# IEC 61400-3-1

Edition 1.0 2019-04

# INTERNATIONAL STANDARD

## Wind energy generation systems –
## Part 3-1: Design requirements for fixed offshore wind turbines

colour inside



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# WIND ENERGY GENERATION SYSTEMS –

## Part 3-1: Design requirements for fixed offshore wind turbines

## FOREWORD



International Standard IEC 61400-3-1 has been prepared by IEC technical committee 88: Wind energy generation systems.

This edition cancels and replaces the first edition of IEC 61400-3 published in 2009. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the first edition of IEC 61400-3:

a) Clause 12 has been merged with Clause 6 in order to acknowledge that the design of the wind turbine support structure is generally site specific for offshore projects;

b) The design load table has been revised to simplify the approach to waves, both for several gust cases with the Normal Sea State, and for a number of cases with the Extreme Sea State. The guidance for load calculations has been altered accordingly;

c) For load safety factors reference is now made directly to IEC 61400-1;

d) Clause 8 on the control system has been aligned with the latest updates in IEC 61400-1;

e) Annex B to edition one on wave spectra has been replaced by a reference to ISO 19901-1;
f) The annex on ice loading has been revised and updated (now Annex D);
g) Two informative annexes concerning tropical cyclones have been introduced: Annex H on wave height assessment and Annex I on safety level;
h) Other parts of the text have been aligned with IEC 61400-1.

This part is to be read in conjunction with IEC 61400-1, *Wind turbines – Part 1: Design requirements*[1].

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

| FDIS | Report on voting |
|---|---|
| 88/708/FDIS | 88/712/RVD |

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

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

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

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

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

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

**IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.**

1 Under preparation. Stage at the time of publication: IEC/RFDIS 61400-1:2018.

# INTRODUCTION

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

Several different parties may be responsible for undertaking the various elements of the design, manufacture, assembly, installation, erection, commissioning, operation and maintenance of an offshore wind turbine and for ensuring that the requirements of this document are met. The division of responsibility between these parties is a contractual matter and is outside the scope of this document.

Any of the requirements of this document may be altered if it can be suitably demonstrated that the safety of the system is not compromised. Compliance with this document does not relieve any person, organization, or corporation from the responsibility of observing other applicable regulations.

The document is not intended to give requirements for floating offshore wind turbines. For floating installations, reference is made to IEC 61400-3-2.

**WIND ENERGY GENERATION SYSTEMS –**

**Part 3-1: Design requirements for fixed offshore wind turbines**

## 1 Scope

This part of IEC 61400 specifies additional requirements for assessment of the external conditions at an offshore wind turbine site and specifies essential design requirements to ensure the engineering integrity of fixed offshore wind turbines. Its purpose is to provide an appropriate level of protection against damage from all hazards during the planned lifetime.

This document focuses on the engineering integrity of the structural components of an offshore wind turbine but is also concerned with subsystems such as control and protection mechanisms, internal electrical systems and mechanical systems.

A wind turbine shall be considered as a fixed offshore wind turbine if the support structure is subject to hydrodynamic loading and it is founded on the seabed. The design requirements specified in this document are not sufficient to ensure the engineering integrity of floating offshore wind turbines. For floating installations, reference is made to IEC 61400-3-2. In the remainder of this document, the term “offshore wind turbine” is assumed to refer to those that are fixed to the seabed.

This document should be used together with the appropriate IEC and ISO standards mentioned in Clause 2. In particular, this document is fully consistent with the requirements of IEC 61400-1. The safety level of the offshore wind turbine designed according to this document shall be at or exceed the level inherent in IEC 61400-1. In some clauses, where a comprehensive statement of requirements aids clarity, replication of text from IEC 61400-1 is included.

## 2 Normative references

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

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

IEC 61400-1:2018, *Wind energy generation systems – Part 1: Design requirements*[2]

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

ISO 2533:1975, *Standard Atmosphere*

ISO 19900:2002, *Petroleum and natural gas industries – General requirements for offshore structures*

ISO 19901-1:2015, *Petroleum and natural gas industries – Specific requirements for offshore structures – Part 1: Metocean design and operating conditions*

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2 Under preparation. Stage at the time of publication: IEC/RFDIS 61400-1:2018.

