

Australian Standard[®]

Wind turbines

**Part 2: Design requirements for small
wind turbines**



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- Australian Industry Group
 - Clean Energy Council
 - Clean Energy Regulator
 - Engineers Australia
-

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Australian Standard[®]

Wind turbines

Part 2: Design requirements for small wind turbines

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PREFACE

This Standard was prepared by the Standards Australia Committee EL-048, Wind Turbine Systems, to supersede AS 61400.2(Int)—2006, *Wind turbines, Part 2: Design requirements for small wind turbines*.

The objective of this Standard is to provide designers, manufacturers, test laboratories and users with requirements for small wind turbines (viz. with a swept area up to 200 m², see Clause 3.48).

The objective of this revision is to confirm the adoption of IEC 61400-2 as a full Australian Standard and update the list of Australian Standards to be used as alternatives to international referenced documents.

For the design and manufacture of products intended to be installed in locations with severe wind climates, such as cyclonic areas of Australia, see the AS/NZS 1170 series and other appropriate Australian wind loading Standards.

This Standard is identical with, and has been reproduced from IEC 61400-2, Ed.2.0 (2006), *Wind turbines—Part 2: Design requirements for small wind turbines*.

As this Standard is reproduced from an International Standard, the following applies:

- (a) Its number appears on the cover and title page while the International Standard number appears only on the cover.
- (b) In the source text ‘this part of IEC 61400’ should read ‘this Australian Standard’.
- (c) A full point substitutes for a comma when referring to a decimal marker.

References to International Standards should be replaced by references to Australian or Australian/New Zealand Standards, as follows:

<i>Reference to International Standard</i>	<i>Australian Standard</i>
IEC	AS
60034 Rotating electrical machines	60034 Rotating electrical machines
60034-1 Part 1: Rating and performance	60034.1 Part 1: Rating and performance
60034-5 Part 5: Degrees of protection provided by the integral design of rotating electrical machines (IP code)—Classification	60034.5 Part 5: Degrees of protection provided by the integral design of rotating electrical machines (IP Code)—Classification
60034-8 Part 8: Terminal markings and direction of rotation	60034.8 Part 8: Terminal markings and direction of rotation (IEC 60034-8, Ed.3 (2007) MOD)
60038 IEC standard voltages	60038 Standard voltages
60204 Safety of machinery—Electrical equipment of machines	60204 Safety of machinery—Electrical equipment of machines
60204-1 Part 1: General requirements	60204.1 Part 1: General requirements (IEC 60204-1, Ed.5 (FDIS) MOD)
ISO/IEC	AS ISO/IEC
17025 General requirements for the competence of testing and calibration laboratories	17025 General requirements for the competence of testing and calibration laboratories
ISO	AS
2394 General principles on reliability for structures	5104 General principles on reliability for structures

The terms ‘normative’ and ‘informative’ have been used in this Standard to define the application of the annex to which they apply. A ‘normative’ annex is an integral part of a Standard, whereas an ‘informative’ annex is only for information and guidance.

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AUSTRALIAN STANDARD

Wind turbines**Part 2:
Design requirements for small wind turbines****1 Scope**

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

This part of IEC 61400 is concerned with all subsystems of SWT such as protection mechanisms, internal electrical systems, mechanical systems, support structures, foundations and the electrical interconnection with the load.

While this part of IEC 61400 is similar to IEC 61400-1, it does simplify and make significant changes in order to be applicable to small turbines.

This part of IEC 61400 applies to wind turbines with a rotor swept area smaller than 200 m², generating at a voltage below 1 000 V a.c. or 1 500 V d.c.

This part of IEC 61400 should be used together with the appropriate IEC and ISO standards (see 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 60034-1, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60034-2, *Rotating electrical machines – Part 2: Methods for determining losses and efficiency of rotating electrical machinery from tests (excluding machines for traction vehicles)*

IEC 60034-5, *Rotating electrical machines – Part 5: Degrees of protection provided by the integral design of rotating electrical machines (IP code) – Classification*

IEC 60034-8, *Rotating electrical machines – Part 8: Terminal markings and direction of rotation*

IEC 60038:1983, *IEC standard voltages*
Amendment 1 (1994)
Amendment 2 (1997)

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

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 2-1: Environmental conditions appearing in nature – Temperature and humidity*

