

INTERNATIONAL STANDARD

IEC
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Second edition
1999-02

Wind turbine generator systems –

Part 1: Safety requirements

*Aérogénérateurs –
Partie 1:
Spécifications de sécurité*



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND TURBINE GENERATOR SYSTEMS –

Part 1: Safety requirements

FOREWORD

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International Standard IEC 61400-1 has been prepared by IEC technical committee 88: Wind turbine systems.

This second edition of IEC 61400-1 cancels and replaces the first edition published in 1994.

The text of this standard is based on the following documents:

FDIS	Report on voting
88/98/FDIS	88/103/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

Annexes A, B and C form an integral part of this standard.

Annex D is for information only.

A bilingual version of this standard may be issued at a later date.

INTRODUCTION

This International Standard outlines minimum safety requirements for wind turbine generator systems and is not intended for use as a complete design specification or instruction manual.

Any of the requirements of this standard may be waived if it can be suitably demonstrated that the safety of the system is not compromised. Nevertheless this waiver does not apply to clause 6.

Compliance with this standard does not relieve any person, organization, or corporation from the responsibility of observing other applicable regulations.

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WIND TURBINE GENERATOR SYSTEMS –

Part 1: Safety requirements

1 Scope and object

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

This standard is concerned with all subsystems of WTGS such as control and protection mechanisms, internal electrical systems, mechanical systems, support structures and the electrical interconnection equipment.

This standard applies to WTGS with a swept area equal to or larger than 40 m².

This standard should be used together with the appropriate IEC/ISO standards identified in clause 2.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 61400. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this part of IEC 61400 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60204-1:1997, *Safety of machinery – Electrical equipment of machines – Part 1: General requirements*

IEC 60364 (all parts), *Electrical installations of buildings*

IEC 60721-2-1:1982, *Classification of environmental conditions – Part 2: Environmental conditions appearing in nature – Temperature and humidity*

IEC 61000-3-2:1998, *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤16 A per phase)*

IEC 61000-3-3:1994, *Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage fluctuations and flicker in low-voltage supply systems for equipment with rated current ≤16 A*

IEC 61000-4-2:1995, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test. Basic EMC publication*

IEC 61000-4-3:1995, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test*

IEC 61000-4-4:1995, *Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test. Basic EMC publication*

IEC 61000-4-5:1995, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC 61024-1:1990, *Protection of structures against lightning – Part 1: General principles*

IEC 61312-1:1995, *Protection against lightning electromagnetic impulse – Part 1: General principles*

ISO 2394:1986, *General principles on reliability for structures*

3 Terms and definitions

For the purpose of this International Standard, the following 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. The averaging time interval shall be a whole number of years to average out non-stationary effects such as seasonality

3.2

annual average wind speed

wind speed averaged according to the definition of annual average

3.3

auto-reclosing cycle

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

blocking (wind turbines)

use of a mechanical pin or other device (other than the ordinary mechanical brake) to prevent movement, for instance of the rotor shaft or yaw mechanism

3.5

brake (wind turbines)

device capable of reducing the rotor speed or stopping rotation

3.6

catastrophic failure (wind turbines)

disintegration or collapse of a component or structure, that results in loss of vital function which impairs safety

3.7

characteristic value (of a material property)

value having a prescribed probability of not being attained in a hypothetical unlimited test series

3.8**complex terrain**

surrounding terrain that features significant variations in topography and terrain obstacles that may cause flow distortion

3.9**control system (wind turbines)**

subsystem that receives information about the condition of the wind turbine and/or its environment and adjusts the turbine in order to maintain it within its operating limits

3.10**cut-in wind speed (V_{in})**

lowest mean wind speed at hub-height at which the wind turbine starts to produce power (see 3.24, hub-height)

3.11**cut-out wind speed (V_{out})**

highest mean wind speed at hub-height at which the wind turbine is designed to produce power (see 3.24, hub-height)

3.12**design limits**

maximum or minimum values used in a design

3.13**dormant failure (also known as latent fault)**

failure of a component or system which remains undetected during normal operation

3.14**downwind**

in the direction of the main wind vector

3.15**electrical power network**

particular installations, substations, lines or cables for the transmission and distribution of electricity

NOTE – The boundaries of the different parts of this network are defined by appropriate criteria, such as geographical situation, ownership, voltage, etc.

3.16**emergency shutdown (wind turbines)**

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

3.17**environmental conditions**

characteristics of the environment (altitude, temperature, humidity, etc.) which may affect the WTGS behaviour

3.18**external conditions (wind turbines)**

factors affecting operation of a wind turbine, including the wind regime, the electrical network conditions, and other climatic factors (temperature, snow, ice, etc.)

3.19

extreme wind speed

highest average wind speed, averaged over t s, that is likely to be experienced within a specified time period of N years ("recurrence period": N years)

NOTE – In this standard recurrence periods of $N = 50$ years and $N = 1$ year and averaging time intervals of $t = 3$ s and $t = 10$ min are used. In popular language, the less precise term "survival wind speed" is often used. In this standard, however, the turbine is designed using extreme wind speeds for design load cases.

3.20

fail-safe

design property of an item which prevents its failures from resulting in critical faults

3.21

gust

temporary change in the wind speed

NOTE – A gust may be characterized by its rise-time, its magnitude and its duration.

3.22

horizontal axis wind turbine

wind turbine whose rotor axis is substantially parallel to the wind flow

3.23

hub (wind turbines)

fixture for attaching the blades or blade assembly to the rotor shaft

3.24

hub-height (wind turbines)

height of the centre of the swept area of the wind turbine rotor above the terrain surface (see 3.55, swept area)

3.25

idling (wind turbines)

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

3.26

inertial subrange

frequency interval of the wind turbulence spectrum, where eddies – after attaining isotropy – undergo successive break-up with negligible energy dissipation

NOTE – At a typical 10 m/s wind speed, the inertial subrange is roughly from 0,02 Hz to 2 kHz.

3.27

isolated operation

stable and temporary operation of a discrete part of a power system after network splitting

3.28

limit state

state of a structure and the loads acting upon it, beyond which the structure no longer satisfies the design requirement (ISO 2394)

NOTE – 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).

3.29

logarithmic wind shear law

see wind profile

3.30**maximum power (wind turbines)**

highest level of net electrical power delivered by a wind turbine in normal operation

3.31**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

3.32**nacelle**

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

3.33**network connection point (wind turbines)**

cable terminals of a single wind turbine or, for a wind power station, the connection point to the electrical bus of the site power collection system

3.34**normal shutdown (wind turbines)**

shutdown in which all stages are under the control of the control system

3.35**operating limits**

set of conditions defined by the WTGS designer that govern the activation of the control and protection system

3.36**parked wind turbine**

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

3.37**power collection system (wind turbines)**

electric connection system that collects the power from one or more wind turbines. It includes all electrical equipment connected between the WTGS terminals and the network connection point

3.38**power law for wind shear**

see wind profile

3.39**power output**

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

NOTE (wind turbines) – The electric power delivered by a WTGS.

3.40**protection system (wind turbine)**

system which ensures that a WTGS remains within the design limits

3.41

rated power

quantity of power assigned, generally by a manufacturer, for a specified operating condition of a component, device or equipment

NOTE (wind turbines) – Maximum continuous electrical power output which a WTGS is designed to achieve under normal operating conditions.

3.42

rated wind speed (V_r)

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

3.43

Rayleigh distribution

probability distribution function, see 3.66 (wind speed distribution)

3.44

reference wind speed (V_{ref})

basic parameter for wind speed used for defining WTGS classes. Other design related climatic parameters are derived from the reference wind speed and other basic WTGS class parameters (see clause 6)

NOTE – A turbine designed for a WTGS 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} .

3.45

resonance

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

3.46

rotationally sampled wind velocity

wind velocity experienced at a fixed point of the rotating wind turbine rotor

NOTE – The turbulence spectrum of a rotationally sampled wind velocity is distinctly different from the normal turbulence spectrum. While rotating, the blade cuts through a wind flow that varies in space. Therefore, the resulting turbulence spectrum will contain sizeable amounts of variance at the frequency of rotation and harmonics of the same.

3.47

rotor speed (wind turbines)

rotational speed of a wind turbine rotor about its axis

3.48

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

3.49

safe life

prescribed service life with a declared probability of catastrophic failure

3.50

scheduled maintenance

preventive maintenance carried out in accordance with an established time schedule

3.51

serviceability limit state

limit state which corresponds with criteria governing function related normal use (ISO 2394)

3.52**standstill**

condition of a WTGS that is stopped

3.53**support structure (wind turbines)**

part of a wind turbine comprising the tower and foundation

3.54**survival wind speed**

popular name for the maximum wind speed that a construction is designed to withstand

NOTE – In this standard, the expression is not used. Design conditions instead refer to extreme wind speed (see 3.19).

3.55**swept area**

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

3.56**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

3.57**turbulence scale parameter**

wave length where the non-dimensional, longitudinal power spectral density is equal to 0,05

NOTE – The wave length is thus defined as $\lambda_1 = V_{hub}/f_0$, where $f_0 S_1(f_0)/\sigma_1^2 = 0,05$

3.58**ultimate limit state**

limit states which generally correspond to maximum load carrying capacity (ISO 2394)

3.59**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

3.60**upwind**

in the direction opposite to the main wind vector

3.61**vertical axis wind turbine**

wind turbine whose rotor axis is vertical

3.62**Weibull distribution**

probability distribution function, see 3.66 (wind speed distribution)

3.63**wind farm**

see 3.64 (wind power station)

3.64**wind power station**

group or groups of wind turbine generators, commonly called a wind farm

3.65

wind profile – wind shear law

mathematical expression for assumed wind speed variation with height above ground

NOTE – 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

3.66

wind speed distribution

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

NOTE – Often used distribution functions are the Rayleigh $P_R(V_0)$, and the Weibull $P_W(V_0)$, functions.