ISO 19901-4:2003, *Petroleum and natural gas industries – Specific requirements for offshore structures – Part 4: Geotechnical and foundation design considerations*

ISO 19902:2007, *Petroleum and natural gas industries – Fixed steel offshore structures*

ISO 19903:2006, *Petroleum and natural gas industries – Fixed concrete offshore structures*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61400-1 and the following apply.

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

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

**3.1**
**air gap**
clearance between the highest water surface that occurs during the extreme environmental conditions and the lowest exposed part not designed to withstand wave impingement

**3.2**
**arch effect**
action of an arch ice (or its collapse) upon a substructure

**3.3**
**arch ice**
ice build-up between substructures or between a substructure and shore that has an arch shape and eventually collapses

**3.4**
**co-directional**
acting in the same direction

**3.5**
**current**
flow of water past a fixed location usually described in terms of a current speed and direction

**3.6**
**diffraction**
phenomenon that describes the bending of waves around obstacles and spreading of waves past openings

**3.7**
**design wave**
deterministic wave with a defined height, period and direction, used for the design of an offshore structure

Note 1 to entry: A design wave may be accompanied by a requirement for the use of a particular periodic wave theory.

**3.8**
**designer**
party or parties responsible for the design of an offshore wind turbine

**3.9**
**environmental conditions**
characteristics of the environment (wind, waves, sea currents, water level, sea/lake ice, marine growth, scour and overall seabed movement, etc.) which may affect the wind turbine behaviour

**3.10**
**external conditions**
external factors affecting operation of an offshore wind turbine, including the environmental conditions, the electrical network conditions, and other climatic factors (temperature, snow, ice, etc.)

**3.11**
**extreme significant wave height**
significant wave height of the sea state over the reference period with an annual probability of exceedance of 1/N ("return period": N years), extrapolated from the extreme distribution of significant wave height at the site

**3.12**
**extreme wave height**
individual wave height (generally the zero up-crossing wave height) with an annual probability of exceedance of 1/N ("return period": N years)

**3.13**
**fast ice cover**
rigid continuous cover of ice not in motion

**3.14**
**fetch**
distance over which the wind blows over the sea with approximately constant wind speed and direction

**3.15**
**fixed offshore wind turbine**
wind turbine with a sub-structure that is subject to hydrodynamic loading and is founded on the seabed

**3.16**
**floating offshore wind turbine**
wind turbine with a sub-structure that is subject to hydrodynamic loading and is supported by buoyancy and a station-keeping system

**3.17**
**foundation**
part of an offshore wind turbine support structure which transfers the loads acting on the structure into the seabed

Note 1 to entry: Different foundation concepts are shown in Figure 1 together with the other parts of an offshore wind turbine support structure.

