

BS EN 61400-24:2010



BSI Standards Publication

Wind turbines

Part 24: Lightning protection

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National foreword

This British Standard is the UK implementation of EN 61400-24:2010. It is identical to IEC 61400-24:2010. It supersedes PD IEC/TR 61400-24:2002 which is withdrawn.

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

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

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Date	Text affected
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Part 24: Lightning protection
(IEC 61400-24:2010)**

Eoliennes -
Partie 24: Protection contre la foudre
(CEI 61400-24:2010)

Windenergieanlagen -
Teil 24: Blitzschutz
(IEC 61400-24:2010)

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Foreword

The text of document 88/366/FDIS, future edition 1 of IEC 61400-24, prepared by IEC TC 88, Wind turbines, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61400-24 on 2010-07-01.

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The following dates were fixed:

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| – latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement | (dop) | 2011-04-01 |
| – latest date by which the national standards conflicting with the EN have to be withdrawn | (dow) | 2013-07-01 |

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61400-24:2010 was approved by CENELEC as a European Standard without any modification.

Annex ZA (normative)

Normative references to international publications with their corresponding European publications

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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
-	-	Power installations exceeding 1 kV a.c.	HD 637 S1 + corr. June	1999 2005
-	-	Lightning Protection Components (LPC) - Part 1: Requirements for connection components	EN 50164-1	-
IEC 60060-1	1989	High-voltage test techniques - Part 1: General definitions and test requirements	HD 588.1 S1	1991
IEC 60068	Series	Environmental testing	EN 60068	Series
IEC 60071	Series	Insulation co-ordination	EN 60071	Series
IEC 60071-2	1996	Insulation co-ordination - Part 2: Application guide	EN 60071-2	1997
IEC 60099-4	-	Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems	EN 60099-4	-
IEC 60099-5	-	Surge arresters - Part 5: Selection and application recommendations	EN 60099-5	-
IEC 60204-1	-	Safety of machinery - Electrical equipment of machines - Part 1: General requirements	EN 60204-1	-
IEC 60204-11	-	Safety of machinery - Electrical equipment of machines - Part 11: Requirements for HV equipment for voltages above 1 000 V a.c. or 1 500 V d.c. and not exceeding 36 kV	EN 60204-11	-
IEC 60243-1	-	Electrical strength of insulating materials - Test methods - Part 1: Tests at power frequencies	EN 60243-1	-
IEC 60243-3	-	Electrical strength of insulating materials - Test methods - Part 3: Additional requirements for 1,2/50 µs impulse tests	EN 60243-3	-
IEC 60364-4-44	-	Low voltage electrical installations - Part 4-44: Protection for safety - Protection against voltage disturbances and electromagnetic disturbances	HD 60364-4-444	-

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60364-5-53 + A1 (mod)	2001 2002	Electrical installations of buildings - Part 5-53: Selection and erection of electrical equipment - Isolation, switching and control	-	-
IEC 60464-2	-	Varnishes used for electrical insulation - Part 2: Methods of test	EN 60464-2	-
IEC/TS 60479-1	-	Effects of current on human beings and livestock - Part 1: General aspects	-	-
IEC/TR 60479-4	-	Effects of current on human beings and livestock - Part 4: Effects of lightning strokes on human beings and livestock	-	-
IEC 60587	-	Electrical insulating materials used under severe ambient conditions - Test methods for evaluating resistance to tracking and erosion	EN 60587	-
IEC 60664-1	-	Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests	EN 60664-1	-
IEC 61000-4-5	-	Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test	EN 61000-4-5	-
IEC/TR 61000-5-2	-	Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 2: Earthing and cabling	-	-
IEC/TS 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	-	-
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	EN 61643-21	-
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 62153-4-3	-	Metallic communication cable test methods - Part 4-3: Electromagnetic Compatibility (EMC) - Surface transfer impedance - Triaxial method	-	-
IEC 62305-1	2006	Protection against lightning - Part 1: General principles	EN 62305-1 + corr. November	2006 2006
IEC 62305-2	2006	Protection against lightning - Part 2: Risk management	EN 62305-2 + corr. November	2006 2006

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>N/HD</u>	<u>Year</u>	<u>Y</u>	<u>E</u>
IEC 62305-3 (mod)	2006	Protection against lightning -	EN 62305-3	2006		
-	-	Part 3: Physical damage to structures and life hazard	+ corr. September 2008 + corr. November 2006 + A11	2008 2006 2009		
IEC 62305-4	2006	Protection against lightning -	EN 62305-4	2006		
		Part 4: Electrical and electronic systems within structures	+ corr. November 2006	2006		
ITU-T Recommendation K.20	-	Resistibility of telecommunication equipment installed in a telecommunications centre to overvoltages and overcurrents	-	-		
ITU-T Recommendation K.21	-	Resistibility of telecommunication equipment installed in customer premises to overvoltages and overcurrents	-	-		
ITU-T Recommendation K46	-	Protection of telecommunication lines using metallic symmetric conductors against lightning-induced surges	-	-		

CONTENTS

FOREWORD	8
1 Scope	10
2 Normative references	10
3 Terms and definitions	12
4 Symbols and units	18
5 Abbreviations	20
6 Lightning environment for wind turbine	20
6.1 General	20
6.2 Lightning current parameters and lightning protection levels (LPL)	20
7 Lightning exposure assessment	22
7.1 General	22
7.2 Assessing the frequency of lightning affecting a wind turbine	23
7.3 Assessing the risk of damage	26
7.3.1 Basic equation	26
7.3.2 Assessment of risk components due to flashes to the wind turbine (S1)	27
7.3.3 Assessment of the risk component due to flashes near the wind turbine (S2)	27
7.3.4 Assessment of risk components due to flashes to a service line connected to the wind turbine (S3)	27
7.3.5 Assessment of risk component due to flashes near a service line connected to the wind turbine (S4)	28
8 Lightning protection of subcomponents	29
8.1 General	29
8.2 Blades	29
8.2.1 General	29
8.2.2 Requirements	29
8.2.3 Verification	29
8.2.4 Protection design considerations	30
8.2.5 Test methods	32
8.3 Nacelle and other structural components	32
8.3.1 General	32
8.3.2 Hub	33
8.3.3 Spinner	33
8.3.4 Nacelle	33
8.3.5 Tower	34
8.3.6 Testing methods	34
8.4 Mechanical drive train and yaw system	34
8.4.1 General	34
8.4.2 Bearings	35
8.4.3 Hydraulic systems	35
8.4.4 Spark gaps and sliding contacts	35
8.4.5 Testing	35
8.5 Electrical low-voltage systems and electronic systems and installations	36
8.5.1 General	36
8.5.2 LEMP protection measures (LPMS)	36
8.5.3 Lightning protection zones (LPZ)	37

