

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Wind energy generation systems –
Part 1: Design requirements**

**Systèmes de génération d'énergie éolienne –
Partie 1: Exigences de conception**



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Part 1: Design requirements**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND ENERGY GENERATION SYSTEMS –

Part 1: Design requirements

FOREWORD

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

This fourth edition cancels and replaces the third edition published in 2005 and Amendment 1:2010. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) general update and clarification of references and requirements;
- b) extension of wind turbine classes to allow for tropical cyclones and high turbulence;
- c) Weibull distribution of turbulence standard deviation for normal turbulence model (NTM);
- d) updated design load cases (DLCs), in particular DLC 2.1 and 2.2;
- e) revision of partial safety factor specifications;
- f) major revision of Clauses 8, 10 and 11;

- g) introduction of cold climate requirements, Clause 14;
- h) new Annex B on design load cases for site-specific or special class S wind turbine design or site suitability assessment;
- i) new Annex J on prediction of the extreme wind speed of tropical cyclones by using Monte Carlo simulation method;
- j) new Annex K on calibration of structural material safety factors and structural design assisted by testing;
- k) new Annex L on assessment and effects of icing climate;
- l) new Annex M on medium wind turbines.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
88/696/FDIS	88/701/RVD

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

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 61400 series, published under the general title *Wind energy generation systems*, can be found on the IEC website.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

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INTRODUCTION

This part of IEC 61400 outlines minimum design requirements for wind turbines and is not intended for use as a complete design specification or instruction manual.

Any of the requirements of this document may be altered if it can be suitably demonstrated that the safety of the system is not compromised. This provision, however, does not apply to the classification and the associated definitions of external conditions in Clause 6. Compliance with this document does not relieve any person, organization, or corporation from the responsibility of observing other applicable regulations.

This document is not intended to give requirements for wind turbines installed offshore, in particular for the support structure. For offshore installations, reference is made to the IEC 61400-3 series.

WIND ENERGY GENERATION SYSTEMS –

Part 1: Design requirements

1 Scope

This part of IEC 61400 specifies essential design requirements to ensure the structural integrity of wind turbines. Its purpose is to provide an appropriate level of protection against damage from all hazards during the planned lifetime.

This document is concerned with all subsystems of wind turbines such as control and protection functions, internal electrical systems, mechanical systems and support structures.

This document applies to wind turbines of all sizes. For small wind turbines, IEC 61400-2 can be applied. IEC 61400-3-1 provides additional requirements to offshore wind turbine installations.

This document is intended to be used together with the appropriate IEC and ISO standards mentioned in Clause 2.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60034 (all parts), *Rotating electrical machines*

IEC 60038, *IEC standard voltages*

IEC 60071-1, *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 60071-2, *Insulation co-ordination – Part 2: Application guidelines*

IEC 60076 (all parts), *Power transformers*

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

IEC 60204-11:2000, *Safety of machinery – Electrical equipment of machines – Part 11: Requirements for HV equipment for voltages above 1 000 V AC or 1 500 V DC and not exceeding 36 kV*

IEC 60364 (all parts), *Low voltage electrical installations*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60664-1, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*

IEC 60664-3, *Insulation coordination for equipment within low-voltage systems – Part 3: Use of coating, potting or moulding for protection against pollution*

IEC 60721 (all parts), *Classification of environmental conditions*

IEC 61000-6-2, *Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity standard for industrial environments*

IEC 61400-3, *Wind turbines – Part 3: Design requirements for offshore wind turbines*

IEC 61400-4, *Wind Turbines – Part 4: Design requirements for wind turbine gearboxes*

IEC 61400-24, *Wind turbines – Part 24: Lightning protection*

IEC 61439 (all parts), *Low-voltage switchgear and controlgear assemblies*

IEC 61800-4, *Adjustable speed electrical power drive systems – Part 4: General requirements – Rating specifications for AC power drive systems above 1 000 V AC and not exceeding 35 kV*

IEC 61800-5-1, *Adjustable speed electrical power drive systems – Part 5-1: Safety requirements – Electrical, thermal and energy*

IEC 62271 (all parts), *High-voltage switchgear and controlgear*

IEC 62305-3, *Protection against lightning – Part 3: Physical damage to structures and life hazard*

IEC 62305-4, *Protection against lightning – Part 4: Electrical and electronic systems within structures*

IEC 62477-1:2012, *Safety requirements for power electronic converter systems and equipment – Part 1: General*

ISO 76, *Rolling bearings – Static load ratings*

ISO 281, *Rolling bearings – Dynamic load ratings and rating life*

ISO 2394, *General principles on reliability for structures*

ISO 2533, *Standard Atmosphere*

ISO 4354, *Wind actions on structures*

ISO 6336-2, *Calculation of load capacity of spur and helical gears – Part 2: Calculation of surface durability (pitting)*

ISO 6336-3:2006, *Calculation of load capacity of spur and helical gears – Part 3: Calculation of tooth bending strength*

ISO 12494:2001, *Atmospheric icing on structures*

ISO 13850, *Safety of machinery – Emergency stop function – Principles for design*

ISO/TS 16281, *Rolling bearings – Methods for calculating the modified reference rating life for universally loaded bearings*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1

annual average

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

Note 1 to entry: The averaging time interval should be a whole number of years (e.g. 10) to average out non-stationary effects such as seasonality.

3.2

annual average wind speed

V_{ave}

wind speed averaged according to the definition of annual average

3.3

auto-reclosing 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) that cannot be released accidentally 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

Note 1 to entry: The brake may operate on, for example, aerodynamic, mechanical or electrical principles.

3.6

characteristic value

value having a prescribed probability of not being attained (i.e. an exceedance probability of less than or equal to a prescribed amount)

3.7

complex terrain

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

3.8

control functions

<wind turbines> functions of the control system that, based on information about the condition of the wind turbine and/or its environment, adjust the turbine in order to maintain it within its operating limits

3.9 control system

<wind turbines> system implementing the turbine control functions, including sensors, logic elements, actuators, communication networks, and power supplies

Note 1 to entry: The intent of the control system is to control operation of the turbine by active and passive means and keep the operating parameters within the limits assumed in the structural design. The control system is likely to include control loops for normal operation as well as alarms and shutdown mechanisms to ensure that limits are not exceeded.

3.10 cut-in wind speed

V_{in}
lowest 10 min average wind speed at hub height at which the wind turbine starts to produce power in the case of steady wind without turbulence

3.11 cut-out wind speed

V_{out}
highest 10 min average wind speed at hub height at which the wind turbine is designed to produce power in the case of steady wind without turbulence

3.12 design limits

maximum or minimum values used in a design

3.13 dormant failure

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 1 to entry: The boundaries of the different parts of this network are defined by appropriate criteria, such as geographical situation, ownership, voltage.

3.16 emergency stop

<wind turbines> rapid shutdown of the wind turbine triggered by manual intervention

3.17 environmental conditions

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

3.18 external conditions

<wind turbines> factors affecting operation of a wind turbine, including the environmental conditions (temperature, snow, ice, etc.) and the electrical network conditions

3.19 extreme wind speed

value of the highest wind speed, averaged over t in seconds, with an annual probability of exceedance of $1/N$ ("return period": N years)

Note 1 to entry: In this document, return 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 document, 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 1 to entry: 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 horizontal

3.23

hub

<wind turbines> fixture for attaching the blades or blade assembly to the rotor shaft

3.24

hub height

z_{hub}

<wind turbines> height of the centre of the swept area (3.57) of the wind turbine rotor above the terrain surface

3.25

idling

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

3.26

inertial sub-range

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

Note 1 to entry: At a typical 10 m/s wind speed, the inertial sub-range is roughly from 0,2 Hz to 1 kHz.

3.27

limit state

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

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

3.28

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

3.29

medium wind turbine

wind turbine with a rotor swept area or, in the case of a ducted or shrouded turbine, the larger of the duct or shroud entry and exit areas greater than 200 m² and less than or equal to 1 000 m²

3.30

nacelle

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

3.31

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

3.32

network loss

loss of electrical network (grid) for a period exceeding any ride through provision in the turbine control system

3.33

normal shutdown

<wind turbines> shutdown in which all stages are under the control of the control system

3.34

operating limits

set of conditions defined by the wind turbine designer that governs the activation of the turbine control functions

3.35

parked wind turbine

turbine being either in a standstill or an idling condition, depending on the design of the wind turbine

3.36

performance level

PL

discrete level used to specify the ability of safety-related parts of control systems to perform a safety function under foreseeable conditions

3.37

power collection system

<wind turbines> electric system that collects the power from one or more wind turbines

Note 1 to entry: It includes all electrical equipment connected between the wind turbine terminals and the network connection point.

3.38

power output

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

Note 1 to entry: For a wind turbine, it is the electric power it delivers.

3.39

primary layer protection function

protection function (3.40) in a protection system with two or more independent layers which may be implemented as a part of the wind turbine control system and is separate from a secondary layer protection function (3.52) with a similar purpose

3.40

protection functions

<wind turbine> functions of the control system which ensure that a wind turbine 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 1 to entry: For a wind turbine, it is the maximum continuous electrical power output which a wind turbine is designed to achieve under normal operating and external conditions.