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

$$P_W(V_0) = 1 - \exp \left[-(V_0/C)^k \right]$$

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

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.

3.67**wind shear**

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

3.68**wind shear exponent**

also commonly known as power law exponent, see 3.65 (wind profile – wind shear law)

3.69**wind speed**

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

NOTE – The wind speed is also the magnitude of the local wind velocity (vector) (see 3.71, wind velocity).

3.70**wind turbine generator system (WTGS)**

system which converts kinetic energy in the wind into electrical energy

3.71**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 – The vector at any point is thus the time derivative of the position vector of the air "parcel" moving through the point.

3.72**WTGS electrical system**

all electrical equipment internal to the WTGS, up to and including the WTGS terminals, including equipment for earthing, bonding and communications. Conductors local to the WTGS which are intended to provide an earth termination network specifically for the WTGS are included

3.73**WTGS terminals**

point or points identified by the WTGS supplier at which the WTGS may be connected to the power collection system. This includes connection for the purposes of transferring energy and communications

3.74**yawing**

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

3.75**yaw misalignment**

horizontal deviation of the wind turbine rotor axis from the wind direction

4 Symbols and abbreviated terms

4.1 Symbols and units

a	slope parameter for turbulence standard deviation model	[-]
C	scale parameter of the Weibull distribution function	[m/s]
Coh	coherency function	
D	rotor diameter	[m]
f	frequency	[s ⁻¹]
f_d	design value for material strength	[-]
f_k	characteristic value for material strength	[-]
F_d	design value for loads	[-]
F_k	characteristic value for loads	[-]
I_{15}	characteristic value of hub-height turbulence intensity at a 10 min average wind speed of 15 m/s	[-]
k	shape parameter of the Weibull distribution function	[-]
K	modified Bessel function	[-]
L	isotropic turbulence integral scale parameter	[m]
L_e	coherency scale parameter	[m]
L_k	velocity component integral scale parameter	[m]
n_i	counted number of fatigue cycles in load bin i	[-]
$N(.)$	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	[y]
p	survival probability	[-]
$P_R(V_0)$	Rayleigh probability distribution, i.e. the probability that $V < V_0$	[-]
$P_W(V_0)$	Weibull probability distribution	[-]
r	magnitude of separation vector projection	[m]
s_i	the stress (or strain) level associated with the counted number of cycles in bin i	[-]
$S_1(f)$	power spectral density function	[m ² /s ²]
S_k	single-sided velocity component spectrum	[m ² /s ²]
T	gust characteristic time	[s]
t	time	[s]
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_{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_0	limit wind speed in wind speed distribution model	[m/s]
V_{out}	cut-out wind speed	[m/s]
V_r	rated wind speed	[m/s]

V_{ref}	reference wind speed averaged over 10 min	[m/s]
$V(y,z,t)$	longitudinal wind velocity component to describe transient horizontal wind shear	[m/s]
$V(z,t)$	longitudinal wind velocity component to describe transient variation for extreme gust and shear conditions	[m/s]
x, y, z	coordinate 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	[-]
δ	coefficient of variation	[-]
Γ	gamma function	[-]
γ_f	partial safety factor for loads	[-]
γ_m	partial safety factor for materials	[-]
γ_n	partial safety factor for consequences of failure	[-]
$\theta(t)$	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	[°]
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]
σ_1	hub-height longitudinal wind velocity standard deviation	[m/s]
σ_k	k^{th} hub-height component wind velocity standard deviation ($k = 1, 2, \text{ or } 3$)	[m/s]

4.2 Abbreviations

A	Abnormal (for partial safety factors)
a.c.	Alternating current
C	Serviceability constraint
d.c.	Direct current
DLC	Design load case
ECD	Extreme coherent gust with direction change
ECG	Extreme coherent gust
EDC	Extreme wind direction change
EOG	Extreme operating gust
EWM	Extreme wind speed model
EWS	Extreme wind shear
F	Fatigue
HAWT	Horizontal axis wind turbine
N	Normal and extreme (for partial safety factors)
NWP	Normal wind profile model
NTM	Normal turbulence model
S	Special IEC WTGS class

T	Transport and erection (for partial safety factors)
U	Ultimate
VAWT	Vertical axis wind turbine
WTGS	Wind turbine generator system(s)

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 WTGS are given in the following clauses. This specification of requirements applies to the design, manufacture, installation and maintenance of WTGS and the associated quality management process. In addition, safety procedures which have been established in the various technologies that are used in the installation, operation and maintenance of WTGS shall be followed.

5.2 Design methods

This standard requires the use of a structural dynamics model to predict design loads. This 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 clause 6, and design situations defined in clause 7. All relevant combinations of external conditions and design situations shall be analyzed. A minimum set of such combinations has been defined as load cases in this standard.

Data from full scale testing of a WTGS may be used to increase confidence in predicted design values and to verify structural dynamics models and design situations.

Verification of the adequacy of the design shall be made by calculation and/or by testing. If test results are used in this verification, the external conditions during the test shall be shown to reflect the characteristic values and design situations defined in this standard. The selection of test conditions, including the test loads, shall take account of the relevant safety factors.

5.3 Safety classes

A WTGS shall be designed according to one of the following two safety classes:

- a normal safety class which applies when a failure results in risk of personal injury or economic and social consequences;
- a special safety class which applies when the safety requirements are determined by local regulations and/or the safety requirements are agreed between the manufacturer and the customer.

Partial safety factors, for normal safety class WTGS, are specified in 7.6 of this standard.

Partial safety factors for special safety class WTGS shall be agreed between the manufacturer and the customer. A WTGS designed according to the special safety class is a WTGS class S turbine as defined in 6.2.

5.4 Quality assurance

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

It is recommended that the quality system complies with the requirements of the relevant ISO publications (see bibliography in annex D).

5.5 Wind turbine markings

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

- WTGS manufacturer and country;
- model and serial number;
- production year;
- rated power;
- reference wind speed, V_{ref} ;
- hub-height operating wind speed range, $V_{in} - V_{out}$;
- operating ambient temperature range;
- IEC WTGS class (see table 1);
- rated voltage at the WTGS terminals;
- frequency at the WTGS terminals or frequency range in the case that the nominal variation is greater than 2 %.

6 External conditions

6.1 General

The external conditions described in this clause shall be considered in the design of a WTGS.

WTGS are subjected to environmental and electrical conditions which 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 further divided into wind conditions and other environmental conditions. The electrical conditions refer to the network conditions. Soil properties are relevant to the design of WTGS foundations.

Each type of external condition may be subdivided into a normal 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.

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.

The normal and extreme conditions which are to be considered in design according to WTGS classes are prescribed in the following subclauses.

6.2 WTGS classes

The external conditions to be considered in design are dependent on the intended site or site type for a WTGS installation. WTGS classes are defined in terms of wind speed and turbulence parameters. The intention of the classes is to cover most applications. 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, see clause 11. The goal is to achieve WTGS classification with clearly varying robustness governed by the wind speed and turbulence parameters. Table 1 specifies the basic parameters which define the WTGS classes.

In cases where a special design (e.g. special wind conditions or other external conditions or a special safety class, see 5.3) is necessary, a further WTGS class, class S, is defined. The design values for the WTGS class S shall be chosen by the designer and specified in the design documentation. For such special designs, the values chosen for the design conditions shall reflect a more severe environment than anticipated for the use of the WTGS.

The particular external conditions of offshore installations require WTGS class S design.

Table 1 – Basic parameters for WTGS classes

WTGS 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	
A I_{15} (–)	0,18	0,18	0,18	0,18	
a (–)	2	2	2	2	
B I_{15} (–)	0,16	0,16	0,16	0,16	
a (–)	3	3	3	3	

where

the values apply at hub-height, and

A designates the category for higher turbulence characteristics,

B designates the category for lower turbulence characteristics,

I_{15} is the characteristic value of the turbulence intensity at 15 m/s,

a is the slope parameter to be used in equation (7).

In addition to these basic parameters, several important further parameters are required to specify completely the external conditions used in WTGS design. In the case of the WTGS classes I_A through IV_B, later referred to as standard WTGS classes, the values of these additional parameters are specified in 6.3, 6.4 and 6.5.

The design lifetime is to be at least 20 years.

For the WTGS class S the manufacturer shall in the design documentation describe the models used and values of essential design parameters. Where the models in clause 6 are adopted, statement of the values of the parameters will be sufficient. The design documentation of WTGS class S shall contain the information listed in annex A.

The abbreviations added in parentheses in the subclause headings in the remainder of this clause are used for describing the wind conditions for the design load cases defined in 7.4.

6.3 Wind conditions

A WTGS shall be designed to withstand safely the wind conditions defined by the selected WTGS 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 which will occur frequently during normal operation of a WTGS, and the extreme wind conditions which are defined as having a 1 year or 50 year recurrence period.

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.

6.3.1 Normal wind conditions

6.3.1.1 Wind speed distribution

The wind speed distribution at the site is significant for the WTGS design because it determines the frequency of occurrence of the individual load conditions. In case of the standard WTGS 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 probability distribution at hub-height is given by:

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

6.3.1.2 The 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 WTGS classes, the normal wind speed profile shall be assumed to be given by the power law:

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

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.