8.5.4	Equipotential bonding within the wind turbine	37
8.5.5	Shielding and line routing	37
8.5.6	Coordinated SPD protection	38
8.5.7	Testing methods for system immunity tests	41
8.6	Electrical high-voltage (HV) power systems	41
9	Earthing of wind turbines and wind farms	43
9.1	General	43
9.1.1	Basic requirements	43
9.1.2	Earth electrode arrangements	43
9.1.3	Earthing system impedance	44
9.2	Equipotential bonding	44
9.2.1	General	44
9.2.2	Lightning equipotential bonding for metal installations	44
9.2.3	Electrically insulated LPS	45
9.3	Structural components	45
9.3.1	General	45
9.3.2	Metal tubular type tower	45
9.3.3	Metal reinforced concrete towers	45
9.3.4	Lattice tower	46
9.3.5	Systems inside the tower	46
9.3.6	Concrete foundation	46
9.3.7	Rocky area foundation	47
9.3.8	Metal mono-pile foundation	47
9.3.9	Offshore foundation	47
9.4	Electrode shape dimensions	47
9.5	Wind farms	48
9.6	Execution and maintenance of the earthing system	48
10	Personal safety	49
11	Documentation of lightning protection system	50
11.1	General	50
11.2	Documentation necessary during assessment for design evaluation	50
11.2.1	General documentation	50
11.2.2	Documentation for rotor blades	51
11.2.3	Documentation of mechanical systems	51
11.2.4	Documentation of electrical and electronic systems	51
11.2.5	Documentation of earthing and bonding systems	51
11.2.6	Documentation of nacelle cover, hub and tower lightning protection systems	51
11.3	Site specific information	52
11.4	Documentation to be provided for LPS inspections	52
11.4.1	Visual LPS inspection report	52
11.4.2	Complete LPS inspection report	52
11.5	Manuals	52
12	Inspection of lightning protection system	52
12.1	Scope of inspection	52
12.2	Order of inspections	53
12.2.1	General	53
12.2.2	Inspection during production of the wind turbine	53
12.2.3	Inspection during installation of the wind turbine	53

12.2.4 Inspection during commissioning of the wind turbine and periodic inspection.....	53
12.2.5 Inspection after dismantling or repair of main parts.....	54
12.3 Maintenance.....	54
Annex A (informative) The lightning phenomenon in relation to wind turbines	55
Annex B (informative) Lightning exposure assessment	66
Annex C (informative) Protection methods for blades	84
Annex D (informative) Test specifications	96
Annex E (informative) Application of lightning protection zones (LPZ) concept at a wind turbine	119
Annex F (informative) Selection and installation of a coordinated SPD protection in wind turbines	124
Annex G (informative) Additional information on bonding and shielding and installation technique.....	128
Annex H (informative) Testing methods for system level immunity tests.....	133
Annex I (informative) Earth termination system	135
Annex J (informative) Example of defined measuring points.....	143
Annex K (informative) Typical lightning damage questionnaire	145
Annex L (informative) Monitoring systems.....	148
Annex M (informative) Guidelines for small wind turbines – Microgeneration.....	149
Bibliography.....	150
Figure 1 – Collection area of the wind turbine	24
Figure 2 – Effective height, H , of wind turbine exposed on a hill.....	24
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	26
Figure 4a – Squirrel cage induction generator (SCIG)	42
Figure 4b – Wound rotor induction generator (WRIG).....	42
Figure 4 – Examples of placement of HV arresters in two typical main electrical circuits of wind turbines	42
Figure A.1 – Processes involved in the formation of a cloud-to-ground flash	57
Figure A.2 – Typical profile of a negative cloud-to-ground flash (not to scale).....	58
Figure A.3 – Definitions of short stroke parameters (typically $T_2 < 2$ ms).....	58
Figure A.4 – Definitions of long stroke parameters (typically 2 ms $< T_{long} < 1$ s) (Figure A.2 in IEC 62305-1)	59
Figure A.5 – Possible components of downward flashes (typical in flat territory and to lower structures) (Figure A.3 in IEC 62305-1)	60
Figure A.6 – Typical profile of a positive cloud-to-ground flash	60
Figure A.7 – Typical profile of a negative upward initiated flash	61
Figure A.8 – Possible components of upward flashes (typical to exposed and/or higher structures) (Figure A.4 in IEC 62305-1).....	63
Figure C.1 – Types of wind turbine blades	85
Figure C.2 – Lightning protection concepts for large modern wind turbine blades	87
Figure C.3 – Lightning induced voltages between lightning conductor or structure and sensor wiring	90
Figure D.1 – Initial leader attachment test setup A (specimen should be tested in several positions representing different directions of the approaching leader).....	99

Figure D.2 – Possible orientations for the initial leader attachment test setup A.....	100
Figure D.3 – Leader connection point must be away from test specimen.....	101
Figure D.4 – Initial leader attachment test setup B.....	102
Figure D.5 – Arrangement for local protection device (e.g. diverter) – Evaluations test setup C.....	103
Figure D.6 – Typical switching impulse voltage rise to flashover (100 µs per division)	104
Figure D.7 – Swept channel test arrangement.....	108
Figure D.8 – Lightning impulse voltage waveform (Figure 6 in IEC 60060-1).....	108
Figure D.9 – Lightning impulse voltage waveform showing flashover on the wave front (Figure 7 in IEC 60060-1)	109
Figure D.10 – Typical jet diverting test electrodes.....	112
Figure D.11 – High-current test arrangement for non-conductive surfaces	114
Figure D.12 – Example of an arrangement for conducted current tests	117
Figure E.1 – Rolling sphere model	120
Figure E.2 – Mesh with large mesh dimension for nacelle with GFRP cover.....	121
Figure E.3 – Mesh with small mesh dimension for nacelle with GFRP cover.....	121
Figure E.4 – Two cabinets both defined as LPZ 2 connected via the shield of a shielded cable.....	122
Figure E.5 – Example: Division of wind turbine into different lightning protection zones	123
Figure E.6 – Example of how to document LPMS division of electrical system into protection zones with indication of where circuits cross LPZ boundaries and showing the long cables running between tower base and nacelle.....	123
Figure F.1 – Point-to-point installation scheme (Figure 53E in IEC 60364-5-53).....	125
Figure F.2 – Earthing connection installation scheme (Figure A.1 in IEC 60364-5-53).....	125
Figure G.1 – Two control cabinets located on different metallic planes inside a nacelle	128
Figure G.2 – Magnetic coupling mechanism.....	129
Figure G.3 – Measuring of transfer impedance.....	131
Figure H.1 – Example circuit of a SPD discharge current test under service conditions.....	134
Figure H.2 – Example circuit of an induction test due to lightning currents	134
Figure I.1 – Minimum length (l_1) of each earth electrode according to the class of LPS (Figure 2 in IEC 62305-3)	138
Figure I.2 – Frequency dependence on the impedance to earth (adapted from Cigré WG C.4.4.02 July 2005 [49]).....	139
Figure J.1 – Example of measuring points.....	143
Figure K.1 – Blade outlines for marking locations of damage	147
Table 1 – Maximum values of lightning parameters according to LPL (Table 5 in IEC 62305-1)	21
Table 2 – Minimum values of lightning parameters and related rolling sphere radius corresponding to LPL (Table 6 in IEC 62305-1).....	22
Table 3 – Collection areas A_1 and A_i of service line depending on whether aerial or buried (corresponds to Table A.3 in IEC 62305-2).....	26
Table 4 – Parameters relevant to the assessment of risk components for wind turbine (corresponds to Table 8 in IEC 62305-2).....	28

