



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

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.180

ISBN 978-2-8322-6600-7

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	7
INTRODUCTION.....	9
1 Scope.....	10
2 Normative references	10
3 Terms and definitions	11
4 Symbols and abbreviated terms.....	19
4.1 Symbols and units.....	19
4.2 Abbreviations.....	20
5 Principal elements	21
5.1 General.....	21
5.2 Design methods	21
5.3 Safety classes	22
5.4 Quality assurance	22
5.5 Rotor–nacelle assembly markings.....	23
6 External conditions – definition and assessment.....	23
6.1 General.....	23
6.2 Wind turbine classes.....	24
6.3 Definition of external conditions at an offshore wind turbine site	24
6.3.1 General	24
6.3.2 Wind conditions	25
6.3.3 Marine conditions	25
6.3.4 Electrical power network conditions	32
6.3.5 Other environmental conditions	32
6.4 Assessment of external conditions at an offshore wind turbine site	33
6.4.1 General	33
6.4.2 The metocean database	33
6.4.3 Assessment of wind conditions	34
6.4.4 Assessment of marine conditions.....	36
6.4.5 Assessment of other environmental conditions	40
6.4.6 Assessment of electrical network conditions	41
6.4.7 Assessment of soil conditions.....	41
7 Structural design	42
7.1 General.....	42
7.2 Design methodology	42
7.3 Loads.....	42
7.3.1 General	42
7.3.2 Gravitational and inertial loads	42
7.3.3 Aerodynamic loads	43
7.3.4 Actuation loads.....	43
7.3.5 Hydrodynamic loads	43
7.3.6 Sea/lake ice loads	43
7.3.7 Other loads.....	44
7.4 Design situations and load cases.....	44
7.4.1 General	44
7.4.2 Power production (DLC 1.1 to 1.6).....	50

7.4.3	Power production plus occurrence of fault or loss of electrical network connection (DLC 2.1 – 2.5)	51
7.4.4	Start up (DLC 3.1 to 3.3).....	53
7.4.5	Normal shutdown (DLC 4.1 to 4.2)	54
7.4.6	Emergency stop (DLC 5.1).....	54
7.4.7	Parked (standstill or idling) (DLC 6.1 to 6.4)	55
7.4.8	Parked plus fault conditions (DLC 7.1 to 7.2)	56
7.4.9	Transport, assembly, maintenance and repair (DLC 8.1 to 8.4).....	57
7.4.10	Sea/lake ice design load cases	60
7.5	Load and load effect calculations	61
7.5.1	General	61
7.5.2	Relevance of hydrodynamic loads.....	61
7.5.3	Calculation of hydrodynamic loads.....	62
7.5.4	Calculation of sea/lake ice loads.....	62
7.5.5	Overall damping assessment for support structure response evaluations.....	62
7.5.6	Simulation requirements	64
7.5.7	Other requirements	65
7.6	Ultimate limit state analysis.....	66
7.6.1	Method	66
7.6.2	Ultimate strength analysis.....	68
7.6.3	Fatigue failure	68
7.6.4	Special partial safety factors.....	69
7.6.5	Assessment of cyclic loading for foundation assessment	69
8	Control system	69
9	Mechanical systems	70
10	Electrical system	70
11	Foundation and substructure design	70
12	Assembly, installation and erection.....	71
12.1	General.....	71
12.2	Planning	72
12.3	Installation conditions	72
12.4	Site access	72
12.5	Environmental conditions	73
12.6	Documentation.....	73
12.7	Receiving, handling and storage	73
12.8	Support structure systems	73
12.9	Assembly of offshore wind turbine.....	73
12.10	Erection of offshore wind turbine.....	74
12.11	Fasteners and attachments.....	74
12.12	Cranes, hoists and lifting equipment	74
13	Commissioning, operation and maintenance	74
13.1	General.....	74
13.2	Design requirements for safe operation, inspection and maintenance	75
13.3	Instructions concerning commissioning	76
13.3.1	General	76
13.3.2	Energization	76
13.3.3	Commissioning tests.....	76
13.3.4	Records.....	76

13.3.5	Post commissioning activities	76
13.4	Operator's instruction manual	76
13.4.1	General	76
13.4.2	Instructions for operations and maintenance record	77
13.4.3	Instructions for unscheduled automatic shutdown	77
13.4.4	Instructions for diminished reliability	77
13.4.5	Work procedures plan	77
13.4.6	Emergency procedures plan	78
13.5	Maintenance manual	78
Annex A (informative)	Key design parameters for an offshore wind turbine	80
A.1	Offshore wind turbine identifiers	80
A.1.1	General	80
A.1.2	Rotor-nacelle assembly (machine) parameters	80
A.1.3	Support structure parameters	80
A.1.4	Wind conditions (based on a 10-min reference period and including wind farm wake effects where relevant)	80
A.1.5	Marine conditions (based on a 3-hour reference period where relevant)	81
A.1.6	Electrical network conditions at turbine	81
A.2	Other environmental conditions	82
A.3	Limiting conditions for transport, erection and maintenance	82
Annex B (informative)	Shallow water hydrodynamics and breaking waves	83
B.1	Selection of suitable wave theories	83
B.2	Modelling of irregular wave trains	84
B.3	Wave height distributions	84
B.3.1	General	84
B.3.2	The Goda model for maximum wave height	84
B.3.3	The Battjes and Groenendijk wave height distribution	87
B.3.4	The Forristall wave and crest height distributions	90
B.4	Breaking waves	92
B.5	Reference documents	95
Annex C (informative)	Guidance on calculation of hydrodynamic loads	96
C.1	General	96
C.2	Morison's equation	97
C.3	Diffraction	98
C.4	Slap and slam loading	99
C.5	Vortex-induced vibrations	102
C.5.1	General	102
C.5.2	Critical velocities for cross-flow motion	103
C.5.3	Critical velocities for in-line motion	104
C.6	Appurtenances	105
C.6.1	General	105
C.6.2	Alternative method for estimating hydrodynamic coefficients accounting for appurtenances and marine growth	105
C.7	Calculation methods	112
C.7.1	General	112
C.7.2	Explicit approach	113
C.7.3	Constrained wave approach	113
C.8	Reference documents	113