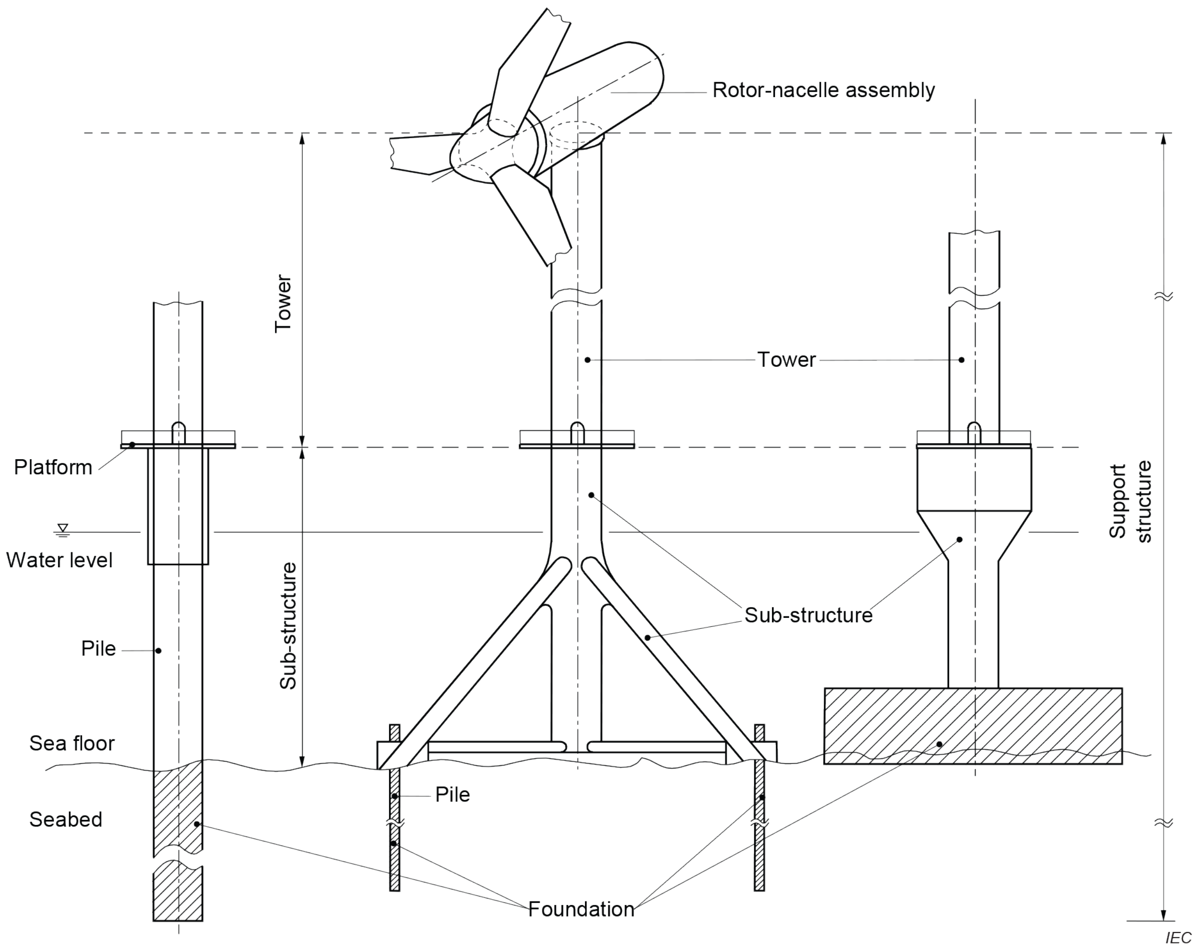


**Figure 1 – Parts of a fixed offshore wind turbine**

**3.18**
**highest astronomical tide**
highest still water level that can be expected to occur under any combination of astronomical conditions and under average meteorological conditions

Note 1 to entry: Storm surges, which are meteorologically generated and essentially irregular, are superimposed on the tidal variations, so that a total still water level above highest astronomical tide may occur.

**3.19**
**hindcasting**
method of simulating historical (metocean) data for a region through numerical modelling

**3.20**
**hub height**
height of the centre of the swept area of the wind turbine rotor above the mean sea level

**3.21**
**hummocked ice**
crushed ice and ice floes piled up into ridges when large ice floes meet with each other or with a rigid obstacle, for example an offshore wind turbine support structure

**3.22**
**ice floe**
sheet of ice in size from metres to several kilometres, not rigidly frozen to a shore, still or in motion

**3.23**
**ice ridge**
angular ice blocks of various sizes that pile up on ice floes as they collide pushed by wind and currents

Note 1 to entry: The part of the ridge that is above the water surface is known as the sail; that below it as the keel. The upper part of the keel can be consolidated, consisting of refrozen ice blocks, refrozen rafted ice or a combination of these, and is known as the consolidated layer.

**3.24**
**icing**
build-up of a cover of ice or frost on parts of an offshore wind turbine that can result in added loads and/or changed properties

**3.25**
**land-locked waters**
waters almost or entirely surrounded by land

**3.26**
**load effect**
effect of a single load or combination of loads on a structural component or system, for example internal force, stress, strain, motion, etc.

**3.27**
**lowest astronomical tide**
lowest still water level that can be expected to occur under any combination of astronomical conditions and under average meteorological conditions

Note 1 to entry: Storm surges, which are meteorologically generated and essentially irregular, are superimposed on the tidal variations, so that a total still water level below lowest astronomical tide may occur.