6.3.1.3 Normal turbulence model (NTM)

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 WTGS 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):

$$\sigma_1 = I_{15} (15 \text{ m/s} + aV_{hub})/(a+1) \quad (7)$$

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 1 as a function of wind speed for the specified values of I_{15} and a .

1) To perform the calculations of load cases in addition to those specified in table 2, it may be appropriate to use different percentile values. Such percentile values shall be determined by adding a value to equation 7 given by:

$$\Delta\sigma_1 = (x-1)(2 \text{ m/s})/I_{15}$$

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

The standard deviation is assumed to be invariant with height.

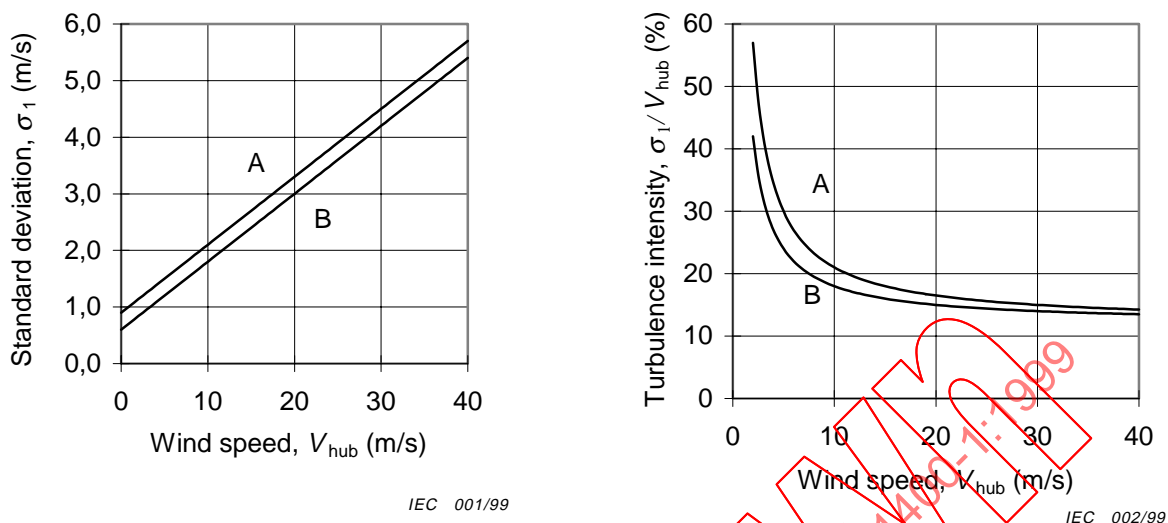


Figure 1 – Characteristic wind turbulence

- 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:

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

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

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

Specifications for stochastic turbulence models which satisfy these requirements are given in annex B. In annex C 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 C.

6.3.2 Extreme wind conditions

The extreme wind conditions are used to determine extreme wind loads on WTGS. 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.

6.3.2.1 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 WTGS designs in the standard WTGS classes, V_{e50} and V_{e1} shall be computed as a function of height z using the following equations:

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

$$V_{e1}(z) = 0,75 V_{e50}(z) \quad (11)$$

where z_{hub} is the hub-height ²⁾.

Short-term deviations from the mean wind direction of $\pm 15^\circ$ shall be assumed.

6.3.2.2 Extreme operating gust (EOG)

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

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

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;

$\beta = 4,8$ for $N = 1$; and

$\beta = 6,4$ for $N = 50$.

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

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

where

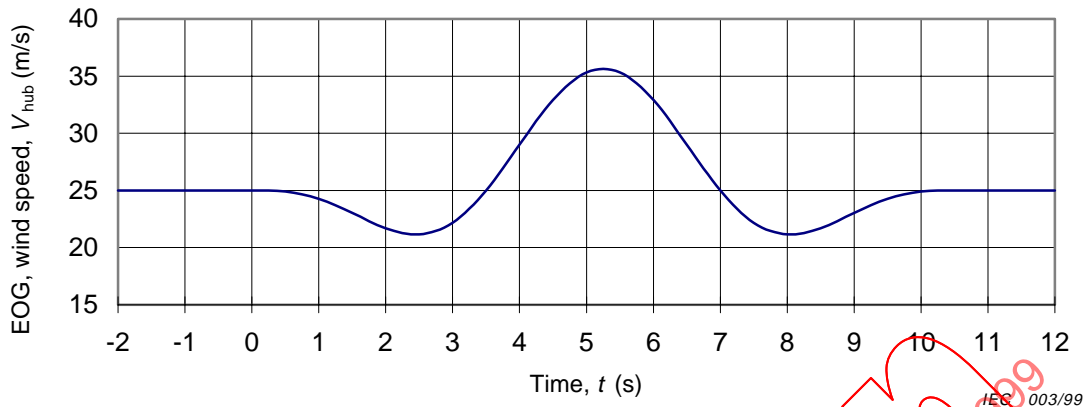
$V(z)$ is defined in equation (6);

$T = 10,5$ 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, turbulence category A, rotor diameter 42 m, hub height 30 m and $V_{hub} = 25$ m/s is shown in figure 2:

²⁾ NOTE – Local structural engineering codes may prescribe a variation of wind speed or dynamic pressure with height which is slightly different from that which results from the relation given above.



**Figure 2 – Example of extreme operating gust ($N = 1$, category A,
 $D = 42$ m, $z_{\text{hub}} = 30$ m, $V_{\text{hub}} = 25$ m/s)**

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

6.3.2.3 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:

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

where

θ_{eN} is limited to the interval $\pm 180^\circ$;

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

D is the rotor diameter;

$\beta = 4,8$ for $N = 1$; and

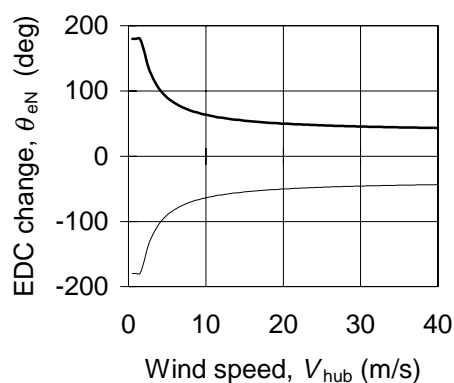
$\beta = 6,4$ for $N = 50$.

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

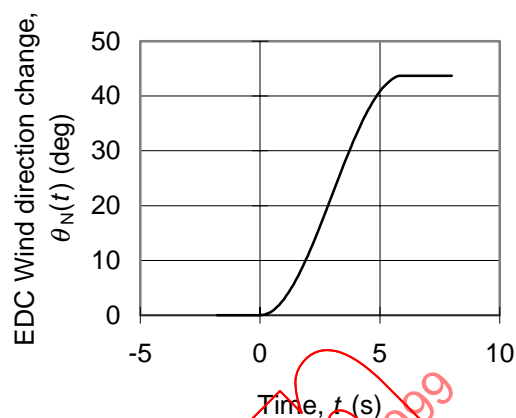
$$\theta_N(t) = \begin{cases} 0 & \text{for } t < 0 \\ 0,5 \theta_{eN} (1 - \cos(\pi t / T)) & \text{for } 0 \leq t \leq T \\ \theta_{eN} & \text{for } t > T \end{cases} \quad (15)$$

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. The wind speed is assumed to follow the normal wind profile of 6.3.1.2, the normal wind profile model (NWP).

As an example, the extreme direction change with a recurrence period of 50 years, turbulence category A, rotor diameter 42 m, hub height 30 m and $V_{\text{hub}} = 25$ m/s is shown in figure 3.



IEC 004/99



IEC 005/99

Figure 3 – Example of extreme direction change magnitude ($N = 50$, category A, $D = 42$ m, $z_{\text{hub}} = 30$ m) **Figure 4 – Example of extreme direction change ($N = 50$, category A, $D = 42$ m, $z_{\text{hub}} = 30$ m, $V_{\text{hub}} = 25$ m/s)**

6.3.2.4 Extreme coherent gust (ECG)

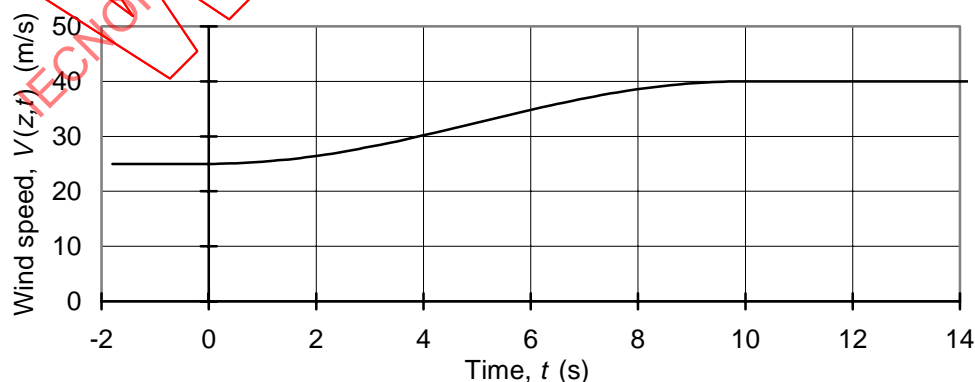
For WTGS designs for the standard WTGS classes, an extreme coherent gust with a magnitude of:

$$V_{\text{cg}} = 15 \text{ m/s}$$

shall be assumed. The wind speed shall be defined by the relations:

$$V(z, t) = \begin{cases} V(z) & \text{for } t < 0 \\ V(z) + 0.5 V_{\text{cg}} (1 - \cos(\pi t/T)) & \text{for } 0 \leq t \leq T \\ V(z) + V_{\text{cg}} & \text{for } t > T \end{cases} \quad (16)$$

where $T = 10$ s is the rise time and $V(z)$ the wind speed given in 6.3.1.2. The normal wind profile model of wind speed as specified in equation (6) shall be used. The extreme coherent gust is illustrated in figure 5 for $V_{\text{hub}} = 25$ m/s.



