

# Wind turbines

## Part 1: Design requirements

ICS 27.180

# National foreword

This British Standard is the UK implementation of EN 61400-1:2005+A1:2010. It is identical to IEC 61400-1:2005 incorporating amendment A1:2010 and corrigendum March 2016. It supersedes BS EN 61400-1:2005 which is withdrawn.

The start and finish of text introduced by amendment is indicated in the text by tags. For example, text altered by IEC amendment 1 is indicated in the text by A1 A1.

The start and finish of text introduced or altered by corrigendum is indicated in the text by tags. Text altered by IEC corrigendum March 2016 is indicated in the text by AC1 AC1.

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

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

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## Amendments/corrigenda issued since publication

| Date          | Comments                                                                   |
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| 31 May 2016   | Implementation of IEC corrigendum March 2016                               |
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|               |                                                                            |

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**Wind turbines**  
**Part 1: Design requirements**  
(IEC 61400-1:2005)

Eoliennes  
Partie 1: Exigences de conception  
(CEI 61400-1:2005)

Windenergieanlagen  
Teil 1: Auslegungsanforderungen  
(IEC 61400-1:2005)

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**CENELEC**

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

**Central Secretariat: Avenue Marnix 17, B-1000 Brussels**

## Foreword

The text of document 88/228/FDIS, future edition 3 of IEC 61400-1, prepared by IEC TC 88, Wind turbines, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61400-1 on 2005-10-01.

This European Standard supersedes EN 61400-1:2004.

The main changes with respect to EN 61400-1:2004 are listed below:

- the title has been changed to “Design requirements” in order to reflect that the standard presents safety requirements rather than requirements for safety or protection of personnel;
- wind turbine class designations have been adjusted and now refer to reference wind speed and expected value of turbulence intensities only;
- turbulence models have been expanded and include an extreme turbulence model;
- gust models have been adjusted and simplified;
- design load cases have been rearranged and amended;
- the inclusion of turbulence simulations in the load calculations is emphasized and a scheme for extreme load extrapolation has been specified;
- the partial safety factors for loads have been adjusted and simplified;
- the partial safety factors for materials have been amended and specified in terms of material types and component classes;
- the requirements for the control and protection system have been amended and clarified in terms of functional characteristics;
- a new clause on assessment of structural and electrical compatibility has been introduced with detailed requirements for assessment, including information on complex terrain, earthquakes and wind farm wake effects.

The following dates were fixed:

- |                                                                                                                                          |       |            |
|------------------------------------------------------------------------------------------------------------------------------------------|-------|------------|
| – latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement | (dop) | 2006-07-01 |
| – latest date by which the national standards conflicting with the EN have to be withdrawn                                               | (dow) | 2006-11-01 |

Annex ZA has been added by CENELEC.

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### Endorsement notice

The text of the International Standard IEC 61400-1:2005 was approved by CENELEC as a European Standard without any modification.

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

|             |      |                                                                                        |
|-------------|------|----------------------------------------------------------------------------------------|
| IEC 60034   | NOTE | Harmonized in EN 60034 series (not modified).                                          |
| IEC 60038   | NOTE | Harmonized as HD 472 S1:1989 (modified).                                               |
| IEC 60146   | NOTE | Harmonized in EN 60146 series (not modified).                                          |
| IEC 60173   | NOTE | Harmonized as HD 27 S1:1978 (not modified).                                            |
| IEC 60227   | NOTE | The HD 21 series is related to, but not directly equivalent with the IEC 60227 series. |
| IEC 60245   | NOTE | The HD 22 series is related to, but not directly equivalent with the IEC 60245 series. |
| IEC 60269   | NOTE | Harmonized in EN/HD 60269 series (modified).                                           |
| IEC 60439   | NOTE | Harmonized in EN 60439 series (not modified).                                          |
| IEC 60446   | NOTE | Harmonized as EN 60446:1999 (not modified).                                            |
| IEC 60529   | NOTE | Harmonized as EN 60529:1991 (not modified).                                            |
| IEC 60898   | NOTE | Harmonized in EN 60898 series (modified).                                              |
| IEC 61310-1 | NOTE | Harmonized as EN 61310-1:1995 (not modified).                                          |
| IEC 61310-2 | NOTE | Harmonized as EN 61310-2:1995 (not modified).                                          |