3.42**rated wind speed** V_r

minimum wind speed at hub height at which a wind turbine's rated power is achieved in the case of steady wind without turbulence

3.43**Rayleigh distribution** P_R

probability distribution function

Note 1 to entry: See 3.68.

3.44**reference wind speed** V_{ref}

basic parameter for wind speed used for defining wind turbine classes

Note 1 to entry: Other design related climatic parameters are derived from the reference wind speed and other basic wind turbine class parameters (see Clause 6).

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

3.45**resistance partial safety factor** γ_M

factor which takes account of possible unfavourable deviations/uncertainties of the material strength parameters and of the resistance model including bias in the resistance model

3.46**rotationally sampled wind velocity**

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

Note 1 to entry: 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** z_0

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**

design property for a critical system which is either very difficult to repair or may cause severe damage to life and property

Note 1 to entry: Such systems are designed to work for the full system lifetime without requirement of any repairs or inspections.

3.50

safety integrity level

SIL

discrete level (one out of a possible four), corresponding to a range of safety integrity values for the control functions, where 4 and 1 belong to the highest and lowest levels, respectively

Note 1 to entry: Target failure measures for the four safety integrity levels are defined in Tables 2 and 3 of IEC 61508-1:2010. These levels can be used for specifying safety integrity requirements of safety functions allocated to the systems. A SIL is not a property of a system, subsystem, element or component. As defined in IEC 61508-1, the phrase "SIL n safety-related system" (where n is 1, 2, 3, or 4) means that the system is potentially capable of supporting safety functions with a safety integrity level up to n .

3.51

scheduled maintenance

preventive maintenance carried out in accordance with an established schedule

3.52

secondary layer protection function

dedicated protection function which operates using a layer of monitoring and logic separate from a primary layer protection function (3.39) with a similar purpose

3.53

site data

environmental, seismic, soil and electrical network data for the wind turbine site

Note 1 to entry: Wind data shall be the statistics of 10 min samples unless otherwise stated.

3.54

standstill

condition of a wind turbine that is stopped

3.55

support structure

<wind turbines> part of a wind turbine comprising the tower and foundation

3.56

survival wind speed

maximum wind speed that a construction is designed to withstand

Note 1 to entry: This is a popular expression that is not used in this document. Design conditions instead refer to extreme wind speed (3.19).

3.57

swept area

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

3.58

turbulence intensity

I

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

3.59

turbulence scale parameter

λ_1

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

Note 1 to entry: The wavelength is thus defined as $\lambda_1 = V_{\text{hub}}/f_0$, where $f_0 S_1(f_0)/\sigma_1^2 = 0,05$.

3.60

turbulence standard deviation

σ_1

standard deviation of the longitudinal component of the turbulent wind velocity at hub height

3.61

ultimate limit state

limit states which generally correspond to maximum load carrying capacity

3.62

unscheduled maintenance

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

3.63

upwind

in the direction opposite to the main wind vector

3.64

vertical axis wind turbine

wind turbine whose rotor axis is vertical

3.65

Weibull distribution

P_w

probability distribution function

Note 1 to entry: See 3.68.

3.66

wind power station

wind farm

group or groups of wind turbines

3.67

wind profile

wind shear law

mathematical expression for assumed wind speed variation with height above ground

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

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

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

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.

3.68

wind speed distribution

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

Note 1 to entry: Often used distribution functions are the Rayleigh, $P_R(V_0)$, and the Weibull, $P_W(V_0)$, functions.

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

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

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.

3.69

wind shear

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

3.70

wind speed

V

speed of motion of a minute amount of air surrounding a specified point in space

Note 1 to entry: It is also the magnitude of the local wind velocity (vector) (see 3.73).

3.71

wind turbine generator system

<wind turbine> system which converts kinetic energy in the wind into electrical energy

3.72

wind turbine site

location of an individual wind turbine either alone or within a wind farm

3.73**wind velocity**

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

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

3.74**wind turbine electrical system**

electrical equipment internal to the wind turbine, up to and including the wind turbine terminals, including equipment for earthing, bonding and communications

Note 1 to entry: Conductors local to the wind turbine, which are intended to provide an earth termination network specifically for the wind turbine, are included.

3.75**wind turbine terminals**

point or points identified by the wind turbine supplier at which the wind turbine may be connected to the power collection system

Note 1 to entry: This includes connection for the purposes of transferring energy and communications.

3.76**yawing**

rotation of the rotor axis about a vertical axis

Note 1 to entry: For horizontal axis wind turbines only.

3.77**yaw misalignment**

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

4 Symbols and abbreviated terms**4.1 Symbols and units**

C	scale parameter of the Weibull distribution function	[m/s]
C_{CT}	turbulence structure correction parameter	
C_T	thrust coefficient	[-]
Coh	coherence function	[-]
D	rotor diameter	[m]
$D_{TV,i}$	standard deviation of terrain variation Δz in i th 30° sector	[m]
$D_{TV,360}$	standard deviation of terrain variation Δz of the 360° circle area	[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_{ref}	reference value of the turbulence intensity corresponding to the 70 % quantile at 15 m/s	[-]
I_{eff}	effective turbulence intensity	[-]
k	shape parameter of the Weibull distribution function	

k_1	empirical adjustment factor for TSI360, $k_1 = 5/3$	[-]
k_2	empirical adjustment factor for TVI360, $k_2 = 3$	[-]
K	modified Bessel function	[-]
L	isotropic turbulence integral scale parameter	[m]
L_e	coherence scale parameter	[m]
L_k	velocity component integral scale parameter	[m]
m	Wöhler curve exponent	[-]
n_i	counted number of fatigue cycles in load bin i	[-]
$N(.)$	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	return period for extreme situations	[years]
p	air pressure	[N/m ²]
$P(V_0)$	probability distribution, i.e. the probability that $V < V_0$	[-]
$P_R(V_0)$	Rayleigh probability distribution, i.e. the probability that $V < V_0$	[-]
P_s	survival probability	[-]
$P_W(V_0)$	Weibull probability distribution	[-]
r	magnitude of separation vector projection	[m]
R	radius of circle segment	[m]
R_0	gas constant	[J/(kg·K)]
S	load function	[-]
s_i	the stress (or strain) level associated with the counted number of cycles in bin i	[-]
$S_1(f)$	power spectral density function for the longitudinal wind velocity component	[m ² /s]
$S_{F,min}$	minimum value of safety factor for tooth breakage	[-]
$S_{H,min}$	minimum value of safety factor for pitting	[-]
$S_k(f)$	one-sided power spectral density function for wind velocity component k : $k = 1$ longitudinal component $k = 2$ lateral component $k = 3$ vertical component	[m ² /s]
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 three seconds), with a recurrence time interval of N years. V_{e1} and V_{e50} for 1 year and 50 years, respectively	[m/s]
V_{gust}	largest gust magnitude with an expected return period of 50 years	[m/s]
V_{hub}	wind speed at hub height	[m/s]
V_{in}	cut-in wind speed	[m/s]

V_0	limit wind speed in wind speed distribution model	[m/s]
V_{50}	extreme wind speed (averaged over 10 minutes) with a recurrence interval of 50 years	[m/s]
V_{100}	extreme wind speed (averaged over 10 minutes) with a recurrence interval of 100 years	[m/s]
V_{out}	cut-out wind speed	[m/s]
V_r	rated wind speed	[m/s]
V_{ref}	reference wind speed	[m/s]
$V_{ref,T}$	reference wind speed for tropical-like conditions	[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	co-ordinate system used for the wind field description; along wind (longitudinal), across wind (lateral) and height respectively	[m]
Z_{NT}	life factor for contact stress for reference test conditions	[-]
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 resistances	[-]
γ_n	partial safety factor for consequences of failure	[-]
$\theta(t)$	wind direction change transient	[deg]
θ_{cg}	angle of maximum deviation from the direction of the average wind speed under gust conditions	[deg]
θ_{eN}	extreme direction change with a return period of N years	[deg]
θ_i	slope of fitted plane for i th 30° sector	[deg]
θ_{360}	slope of the fitted 360° plane	[deg]
$\theta_{1year,min}$	minimum ambient temperature to be expected in hourly average	[K]
$\theta_{min,operation}$	minimum allowable ambient temperature for wind turbine operation	[K]
λ_1	turbulence scale parameter defined as the wavelength where the non-dimensional, longitudinal power spectral density, $fS_1(f)/\sigma_1^2$, is equal to 0,05	[m]
ρ	air density	[kg/m ³]
$\hat{\sigma}$	estimated wind speed standard deviation	[m/s]
$\hat{\sigma}_c$	representative ambient turbulence standard deviation	[m/s]
$\hat{\sigma}_{eff}$	effective estimated wind speed standard deviation	[m/s]
σ_{wake}	wind speed standard deviation in the wake	[m/s]