IEC 006/99

Figure 5 – Extreme coherent gust ($V_{\text{hub}} = 25$ m/s) (ECG)

6.3.2.5 Extreme coherent gust with direction change (ECD)

In this case, the rise in wind speed (described by ECG, see figure 5) shall be assumed to occur simultaneously with the direction change θ_{cg} , where θ_{cg} is defined by the relations:

$$\theta_{cg}(V_{hub}) = \begin{cases} 180^\circ & \text{for } V_{hub} < 4 \text{ m/s} \\ \frac{720^\circ \text{ m/s}}{V_{hub}} & \text{for } 4 \text{ m/s} \leq V_{hub} \leq V_{ref} \end{cases} \quad (17)$$

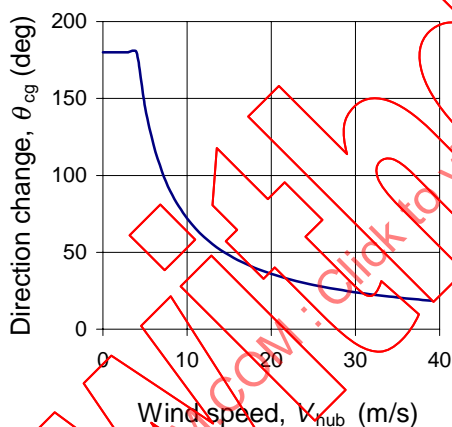
The simultaneous direction change is then given by:

$$\theta(t) = \begin{cases} 0^\circ & \text{for } t < 0 \\ \pm 0,5 \theta_{cg} (1 - \cos(\pi t/T)) & \text{for } 0 \leq t \leq T \\ \pm \theta_{cg} & \text{for } t > T \end{cases} \quad (18)$$

where $T = 10 \text{ s}$ is the rise time.

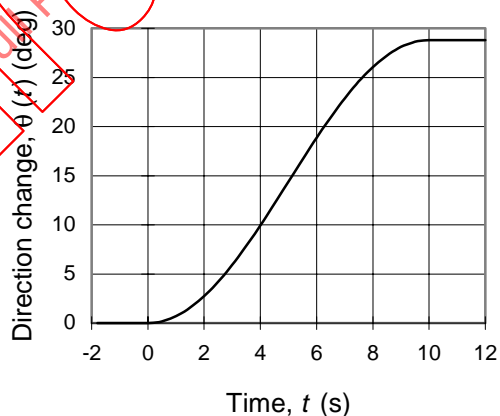
The normal wind profile model as specified in equation (6) shall be used.

The direction change, θ_{cg} , as a function of V_{hub} and as a function of time for $V_{hub} = 25 \text{ m/s}$ is shown in figures 6 and 7, respectively.



IEC 007/99

Figure 6 – The direction change for ECD



IEC 008/99

Figure 7 – Time development of direction change for $V_{hub} = 25 \text{ m/s}$

6.3.2.6 Extreme wind shear (EWS)

The extreme wind shear with a recurrence period of 50 years shall be accounted for using the following two wind speed transients:

- for transient vertical shear:

$$V(z,t) = \begin{cases} V_{\text{hub}} \left(\frac{z}{z_{\text{hub}}} \right)^{\alpha} + \left(\frac{z - z_{\text{hub}}}{D} \right) \left(2,5 + 0,2 \beta \sigma_1 \left(\frac{D}{\Lambda_1} \right)^{1/4} \right) \left(1 - \cos \left(\frac{2 \pi t}{T} \right) \right) & \text{for } 0 \leq t \leq T \\ V_{\text{hub}} \left(\frac{z}{z_{\text{hub}}} \right)^{\alpha} & \text{for } t < 0 \text{ and } t > T \end{cases} \quad (19)$$

- for transient horizontal shear:

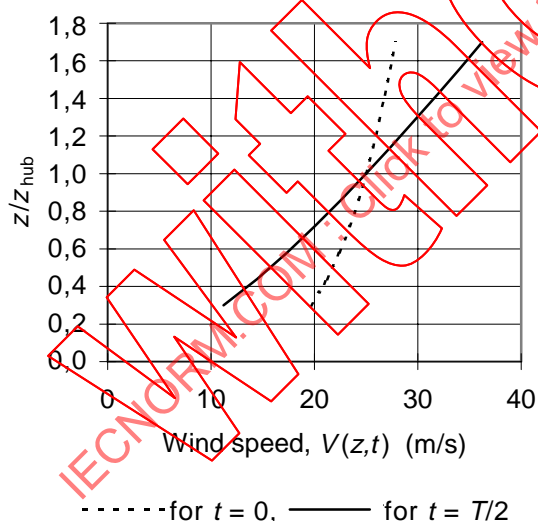
$$V(y,z,t) = \begin{cases} V_{\text{hub}} \left(\frac{z}{z_{\text{hub}}} \right)^{\alpha} + \left(\frac{y}{D} \right) \left(2,5 + 0,2 \beta \sigma_1 \left(\frac{D}{\Lambda_1} \right)^{1/4} \right) \left(1 - \cos \left(\frac{2 \pi t}{T} \right) \right) & \text{for } 0 \leq t \leq T \\ V_{\text{hub}} \left(\frac{z}{z_{\text{hub}}} \right)^{\alpha} & \text{for } t < 0 \text{ and } t > T \end{cases} \quad (20)$$

where

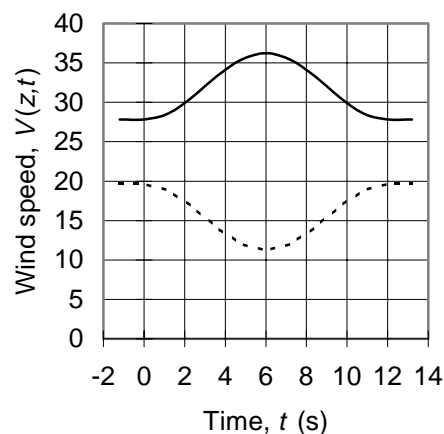
$\alpha = 0,2$; $\beta = 6,4$; $T = 12$ s;

Λ_1 is the turbulence scale parameter, according to equation (9) and

D is the rotor diameter.



IEC 009/99



IEC 010/99

Figure 8 – Extreme vertical wind shear, wind profile before onset ($t = 0$, dashed line) and at maximum shear ($t = 6$ s, full line) ($N = 50$, turbulence category A, $z_{\text{hub}} = 30$ m, $V_{\text{hub}} = 25$ m/s, $D = 42$ m)

Figure 9 – Wind speeds at rotor top and bottom respectively illustrate the time development of wind shear (assumptions as in figure 8)

The sign for the horizontal wind shear transient shall be chosen so that the worst transient loading occurs. The two extreme wind shears are considered independently from each other and are therefore not applied simultaneously. As an example the 50 year extreme vertical wind shear is illustrated in figure 8 which shows the wind profiles before onset of the extreme event ($t = 0$ s) and at maximum shear ($t = 6$ s) and figure 9 shows the wind speeds at the top and the bottom of the rotor to illustrate the time development of the shear. In both figures, turbulence category A and $V_{hub} = 25$ m/s, $z_{hub} = 30$ m, rotor diameter $D = 42$ m are assumed.

6.4 Other environmental conditions

Environmental (climatic) conditions other than wind can affect the integrity and safety of the WTGS, 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:

- temperature;
- humidity;
- air density;
- solar radiation;
- rain, hail, snow and ice;
- chemically active substances;
- mechanically active particles;
- lightning;
- earthquakes;
- salinity.

An offshore 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 return period shall not interfere with the designed normal operation of a WTGS.

Unless correlation exists, other extreme environmental conditions according to 6.4.2, shall be combined with the normal wind conditions according to 6.3.1.

6.4.1 Other normal environmental conditions

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

- normal system operation ambient temperature range of -10 °C to $+40$ °C;
- relative humidity of up to 95 %;
- atmospheric content equivalent to that of a non-polluted inland atmosphere (see IEC 60721-2-1);
- solar radiation intensity of $1\,000$ W/m²;
- air density of $1,225$ kg/m³.

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

6.4.2 Other extreme environmental conditions

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

6.4.2.1 Temperature

The design values for the extreme temperature range shall be at least $-20\text{ }^{\circ}\text{C}$ to $+50\text{ }^{\circ}\text{C}$ for the standard WTGS classes.

6.4.2.2 Lightning

The provisions of lightning protection required in 10.6 may be considered as adequate for wind turbines in the standard WTGS classes.

6.4.2.3 Ice

No minimum ice requirements are given for the standard WTGS classes.

6.4.2.4 Earthquakes

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

6.5 Electrical power network conditions

The normal conditions at the WTGS 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 $\pm 10\%$
- Frequency
Nominal value $\pm 2\%$
- Voltage imbalance
The ratio of the negative-sequence component of voltage to the positive-sequence component will not exceed 2% .
- Outages
Electrical network outages shall be assumed to occur 20 times per year. The maximum outage duration for which the turbine shall be designed shall be at least one week.

7 Structural design

7.1 General

Wind turbine structural design shall be based on verification of the structural integrity of the load-carrying components. The ultimate and fatigue strength of structural members shall be verified by calculations and/or tests to demonstrate the structural integrity of a WTGS with the appropriate safety level.

