

Wind energy generation systems - Part 24: Lightning protection

EESTI STANDARDI EESSÕNA

NATIONAL FOREWORD

See Eesti standard EVS-EN IEC 61400-24:2019 sisaldab Euroopa standardi EN IEC 61400-24:2019 ingliskeelset teksti.	This Estonian standard EVS-EN IEC 61400-24:2019 consists of the English text of the European standard EN IEC 61400-24:2019.
Standard on jõustunud sellekohase teate avaldamisega EVS Teatajas	This standard has been endorsed with a notification published in the official bulletin of the Estonian Centre for Standardisation.
Euroopa standardimisorganisatsioonid on teinud Euroopa standardi rahvuslikele liikmetele kättesaadavaks 30.08.2019.	Date of Availability of the European standard is 30.08.2019.
Standard on kättesaadav Eesti Standardikeskusest.	The standard is available from the Estonian Centre for Standardisation.

Tagasisidet standardi sisu kohta on võimalik edastada, kasutades EVS-i veebilehel asuvat tagasiside vormi või saates e-kirja meiliaadressile standardiosakond@evs.ee.

ICS 27.180

Standardite reprodutseerimise ja levitamise õigus kuulub Eesti Standardikeskusele

Andmete paljundamine, taastekitamine, kopeerimine, salvestamine elektroonsesse süsteemi või edastamine ükskõik millises vormis või millisel teel ilma Eesti Standardikeskuse kirjaliku loata on keelatud.

Kui Teil on küsimusi standardite autorikaitse kohta, võtke palun ühendust Eesti Standardikeskusega:

Koduleht www.evs.ee; telefon 605 5050; e-post info@evs.ee

The right to reproduce and distribute standards belongs to the Estonian Centre for Standardisation

No part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, without a written permission from the Estonian Centre for Standardisation.

If you have any questions about copyright, please contact Estonian Centre for Standardisation:

Homepage www.evs.ee; phone +372 605 5050; e-mail info@evs.ee

English Version

**Wind energy generation systems - Part 24: Lightning protection
(IEC 61400-24:2019)**

Systèmes de génération d'énergie éolienne - Partie 24 :
Protection contre la foudre
(IEC 61400-24:2019)

Windenergieanlagen - Teil 24: Blitzschutz
(IEC 61400-24:2019)

This European Standard was approved by CENELEC on 2019-08-07. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.



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

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

European foreword

The text of document 88/709/FDIS, future edition 2 of IEC 61400-24, prepared by IEC/TC 88 "Wind energy generation systems" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN IEC 61400-24:2019.

The following dates are fixed:

- latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2020-05-07
- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2022-08-07

This document supersedes EN 61400-24:2010 and all of its amendments and corrigenda (if any).

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

Endorsement notice

The text of the International Standard IEC 61400-24:2019 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 60060-1:2010	NOTE	Harmonized as EN 60060-1:2010 (not modified)
IEC 60071 (series)	NOTE	Harmonized as EN 60071 (series)
IEC 60071-2:2018	NOTE	Harmonized as EN IEC 60071-2:2018 (not modified)
IEC 60099-4	NOTE	Harmonized as EN 60099-4
IEC 60099-5	NOTE	Harmonized as EN IEC 60099-5
IEC 60204-1	NOTE	Harmonized as EN 60204-1
IEC 60204-11	NOTE	Harmonized as EN IEC 60204-11
IEC 60243 (series)	NOTE	Harmonized as EN 60243 (series)
IEC 60243-1	NOTE	Harmonized as EN 60243-1
IEC 60243-3	NOTE	Harmonized as EN 60243-3
IEC 60464-2	NOTE	Harmonized as EN 60464-2
IEC 60587	NOTE	Harmonized as EN 60587
IEC 62561 (series)	NOTE	Harmonized as EN IEC 62561 (series)
IEC 62561-1	NOTE	Harmonized as EN 62561-1
IEC 62793	NOTE	Harmonized as EN IEC 62793
IEC 62858	NOTE	Harmonized as EN 62858