$\hat{\sigma}_T$	maximum centre-wake wind speed standard deviation	[m/s]
$\hat{\sigma}_\sigma$	standard deviation of estimated wind speed standard deviation $\hat{\sigma}$	[m/s]
$\hat{\sigma}_{1,ETM}$	extreme ambient turbulence standard deviation	[m/s]
σ_1	hub-height longitudinal wind velocity standard deviation	[m/s]
σ_2	hub-height lateral wind velocity standard deviation	[m/s]
σ_3	hub-height upward wind velocity standard deviation	[m/s]
Φ	standardized normal probability function	[-]
$E[]$	expected value of parameter inside brackets	[-]
$Var[]$	variance of parameter inside brackets	[-]

4.2 Abbreviated terms

A	abnormal (for partial safety factors)
AC	alternating current
DC	direct current
CC	cold climate
COV	coefficient of variation
DLC	design load case
DWM	dynamic wake meandering
ECD	extreme coherent gust with direction change
EDC	extreme wind direction change
EOG	extreme operating gust
ETM	extreme turbulence model
EWM	extreme wind speed model
EWS	extreme wind shear
F	fatigue
FMEA	failure mode and effect analysis
HV	high voltage
IAC	internal arc classification
IC	icing climate
LTC	low temperature climate
LVRT	low voltage ride through
N	normal and extreme (for partial safety factors)
NWP	normal wind profile model
NTM	normal turbulence model
S	special IEC wind turbine class
T	transport and erection (for partial safety factors)
TSI	terrain slope index
TVI	terrain variation index
U	ultimate
ULS	ultimate limit state

5 Principal elements

5.1 General

The engineering and technical requirements to ensure the safety of the structural, mechanical, electrical and control systems of the wind turbine are given in the following clauses. This specification of requirements applies to the design, manufacture, installation and manuals for operation and maintenance of a wind turbine and the associated quality management process. In addition, safety procedures, which have been established in the various practices that are used in the installation, operation and maintenance of wind turbine, are taken into account.

5.2 Design methods

This document requires the use of an aeroelastic dynamics model to predict design loads. Such a model shall be used to determine the loads over a range of wind speeds, using the turbulence conditions and other wind conditions defined in Clause 6 and design situations defined in Clause 7. All relevant combinations of external conditions and design situations shall be analysed. A minimum set of such combinations has been defined as load cases in this document.

Data from full scale testing of a wind turbine shall be used to increase confidence in predicted design values and to verify structural dynamics models and design situations as specified in 7.2.

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 document. The selection of test conditions, including the test loads, shall take account of the relevant safety factors.

5.3 Safety classes

A wind turbine 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 other social or economic consequence;
- a special safety class that 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 wind turbines, are specified in 7.6.

Partial safety factors for special safety class wind turbines shall be agreed between the manufacturer and the customer. A wind turbine designed according to a special safety class shall be classified as a class S wind 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 wind turbines and all their components.

It is recommended that the quality system comply with the requirements of ISO 9001.

5.5 Wind turbine markings

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

- wind turbine manufacturer and country;
- model and serial number;
- production year;
- rated power;
- reference wind speed, V_{ref} ;
- hub height operating wind speed range, $V_{\text{in}} - V_{\text{out}}$;
- operating ambient temperature range;
- IEC wind turbine class (see Table 1);
- rated voltage at the wind turbine terminals;
- frequency at the wind turbine 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 Clause 6 shall be considered in the design of a wind turbine.

Wind turbines are subjected to environmental and electrical conditions that may affect their loading, durability and operation. To ensure the appropriate level of safety and reliability, 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 electrical power network conditions. Soil properties are relevant to the design of wind turbine foundations.

The external conditions are subdivided into normal and extreme categories. The normal external conditions generally concern recurrent structural loading conditions, while the extreme external conditions represent rare external design conditions. The design load cases shall consist of potentially critical combinations of these external conditions with wind turbine operational modes and other design situations.

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

The normal and extreme conditions, which are to be considered for design according to wind turbine classes, are prescribed in 6.2 to 6.4.

6.2 Wind turbine classes

The external conditions to be considered for design are dependent on the intended site or site type for a wind turbine installation. Wind turbine classes are defined in terms of wind speed, wind turbine class I, II and III, and turbulence parameters, turbulence category A+, A, B, and C. The intention of the classes is to cover most applications. The values of wind speed and turbulence parameters are intended to represent many different sites and do not give a precise representation of any specific site, see 11.3. The wind turbine classification offers a range of robustness clearly defined in terms of the wind speed and turbulence parameters. In order to allow the use of wind turbine classes for areas, which may experience very high extreme winds in an otherwise moderate wind climate, a T class reference wind speed is included. Such conditions may be found in areas subject to tropical cyclones. This reference wind speed may be used with the average wind speed in class I to III and turbulence categories A+ to C¹. Table 1 specifies the basic parameters, which define the wind turbine classes.

Table 1 – Basic parameters for wind turbine classes

Wind turbine class		I	II	III	S	
V_{ave}		(m/s)	10	8,5	7,5	Values specified by the designer
V_{ref}	(m/s)		50	42,5	37,5	
	Tropical (m/s) $V_{ref,T}$		57	57	57	
A+		I_{ref} (-)	0,18			
A		I_{ref} (-)	0,16			
B		I_{ref} (-)	0,14			
C		I_{ref} (-)	0,12			
The parameter values apply at hub height and						
V_{ave} is the annual average wind speed;						
V_{ref} is the reference wind speed average over 10 min;						
$V_{ref,T}$ is the reference wind speed average over 10 min applicable for areas subject to tropical cyclones;						
A+ designates the category for very high turbulence characteristics;						
A designates the category for higher turbulence characteristics;						
B designates the category for medium turbulence characteristics;						
C designates the category for lower turbulence characteristics; and						
I_{ref} is a reference value of the turbulence intensity (see 6.3.2.3).						

Class T assumes all wind model parameters to be the same and allows the combination of $V_{ref,T}$ with all turbulence categories. It does not cover all the areas prone to tropical cyclones. A site assessment based on Clause 11 is needed, as a minimum assessing that V_{50} is below V_{ref} of class T ($V_{ref,T}$).

An optional wind turbine class CC, which may be used for areas with cold climate, is defined in Clause 14. The optional wind turbine class specifies additional requirements and parameters to what is given in Clause 6.

¹ A turbine class using for example the annual average wind speed of class II and turbulence category B together with the T class reference wind speed is designated class IIB,T.

A further wind turbine class, class S, is defined for use when special wind or other external conditions or a special safety class, see 5.3, are required by the designer and/or the customer. The design values for the wind turbine 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 an environment at least as severe as is anticipated for the use of the wind turbine.

Wind turbines to be designed for site-specific or very extreme conditions may require wind turbine class S design.

In addition to the basic parameters showed in Table 1, several other important parameters are required to completely specify the external conditions to be used in wind turbine design. In the case of the wind turbine classes I_{A+} through III_C, later referred to as the standard wind turbine classes, the values of these additional parameters are specified in 6.3, 6.4 and 6.5.

The design lifetime for wind turbine classes I to III shall be at least 20 years.

For the wind turbine class S the manufacturer shall, in the design documentation, describe the models used and values of design parameters. Where the models in Clause 6 are adopted, statement of the values of the parameters will be sufficient. The design documentation of wind turbine class S shall contain the information listed in Annex A. Guidance on turbine class S design load cases is given in Annex B.

The abbreviations added in parentheses in the subclause headings in 6.3.2.2 to 6.3.3.7 are used for describing the wind conditions for the design load cases defined in 7.4.

6.3 Wind conditions

6.3.1 General

A wind turbine shall be designed to safely withstand the wind conditions defined by the selected wind turbine 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 wind turbine, and the extreme wind conditions that are defined as having a 1-year or 50-year return period.

The wind conditions include a constant mean flow combined, in many cases, with either a varying deterministic gust profile or with turbulence. In all cases, the influence of an inclination of the mean flow with respect to a horizontal plane of 8° shall be considered. This flow inclination angle shall be assumed to be invariant with height.

The expression "turbulence" denotes random variations in the wind velocity from 10 min averages. The turbulence model, when used, shall include the effects of varying wind speed, shears and direction and allow rotational sampling through varying shears. The three vector components of the turbulent wind velocity are defined as

- longitudinal – along the direction of the mean wind velocity,
- lateral – horizontal and normal to the longitudinal direction, and
- upward – normal to both the longitudinal and lateral directions, i.e. tilted from the vertical by the mean flow inclination angle.

For the standard wind turbine classes, the random wind velocity field for the turbulence models shall satisfy the Kaimal model together with the coherence model described in Annex C. This model satisfies the following requirements.

