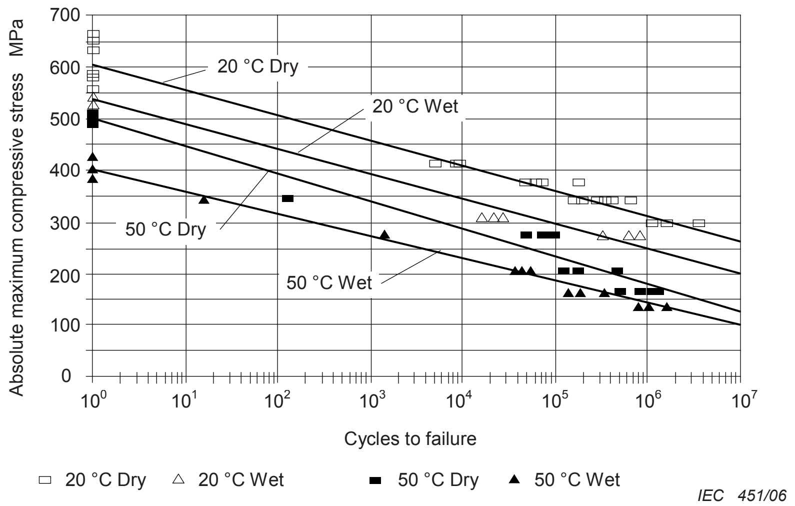


Figure E.3 – Typical environmental effects on glass fibre composites (Figure 25 from reference [E.2])

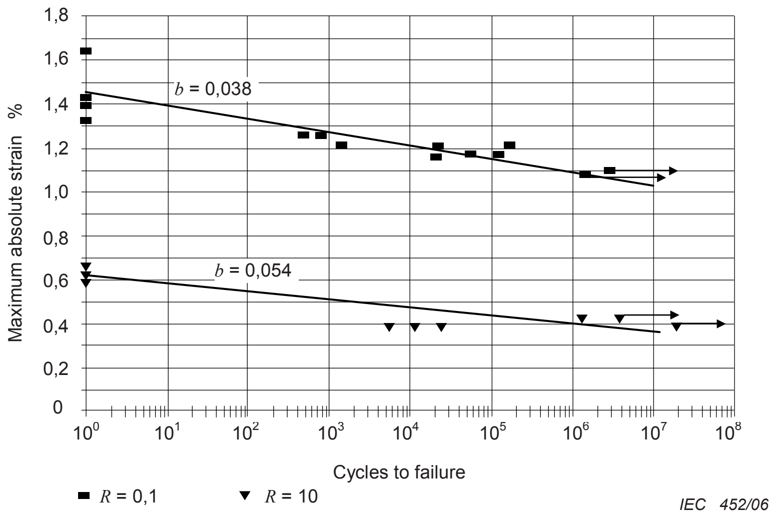


Figure E.4 – Fatigue strain diagram for large tow unidirectional 0° carbon fibre/vinyl ester composites, *R* = 0,1 and 10 (Figure 107 from reference [E.2])

E.4.3 Metals

Fatigue strength

Fatigue material factor – steel = 1,9 (reference [E.3])

Fatigue material factor – aluminium = 3,5 (reference [E.3])

Again, these factors convert from ultimate tensile strength to fatigue strength. Typical curves are shown in Figure E.5 below. Similar curves can be utilized for other alloys or metals such as titanium.

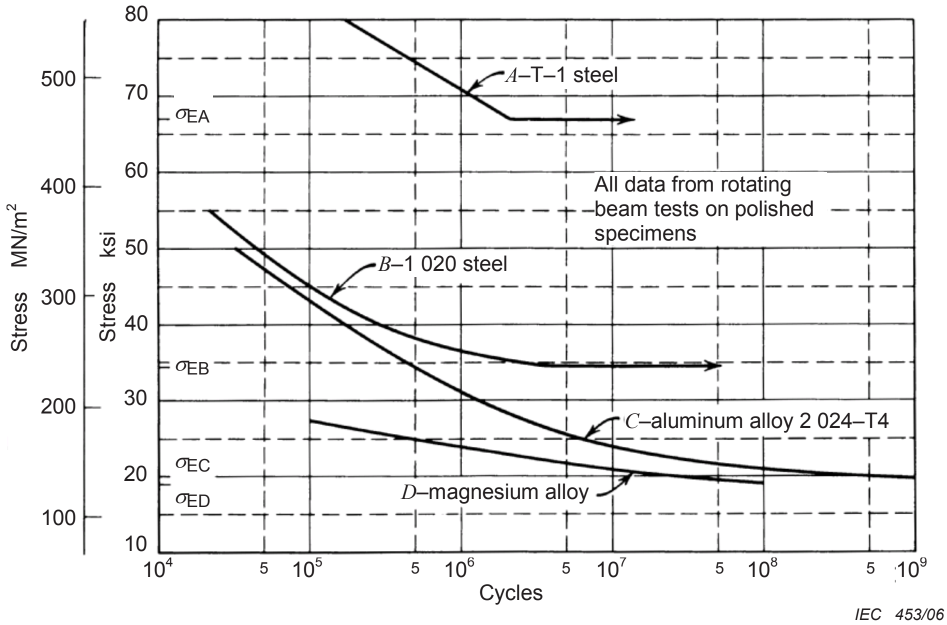


Figure E.5 – S-N curves for fatigue of typical metals

Environmental Effects – If no stress corrosion cracking tests have been conducted, the following environmental material factors apply (reference [E.4]).

Environmental material factor of safety – steel = 1,3

Environmental material factor of safety – aluminium = 1,3

Environmental material factor of safety – titanium = 4,2

E.4.4 Wood

Fatigue material factor of safety – softwood = 3,4 (reference [E.5])

Environmental materials factor of safety – softwood = 1,6 (reference [E.6])

If the design does not include analysis or testing of detail regions such as steps, joints, geometry changes, etc., an additional factor of 2,8 shall be applied to account for geometry effects (reference [E.7]).

Additional supporting data are supplied below in Figures E.6 to E.10.

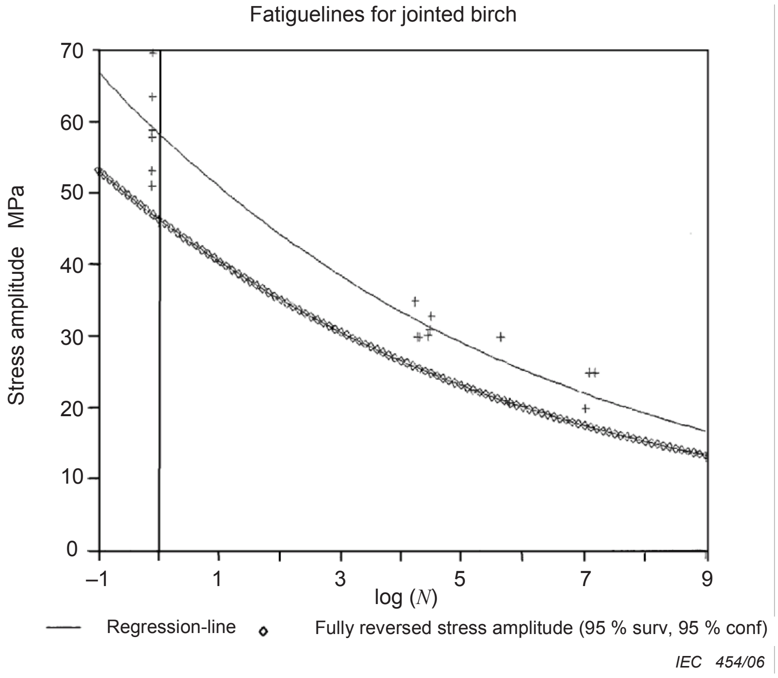


Figure E.6 – Fatigue life data for jointed softwood (from reference [E.5])

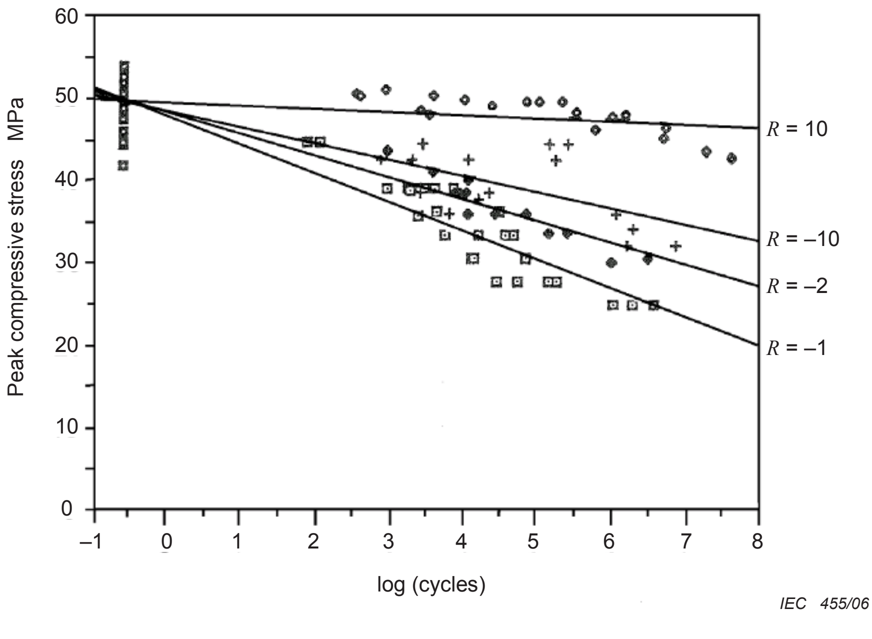


Figure E.7 – Typical S-N curve for wood (from reference [E.5])

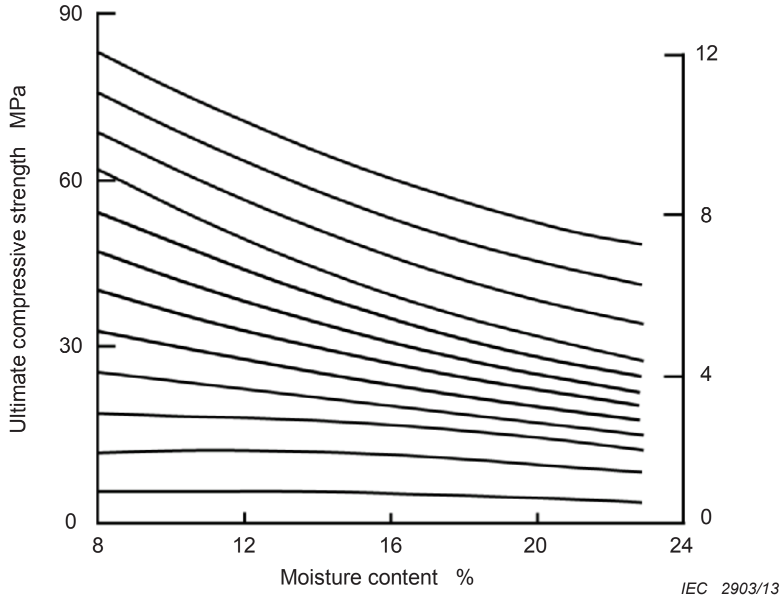
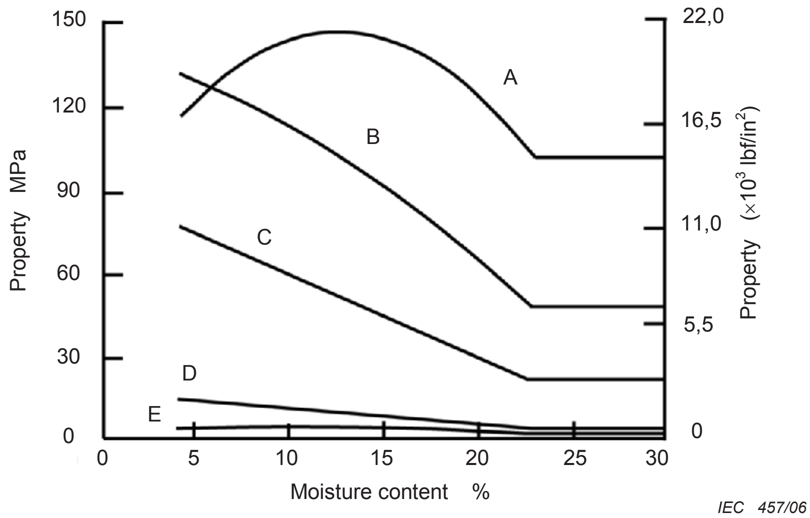
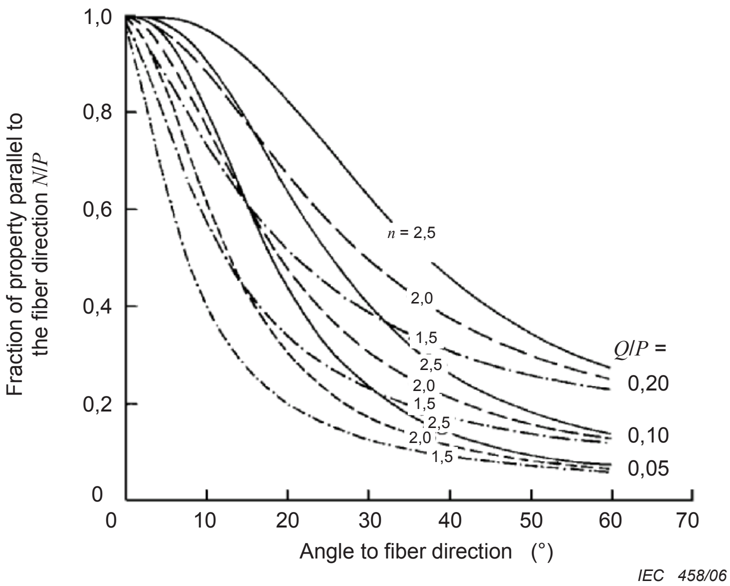


Figure E.8 – Effect of moisture content on compressive strength of lumber parallel to grain (Figure 4-13 from reference [E.6])



A, tension parallel to grain; B, bending; C, compression parallel to grain; D, compression perpendicular to grain; and E, tension perpendicular to grain

Figure E.9 – Effect of moisture content on wood strength properties (Figure 4-11 from reference [E.6])



Q/*P* is ratio of mechanical property across the grain (*P*); n is an empirically determined constant

Figure E.10 – Effect of grain angle on mechanical property of clear wood according to Hankinson-type formula (Figure 4-4 from reference [E.6])

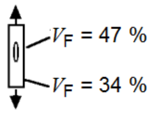
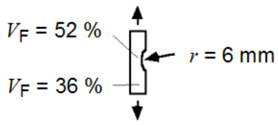
E.5 Geometry effects

Structural design evaluation assumes that the manufacturer has properly accounted for geometry effects as related to fracture and fatigue. For typical stress concentrations of homogeneous materials, any applicable book on machine design can be utilized, e.g. reference [E.7].

For composites, Table E.2 (from reference [E.2]) may be utilized to determine the influence of geometry on durability of a composite structure.

In Table E.2, F is the additional material factor of safety, which shall be applied to accommodate the effects of geometry if they have not been addressed in items a) to e) of Clause E.4 above.