IEC 61400-1, *Wind turbines – Part 1: Design requirements*

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

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

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

IEC 61643-1, *Low-voltage surge protective devices – Part 1: Surge protective devices connected to low-voltage power distribution systems – Requirements and tests*

ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*

ISO 2394, *General principles on reliability for structures*

3 Terms and definitions

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

3.1

annual average

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

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

3.2

annual average wind speed

wind speed averaged according to the definition of annual average

3.3

auto-reclosing cycles

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

3.4

brake (for wind turbines)

device capable of reducing the rotor speed or stopping rotation

3.5**catastrophic failure** (for wind turbines)

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

3.6**characteristic value** (of a material property)

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

3.7**control system** (for wind turbines)

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

3.8**cut-in wind speed** V_{in}

lowest mean wind speed at hub height at which the wind turbine produces power

3.9**cut-out wind speed** V_{out}

highest mean wind speed at hub height at which the wind turbine is designed to produce power

3.10**design limits**

maximum or minimum values used in a design

3.11**design situation**

possible mode of wind turbine operation, for example power production, parking, etc.

3.12**design wind speed**

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

3.13**downwind**

in the main wind direction

3.14**emergency shutdown** (for wind turbines)

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

3.15**environmental conditions**

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

3.16**external conditions** (for wind turbines)

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

3.17**extreme wind speed**

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

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

3.18**fail-safe**

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

3.19**furling**

a passive overspeed control mechanism by means of reducing the projected swept area

3.20**gust**

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

NOTE A gust can be characterized by its rise-time, its amplitude and its duration.

3.21**horizontal axis wind turbine**

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

3.22**hub** (for wind turbines)

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

3.23**hub height** (for wind turbines)

height of the centre of the wind turbine rotor above the terrain surface. For a vertical axis wind turbine, the hub height is the height of the equator plane

3.24**idling** (for wind turbines)

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

3.25**limit state**

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

[ISO 2394, 2.2.9, 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 (ISO 2394).

3.26**load case**

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

3.27**logarithmic wind shear law**

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

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**normal shutdown** (for wind turbines)

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

3.31**operating limits**

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

3.32**parked wind turbine**

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

3.33**parking**

situation to which a wind turbine returns after a normal shutdown

3.34**power law for wind shear**

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

3.35**power output**

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

NOTE For wind turbines, this is the electric power delivered by a wind turbine.

3.36**protection system** (wind turbine)

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

3.37**Rayleigh distribution**

a probability distribution function often used for wind speeds. The distribution depends on one adjustable parameter – the scale parameter, which controls the average wind speed

NOTE The Rayleigh distribution is identical to a Weibull distribution (see 3.55) with shape parameter 2.

3.38**reference wind speed**

V_{ref}

basic parameter for wind speed used for defining SWT classes. Other design related climatic parameters are derived from the reference wind speed and other basic SWT class parameters

NOTE A turbine designed for a SWT class with a reference wind speed, V_{ref} , is designed to withstand climates for which the extreme 10 min average wind speed with a recurrence period of 50 years at turbine hub height is lower than or equal to V_{ref} (see 3.17).

3.39**resonance**

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

3.40**rotor speed** (for wind turbines)

rotational speed of a wind turbine rotor about its axis

3.41**roughness length**

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

3.42**safe life**

prescribed service life with a declared probability of catastrophic failure

3.43**scheduled maintenance**

preventive maintenance carried out in accordance with an established time schedule

3.44**shutdown** (for wind turbines)

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

3.45**standstill**

condition of a wind turbine generator system that is stopped

3.46**support structure** (for wind turbines)

part of a wind turbine comprising the tower and foundation

3.47**survival wind speed** (deprecated)

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

NOTE This term is not used in the IEC 61400 series; the design conditions instead refer to extreme wind speed (see 3.17).

3.48**Small Wind Turbine****SWT**

a system of 200 m² rotor swept area or less that converts kinetic energy in the wind into electrical energy

3.49**swept area**

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

3.50**turbulence intensity**

ratio of the wind speed standard deviation to the mean wind speed, determined from the same set of measured data samples of wind speed, and taken over a specified period of time

3.51**ultimate limit state**

limit states which generally correspond to maximum load carrying capacity

3.52**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

3.53**upwind**

in the direction opposite to the main wind direction

3.54**vertical axis wind turbine**

wind turbine whose rotor axis is vertical

3.55**Weibull distribution**

probability distribution function often used for wind speeds. This distribution function depends on two parameters, the shape parameter, which controls the width of the distribution and the scale parameter, which in turn controls the average wind speed

NOTE See 3.60, wind speed distribution.