Annex ZA

(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE 1 Where an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60364-4-44	-	Low-voltage electrical installations - Part 4-44: Protection for safety - Protection against voltage disturbances and electromagnetic disturbances	HD 60364-4-442	-
IEC 60364-5-53	-	Low-voltage electrical installations -- Part-5-53: Selection and erection of electrical equipment - Protection, isolation, switching, control and monitoring		-
IEC 60364-5-54	-	Low-voltage electrical installations - Part 5-54: Selection and erection of electrical equipment - Earthing arrangements and protective conductors	HD 60364-5-54	-
IEC 60364-6	-	Low voltage electrical installations - Part 6: Verification	HD 60364-6	-
IEC 60664-1	-	Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests	EN 60664-1	-
IEC 61000-1	series	Electromagnetic compatibility (EMC) - Part 1-2: General - Methodology for the achievement of functional safety of electrical and electronic systems including equipment with regard to electromagnetic phenomena	EN 61000-1	series
IEC 61000-4-5	-	Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test	EN 61000-4-5	-
IEC 61000-4-9	-	Electromagnetic compatibility (EMC) – Part 4-9: Testing and measurement techniques – Impulse magnetic field immunity test	EN 61000-4-9	-
IEC 61000-4-10	-	Electromagnetic compatibility (EMC) – Part 4-10: Testing and measurement techniques – Damped oscillatory magnetic field immunity test	EN 61000-4-10	-

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 61400-23	-	Wind turbines - Part 23: Full-scale structural testing of rotor blades	EN 61400-23	-
IEC 61587-3	-	Mechanical structures for electronic equipment - Tests for IEC 60917 and IEC 60297 - Part 3: Electromagnetic shielding performance tests for cabinets and subracks	EN 61587-3	-
IEC 61643-11	-	Low-voltage surge protective devices - Part 11: Surge protective devices connected to low-voltage power systems - Requirements and test methods	EN 61643-11	-
IEC 61643-12	-	Low-voltage surge protective devices - Part 12: Surge protective devices connected to low-voltage power distribution systems - Selection and application principles	CLC/TS 61643-12	-
IEC 61643-21	-	Low voltage surge protective devices - Part 21: Surge protective devices connected to telecommunications and signalling networks - Performance requirements and testing methods		-
IEC 61643-22	-	Low-voltage surge protective devices - Part 22: Surge protective devices connected to telecommunications and signalling networks - Selection and application principles	CLC/TS 61643-22	-
IEC 61936-1	-	Power installations exceeding 1 kV a.c. - Part 1: Common rules	EN 61936-1	-
IEC 62305-1 (mod) 2010	2010	Protection against lightning - Part 1: General principles	EN 62305-1	2011
IEC 62305-2 (mod) 2010	2010	Protection against lightning - Part 2: Risk management	EN 62305-2	2012
IEC 62305-3 (mod) 2010	2010	Protection against lightning - Part 3: Physical damage to structures and life hazard	EN 62305-3	2011
IEC 62305-4 (mod) 2010	2010	Protection against lightning - Part 4: Electrical and electronic systems within structures	EN 62305-4	2011
IEC/TR 60479-4	-	Effects of current on human beings and livestock -- Part 4: Effects of lightning strokes on human beings and livestock		-
IEC/TR 61000-5-2	-	Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 2: Earthing and cabling		-
IEC/TS 60479-1	-	Effects of current on human beings and livestock - Part 1: General aspects		-
IEC/TS 61936-2	-	Power installations exceeding 1 kV a.c.- and 1,5 kV d.c. - Part 2: d.c.		-
ITU-T K.20	-	Resistibility of telecommunication-equipment installed in a telecommunication centre to overvoltages and overcurrents		-

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
ITU-T K.21	-	Resistibility of telecommunication-equipment installed in customer premises to overvoltages and overcurrents		-