Table E.2 – Geometric discontinuities

Detail	Sketch		F
Simple coupon (straight material)			1,0
Bonded stiffener (beam-web)			1,2
Cracked transverse 90° patch			1,0
Single interior 0° ply drop		$V_F < 0,4$	1,2
		$V_F > 0,4$	- - -
Double interior 0° ply drop		$V_F < 0,4$	1,6
		$V_F > 0,4$	1,0
Locally higher fiber content			1,4
Surface indentation (V_f increased, thickness reduced by 25 %)			2,5

E.6 Reference documents

[E.1] ECN-C-96-033, *Verification of design loads for small wind turbines,* F.J.L. Van Hulle et al. Table 2.6 Safety Factors in IEC 1400-2 and Danish Code

[E.2] MANDELL, J.F., SAMBORSKY, D.D., and CAIRNS, D.S., *Fatigue of composite materials and substructures for wind turbine blades*, SAND REPORT, SAND2002-0771, Unlimited Release, Sandia National Laboratories, March 2002.

[E.3] HIGDON, OHLSEN, STILES, WEESE, and RILEY, *Mechanics of Materials*, 3rd Edition, John Wiley and Sons, Inc., New York, New York, 1976, pp. 572, 674-675.

[E.4] HERTZBERG, R. W., *Deformation and Fracture Mechanics of Engineering Materials*, Fourth Edition, John Wiley and Sons, Inc, New York, New York, 1996, pp. 508-509.

[E.5] BOERSTRA, G.K., ZWART, G.G.M., *Proposal, Design Envelope Wood Epoxy Laminate as a Completion of NEN 6096*, Paragraph 4.3.5.4, WindMaster Nederland, 1992, p. 11.

[E.6] Forest Products Laboratory, 1999, *Wood handbook--Wood as an engineering material*. Gen. Tech. Rep. FPL-GTR-113, Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, "Chapter 4 Material properties of Wood"

[E.7] NORTON, R. L., *Machine Design – An Integrated Approach*, Prentice-Hall, Upper Saddle River, New Jersey, 1996, Appendix E – Stress concentration factors, pp. 1005 – 1012.

Annex F
(informative)

Development of the simplified loads methodology

F.1 Symbols used in this annex

A	rotor swept area	[m^2]
A_{proj}	component area projected on to a plane perpendicular to the wind direction	[m^2]
B	number of blades	[-]
c	blade chord	[m]
C_d	drag coefficient	[-]
C_f	force coefficient	[-]
C_l	lift coefficient	[-]
C_p	power coefficient	[-]
C_T	thrust coefficient	[-]
D	rotor diameter	[m]
e_r	distance from the centre of gravity of the rotor to the rotation axis	[m]
F	force	[N]
F_{zB}	force in z direction on the blade at the blade root	[N]
$F_{x\text{-shaft}}$	axial shaft load	[N]
g	acceleration due to gravity: 9,81	[m/s^2]
G	multiplier for generator short circuit	[-]
I_B	blade moment of inertia	[kgm^2]
L_{rt}	distance between the rotor centre and the yaw axis	[m]
L_{rb}	distance between rotor centre and first bearing	[m]
m_B	blade mass	[kg]
m_r	rotor mass being the mass of the blades plus the mass of the hub	[kg]
M_{xB}, M_{yB}	blade root bending moments	[Nm]
M_{brake}	torque on the low speed shaft caused by the brake	[Nm]
$M_{x\text{-shaft}}$	torsion moment on the rotor shaft at the first bearing	[Nm]
M_{shaft}	shaft bending moment at the first bearing	[Nm]
n	rotor speed	[r/min]
P	electrical power	[W]
P_r	rotor power	[W]
Q	rotor torque	[Nm]
r	radial coordinate	[m]
R	radius of the rotor	[m]
R_{cog}	distance between the centre of gravity of a blade and the rotor centre	[m]
V	wind speed	[m/s]
V_{ave}	annual average wind speed at hub height	[m/s]

V_{design}	design wind speed defined as 1,4 V_{ave}	[m/s]
V_{eN}	expected extreme wind speed (averaged over 3 s), with a recurrence time interval of N years. V_{e1} and V_{e50} for 1 year and 50 years, respectively	[m/s]
V_{hub}	wind speed at hub height averaged over 10 min	[m/s]
V_{tip}	speed of the blade tip	[m/s]
W	relative wind speed	[m/s]
Δ	range	[-]
γ	yaw angle	[-]
η	efficiency of the components between the electric output and the rotor (typically generator, gearbox and conversion system)	[-]
λ	tip speed ratio	[-]
λ_{e50}	tip speed ratio at V_{e50}	[-]
ρ	air density, here assumed 1,225	[kg/m^3]
ψ	Azimuth angle of the rotor (0° is blade vertically up)	[°]
ω_n	rotational speed of the rotor	[rad/s]
ω_{yaw}	yaw rate	[rad/s]

Subscripts:

ave	average
B	blade
design	input parameter for the simplified design equations
H	helicopter
hub	hub height
max	maximum
proj	projected
r	rotor
shaft	shaft

F.2 General

This annex provides background for the simple design equations in this standard. Giving the background and derivation of the equations serves several purposes:

- creating a better understanding of the simple design equations;
- making clear what kind of physics is included in the equations and thus what is not (e.g. flutter, shroud);
- by giving the background of the equation it is hoped that manufacturers with special concepts will be able to go back to the basics of the equations and derive equations which are more applicable to their design.

F.3 Caution regarding use of simplified equations

The simplified design equations were developed in previous editions and validated against the then available measurements. Subsequently there have been concerns expressed regarding a number of load cases:

- The treatment of fatigue in load case A (in this annex) may not be sufficiently conservative. Ordinarily such a lack of conservatism would be masked by the static load cases especially when used with the full safety factors. Therefore care should be taken if reducing safety factors in the static load cases as this could cause fatigue to become an issue. See further explanation in load case A in Clause F.4 below.
- The treatment of maximum thrust in load case D (in this annex) may not be sufficiently conservative if the rotational speed of the turbine at 2,5 V_{ave} is high. If this is the case then an increased value of C_T should be used as noted in load case D Clause F.4 below.

F.4 General relationships

In general the following relations are valid:

$$\omega_n = \frac{2\pi n}{60} = \frac{\pi n}{30} \tag{F.1}$$

where

n is the rotor rotational speed [r/min];

ω_n is the rotor rotational speed [rad/s].

$$\lambda = \frac{V_{tip}}{V_{hub}} = \frac{\omega_n R}{V_{hub}} = \frac{R}{V_{hub}} \frac{\pi n}{30} \tag{F.2}$$

where

λ is the tip speed ratio [-];

V_{tip} is the speed of the blade tip [m/s];

V_{hub} is the wind speed at hub height [m/s];

R is the radius of the rotor [m].

$$Q = \frac{P_r}{\omega_n} = \frac{P}{\eta \omega_n} = \frac{30P}{\eta \pi n} \tag{F.3}$$

where

Q is the rotor torque [Nm];

P_r is the rotor power [W];

P is the electrical power [W].

Further, certain design inputs are defined for use in IEC 61400-2:

V_{design}	is the design wind speed defined as 1,4 V_{ave}. V_{ave} is wind turbine class dependent.
P_{design} and n_{design}	are then respectively the power and rotor rotational speed at V_{design}.

Load case A: normal operation

Load case A is a fatigue load case with constant range. The basic idea behind the ranges is that the turbine speed cycles between 0,5 and 1,5 “rated”. Since “rated” is a term with many different meanings, the “design” term is introduced instead. This term was defined above.

> **CAUTION:** The treatment of fatigue in the simplified equations generally predicts very small fatigue loads. The number of fatigue cycles used in the simplified

equations is the number of times the blade passes the tower in the design lifetime (which is an artificially large number) which may compensate for these low loads. However, the predicted fatigue loads are so small that a designer might conclude that all fatigue cycles will be below the fatigue limit and therefore may neglect fatigue altogether. This would be unwise as a comparison with aeroelastic models reveals. The interplay of the number of cycles and the loads varies with the size of the turbine, and as an example for one turbine the under-prediction by the simplified equations is a factor of 2,4 for the tower top thrust, and 7,7 for the shaft bending moment. The reason for the under-prediction of the shaft bending appears to relate at least in part to the omission of gyroscopic loads due to yawing from the fatigue case in the simplified equations. Plainly the discrepancies for these examples are significant and indicate real potential for a turbine and tower to be under-designed. For this reason care should be taken if reducing safety factors in the static load cases as this could cause fatigue to become an issue.

The speed range, by varying n from 0,5 n_{design} to 1,5 n_{design} gives the following range in F_z (this assumes a variable rotor speed):

$$\Delta F_{zB} = m_B R_{cog}\left(\frac{\pi 1{,}5 n_{\text{design}}}{30}\right)^2 - m_B R_{cog}\left(\frac{\pi 1{,}5 n_{\text{design}}}{30}\right)^2 = 2 m_B R_{cog}\left(\frac{\pi n_{\text{design}}}{30}\right)^2 = 2 m_B R_{cog}\omega^2_{n,\text{design}} \quad \text{(F.4)}$$

where

m_B is the blade mass;

R_{cog} is the distance between the blade's centre of gravity and the rotor centre;

n_{design} is the design rotor speed defined as the rotor speed at V_{design}.

For the edgewise bending moment, the edgewise moment range consists of a term due to torque variations (from 1,5 Q_{design} to 0,5 Q_{design} equally divided among B blades) and a term due to the moment of the blade weight.

$$\Delta M_{xB} = \frac{Q_{\text{design}}}{B} + 2 m_B g R_{cog} \quad \text{(F.5)}$$

The derivation of the flap moment is slightly more complicated.

$$F_{\text{axial}} = C_T \times \tfrac{1}{2}\rho V_{\text{hub}}^2 A = C_T \times \tfrac{1}{2}\rho V_{\text{hub}}^2 \pi R^2 \quad \text{(F.6)}$$

$$P_r = C_p \times \tfrac{1}{2}\rho V_{\text{hub}}^3 A = C_p \times \tfrac{1}{2}\rho V_{\text{hub}}^3 \pi R^2 \quad \text{(F.7)}$$

where

ρ is the air density, here assumed 1,225 [kg/m^3];

A is the rotor swept area [m^2];

R is the rotor radius [m];

P_r is the rotor power [W].

Assuming that C_T is 3/2 C_p (reference [F.1], Chapter 3) and combining Equations (F.6) and (F.7) gives:

$$F_{\text{axial}} = \frac{3}{2}\frac{P_r}{V_{\text{hub}}} \quad \text{(F.8)}$$

Inserting V_{hub} from Equation (F.2) and P_{r} from Equation (F.3) leads to:

$$F_{\text{axial}} = \frac{3}{2}\frac{30\lambda}{R\pi n}P_{\text{r}} = \frac{3}{2}\frac{30\lambda}{R\pi n}\frac{Q\pi n}{30} = \frac{3}{2}\frac{\lambda Q}{R} \tag{F.9}$$

Assuming this load applies at 2/3 R, and dividing by the number of blades gives:

$$M_{\text{yB}} = \frac{\lambda Q}{B} \tag{F.10}$$

This assumes that the cone angle is sufficiently small to neglect centrifugal components.

The edge moment range is determined by assuming Q varies from 0,5 Q_{design} to 1,5 Q_{design}.

$$\Delta M_{\text{yB}} = \frac{\lambda_{\text{design}} Q_{\text{design}}}{B} \tag{F.11}$$

The axial load on the shaft is equal to the axial load of the rotor as given in Equation (F.9)

$$\Delta F_{\text{x-shaft}} = \frac{3}{2}\frac{\lambda_{\text{design}} Q_{\text{design}}}{R} \tag{F.12}$$

The shaft torsion range consists of a torque term plus an eccentricity term. The eccentricity term assumes the rotor centre of mass is offset from the shaft by 0,005 R (unless better data is available), causing a gravity torque range.

$$\Delta M_{\text{x-shaft}} = Q_{\text{design}} + 2 m_{\text{r}}\, g\, e_{\text{r}} \tag{F.13}$$

The shaft bending is assumed to be maximal at the first bearing. For shaft bending the rotor mass and the axial load eccentricity (caused by wind shear) have to be taken into account.

With the assumption that this eccentricity is R/6, which was decided by the original IEC 61400-2 working group, this results in the following range:

$$\Delta M_{\text{shaft}} = 2 m_{\text{r}}\, g L_{\text{rb}} + \frac{R}{6}\Delta F_{\text{x-shaft}} \tag{F.14}$$

where

L_{rb} is the distance between the rotor plane and the first bearing;

m_{r} is the mass of the rotor (blades, hub, etc.).

Load case B: yawing

In this load case the turbine is yawing with $\omega_{\text{yaw,max}}$ and the rotor is spinning with $\omega_{\text{n,design}}$.

The flapwise bending moment is assumed to consist of three terms: centrifugal force, gyroscopic, and eccentricity of axial load.

The centrifugal force on the blade due to the yaw rate, multiplied by the distance between blade root and centre of mass of the blade:

$$M_{\text{yB,centrifugal}} = m_{\text{B}}\omega_{\text{yaw,max}}^2 L_{\text{rt}} R_{\text{cog}} \tag{F.15}$$

where

L_{rt} is the distance between the blade root centre and the yaw axis [m].

Gyroscopic moment

The derivation of the gyroscopic force on a blade due to yaw rate and rotational speed is given below in Equation (F.16). On page 238 of reference [F.1][3] a slightly more elaborate derivation is given.

$$M_{yB,gyroscopic} = \int_0^R 2\omega_n \omega_{yaw} \cos\psi \, r^2 m(r) dr = 2\omega_{yaw} I_B \omega_n \cos\psi \qquad (F.16)$$

Which is maximum for ψ = 0.

The last term accounts for the offset of the axial force due to wind shear or skewed flow. The total formula for the flapwise bending moment for the case the rotor is spinning at n_{design} and the rotor is moving with $\omega_{yaw,max}$ with respect to the tower, is then:

$$M_{yB} = m_B \omega_{yaw.max}^2 L_{rt} R_{cog} + 2\omega_{yaw,max} I_B \omega_{n,design} + \frac{R}{9} \Delta F_{x-shaft} \qquad (F.17)$$

For the shaft the equation is derived as follows.

Gyroscopic loads

For a two bladed machine the inertia of the rotor around the yaw axis depends on the azimuth angle. Advanced textbooks on rigid body dynamics give the equation for the maximum moment:

$$M_{shaft} = 2B\omega_{yaw.max} \omega_{n,design} I_B \qquad (F.18)$$

For a three or more bladed machine the inertia of the rotor does not change with azimuth.

The following equation then applies:

$$M_{shaft} = B\omega_{yaw.max} \omega_{n,design} I_B \qquad (F.19)$$

Adding the mass loads and the axial load eccentricity leads to:

For two bladed rotors:

$$M_{shaft} = 4\omega_{yaw.max} \omega_{n,design} I_B + m_r g L_{rb} + \frac{R}{6} \Delta F_{x-shaft} \qquad (F.20)$$

For three or more bladed rotors:

$$M_{shaft} = B\omega_{yaw.max} \omega_{n,design} I_B + m_r g L_{rb} + \frac{R}{6} \Delta F_{x-shaft} \qquad (F.21)$$

[3] References in square brackets refer to references listed in Clause F.5.

where

L_{rb} is the distance between rotor centre and first bearing [m].

Load case C: yaw error

A fixed yaw turbine will operate at a yaw error much of the time. An extreme load might occur if the rotor has a yaw error and the instantaneous wind places the entire blade at the angle of attack for maximum lift. The following analysis is a simplified representation of this condition.

The relative wind speed at a blade radius, r, is approximately

$$W = r\omega_n + V_{hub}\sin\gamma\cos\psi \quad (F.22)$$

This ignores the normal component of relative wind, which is usually small compared with the tangential component.