- a) The turbulence standard deviation, σ_1 , with values given in the following subclauses, shall be assumed to be invariant with height. The components normal to the mean wind direction shall have the following minimum standard deviations²:
- lateral component: $\sigma_2 \geq 0,7 \sigma_1$;
 - upward component: $\sigma_3 \geq 0,5 \sigma_1$;
- b) The longitudinal turbulence scale parameter, A_1 , at hub height z shall be given by

$$A_1 = \begin{cases} 0,7z & z \leq 60m \\ 42m & z \geq 60m \end{cases} \quad (5)$$

The power spectral densities of the three orthogonal components, $S_1(f)$, $S_2(f)$, and $S_3(f)$ shall asymptotically approach the following forms as the frequency in the inertial sub-range increases:

$$S_1(f) = 0,05 \sigma_1^2 (A_1 / V_{\text{hub}})^{-2/3} f^{-5/3} \quad (6)$$

$$S_2(f) = S_3(f) = \frac{4}{3} S_1(f) \quad (7)$$

- c) A recognized model for the coherence, defined as the magnitude of the co-spectrum divided by the auto-spectrum for the longitudinal velocity components at spatially separated points in a plane normal to the longitudinal direction, shall be used.

As an alternative, the corresponding Mann model may be applied as described in Annex C.

Other turbulence models may be applied; however, for the standard wind turbine classes (I to III), the turbulence model shall satisfy the requirements a) to c) and also result in fatigue loads that are higher or equal to the fatigue loads generated using the models in Annex C. For Class S, a validated turbulence model may be applied.

6.3.2 Normal wind conditions

6.3.2.1 Wind speed distribution

The wind speed distribution is significant for wind turbine design because it determines the frequency of occurrence of individual load conditions for the normal design situations. The mean value of the wind speed for an averaging period of 10 min shall be assumed to follow a Rayleigh distribution at hub height given by

$$P_R(V_{\text{hub}}) = 1 - \exp\left[-\pi(V_{\text{hub}} / 2V_{\text{ave}})^2\right] \quad (8)$$

where, in the standard wind turbine classes, V_{ave} shall be chosen from Table 1.

6.3.2.2 Normal wind profile model (NWP)

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

$$V(z) = V_{\text{hub}} (z/z_{\text{hub}})^\alpha \quad (9)$$

² The actual values can depend on the choice of turbulence model and the requirements in b)

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

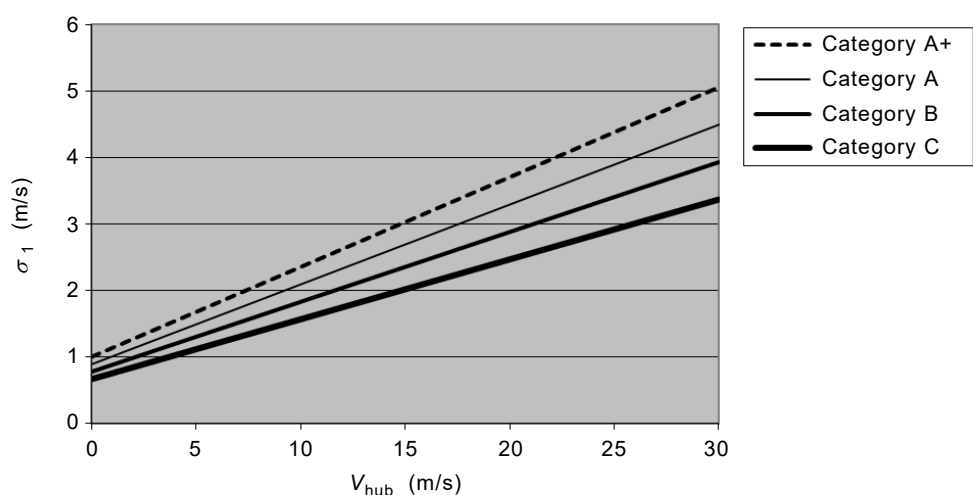
The assumed wind profile is used to define the average vertical wind shear across the rotor swept area.

6.3.2.3 Normal turbulence model (NTM)

For the normal turbulence model, the representative value of the turbulence standard deviation, σ_1 , shall be given by the 90 % quantile for the given hub height wind speed. This value for the standard wind turbine classes shall be given by

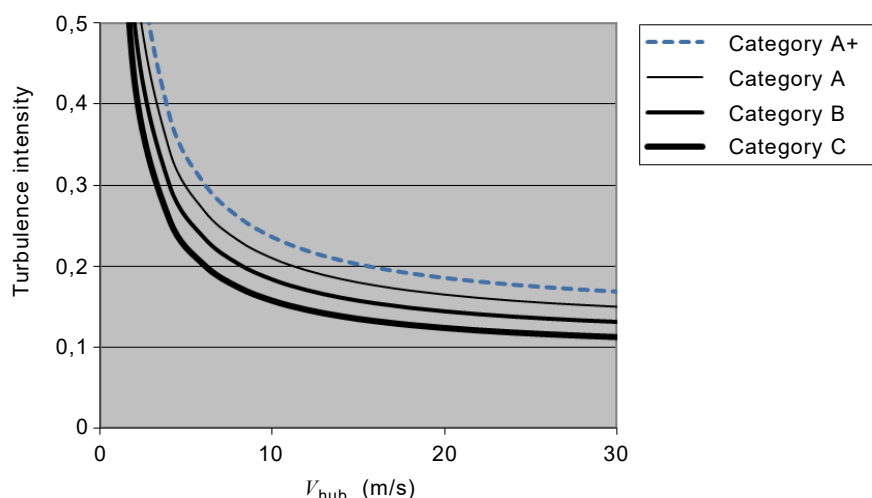
$$\sigma_1 = I_{\text{ref}} (0,75V_{\text{hub}} + b); \quad b = 5,6 \text{ m/s} \quad (10)$$

Values for the turbulence standard deviation σ_1 and the turbulence intensity σ_1/V_{hub} are shown in Figure 1.



IEC

Figure 1a – Turbulence standard deviation



IEC

Figure 1b – Turbulence intensity

Figure 1 – Turbulence standard deviation and turbulence intensity for the normal turbulence model (NTM)

Values for I_{ref} are given in Table 1.

As an alternative to Equation (10), a Weibull distribution shall be assumed for σ_1 with Weibull scale and shape parameters:

$$P_W(\sigma_1 < \sigma_0) = 1 - \exp \left[- \left(\frac{\sigma_0}{C} \right)^k \right] \quad (11)$$

where

$$k = 0,27 \, V_{\text{hub}} (\text{s/m}) + 1,4$$

$$C = I_{\text{ref}} (0,75 V_{\text{hub}} + 3,3 \text{ m/s}) \quad (12)$$

6.3.3 Extreme wind conditions

6.3.3.1 General

The extreme wind conditions include wind shear events, as well as peak wind speeds due to storms and rapid changes in wind speed and direction.

6.3.3.2 Extreme wind speed model (EWM)

The EWM shall be either a steady or a turbulent wind model. The wind models shall be based on the reference wind speed, V_{ref} , and a fixed turbulence standard deviation, σ_1 . If the wind turbine type is designed for a T class reference wind speed, V_{ref} shall be replaced by $V_{\text{ref,T}}$ in the extreme wind speed model while keeping other parameters.

For the steady extreme wind model, the extreme wind speed, V_{e50} , with a return period of 50 years, and the extreme wind speed, V_{e1} , with a return period of 1 year, shall be computed as a function of height, z , using the following equations:

$$V_{\text{e50}}(z) = 1,4 V_{\text{ref}} \left(\frac{z}{z_{\text{hub}}} \right)^{0,11} \quad (13)$$

and

$$V_{\text{e1}}(z) = 0,8 V_{\text{e50}}(z) \quad (14)$$

In the steady extreme wind model, allowance for short-term deviations from the mean wind direction shall be made by assuming constant yaw misalignment in the range of $\pm 15^\circ$.

For the turbulent extreme wind speed model, the 10 min average wind speeds as functions of z with return periods of 50 years and 1 year, respectively, shall be given by

$$V_{50}(z) = V_{\text{ref}} \left(\frac{z}{z_{\text{hub}}} \right)^{0,11} \quad (15)$$

$$V_1(z) = 0,8 V_{50}(z) \quad (16)$$

The longitudinal turbulence standard deviation³ shall be

$$\sigma_1 = 0,11 V_{\text{hub}} \quad (17)$$

6.3.3.3 Extreme operating gust (EOG)

The hub height gust magnitude V_{gust} ⁴ shall be given for the standard wind turbine classes by the following relationship:

$$V_{\text{gust}} = \text{Min} \left\{ 1,35 (V_{\text{e1}} - V_{\text{hub}}); \quad 3,3 \left(\frac{\sigma_1}{1 + 0,1 \left(\frac{D}{A_1} \right)} \right) \right\} \quad (18)$$

where

σ_1 is given in Equation (10);

A_1 is the turbulence scale parameter, according to Equation (5);

D is the rotor diameter.

The wind speed shall be defined by Equation (19):

$$V(z,t) = \begin{cases} V(z) - 0,37 V_{\text{gust}} \sin(3\pi t / T) (1 - \cos(2\pi t / T)) & \text{for } 0 \leq t \leq T \\ V(z) & \text{otherwise} \end{cases} \quad (19)$$

where

$V(z)$ is defined in Equation (9);

$T = 10,5$ s.

An example of the extreme operating gust ($V_{\text{hub}} = 25$ m/s, Class I_A, $D = 42$ m) is shown in Figure 2.