The structural analysis shall be based on ISO 2394.

An acceptable safety level shall be ascertained and verified by calculations and/or tests to demonstrate that the design loading will not exceed the relevant design resistance.

Calculations shall be performed using appropriate methods. Descriptions of the calculation methods shall be provided in the design documentation. The descriptions shall include evidence of the validity of the calculation methods or references to suitable verification studies. The load level in any test shall reflect the factors of safety in the corresponding calculation.

7.2 Design methodology

It shall be verified that limit states are not exceeded for the wind turbine design. Model testing and prototype tests may also be used as a substitute for calculation to verify the structural design, as specified in ISO 2394.³⁾

7.3 Loads

Loads described in 7.3.1 through 7.3.4 shall be considered for the design calculations.

7.3.1 Inertial and gravitational loads

Inertial and gravitational loads are static and dynamic loads acting on WTGS resulting from vibration, rotation, gravity and seismic activity.

7.3.2 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 WTGS.

The airflow is dependent upon the rotational speed of the rotor, the average wind speed across the rotor plane, the turbulence, the density of the air, and the aerodynamic shapes of the wind turbine components and their interactive effects, including aeroelastic effects.

7.3.3 Operational loads

Operational loads result from the operation and control of WTGS. They are identified as being in several categories. These are the control of rotor speed such as torque control by pitching of blades or other aerodynamic devices. They include drive train mechanical braking and transient loads, caused by rotor stopping and starting, generator connection and disconnection and yawing loads.

7.3.4 Other loads

Other loads such as wave loads, wake loads, impact loads, ice loads, etc. may occur and shall be included where appropriate, see clause 11.

3) ISO 2394 defines the ultimate and serviceability limit states as follows: A state of a structure and the loads acting upon it, beyond which the structure no longer satisfies the design requirement. The purpose of design calculations is to keep the probability of a limit state being reached below a certain value prescribed for the type of structure in question.

For example, *Ultimate limit states* correspond to:

- loss of equilibrium of the structure, or of a part of the structure, considered as a rigid body (e.g. overturning);
- rupture of critical sections of the structure caused by exceeding the ultimate strength (in some cases reduced by repeated loading) or the ultimate deformation of the material;
- transformation of the structure into a mechanism (collapse), loss of stability (buckling, etc.).

For example, *Serviceability limit states* correspond to:

- deformations which affect the efficient use or appearance of structural or non-structural elements;
- excessive vibrations producing discomfort or affecting non-structural elements or equipment (especially if resonance occurs);
- local damage (including cracking) which reduces the durability of a structure or affects the efficiency or appearance of structural or non-structural elements.

To control serviceability limit states by design it is often necessary to use one or more constraints which describe acceptable deformations, accelerations, crack widths, etc.

7.4 Design situations and load cases

This subclause describes the construction of design load cases of WTGS and specifies a minimum number to be considered.

For design purposes, the life of a WTGS can be represented by a set of design situations covering the most significant conditions which the WTGS 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 WTGS may be calculated from the following combinations:

- normal design situations and normal external conditions;
- normal design situations and extreme external conditions;
- fault design situations and appropriate external conditions;
- transportation, installation and maintenance design situations and the appropriate external conditions.

If any 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 WTGS components. As a minimum, the design load cases in table 2 shall be considered. In that table the design load cases are specified for each design situation by the description of the wind, electrical and other external conditions.

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

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.

The design situations indicated with U, are classified as normal (N), abnormal (A), or transport and erection (T). Normal design situations are expected to occur frequently within the lifetime of a turbine. The turbine is in a normal state or may have experienced minor faults or abnormalities. Abnormal design situations are less likely to occur. They usually correspond to design situations with more severe faults like protection system faults. The type of design situation, N, A, or T, determines the partial safety factor γ to be applied to the ultimate loads. These factors are given in tables 3 and 4 in 7.6.

When a wind speed range is indicated in table 2, wind speeds leading to the most adverse condition for WTGS design shall be considered. The range may be divided into a number of bins; an appropriate fraction of the WTGS life shall be allocated to each bin. In the definition of the design load cases, reference is made to the wind conditions described in clause 6.

Table 2 – Design load cases

Design situation	DLC	Wind condition*	Other conditions	Type of analysis	Partial safety factors
1) Power production	1.1	NTM $V_{hub} = V_r$ or V_{out}		U	N
	1.2	NTM $V_{in} < V_{hub} < V_{out}$		F	*
	1.3	ECD $V_{hub} = V_r$		U	N
	1.4	NWP $V_{hub} = V_r$ or V_{out}	External electrical fault	U	N
	1.5	EOG ₁ $V_{hub} = V_r$ or V_{out}	Loss of electrical connection	U	N
	1.6	EOG ₅₀ $V_{hub} = V_r$ or V_{out}		U	N
	1.7	EWS $V_{hub} = V_r$ or V_{out}		U	N
	1.8	EDC ₅₀ $V_{hub} = V_r$ or V_{out}		U	N
	1.9	ECG $V_{hub} = V_r$		U	N
2) Power production plus occurrence of fault	2.1	NWP $V_{hub} = V_r$ or V_{out}	Control system fault	U	N
	2.2	NWP $V_{hub} = V_r$ or V_{out}	Protection system or preceding internal electrical fault	U	A
	2.3	NTM $V_{in} < V_{hub} < V_{out}$	Control or protection system fault	F	*
3) Start up	3.1	NWP $V_{in} < V_{hub} < V_{out}$		F	*
	3.2	EOG ₁ $V_{hub} = V_{in}, V_r$ or V_{out}		U	N
	3.3	EDC ₁ $V_{hub} = V_{in}, V_r$ or V_{out}		U	N
4) Normal shut down	4.1	NWP $V_{in} < V_{hub} < V_{out}$		F	*
	4.2	EOG ₁ $V_{hub} = V_r$ or V_{out}		U	N
5) Emergency shut down	5.1	NWP $V_{hub} = V_r$ or V_{out}		U	N
6) Parked (standing still or idling)	6.1	EWM $V_{hub} = V_{e50}$	Possible loss of electrical power network	U	N
	6.2	NTM $V_{hub} < 0,7 V_{ref}$		F	*
7) Parked and fault conditions	7.1	EWM $V_{hub} = V_{e1}$		U	A
8) Transport, assembly, maintenance and repair	8.1	To be stated by the manufacturer		U	T
For abbreviations, see next page.					
* If no cut-out wind speed V_{out} is defined, the value of V_{ref} should be used.					

DLC	Design load case
ECD	Extreme coherent gust with direction change (see 6.3.2.5)
ECG	Extreme coherent gust (see 6.3.2.4)
EDC	Extreme direction change (see 6.3.2.3)
EOG	Extreme operating gust (see 6.3.2.2)
EWM	Extreme wind speed model (see 6.3.2.1)
EWS	Extreme wind shear (see 6.3.2.6)
Subscript	Recurrence period in years
NTM	Normal turbulence model (see 6.3.1.3)
NWP	Normal wind profile model (see 6.3.1.2)
F	Fatigue
U	Ultimate
N	Normal and extreme
A	Abnormal
T	Transport and erection
*	Partial safety factor for fatigue (see 7.6.3)

7.4.1 Power production (DLC 1.1 – 1.9)

In this design situation, a WTGS is running and connected to the electric load. The assumed WTGS configuration shall take into account rotor imbalance. The maximum mass and aerodynamic imbalances (e.g. blade pitch and twist deviations) specified for rotor manufacture 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, for example direction change with characteristic yaw misalignment (DLC 1.8) or gust with loss of electrical connection (DLC 1.5).

Design load cases (DLC) 1.1 and 1.2 embody the requirements for loads resulting from atmospheric turbulence. DLC 1.3 and 1.6 – 1.9 specify transient cases which have been selected as potentially critical events in the life of a WTGS. In DLC 1.4 and 1.5 transitional events due to external faults and loss of electrical load are considered.

7.4.2 Power production plus occurrence of fault (DLC 2.1 – 2.3)

Any fault in the control or protection systems, or internal fault in the electrical system, significant for WTGS 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 analyzed. For DLC 2.2, the occurrence of faults in the protection or internal electrical systems which are considered to be rare events shall be analyzed. If a fault does not cause an immediate shutdown and the consequent loading can lead to significant fatigue damage, the likely duration of this situation shall be evaluated in DLC 2.3.

7.4.3 Start up (DLC 3.1 – 3.3)

This design situation includes all the events resulting in loads on a WTGS during the transients from any stand still or idling situation to power production.

7.4.4 Normal shut down (DLC 4.1 – 4.2)

This design situation includes all the events resulting in loads on a WTGS during normal transient situations from a power production situation to a stand-still or idling condition.

7.4.5 Emergency shut down (DLC 5.1)

Loads arising from emergency shut down shall be considered.

7.4.6 Parked (stand-still or idling) (DLC 6.1 – 6.2)

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. 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 on a parked wind turbine shall be taken into account.

7.4.7 Parked plus fault conditions (DLC 7.1)

Deviations from the normal behaviour of a parked WTGS, resulting from faults on the electrical network or in the WTGS, shall require analysis. If any fault other than a loss of electrical power network produces deviations from the normal behaviour of the WTGS in parked situations, the possible consequences shall be the subject of analysis. The fault condition shall be combined with the extreme wind speed model (EWM) and a recurrence period of one year.

7.4.8 Transport, assembly, maintenance and repair (DLC 8.1)

The manufacturer shall state all the wind conditions and design situations assumed for transport, assembly, maintenance and repair of a WTGS. The maximum allowed wind conditions shall be considered in the design if they can produce significant loading on the WTGS.