The blade root flap moment is approximately

$$M_{yB} = \tfrac{1}{2}\rho c_{ave} C_{l,max} \int_0^R r(r\omega_n + V_{hub}\sin\gamma\cos\psi)^2 dr \quad (F.23)$$

This will be maximum for $\Psi = 0$, the advancing blade.

Integrating this expression yields

$$M_{yB} = \frac{1}{2}\rho\, c_{ave} C_{l,max}\left[\frac{1}{4}R^4\omega_n^2 + \frac{2}{3}R^3\omega_n V_{hub}\sin\gamma + \frac{1}{2}R^2 V_{hub}^2\sin^2\gamma\right] \quad (F.24)$$

For a yaw error of 30° this becomes, after some rearrangement

$$M_{yB} = \frac{1}{8}\rho\, A_{proj,B} C_{l,max} R^3 \omega_{n,design}^2 \left[1 + \frac{4}{3\lambda_{design}} + \frac{1}{2}\left(\frac{1}{\lambda_{design}}\right)^2\right] \quad (F.25)$$

Load case D: maximum thrust

The equation for this load case does not need much explanation. It is a simple force coefficient combined with a dynamic pressure

$$F_{x-shaft} = C_T \tfrac{1}{2}\rho(2{,}5 \times V_{ave})^2 \pi R^2 \quad (F.26)$$

where

C_T is the thrust coefficient, equal to 0,5.

The equation was tuned using thrust loads predicted by simulations (aero-elastic models). The combination of 2,5 V_{ave} and a C_T of 0,5 gave comparable results to those models. However, caution should be exercised with wind turbines that operate at high rotational speeds at 2,5 V_{ave}, where a C_T of 8/9 may be more appropriate.

Load case E: maximum rotational speed

This load case is assumed to be dominated by the maximum rpm.

For the blade load only the centrifugal force is considered.

$$F_{zB} = m_B R_{cog} \left(\frac{\pi n_{max}}{30} \right)^2 = m_B \omega_{n,max}^2 R_{cog} \tag{F.27}$$

For the shaft only the shaft bending moment is considered, it is assumed that the rotor has an imbalance with the rotor centre of mass a distance e_r from the shaft centre. No yawing is assumed.

$$M_{shaft} = M_{r-mass} + M_{r-imbalance} = m_r g L_{rb} + m_r e_r \omega_{n,max}^2 L_{rb} \tag{F.28}$$

Load case F: short at load connection

This load case assumes a high short circuit torque in the generator. The constants have been selected after talking to experts in this field, and consulting other standards such as Dutch Design Assessment (**NEN 6096/2**, 1994) and the Germanischer Lloyd "Blue Book".

The design torque is to be multiplied with the following value G, unless more accurate numbers are known for the generator.

Generator	Multiplier G
Synchronous or asychronous	2
Permanent magnet generator	2

Thus

$$M_{x-shaft} = G \times Q_{design} \tag{F.29}$$

$$M_{x,B} = \frac{G \times Q_{design}}{B} + m_B g R_{cog} \tag{F.30}$$

Load case G: shutdown

The maximum shaft torque is assumed to be equal to the brake torque (in case there is a brake present) plus the rated generator torque (thus assuming that the brake is applied while the generator still delivers rated torque).

$$M_{x-shaft} = M_{brake} + Q_{design} \tag{F.31}$$

where

M_{brake} is the brake torque on the low speed shaft.

The blade load during shutdown is assumed to be determined by the shaft torque and blade mass, thus being:

$$M_{x,B} = \frac{M_{x-shaft}}{B} + m_B g R_{cog} \tag{F.32}$$

In case the turbine has a gearbox and a high-speed shaft brake, the shaft torque calculated in Equation (F.31) should be increased to account for drive train dynamics. In the absence of any proven more accurate values the shaft torque shall be multiplied by a dynamic amplification factor of two.

Load case H: extreme wind loading

Load case H is actually two sets of equations of which one set is used depending on the turbine's design. One set is for turbines which will be parked in high winds, like most actively controlled turbines. The other set is for turbines which will have their rotors spinning, like most passively controlled turbines (such as furling). The wind speed V_{e50} is commonly referred to as "survival" wind speed but is more precisely referred to as the extreme wind speed (3-s gust with a recurrence period of 50 years) per definition 3.19.

> **CAUTION:** Care should be taken in using Equation (42) (i.e. Equation (F.42)). This is because Fx is proportional to (tip speed ratio)^2 and so if the rotor speed is controlled to a low value then the equation predicts a thrust force that can approach zero. This can be far lower than that suggested by the thrust in the parked rotor case (Equation (41), i.e. Equation (F.34)), which is obviously wrong. Therefore if the spinning rotor is controlled to a very low speed then the higher thrust given by Equation (41) (i.e. Equation (F.34)) shall be used instead of the lower thrust given by Equation (42) (i.e. F.42).

Parked rotors

For turbines which will be parked, the out of plane blade root bending moment is dominated by drag and thus defined as:

$$M_{yB} = C_d \tfrac{1}{2} \rho V_{e50}^2 A_{proj,B} \times \tfrac{1}{2} R \quad \text{(F.33)}$$

where

C_d is the drag coefficient and shall be taken as 1,5;

$A_{proj,B}$ is the planform area of the blade.

Equation (F.33) assumes the drag of the blade to have its centre of pressure at the midspan, which for most blades is conservative. It also assumes that the planform of the blade is completely perpendicular to the wind.

For a parked rotor the shaft thrust load is calculated as given by Equation (F.34).

$$F_{x-shaft} = B \times C_d \tfrac{1}{2} \rho V_{e50}^2 A_{proj,B} \quad \text{(F.34)}$$

This is simply the drag on all blades summed together.

A fully feathered blade will be subjected primarily to lift forces rather than drag forces. Variations in wind direction will place the blade at high-lift angles of attack. In this case the force is determined by the maximum lift coefficient rather than the maximum drag coefficient. Since these two values are of comparable magnitude these simple equations are also applied to the feathered rotor.

Spinning rotors

For turbines that have their rotor spinning at V_{e50}, it is expected that, at some location on the rotor $C_{l,max}$ will occur on one of the blades due to variations in wind direction. Thus the blade root bending moment is:

$$M_{yB} = \int_0^R C_{l,max} \frac{r}{R} \tfrac{1}{2} \rho V_{e50}^2 c\, r dr \approx C_{l,max} \tfrac{1}{6} \rho V_{e50}^2 A_{proj,B} R \qquad (F.35)$$

This assumes a triangular lift distribution which is $C_{l,max}$ at the tip and zero at the root. It further assumed a constant chord. If accurate data is not available on $C_{l,max}$, a value of 2,0 shall be used.

For a spinning rotor the calculation of thrust force is based on helicopter theory. The helicopter thrust coefficient is based on tip speed rather than wind speed.

$$C_{T,H} = \frac{T}{\rho \pi R^2 (\omega_n R)^2} \qquad (F.36)$$

Reference [F.2], page 345, shows that the maximum thrust coefficient for a helicopter rotor is approximately

$$\frac{C_{T,Hmax}}{\sigma} = 0,17 \qquad (F.37)$$

where σ is the rotor solidity, $\sigma = \frac{Bc_{ave}}{\pi R}$ and C_{ave} is the average blade chord. This value occurs at an advance ratio, $\frac{V}{\omega_n R}$ (the inverse of the tip speed ratio), of zero. At an advance ratio of 0,5 the thrust coefficient is reduced to approximately 0,06 for level flight, but the value remains near 0,17 for transient events. For this reason a constant value of 0,17 independent of advance ratio is used.

Converting the helicopter thrust coefficient to a wind turbine coefficient yields

$$C_T = 2 C_{T,H} \lambda^2 \qquad (F.38)$$

Combining Equations (F.37) and (F.38) yields:

$$C_T = 0,34 \sigma \lambda^2 \qquad (F.39)$$

Using Equation (F.40) and the form of Equation (F.26), yields:

$$F_{x-shaft} = 0,34 \sigma \lambda_{e50}^2 \tfrac{1}{2} \rho V_{e50}^2 A \qquad (F.40)$$

where

σ is the rotor solidity ($B \times A_{proj,B} / A$);
λ_{e50} is the tip speed ratio at V_{e50}, which if not known can be estimated by:

$$\lambda_{e50} = \frac{n_{max} \pi R}{30\, V_{e50}} \qquad (F.41)$$

Taking terms together in Equation (F.40) leads to:

$$F_{x-shaft} = 0,17 B A_{proj,B} \lambda_{e50}^2 \rho V_{e50}^2 \qquad (F.42)$$

For both cases, spinning and parked, for the calculation of the tower or support structure loads the thrust force shall be combined with the drag on the tower or support structure, and nacelle. That drag can then be estimated per component by using Equation (F.43).

$$F = C_f \, ½ \rho V_{e50}^2 A_{proj} \tag{F.43}$$

where

C_f is the force coefficient;

A_{proj} is the projected area of the component under consideration projected on to a plane perpendicular to the wind direction.

Load case I: maximum exposure

In this load case the turbine is assumed to be completely stationary. Based on the shape and the dimensions of the component, lift and/or drag forces shall be taken into account. The basic equation is given below.

$$F = C_f \times ½ \rho V_{ref}^2 A_{proj} \tag{F.44}$$

where

V_{e1} is the one-year extreme wind speed.

The loads shall be calculated for all components exposed to the wind. The resulting stresses throughout the wind turbine shall be calculated.

F.5 Reference documents

[F.1] BURTON, T., SHARPE, D, JENKINS, N, and BOSSANYI, E., *Wind Energy Handbook*, John Wiley and Sons, 2001.

[F.2] PROUTY, R.W., Helicopter Performance, Stability and Control, PWS Publishers, 1986

[F.3] Dutch Design Assessment (**NEN 6096/2**, 1994)

[F.4] Germanischer Lloyd Industrial Services GmbH, Renewables Certification, *Guideline for the Certification of Wind Turbines*, commonly known as the "GL Blue Book"

Annex G
(informative)

Example of test reporting formats

G.1 Overview

Annex G contains examples of reporting formats. Clause G.2 is defined within this standard. Clauses G.3 and G.4 are in accordance with the drawn from other standards and are purely for the convenience of the reader and for the convenience of preparing a label in accordance with Annex M if desired. Please refer to IEC 61400-11 and IEC 61400-12-1 for further guidance.

G.2 Duration test

G.2.1 General

Below are two examples for reporting format of the duration test results:

G.2.2 Table summarizing the duration test results

Table G.1 – Example duration test result

	Hours of power production above:				max gust	I_{15}	# Data points	T_T	T_U	T_F	T_N	O
		9 m/s	13,5 m/s	18,8 m/s								
Month	0 m/s	[$1,2\times V_{ave}$]	[$1,8\times V_{ave}$]	[$2,5\times V_{ave}$]	(m/s)	(%)		(h)	(h)	(h)	(h)	(%)
Overall	2 704,9	710,6	215,0	1,0	41,9	19,0	255	7 094	172,5	152,0	624,6	90,8
Jun 2008	238,2	36,2	3,8	-	28,6	18,5	5	518	11,3	7,8	3,3	99,3
Jul	256,0	8,5	0,3	-	23,9	-	-	744	78,2	2,2	38,8	94,1
Aug	115,8	4,5	0,0	-	19,2	-	-	744	6,3	20,0	323,0	55,0
Sep	120,5	11,7	1,8	-	22,4	-	-	720	36,2	30,3	174,7	73,3
Oct	236,0	45,0	12,2	-	32,8	17,3	10	744	0,7	1,3	0,0	100,0
Nov	348,0	98,7	22,5	-	37,0	20,9	40	720	22,1	0,0	0,0	100,0
Dec	339,7	160,5	54,8	0,5	41,4	17,4	68	744	7,9	27,2	32,8	95,4
Jan 2009	385,0	155,5	56,0	0,5	38,8	19,9	76	744	4,9	32,0	36,5	94,8
Feb	333,2	10,3	36,8	-	41,9	20,0	23	672	3,2	27,0	0,0	100,0
Mar	332,5	8,7	26,8	-	36,7	18,0	33	744	1,7	4,2	15,5	97,9

Table G.1 above for a SWT class III provides the key overall results but also the breakdown for each month. The report further will describe the reason for any time classified as T_U, T_E and T_N. The column labelled I_{15} is the turbulence intensity based on a 10-min statistics. The max gust is the highest instantaneous (3 s) wind speed measured during the test.

G.2.3 Plot showing any potential power degradation

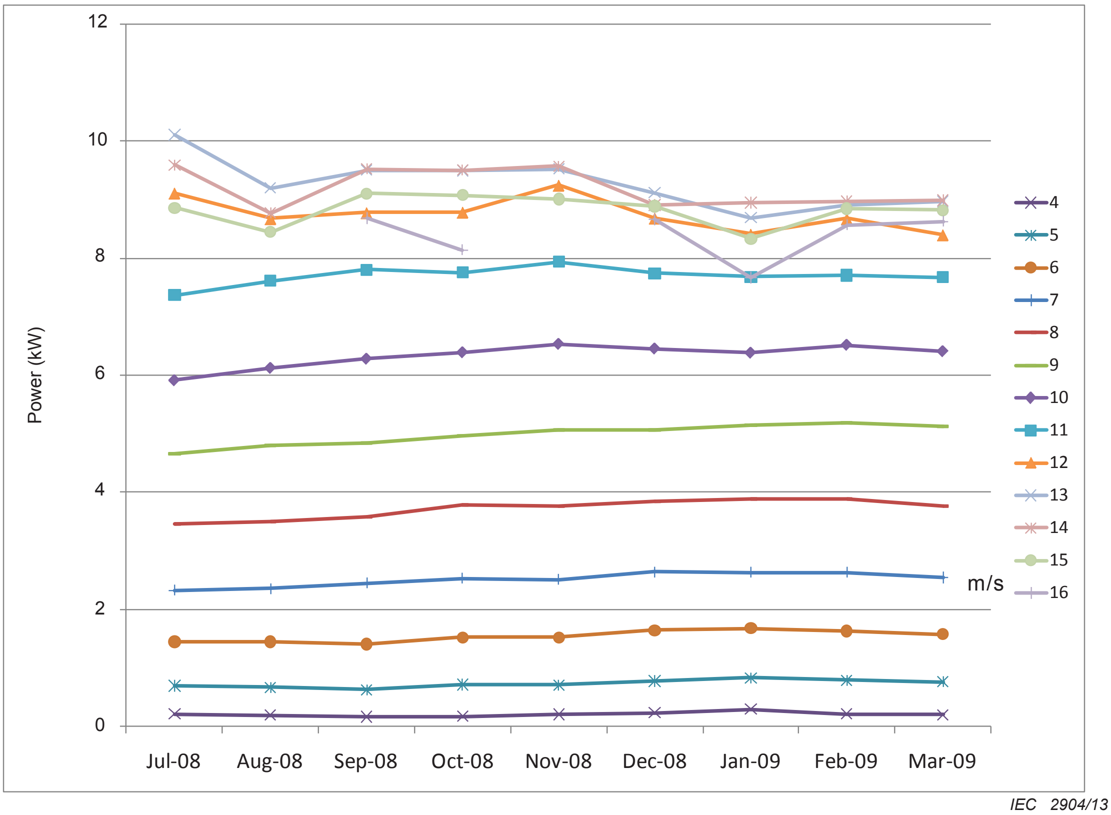


Figure G.1 – Example power degradation plot

The power degradation (see 13.4.2.5) plot in Figure G.1 shows the trend in the binned power level (based on 10-min averages) for several wind speeds from month to month. Only data from within the measurement sector is used to assure good inflow conditions. The data should also be sea level normalised to reduce the effect of air density on the plot. The objective for the plot is to look for trends that might suggest hidden degradation of the turbine system. Some changes are still expected due to seasonal effects such as temperatures, air density, etc.