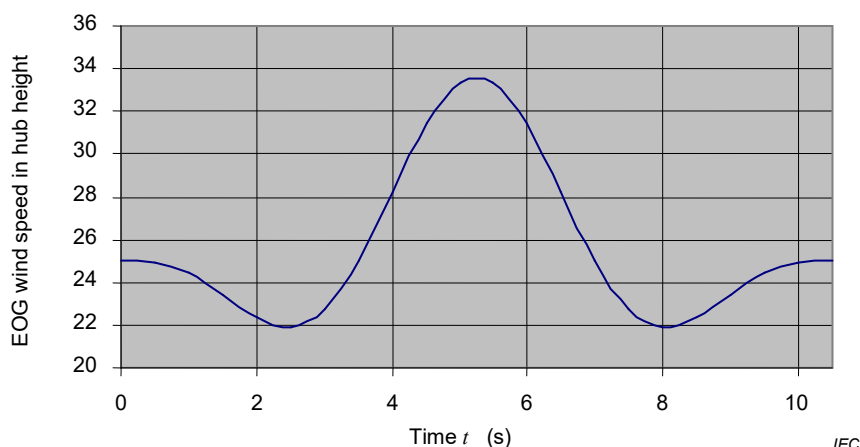


Figure 2 – Example of extreme operating gust

³ The turbulence standard deviation for the turbulent extreme wind model is not related to the normal (NTM) or the extreme turbulence model (ETM). The steady extreme wind model is related to the turbulent extreme wind model by a peak factor of approximately 3,5.

⁴ The gust magnitude is calibrated, together with the probability of an operation event such as starts and stops, to give a return period of 50 years.

6.3.3.4 Extreme turbulence model (ETM)

The extreme turbulence model shall use the normal wind profile model in 6.3.2.2 and turbulence with longitudinal component standard deviation given by

$$\sigma_1 = c \ I_{\text{ref}} \left(0,072 \left(\frac{V_{\text{ave}}}{c} + 3 \right) \left(\frac{V_{\text{hub}}}{c} - 4 \right) + 10 \right); \quad c = 2 \text{ m/s.} \quad (20)$$

6.3.3.5 Extreme direction change (EDC)

The extreme direction change magnitude, θ_e , shall be calculated using the following relationship:

$$\theta_e = \pm 4 \arctan \left(\frac{\sigma_1}{V_{\text{hub}} \left(1 + 0,1 \left(\frac{D}{A_1} \right) \right)} \right) \quad (21)$$

where

σ_1 is given by Equation (10) for the NTM;

θ_e is limited to the interval $\pm 180^\circ$;

A_1 is the turbulence scale parameter, according to Equation (5);

D is the rotor diameter.

The extreme direction change transient, $\theta(t)$, shall be given by

$$\theta(t) = \begin{cases} 0^\circ & \text{for } t < 0 \\ \pm 0,5\theta_e(1 - \cos(\pi t / T)) & \text{for } 0 \leq t \leq T \\ \theta_e & \text{for } t > T \end{cases} \quad (22)$$

where $T = 6$ s is the duration of the extreme direction change. 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 shall follow the normal wind profile model in 6.3.2.2.

As an example, the magnitude of the extreme direction change with turbulence category A, $D = 42$ m, $z_{\text{hub}} = 30$ m is shown in Figure 3 for varying V_{hub} . The corresponding transient for $V_{\text{hub}} = 25$ m/s is shown in Figure 4.

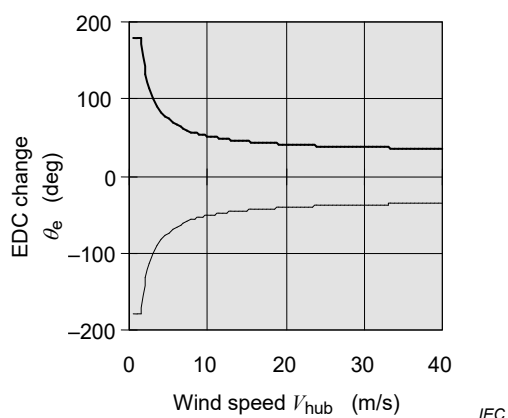


Figure 3 – Example of extreme direction change magnitude

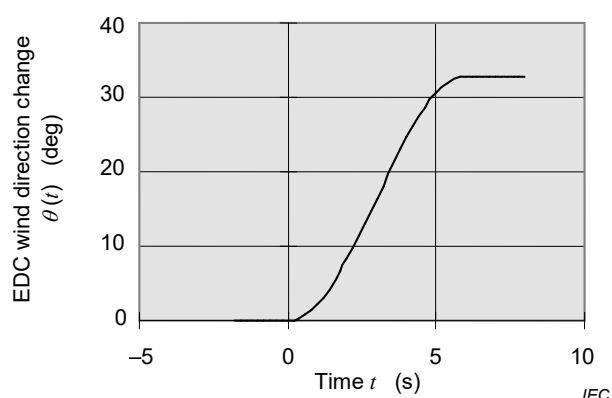


Figure 4 – Example of extreme direction change transient

6.3.3.6 Extreme coherent gust with direction change (ECD)

The extreme coherent gust with direction change shall have a magnitude of

$$V_{cg} = 15 \text{ m/s} \quad (23)$$

The wind speed shall be defined by

$$V(z, t) = \begin{cases} V(z) & \text{for } t \leq 0 \\ V(z) + 0,5 V_{cg} (1 - \cos(\pi t / T)) & \text{for } 0 \leq t \leq T \\ V(z) + V_{cg} & \text{for } t \geq T \end{cases} \quad (24)$$

where $T = 10 \text{ s}$ is the rise time and the wind speed $V(z)$ is given by the normal wind profile model in 6.3.2.2. The rise in wind speed during the extreme coherent gust is illustrated in Figure 5 for $V_{hub} = 25 \text{ m/s}$.

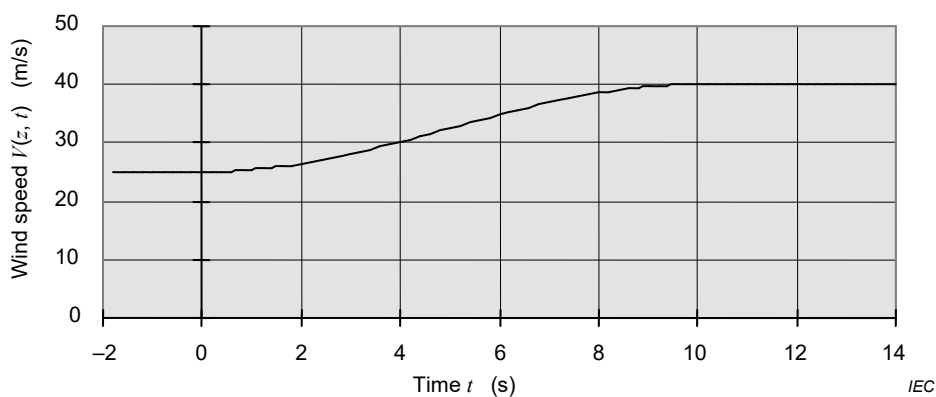


Figure 5 – Example of extreme coherent gust amplitude for ECD

The rise in wind speed shall be assumed to occur simultaneously with the direction change θ from 0° up to and including θ_{cg} , where the magnitude θ_{cg} is defined by

$$\theta_{cg}(V_{hub}) = \begin{cases} 180^\circ & \text{for } V_{hub} < 4 \text{ m/s} \\ \frac{720^\circ (\text{m/s})}{V_{hub}} & \text{for } 4 \text{ m/s} < V_{hub} < V_{ref} \end{cases} \quad (25)$$

The simultaneous direction change is then given by

$$\theta(t) = \begin{cases} 0^\circ & \text{for } t < 0 \\ \pm 0,5\theta_{cg}(1 - \cos(\pi t / T)) & \text{for } 0 \leq t \leq T \\ \pm\theta_{cg} & \text{for } t > T \end{cases} \quad (26)$$

where $T = 10$ s is the rise time.

The direction change magnitude, θ_{cg} , and the direction change $\theta(t)$ are shown in Figures 6 and 7, as a function of V_{hub} and as a function of time for $V_{hub} = 25$ m/s, respectively.

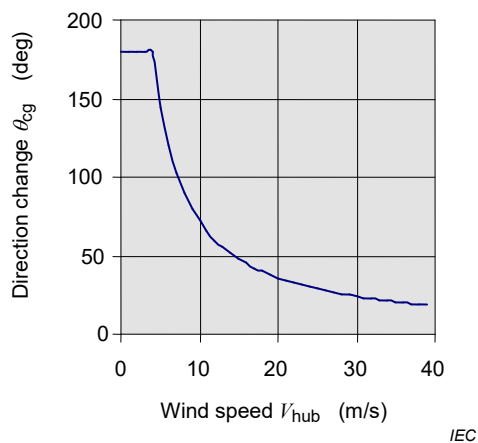


Figure 6 – Direction change for ECD

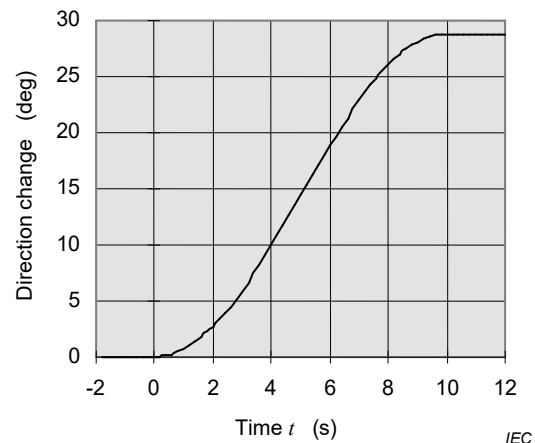


Figure 7 – Example of direction change transient

6.3.3.7 Extreme wind shear (EWS)

The extreme wind shear shall be accounted for using the following wind speed transients.