### Foreword to amendment 1

The text of document 88/374/FDIS, future amendment 1 to IEC 61400-1:2005, prepared by IEC TC 88, Wind turbines, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as amendment A1 to EN 61400-1:2005 on 2010-11-01.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN and CENELEC shall not be held responsible for identifying any or all such patent rights.

The following dates were fixed:

- latest date by which the amendment has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2011-08-01
- latest date by which the national standards conflicting with the amendment have to be withdrawn (dow) 2013-11-01

### Endorsement notice

The text of amendment 1:2010 to the International Standard IEC 61400-1:2005 was approved by CENELEC as an amendment to the European Standard without any modification.

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

|                  |      |                                                     |
|------------------|------|-----------------------------------------------------|
| IEC 60034 series | NOTE | Harmonized in EN 60034 series (partially modified). |
| IEC 60146 series | NOTE | Harmonized in EN 60146 series (not modified).       |
| IEC 60269 series | NOTE | Harmonized in EN 60269 series (partially modified). |
| IEC 60439 series | NOTE | Harmonized in EN 60439 series (partially modified). |
| IEC 60446:2007   | NOTE | Harmonized as EN 60446:2007 (not modified).         |
| IEC 60529:1989   | NOTE | Harmonized as EN 60529:1991 (not modified).         |
| IEC 60617        | NOTE | Harmonized in EN 60617 series (not modified).       |
| IEC 60898        | NOTE | Harmonized as EN 60898.                             |
| IEC 61310-1:2007 | NOTE | Harmonized as EN 61310-1:2008 (not modified).       |
| IEC 61310-2:2008 | NOTE | Harmonized as EN 61310-2:2008 (not modified).       |
| ISO 9001         | NOTE | Harmonized as EN ISO 9001.                          |

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

The standard is not intended to give requirements for wind turbines installed offshore, in particular for the support structure. A future document dealing with offshore installations is under consideration.

## WIND TURBINES –

### Part 1: Design requirements

#### 1 Scope

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

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

This standard applies to wind turbines of all sizes. For small wind turbines IEC 61400-2 may be applied.

This standard should be used together with the appropriate IEC and ISO standards mentioned in Clause 2.

#### 2 Normative references

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

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

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

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

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

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

IEC 61000-6-1, *Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments*

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

IEC 61000-6-4, *Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments*

IEC 61400-2, *Wind turbines – Part 2: Design requirements for small wind turbines*

IEC 61400-21, *Wind turbines – Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines*

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

 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*

ISO 76:2006, *Rolling bearings – Static load ratings*

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

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

ISO 2533:1975, *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 81400-4, *Wind turbines – Part 4: Design and specification of gearboxes* 

### **3 Terms and definitions**

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

#### **3.1**

##### **annual average**

mean value of a set of measured data of sufficient size and duration to serve as an estimate of the expected value of the quantity. The averaging time interval should be a whole number of years to average out non-stationary effects such as seasonality

#### **3.2**

##### **annual average wind speed**

$V_{ave}$

wind speed averaged according to the definition of annual average

#### **3.3**

##### **auto-reclosing 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 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 and protection 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**

#### **cut-in wind speed**

$V_{in}$

lowest wind speed at hub height at which the wind turbine starts to produce power in the case of steady wind without turbulence

### **3.10**

#### **cut-out wind speed**

$V_{out}$

highest wind speed at hub height at which the wind turbine is designed to produce power in the case of steady wind without turbulence

### **3.11**

#### **design limits**

maximum or minimum values used in a design

### **3.12**

#### **dormant failure**

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

### **3.13**

#### **downwind**

in the direction of the main wind vector

### **3.14**

#### **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.

### **3.15**

#### **emergency shutdown (wind turbines)**

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

### **3.16**

#### **environmental conditions**

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

### **3.17**

#### **external conditions (wind turbines)**

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

### **3.18**

#### **extreme wind speed**

value of the highest wind speed, averaged over  $t$  s, with an annual probability of exceedance of  $1/N$  ("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.