G.3 Power/energy performance

G.3.1 General

G.3.1 The following Figures G.2 and G.3 and Table G.2 are examples of how this information can be presented. The content should be included even if the format is different.

G.3.2 A plot showing the binned sea level normalized power curve. The power curve should also show any power consumption below cut in wind speed. The plot should show the uncertainty bands indicating the standard uncertainty on power in both directions.

Note that some wind turbines will adjust their settings (e.g. blade pitch) to accommodate for air density effects. For those turbines no additional air density normalization should be done.

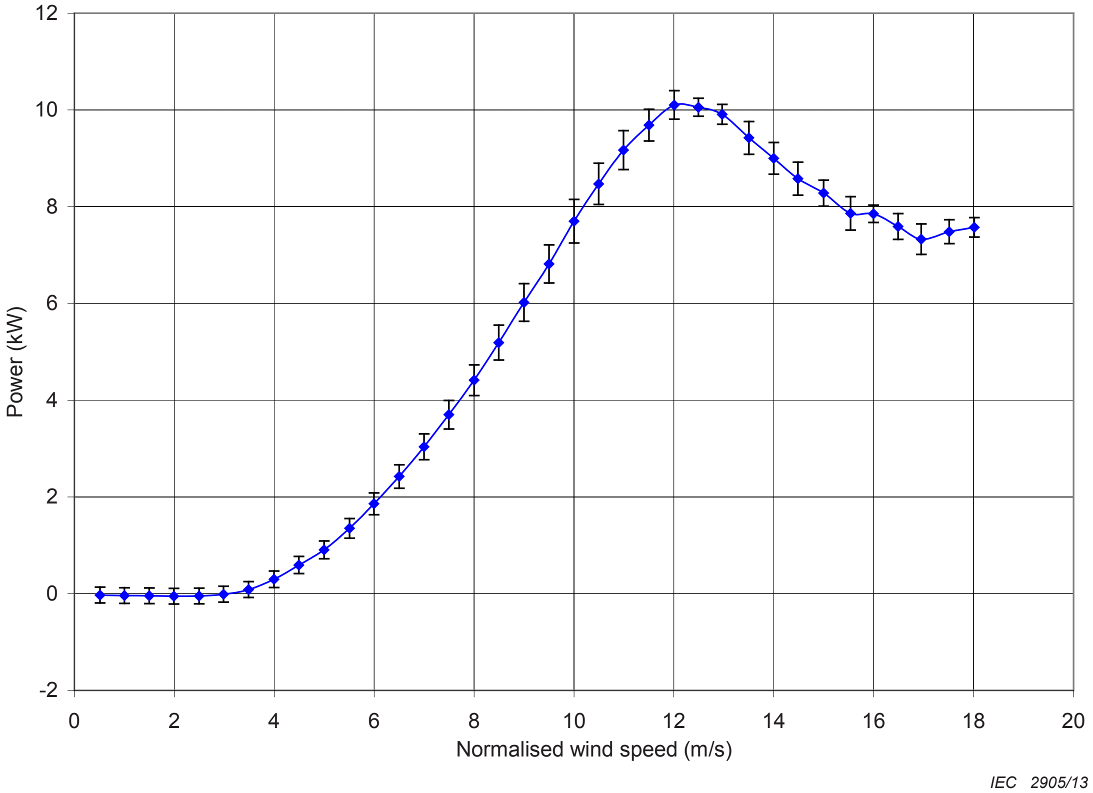


Figure G.2 – Example binned sea level normalized power curve

G.3.3 A scatter plot of the measured power and wind speed used for the binned power curve. Average, maximum and minimum and standard deviation for each data point should be shown.

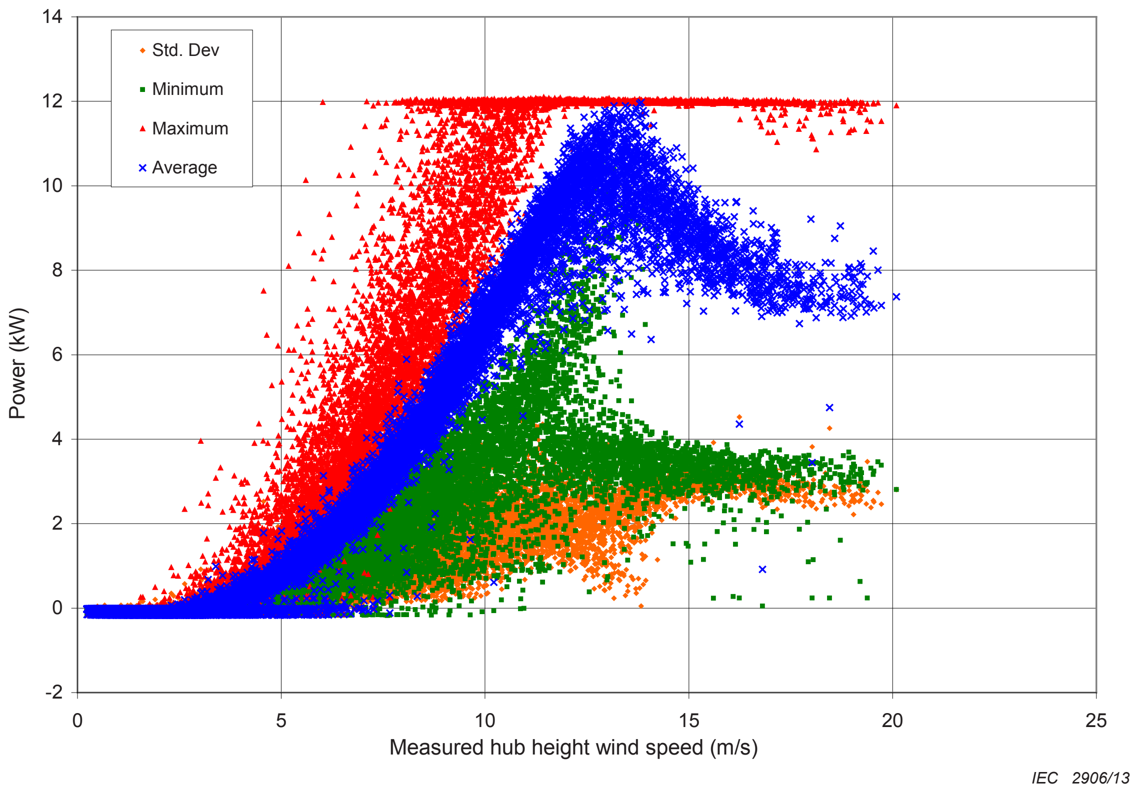


Figure G.3 – Example scatter plot of measured power and wind speed

G.3.4 Table with the calculated annual energy production for sea level air density

Table G.2 – Example calculated annual energy production (AEP) table

Estimated annual energy production, database A (all valid data)					
Reference air density:	1,225	kg/m^3			
Cut-out wind speed:	25,00	m/s			
Hub height annual average wind speed (Rayleigh)	AEP-measured	Standard Uncertainty In AEP- measured		AEP-extrapolated	Complete if AEP measured is at least 95% of AEP extrapolated
m/s	kWh	kWh	%	kWh	
4	7,884	1,717	22%	7,884	Complete
5	15,327	1,948	13%	15,329	Complete
6	23,516	2,144	9%	23,572	Complete
7	30,967	2,271	7%	31,330	Complete
8	36,718	2,325	6%	37,924	Complete
9	40,459	2,314	6%	43,158	Incomplete
10	42,350	2,254	5%	47,049	Incomplete
11	42,770	2,160	5%	49,696	Incomplete
AEP measured assumes zero power between highest bin and cutout AEP extrapolated assumes power in last bin between last bin and cutout					

G.4 Acoustic noise test

For the acoustic noise test an immission map is required. The following Figure G.4 is an example of how this information can be presented. The content should be included even if the format is different.

The plot shows sound pressure levels which are calculated from a declared apparent sound power level for a range of wind speeds and distances to the centre of the wind turbine rotor.

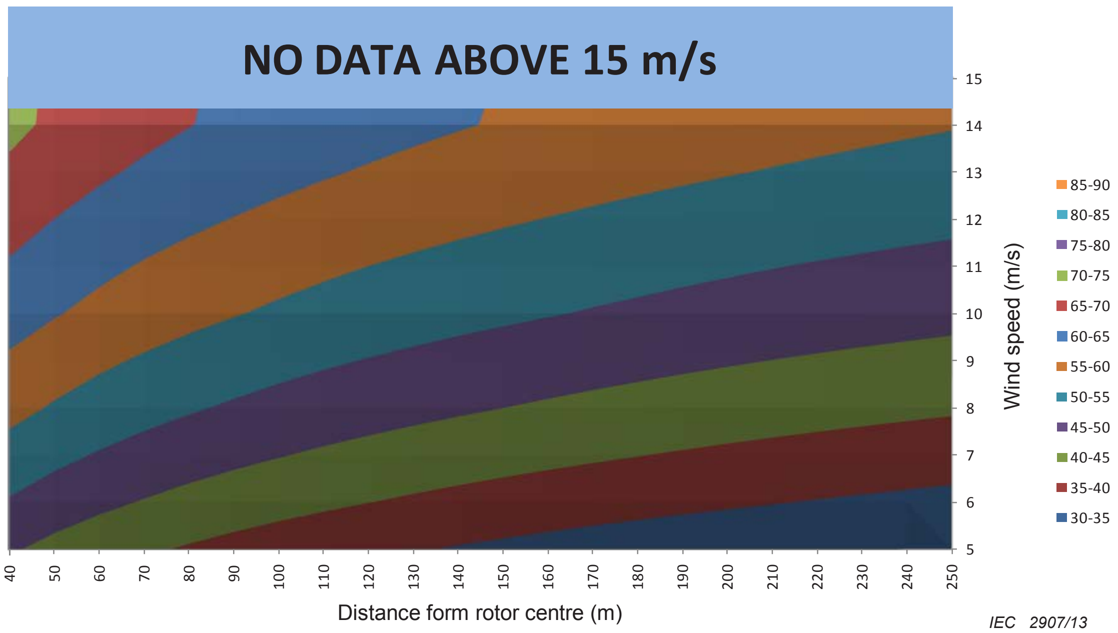


Figure G.4 – Example immission noise map

Annex H
(informative)

EMC measurements

H.1 Overview

In order to obtain repeatable and comparable EMC measurement results, the generic EMC standard IEC 61000-6-3:2006 and the referenced measurements standards CISPR 16-2-1:2008 and CISPR 16-2-3:2006 are not specific enough to evaluate the electromagnetic compatibility of the electrical system of a small wind turbine.

To avoid variations of the measurement results the test setup is specified in this annex. The following subclauses H.2 and H.3 propose a test setup to evaluate EMC of wind turbines whose generator, inverter and controller are closely coupled in the nacelle or base of the wind turbine.

Where the following test is considered for a system whose inverter and/or controller are not closely coupled with the generator in the nacelle or base of the turbine, additional measures are recommended to retain the validity of the results for a given turbine installation. It may be necessary that an appropriately specified EMC filter at the turbine input to the inverter and controller is necessary to limit emissions from the turbine cabling, slip rings and generator. Alternatively, EMC screened cable will limit emissions from the turbine cabling itself.

H.2 Measurement for radiated emissions

Additional to the requirements listed in the CISPR 16-2-3:2006 the test setup should be as shown in Figure H.1 or Figure H.2.

The electrical load can be placed outside the anechoic chamber. In this case, the cable shall be mounted onto 0,1 m dielectric spacers in the anechoic chamber and filtered at the wall entrance to avoid EMC disturbances from outside the chamber.

It shall be ensured that the test (e.g. motor) and measurement equipment has no influence on the results, due to additional emissions.

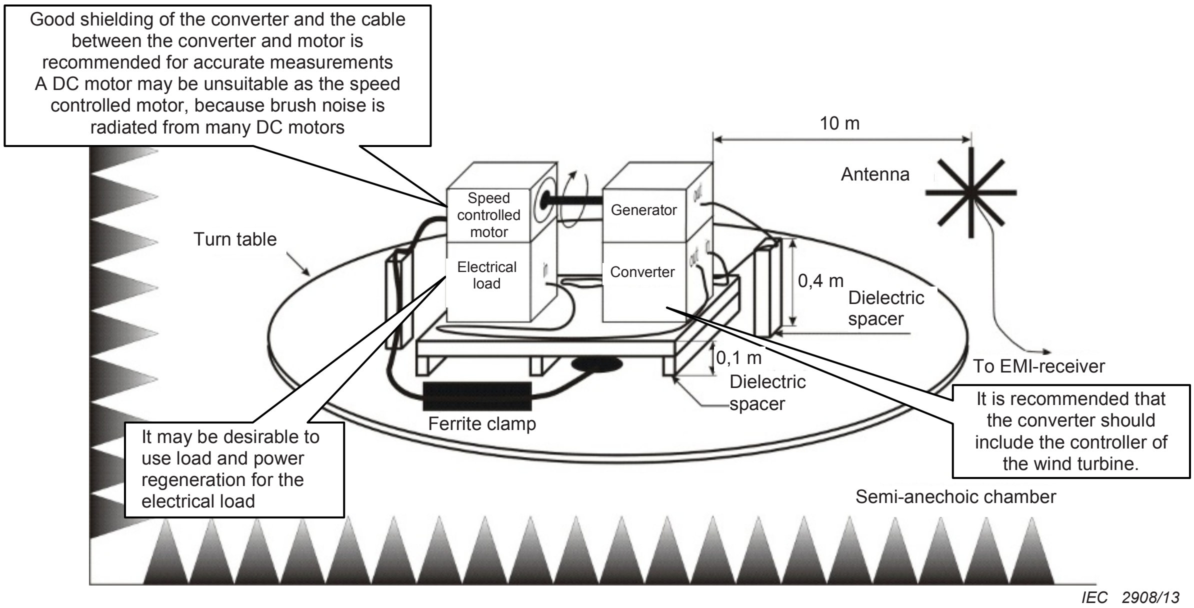


Figure H.1 – Measurement setup of radiated emissions (set up type A)

If the generator has only generator without other electrical devices which emit specific noise, and when it can be assumed that the emission noise from generator is very low, the test setup can be used as shown in Figure H.2.

Power-supply unit (CVCF) that is assumed to be the generator generate the output that should be simulate the output waveform from generator such as a.c., d.c. and rectified waveform.

It may be necessary to setup the cables same as typical usage length and type.