Table 5 – Minimum dimensions of conductors connecting different bonding bars/points or connecting bonding bars/points to the earth termination system (Table 8 in IEC 62305-3)	45
Table 6 – Minimum dimensions of conductors connecting internal metal installations to the bonding bar/point (Table 9 in IEC 62305-3).....	45
Table 7 – LPS General inspection intervals.....	54
Table A.1 – Cloud-to-ground lightning current parameters (adapted from Table A.1 in IEC 62305-1)	59
Table A.2 – Upward initiated lightning current parameters	62
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 (Table D.1 in IEC 62305-1)	64
Table B.1 – Sources of damage, types of damage and types of loss according to point of strike (corresponds to Table 1 in IEC 62305-2)	67
Table B.2 – Risk in a wind turbine for each type of damage and of loss (corresponds to Table 2 in IEC 62305-2)	68
Table B.3 – Values of probability, P_A , that a lightning flash to a wind turbine will cause shock to living beings due to dangerous touch and step voltages (corresponds to Table B.1 in IEC 62305-2).....	71
Table B.4 – Values of probability, P_B , depending on the protection measures to reduce physical damage (corresponds to Table B.2 in IEC 62305-2)	71
Table B.5 – Values of probability P_{SPD} as a function of the LPL for which the SPDs are designed (Table B.3 in IEC 62305-2)	72
Table B.6 – Values of probability, P_{LD} , depending on the resistance, R_S , of the cable screen and the impulse withstand voltage, U_W , of the equipment (Table B.6 in IEC 62305-2)	73
Table B.7 – Values of probability, P_{LI} , depending on the resistance, R_S , of the cable screen and the impulse withstand voltage, U_W , of the equipment (Table B.7 in IEC 62305-2)	74
Table B.8 – Values of reduction factors r_a and r_u as a function of the type of surface of soil or floor (corresponds to Table C.2 in IEC 62305-2).....	76
Table B.9 – Values of reduction factor r_p as a function of provisions taken to reduce the consequences of fire (Table C.3 in IEC 62305-2)	76
Table B.10 – Values of reduction factor r_f as a function of risk of fire of the wind turbine (corresponds to Table C.4 in IEC 62305-2)	76
Table B.11 – Values of factor h_Z increasing the relative amount of loss in presence of a special hazard (corresponds to Table C.5 in IEC 62305-2).....	77
Table B.12 – Typical mean values of L_t , L_f and L_o (corresponds to Table C.7 in IEC 62305-2)	77
Table B.13 – Values of factor K_d as a function of the characteristics of the shielded service line (corresponds to Table D.1 in IEC 62305-2).....	79
Table B.14 – Values of factor K_p as a function of the protection measures (Table D.2 in IEC 62305-2)	79
Table B.15 – Impulse withstand voltage U_W as a function of the type of cable (Table D.3 in IEC 62305-2)	79
Table B.16 – Impulse withstand voltage U_W as a function of the type of apparatus (Table D.4 in IEC 62305-2)	79
Table B.17 – Values of probability P'_B , P'_C , P'_V and P'_W as function of the failure current I_a (Table D.5 in IEC 62305-2)	80
Table C.1 – Material, configuration and minimum nominal cross-sectional area of air-termination conductors, air-termination rods and down conductors (corresponds to Table 6 in IEC 62305-3, future edition 2')	92

Table C.2 – Physical characteristics of typical materials used in lightning protection systems (Table D.2 in IEC 62350-1)	93
Table C.3 – Temperature rise [K] for different conductors as a function of W/R (Table D.3 in IEC 62305-1)	94
Table E.1 – Definition of lightning protection zones according to IEC 62305-1	119
Table F.1 – Discharge and impulse current levels for TN systems given in IEC 60364-5-53	127
Table F.2 – Example of increased discharge and impulse current levels for TN systems	127
Table I.1 – Impulse efficiency of several ground rod arrangements relative to a 12 m vertical ground rod (100 %) (adapted from Cigré WG C.4.4.02 July 2005)	140
Table I.2 – Symbols used in Tables I.3 to I.6	140
Table I.3 – Formulae for different earthing electrode configurations	141
Table I.4 – Formulae for buried ring electrode combined with vertical rods	142
Table I.5 – Formulae for buried ring electrode combined with radial electrodes	142
Table I.6 – Formulae for buried straight horizontal electrode combined with vertical rods	142
Table J.1 – Measuring points and resistances to be recorded	144

WIND TURBINES –

Part 24: Lightning protection

1 Scope

This International Standard applies to lightning protection of wind turbine generators and wind power systems.

Normative references are made to generic standards for lightning protection, low-voltage systems and high-voltage systems for machinery and installations and electromagnetic compatibility (EMC).

This standard defines the lightning environment for wind turbines and application of the environment for risk assessment for the wind turbine. It defines requirements for protection of blades, other structural components and electrical and control systems against both direct and indirect effects of lightning. Test methods to validate compliance are recommended.

Guidance on the use of applicable lightning protection, industrial electrical and EMC standards including earthing is provided.

Guidance regarding personal safety is provided.

Guidelines for damage statistics and reporting are provided.

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 60060-1:1989, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60068 (all parts), *Environmental testing*

IEC 60071 (all parts), *Insulation Co-ordination*

IEC 60071-2:1996, *Insulation Co-ordination – Part 2: Application guide*

IEC 60099-4, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

IEC 60099-5, *Surge arresters – Part 5: Selection and application recommendations*

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

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

IEC 60243-1, *Electrical strength of insulating materials – Test methods – Part 1: Tests at power frequencies*

IEC 60243-3, *Electric strength of solid insulating materials – Test methods – Part 3: Additional requirements for 1,2/50 μ s impulse tests*

IEC 60364-4-44, *Low-voltage electrical installations – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances*

IEC 60364-5-53:2001, *Electrical installations of buildings – Part 5-53: Selection and erection of electrical equipment – Isolation, switching and control*
Amendment 1(2002)¹⁾

IEC 60464-2, *Varnishes used for electrical insulation – Part 2: Methods of test*

IEC/TS 60479-1, *Effects of current on human beings and livestock – Part 1: General aspects*

IEC 60479-4, *Effects of current on human beings and livestock – Part 4: Effects of lightning strokes on human beings and livestock*

IEC 60587, *Electrical insulating materials used under severe ambient conditions – Test methods for evaluating resistance to tracking and erosion*

IEC 60664-1, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*

IEC 61000-4-5, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC/TR 61000-5-2, *Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 2: Earthing and cabling*

IEC/TS 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*

IEC 61643-12, *Low-voltage surge protective devices – Part 12: Surge protective devices connected to low-voltage power distribution systems – Selection and application principles*

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*

IEC 62153-4-3, *Metallic communication cable test methods – Part 4-3: Electromagnetic compatibility (EMC) – Surface transfer impedance – Triaxial method*

IEC 62305-1:2006, *Protection against lightning – Part 1: General principles*

¹⁾ There exists a consolidated edition 3.1 (2002) that comprises IEC 60364-5-53 (2001) and its Amendment 1 (2002).