3.56**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).

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

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

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.

3.57

wind shear

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

3.58

wind shear exponent

also commonly known as power law exponent (see 3.56, wind profile – wind shear law)

3.59

wind speed

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

NOTE The wind speed is also the magnitude of the local wind velocity (vector) (see 3.61).

3.60

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.

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

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

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.

3.61**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.

3.62**yawing**

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

3.63**yaw rate**

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

3.64**yaw misalignment**

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

4 Symbols and abbreviated terms**4.1 Symbols**

A	cross section area	[m ²]
A_{proj}	the component area projected on to a plane perpendicular or parallel to the wind direction	[m ²]
a	slope parameter for turbulence standard deviation model	[-]
B	number of blades	[-]
C	scale parameter of the Weibull distribution function	[m/s]
C_d	drag coefficient	[-]
C_f	force coefficient	[-]
C_l	lift coefficient	[-]
C_T	thrust coefficient	[-]
Coh	coherency function	[-]
D	rotor diameter	[m]
e_r	distance from the centre of gravity of the rotor to the rotation axis	[m]
F	force	[N]
F_{zB}	force on the blade at the blade root in the spanwise direction	[N]
$F_{x\text{-shaft}}$	axial shaft load	[N]
f	frequency	[s ⁻¹]
f_k	characteristic value for material strength	[-]
G	ratio between rated torque and short circuit torque for a generator	[-]
g	acceleration due to gravity: 9,81	[m/s ²]

I_B	mass moment of inertia of the blade about the blade root flap axis	[kgm ²]
I_{15}	characteristic value of hub-height turbulence intensity at a 10 min average wind speed of 15 m/s	[-]
K	modified Bessel function	[-]
k	shape parameter of the Weibull distribution function	[-]
L	isotropic turbulence integral scale parameter	[m]
L_{lt}	distance between the lifting point and the top of the tower	[m]
L_{rt}	distance between the rotor centre and the yaw axis	[m]
L_{rb}	distance between rotor centre and first bearing	[m]
L_c	coherency scale parameter	[m]
L_k	velocity component integral scale parameter	[m]
M_{xB}, M_{yB}	blade root bending moments	[Nm]
M_{brake}	torque on the low speed shaft caused by the brake	[Nm]
$M_{x-shaft}$	torsion moment on the rotor shaft at the first bearing	[Nm]
M_{shaft}	combined bending moment for the shaft at the first bearing (nearest to rotor)	[Nm]
M_{tower}	the bending moment in the tower at the lifting point attachment	[Nm]
m_B	blade mass	[kg]
$m_{overhang}$	the mass of the tower between the lifting point and the top of the tower	[kg]
m_r	rotor mass being the mass of the blades plus the mass of the hub	[kg]
$m_{tower top}$	the mass of the nacelle and rotor combined	[kg]
$N(.)$	is the number of cycles to failure as a function of the stress (or strain) indicated by the argument (i.e. the characteristic S-N curve)	[-]
N	recurrence period for extreme situations	[yr]
n	rotor speed	[r.p.m.]
n_i	counted number of fatigue cycles in load bin i	[-]
O	operational time fraction	[%]
P	electrical power	[W]
$P_R(V_0)$	Rayleigh cumulative probability distribution, i.e. the probability that $V < V_0$	[-]
$P_W(V_0)$	Weibull cumulative probability distribution	[-]
p	survival probability	[-]
Q	rotor torque	[Nm]
R	radius of the rotor	[m]
R_{cog}	radial distance between the centre of gravity of a blade and the rotor centre	[m]
r	magnitude of separation vector projection	[m]
$S_1(f)$	power spectral density function	[m ² /s]
S_k	single sided velocity component spectrum	[m ² /s]
s_i	the stress (or strain) level associated with the counted number of cycles in bin i	[-]