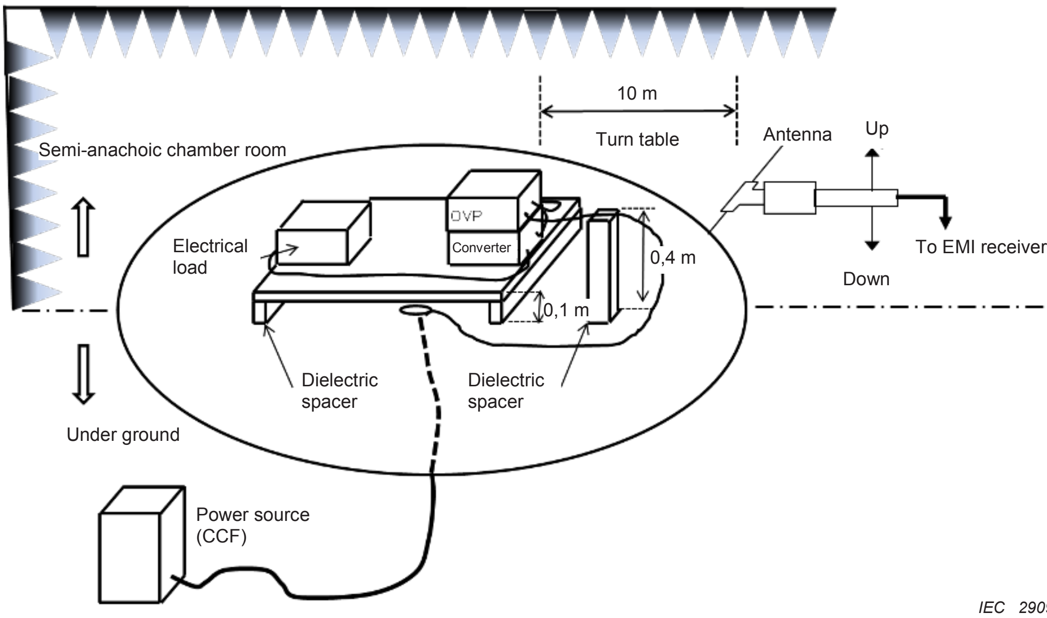


Figure H.2 – Measurement setup of radiated emissions (set up type B)

H.3 Measurements of conducted emissions

Additional to the requirements listed in the CISPR 16-2-1:2008 the test setup should be as shown in Figures H.3 or H.4 below. If required the electrical load can be placed off the metal ground plane. The specification of the measuring apparatus is described in the CISPR 16-1-2:2003, Amendment 1:2004 and Amendment 2:2006.

Remark: According to the CISPR 16-2-1:2008 the distance between the outer edge of the metal ground plane and the generator / converter shall be set at least 0,5 m.

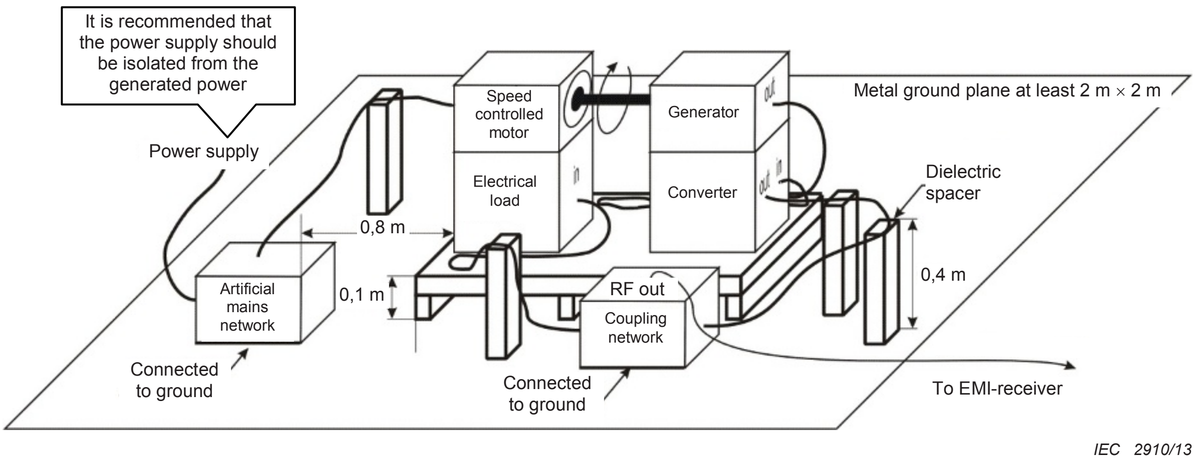


Figure H.3 – Measurement setup of conducted emissions (setup type A)

When the setup of type B has chosen at the measurement of radiated emissions, measurement setup B should be chosen at conducted emissions (see Figure H.4).

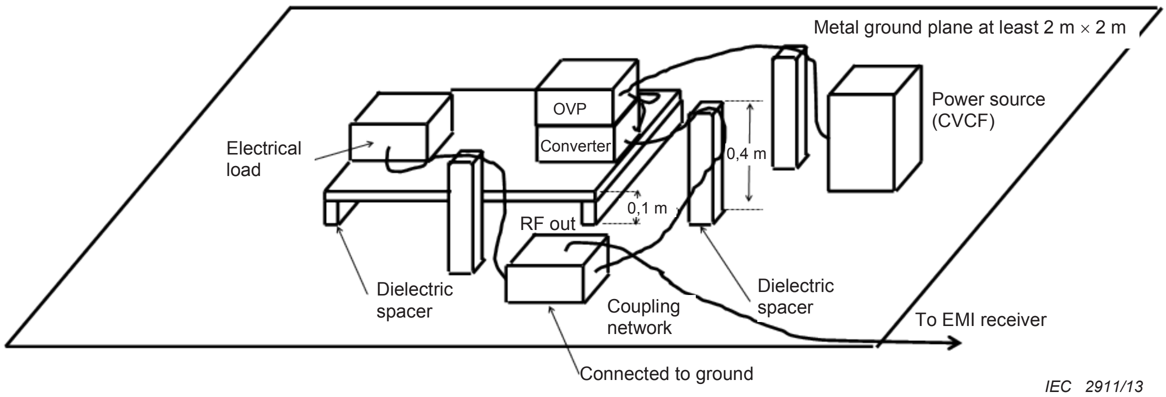


Figure H.4 – Measurement setup of conducted emissions (setup type B)

H.4 Reference documents

[H.1] IEC 61000-6-3:2006, *Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments* Amendment 1:2010

[H.2] CISPR 16-1-2:2003, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-2: Radio disturbance and immunity measuring apparatus – Ancillary equipment – Conducted disturbances*

Amendment 1:2004
Amendment 2:2006

[H.3] CISPR 16-2-1:2008, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-1: Methods of measurement of disturbances and immunity – Conducted disturbance measurements*
Amendment 1:2010
Amendment 2:2013

[H.4] CISPR 16-2-3:2006, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-3: Methods of measurement of disturbances and immunity – Radiated disturbance measurements*
Amendment 1:2010

Annex I
(normative)

Natural frequency analysis

The main natural frequencies of the wind turbine shall be evaluated by means of a resonance diagram (e.g. Campbell diagram). It shall contain the natural frequencies (f_N) and the relevant excitation frequencies (f_E) of the wind turbine. At least the natural frequencies of the main structural components of the wind turbine shall be considered. These are the natural frequencies of the: tower or support structure; rotor blades; and, depending on the design: drive train; bracing between rotor blades and hub (e.g. stiffeners) and bracing of tower (e.g. guyed tower or other support structure). The relevant excitation frequencies to be considered are at least the rotor speed $1P_{\mathrm{H}}$ plus multiples ($2P_{\mathrm{H}}$, $3P_{\mathrm{H}}$ ...) and the rotor speed multiplied by the number of blades plus multiples (e.g. $3P_{\mathrm{H}}$, $6P_{\mathrm{H}}$, $9P_{\mathrm{H}}$ ... in case of a three-bladed rotor). See Figure I.1 for an example of a Campbell diagram. The wind speed versus r.p.m. curve shall be considered in this evaluation.

The natural frequencies can be obtained by simulation or by measurement on the actual wind turbine. It is possible to extend the analysis to consider variation of natural frequencies with different rotor speeds.

Generally the occurrences of resonances in the operating speed range of the wind turbine shall be avoided. Where they cannot be avoided any load amplifications shall be considered in the design of the structure. If necessary, appropriate design or controller adaptations shall be carried out.

Variable speed wind turbines will generally pass though the natural frequencies of the system due to the unsteady nature of the wind. It should not generally be assumed that this will lead to damaging resonance conditions. However a control function that decouples the relationship between wind speed and rotor speed (for example a rotor overspeed control that maintains a constant speed) can lead to damaging resonance.

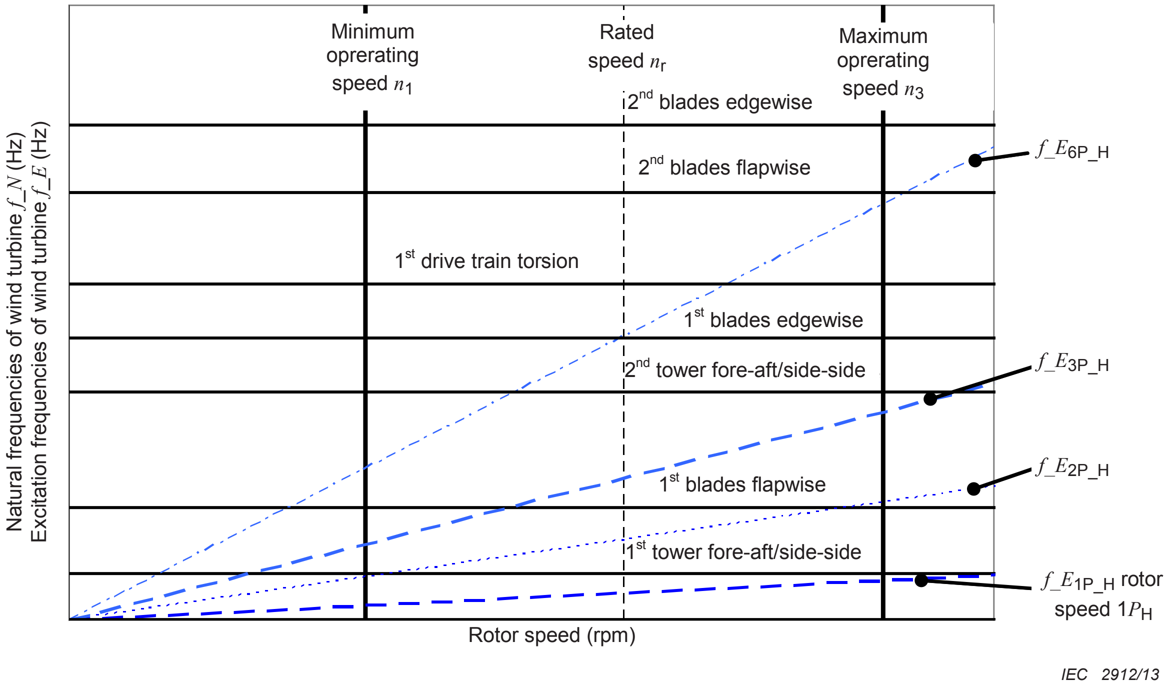


Figure I.1 – Example of a Campbell diagram

Annex J
(informative)

Extreme environmental conditions

J.1 Overview

In the design documentation, it shall be clearly stated if the wind turbine type has been designed for operation outside of standard external conditions specified in 6.4.1 of this standard, which may include icing, saline, cold or hot conditions. It shall also be stated how this has been done, for example how the following have been considered:

J.2 Extreme conditions

a) Component ratings and material properties, such as steel with sufficient impact strength at low temperature or electronic component rating at high temperature.
b) The use of different materials may affect thermal expansion and should be considered e.g. on how it might change the system rigidity.
c) Lubrication e.g. temperature variation will cause lubricant properties to change.
d) Protection of components against moisture and condensation.
e) Allowable temperatures for assembly, commissioning, operation and maintenance should be documented and make note of special considerations (e.g. curing of concrete or epoxy).
f) Erosion of the blades shall be addressed if particulate matter is present, e.g. sand, salt.

J.3 Low temperature

a) Startup procedures shall be considered, e.g. after grid failure during low temperature / icing, including switch-on times, delays or equipment heating.
b) Special maintenance requirements related to low temperature / icing should be documented.
c) Effects on operation, e.g. startup wind speed.

J.4 Ice

a) In the static ice loading case at 3 V_{ave} (6.4.3.4), the possibility of frozen mechanisms such as furling hinge, pitch mechanisms and external sensors should be considered.
b) Aerodynamic and mass imbalance due to ice should be considered in design load estimation. Vibration detection may be used for protection.
c) Prevention of ice accumulation by passive or active means, on sensors, blades, etc. should be considered.
d) Protection and sealing, e.g. to prevent ice and snow from filling the generator or nacelle. Ice and snow that builds up inside or around the nacelle can cause malfunction or corrosion of the electric and mechanical components.
e) Recommended safety distance in case of ice throws.
f) There is the possibility of increased power output due to low turbulence, high air density, and/or ice accumulation that changes the aerodynamics of the rotor, for example increases the radius of the leading edge. These may all lead to overproduction on stall controlled machines, but could affect other machines.

J.5 High temperature

Although cold conditions have a more detrimental impact than hot conditions on the strength and properties of wind turbine materials, there are some situations in hot climates that need to be considered by small wind turbine manufacturers and accommodated in turbine design and installation.

a) Electronic components shall be suitably rated.

b) Sand and dust: the entire machine should be well sealed.

c) Exposed, especially structural plastics shall be UV stable.

d) Turbine should be well earthed to dissipate build-up of static charge on components.

J.6 Marine

a) Appropriate water proofing and corrosion protection should be implemented.

b) Dissimilar metal and general material combinations shall be carefully selected.

Annex K
(informative)

Extreme wind conditions of tropical cyclones

K.1 General

The external conditions defined for SWT classes I, II, III and IV do not cover wind conditions experienced in tropical cyclones (hurricanes, cyclones and typhoons). Such conditions may require wind turbine class S design, however not all the wind turbines installed in tropical cyclone areas are necessarily required to be "S Class" turbines. This is because the frequency and the magnitude of a tropical cyclone depend upon the geographical conditions as well as meteorological conditions.

This annex aims to enable easy design of wind turbines for installation in a tropical cyclone area such as illustrated in Figure K.2 by describing the general characteristics of tropical cyclones.

K.2 Using SWT classes in tropical cyclone areas

The initial important work is to identify a SWT class which is to be built at a particular site in a tropical cyclone climate region. This work consists of analysing observed annual maximum wind speeds (extremes of tropical cyclones) and estimating the reference wind speed V_{ref} which is an extreme value of 50-year recurrence periods at the site.

An appropriate statistical extreme value theory may be applied in predicting V_{ref} at the site. However, such a rare event as annual maximum wind speed, the volume of the parent data is usually insufficient to apply a statistical extreme theory. In such case, certain supplementary methods may be applied such as using a Monte Carlo Simulation to reduce uncertainty of the estimation. A CFD model may improve the estimation by taking the geometrical conditions into account. An introduction of estimation methods of extremes is described in the references listed at K.5.

K.3 Extreme wind conditions

K.3.1 Definition of tropical cyclones

Hurricanes, cyclones and typhoons are severe depressions generated on ocean surface in tropical or subtropical zone and called tropical cyclone. A tropical cyclone is defined as a tropical storm which has 10-min average wind speeds above 32,7 m/s (64 knots). A strong or severe tropical cyclone has 10-min average wind speeds above 50 m/s, which influences the statistic prediction of a reference wind speed V_{ref}.

K.3.2 General features of tropical cyclones

Tropical cyclones are seasonal and regional oceanic meteorological phenomena. Each tropical cyclone region has its typical pattern and tracks of the cyclones. Influenced by topographical conditions, a landed cyclone may accelerate wind speeds. For these reasons, cyclone oriented maximum annual 10-min average wind speeds should be carefully analysed.

The number of cyclones annually generated or landed in a region or at a site is an important parameter in analyzing extreme values. For example, the average number of typhoons annually generated in the sea waters around Japan in the past 60 years is 26 per year, while the average number that reaches the land surface of Japan is only 3 per year. Because of this most of the regions and sites have a limited number of observed maximum annual 10-min average wind speed data points. The minimum requirement for estimation of V_{ref} by using traditional extreme statistics should be at least two independent observed maximum annual 10-min average wind speed data generated by cyclones within the past 50 years in a region or at a site under consideration.