IEC 62305-2:2006, *Protection against lightning – Part 2: Risk management*

IEC 62305-3:2006, *Protection against lightning – Part 3: Physical damage to structures and life hazard*

IEC 62305-4:2006, *Protection against lightning – Part 4: Electrical and electronic systems within structures*

EN 50164-1, *Lightning Protection Components (LPC) – Part 1: Requirements for connection components*

CLC HD 637 S1, *Power installations exceeding 1kV A.C.*

ITU-T K.2, *Resistibility of telecommunication equipment installed in a telecommunications centre to overvoltages and overcurrents*

ITU-T K.21, *Resistibility of telecommunications equipment installed in customer premises to overvoltages and overcurrents*

ITU-T K.46, *Protection of telecommunication lines using metallic symmetric conductors against lightning-induced surges*

3 Terms and definitions

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

3.1

air-termination system

part of an external LPS using metallic elements such as rods, mesh conductors or catenary wires intended to intercept lightning flashes

3.2

average steepness of the front of short stroke current

average rate of change of current within a time interval $\Delta t = t_2 - t_1$

NOTE It is expressed by the difference $\Delta i = i(t_2) - i(t_1)$ of the values of the current at the start and at the end of this interval, divided by the time interval $\Delta t = t_2 - t_1$ (see Figure A.3).

3.3

bonding bar

bar on which metal installations, electric power lines, telecommunication lines and other cables can be bonded to an LPS

3.4

collection area

A_d

for a structure, area of ground surface which has the same annual frequency of direct lightning flashes as the structure

3.5

connecting leader

lightning leader developing from a structure as a response to an external electric field imposed either by a charged cloud overhead or by a downward leader approaching the structure

3.6

conventional earthing impedance

ratio of the peak values of the earth-termination voltage and the earth-termination current which, in general, do not occur simultaneously

3.7

coordinated SPD protection

set of SPD properly selected, coordinated and installed to reduce failures of electrical and electronic systems

NOTE Coordination of SPD protection must include the connecting circuits to provide insulation coordination of complete systems.

3.8

down-conductor system

part of an external LPS intended to conduct lightning current from the air-termination system to the earth-termination system

3.9

downward flash

lightning flash initiated by a downward leader from cloud to earth

NOTE A downward flash consists of a first short stroke, which can be followed by subsequent short strokes and may include a long stroke.

3.10

earth electrode

part or a group of parts of the earth-termination system which provides direct electrical contact with and disperses the lightning current to the earth

3.11

earth-termination system

part of an external LPS which is intended to conduct and disperse lightning current into the earth

3.12

effective height

H

for a wind turbine, the highest point the blades reach, i.e. hub height plus rotor radius

3.13

external lightning protection system

part of the LPS consisting of an air-termination system, a down-conductor system and an earth-termination system

NOTE The down conductor is often placed inside wind turbine blades.

3.14

flash charge

Q_{flash}

time integral of the lightning current for the entire lightning flash duration

3.15

foundation earth electrode

reinforcement steel of foundation or additional conductor embedded in the concrete foundation of a structure and used as an earth electrode

3.16
ground flash density

N_g

the number of lightning flashes per square kilometre per year in the region where the structure is located

3.17
internal lightning protection system

part of the LPS consisting of lightning equipotential bonding and/or electrical insulation of external LPS

NOTE Compliance with the separation distance and the reduction of the electromagnetic effects of lightning current within the structure to be protected may be considered as parts of an internal lightning protection system.

3.18
interception efficiency

probability with which the air-termination system of an LPS intercepts a lightning flash

3.19
leader connection point

place in the air gap between test object and HV electrode where positive and negative leaders meet and the discharge is initiated

3.20
LEMP protection measures system
LPMS

complete system of protection measures for internal systems against LEMP

3.21
lightning current

i

current flowing at the point of strike

3.22
lightning electromagnetic impulse
LEMP

electromagnetic effects of lightning current

NOTE It includes conducted surges as well as radiated impulse electromagnetic field effects.

3.23
lightning equipotential bonding

bonding to LPS of separated metallic parts by direct conductive connections or via surge protective devices to reduce potential differences caused by lightning current

3.24
lightning flash to a structure

lightning flash striking a structure to be protected

3.25
lightning flash to earth

electric discharge of atmospheric origin between cloud and earth consisting of one or more strokes

NOTE A negative flash lowers negative charge from the thundercloud to the earth. A positive flash results in positive charge being transferred from the thundercloud to the earth.

3.26

lightning protection level

LPL

number related to a set of lightning current parameter values relevant to the probability that the associated maximum and minimum design values will not be exceeded in naturally occurring lightning

NOTE Lightning protection level is used to design protection measures according to the relevant set of lightning current parameters.

3.27

lightning protection system

LPS

complete system used to reduce physical damage due to lightning flashes to a structure

NOTE It consists of both external and internal lightning protection systems.

3.28

lightning protection zone

LPZ

zone where the lightning electromagnetic environment is defined

NOTE The zone boundaries of an LPZ are not necessarily physical boundaries (e.g. walls, floor and ceiling).

3.29

lightning stroke

single discharge in a lightning flash to earth

3.30

long stroke

part of the lightning flash which corresponds to a continuing current

NOTE The duration time T_{long} (time from the 10 % value on the front to the 10 % value on the tail) of this continuing current is typically more than 2 ms and less than 1 s (see Figure A.4).

3.31

magnetic shield

closed, metallic, grid-like or continuous screen enveloping the structure to be protected, or part of it, used to reduce failures of electrical and electronic systems

NOTE The protection effect of a magnetic shield is achieved through attenuation of the magnetic field.

3.32

metal installations

metal items in the structure, which may form a path for lightning current, such as the nacelle bed plate, elevator guide rails and wires, ladders, platforms and interconnected reinforcing steel

3.33

multiple strokes

lightning flash consisting on average of 3 or 4 strokes

The typical time interval between the strokes is about 50 ms.

NOTE Events having up to a few dozen strokes with intervals between them ranging from 10 ms to 250 ms have been reported.

3.34

natural component of LPS

conductive component installed not specifically for lightning protection which can be used in addition to the LPS or in some cases could provide the function of one or more parts of the LPS

NOTE Examples of the use of this term include:

- natural air termination;
- natural down conductor;
- natural earthing electrode.

3.35

number of dangerous events due to flashes to a structure

N_d

expected average annual number of dangerous events due to lightning flashes to a structure

3.36

peak value

I

maximum value of the lightning current

3.37

point of strike

point where a lightning flash strikes the earth or a protruding structure (e.g. structure, LPS, service line, tree, etc.)

NOTE A lightning flash may have more than one point of strike.

3.38

receptor

a form of air termination on wind turbine blades, for example discrete metal studs through the blade surface connected to a down conductor system

3.39

risk

R

value of probable average annual loss (humans and goods) due to lightning, relative to the total value (humans and goods) of the structure to be protected

3.40

separation distance

distance between two conductive parts at which no dangerous sparking can occur

3.41

service line

power line or telecommunication line connected to the structure to be protected

3.42

short stroke

part of the lightning flash which corresponds to an impulse current

NOTE This current has a time to half value T_2 typically less than 2 ms (see Figure A.3).