This document is a preview generated by EVS

CONTENTS

FOREWORD.....	11
1 Scope.....	13
2 Normative references	13
3 Terms and definitions	15
4 Symbols and units	21
5 Abbreviated terms	24
6 Lightning environment for wind turbine	25
6.1 General.....	25
6.2 Lightning current parameters and lightning protection levels (LPL).....	25
7 Lightning exposure assessment.....	26
7.1 General.....	26
7.2 Assessing the frequency of lightning affecting a single wind turbine or a group of wind turbines.....	28
7.2.1 Categorization of lightning events	28
7.2.2 Estimation of average number of lightning flashes to a single or a group of wind turbines	28
7.2.3 Estimation of average annual number of lightning flashes near the wind turbine (N_M)	31
7.2.4 Estimation of average annual number of lightning flashes to the service lines connecting the wind turbines (N_L)	32
7.2.5 Estimation of average annual number of lightning flashes near the service lines connecting the wind turbine (N_I)	32
7.3 Assessing the risk of damage	33
7.3.1 Basic equation	33
7.3.2 Assessment of risk components due to flashes to the wind turbine (S1).....	34
7.3.3 Assessment of the risk component due to flashes near the wind turbine (S2)	34
7.3.4 Assessment of risk components due to flashes to a service line connected to the wind turbine (S3)	35
7.3.5 Assessment of risk component due to flashes near a service line connected to the wind turbine (S4)	35
8 Lightning protection of subcomponents.....	36
8.1 General.....	36
8.1.1 Lightning protection level (LPL)	36
8.1.2 Lightning protection zones (LPZ)	37
8.2 Blades	37
8.2.1 General	37
8.2.2 Requirements	37
8.2.3 Verification	38
8.2.4 Protection design considerations	38
8.2.5 Test methods.....	41
8.3 Nacelle and other structural components	42
8.3.1 General	42
8.3.2 Hub	42
8.3.3 Spinner.....	42
8.3.4 Nacelle	43
8.3.5 Tower	43
8.3.6 Verification methods	44

8.4	Mechanical drive train and yaw system	44
8.4.1	General	44
8.4.2	Bearings	44
8.4.3	Hydraulic systems	45
8.4.4	Spark gaps and sliding contacts	46
8.4.5	Verification	46
8.5	Electrical low-voltage systems and electronic systems and installations	46
8.5.1	General	46
8.5.2	Equipotential bonding within the wind turbine	50
8.5.3	LEMP protection and immunity levels	51
8.5.4	Shielding and line routing	52
8.5.5	SPD protection	53
8.5.6	Testing methods for system immunity tests	57
8.6	Electrical high-voltage (HV) power systems	57
9	Earthing of wind turbines	59
9.1	General	59
9.1.1	Purpose and scope	59
9.1.2	Basic requirements	59
9.1.3	Earth electrode arrangements	59
9.1.4	Earthing system impedance	60
9.2	Equipotential bonding	60
9.2.1	General	60
9.2.2	Lightning equipotential bonding for metal installations	60
9.3	Structural components	61
9.3.1	General	61
9.3.2	Metal tubular type tower	61
9.3.3	Metal reinforced concrete towers	61
9.3.4	Lattice tower	61
9.3.5	Systems inside the tower	62
9.3.6	Concrete foundation	62
9.3.7	Rocky area foundation	62
9.3.8	Metal mono-pile foundation	63
9.3.9	Offshore foundation	63
9.4	Electrode shape dimensions	63
9.5	Execution and maintenance of the earthing system	64
10	Personal safety	64
11	Documentation of lightning protection system	66
11.1	General	66
11.2	Documentation necessary during assessment for design evaluation	66
11.2.1	General	66
11.2.2	General documentation	66
11.2.3	Documentation for rotor blades	66
11.2.4	Documentation of mechanical systems	67
11.2.5	Documentation of electrical and electronic systems	67
11.2.6	Documentation of earthing and bonding systems	67
11.2.7	Documentation of nacelle cover, hub and tower lightning protection systems	67
11.3	Site-specific information	68
11.4	Documentation to be provided in the manuals for LPS inspections	68