K.3.3 Extreme wind conditions

K.3.3.1 Observed data

Table K.1 shows global top five 10-min average maximum extreme wind speeds recorded at meteorological stations for typical cyclone areas. Note that the recurrence period is not identified for each extreme value.

Table K.1 – Top five average extreme wind speeds recorded at meteorological stations

Rank	USA Atlantic coastal hurricanes [a]			France Atlantic coastal cyclones [c]			Typhoon – Japan [b]		
	Extreme value m/s	Year, name	Period since, height m [d]	Extreme value m/s	Year, town	Period since, height m [d]	Extreme value m/s	Year, loca-tion	Period since, height m [d]
1	74,4	1992, Andrew	1980, 10,0	40	1987, Quimper	1981, 10,0	69,8	1965, Cape Muroto	1961, 41,8
2	66,7	2004, Charley	1980, 10,0	32	1999, Orly	1981, 10,0	69,3	1951, Cape Muroto	1961, 41,8
3	61,6	1989, Hugo	1980, 10,0	31	1984, Millau	1981, 10,0	60,8	1966, Miyako Island	1961, 11,4
4	56,5	2005, Katrina	1980, 10,0	30	1999, La Rochelle	1981, 10,0	60,0	1942, Mt. Unzen	1961, 51,7 (a.s.l.)
5	53,9	2004, Ivan	1980, 10,0	30	1982, Millau	1981, 10,0	54,3	1968, Miyako Island	1961, 11,4

NOTE These are not instantaneous maxima, they are sustained average maxima as defined for each dataset.

a Maximum 1-min average winds, (from appendix A of reference [K.11]).[4]

b Measuring equipment were vane-type (propeller) and data is 10-min average.

c Maximum 10-min average wind speeds.

d Heights are measurement heights above ground level except where noted otherwise.

Table K.2 shows global top five instantaneous extreme wind speeds (gusts) recorded at meteorological stations. Note that because of the limitations of the measuring equipment these instantaneous gusts may be of shorter duration than a standard 3-s gust.

[4] References in square brackets refer to references listed in Clause K.5.

Table K.2 – Extreme wind speeds recorded at meteorological stations

Rank	USA Atlantic coastal hurricanes [a]			France Atlantic coastal Cyclones [d]			Typhoon – Japan [b]		
	Extreme value m/s	Description	Period since, height [e] m	Extreme value m/s	Year, town	Period since, height [e] m	Extreme value [c] m/s	Year, location	Period since, height [e] m
1	80 [a]	Modelled 100 year [a]	1900, 10,0	52	1987, Quimper	1981, 10,0	85,3	1966, Miyako Island	1961, 11,4
2				51	2009, Perpignan	1981, 10,0	84,5	1961, Cape Muroto	1961, 41,8
3				48	1999, St Brieuc	1981, 10,0	79,8	1968, Miyako Island	1961, 11,4
4				48	1986, Chambery	1981, 10,0	78,9	1970, Nase	1967, 20,7
5				45	1990, Quimper	1981, 10,0	77,1	1965, Cape Muroto	1961, 41,8

NOTE These are not instantaneous maxima, they are sustained average maxima as defined for each dataset.

[a] Simulated data for 3-s gust with 100-year recurrence period see reference [K.8].

[b] Measuring equipment were vane-type (propeller) anemometers.

[c] 1-s averaged equivalent.

[d] Maximum of the measured 0,5-s, see reference [K.10].

[e] Heights are measurement heights above ground level except where noted otherwise.

K.3.3.2 Turbulence intensity

The characteristic value of hub-height turbulence intensity at a 10-min average wind speed of 15 m/s (I_{15}) is another important parameter that defines SWT classes. In the absence of evidence otherwise the I_{15} for standard SWT classes I to IV is assumed to be valid for locations that experience tropical storms.

K.3.3.3 Extreme wind shear

Under extreme gust conditions, the wind shear becomes steeper. This means high winds driven by tropical cyclones at high altitudes will even stress small wind turbines mounted at low heights.

K.3.3.4 Wind direction reversal

Mid-way through the duration of the tropical cyclone the wind direction changes through 180° over a period of half an hour or more. This is relevant as any turbine that is protected by utilizing a parked state with reduced exposure shall re-park in mid cyclone. It is common that electrical network outage occurs during these storm conditions and therefore care shall be taken for fail-safe design.

K.4 Stochastic simulation (Monte Carlo simulation)

In the areas where the strong wind is dominated by extratropical cyclones, the extreme wind speed can be estimated from a nearby reference meteorological station by using the Measure-Correlate-Predict (MCP) method as described in Annex E of IEC 61400-1:2005. On the other hand, tropical and subtropical regions, where both tropical and extratropical cyclones are dominant, are known as mixed climates and the examination of each significant wind-producing meteorological phenomenon are required as mentioned by Gomes and Vickery (1978). It was noticed that the MCP method underestimates the extreme wind speed in mixed climate regions as shown in Figure K.1. An alternative approach is to extend measured data using stochastic models to create pseudo data that is a better prediction than simple correlation and prediction. These are often called Monte Carlo models. They are especially useful where the available data is limited.

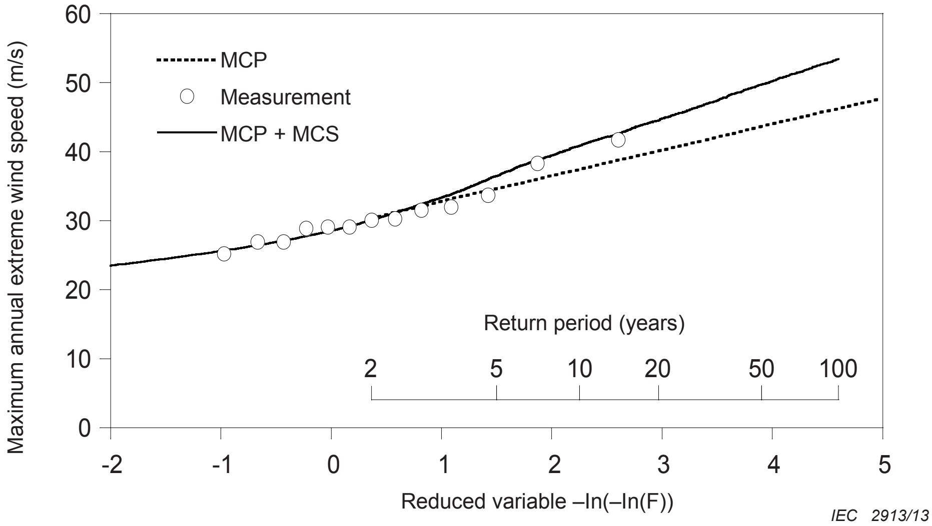


Figure K.1 – Comparison of predicted and observed extreme winds in a mixed climate region (after Isihara, T. and Yamaguchi, A.)

Figure K.1 shows a combined extreme wind speed distribution estimated by a Monte Carlo simulation and compared with actual measurements. Estimated probability distribution by the MCP method with Gumbel analysis is also plotted for comparison. It is obvious that the Monte Carlo method shows good agreement with the measurement, while the MCP method underestimates the extreme wind speeds at low recurrence dominated by tropical cyclones.

K.5 Reference documents

[K.1] ISHIHARA, T. and YAMAGUCHI, A. (2010), Prediction of the extreme wind speed in mixed climate regions by using Monte Carlo simulation and Measure-Correlate-Predict method, (Submitted to *Journal of Wind Engineering, JAWE*)

[K.2] GOMES, L. and VICKERY, B. J (1978), Extreme wind speeds in mixed climates, J. Wind Eng. Indust. Aerodyn., 2, 331-334.

[K.3] GEORGIOU, P. N., DAVENPORT, A. G. and VICKERY, B. J. (1983), Design wind speeds in regions dominated by tropical cyclones, J. Wind Eng. Indust. Aerodyn., 13, 139-152.

[K.4] SCHLOEMER, R. W. (1954), Analysis and synthesis of hurricane wind patterns over, Lake Okeechobee, Florida. Hydrometeorological Report, No.31.

[K.5] ISHIHARA, T., SIANG, K. K., LEONG, C. C. and FUJINO, Y. (2005), Wind field model and mixed probability distribution function for typhoon simulation, The Sixth Asia-Pacific Conference on Wind Engineering, 412-426.

[K.6] VICKERY, P. J. and TWISDALE, L. A. (1995), Prediction of hurricane wind speeds in the United States, Journal of Structural Engineering, ASCE, 121(11), 1691-1699.

[K.7] ISHIHARA T. and HIBI K. (2002), Numerical study of turbulent wake flow behind a three-dimensional steep hill, Wind and Structures, Vol.5, No.2-4, 317-328.

[K.8] YASUI, H., OHKUMA, T., MARUKAWA, H. and KATAGIRI, J. (2002), Study on evaluation time in typhoon simulation based on Monte Carlo method, J. Wind Eng. Indust. Aerodyn., 90, 1529-1540.

[K.9] VICKERY, P. J, WADHERA, D., W, TWISDALE, L. A.,.LAVELLE, F.M; U.S. Hurricane Wind Speed Risk and Uncertainty; Journal of Structural Engineering, Vol. 135, No. 3, March 2009

[K.10] SABRE, M. (2011); Analysis of the strongest cyclones on French Atlantic coast, CSTB Report EN-CAPE 11.035-C V0.

[K.11] NOAA Technical Memorandum NWS TPC-5; "THE DEADLIEST, COSTLIEST, AND MOST INTENSE UNITED STATES TROPICAL CYCLONES FROM 1851 TO 2006 (AND OTHER FREQUENTLY REQUESTED HURRICANE FACTS); see http://www.nhc.noaa.gov/pdf/NWS-TPC-5.pdf

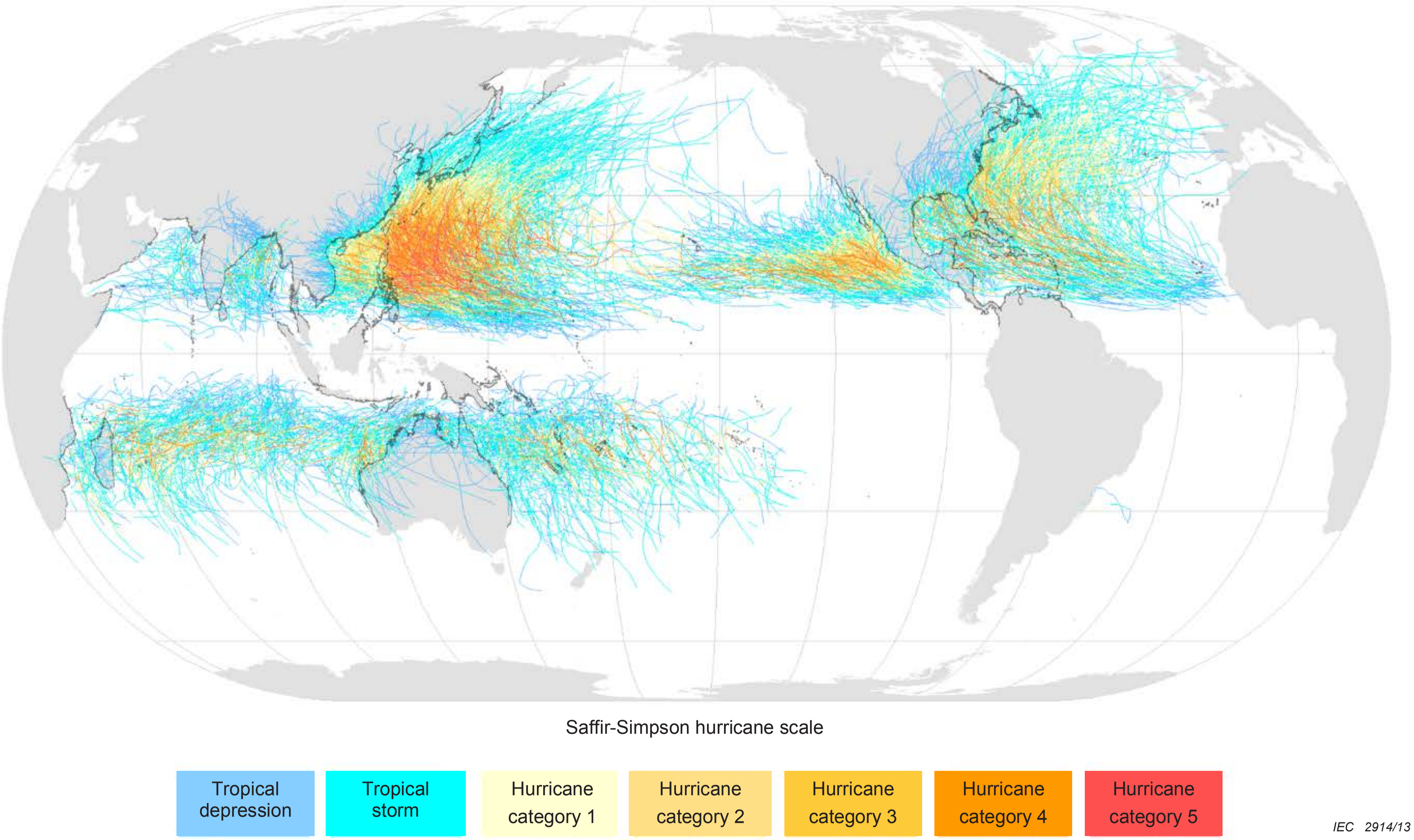


Figure K.2 – Tropical cyclone tracks between 1945 and 2006
(Data from the Joint Typhoon Warning Center and the U.S. National Oceanographic and Atmospheric Administration)

Annex L
(informative)

Other wind conditions

L.1 General

The purpose of this annex is to illustrate that other inflow conditions exist which are not covered elsewhere in the standard, and which can have significant detrimental effects on the longevity, safety, function and performance of SWTs.

The four standard SWT classes, wind conditions and load cases defined earlier in this standard are intended to be representative for typical wind turbine environments, similar to where large wind turbines are installed, with a relatively unobstructed air flow. As stated in 6.3 these are termed standard wind conditions (SWC).

However, SWTs are in some cases installed in environments where other wind conditions (OWC) exist. Therefore the standard wind conditions model is no longer valid for use by the designer without modification. Sometimes these other wind conditions are simple in nature, and sometimes they are complex in nature. This annex is organised to treat each aspect in isolation.

L.2 Typical situations

Examples of environments where other wind conditions have been observed include urban areas, rooftops, forested areas, mountainous or hilly areas. Each environment has its own characteristics that influence the wind. For instance, the wind over rooftop will be influenced by a range of parameters, such as the pitch of the roof, the orientation of the building, and the surroundings. Therefore it is difficult to generalize the inflow conditions for even similar types of complex environments. This annex contains a few examples of other inflow conditions, supported by actual measurements for example in Figures L.3, L.4, L.5, L.6, L.7, L.8 and L.9. The measured values are not intended to be representative for every complex situation but rather to be viewed as indicative figures.

This annex excludes the downstream wake effects from other operating wind turbines.

Other inflow conditions can include extreme turbulence, differing gust factors, extreme wind direction changes and be inclined with a vertical wind component (both average inclined flow as well as temporary vertical wind) and may be directionally-dependent.