T	gust characteristic time	[s]
t	time	[s]
T_d	design life	[s]
T_E	excluded time	[h]
T_N	time during which the turbine was not operational	[h]
T_T	total time elapsed in the duration test	[h]
T_U	unknown time	[h]
V	wind speed	[m/s]
$V(z)$	wind speed at height z	[m/s]
V_{ave}	annual average wind speed at hub height	[m/s]
V_{cg}	extreme coherent gust magnitude over the whole rotor swept area	[m/s]
V_{design}	design wind speed	[m/s]
V_{eN}	expected extreme wind speed (averaged over 3 s), with a recurrence time interval of N years. V_{e1} and V_{e50} for 1 year and 50 years, respectively	[m/s]
V_{gustN}	largest gust magnitude with an expected recurrence period of N years.	[m/s]
V_{hub}	wind speed at hub height averaged over 10 min	[m/s]
V_{in}	cut-in wind speed	[m/s]
$V_{max,shutdown}$	the maximum wind speed at which the manufacturer allows a normal shutdown	[m/s]
V_0	limit wind speed in wind speed distribution model	[m/s]
V_{out}	cut-out wind speed	[m/s]
V_{ref}	reference wind speed averaged over 10 min	[m/s]
V_{tip}	speed of the blade tip	[m/s]
$V(z, t)$	longitudinal wind velocity component to describe transient variation for extreme gust and shear conditions	[m/s]
W	section modulus used in stress calculations	[m ³]
x, y, z	co-ordinate system used for the wind field description; along wind (longitudinal), across wind (lateral) and height respectively	[m]
z_{hub}	hub height of the wind turbine	[m]
z_r	reference height above ground	[m]
z_0	roughness length for the logarithmic wind profile	[m]
α	wind shear power law exponent	[-]
β	parameter for extreme direction change model and extreme operating gust model	[-]
Γ	gamma function	[-]
γ_l	partial safety factor for loads	[-]
γ_m	partial safety factor for materials	[-]
Δ	range	[-]
$\theta(t)$	wind direction change transient	[°]

θ_{cg}	angle of maximum deviation from the direction of the average wind speed under gust conditions	[°]
θ_{eN}	extreme direction change with a recurrence period of N years	[°]
η	efficiency of the components between the electric output and the rotor (typically generator, gearbox and conversion system)	[-]
Λ_1	turbulence scale parameter defined as the wave length where the non-dimensional, longitudinal power spectral density, $fS_1(f)/\sigma_1^2$, is equal to 0,05	[m]
λ	tip speed ratio	[-]
ρ	air density, here assumed 1,225	[kg/m ³]
σ_1	hub-height longitudinal wind velocity standard deviation	[m/s]
σ_2	hub-height vertical wind velocity standard deviation	[m/s]
σ_3	hub-height lateral wind velocity standard deviation	[m/s]
σ_d	design stress	[MPa]
σ_k	k^{th} hub-height component wind velocity standard deviation ($k = 1, 2, \text{ or } 3$)	[m/s]
ω_n	rotational speed of the rotor	[rad/s]
ω_{yaw}	yaw rate	[rad/s]

Subscripts:

ave	average
B	blade
design	input parameter for the simplified design equations
e50	once per 50 year extreme (averaged over 3 s)
hub	hub
max	maximum
r	rotor
shaft	shaft
x	in the x-direction
y	in the y-direction
z	in the z-direction

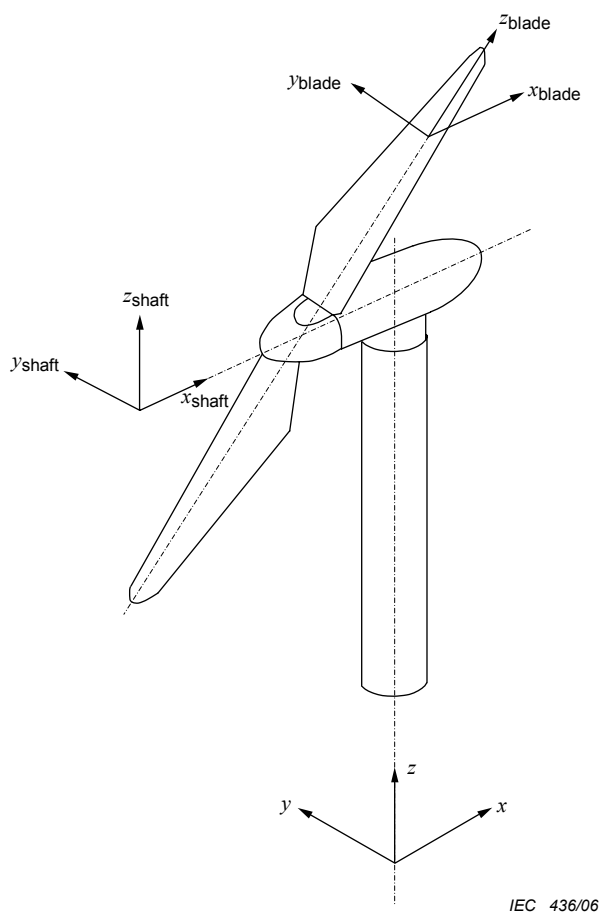
Abbreviations:

a.c.	Alternating Current
d.c.	Direct Current
DLC	Design Load Case
ECD	Extreme Coherent gust with Direction change
ECG	Extreme Coherent Gust
EDC	Extreme wind Direction Change
EMC	Electromagnetic Compatibility
EOG	Extreme Operating Gust
EWM	Extreme Wind speed Model
F	Fatigue
GFCI	Ground Fault Circuit Interrupter

HAWT	Horizontal Axis Wind Turbine
NWP	Normal Wind Profile model
NTM	Normal Turbulence Model
S	Special IEC wind turbine class
SWT	Small Wind Turbine
U	Ultimate

4.2 Coordinate system

To define the directions of the loads, the system of axes shown in Figure 1 is used.



Tower

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

Shaft

x-shaft is such that a positive moment about the x axis acts in the rotational direction. y and z shaft are not used, only the combined moment is used. The shaft axis system rotates with the nacelle.

Blade

x-blade is such that a positive moment about the x-axis acts in the rotational direction. y-blade is such that a positive moment acts to bend the blade tip downwind. z-blade is positive towards blade tip.

Note that the blade coordinate system follows the right-hand convention for a rotor that spins clockwise and the left-hand convention for a rotor that spins counterclockwise when viewed from an upwind location. The blade axis system rotates with the rotor.

Figure 1 – Definition of the system of axes for HAWT

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 Subclauses. This specification of requirements applies to the design, manufacture, installation and maintenance of the wind turbine and the associated quality management process.

Annex A gives guidance on how this part of IEC 61400 can be used in the type certification of small wind turbines.

5.2 Design methods

The design method for turbines covered under this part of IEC 61400 is depicted in Figure 2. A simplified approach is permitted for a variety of turbine configurations. For turbines with a swept rotor area of less than 2 m², the tower is not considered part of the design.

Primary turbine data are measured in a “design data test” (see 9.2), after which values of predicted design loads shall be obtained in one or a combination of the following three ways:

- For certain turbine configurations, a simplified calculation method is given.
A limited set of load cases is given in 7.4 with simple formulas and simplified external conditions.
- Use of a structural dynamics model in combination with design data testing and limited full-scale load measurements to verify the model.
This model shall be used to determine the loads over a range of wind speeds, using the turbulence conditions and other extreme wind conditions defined in 6.3, and design situations defined in 7.5. All relevant combinations of external conditions and design situations shall be analyzed. A minimum set of such combinations has been defined as load cases in this part of IEC 61400.
- Full scale load measurement with load extrapolation.