3.43

SPD tested with I_{imp}

SPDs which withstand the partial lightning current with a typical waveform 10/350 μ s require a corresponding impulse test current I_{imp}

NOTE For power lines, a suitable test current I_{imp} is defined in the Class I test procedure of IEC 61643-1.

3.44

SPD tested with I_n

SPDs which withstand induced surge currents with a typical waveform 8/20 μ s require a corresponding impulse test current I_n

NOTE For power lines, a suitable test current I_n is defined in the Class II test procedure of IEC 61643-1.

3.45

specific energy

W/R

time integral of the square of the lightning current for the entire flash duration

NOTE It represents the energy dissipated by the lightning current in a unit resistance.

3.46

surge

transient wave appearing as overvoltage and/or overcurrent caused by LEMP

NOTE 1 Surges caused by LEMP can arise from (partial) lightning currents, from induction effects in installation loops and as residual surges downstream of SPD.

NOTE 2 Surges may arise from other sources such as switching operations or fuses operating.

3.47

surge protective device

SPD

device intended to limit transient overvoltages and divert surge currents

It contains at least one non-linear component.

3.48

thunderstorm days

T_d

number of thunderstorm days per year obtained from isokeraunic maps

3.49

tolerable risk R_T

maximum value of the risk which can be tolerated for the structure to be protected

3.50

upward flash

lightning flash initiated by an upward leader from an earthed structure to cloud

NOTE An upward flash consists of a first long stroke with or without multiple superimposed short strokes. One or more short strokes may be followed by a long stroke.

3.51

voltage protection level

U_P

parameter that characterises the performance of the SPD in limiting the voltage across its terminals, which is selected from a list of preferred values

This value shall be greater than the highest value of the measured limiting voltages.

4 Symbols and units

A_d	Collection area of lightning flashes to an isolated structure
A_i	Collection area of lightning flashes to a service line
A_l	Collection area of lightning flashes near a service line
A_m	Area of influence for lightning flashes near a structure
c_s	Latent heat of melting
c_t	Total value of structure in currency
c_w	Thermal capacity
C	Mean value of possible loss
C_e	Environmental factor
C_d	Location factor
C_t	Correction factor for a HV/LV transformer on the service line
D1	Injury to living beings
D2	Physical damage
D3	Failure of electrical and electronic systems
h_z	Factor increasing the loss when a special hazard is present
i	Current
I	Peak current
I_n	Nominal test current; discharge current
I_t	Current in cable shield
I_{imp}	Impulse test current
di/dt	Time derivative of current, average steepness
$di/dt_{30/90\%}$	Current steepness between points of 30 % and 90 % peak amplitude on front
L_A	Loss related to injury to living beings
L_B	Loss in a structure related to physical damage (lightning flashes to structure)
L_C	Loss related to failure of internal systems (lightning flashes to service line)
L_M	Loss related to failure of internal systems (lightning flashes near structure)
L_U	Loss related to injury of living beings (lightning flashes to service line)
L_V	Loss in a structure due to physical damage (lightning flashes to service line)
L_W	Loss related to failure of internal systems (lightning flashes to service line)
L_f	Loss due to injury due to touch and step voltage
L_o	Loss due to physical damage
L_t	Loss due to failure of internal systems
L_x	Amount of consequent loss for component x
L_Z	Loss related to failure of internal systems (lightning flashes near a service line)
L1	Loss of human life in a structure
L2	Loss of service to the public in a structure
L3	Loss of cultural heritage in a structure
L4	Loss of economic value in a structure
n_p	Number of possible endangered persons (victims)
n_t	Exposed total number of persons present in structure
N_D	Number of dangerous events due to lightning flashes to a structure per annum
N_x	Number of dangerous events for component x per annum
N_d	Number of lightning flashes to a structure per annum
N_M	Number of lightning flashes near a structure per annum
N_L	Number of lightning flashes to a service line per annum
N_l	Number of lightning flashes near a service line per annum
$N_{d,x}$	Number of lightning flashes to a structure at the "x" end of a service line per annum
N_g	Ground flash density per annum
P_A	Probability that lightning flashes to structure will cause shock to living beings
P_B	Probability that lightning flashes to a structure will cause physical damage
P_C	Probability of failure of internal systems caused by lightning flashes to the structure

P_{LD}	Probability that lightning flashes to a service line will cause failure of internal systems
P_{LI}	Probability that lightning flashes near a service line will cause failure of internal systems
P_M	Probability that lightning flashes near a structure will cause failure of internal systems
P_{SPD}	Probability failure of internal systems given that SPD protection is applied
P_U	Probability that lightning flashes to a service line will cause injury to living beings
P_V	Probability that lightning flashes to a service line will cause physical damage
P_V	Probability that lightning flashes to a service line will cause failure of internal systems
P_x	Probability of damage for a structure x
P_Z	Probability that lightning flashes near a service line will cause failure of internal systems
r_a	Reduction factor associated with the type of surface soil
r_f	Factor reducing the loss due to physical damage depending on the risk of fire
r_p	Factor reducing the loss due to physical damage depending on provisions taken
r_u	Factor reducing the loss of human life depending on type of floor
R	Risk
R	Rolling sphere radius
R_S	Cable shield resistance per unit length
R_T	Tolerable risk
R_x	Risk component x
S	Spacing between earth rods
t_p	Time in hours per annum in which persons are present in a dangerous place
t or T	Time
Δt	Time interval
t_x	Time parameter
t_{long}	Time duration of long stroke
T_d	Thunderstorm days
u_a, u_c	Anode or cathode voltage drop
U_C	Voltage between shield and wires of cable
U_W	Impulse withstand voltage
U_p	Voltage protection level
Q	Charge of the lightning current
Q_{flash}	Flash charge
Q_{short}	Short stroke charge
Q_{long}	Long stroke charge
W/R	Specific energy
Z_T	Transfer impedance
α	Temperature coefficient of the resistance (1/K)
γ	Material density
μ_0	Permeability of air (vacuum)
Φ	Magnetic flux
ρ	Resistivity
ρ_0	Specific ohmic resistance at ambient temperature
θ	Temperature
θ_0	Start temperature
θ_s	Melting temperature
θ_u	Ambient temperature
A	Ampere
kA	Kiloampere
C	Coulomb
°C	degrees Celsius
H	Henry
K	Kelvin

S	Siemens
G	Gram
kg	Kilogram
MJ	Megajoule
μm	Micrometre
mm	Millimetre
cm	Centimetre
m	Metre
km	Kilometre
ms	Millisecond
Ω	Ohm
S	Second
μs	Microsecond
V	Volt
Wb	Weber

5 Abbreviations

LPS	Lightning protection system
LPL	Lightning protection level
LPZ	Lightning protection zone
LEMP	Lightning electromagnetic impulse
LPMS	Lightning protection measures system
SEMP	Switching electromagnetic impulse
SPD	Surge protective device
PE	Protective earth
OCPD	Overcurrent protection device
QA	Quality assurance system
GFRP	Glass fibre reinforced plastic
CFRP	Carbon fibre reinforced plastic
CFC	Carbon fibre composite

6 Lightning environment for wind turbine

6.1 General

The lightning environment for wind turbines in terms of lightning current parameter values to be used for dimensioning, analysis and testing of the lightning protection systems is defined in IEC 62305-1.