Transient (positive and negative) vertical shear:

$$V(z, t) = \begin{cases} V_{hub} \left(\frac{z}{z_{hub}} \right)^\alpha \pm \left(\frac{z - z_{hub}}{D} \right) \left(2,5[\text{m/s}] + 0,2\beta\sigma_1 \left(\frac{D}{A_1} \right)^{1/4} \right) (1 - \cos(2\pi t / T)) & \text{for } 0 \leq t \leq T \\ V_{hub} \left(\frac{z}{z_{hub}} \right)^\alpha & \text{otherwise} \end{cases} \quad (27)$$

Transient horizontal shear:

$$V(y, z, t) = \begin{cases} V_{\text{hub}} \left(\frac{z}{z_{\text{hub}}} \right)^{\alpha} \pm \left(\frac{y}{D} \right) \left(2,5 [\text{m/s}] + 0,2\beta\sigma_1 \left(\frac{D}{A_1} \right)^{1/4} \right) (1 - \cos(2\pi t / T)) & \text{for } 0 \leq t \leq T \\ V_{\text{hub}} \left(\frac{z}{z_{\text{hub}}} \right)^{\alpha} & \text{otherwise} \end{cases} \quad (28)$$

where for both vertical and horizontal shear:

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

σ_1 is given by Equation (10) for the NTM;

A_1 is the turbulence scale parameter, according to Equation (5);

D is the rotor diameter.

The sign for the horizontal wind shear transient shall be chosen so that the worst transient loading occurs. The two extreme wind shears are not applied simultaneously.

As an example, the extreme vertical wind shear (turbulence category A, $z_{\text{hub}} = 30$ m, $V_{\text{hub}} = 25$ m/s, $D = 42$ m) 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). Figure 9 shows the wind speeds at the top and the bottom of the rotor, to illustrate the time development of the shear (assumptions as in Figure 8).

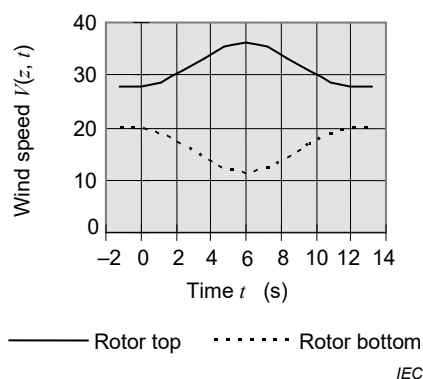
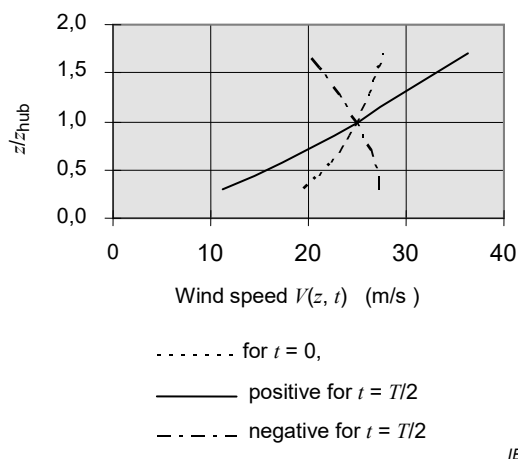


Figure 8 – Examples of extreme positive and negative vertical wind shear, wind profile before onset ($t = 0$, dashed line) and at maximum shear ($t = 6$ s, full line)

Figure 9 – Example of wind speeds at rotor top and bottom, respectively, which illustrate the transient positive wind shear

6.4 Other environmental conditions

6.4.1 General

Environmental (climatic) conditions other than wind can affect the integrity and safety of wind turbines, by thermal, photochemical, corrosive, mechanical, electrical or other physical action. Moreover, combinations of climatic conditions may increase their effects.

The following other environmental conditions, at least, shall be taken into account and the resulting action stated in the design documentation:

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

An offshore environment requires additional consideration, as per IEC 61400-3.

An optional cold climate class is defined in Clause 14.

The climatic conditions taken into account shall be defined in terms of either representative values or limits of the variable conditions. The probability of simultaneous occurrence of climatic conditions shall be taken into account when the design values are selected.

Variations in climatic conditions within the normal limits corresponding to a 1-year return period shall not interfere with the designed normal operation of a wind turbine.

Unless correlation exists, other extreme environmental conditions according to 6.4.3 shall be combined with normal wind conditions according to 6.3.2. A general description on how to combine design situations with external conditions is given in 7.4.

6.4.2 Normal other environmental conditions

The normal other environmental condition values that shall be taken into account are the following:

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

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

6.4.3 Extreme other environmental conditions

6.4.3.1 General

The extreme other environmental conditions that shall be considered for wind turbine design are temperature, lightning, ice and earthquakes (see 11.6 for assessment of earthquake conditions).

6.4.3.2 Temperature

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

6.4.3.3 Lightning

The provisions of lightning protection required in 10.7 may be considered as adequate for turbine designs for the standard wind turbine classes.

6.4.3.4 Ice

No minimum ice requirements are given for the standard wind turbine classes. For cold climate, ice requirements are given in Clause 14 and Annex L.

6.4.3.5 Earthquakes

No minimum earthquake requirements are given for the standard wind turbine classes. For consideration of earthquake conditions and effects, see 11.6 and Annex D.

6.5 Electrical power network conditions

The normal conditions at the wind turbine terminals to be considered are listed below.

Normal electrical power network conditions apply when the following parameters fall within the ranges stated below.

- Voltage – nominal value (according to IEC 60038) $\pm 10\%$.
- Frequency – nominal value $\pm 2\%$.
- Voltage imbalance – the ratio of the negative-sequence component of voltage not exceeding 2% .
- Auto-reclosing cycles – auto-reclosing cycle periods of 0,1 s to 5 s for the first reclosure and 10 s to 90 s for a second reclosure shall be considered.
- Outages – electrical network outages shall be assumed to occur 20 times per year. An outage of up to 6 h⁵ shall be considered a normal condition. An outage of up to 1 week shall be considered an extreme condition.

7 Structural design

7.1 General

The integrity of the load-carrying components of the wind turbine structure shall be verified and an acceptable safety level shall be ascertained. The ultimate and fatigue strength of structural members shall be verified by calculations, tests or both to demonstrate the structural integrity of a wind turbine with the appropriate safety level.

The structural analysis shall be based on ISO 2394.

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 for strength verification shall correspond to the safety factors appropriate for the characteristic loads according to 7.6.

⁵ Six hours of operation is assumed to correspond to the duration of the severest part of a storm.

Tower, rotor, and drive train resonances shall be identified for the frequency range up to and including 2 times the blade passing frequency excitation. Possible resonances shall be investigated at turbulence levels of 30 % of the NTM category C design turbulence for DLC 1.2, see 7.4.2. If high resonant loads are found at low turbulence, means shall be taken to avoid the resonances or they shall be included in the design loads.

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.

The design calculations shall be based on validated methods and recognized codes.

The design methodology assumes that the aeroelastic simulation model used for the specific design calculations is subsequently validated by measurements. Such measurements shall be made on a wind turbine that is dynamically and structurally similar to, but may differ in detail (such as alternative tower designs) from the turbine designed. Requirements for load measurements can be found in IEC 61400-13.

7.3 Loads

7.3.1 General

Loads described in 7.3.2 through 7.3.5 shall be considered for the design calculations.

7.3.2 Gravitational and inertial loads

Gravitational and inertial loads are static and dynamic loads that result from gravity, vibration, rotation and seismic activity.

The allowable tolerances in tower verticality shall be stated in the design documentation and shall include initial and long term effects due to permanent soil subsidence. The effect of tower verticality on gravitational loads shall be taken into account separately during the structural analysis of tower and foundation.

7.3.3 Aerodynamic loads

Aerodynamic loads are static and dynamic loads that are caused by the airflow and its interaction with the stationary and moving parts of wind turbines.

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

It is not required in the aerodynamic load calculations to account for geometric tolerances in tower verticality of less than or equal to 3°.

7.3.4 Actuation loads

Actuation loads result from the operation and control of wind turbines. They are in several categories including torque control from a generator or inverter or both, yaw and pitch actuator loads and mechanical braking loads. In each case, it is important in the calculation of response and loading to consider the range of actuator forces available, including friction. In particular, for mechanical brakes, the range of friction, spring force or pressure as influenced by temperature, and ageing shall be taken into account in checking the response and the loading during any braking event.