### **3.19**

#### **fail-safe**

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

### **3.20**

#### **gust**

temporary change in the wind speed

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

### **3.21**

#### **horizontal axis wind turbine**

wind turbine whose rotor axis is substantially horizontal

### **3.22**

#### **hub (wind turbines)**

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

### **3.23**

#### **hub height (wind turbines)**

$z_{\text{hub}}$   
height of the centre of the swept area of the wind turbine rotor above the terrain surface. (see 3.51, swept area)

### **3.24**

#### **idling (wind turbines)**

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

### **3.25**

#### **inertial sub-range**

frequency interval of the 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 sub-range is roughly from 0, 2 Hz to 1 kHz.

### **3.26**

#### **limit state**

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

 [2.2.9 of ISO 2394, modified] 

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 (see ISO 2394).

### **3.27**

#### **logarithmic wind shear law**

see 3.62

**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**

**nacelle**

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

**3.30**

**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

**3.31**

**network loss**

loss of network for period exceeding any ride through provision in the turbine control system

**3.32**

**normal shutdown (wind turbines)**

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

**3.33**

**operating limits**

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

**3.34**

**parked wind turbine**

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

**3.35**

**power collection system (wind turbines)**

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

**3.36**

**power law for wind shear**

see 3.62

**3.37**

**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 wind turbine

**3.38**

**protection functions (wind turbine)**

functions of the control and protection system which ensure that a wind turbine remains within the design limits

### **3.39**

#### **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 wind turbine is designed to achieve under normal operating and external conditions.

### **3.40**

#### **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

### **3.41**

#### **Rayleigh distribution**

$P_R$

probability distribution function, see 3.63

### **3.42**

#### **reference wind speed**

$V_{ref}$

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

NOTE 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 recurrence period of 50 years at turbine hub height is lower than or equal to  $V_{ref}$ .

### **3.43**

#### **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.

### **3.44**

#### **rotor speed (wind turbines)**

rotational speed of a wind turbine rotor about its axis

### **3.45**

#### **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

### **3.46**

#### **scheduled maintenance**

preventive maintenance carried out in accordance with an established time schedule

### **3.47**

#### **site data**

environmental, seismic, soil and electrical network data for the wind turbine site. Wind data shall be the statistics of 10 min samples unless otherwise stated

**3.48**

**standstill**

condition of a wind turbine that is stopped

**3.49**

**support structure (wind turbines)**

part of a wind turbine comprising the tower and foundation

**3.50**

**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 3.18).

**3.51**

**swept area**

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

**3.52**

**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

**3.53**

**turbulence scale parameter**

$\lambda_1$

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

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

**3.54**

**turbulence standard deviation**

$\sigma_1$

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

**3.55**

**ultimate limit state**

limit states which generally correspond to maximum load carrying capacity

**A1** [2.2.10 of ISO 2394 , modified] **A1**

**3.56**

**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

**3.57**

**upwind**

in the direction opposite to the main wind vector

**3.58**

**vertical axis wind turbine**

wind turbine whose rotor axis is vertical

### 3.59

#### Weibull distribution

$P_W$

probability distribution function, see 3.63

### 3.60

#### wind farm

see 3.61

### 3.61

#### wind power station

group or groups of wind turbines, commonly called a wind farm

### 3.62

#### wind profile – wind shear law

mathematical expression for assumed wind speed variation with height above ground

NOTE 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;

$\alpha$  is the wind shear (or power law) exponent

### 3.63

#### 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.

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

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

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

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;  
 $\Gamma$  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  $V_{\text{ave}}$  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 yield the corresponding probability density functions

### **3.64**

#### **wind shear**

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

### **3.65**

#### **wind shear exponent**

$\alpha$

also commonly known as power law exponent, see 3.62

### **3.66**

#### **wind speed**

$V$

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

NOTE It is also the magnitude of the local wind velocity (vector) (see 3.69).