11.5	Manuals	68
12	Inspection of lightning protection system	68
12.1	Scope of inspection	68
12.2	Order of inspections	68
12.2.1	General	68
12.2.2	Inspection during production of the wind turbine	69
12.2.3	Inspection during installation of the wind turbine	69
12.2.4	Inspection during commissioning of the wind turbine and periodic inspection	69
12.2.5	Inspection after dismantling or repair of main parts	70
12.3	Maintenance	71
Annex A	(informative) The lightning phenomenon in relation to wind turbines	72
A.1	Lightning environment for wind turbines	72
A.1.1	General	72
A.1.2	The properties of lightning	72
A.1.3	Lightning discharge formation and electrical parameters	72
A.1.4	Cloud-to-ground flashes	73
A.1.5	Upward initiated flashes	79
A.2	Lightning current parameters relevant to the point of strike	82
A.3	Leader current without return stroke	83
A.4	Lightning electromagnetic impulse, LEMP, effects	83
Annex B	(informative) Lightning exposure assessment	84
B.1	General	84
B.2	Methodology to estimate the average annual flashes or strokes to the wind turbines of a wind farm and upward lightning activity in wind turbines	84
B.2.1	General	84
B.2.2	Methodology to determine average annual flashes to turbines of a wind farm estimation by increase of the location factor to consider upward lightning from wind turbines	84
B.2.3	Upward lightning percentage in wind farms	88
B.3	Explanation of terms	88
B.3.1	Damage and loss	88
B.3.2	Composition of risk	90
B.3.3	Assessment of risk components	90
B.3.4	Frequency of damage	91
B.3.5	Assessment of probability, P_X , of damage	92
B.4	Assessing the probability of damage to the wind turbine	93
B.4.1	Probability, P_{AT} , that a lightning flash to a wind turbine will cause dangerous touch and step voltage	93
B.4.2	Probability, P_{AD} , that a lightning flash to the wind turbine will cause injury to an exposed person on the structure	94
B.4.3	Probability, P_B , that a lightning flash to the wind turbine will cause physical damage	94
B.4.4	Probability, P_C , that a lightning flash to the wind turbine will cause failure of internal systems	96
B.4.5	Probability, P_M , that a lightning flash near the wind turbine will cause failure of internal systems	96
B.4.6	Probability, P_U , that a lightning flash to a service line will cause injury to human beings owing to touch voltage	96
B.4.7	Probability, P_V , that a lightning flash to a service line will cause physical damage	97

B.4.8	Probability, P_W , that a lightning flash to a service line will cause failure of internal systems	97
B.4.9	Probability, P_Z , that a lightning flash near an incoming service line will cause failure of internal systems.....	98
B.4.10	Probability P_P that a person will be in a dangerous place	99
B.4.11	Probability P_e that equipment will be exposed to damaging event.....	99
B.5	Assessing the amount of loss L_X in a wind turbine	99
B.5.1	General	99
B.5.2	Mean relative loss per dangerous event.....	99
Annex C (informative)	Protection methods for blades	101
C.1	General.....	101
C.1.1	Types of blades and types of protection methods for blades	101
C.1.2	Blade damage mechanism	102
C.2	Protection methods	103
C.2.1	General	103
C.2.2	Lightning air-termination systems on the blade surface or embedded in the surface	104
C.2.3	Adhesive metallic tapes and segmented diverter strips	104
C.2.4	Internal down conductor systems.....	105
C.2.5	Conducting surface materials.....	105
C.3	CFRP structural components	106
C.4	Particular concerns with conducting components	107
C.5	Interception efficiency	108
C.6	Dimensioning of lightning protection systems	109
C.7	Blade-to-hub connection	111
C.8	WTG blade field exposure	111
C.8.1	General	111
C.8.2	Application.....	112
C.8.3	Field exposure	112
Annex D (normative)	Test specifications	113
D.1	General.....	113
D.2	High-voltage strike attachment tests	113
D.2.1	Verification of air termination system effectiveness.....	113
D.2.2	Initial leader attachment test.....	113
D.2.3	Subsequent stroke attachment test.....	123
D.3	High-current physical damage tests	127
D.3.1	General	127
D.3.2	Arc entry test.....	127
D.3.3	Conducted current test	132
Annex E (informative)	Application of lightning environment and lightning protection zones (LPZ)	137
E.1	Lightning environment for blades	137
E.1.1	Application.....	137
E.1.2	Examples of simplified lightning environment areas	137
E.1.3	Area transitions	139
E.2	Definition of lightning protection zones for turbines (not blades).....	139
E.2.1	General	139
E.2.2	LPZ 0	140
E.2.3	Other zones.....	141