7.3.5 Other loads

Other loads such as wake loads, impact loads, ice loads, tower loads resulting for example from vortex-induced vibrations might occur and shall be considered where appropriate. For other loads associated with cold climate, see Clause 14 and Annex L.

7.4 Design situations and load cases

7.4.1 General

Subclause 7.4 describes the design load cases for a wind turbine and specifies a minimum number to be considered.

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

The load cases shall be determined from the combination of operational modes or other design situations, such as specific assembly, erection or maintenance conditions, with the external conditions. All relevant load cases with a reasonable probability of occurrence shall be considered, together with the behaviour of the control system. The design load cases used to verify the structural integrity of a wind turbine shall be calculated by combining the following:

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

If 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. 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.

If the wind turbine controller can, during design load cases with a deterministic wind model, cause the wind turbine to shut down prior to reaching maximum yaw angle and/or wind speed, then it shall be shown that the turbine can reliably shut down under turbulent conditions with the same deterministic wind condition change.

Other design load cases shall be considered, if relevant to the structural integrity of the specific wind turbine design.

For each design load case, 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, with reference to material strength, blade tip deflection and structural stability.

The design load cases indicated with "U" are classified as normal (N) or abnormal (A). Normal design load cases are expected to occur frequently. 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 severe faults that result in the activation of system protection functions. The type of design situation, N or A, determines the partial safety factor γ_f to be applied to the ultimate loads. These factors are given in Table 3.

Table 2 – Design load cases (DLC)

Design situation	DLC	Wind condition	Other conditions	Type of analysis	Partial safety factors
1) Power production	1.1	NTM $V_{in} < V_{hub} < V_{out}$	For extrapolation of extreme events	U	N
	1.2	NTM $V_{in} < V_{hub} < V_{out}$		F	*
	1.3	ETM $V_{in} < V_{hub} < V_{out}$		U	N
	1.4	ECD $V_{hub} = V_r - 2 \text{ m/s}, V_r, V_r + 2 \text{ m/s}$		U	N
	1.5	EWS $V_{in} < V_{hub} < V_{out}$		U	N
2) Power production plus occurrence of fault	2.1	NTM $V_{in} < V_{hub} < V_{out}$	Normal control system fault or loss of electrical network or primary layer control function fault (see 7.4.3)	U	N
	2.2	NTM $V_{in} < V_{hub} < V_{out}$	Abnormal control system fault or secondary layer protection function related fault (see 7.4.3)	U	A
	2.3	EOG $V_{hub} = V_r \pm 2 \text{ m/s}$ and V_{out}	External or internal electrical fault including loss of electrical network	U	A
	2.4	NTM $V_{in} < V_{hub} < V_{out}$	Control system fault, electrical fault or loss of electrical network	F	*
	2.5	NWP $V_{in} < V_{hub} < V_{out}$	Low voltage ride through	U	N
3) Start-up	3.1	NWP $V_{in} < V_{hub} < V_{out}$		F	*
	3.2	EOG $V_{hub} = V_{in}, V_r \pm 2 \text{ m/s}$ and V_{out}		U	N
	3.3	EDC $V_{hub} = V_{in}, V_r \pm 2 \text{ m/s}$ and V_{out}		U	N
4) Normal shutdown	4.1	NWP $V_{in} < V_{hub} < V_{out}$		F	*
	4.2	EOG $V_{hub} = V_r \pm 2 \text{ m/s}$ and V_{out}		U	N
5) Emergency stop	5.1	NTM $V_{hub} = V_r \pm 2 \text{ m/s}$ and V_{out}		U	N
6) Parked (standing still or idling)	6.1	EWM 50-year return period		U	N
	6.2	EWM 50-year return period	Loss of electrical network connection	U	A
	6.3	EWM 1-year return period	Extreme yaw misalignment	U	N
	6.4	NTM $V_{hub} < 0,7 V_{ref}$		F	*
7) Parked and fault conditions	7.1	EWM 1-year return period		U	A
8) Transport, assembly, maintenance and repair	8.1	NTM V_{maint} to be stated by the manufacturer		U	N
	8.2	EWM 1-year return period		U	A

Key	
DLC	Design load case
ECD	Extreme coherent gust with direction change (see 6.3.3.6)
EDC	Extreme direction change (see 6.3.3.5)
EOG	Extreme operating gust (see 6.3.3.3)
EWM	Extreme wind speed model (see 6.3.3.2)
EWS	Extreme wind shear (see 6.3.3.7)
NTM	Normal turbulence model (see 6.3.2.3)
ETM	Extreme turbulence model (see 6.3.3.4)
NWP	Normal wind profile model (see 6.3.2.2)
$V_r \pm 2$ m/s	Sensitivity to all wind speeds in the range shall be analysed
F	Fatigue (see 7.6.3)
U	Ultimate strength (see 7.6.2)
N	Normal
A	Abnormal
*	Partial safety for fatigue (see 7.6.3)

When a wind speed range is indicated in Table 2, wind speeds leading to the most adverse condition for wind turbine design shall be considered. The range of wind speeds may be represented by a set of discrete values, in which case the resolution shall be sufficient to assure accuracy of the calculation⁶. In the definition of the design load cases, reference is made to the wind conditions described in Clause 6.

In the further specifications of design load cases (DLCs) in 7.4.2 to 7.4.9, some DLCs allow alternative formulations. Where alternatives are mentioned, the party designing to this document shall decide which alternative shall be used throughout the analysis of the DLC.

7.4.2 Power production (DLC 1.1 to 1.5)

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

Design load cases (DLCs) 1.1 and 1.2 embody the requirements for loads resulting from atmospheric turbulence that occurs during normal operation of a wind turbine throughout its lifetime (NTM). DLC 1.3 embodies the requirements for ultimate loading resulting from extreme turbulence conditions. DLC 1.4 and 1.5 specify transient cases that have been selected as potentially critical events in the life of a wind turbine.

The statistical analysis of DLC 1.1 simulation data, see 7.6.2.2 and Annex G, shall include at least the calculation of extreme values of the blade root in-plane moment and out-of-plane moment and tip deflection. If the extreme design values of the blade root moments derived from DLC 1.1 are exceeded by the extreme design values derived for DLC 1.3, the further analysis of DLC 1.1 may be omitted.

If the extreme design values of the blade root moments derived from DLC 1.1 are not exceeded by the extreme design values derived for DLC 1.3, the factor c in Equation (20) for

⁶ In general, a resolution of 2 m/s is considered sufficient. However, in the wind speed range where the power curve rises quickly, 2 m/s steps may be too large to assure accuracy.

the extreme turbulence model used in DLC 1.3 may be increased until the extreme design values of the blade root moments computed in DLC 1.3 are equal to or exceed the relevant extremes. The characteristic values of the loads relevant for other turbine components may be determined from this analysis based on DLC 1.3 with the increased c value. As an alternative to this analysis, the appropriate characteristic values of all load components relevant for each specific turbine component may be directly determined or extrapolated from the simulation.

7.4.3 Power production plus occurrence of fault or loss of electrical network connection (DLC 2.1 to 2.5)

7.4.3.1 General

This design situation involves a transient event triggered by a fault or by the loss of electrical network connection while the turbine is producing power. Any fault in the control system, or internal fault in the electrical system, significant for wind turbine loading (such as generator short circuit) shall be considered. This design situation is considered to be relevant for fatigue analysis as well, see DLC 2.4.

A failure mode and effect analysis (FMEA) or equivalent fault analysis shall be carried out to determine fault events relevant for the wind turbine loading.

The azimuth position for the rotor at the time of a fault may have significant influence on the load level. The azimuth position at time of occurrence for the fault should be random.

Faults in the control system shall be considered in DLC 2.1 and DLC 2.2 as described in 7.4.3.2. For architectures where turbine safety is ensured by two independent sets of functions (via primary layer control functions and secondary layer protection functions, respectively), the method described in 7.4.3.3 may be used. See Clause 8 for guidance on identification of failure modes, assessment of failure mode return periods, fault exclusions, and measures to avoid common-cause failures.

7.4.3.2 Control system failure (DLC 2.1 and DLC 2.2) – Quantitative approach

For DLC 2.1, the following shall be considered as normal events:

- a) control system failure related events that have an expected failure mode return period that is equal to or less than 50 years;
- b) control system failure related events where the expected failure mode return period cannot be obtained;
- c) loss of electrical network connection.

For events with expected failure mode return periods between 10 and 50 years, the partial load factor applied is found as function of the failure mode return period as stated in Table 3.

For DLC 2.2, control system failure events or internal electrical and mechanical system faults with expected failure mode return period greater than 50 years shall be considered as abnormal.

Fault events with a return period in excess of 2000 years and fault events that are not relevant for wind turbine loading may be disregarded. The fault event return period is based on the statistical calculation of the probability of an event whereby a control or internal electrical system part is in or enters a failed state such that a structural failure could occur.