### **3.67**

#### **wind turbine generator system (wind turbine)**

system which converts kinetic energy in the wind into electrical energy

### **3.68**

#### **wind turbine site**

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

### **3.69**

#### **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.

### **3.70**

#### **wind turbine electrical system**

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

### 3.71

#### 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. This includes connection for the purposes of transferring energy and communications

### 3.72

#### yawing

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

### 3.73

#### 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]                |
| $f$        | frequency                                                                                                                                | [s <sup>-1</sup> ] |
| $f_d$      | design value for material strength                                                                                                       | [-]                |
| $f_k$      | characteristic value for material strength                                                                                               | [-]                |
| $F_d$      | design value for loads                                                                                                                   | [-]                |
| $F_k$      | characteristic value for loads                                                                                                           | [-]                |
| $I_{ref}$  | expected value of hub-height turbulence intensity at a 10 min average wind speed of 15 m/s                                               | [-]                |
| $I_{eff}$  | effective turbulence intensity                                                                                                           | [-]                |
| $k$        | shape parameter of the Weibull distribution function                                                                                     | [-]                |
| $K$        | 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 $i$                                                                                         | [-]                |
| $N(.)$     | 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                                                                                                 | [years]            |
| $p$        | 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 for the longitudinal wind velocity component                                                                                          | [m <sup>2</sup> /s] |
| $S_k$         | one-sided velocity component spectrum                                                                                                                                 | [m <sup>2</sup> /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 recurrence 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]               |
| $V_{out}$     | cut-out wind speed                                                                                                                                                    | [m/s]               |
| $V_r$         | rated wind speed                                                                                                                                                      | [m/s]               |
| $V_{ref}$     | reference wind speed                                                                                                                                                  | [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]                 |
| $z_{hub}$     | hub height of the wind turbine                                                                                                                                        | [m]                 |
| $z_r$         | reference height above ground                                                                                                                                         | [m]                 |
| $z_0$         | roughness length for the logarithmic wind profile                                                                                                                     | [m]                 |
| $\alpha$      | wind shear power law exponent                                                                                                                                         | [-]                 |
| $\beta$       | parameter for extreme direction change model                                                                                                                          | [-]                 |
| $\delta$      | coefficient of variation                                                                                                                                              | [-]                 |
| $\Gamma$      | gamma function                                                                                                                                                        | [-]                 |
| $\gamma_f$    | partial safety factor for loads                                                                                                                                       | [-]                 |
| $\gamma_m$    | partial safety factor for materials                                                                                                                                   | [-]                 |
| $\gamma_n$    | partial safety factor for consequences of failure                                                                                                                     | [-]                 |
| $\theta(t)$   | wind direction change transient                                                                                                                                       | [deg]               |
| $\theta_{cg}$ | angle of maximum deviation from the direction of the average wind speed under gust conditions                                                                         | [deg]               |
| $\theta_e$    | extreme direction change with a recurrence period of $N$ years                                                                                                        | [deg]               |