E.2.4	Zone boundaries.....	142
E.2.5	Zone protection requirements	143
Annex F (informative) Selection and installation of a coordinated SPD protection in wind turbines		146
F.1	Location of SPDs	146
F.2	Selection of SPDs	146
F.3	Installation of SPDs	146
F.4	Environmental stresses of SPDs	147
F.5	SPD status indication and SPD monitoring in case of an SPD failure	148
F.6	Selection of SPDs with regard to protection level (U_p) and system level immunity	148
F.7	Selection of SPDs with regard to overvoltages created within wind turbines	148
F.8	Selection of SPDs with regard to discharge current (I_n) and impulse current (I_{imp})	148
Annex G (informative) Information on bonding and shielding and installation technique		150
G.1	Additional information on bonding	150
G.2	Additional information on shielding and installation technique	151
Annex H (informative) Testing methods for system level immunity tests		154
Annex I (informative) Earth termination system		159
I.1	General.....	159
I.1.1	Types of earthing systems	159
I.1.2	Construction	159
I.2	Electrode shape dimensions	161
I.2.1	Type of arrangement	161
I.2.2	Frequency dependence on earthing impedance	163
I.3	Earthing resistance expressions for different electrode configurations	164
Annex J (informative) Example of defined measuring points.....		167
Annex K (informative) Classification of lightning damage based on risk management		169
K.1	General.....	169
K.2	Lightning damage in blade	169
K.2.1	Classification of blade damage due to lightning	169
K.2.2	Possible cause of blade damage due to lightning.....	170
K.2.3	Countermeasures against blade damage due to lightning	171
K.3	Lightning damage to other components.....	173
K.3.1	Classification of damage in other components due to lightning	173
K.3.2	Countermeasures against lightning damage to other components	173
K.4	Typical lightning damage questionnaire	173
K.4.1	General	173
K.4.2	Sample of questionnaire	173
Annex L (informative) Monitoring systems.....		177
Annex M (informative) Guidelines for small wind turbines		179
Annex N (informative) Guidelines for verification of blade similarity		180
N.1	General.....	180
N.2	Similarity constraints.....	180
Annex O (informative) Guidelines for validation of numerical analysis methods.....		183
O.1	General.....	183
O.2	Blade voltage and current distribution	183
O.3	Indirect effects analysis	184

Annex P (informative) Testing of rotating components	185
P.1 General.....	185
P.2 Test specimen	185
P.2.1 Test specimen representing a stationary / quasi stationary bearing	185
P.2.2 Test specimen representing a rotating bearing	185
P.3 Test setup.....	185
P.3.1 Test set-up representing a stationary/quasi-stationary bearing	185
P.3.2 Test set-up representing a rotating bearing.....	186
P.4 Test procedure.....	187
P.5 Pass/fail criteria	188
Annex Q (informative) Earthing systems for wind farms	189
Bibliography.....	190
 Figure 1 – Collection area of the wind turbine	30
Figure 2 – Example of collection area for a complete wind farm (A_{DWF}) with 10 wind turbines (black points) considering overlapping.....	31
Figure 3 – Collection area of wind turbine of height H_a and another structure of height H_b connected by underground cable of length L_c	33
Figure 4 – Examples of possible SPM (surge protection measures)	49
Figure 5 – Interconnecting two LPZ 1 using SPDs.....	50
Figure 6 – Interconnecting two LPZ 1 using shielded cables or shielded cable ducts.....	50
Figure 7 –Magnetic field inside an enclosure due to a long connection cable from enclosure entrance to the SPD	53
Figure 8 –Additional protective measures	54
Figure 9 – Examples of placement of HV arresters in two typical main electrical circuits of wind turbines	58
Figure A.1 – Processes involved in the formation of a downward initiated cloud-to-ground flash.....	74
Figure A.2 – Typical profile of a negative cloud-to-ground flash	75
Figure A.3 – Definitions of short stroke parameters (typically $T_2 < 2$ ms)	75
Figure A.4 – Definitions of long stroke parameters (typically $2 \text{ ms} < T_{\text{long}} < 1$ s).....	76
Figure A.5 – Possible components of downward flashes (typical in flat territory and to lower structures).....	78
Figure A.6 – Typical profile of a positive cloud-to-ground flash.....	79
Figure A.7 – Processes involved in the formation of an upward initiated cloud-to-ground flash during summer and winter conditions.....	79
Figure A.8 – Typical profile of a negative upward initiated flash	80
Figure A.9 – Possible components of upward flashes (typical to exposed and/or higher structures)	81
Figure B.1 – Winter lightning world map based on LLS data and weather conditions.....	86
Figure B.2 – Detailed winter lightning maps based on LLS data and weather conditions	87
Figure B.3 – Ratio h/d description	87
Figure C.1 – Types of wind turbine blades	101
Figure C.2 – Lightning protection concepts for large modern wind turbine blades.....	104
Figure C.3 – Voltages between lightning current path and sensor wiring due to the mutual coupling and the impedance of the current path	107
Figure D.1 – Example of initial leader attachment test setup A.....	115