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

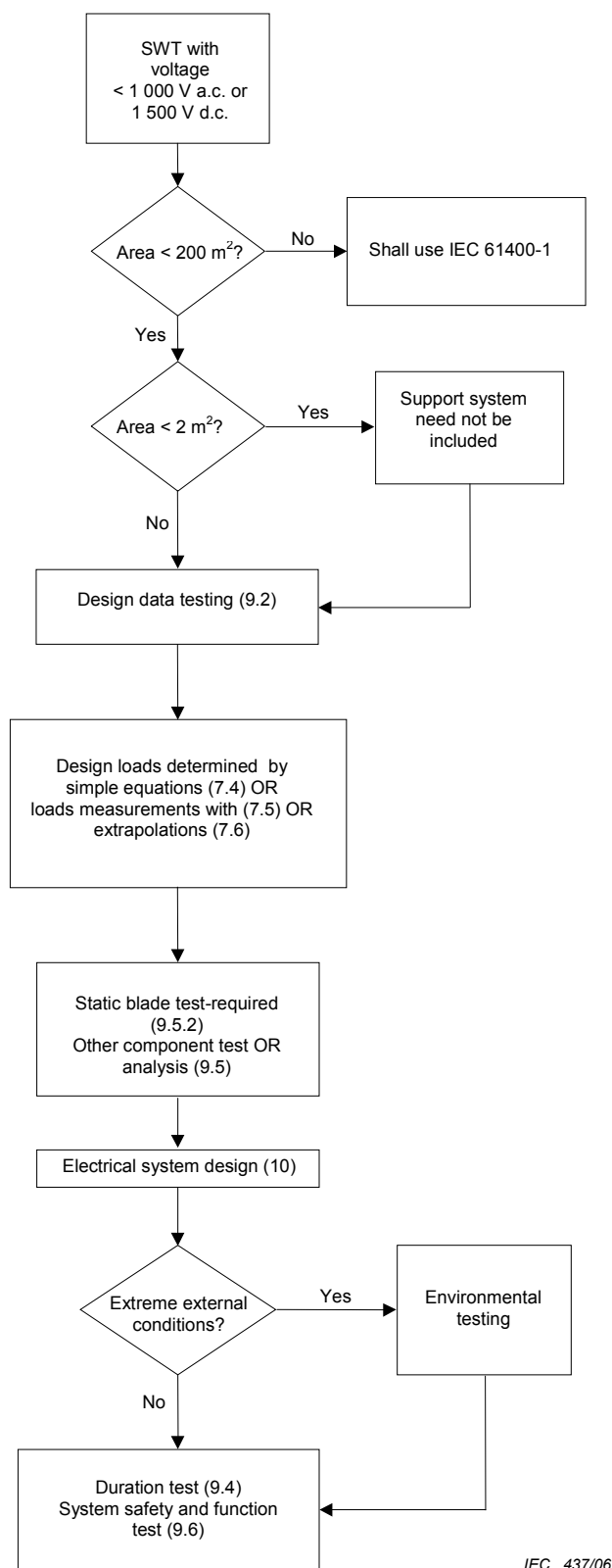
For all turbines, a static blade test is required (9.5). To verify the adequacy of other load carrying components, either calculations or testing is required. Test conditions shall reflect the design loads including the relevant safety factors.

Finally, for all turbines, a safety and function test (9.6) and duration test (9.4) are required.

5.3 Quality assurance

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

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



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Figure 2 – IEC 61400-2 decision path

6 External conditions

6.1 General

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

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

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

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

6.2 SWT classes

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

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

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

Table 1 – Basic parameters for SWT classes

SWT Class	I	II	III	IV	S
V_{ref} (m/s)	50	42,5	37,5	30	Values to be specified by the designer
V_{ave} (m/s)	10	8,5	7,5	6	
I_{15} (-)	0,18	0,18	0,18	0,18	
a (-)	2	2	2	2	
where					
- the values apply at hub height, and I_{15} is the dimensionless characteristic value of the turbulence intensity at 15 m/s, a is the dimensionless slope parameter to be used in equation (7).					

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

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 7.5. (Note that for the simple load calculations, the wind conditions are simplified as well.)

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

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

6.3 Wind conditions

6.3.1 General

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

In all cases the influence of an inclination of mean flow with respect to the horizontal plane of up to 8° shall be considered. The flow inclination angle may be assumed to be invariant with height.

NOTE Oblique inflow can have an effect on furling if the furl direction is chosen poorly with respect to the rotational direction of the rotor.

6.3.2 Normal wind conditions

6.3.2.1 Wind speed distribution

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

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

6.3.2.2 Normal Wind Profile model (NWP)

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

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

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

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

6.3.2.3 Normal Turbulence model (NTM)

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

- a) The characteristic value of the standard deviation of the longitudinal wind velocity component shall be given by²:

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

Values for I_{15} and a are given in Table 1. The characteristic values of the standard deviation, σ_1 , and of the turbulence intensity, σ_1/V_{hub} , are shown below in Figure 3.