|                             |                                                                                                                                                              |                     |
|-----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|
| $\lambda_1$                 | 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]                 |
| $\hat{\sigma}$              | estimated turbulence standard deviation                                                                                                                      | [m/s]               |
| $\hat{\sigma}_{\text{eff}}$ | effective estimated turbulence standard deviation                                                                                                            | [m/s]               |
| $\sigma_{\text{wake}}$      | wake turbulence standard deviation                                                                                                                           | [m/s]               |
| $\hat{\sigma}_T$            | maximum centre-wake turbulence standard deviation                                                                                                            | [m/s]               |
| $\hat{\sigma}_{\sigma}$     | standard deviation of estimated turbulence standard deviation $\hat{\sigma}$                                                                                 | [m/s]               |
| $\sigma_1$                  | hub-height longitudinal wind velocity standard deviation                                                                                                     | [m/s]               |
| $\boxed{A_1} \sigma_2$      | hub-height transversal wind velocity standard deviation                                                                                                      | [m/s]               |
| $\sigma_3$                  | hub-height vertical wind velocity standard deviation                                                                                                         | [m/s] $\boxed{A_1}$ |
| $E\langle \rangle$          | expected value of parameter inside brackets                                                                                                                  | [-]                 |
| $Var\langle \rangle$        | variance of parameter inside brackets                                                                                                                        | [-]                 |

## 4.2 Abbreviations

|      |                                                     |
|------|-----------------------------------------------------|
| A    | abnormal (for partial safety factors)               |
| a.c. | alternating current                                 |
| d.c. | direct current                                      |
| DLC  | design load case                                    |
| 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                                             |
| 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) |
| U    | ultimate                                            |

## 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 standard requires the use of a structural 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 standard.

Data from full scale testing of a wind turbine 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 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 of this standard.

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 is 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,  $V_{\text{ref}}$ ;
- 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 this clause 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, etc.

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

### **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 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 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. Table 1 specifies the basic parameters, which define the wind turbine classes.

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.

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

Table 1 – Basic parameters for wind turbine classes<sup>1</sup>

| Wind turbine class     | I    | II   | III  | S                                |
|------------------------|------|------|------|----------------------------------|
| $V_{\text{ref}}$ (m/s) | 50   | 42,5 | 37,5 | Values specified by the designer |
| A $I_{\text{ref}}$ (-) | 0,16 |      |      |                                  |
| B $I_{\text{ref}}$ (-) | 0,14 |      |      |                                  |
| C $I_{\text{ref}}$ (-) | 0,12 |      |      |                                  |

In Table 1, the parameter values apply at hub height and

$V_{\text{ref}}$  is the reference wind speed average over 10 min,

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

$I_{\text{ref}}$  is the expected value of the turbulence intensity<sup>2</sup> at 15 m/s.

In addition to these basic parameters, 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<sub>A</sub> through III<sub>C</sub>, 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.

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 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 recurrence period.

<sup>1</sup> The annual average wind speed no longer appears in Table 1 as a basic parameter for the wind turbine classes in this edition of the standard. The annual average wind speed for wind turbine designs according to these classes is given in equation (9).

<sup>2</sup> Note that  $I_{\text{ref}}$  is defined as the mean value in this edition of the standard rather than as a representative value.

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 up to 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 following requirements:

- a) the turbulence standard deviation,  $\sigma_1$ , 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 deviations<sup>3</sup>:

- lateral component –  $\sigma_2 \geq 0,7\sigma_1$
- upward component –  $\sigma_3 \geq 0,5\sigma_1$

- b) the longitudinal turbulence scale parameter,  $\Lambda_1$ , at hub height  $z$  shall be given by

$$\Lambda_1 = \begin{cases} 0,7z & z \leq 60\text{ m} \\ 42\text{ m} & z \geq 60\text{ m} \end{cases} \quad (5)$$

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:

$$S_1(f) = 0,05 \sigma_1^2 (\Lambda_1 / V_{\text{hub}})^{-2/3} f^{-5/3} \quad (6)$$

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

- 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.

The recommended turbulence model that satisfies these requirements is the Mann uniform shear turbulence model in Annex B. Another frequently used model that satisfy these requirements is also given in Annex B. Other models should be used with caution, as the choice may affect the loads significantly.