7.5 Load calculations

Loads as described in 7.3.1 through 7.3.4 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 WTGS 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 vibrational modes;
- aeroelastic effects;
- the behaviour of the control and protection system of the WTGS.

7.6 Ultimate limit state analysis

7.6.1 Method

The partial safety factors are dependent on the uncertainties and variabilities in loads and materials, the uncertainties in the analysis methods, and the importance of structural components with respect to the consequences of failure.

7.6.1.1 Partial safety factors

To assure safe design values for loads and materials, the uncertainties and variabilities in loads and materials are covered by partial safety factors for loads and materials defined in (21) and (22).

$$F_d = \gamma_f F_k \quad (21)$$

where

F_d is the design value for the load;

γ_f is the partial safety factor for the load; and

F_k is the characteristic value for the load. In this standard, the alternative term “representative value” is used in some cases, where a characteristic value is not easily evaluated statistically.

$$f_d = \frac{1}{\gamma_m} f_k \quad (22)$$

where

f_d is the design value for the material;

γ_m is the partial safety factor for the material; and

f_k is the characteristic value of the material property.

The partial safety factors for loads used in this standard are meant to take account of:

- the possibility of unfavourable deviations of the load from the characteristic value;
- uncertainties in the loading model.

The partial safety factors for materials used in this standard are meant to take account of:

- the possibility of unfavourable deviations of the strength of material from the characteristic value;
- possible inaccurate assessment of the resistance of sections or load-carrying capacity of parts of the structure;
- uncertainties in the geometrical parameters;
- uncertainties in the relation between the material properties in the structure and those measured by tests on control specimens, i.e. uncertainty in the conversion.

These different uncertainties are sometimes accounted for by means of individual partial safety factors, but in this standard as in most others, the load related factors are combined into one factor γ_f and the material related factors into one factor γ_m . The consequences of failure factor, γ_n , is introduced to distinguish between:

Component class 1: used for "fail-safe" structural components whose failure does not result in the failure of a major part of a WTGS;

Component class 2: used for "non fail-safe" structural components whose failures lead rapidly to the failure of a major part of a WTGS.

For the ultimate limit state analysis of the WTGS, the following four types of analysis shall be performed where relevant:

- analysis of ultimate strength (see 7.6.2);
- analysis of fatigue failure (see 7.6.3);
- stability analysis (buckling, etc.) (see 7.6.4);
- critical deflection analysis (mechanical interference between blade and tower, etc.) (see 7.6.5).

The general equation for non-exceedance of the ultimate limit state is:

$$\gamma_n \times S(F_d) \leq R(f_d) \quad (23)$$

Each type of analysis requires a different formulation of the load and resistance functions, S and R , and deals with different sources of uncertainties through the use of safety factors.

7.6.1.2 Application of recognized material codes

When determining the structural integrity of elements of a WTGS, national or international design codes for the relevant material may be employed. Special care shall be taken when partial safety factors from national or international design codes are used together with partial safety factors from this standard. It shall be ensured that the resulting safety level is not less than the intended safety level in this standard.

Different codes subdivide the partial safety factors for materials γ_m into several material factors accounting for separate types of uncertainty, for example inherent variability of the material strength, extent of production control, or production method. The material factors given in this standard correspond to the so-called "general partial safety factors for materials" accounting for the inherent variability of the strength parameters. If the code gives partial safety factors or uses reduction factors on the characteristic values to account for other uncertainties, these shall also be taken into account.

Individual codes may choose different factorizations of partial safety factors on the load and the material parts of the design verification. The division of factors intended here is the one defined in ISO 2394. If the division of factors in the code of choice deviates from that of ISO 2394, the necessary adjustments in the code of choice shall be taken into account in the verification according to this standard.

7.6.2 Ultimate strength analysis

The resistance R generally corresponds with the maximum allowable design values of material resistance, hence $R(f_d) = f_d$, whilst the function S for ultimate strength analysis is usually defined as the highest value of the structural response in terms of stress. For multiple simultaneous loads the equation then becomes:

$$S(\gamma_{f1} F_{k1}, \dots, \gamma_{fn} F_{kn}) \leq \frac{1}{\gamma_m \times \gamma_n} \times f_k \quad (24)$$

7.6.2.1 Partial safety factors for loads

Where the loads from various sources can be evaluated separately, the load factors shall have the values specified in table 3 as a minimum.

Table 3 – Partial safety factors for loads γ_f

Source of loading	Unfavourable loads			Favourable loads
	Type of design situation (see table 2)			All design situations
	Normal and extreme	Abnormal	Transport and erection	
Aerodynamic	1,35	1,1	1,5	0,9
Operational	1,35	1,1	1,5	0,9
Gravity	1,1/1,35*	1,1	1,25	0,9
Other inertia	1,25	1,1	1,3	0,9

* In the event of the masses not being determined by weighing.

In many cases, especially where varying loads result in dynamic load effects, the loads from various sources cannot be evaluated separately. In these cases, the partial safety factors for loads γ_f shall be taken as the highest of the partial safety factors for loads in table 3 for the relevant design situation.

Alternatively, the computation of stresses and stress resultants can be performed with the combined loading corresponding to representative or characteristic values. Systematic variation of uncertain parameters of the governing equations shall be made in such a way that the level of safety implicitly defined by the partial safety factors for loads in table 3 is maintained.

7.6.2.2 Partial safety factors for materials where recognized design codes are not available

The partial safety factors for materials shall be determined in relation to the adequacy of the available material properties test data. The value of the general partial safety factors for materials accounting for the inherent variability of the strength parameter shall be not less than 1,1 when applied to characteristic material properties of 95 % survival probability p with 95 % confidence limit. 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 general factor shall be taken from table 4. To derive the global partial safety factors for materials from this general factor, it is necessary to account for scale effects, tolerances degradation due to external actions, i.e. ultraviolet radiation, humidity and defects that would not normally be detected.

Table 4 – General partial safety factors for materials for inherent variability

p %	$\delta = 10$ %	$\delta = 15$ %	$\delta = 20$ %	$\delta = 25$ %	$\delta = 30$ %
99 %	1,02	1,05	1,07	1,12	1,17
98 %	1,06	1,09	1,13	1,20	1,27
95 %	1,10	1,16	1,22	1,32	1,43
90 %	1,14	1,22	1,32	1,45	1,60
80 %	1,19	1,30	1,44	1,62	1,82

Partial safety factors for consequences of failure:

Components class 1: $\gamma_n = 1,0$

Components class 2: $\gamma_n = 1,0$.

7.6.2.3 Partial safety factors for materials for where recognized design codes are available

The combined partial safety factors for loads, materials and the consequences of failure, γ_f , γ_m , and γ_n , shall be not less than those specified in 7.6.2.1 and 7.6.2.2.

Where the survival probability p and the coefficient δ are not specified for the material, values $p = 95\%$ and $\delta = 10\%$ can be assumed.

7.6.3 Fatigue failure

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:

$$\text{Damage} = \sum_i \frac{n_i}{N(\gamma_m \gamma_n \gamma_f s_i)} \leq 1,0 \quad (25)$$

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_m , γ_n , γ_f are the appropriate partial safety factors for materials, consequences of failure, and loads respectively.

7.6.3.1 Partial safety factor for loads

The partial safety factor for loads γ_f shall be 1,0 for all normal and abnormal design situations.

7.6.3.2 Partial safety factors for materials where recognized codes are not available

The partial safety factor for materials γ_m shall be 1,1 provided that the S-N curve is based on not less than 95 % survival probabilities with 95 % confidence limits and a coefficient of variation of 10 %. If the characteristic material properties are derived for other survival probabilities p and/or other coefficients of variation δ the relevant general safety factor for materials shall be taken from table 4. The fatigue strengths shall be derived from a statistically significant number of tests and the derivation of characteristic values shall account for scale effects, tolerances, degradation due to external actions, such as ultraviolet radiation, and defects which would not normally be detected.

Partial safety factors for consequences of failure

Components class 1: $\gamma_n = 1,0$

Components class 2: $\gamma_n = 1,15$.

7.6.3.3 Partial material factors where recognized design codes are available

The combined partial safety factors for loads, materials and consequences of failure shall not be less than those specified in 7.6.3.1 and 7.6.3.2.

Where the survival probability p and the coefficient δ are not specified for the material property, values $p = 95\%$ and $\delta = 10\%$ can be assumed.

7.6.4 Stability

No kink or buckling may occur in a component under characteristic load. Under design load, only the load-carrying parts of “non-fail-safe” components shall not kink or buckle. For all other components elastic buckling may occur under this load.

A minimum value for the partial safety factor for loads γ_f shall be chosen in accordance with 7.6.2.1 to deal with uncertainties in extreme loads.

7.6.5 Critical deflection analysis

It shall be verified that no deflections affecting WTGS safety occur in the design conditions detailed in table 2. One of the most important considerations is to verify that no mechanical interference between blade and tower can occur.

The maximum elastic deflection in the unfavourable direction shall be determined for the load cases detailed in table 2 and multiplied by the combined partial safety factor for loads, material and consequences of failure.

Partial safety factor for loads

The partial safety factors for loads γ_f shall be chosen from table 3.

Partial safety factor for materials

The partial safety factor for materials γ_m shall be chosen according to 7.6.2. Particular attention shall be paid to geometrical uncertainties and the accuracy of the deflection calculation method.

Partial safety factor for consequences of failure

Components class 1: $\gamma_n = 1,0$

Components class 2: $\gamma_n = 1,0$.