**3.28**
**manufacturer**
party or parties responsible for the manufacture and construction of an offshore wind turbine

**3.29**
**marine conditions**
characteristics of the marine environment (waves, sea currents, water level, sea/lake ice, marine growth, seabed movement and scour, etc.) which may affect the wind turbine behaviour

**3.30**
**marine growth**
surface coating on structural components caused by plants, animals and bacteria

**3.31**
**mean sea level**
average level of the sea over a period of time long enough to remove variations due to waves, tides and storm surges

**3.32**
**mean zero crossing period**
average period of the zero-crossing (up or down) waves in a sea state

Note 1 to entry: Relations exist between mean zero crossing period and peak period.

**3.33**
**metocean**
abbreviation of meteorological and oceanographic

**3.34**
**moving ice**
portions of sea/lake ice that move under the action of wind and /or currents

**3.35**
**multi-directional**
acting in multiple directions

**3.36**
**offshore wind turbine site**
location or intended location of an individual offshore wind turbine either alone or within a wind farm

**3.37**
**peak wave period**
period of the peak energy in the wave spectrum

**3.38**
**pile penetration**
vertical distance from the sea floor to the bottom of the pile

**3.39**
**power collection system**
electrical system that collects the power from one or more wind turbines

Note 1 to entry: The power collection system includes all electrical equipment connected between the wind turbine terminals and the network connection point. For offshore wind farms, the power collection system may include the connection to shore.

**3.40**
**rafted ice**
sea/lake ice sheet that converges toward another and slides on top of the other (overthrusted) resulting in a local increase in ice thickness

**3.41**
**reference period**
period during which stationarity is assumed for a given stochastic process, for example wind speed, sea elevation or response

**3.42**
**refraction**
process by which wave energy is redistributed as a result of changes in the wave propagation velocity due to variations in water depth and/or current velocity

**3.43**
**rotor–nacelle assembly**
part of an offshore wind turbine carried by the support structure

**3.44**
**sea floor**
interface between the sea and the seabed

**3.45**
**sea floor slope**
local gradient of the sea floor, for example associated with a beach

**3.46**
**sea/lake ice**
frozen seawater or lake freshwater

**3.47**
**sea state**
condition of the sea in which its statistics remain stationary

**3.48**
**seabed**
materials below the sea floor in which a support structure is founded

**3.49**
**seabed movement**
movement of the seabed due to natural geological processes

**3.50**
**scour**
removal of seabed soils by currents and waves or caused by structural elements interrupting the natural flow regime above the sea floor

**3.51**
**shallow water**
depth in which the presence of the seabed has a pronounced effect on the wave hydrodynamics

Note 1 to entry: The distinction between shallow water and non-shallow water is defined in Figure B.1. For extreme sea states a site may have to be considered as shallow while for normal conditions it can be considered deep.

**3.52**
**significant wave height**
statistical measure of the height of waves in a sea state, defined as either the average height of the highest one third of the zero up-crossing waves or as $4 \times \sigma_\eta$ where $\sigma_\eta$ is the standard deviation of the sea surface elevation

Note 1 to entry: The former height is called the statistical significant wave height (usually denoted $H_{1/3}$[3], while the latter height is called the spectral significant wave height (denoted by $H_s$ or $H_{m0}$).

**3.53**
**significant wave period**
statistical measure of the period of waves in a sea state, defined as the average period of the highest one third of the zero up-crossing waves, denoted $T_{1/3}$

Note 1 to entry: Relations exist between the peak period $T_p$ and $T_{1/3}$.

**3.54**
**splash zone**
external region of support structure that is frequently wetted due to waves and tidal variations

Note 1 to entry: This is defined as the zone between

– the highest still water level with a return period of 1 year increased by the crest height of a wave with height equal to the significant wave height with a return period of 1 year, and

– the lowest still water level with a return period of 1 year reduced by the trough depth of a wave with height equal to the significant wave height with a return period of 1 year.

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3 In deep water, $H_{1/3} \approx 0{,}956 H_s$ regardless of wave spectral form (ISO 21650:2007).

**3.55**
**still water level**
abstract water level calculated by including the effects of tides and storm surge but excluding variations due to waves

Note 1 to entry: Still water level can be above, at, or below mean sea level.