<sup>3</sup> The actual values may depend on the choice of turbulence model and the requirements in b).

### 6.3.1 Normal wind conditions

#### 6.3.1.1 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 over a time 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,  $V_{\text{ave}}$  shall be chosen as

$$V_{\text{ave}} = 0,2 V_{\text{ref}} \quad (9)$$

#### 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 the standard wind turbine classes, the normal wind speed profile shall be given by the power law:

$$V(z) = V_{\text{hub}}(z/z_{\text{hub}})^\alpha \quad (10)$$

The power law exponent,  $\alpha$ , 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)

For the normal turbulence model, the representative value of the turbulence standard deviation,  $\sigma_1$ , shall be given by the 90 % quantile<sup>4</sup> for the given hub height wind speed. This value for the standard wind turbine classes shall be given by

$$\sigma_1 = I_{\text{ref}}(0,75V_{\text{hub}} + b); \quad b = 5,6 \text{ m/s} \quad (11)$$

Values for the turbulence standard deviation  $\sigma_1$  and the turbulence intensity  $\sigma_1/V_{\text{hub}}$  are shown in Figures 1a and 1b.

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

<sup>4</sup> Note, if other quantiles are desired for additional optional load calculations, they may be approximated for the standard classes by assuming a log-normal distribution and

$$E\langle\sigma_1|V_{\text{hub}}\rangle = I_{\text{ref}}(0,75V_{\text{hub}} + c); \quad c = 3,8 \text{ m/s}$$

$$\text{Var}\langle\sigma_1|V_{\text{hub}}\rangle = (I_{\text{ref}}(1,4 \text{ m/s}))^2$$

A1

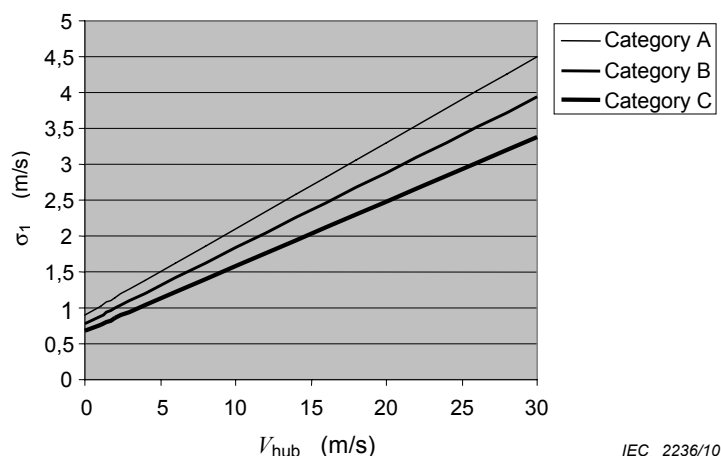


Figure 1a –Turbulence standard deviation for the normal turbulence model (NTM)

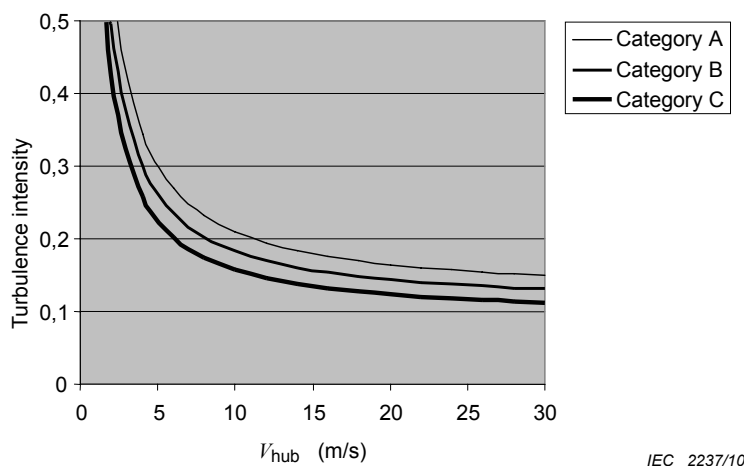


Figure 1b – Turbulence intensity for the normal turbulence model (NTM) A1

Figure 1 – Normal turbulence model (NTM)

### 6.3.2 Extreme wind conditions

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.