L.3 Directionally dependent flow

Care should be taken when analysing data to ensure that the averages are not masking design-critical extremes that are only present when wind is coming from certain directions. For example if the SWT is placed close to a wall, turbulence can be particularly severe from one or more wind directions which may be rare. Similarly obstacles can cause e.g. extreme wind direction changes that are larger than would otherwise be expected when looking at average turbulence conditions containing all wind directions. This can also exist with inclined flows.

L.4 Inclined flow

In 6.3, this standard defines wind conditions where the inclination of the mean flow with respect to the horizontal plane is at most 8°, but this number could be larger. Quantitative field data is scarce but CFD simulations and experience suggest that this is especially problematic on the tops of tall buildings and cliff tops (see Figure L.1 and L.2).

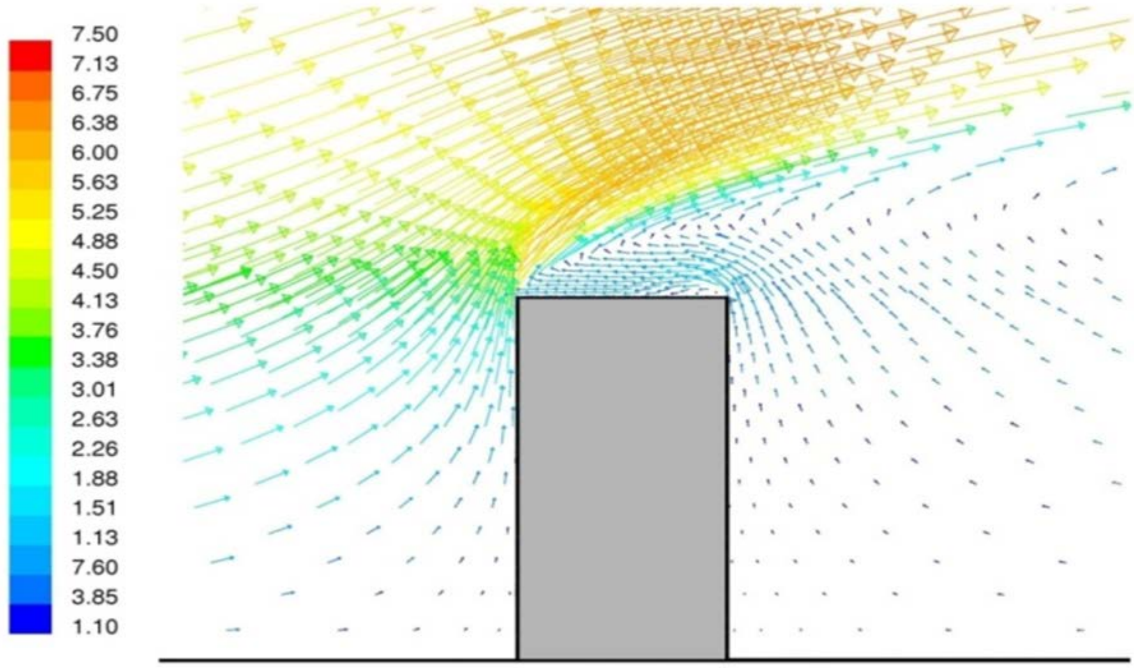
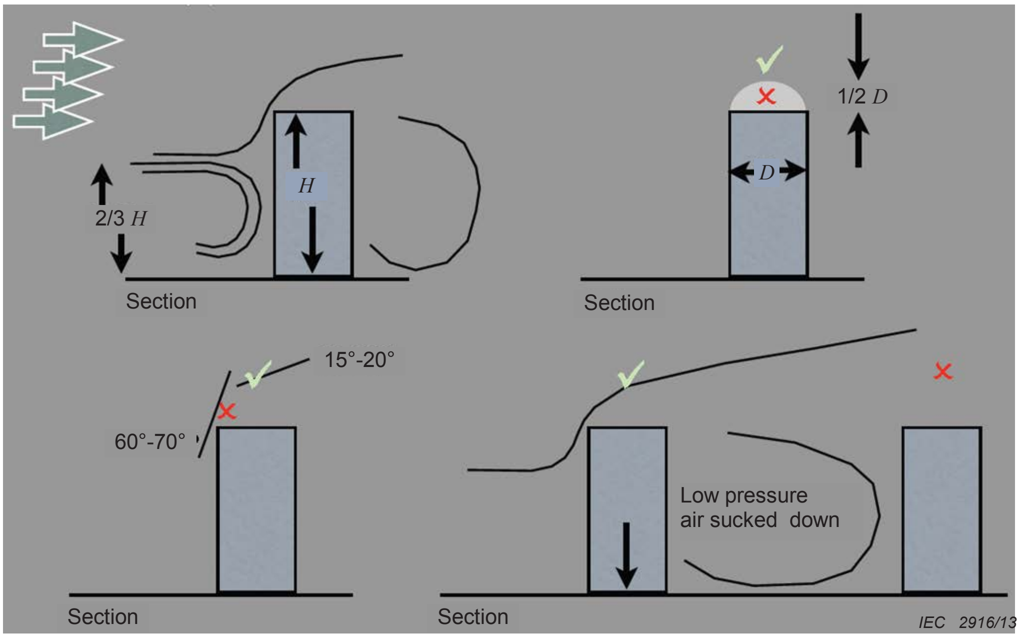


Figure L.1 – Simulation showing inclined flow on a building (courtesy Sander Mertens)



Places that are particularly unsuitable for SWTs are marked with X.

Source: Quiet Revolution Ltd derived from field experience and CFD studies, See also reference [L.1] and reference [L.2] in Clause L.8.

Figure L.2 – Example wind flow around a building

L.5 Turbulence

The normal wind conditions specified in 6.3.1 include the normal turbulence model (NTM), which is used e.g. for fatigue load case calculations with aero-elastic models. That can be compared to the following examples of real world turbulence in complex environments.

In each graph below the turbulence measurement results are presented in the following way: The thin solid line shows bin average turbulence intensity $\sigma 1/V_{\text{hub}}$ as a function of 10-min mean wind speed V_{hub} (binned with bin size 1 m/s). The standard deviation of $\sigma 1/V_{\text{hub}}$ is shown with error bars above and below the average $\sigma 1/V_{\text{hub}}$. The dotted line with crosses shows the estimated 90 % quantile of turbulence intensity (following 11.9 of IEC 61400-1:2005).

To simplify comparisons between the measurements and the standard, the graphs also contain a thick solid line representing the NTM with the turbulence parameters I_{15} and a as defined for the standard SWT classes in Table 1. In addition, the measured probability distribution of 10-min mean wind speed V_{hub} is shown on the bar graph.

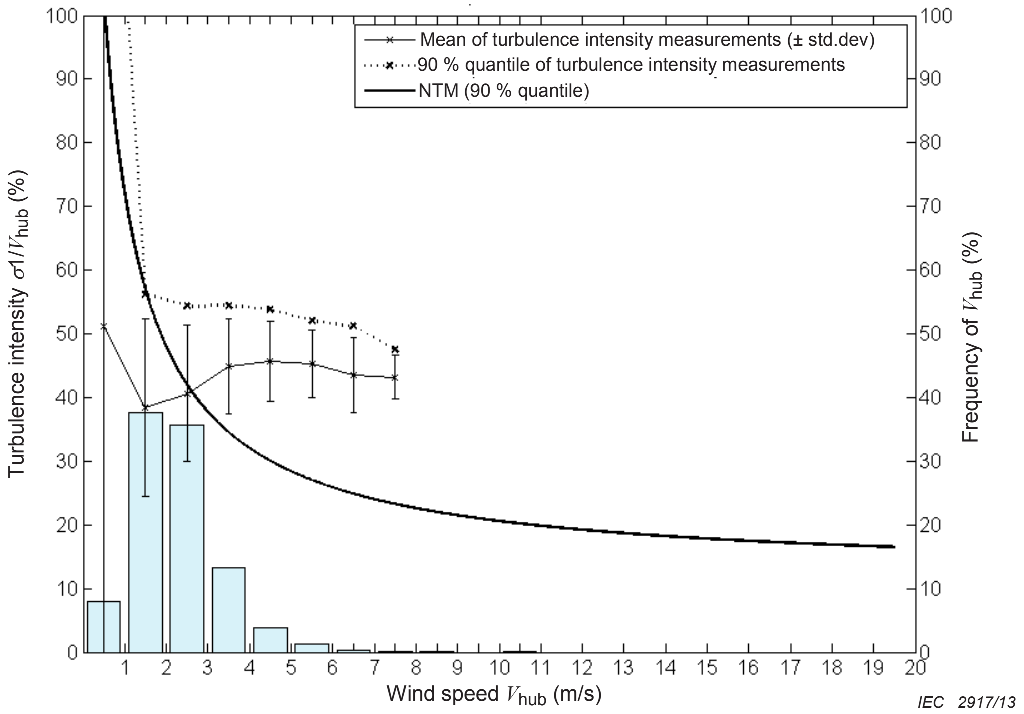


Figure L.3 – Turbulence intensity and wind speed distribution, 5 m above treetops in a forest north of Uppsala, Sweden, during Jan-Dec 2009

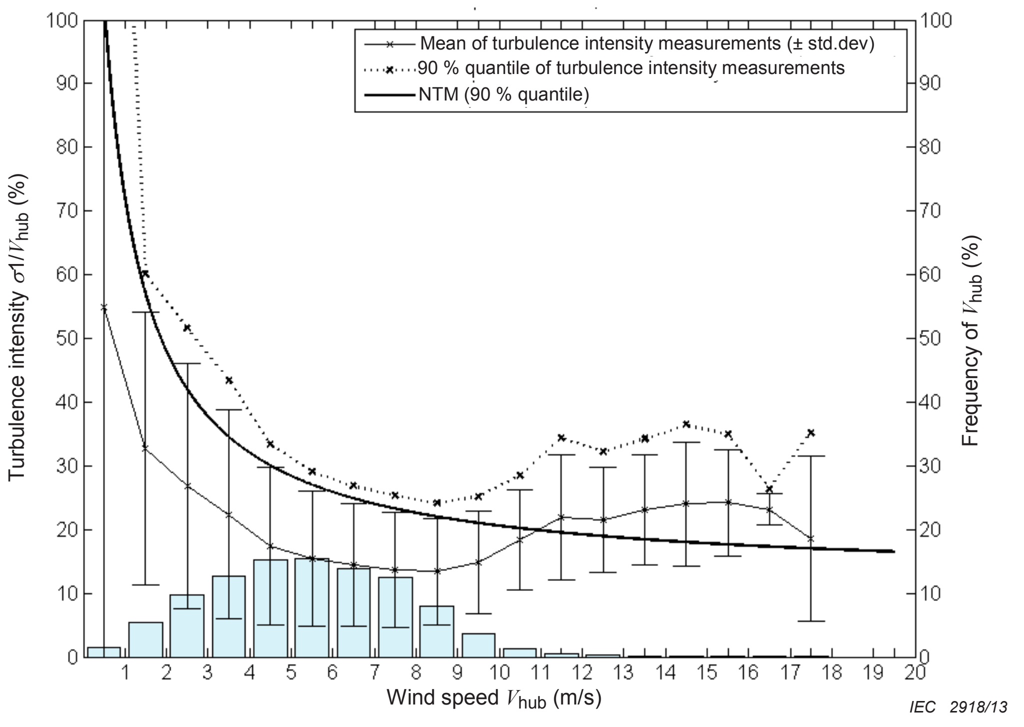


Figure L.4 – Turbulence intensity and wind speed distribution, 69 m above treetops in a forest north of Uppsala, Sweden, during 2009 (limited data for high wind speeds)

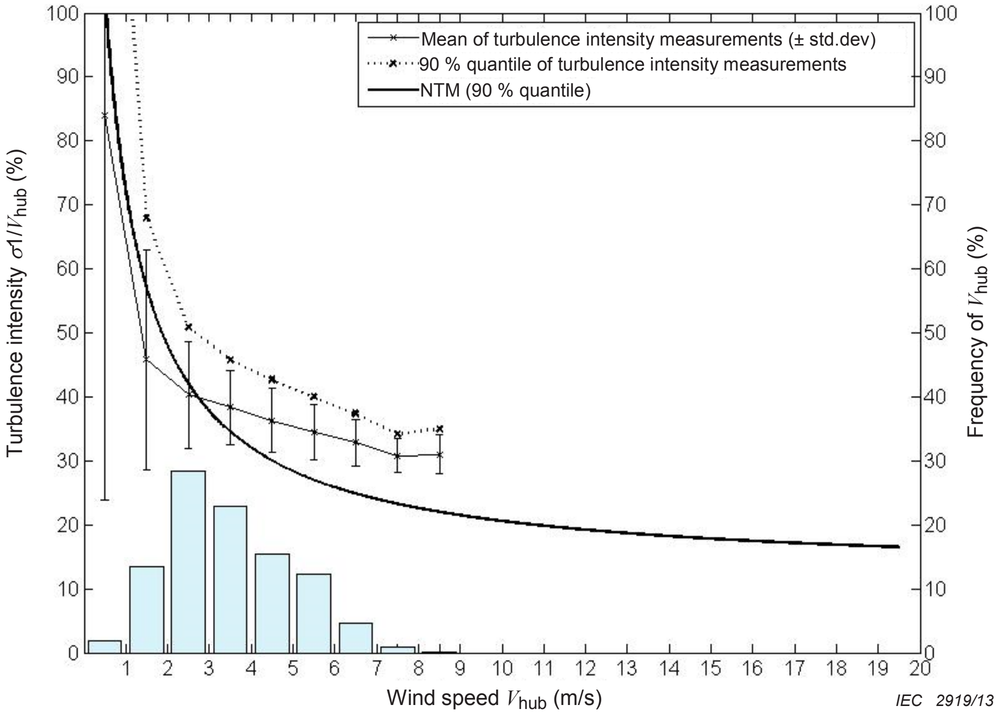


Figure L.5 – Turbulence intensity and wind distribution, 2 m above rooftop in Melville, Western Australia, during Jan-Feb 2009, reference [L.4][5]

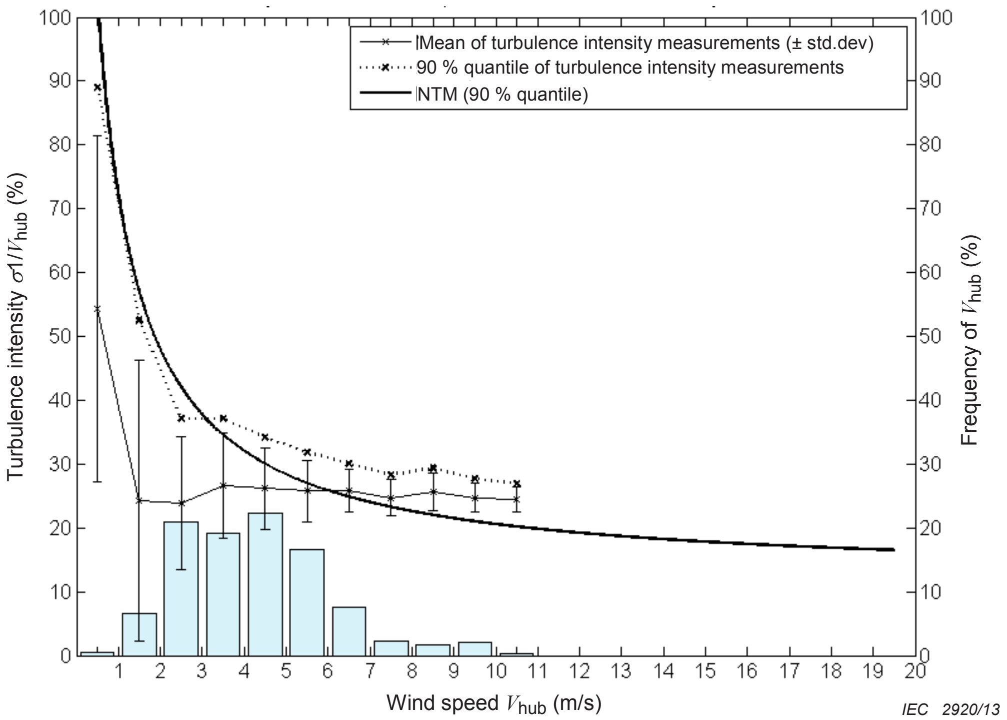


Figure L.6 – Turbulence intensity and wind speed distribution, 5,7 m above a rooftop in Port Kennedy, Western Australia, during Feb-Mar 2010, reference [L.4]

5 References in square brackets refer to references listed in Clause L.8.

As can be seen in reviewing Figures L.3, L.4, L.5, L.6, L.7, L.8 and L.9 above and below, the NTM with the parameters defined for the standard SWT classes does not well represent the complex environments. Note that for all sites above, the 90 % quantile of turbulence intensity measurements is higher than the model for the typical operational range of wind turbines when the wind speed is above approximately 3 m/s. The higher measurements compared to models, over the range 0,2 V_{ref} to 0,4 V_{ref} (typically 6 m/s to 20 m/s), would indicate per 11.9 in IEC 61400-1:2005 that a wind turbine designed to these model values would not be suitable for the site.