**3.56**
**storm surge**
change in water level caused by atmospheric change and/or wind associated with a storm

**3.57**
**sub-structure**
part of an offshore wind turbine support structure which extends upwards from the seabed and connects the foundation to the tower

**3.58**
**support structure**
part of an offshore wind turbine consisting of the tower, sub-structure and foundation

**3.59**
**swell**
sea state in which waves generated by winds remote from the site have travelled to the site, rather than being locally generated

**3.60**
**tidal current**
current resulting from tides

**3.61**
**tidal range**
vertical distance between the highest astronomical tide and the lowest astronomical tide

**3.62**
**tides**
regular and predictable movements of the sea generated by astronomical forces

**3.63**
**tower**
part of an offshore wind turbine support structure which connects the sub-structure to the rotor-nacelle assembly

**3.64**
**tsunami**
long period sea waves caused by rapid vertical movements of the sea floor

**3.65**
**uni-directional (wind and/or waves)**
acting in a single direction

**3.66**
**water depth**
vertical distance between the sea floor and the still water level

Note 1 to entry: As there are several definitions for the still water level (see 3.55) there can be several water depth values.

**3.67**
**wave crest elevation**
vertical distance between the crest of a wave and the still water level

**3.68**
**wave direction**
mean direction from which the wave is travelling

**3.69**
**wave height**
vertical distance between the highest and lowest points on the water surface of an individual zero up-crossing wave

**3.70**
**wave period**
time interval between the two zero up-crossings which bound a zero up-crossing wave

**3.71**
**wave spectral peak frequency**
frequency of the peak energy in the wave spectrum, the inverse of the wave peak period

**3.72**
**wave spectrum**
frequency domain description of the sea surface elevation in a sea state

**3.73**
**wave steepness**
ratio of the wave height to the wave length

**3.74**
**weather downtime**
one or more intervals of time during which the environmental conditions are too severe to allow for execution of a specified marine operation

**3.75**
**weather window**
interval of time during which the environmental conditions allow for execution of a specified marine operation

**3.76**
**wind profile – wind shear law**
mathematical expression for assumed wind speed variation with height above still water level

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

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

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

where

$V(z)$ is the wind speed at height $z$;

$z$ is the height above the still water level;

$z_r$ is a reference height above the still water level used for fitting the profile;

$z_0$ is the roughness length;

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

**3.77**
**wind sea**
sea state being generated by local winds

**3.78**
**zero up-crossing wave**
portion of a time history of wave elevation between zero up-crossings

Note 1 to entry: A zero up-crossing occurs when the sea surface rises (rather than falls) through the still water level.

# 4 Symbols and abbreviated terms

For the purposes of this document, the symbols and abbreviated terms given in IEC 61400-1 and the following apply:

## 4.1 Symbols and units

| | | |
|---|---|---|
| $A_C$ | Charnock's constant | [-] |
| $d$ | water depth | [m] |
| $f_p$ | wave spectral peak frequency | [Hz] |
| $g$ | acceleration due to gravity | [m/s$^2$] |
| $h$ | thickness of sheet sea/lake ice | [m] |
| $h_c$ | thickness of sea/lake ice ridge consolidated layer or refrozen rafted layer | [m] |
| $h_N$ | thickness of sea/lake ice with a return period of $N$ years | [m] |
| $h_m$ | ice thickness equal to the long-term mean value of the annual maximum ice sheet thickness for winters with ice | [m] |
| $H$ | individual wave height | [m] |
| $H_B$ | breaking wave height | [m] |
| $H_N$ | individual wave height with a return period of $N$ years | [m] |
| $H_s$ | spectral significant wave height | [m] |
| $H_{sN}$ | spectral significant wave height with a return period of $N$ years | [m] |
| $H_{1/3}$ | statistical significant wave height | [m] |
| $k$ | wave number | [-] |
| $K_{max}$ | accumulated freezing degree-days | [°C] |
| $s$ | sea floor slope | [°] |
| $p(V_{hub})$ | probability density function of hub height wind speed | [-] |
| $S_\eta$ | single sided wave spectrum | [m$^2$/Hz] |
| $R_d$ | design value for component resistance | [-] |
| $R_k$ | characteristic value for component resistance | [-] |
| $S_d$ | design value for load effect | [-] |
| $S_k$ | characteristic value for load effect | [-] |
| $t$ | time | [s] |
| $T$ | wave period | [s] |
| $T_p$ | peak spectral period | [s] |
| $T_z$ | mean zero-crossing wave period | [s] |
| $U_N$ | current velocity, with a return period of $N$ years | [m/s] |