#### 6.3.2.1 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,  $V_{\text{ref}}$ , and a fixed turbulence standard deviation,  $\sigma_1$ .

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

$$V_{\text{e50}}(z) = 1,4 V_{\text{ref}} \left( \frac{z}{z_{\text{hub}}} \right)^{0,11} \quad (12)$$

$$\text{and } V_{e1}(z) = 0,8 V_{e50}(z) \quad (13)$$

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 recurrence periods of 50 years and 1 year, respectively, shall be given by

$$V_{50}(z) = V_{\text{ref}} \left( \frac{z}{z_{\text{hub}}} \right)^{0,11} \quad (14)$$

$$V_1(z) = 0,8 V_{50}(z) \quad (15)$$

The longitudinal turbulence standard deviation<sup>5</sup> shall be:

$$\sigma_1 = 0,11 V_{\text{hub}} \quad (16)$$

### 6.3.2.2 Extreme operating gust (EOG)

The hub height gust magnitude  $V_{\text{gust}}$ <sup>6</sup> shall be given for the standard wind turbine classes by the following relationship:

$$V_{\text{gust}} = \text{Min} \left\{ 1,35(V_{e1} - V_{\text{hub}}); \quad 3,3 \left( \frac{\sigma_1}{1 + 0,1 \left( \frac{D}{\lambda_1} \right)} \right) \right\} \quad (17)$$

where

$\sigma_1$  is given in equation (11);

$\lambda_1$  is the turbulence scale parameter, according to equation (5);

$D$  is the rotor diameter.

The wind speed shall be defined by the equation:

$$V(z, t) = \begin{cases} V(z) - 0,37 V_{\text{gust}} \sin(3\pi t / T) (1 - \cos(2\pi t / T)) & \text{for } 0 \leq t \leq T \\ V(z) & \text{otherwise} \end{cases} \quad (18)$$

where

$V(z)$  is defined in equation (10)

$T = 10,5$  s.

An example of the extreme operating gust ( $V_{\text{hub}} = 25$  m/s, Class I<sub>A</sub>,  $D = 42$  m) is shown in Figure 2:

<sup>5</sup> 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.

<sup>6</sup> The gust magnitude was calibrated to together with the probability of an operation event such as starts and stops to give a recurrence period of 50 years.

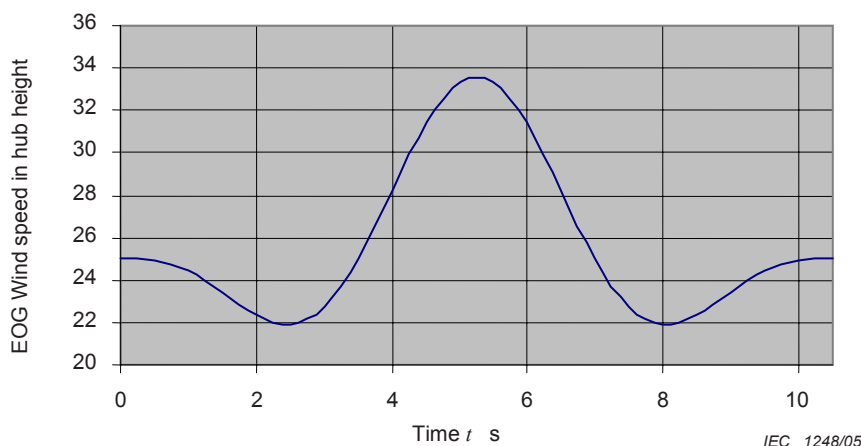


Figure 2 – Example of extreme operating gust

### 6.3.2.3 Extreme turbulence model (ETM)

The extreme turbulence model shall use the normal wind profile model in 6.3.1.2 and turbulence with longitudinal component standard deviation given by

$$\sigma_1 = c \cdot I_{\text{ref}} \left( 0,072 \left( \frac{V_{\text{ave}}}{c} + 3 \right) \left( \frac{V_{\text{hub}}}{c} - 4 \right) + 10 \right); c = 2 \text{ m/s.} \quad (19)$$