Figure D.2 – Possible orientations for the initial leader attachment test setup A.....	116
Figure D.3 – Definition of the blade length axis during strike attachment tests	117
Figure D.4 – Example of the application of angles during the HV test.....	117
Figure D.5 – Example of leader connection point away from test specimen.....	118
Figure D.6 – Initial leader attachment test setup B	119
Figure D.7 – Typical switching impulse voltage rise to flashover (100 μ s per division).....	121
Figure D.8 – Subsequent stroke attachment test arrangement	124
Figure D.9 – Lightning impulse voltage waveform	125
Figure D.10 – Lightning impulse voltage chopped on the front	125
Figure D.11 – HV electrode positions for the subsequent stroke attachment test.....	127
Figure D.12 – High-current test arrangement for the arc entry test.....	129
Figure D.13 – Typical jet diverting test electrodes	130
Figure D.14 – Example of an arrangement for conducted current tests.....	134
Figure E.1 – Examples of generic blade lightning environment definition.....	138
Figure E.2 – Rolling sphere method applied on wind turbine	141
Figure E.3 – Mesh with large mesh dimension for nacelle with GFRP cover	142
Figure E.4 – Mesh with small mesh dimension for nacelle with GFRP cover.....	142
Figure E.5 – Two cabinets both defined as LPZ 2 connected via the shield of a shielded cable.....	143
Figure E.6 – Example: division of wind turbine into different lightning protection zones.....	144
Figure E.7 – Example of how to document a surge protection measures (SPM) system by division of the electrical system into protection zones with indication of where circuits cross LPZ boundaries and showing the long cables running between tower base and nacelle.....	145
Figure F.1 – Point-to-point installation scheme	147
Figure F.2 – Earthing connection installation scheme.....	147
Figure G.1 – Two control cabinets located on different metallic planes inside a nacelle	150
Figure G.2 – Magnetic coupling mechanism.....	151
Figure G.3 – Measuring of transfer impedance.....	153
Figure H.1 – Example circuit of a SPD discharge current test under service conditions.....	155
Figure H.2 – Typical test set-up for injection of test current.....	157
Figure H.3 – Example circuit of an induction test for lightning currents.....	158
Figure I.1 – Minimum length (l_1) of each earth electrode according to the class of LPS	162
Figure I.2 – Frequency dependence on the impedance to earth	163
Figure J.1 – Example of measuring points.....	167
Figure K.1 – Recommended countermeasures schemes according to the incident classification	171
Figure K.2 – Blade outlines for marking locations of damage	176
Figure N.1 – Definitions of blade aerofoil nomenclature	182
Figure O.1 – Example geometry for blade voltage and current distribution simulations.....	183
Figure O.2 – Example geometry for nacelle indirect effects simulations	184
Figure P.1 – Possible test setup for a pitch bearing	185
Figure P.2 – Possible injection of test current into a pitch bearing.....	186
Figure P.3 – Possible test setup for a main bearing	187
Figure P.4 – Example measurement of the series resistance of the test sample	188