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

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

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

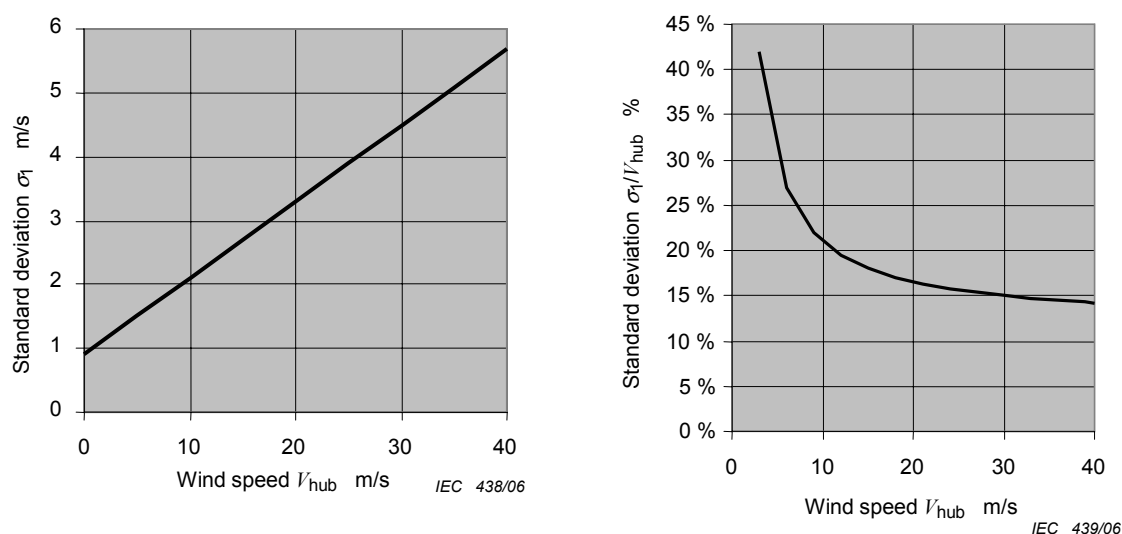


Figure 3 – Characteristic wind turbulence

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

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

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

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

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

6.3.3 Extreme wind conditions

6.3.3.1 General

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

6.3.3.2 Extreme Wind speed Model (EWM)

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

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

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

where z_{hub} is hub height.

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

6.3.3.3 Extreme Operating Gust (EOG)

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

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

where

σ_1 is the standard deviation, according to equation (7);

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

D is the rotor diameter;

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

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

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

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

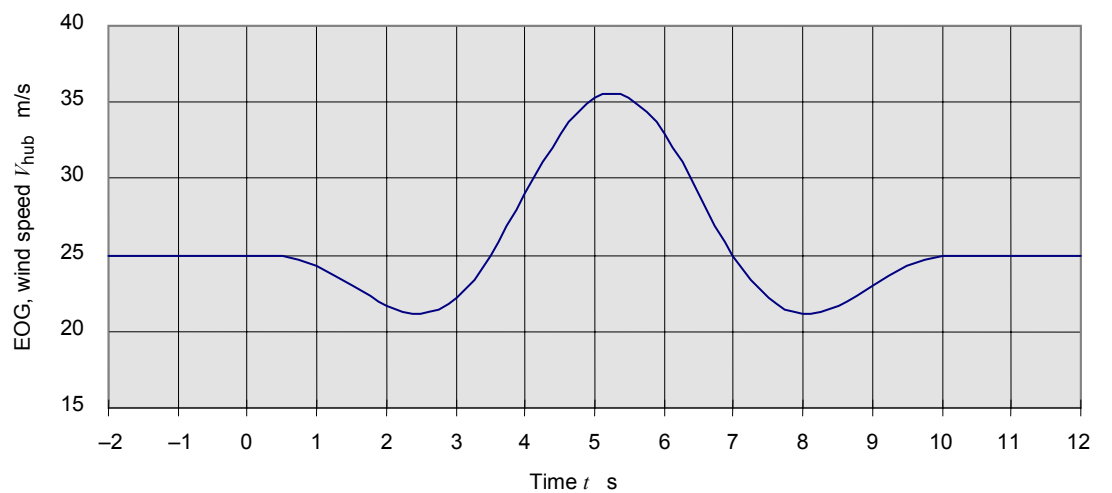
where

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

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

$T = 14,0$ s for $N = 50$.

As an example, the extreme operating gust with a recurrence period of one year and $V_{\text{hub}} = 25$ m/s is shown in Figure 4.



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Figure 4 – Example of extreme operating gust ($N = 1$, $V_{\text{hub}} = 25$ m/s)

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

6.3.3.4 Extreme Direction Change (EDC)

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

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

where

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

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

D is the rotor diameter;

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

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

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

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

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

As an example, the extreme direction change with a recurrence period of 50 years and $V_{\text{hub}} = 25$ m/s is shown in Figure 5 and Figure 6.