The conclusion is that these environments can have much more severe turbulence conditions than is specified in the main body of this standard.

L.6 Extreme wind direction changes

In 6.3.3.4, extreme direction changes (EDC) of the wind, and elsewhere corresponding SWT load cases, are defined. These can be compared with the following examples of real world extreme events in complex environments.

Extreme wind direction changes have been studied in Japan above the roof of a two-story building surrounded by structures of different types and compared to the EDC model. The data points in the graph below show examples of measured extreme direction changes. For comparison, lines in the same graph show the EDC model for the recurrence period N of 1 year and 50 years (using a rotor diameter of 5 m and a hub height of 20 m).

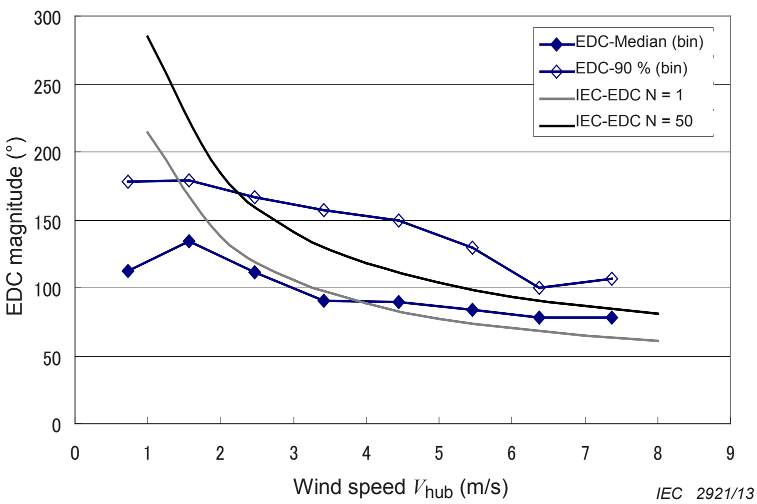


Figure L.7 – Example extreme direction changes; 1,5 m above a rooftop in Tokyo, Japan during three months February-May of 2007 (0,5 Hz data, reference [L.5])

During these few months of measurements, extreme direction changes were observed that are much larger than the model for 50 years recurrence period. Measurements during the five months September 2010 to February 2011 (1 Hz data) support this observation.

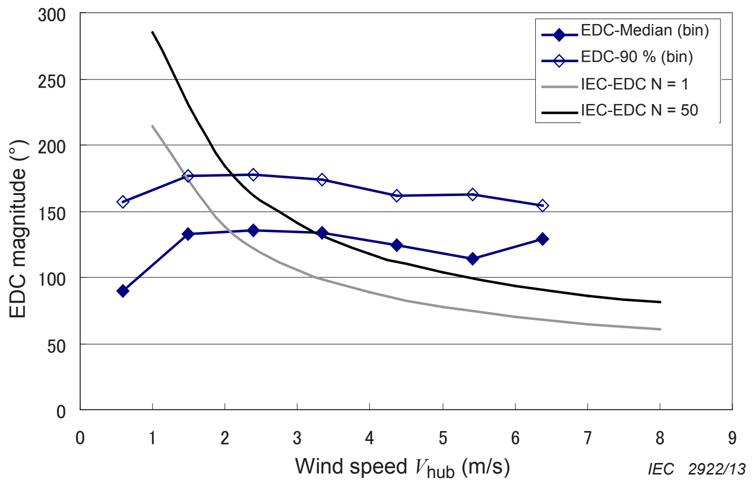


Figure L.8 – Example extreme direction changes; 1,5 m above a rooftop in Tokyo, Japan during five months September 2010 to February 2011 (1,0 Hz data, reference [L.5])

L.7 Gust factors

In 6.3.3.2, the extreme wind speed model (EWM) assumes a gust factor of 1,4. The gust factor is the ratio of the maximum 3-s average wind speed to the 10-min average wind speed. When measured at a height of 10 m, the gust factor usually varies over a small range: 1,45 is typical for a high latitude gale, while hurricanes can measure from 1,55 up to 1,66 (reference [L.6]). However other measurements in an urban rooftop environment in Australia have shown that the gust factor during one storm can be much higher, typically 4 and as high as 5,5 (when using 10-min averages) (reference [L.7]).

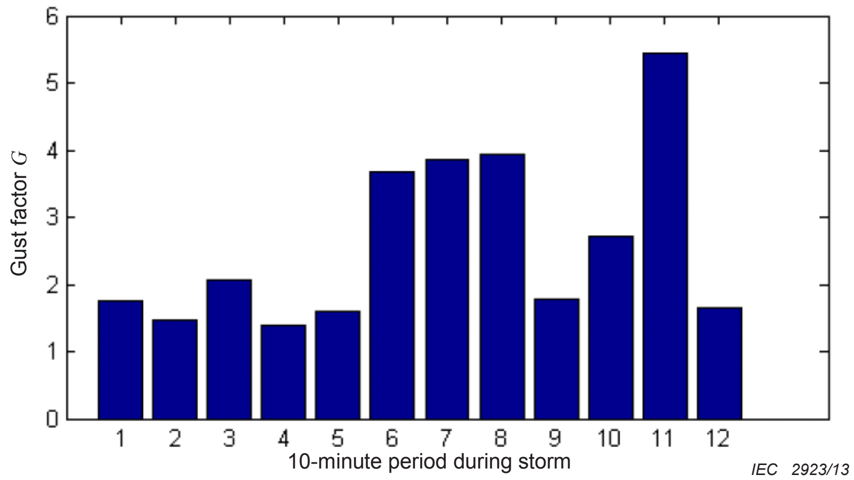


Figure L.9 – Gust factor measurements during storm in Port Kennedy, Western Australia, during March 2010, measured 5 m above rooftop compared with 10-min average wind speed

Note that also other extreme load cases, such as the extreme operating gust, can be more severe.

L.8 Reference documents

[L.1] Carbon Trust, Small Scale Wind Energy, Policy insights and practical guidance, 2008

[L.2] Met Office, Small-scale wind energy, Technical report, to accompany the Carbon Trust report, 2008 cited above

[L.3] CARPMAN, N., Turbulence Intensity in Complex Environments and its Influence on Small Wind Turbines; Uppsala University 2011; thesis

[L.4] WHALE, J., RUIN, S. and TOKUYAMA, H. Turbulence Intensity Values at Potential SWT Sites in Non-open Terrain, Presented at the International Energy Agency Task 27 Meeting, Ithaca, New York, April 28-29, 2012.

[L.5] TOKUYAMA, H., Analysis of field data regarding extreme wind direction changes on an urban rooftop site, unpublished data supplied to IEC 61400 MT2 committee, courtesy Nasu Denki Tekko Corporation

[L.6] HOLMES, J.D., Atmospheric boundary layers and turbulence, 2001, http://www.hurricaneengineering.lsu.edu

[L.7] DOWLEY, Mark., A Successful Roof-top Wind Power Project?, Murdoch University, MSc thesis 2010

[L.8] IEC 61400-1:2005, *Wind turbines – Part 1: Design requirements*

Annex M
(informative)

Consumer label

M.1 General

This annex describes a consumer label, hereafter called a label. If a label looking similar to the label in this annex is provided, this entire annex shall be followed.

It is recommended that a label be provided for each small wind turbine model. The label is based on tests conducted per the relevant IEC standards on one or more individual wind turbines (same model but different serial numbers), and can then be used for wind turbines of the same fundamental design.

The label can be shown on shipping containers or packaging, the turbine itself, operation and maintenance manuals and marketing literature related to that wind turbine model. A web site shows more detailed information and can also be used to ensure the validity of the label itself.

M.2 Administration

M.2.1 General

An organisation that publishes a label is below called the labelling organisation. The intention is that results displayed on a label will be comparable to results on other labels, regardless of who publishes the label. Therefore it is necessary that the labelling organisation shall at all times act in an objective manner.

M.2.2 Test summary report

The labelling organisation publishes a test summary report. The test summary report shall have the following minimum contents, which may be achieved by publishing the full measurement reports:

1) Name of labelling organisation, publication date of test summary report and unique test summary report number with current revision number.
2) A photograph of the turbine tested.
3) The specification provided by the manufacturer in accordance with 11.2.2.
4) The name and contact information of the manufacturer.
5) The tested turbine configuration, as verified by the test organisation including as a minimum:
    a) model name and serial number;
    b) support structure;
    c) hub height;
    d) general description of main components;
    e) rotor diameter (m) (if applicable);
    f) swept area (m^2);
    g) number of blades;
    h) upwind or downwind rotor (if applicable);
    i) VAWT or HAWT or other;
    j) direction of rotation;

k) cut-in wind speed (m/s);

l) cut-out wind speed if observed (m/s);

m) observed max. 3 s gust during duration test (m/s);

n) power form;

o) observed ambient temperature range during duration test (°C).

6) Power curve and annual energy production (see Annex H for example formats).

7) Measured and declared sound power level at a wind speed of 8 m/s, plus immission noise map (per IEC 61400-11).

8) Duration test results per 13.4.4 and turbine test class.

9) References to measurement reports with as a minimum the originating organisation, date issued, and unique report number.

10) A short description of how the requirements of ISO/IEC 17025 and relevant standards used to define the test requirements (e.g. IEC 61400-12-1) have been fulfilled, stating as a minimum whether any accredited test organisations were involved.

M.2.3 Publication of labels

When the labelling organisation deems that the requirements for labelling stated in this annex are fulfilled, they will publish the test summary report and a copy of the label on the web URL described in M.4 below. The labelling organisation shall obtain written consent from the manufacturer to do this.

M.2.4 Wind turbine variants

As described in Annex A wind turbines can appear in different variations. Therefore, the label and all documentation in relation to that needs to clearly indicate which variant it refers to.

M.3 Tests for labelling

M.3.1 General

The label summarizes the results of the following three tests, which are to be documented in measurement reports that meet the requirements of ISO/IEC 17025:

- duration test per section 13.4 of this standard IEC 61400-2; and,
- power performance test per IEC 61400-12-1; and
- acoustic noise test per IEC 61400-11.

The standards listed in Clause 2 shall be used, and note the requirement to "investigate the possibility of applying the most recent editions of the normative documents".

It is recommended that all tests for a particular label are carried out on the same site, by the same test organisation and using one wind turbine (i.e. one serial number). Deviations from this principle are allowed only if this is clearly stated in the test summary report (with a detailed description of the circumstances, such as different serial numbers used) and, if more than one wind turbine is used, it is assured that they are essentially the same. It is for example not allowed to test power performance with one set of blades configured for maximum power production, and test for noise with another set of blades designed for minimum noise.

M.3.2 Duration test

On the label the "turbine test class" shall show the SWT class for which the duration test has been completed in accordance with 13.4.

M.3.3 Power curve and reference annual energy

A power curve shall be measured in accordance with the small wind turbine annex (Annex H) of IEC 61400-12-1:2005. The corresponding reference annual energy shall be displayed as “reference annual energy” on the label.

M.3.4 Acoustic noise test

An acoustic noise test shall be conducted in accordance with IEC 61400-11. For the label only the apparent sound power level at 8,0 m/s at hub height shall be used. The IEC 61400-14 is then used to convert the measured sound power level at a wind speed of 8,0 m/s from one or more tests into a declared sound power level, which is displayed as “declared sound power level” on the label. This is in IEC 61400-14 called declared apparent sound power level and accounts for variability of the noise within a wind turbine population and the uncertainty in the measurements. The label takes no account of noise character.

Some models of small wind turbines will require test sites with very low background noise levels to conduct the testing.

M.4 Label layout

The label shall include information in the format shown in the sample of Figure M.1.

The example information in the gray parts of the label is to be replaced with the relevant information from the measurements of the wind turbine in question, or for the website URL.

No thousands separator is used. Numerical values on the label are displayed with decimals rounded to one decimal point for declared sound power level, and to the nearest integer for other values (e.g. 8 567,53 kWh/yr would be displayed as 8 568 kWh/yr; and 88,54 dB(A) would be displayed as 88,5 dB(A)).

The “published date” on the label is the publication date of the corresponding test summary report in the format YYYY-MM-DD.

A label is considered valid only if the consumer is able to find a copy of the label, together with the corresponding test summary report, on the web site URL stated on the label.

The example URL www.ieawind.org on the samples is to be replaced with the relevant URL for that particular label.

The label may be translated to other languages and an example of a bilingual version is shown in Figure M.2.

M.5 Reference documents

[M.1] Consumer Label For Small Wind Turbines: Recommended Practices For Wind Turbine Testing And Evaluation; IEA Wind (task 27); 2011-03-04 (edition1)

Test Results

Manufacturer	**Manufacturer**
Model	**Model**
Reference Annual Energy at 5 m/s average wind speed, actual production will vary depending on site conditions	**### kWh/yr**
Declared Sound Power Level at 8 m/s	**## dB(A)**
Turbine Test Class (I-IV or S for Special)	**II**
Tested by	**Test Organisation**
Published Date (Year-Month-Day)	**2011-03-04**

For more information, see
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IEC 2924/13

Figure M.1 – Sample label in English

Test Results / Résultats des Essais

Manufacturer / Fabricant	**Manufacturer**
Model / Modèle	**Model**
Reference Annual Energy / Énergie Annuelle de Référence at 5 m/s average wind speed, actual production will vary depending on site conditions / vitesse moyenne du vent à 5 m/s, la production réelle peut varier selon les conditions du site	**### kWh/yr**
Declared Sound Power Level / Niveau de Puissance de Bruit Déclaré at 8 m/s / à 8 m/s	**## dB(A)**
Turbine Test Class / Classe d´Éolienne Testée (I-IV or S for Special) / (I-IV ou S pour Spécial)	**II**
Tested by / Testé par	**Test Organisation / Organisme d´Essai**
Published Date / Date de Publication (Year-Month-Day) / (Année-Mois-Jour)	**2011-03-04**

For more information, see / Pour plus d'informations, voir
www.ieawind.org

IEC 2925/13

Figure M.2 – Sample bilingual label (English/French)

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