### 6.3.2.4 Extreme direction change (EDC)

The extreme direction change magnitude,  $\theta_e$ , shall be calculated using the following relationship:

$$\theta_e = \pm 4 \arctan \left( \frac{\sigma_1}{V_{\text{hub}} \left( 1 + 0,1 \left( \frac{D}{\Lambda_1} \right) \right)} \right) \quad (20)$$

where

$\sigma_1$  is given by equation (11) for the NTM;

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

$\Lambda_1$  is the turbulence scale parameter, according to equation (5); and

$D$  is the rotor diameter.

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

$$\theta(t) = \begin{cases} 0^\circ & \text{for } t < 0 \\ \pm 0,5\theta_e (1 - \cos(\pi t / T)) & \text{for } 0 \leq t \leq T \\ \theta_e & \text{for } t > T \end{cases} \quad (21)$$

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 6.3.1.2.

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  $V_{\text{hub}}$ . The corresponding transient for  $V_{\text{hub}} = 25$  m/s is shown in Figure 4.

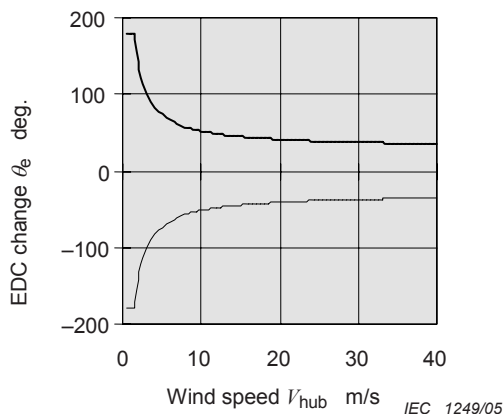


Figure 3 – Example of extreme direction change magnitude

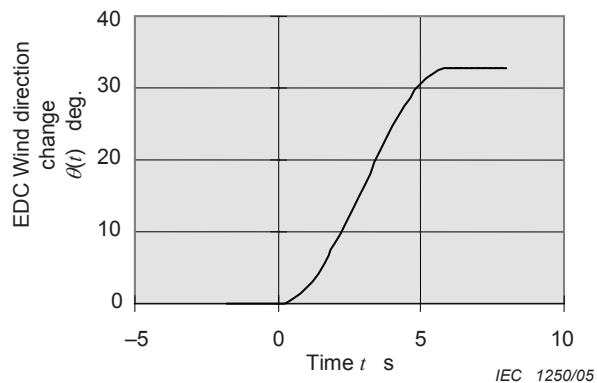


Figure 4 – Example of extreme direction change

#### 6.3.2.5 Extreme coherent gust with direction change (ECD)

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

$$V_{\text{cg}} = 15 \text{ m/s} \quad (22)$$

The wind speed shall be defined by

$$V(z, t) = \begin{cases} V(z) & \text{for } t \leq 0 \\ V(z) + 0,5 V_{\text{cg}} (1 - \cos(\pi t / T)) & \text{for } 0 \leq t \leq T \\ V(z) + V_{\text{cg}} & \text{for } t \geq T \end{cases} \quad (23)$$

where  $T = 10$  s is the rise time and the wind speed  $V(z)$  is given by the normal wind profile model in 6.3.1.2. The rise in wind speed during the extreme coherent gust is illustrated in Figure 5 for  $V_{\text{hub}} = 25$  m/s.