An informative discussion of the lightning phenomenon in relation to wind turbines is included in Annex A.

6.2 Lightning current parameters and lightning protection levels (LPL)

In IEC 62305-1, four lightning protection levels (I to IV) are introduced. For each LPL, a set of maximum and minimum lightning current parameters is fixed.

The maximum values of lightning current parameters relevant to LPL I will not be exceeded with a probability of 99 %. The maximum values of lightning current parameters relevant to LPL I are reduced to 75 % for LPL II and to 50 % for LPL III and IV (linear for I , Q and di/dt , but quadratic for W/R). The time parameters are unchanged.

**Table 1 – Maximum values of lightning parameters according to LPL
(Table 5 in IEC 62305-1)**

First short positive stroke			LPL			
Current parameters	Symbol	Unit	I	II	III	IV
Peak current	I	kA	200	150	100	
Short stroke charge	Q_{short}	C	100	75	50	
Specific energy	W/R	MJ/Ω	10	5,6	2,5	
Time parameters	T_1 / T_2	μs / μs	10/350			
First short negative stroke ^a			LPL			
Peak current	I	kA	100	75	50	
Average steepness	di/dt	kA/μs	100	75	50	
Time parameters	T_1 / T_2	μs / μs	1/200			
Subsequent short stroke ^a			LPL			
Current parameters	Symbol	Unit	I	II	III	IV
Peak current	I	kA	50	37,5	25	
Average steepness	di/dt	kA/μs	200	150	100	
Time parameters	T_1 / T_2	μs / μs	0,25 / 100			
Long stroke			LPL			
Current parameters	Symbol	Unit	I	II	III	IV
Long stroke charge	Q_{long}	C	200	150	100	
Time parameter	T_{long}	s	0,5			
Flash			LPL			
Current parameters	Symbol	Unit	I	II	III	IV
Flash charge	Q_{flash}	C	300	225	150	

^a The use of this wave shape concerns only calculations and not testing.

^a The use of this wave shape concerns only calculations and not testing.

The maximum values of lightning current parameters for the different lightning protection levels are given in Table 1 and are used to design lightning protection components (e.g. cross section of conductors, thickness of metal sheets, current loading capability of SPDs, separation against dangerous sparking) and to define test parameters simulating the effects of lightning on such components (see Annex D and IEC 62305-1).

NOTE For wind turbines placed in certain geographical areas where they are exposed to high numbers of upward lightning particularly during winter, it may be relevant to increase the required durability of air termination systems (e.g. receptors) with regard to flash charge to more than lightning protection level I, $Q_{\text{flash}} = 300$ C, as this parameter decides the wear (melting) of materials and therefore influences the need for maintenance of air termination systems.

The minimum values of lightning current amplitude for the different LPLs are used to derive the rolling sphere radius in order to define the lightning protection zone LPZ O_B , which is not exposed to lightning attachment. The minimum values of lightning current parameters together with the related rolling sphere radius are given in Table 2. They are used for positioning of the air termination system and to define the lightning protection zone LPZ O_B .

Table 2 – Minimum values of lightning parameters and related rolling sphere radius corresponding to LPL (Table 6 in IEC 62305-1)

Interception criteria			LPL			
	Symbol	Unit	I	II	III	IV
Minimum peak current	I	kA	3	5	10	16
Rolling sphere radius	r	m	20	30	45	60

7 Lightning exposure assessment

7.1 General

Wind turbines are tall structures and are often placed in such a way that they are very exposed to lightning. It has long been recognised that wind turbines generally need to be protected against lightning as a precaution against economical losses due to damage and loss of revenue, as protection against hazards to living beings (primarily service personnel) and as a means to reduce the maintenance required.

The design of any lightning protection system should take into account the risk of lightning flashes striking and/or damaging the structure in question. Lightning damage to an unprotected wind turbine can take the form of damage to the blades, to the mechanical parts and to the electrical and control systems. Furthermore, people in and around wind turbines are exposed to hazards from step/touch voltages or explosions and fires caused by a lightning flash.

The goal of any lightning protection system is to reduce the hazards to a tolerable level R_T . The tolerable level is based on an acceptable risk if human safety is involved. If the risk is below the level acceptable for humans then the need for further protection may be based on a purely economic analysis, which is done by assessing the cost of the lightning protection system against the cost of the damage it will prevent.

It is the responsibility of the authority having jurisdiction to identify the value of tolerable risk. A representative value of tolerable risk R_T , where lightning flashes involve loss of human life or permanent injuries is $10^{-5} \text{ year}^{-1}$.

NOTE Values for tolerable risk are given in IEC 62305-2, Table 7.

The risk of lightning flashes attaching to any structure is a function of structure height, the local topography and the local level of lightning activity. Risks associated with lightning can be assessed in detail in accordance with IEC 62305-2. However, as the procedures described therein are quite elaborate, guidance is given here on how to make a simple lightning exposure assessment for individual wind turbines, and how to extend it to groups of wind turbines and wind farms.

Information about local lightning conditions should be collected whenever possible (for example at high latitudes where winter lightning may pose a special threat).

As a word of caution, it should be mentioned that such a risk assessment will never be more accurate than the information entered into the calculation, and furthermore, because the assessment is probabilistic, because lightning occurrence information is statistical averages, and because the lightning event in itself is stochastic in nature, the user should not expect very accurate short-term prediction of the number of lightning events for individual wind turbines or wind farms. However, a risk assessment does make it possible to evaluate the risk reduction achieved by applying lightning protection and will allow for example for comparison of risks for different wind turbine projects. Further details are provided in Annex B.

7.2 Assessing the frequency of lightning affecting a wind turbine

The first stage in the lightning risk analysis is the estimation of the frequency of lightning flashes to the wind turbine. IEC 62305-2 gives guidance on how this number can be estimated. When assessing the frequency of lightning flashes to a structure, the collection of data detailing the local ground flash density (N_g) is necessary. National organisations such as weather bureaus are likely to be able to provide this information. If the ground flash density is not available, it may be estimated using the following relationship:

$$N_g \approx 0,1 \cdot T_d \quad (1)$$

where

N_g [$\text{km}^{-2} \cdot \text{year}^{-1}$] is the annual average ground flash density;
 T_d [year^{-1}] is the number of thunder storm days per year obtained from isokeraunic maps (typically available from the national weather bureau).

The average annual number of dangerous events that may endanger a wind turbine may be separated into:

N_D [year^{-1}] due to lightning flashes to the wind turbine;
 N_M [year^{-1}] due to lightning flashes near the wind turbine (within 250 m);
 N_L [year^{-1}] due to lightning flashes to the service lines connecting the wind turbine, i.e. the power cable and the communication cable connecting the wind turbine;
 N_I [year^{-1}] due to lightning flashes near the service lines connecting the wind turbine, i.e. the power cable and the communication cable connecting the wind turbine;
 $N_{D,b}$ [year^{-1}] due to lightning flashes to a wind turbine or another structure at the (other) "b" end of the service lines connecting the wind turbine in question.