The elastic deflection shall then be added to the undeflected position in the most unfavourable direction and the resulting position compared to the requirement for non-interference.

7.6.6 Special partial safety factors

Lower partial safety factors for loads may be used where the magnitudes of loads have been established by measurement or by analysis confirmed by measurement to a higher than normal degree of confidence. The values of all partial safety factors used shall be stated in the design documentation.

8 Control and protection system

8.1 General

WTGS operation and safety shall be governed by a control and protection system which meets the requirements of this clause.

Manual or automatic intervention shall not compromise the function of the protection system. Any device allowing manual intervention shall be clearly visible and identifiable by appropriate marking where necessary.

Settings of the control and protection system shall be protected against unauthorized interference.

Any single failure in the sensing or the activation parts of the control system shall not lead to a malfunction of the protection system.

8.2 Wind turbine control

The control system of a WTGS shall control the operation by active or passive means and keep the operating parameters within their normal limits. Where selection of control mode can be exercised, for example for maintenance, control in each mode shall override all other control, with the exception of the emergency stop button. Mode selection shall be governed by a selector which can be locked in each position corresponding with a single mode. When certain functions are controlled numerically, access codes shall be provided to appropriately select the function.

The control system may govern functions or parameters such as:

- power limitation;
- rotor speed;
- connection of the electrical load;
- start-up and shutdown procedures;
- shutdown at loss of electrical network or electrical load;
- cable twist limits;
- alignment to the wind.

8.3 Wind turbine protection

The protection system shall be activated when, as a result of control system failure or of the effects of an internal or external failure or of a dangerous event, a WTGS is not kept within its normal operation limits. The protection system shall then maintain the WTGS in a safe condition. The activation levels for the protection system shall be set in such a way that design limits are not exceeded.

The protection system shall be activated in such cases as:

- overspeed;
- generator overload or fault;
- excessive vibration;
- failure to shut down following network loss, disconnection from the network or loss of load;
- abnormal cable twist (due to nacelle rotation by yawing).

The protection system shall be designed for fail-safe operation. The protection system shall in general be able to protect a WTGS from any single failure or fault in a power source or in any non-safe-life component within the protection system.

If two or more failures are interdependent or have a common cause, they shall be treated as a single failure.

All non-redundant components of the protection system shall be analyzed for ultimate strength and fatigue failure and ultimate loads and meet the requirements of 8.4.

8.4 Functional requirements of the control and protection system

The protection system shall include one or more systems (mechanical, electrical or aerodynamic) capable of bringing the rotor to rest or to an idling state from any operating condition. At least one of these shall act on the low speed shaft or on the rotor of a WTGS. Means shall be provided for bringing the rotor to a complete stop from a hazardous idling state in any wind speed less than V_{e1} . Disengagement of any emergency stop button following its use shall require an appropriate action. Disengagement shall not result in restart, only permit restart.

Measures shall be taken to reduce the risk from dormant failures. Non-safe life components and systems shall fail to a safe condition or their condition shall be automatically monitored; in either case their failure shall result in a machine shutdown. Safe-life designed components shall be inspected at adequate intervals.

An emergency stop button, which will override the automatic control system and result in a machine shutdown, shall be provided at every major working place.

In cases of conflict the protection function shall overrule the control function.

The automatic restart of a wind turbine shall not be possible where the shutdown was initiated by an internal fault or trip which is critical to the turbine safety.

9 Mechanical systems

9.1 General

The “mechanical systems” of a WTGS may include

- elements of the drive train such as gearbox(es), shaft(s) and coupling(s)
- auxiliary items such as brake(s), blade pitch control(s), yaw drive(s).

Auxiliary items may be driven by electrical, hydraulic or pneumatic means.

9.2 Errors of fitting

Errors likely to be made when fitting or refitting certain parts which could be a source of risk shall be made impossible by the design of such parts or, failing this, by information given on the parts themselves and/or housings. The same information shall be given on the moving parts and/or their housings where the direction of movement shall be known to avoid a risk. Any further information that may be necessary shall be given in the operator's instruction and maintenance manuals.

Where a faulty connection can be a source of risk, incorrect connections shall be made impossible by the design or, failing this, precautions shall be taken to avoid faulty connection by information given on the pipes, hoses and/or connector blocks.

9.3 Hydraulic or pneumatic systems

Where auxiliary items are powered by hydraulic or pneumatic energy the systems shall be so designed, constructed and equipped as to avoid all potential hazards associated with these types of energy. Means of isolating or discharging accumulated energy shall be included in the design.

All pipes and/or hoses carrying hydraulic oil or compressed air and their attachments shall be designed to withstand or be protected from foreseen internal and external stresses.

Precautions shall be taken to minimize risk of injury arising as a consequence of rupture.

10 Electrical system

10.1 General

The "electrical system" of a (multiple) WTGS installation comprises all electrical equipment installed in each individual WTGS up to and including the WTGS terminals; in the following referred to as the "WTGS electrical system".

The power collection system is not covered in this standard.

10.2 General requirements for the WTGS electrical system

All electrical components and systems shall meet the requirements of IEC 60204-1.

The design of a WTGS electrical system shall ensure minimal hazards to people and livestock as well as minimal potential damage to the WTGS and external electrical system during operation and maintenance of the WTGS under all normal and extreme external conditions defined in clause 6.

A WTGS electrical system, including all electrical equipment and components, shall comply with the relevant IEC standards. Specifically, the design of a WTGS electrical system shall comply with the requirements of IEC 60364. For WTGS which contain circuits supplied at nominal voltages greater than 1 000 V a.c. or 1 500 V d.c., the manufacturer shall state the design standard used. The design of the electrical system shall take into account the fluctuating nature of the power generation from wind turbines.

A WTGS electrical system shall comply with relevant IEC standards on electromagnetic compatibility, including IEC 61000-3-2, IEC 61000-3-3, IEC 61000-4-2, IEC 61000-4-3, IEC 61000-4-4, IEC 61000-4-5.

10.3 Protective devices

A WTGS electrical system shall, in addition to the requirements of IEC 60364, include suitable devices that ensure protection against malfunctioning of both the WTGS and the external electrical system which may lead to an unsafe condition or state.

10.4 Disconnect devices

It shall be possible to disconnect a WTGS electrical system from all electrical sources of energy as required for maintenance or testing.

Semiconductor devices shall not be used alone as disconnect devices.

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 energized while all other circuits are de-energized.

10.5 Earth system

The design of a WTGS shall include a local earth electrode system to meet the requirements of IEC 60364 (for the correct operation of the electrical installation) and IEC 61024-1 (for lightning protection). The range of soil conditions for which the earth electrode system is adequate shall be stated in the design documentation, together with recommendations should other soil conditions be encountered.

The choice and installation of the equipment of the earthing arrangement (earth electrodes, earthing conductors, main earthing terminals and bars) shall be made in accordance with IEC 60364-5-54.

Any electrical system operating above 1 000 V a.c. or 1 500 V d.c. shall be able to be earthed for maintenance.

10.6 Lightning protection

The lightning protection of a WTGS shall be designed in accordance with IEC 61024-1. It is not necessary for protective measures to extend to all parts of the WTGS, provided safety is not compromised.

10.7 Electrical cables

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. Underground cables shall, if not protected by a conduit or duct, be marked by cable covers or suitable marking tape.

10.8 Self-excitation

Any electrical system that can self-excite the WTGS shall be disconnected and remain safely disconnected in the event of loss of network power.

If a capacitor bank is connected in parallel with a network-connected WTGS (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 WTGS electric generator. Alternatively, if capacitors are fitted, it shall be sufficient to show that the capacitors cannot cause self-excitation.

10.9 Over-voltage protection

The over-voltage protection shall be designed in accordance with the requirements of IEC 61312-1.

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

10.10 Harmonics and power conditioning equipment

The power conditioning equipment, such as invertors, power electronic controllers, and static VAR compensators, shall be designed so that harmonic line currents and voltage waveform distortion do not interfere with electrical network protective relaying. Specifically, for network-connected WTGS the voltage harmonics generated by the WTGS 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.

11 Assessment of external conditions

11.1 General

WTGS are subjected to environmental and electrical conditions which may affect their loading, durability and operation. In addition to the environmental conditions, account has to be taken of the soil properties at the site where the WTGS is located.

It shall be assessed that the environmental, electrical and soil properties are more benign than those assumed for the design of a WTGS. If the site conditions are more severe than those assumed, the engineering integrity shall be demonstrated.

All offshore sites shall require WTGS class S turbines.

11.2 Assessment of wind conditions

As a minimum requirement, the wind conditions at the site shall be assessed according to the basic parameters listed below in terms of which the WTGS classes are defined.

- reference wind speed: V_{ref}
- annual average wind speed: V_{ave}
- turbulence intensity at $V_{\text{hub}} = 15 \text{ m/s}$: I_{15}

where I_{15} is the characteristic value of hub-height turbulence intensity at a 10 min average wind speed of 15 m/s. The characteristic value is calculated by adding the measured standard deviation of the turbulence intensity to the measured or estimated mean value.

The wind conditions shall be assessed from monitoring measurements made at the site, long term records or from local codes or standards. Where appropriate, the site conditions shall be correlated with long term data from local meteorological stations.

The monitoring period shall be sufficient to obtain a minimum of six months of reliable data. Where seasonal variations contribute significantly to the wind conditions, the monitoring period shall include these effects.

The value I_{15} shall be determined using appropriate statistical techniques applied to measured data obtained at wind speeds greater than 10 m/s ⁴⁾. Where topographical or other local effects may influence the turbulence intensity then these effects shall be represented in the data.