Table 1 – Maximum values of lightning parameters according to LPL (adapted from IEC 62305-1)	25
Table 2 – Minimum values of lightning parameters and related rolling sphere radius corresponding to LPL (adapted from IEC 62305-1).....	26
Table 3 – Collection areas A_L and A_I of service line depending on whether aerial or buried	33
Table 4 – Parameters relevant to the assessment of risk components for wind turbine (corresponds to IEC 62305-2)	36
Table 5 – Verification of bearing and bearing protection design concepts.....	45
Table 6 – LPS General inspection intervals.....	70
Table A.1 – Cloud-to-ground lightning current parameters	77
Table A.2 – Upward initiated lightning current parameters	81
Table A.3 – Summary of the lightning threat parameters to be considered in the calculation of the test values for the different LPS components and for the different LPL.....	82
Table B.1 – Recommended values of individual location factors.....	85
Table B.2 – Range of upward lightning activity as a function of winter lightning activity for wind farm located in flat terrain	88
Table B.3 – Values of probability, P_A , that a lightning flash to a wind turbine will cause shock to human beings owing to dangerous touch and step voltages (corresponds to IEC 62305-2)	93
Table B.4 – Values of reduction factor r_t as a function of the type of surface of soil or floor (corresponds to IEC 62305-2)	93
Table B.5 – Values of factor P_O according to the position of a person in the exposed area (corresponds to IEC 62305-2)	94
Table B.6 – Values of probability, P_{LPS} , depending on the protection measures to protect the exposed areas of the wind turbine against direct lightning flash and to reduce physical damage (corresponds to IEC 62305-2)	94
Table B.7 – Values of probability P_S that a flash to a wind turbine will cause dangerous sparking (corresponds to IEC 62305-2).....	95
Table B.8 – Values of reduction factor r_p as a function of provisions taken to reduce the consequences of fire (corresponds to IEC 62305-2)	95
Table B.9 – Values of reduction factor r_f as a function of risk of fire of the wind turbine (corresponds to IEC 62305-2)	95
Table B.10 – Values of probability P_{LI} depending on the line type and the impulse withstand voltage U_{WV} of the equipment (corresponds to IEC 62305-2)	98
Table B.11 – Loss values for each zone (corresponds to IEC 62305-2).....	99
Table B.12 – Typical mean values of L_T , L_D , L_F and L_O (corresponds to IEC 62305-2).....	100
Table C.1 – Material, configuration and minimum nominal cross-sectional area of air-termination conductors, air-termination rods, earth lead-in rods and down conductors ^a (corresponds to IEC 62305-3)	109
Table C.2 – Physical characteristics of typical materials used in lightning protection systems (corresponds to IEC 62305-1)	110
Table C.3 – Temperature rise [K] for different conductors as a function of W/R (corresponds to IEC 62305-1)	111
Table C.4 – Range of distribution of direct strikes from field campaigns collecting data on attachment distribution vs. the distance from the tip of wind turbine blades, 39 m to 45 m blades with and without CFRP.....	112
Table D.1 – Test current parameters corresponding to LPL I.....	131

Table D.2 – Test current parameters for winter lightning exposure testing (duration maximum 1 s)	131
Table D.3 – Test current parameters corresponding to LPL I	135
Table D.4 – Test current parameters corresponding to LPL I (for flexible paths).....	135
Table D.5 – Test current parameters for winter lightning exposure testing (duration maximum 1 s)	136
Table E.1 – Blade area definition for the example in concept A	139
Table E.2 – Blade area definition for the example in concept B	139
Table E.3 – Definition of lightning protection zones according to IEC 62305-1	140
Table F.1 – Discharge and impulse current levels for TN systems given in IEC 60364-5-53	149
Table F.2 – Example of increased discharge and impulse current levels for TN systems	149
Table I.1 – Impulse efficiency of several ground rod arrangements relative to a 12 m vertical ground rod (100 %).....	164
Table I.2 – Symbols used in Tables I.3 to I.6.....	164
Table I.3 – Formulae for different earthing electrode configurations	165
Table I.4 – Formulae for buried ring electrode combined with vertical rods	165
Table I.5 – Formulae for buried ring electrode combined with radial electrodes	166
Table I.6 – Formulae for buried straight horizontal electrode combined with vertical rods....	166
Table J.1 – Measuring points and resistances to be recorded	168
Table K.1 – Classification of blade damage due to lightning.....	170
Table K.2 – Matrix of blade damages due to lightning, taking account of risk management.....	172
Table K.3 – Classification of damage to other components due to lightning.....	173
Table L.1 – Considerations relevant for wide area lightning detection systems.....	177
Table L.2 – Considerations relevant for local active lightning detection systems	178
Table L.3 – Considerations relevant for local passive lightning detection systems.....	178
Table N.1 – Items to be checked and verified when evaluating similarity.....	181
Table P.1 – Test sequence for high current testing of rotating components	188

INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND ENERGY GENERATION SYSTEMS –**Part 24: Lightning protection****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 61400-24 has been prepared by IEC technical committee 88: Wind energy generation systems.

This second edition cancels and replaces the first edition, published in 2010. This edition constitutes a technical revision.

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

- a) it is restructured with a main normative part, while informative information is placed in annexes.