The average annual frequency of lightning flashes attaching to the wind turbine can be assessed as:

$$N_D = N_g \cdot A_d \cdot C_d \cdot 10^{-6} \quad (2)$$

where

A_d [m^2] is the collection area of lightning flashes to the structure;
 C_d is the environmental factor.

Appropriate values are $C_d = 1$ for wind turbines on flat land and $C_d = 2$ for wind turbines on a hill or a mountain ridge.

NOTE 1 Wind turbines placed at locations known to be very exposed to lightning in general or to winter lightning in particular may be assigned a higher environmental factor C_d to consider upward lightning being triggered under such conditions.

NOTE 2 Wind turbines placed off shore may have to be assigned an environmental factor C_d of 3 to 5 to get a realistic estimate of the frequency of lightning attachment.

The collection area of a structure is defined as an area of ground surface which has the same annual frequency of lightning ground flashes as the structure. For isolated structures, the equivalent collection area is the area enclosed with a border line obtained from the intersection between the ground surface and a straight line with a 1:3 slope which passes from the upper parts of the structure (touching it there) and rotating around it.

It is recommended that all wind turbines are modelled as a tall mast with a height equal to the hub height plus one rotor radius. This is recommended for wind turbines with any type of blades including blades made solely from non-conductive material such as glass-fibre reinforced plastic.

Figure 1 shows the collection area produced by a wind turbine placed on flat ground. Clearly this is a circle with a radius of three times the turbine height.

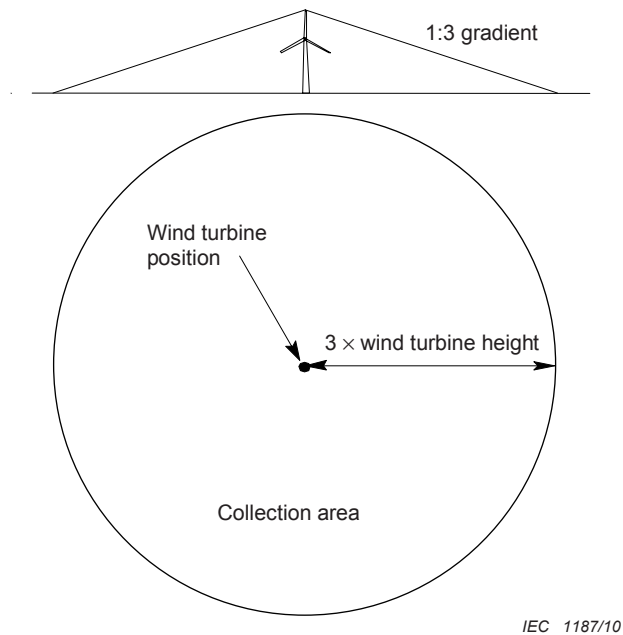


Figure 1 – Collection area of the wind turbine

The following equation can therefore be used when estimating the annual number of lightning flashes to a wind turbine placed on flat ground.

$$N_d = N_g \cdot A_d \cdot 10^{-6} = N_g \cdot 9\pi \cdot H^2 \cdot 10^{-6} \quad (3)$$

where

H [m] is the height of the wind turbine.

In more complex terrain, it is appropriate to consider the effective height of the wind turbine including the height of the wind turbine position, e.g. if placed exposed on hills or ridges (see Figure 2). IEC 62305-2 provides guidance for structures in complex terrain or in proximity to other structures.

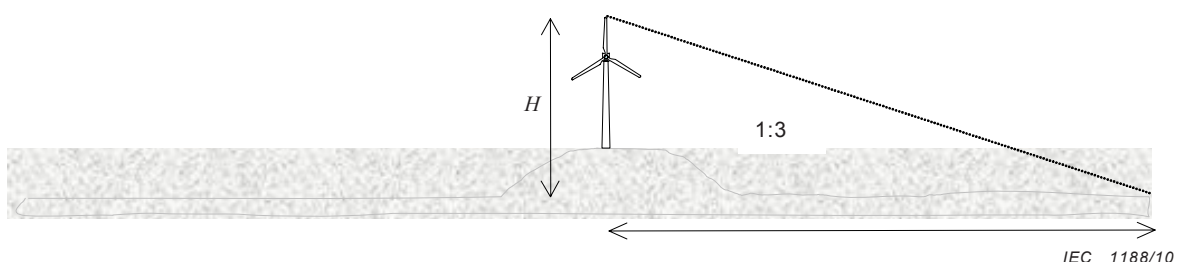


Figure 2 – Effective height, H , of wind turbine exposed on a hill

Furthermore, wind turbines may be endangered by lightning flashes near the wind turbine:

$$N_M = N_g \cdot (A_m - A_d C_d) \cdot 10^{-6} \quad (4)$$

where

A_m [m²] is the collection area for lightning flashes near the structure which is the area within a distance of 250 m.

When proper lightning protection is applied to a wind turbine and the service lines connecting it, it may be assumed that the protection also includes protection against damage to the wind turbine due to lightning flashes near the wind turbine and due to lightning flashes near service lines connecting the wind turbine.

Large wind turbines are usually connected to a high-voltage power cable collection system and also usually connected to an external control centre via a communication line, both these service lines may be affected by lightning flashes to the service line or near to it (see Figure 3). In case the communication line is an optical fibre connection (which is recommended), the risk of lightning damaging the communication line may be neglected.

The number of lightning flashes to a service line connecting a wind turbine can be assessed according to IEC 62305-2, Annex A as:

$$N_L = C_d \cdot C_t \cdot N_g \cdot A_l \cdot 10^{-6} \quad (5)$$

And the number of lightning flashes near a service line (i.e. close enough to affect the line) can be assessed as:

$$N_I = C_e \cdot C_t \cdot N_g \cdot A_i \cdot 10^{-6} \quad (6)$$

where

C_d is a location factor: say 1 in flat areas and 2 in hilly terrain;

C_e is an environmental factor, which is 1 for rural areas;

C_t is a transformer factor;

A_l [m²] is the collection area of lightning flashes to the service line – see Table 3;