The characteristics of the anemometer, sampling rate and averaging time used to obtain measured data can influence the assessment of turbulence intensity. These effects shall be considered when predicting the turbulence intensity from measured data.

For complex terrain, the wind conditions shall be assessed from measurements made at the site. In addition, consideration shall be given to the effect of topography on the wind speed, wind profile, turbulence intensity and flow inclination at each turbine location.

Wake effects from neighbouring machines shall be considered for WTGS operating in wind farms.

11.3 Assessment of other environmental conditions

The following environmental conditions shall be assessed for comparison with the assumptions made for design of the WTGS:

- normal and extreme temperature ranges;
- icing;
- humidity;
- solar radiation;
- chemically active substances;
- earthquakes;
- salinity.

4) Note, for example, that when low frequency trends exist in wind speed data, caution should be exercised in evaluating turbulence intensity and other parameters.

11.4 Assessment of electrical network conditions

The electrical conditions at the interconnection between a WTGS and the existing electrical network at a proposed site shall be assessed to ensure compatibility with the WTGS and, where appropriate, any electrical equipment between the WTGS and the existing electrical network. These shall include, but not be restricted to the following:

- normal supply voltage and range;
- normal supply frequency and range;
- voltage imbalance;
- symmetric and unsymmetric faults;
- number of electrical network outages;
- auto-reclosing cycles;
- short-circuit impedance at the wind turbine terminals;
- ambient harmonic voltage distortion.

11.5 Assessment of soil conditions

The soil properties at a proposed site shall be assessed by investigation and with reference to available local building codes.

12 Assembly, installation and erection

12.1 General

The manufacturer of a WTGS shall provide a manual clearly describing installation requirements for the WTGS equipment. The installation of a WTGS shall be performed by personnel trained or instructed in these activities.

The site of a WTGS facility shall be prepared, maintained, operated and managed so that work can be performed in a safe and efficient manner. This should include procedures to prevent unauthorized access where appropriate. The operator should identify and eliminate existing and potential hazards.

Checklists of planned activities shall be prepared and logs of completed work and results of that work should be kept.

When appropriate, installation personnel shall use approved eye, feet, hearing, and head protection. All personnel climbing towers, or working above ground or water level, should be trained in such work and shall use approved safety belts, safety climbing aids or other safety devices. When appropriate, a buoyancy aid should be used around water.

All equipment shall be kept in good repair and be suitable for the task for which it is intended. Cranes, hoists and lifting equipment, including all slings, hooks and other apparatus, shall be adequate for safe lifting.

Particular consideration should be given to installation of WTGS under unusual conditions, such as hail, lightning, high winds, earthquake, icing, etc.

In the case of a tower standing without a nacelle, appropriate means shall be taken to avoid critical wind speeds for vortex generated transverse vibrations. The critical wind speeds and precaution measures shall be included in the installation manual.

12.2 Planning

The assembly, erection and installation of WTGS and associated equipment shall be planned in order that the work is carried out safely and in accordance with local and national regulations. The planning shall include, where appropriate, consideration of the following:

- rules for safe execution of excavation work;
- detailed drawings and specifications of the work and inspection plan;
- rules for the proper handling of embedded items, such as foundations, bolts, anchors and reinforcement steel;
- rules for concrete composition, delivery, sampling, pouring, finishing and placement of conduits;
- safety rules for blasting;
- procedures for installation of tower and other anchors;
- procedures for quality assurance.

12.3 Installation conditions

During the installation of a WTGS the site shall be maintained in such a state that it does not present a safety risk.

12.4 Site access

Access to a site shall be safe and the following shall be taken into account:

- barriers and routes of travel;
- traffic;
- road surface;
- road width;
- clearance;
- access weight bearing capacity;
- movement of equipment at the site.

12.5 Environmental conditions

During installation, environmental limits specified by the manufacturer shall be observed. Items such as the following should be considered:

- wind speed;
- snow and ice;
- ambient temperature;
- blowing sand;
- lightning;
- visibility;
- rain.

12.6 Documentation

The manufacturer of a WTGS shall provide drawings, specifications and instructions for assembly procedures, installation and erection of the WTGS. The manufacturer shall provide details of all loads, weights, lifting points and special tools and procedures necessary for the handling and installation of the WTGS.

12.7 Receiving, handling and storage

Handling and transport of wind turbine generator equipment during installation shall be performed with equipment confirmed to be suitable to the task and in accordance with the manufacturer's recommended practice.

WTGS are often sited on hilly terrain. Therefore, heavy equipment shall be set down in such a manner that it cannot shift. A suitably-sized, level lay-down area is preferred for all handling and assembly operations. Where this cannot be provided, all heavy equipment shall be securely blocked in a stable position.

Where there is risk of movement and damage by the wind, blades, nacelles, other aerodynamic parts and light crates shall be secured with ropes and stakes, or ground anchors.

12.8 Foundation/anchor systems

Where specified by the manufacturer for safe installation or assembly, special tools, jigs and fixtures and other apparatus shall be used.

12.9 Assembly of WTGS

A WTGS shall be assembled according to the manufacturer's instructions. Inspection shall be carried out to confirm proper lubrication and pre-service conditioning of all components.

12.10 Erection of WTGS

A WTGS shall be erected by personnel trained and instructed in proper and safe erection practices.

No part of a WTGS electrical system shall be energized during erection unless it is necessary for the erection process. In this case, the energization of such equipment shall be carried out in accordance with a written procedure to be provided by the WTGS supplier.

All elements where motion (rotation or translation) may result in a potential hazard shall be secured from unintentional motion throughout the erection process.

12.11 Fasteners and attachments

Threaded fasteners and other attachment devices shall be installed according to the WTGS manufacturer's recommended torque and/or other instructions. Fasteners identified as critical shall be checked and procedures for confirming installation torque and other requirements shall be obtained and used.

In particular, inspection shall be carried out to confirm the following:

- proper assembly and connection of guys, cables, turn buckles, gin poles and other apparatus and devices;
- proper attachment of lifting devices required for safe erection.

12.12 Cranes, hoists and lifting equipment

Cranes, hoists and lifting equipment, including all hoisting slings, hooks and other apparatus required for safe erection, shall be adequate for safe lifting and final placement of the loads. Manufacturer's instructions and documentation with respect to erection and handling should provide information on expected loads and safe lifting points for components and/or assemblies. All hoisting equipment, slings and hooks shall be tested and certified for safe load.

13 Commissioning, operation and maintenance

13.1 General

The commissioning, operation, inspection, and maintenance procedures shall be planned with the safety of personnel in mind and specified in the WTGS manual.

The design shall incorporate provisions for safe access for inspection and maintenance of all components.

The requirements of clause 10 also cover electrical measurement equipment temporarily installed in the wind turbine for the purpose of measurements.

When appropriate, operation and maintenance personnel shall use approved eye, feet, hearing and head protection. All personnel climbing towers, or working above ground or water level, shall be trained in such work and shall use approved safety belt, safety climbing aids or other safety devices. When appropriate, a buoyancy aid should be used around water.

13.2 Commissioning

Commissioning shall be carried out in accordance with the manufacturer's recommended instructions.

13.2.1 Energization

The manufacturer's instructions shall include a procedure for initial energization of the WTGS electrical system.

13.2.2 Commissioning tests

WTGS shall be tested, after installation, to confirm proper, safe and functional operation of all devices, controls and apparatus and be tested in accordance with the manufacturer's recommended procedures. Testing shall include, but not be limited to:

- safe start-up;
- safe shutdown;
- safe emergency shutdown;
- safe shutdown from overspeed or representative simulation thereof;
- function test of protection system.

13.2.3 Records

Proper records shall be kept describing testing, commissioning, control parameters and results.

13.2.4 Post commissioning activities

At the completion of installation, and following operation for the manufacturer recommended running-in period, the specific actions that may be required by the manufacturer shall be completed.

These can include, but are not limited to preloading of fasteners, changing of lubrication fluids, checking other components for proper setting and operation and proper adjustment of control parameters.

The WTGS site should be refurbished to remove hazards and prevent erosion.

13.3 Operations

The operation of a WTGS shall be performed by personnel suitably trained or instructed in this activity.

The normal operation of a WTGS by the operating personnel shall be possible at ground level. A tagged, local, manual override on the automatic/remote control system shall be provided.

13.3.1 Operations manual

An operator's instruction manual shall be supplied by the WTGS manufacturer and augmented with information on special local conditions at the time of commissioning, as appropriate. The manual should include:

- system safe operating limits and descriptions;
- start and shutdown procedures;
- an alarm's action list;
- emergency procedures plan.

The manual shall be available to the operation and maintenance personnel and shall be written in a language that can be read and understood by the operator.

13.3.2 Operations and maintenance record

Operations and maintenance records shall be kept and should include the following:

- wind turbine identification;
- energy produced;
- operating hours;
- shutdown hours;
- date and time of fault reported;
- date and time of service or repair;
- nature of fault or service;
- action taken;
- parts replaced.

13.3.3 Unscheduled automatic shutdown

Following any unscheduled automatic shutdown caused by a fault or malfunction, unless specified otherwise in the operations manual or instructions, the operator shall investigate the cause before a WTGS is restarted. All unscheduled automatic shutdowns should be recorded.

External events detected as faults but not critical for the future safety of a WTGS, such as loss and reinstatement of the electrical load, may allow automatic return to normal operation after completion of the shutdown cycle.

13.3.4 Diminished reliability

Action shall be taken to eliminate the root cause of any indication or warning of abnormality or diminished reliability.