7.4.3.3 Control system failure (DLC 2.1 and DLC 2.2) – Two-layer approach

This approach can be used for control system architectures consisting of two or more independent layers. Within this approach,

- a) primary layer control and protection functions aim to keep the turbine operating parameters within their normal operating limits and their design limits, respectively, and
- b) secondary layer protection functions aim to keep the turbine operating parameters within their design limits. These shall be activated as a result of failure of the primary layer control functions or as a result of the effects of an internal or external failure or dangerous event.

For DLC 2.1, primary layer control function faults, activation of primary layer protection functions or loss of electrical network connection shall be considered as normal events. Control function faults which lead to exceedance of the limits and the activation of the secondary layer protection functions shall be included in DLC 2.2.

Primary layer control function faults considered in DLC 2.1 typically include faults relating to rotor speed, yaw angle, and blade pitch angles.

For DLC 2.2, rare events that have relevance for the wind turbine loading, including faults relating to activation of secondary layer protection functions, shall be considered as abnormal. Such faults may include erroneous activation of actuators, non-activation of braking systems, and blocking of the pitch system. This load case shall at least address the following: independent overspeed protection, generator overload/fault protection, uncontrolled blade pitch protection (blade pitch runaway), uncontrolled yaw protection and excessive vibration or shock protection.

7.4.3.4 Other power production plus occurrence of fault or loss of electrical network connection (DLC 2.3 to 2.5)

For DLC 2.3, the potentially significant wind event, the extreme operating gust (EOG), is combined with loss of one or more phases in a multiphase electrical network connection and considered as an abnormal event. In this case, the timing of these two events shall be chosen to achieve the worst loading.

As an alternative to the specification of DLC 2.3 above and in Table 2, DLC 2.3 may instead be considered as a normal event (i.e. a partial safety factor for load of 1,35) to be analysed using stochastic wind simulations ($NTM - V_{in} < V_{hub} < V_{out}$) combined with an internal or external electrical system fault (including loss of electrical network connection). In this case, 12 response simulations shall be carried out for each considered mean wind speed. For each response simulation, the extreme response after the electrical fault has occurred is sampled. The fault shall be introduced after the effect of initial conditions has become negligible. For each mean wind speed, a nominal extreme response is evaluated as the mean of the 12 sampled extreme responses plus three times the standard deviation of the 12 samples. The characteristic response value for DLC 2.3 is determined as the extreme value among the nominal extreme responses.

If a fault or loss of electrical network connection does not cause an immediate shutdown and the subsequent loading can lead to significant fatigue damage, the likely duration of this situation along with the resulting fatigue damage in normal turbulence conditions (NTM) shall be evaluated in DLC 2.4. The manufacturer shall estimate the expected frequency/duration for the events⁷.

⁷ If there is no relevant data/information available, the following frequency/duration can be applied for the below listed events:

- 10 shut-downs per year for overspeed event;
- 24 hours per year of operation for events with yaw error;
- 24 hours per year of operation for events with pitch error;
- 20 times per year with loss of electrical network connection.

For DLC 2.5, the event of low voltage ride through (LVRT)⁸ is considered as normal. The design low voltage ride through event shall be specified by voltage drop and duration.

7.4.4 Start-up (DLC 3.1 to 3.3)

This design situation includes all the events resulting in loads on a wind turbine during the transients from any standstill or idling situation to power production. The number of occurrences shall be estimated based on the control system behaviour.⁹

For DLC 3.2, at least four different timing events between the EOG and the start-up event shall be considered for each wind speed. The first timing shall be chosen so that the beginning of the EOG occurs when the power production reaches 50 % of maximum power. The last timing shall be chosen so that the beginning of the EOG occurs when the power production reaches 95 % of maximum power. At least two additional timings shall be chosen, evenly distributed within the interval from 50 % to 95 % of maximum power.

For each wind speed, the characteristic value of the load may be computed as the average value of the extreme computed transient value for the four defined distinct points of time.

As an alternative to the EOG gust, the DLC 3.2 may instead be analysed using at least 12 stochastic wind simulations for each mean wind speed with the ETM. For each mean wind speed, a nominal extreme response is evaluated as the mean of the simulated extremes.

7.4.5 Normal shutdown (DLC 4.1 to 4.2)

This design situation includes all the events resulting in loads on a wind turbine during normal transient situations from a power production situation to a standstill or idling condition. The number of occurrences shall be estimated based on the control system behaviour.¹⁰

For DLC 4.2, the timing of the gust and the shutdown event shall be chosen such that the EOG gust starts at different times relative to the shutdown, with minimum six events evenly distributed from 10 s before the beginning of the shutdown, till the power reaches 50 % of the initial power production level.

At least four evenly distributed rotor azimuth positions shall be applied for each distinct point of time. For each wind speed, the characteristic value of the load may be computed as the mean value of the extreme computed loads among all timings and azimuth positions considered.

If, due to the safety and control system, a shutdown event is automatically triggered during the EOG gust, that event shall also be considered in the analysis.

⁸ Low voltage ride through situations are normally defined by the electrical utilities as situations with grid disturbances or failures the wind turbine should be able to handle without shutting down. The reason for a demand for riding through these situations is that if the wind turbines (especially in wind farms) shut down it can result in a collapse of the grid.

⁹ If historical data on start-ups for similar wind turbines are unavailable, the following annual frequencies for DLC 3.1 can be assumed:

- 1000 start-up procedures at V_{in} ;
- 50 start-up procedures at V_r ;
- 50 start-up procedures at maximum start-up wind speed.

¹⁰ If historical data on shutdowns for similar wind turbines are unavailable, the following annual frequencies for DLC 4.1 can be assumed:

- 1000 shut-down procedures at V_{in} ;
- 50 shut-down procedures at V_r ;
- 50 shut-down procedures at V_{out} .

As an alternative to the EOG gust, the DLC 4.2 may instead be analysed using at least 12 stochastic wind simulations for each mean wind speed with the ETM. For each mean wind speed, a nominal extreme response is evaluated as the mean of simulated extremes.

7.4.6 Emergency stop (DLC 5.1)

Loads arising from activation of the emergency stop button shall be considered.

The azimuth position for the rotor at the time of a fault may have significant influence on the load level. The azimuth position at time of occurrence for the fault should be random.

7.4.7 Parked (standstill or idling) (DLC 6.1 to 6.4)

In this design situation, the rotor of a parked wind turbine is either in a standstill or idling condition. In DLC 6.1, 6.2 and 6.3, this situation shall be considered with the extreme wind speed model (EWM). For DLC 6.4, the normal turbulence model (NTM) shall be considered.

For design load cases, where the wind conditions are defined by EWM, either the steady extreme wind model or the turbulent extreme wind model may be used. If the turbulent extreme wind model is used, the response shall be estimated using either a full dynamic simulation or a quasi-steady analysis with appropriate corrections for gusts and dynamic response using the formulation in ISO 4354. If the steady extreme wind model is used, the effects of resonant response shall be estimated from the quasi-steady analysis above. If the ratio of resonant to background response (R/B) is less than 5 %, a static analysis using the steady extreme wind model may be used. If slippage in the wind turbine yaw system can occur at the characteristic load, the largest possible unfavourable slippage shall be added to the mean yaw misalignment. If the wind turbine has a yaw system where yaw movement is expected in the extreme wind situations (e.g. free yaw, passive yaw or semi-free yaw), the turbulent wind model shall be used and the yaw misalignment will be governed by the turbulent wind direction changes and the turbine yaw dynamic response. Also, if the wind turbine is subject to large yaw movements or change of equilibrium during a wind speed increase from normal operation to the extreme situation, this behaviour shall be included in the analysis.

In DLC 6.1, for a wind turbine with an active yaw system, a yaw misalignment of up to $\pm 15^\circ$ using the steady extreme wind model or a mean yaw misalignment of $\pm 8^\circ$ using the turbulent extreme wind model shall be imposed, provided restraint against slippage in the yaw system can be assured.

In DLC 6.2, a loss of the electrical power network at an early stage in a storm containing the extreme wind situation shall be assumed. Unless power back-up is provided for the control and yaw system with a capacity for yaw alignment for a period of at least 6 h, the effect of a wind direction change of up to $\pm 180^\circ$ shall be analysed.

The partial safety factors for loads for DLC 6.1 and DLC 6.2 in Table 3 are derived by assuming that the coefficient of variation of the annual maximum wind speed is smaller than 15 %; for other COV, see footnote 31 in 11.3.2.

In DLC 6.3, the extreme wind with a 1-year return period shall be combined with an extreme yaw misalignment. An extreme yaw misalignment of up to $\pm 30^\circ$ using the steady extreme wind model or a mean yaw misalignment of $\pm 20^\circ$ using the turbulent wind model shall be assumed.

If for the cases DLC 6.1 with steady extreme wind model, DLC 6.2 and DLC 6.3, yaw misalignment is evaluated using discrete values, the increment in yaw misalignment shall be not more than 10° in the sector of the maximum lift force on the blades.

In DLC 6.4, the expected number of hours of non-power production time at a fluctuating load appropriate for each wind speed where significant fatigue damage can occur to any components (e.g. from the weight of idling blades) shall be considered.