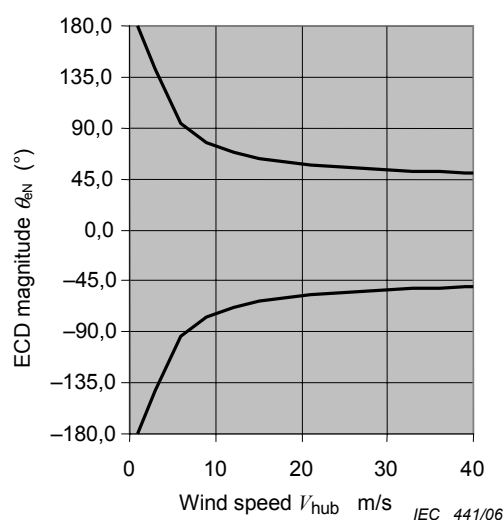


Figure 5 – Example of extreme direction change magnitude
($N = 50$, $D = 5$ m, $z_{\text{hub}} = 20$ m)

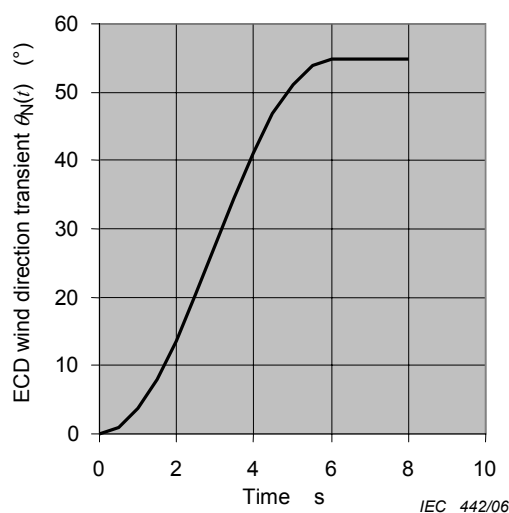


Figure 6 – Example of extreme direction change
($N = 50$, $V_{\text{hub}} = 25$ m/s)

6.3.3.5 Extreme Coherent Gust (ECG)

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

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

where $T = 10$ s is the rise time. The normal wind profile model of wind speed as specified in equation (6) shall be used. The extreme coherent gust is illustrated in Figure 7 for $V_{hub} = 25$ m/s.

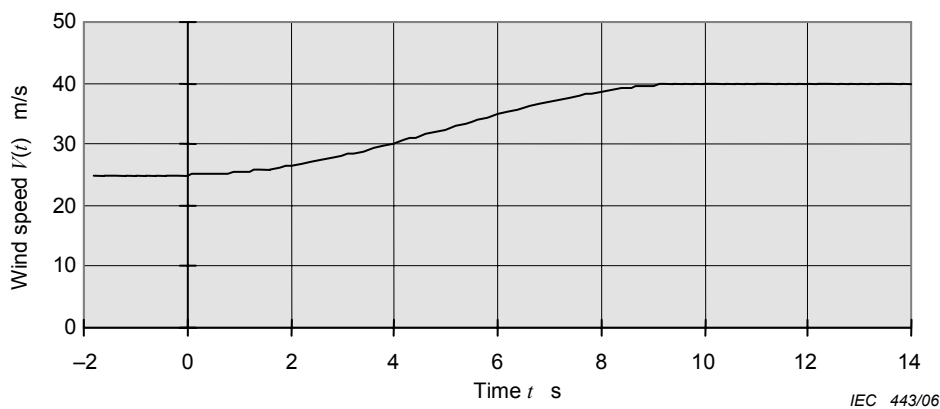


Figure 7 – Extreme coherent gust ($V_{hub} = 25$ m/s) (ECG)

6.3.3.6 Extreme Coherent gust with Direction change (ECD)

In this case, the rise in wind speed (described by ECG, see Figure 7) shall be assumed to occur simultaneously with the direction change θ_{cg} , where θ_{cg} is defined by the relations:

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

The direction change, θ_{cg} , as a function of V_{hub} and as a function of time for $V_{hub} = 25$ m/s is shown in Figure 8 and Figure 9, respectively.