Annex D (informative) Recommendations for design of offshore wind turbine support structures with respect to ice loads	115
D.1 Introductory remarks	115
D.2 General.....	115
D.3 Choice of ice thickness	116
D.4 Load cases	117
D.4.1 General	117
D.4.2 Horizontal load from fast ice cover originating from temperature fluctuations (DLC D1)	117
D.4.3 Horizontal load from fast ice cover originating from water level fluctuations and arch effect (DLC D2)	118
D.4.4 Horizontal load from moving ice (DLC D3, D4, D7 and D8)	118
D.4.5 Vertical load from fast ice cover (DLC D5)	122
D.4.6 Pressure from ice ridges (DLC D6)	123
D.4.7 Dynamic loading (DLC D3, D4, D7, and D8).....	123
D.5 Requirements on stochastic simulation	126
D.6 Requirements on model testing	126
D.7 Reference documents	127
D.8 Databases for ice conditions	129
Annex E (informative) Offshore wind turbine foundation and substructure design.....	130
Annex F (informative) Statistical extrapolation of operational metocean parameters for ultimate strength analysis	131
F.1 General.....	131
F.2 Use of IFORM to determine 50-yr significant wave height conditional on mean wind speed.....	131
F.3 Examples of joint distributions of V and H_S and approximations to the environmental contour	133
F.4 Choice of sea state duration	135
F.5 Determination of the extreme individual wave height to be embedded in SSS	135
F.6 Reference documents	136
Annex G (informative) Corrosion protection	137
G.1 General.....	137
G.2 The marine environment	137
G.3 Corrosion protection considerations	138
G.4 Corrosion protection systems – Support structures	138
G.5 Corrosion protection in the rotor–nacelle assembly	139
G.6 Reference documents	140
Annex H (informative) Prediction of extreme wave heights during tropical cyclones	141
H.1 General.....	141
H.2 Wind field estimation for tropical cyclones.....	141
H.3 Wave estimation for tropical cyclones	142
H.4 Reference documents	142
H.5 Databases for tropical storms conditions.....	143
Annex I (informative) Recommendations for alignment of safety levels in tropical cyclone regions.....	144
I.1 General.....	144
I.2 Global robustness level criteria	144
I.3 Design load cases.....	145
Bibliography.....	147

Figure 1 – Parts of a fixed offshore wind turbine	13
Figure 2 – Design process for an offshore wind turbine	22
Figure 3 – Definition of water levels	30
Figure 4 – The two approaches to calculate the design load effect.....	67
Figure B.1 – Regular wave theory selection diagram.....	83
Figure B.2 – Comparison of wave height distribution results	92
Figure C.1 – Breaking wave and cylinder parameters.....	100
Figure C.2 – Oblique inflow parameters	101
Figure C.3 – Distribution over height of the maximum impact line force ($\gamma = 0^\circ$)	102
Figure C.4 – Response of model and full-scale cylinder in-line and cross-flow	104
Figure C.5 – Geometrical definition of blocking and shielding	109
Figure C.6 – Influence of a fixed boundary on the drag coefficient on a circular cylinder in oscillatory supercritical flow $KC > 20$, $Re = 10^5 - 2 \times 10^6$	110
Figure C.7 – Shielding factors.....	111
Figure C.8 – Recommended value for the added mass coefficient C_m of a circular cylinder; influence of a fixed boundary	112
Figure D.1 – Ice force coefficients for plastic limit analysis	121
Figure D.2 – Ice load history for frequency lock-in conditions.....	125
Figure D.3 – Time history of horizontal force component of ice load acting on a conical structure	125
Figure F.1 – Example of the construction of the 50-year environmental contour for a 3- hour sea state duration.	132
Table 1 – Conversion between extreme wind speeds of different averaging periods.....	34
Table 2 – Design load cases	46
Table 3 – Design load cases for sea/lake ice	61
Table B.1 – Constants h_1 and h_2 and normalised wave heights h_x % as a function of H_{tr}	88
Table B.2 – Breaking wave type.....	94
Table I.1 – Additional load cases for tropical cyclone affected regions	146

INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND ENERGY GENERATION SYSTEMS –**Part 3-1: Design requirements for fixed offshore wind turbines****FOREWORD**

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

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*

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*