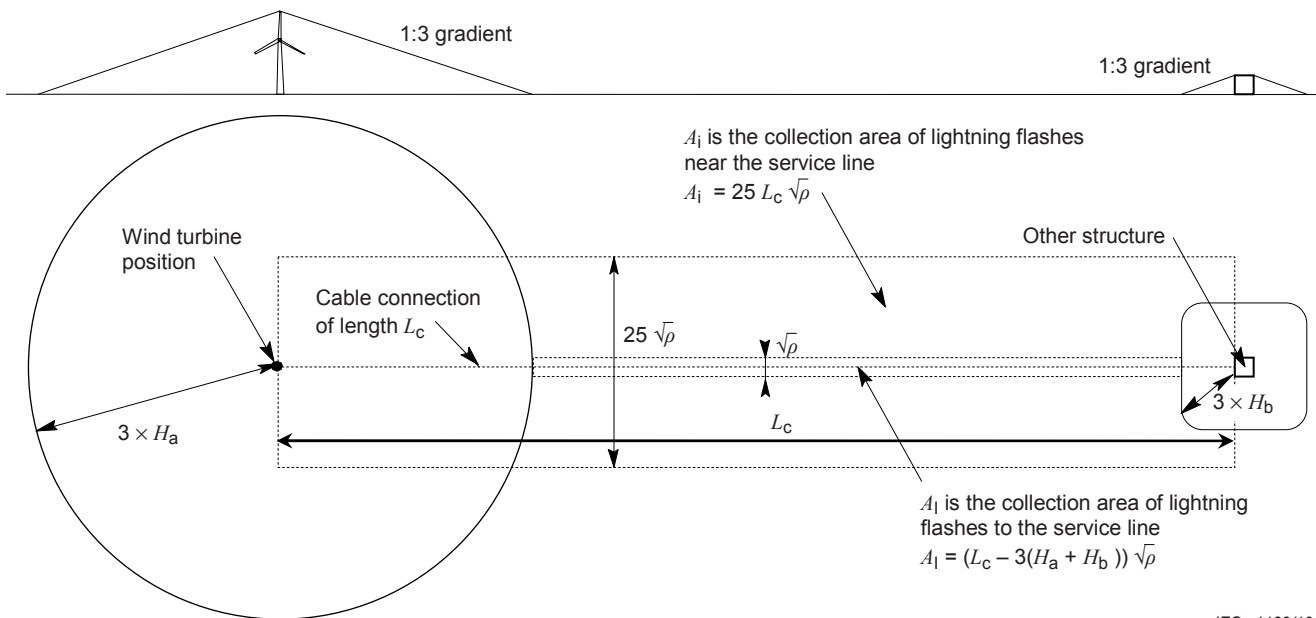
A_i [m²] is the collection area of lightning flashes near the service line – see Table 3.

The transformer factor $C_t = 1$ if there is no transformer between the point of lightning attachment and the wind turbine, and $C_t = 0,2$ if there is. As there is usually a high-voltage transformer in large wind turbines, $C_t = 0,2$ can be assumed for the medium-voltage cables connecting the wind turbine to the grid (see IEC 62305-2, Annex A).

NOTE 3 $C_d=0$ for submarine service lines (submarine high-voltage cables and communication cables).

Table 3 – Collection areas A_i and A_l of service line depending on whether aerial or buried (corresponds to Table A.3 in IEC 62305-2)

	Aerial	Buried
A_l	$(L_c - 3(H_a + H_b)) \sqrt{\rho}$	$(L_c - 3(H_a + H_b)) \sqrt{\rho}$
A_i	$1\,000 L_c$	$25 L_c \sqrt{\rho}$
L_c [m]	is the length of the service line from the wind turbine to the next structure on the line. A maximum value $L_c = 1\,000$ m should be assumed.	
H_a [m]	is the height of the wind turbine connected at the "a" end of the service line.	
H_b [m]	is the height of the wind turbine (or other structure) connected at the "b" end of the service line.	
H_c [m]	is the height of the service line conductors above ground.	
ρ [Ω m]	is the resistivity of the soil where the service line is buried. A maximum value $\rho = 500$ Ω m should be assumed.	



IEC 1189/10

Lightning flashes inside the narrow area A_l along the cable route may penetrate to and affect the cable directly, while lightning flashes inside the wider area A_i may induce transients and cause pin-hole punctures of the cable insulation.

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

NOTE In wind farms, the collection areas of neighbouring wind turbines may often overlap. In such cases, the collection areas should simply be divided between the turbines where the 1:3 gradient lines from the top of the wind turbines intersect.

7.3 Assessing the risk of damage

7.3.1 Basic equation

The risk of lightning causing damage to a wind turbine installation and thereby financial losses can be considered as the sum of many risk components. Each risk component may be expressed by the following general equation

$$R_X = N_X \cdot P_X \cdot L_X \quad (7)$$

where

- N_X [year⁻¹] is the number of dangerous events per annum;
 P_X is the probability of damage to the structure (a function of various protection measures);
 L_X is the consequent loss.

This basic equation is to be used for assessing the risk of damage based on the probability of damage of various types and the consequent loss (see Annex B).

In case the risk is found to be too high, protection measures have to be applied as necessary to reduce the risk to less than the tolerable risk R_T .

$$R_X \leq R_T \quad (8)$$

NOTE The tolerable risk R_T may be stipulated by authorities.

7.3.2 Assessment of risk components due to flashes to the wind turbine (S1)

For evaluation of risk components related to lightning flashes to the wind turbine, the following relationship apply:

- component related to injury to living beings (D1)

$$R_A = N_D \cdot P_A \cdot L_A \quad (9)$$

- component related to physical damage (D2)

$$R_B = N_D \cdot P_B \cdot L_B \quad (10)$$

- component related to failure of internal systems (D3)

$$R_C = N_D \cdot P_C \cdot L_C \quad (11)$$

Parameters to assess these risk components are given in Table 4.

7.3.3 Assessment of the risk component due to flashes near the wind turbine (S2)

For evaluation of the risk component related to lightning flashes near the wind turbine, the following relationship applies:

- component related to injury to failure of internal systems (D3)

$$R_M = N_M \cdot P_M \cdot L_M \quad (12)$$

Parameters to assess these risk components are given in Table 4.

7.3.4 Assessment of risk components due to flashes to a service line connected to the wind turbine (S3)

For evaluation of risk components related to lightning flashes to an incoming service line connected to the wind turbine, the following relationship apply:

- component related to injury to living beings (D1)

$$R_U = (N_L + N_{D,b}) \cdot P_U \cdot L_U$$

- component related to physical damage (D2)

$$R_V = (N_L + N_{D,b}) \cdot P_V \cdot L_V \quad (14)$$

- component related to failure of internal systems (D3)

$$R_W = (N_L + N_{D,b}) \cdot P_W \cdot L_W \quad (15)$$

Parameters to assess these risk components are given in Table 4.

7.3.5 Assessment of risk component due to flashes near a service line connected to the wind turbine (S4)

For evaluation of the risk component related to lightning flashes near a service line connected to the wind turbine, the following relationship apply:

- component related to failure of internal systems (D3)

$$R_Z = (N_I - N_L) \cdot P_Z \cdot L_Z \quad (16)$$

For the purpose of this assessment, if $(N_I - N_L) < 0$, then assume $(N_I - N_L) = 0$.

Parameters to assess these risk components are given in Table 4.

Table 4 – Parameters relevant to the assessment of risk components for wind turbine (corresponds to Table 8 in IEC 62305-2)

	Average annual number of dangerous events due to flashes
N_D [year ⁻¹]	to the wind turbine
N_M [year ⁻¹]	near the wind turbine
N_L [year ⁻¹]	to a service line entering the wind turbine
N_I [year ⁻¹]	near a service line entering the wind turbine
$N_{D,b}$ [year ⁻¹]	to a structure at the "b" end of a service line (see Figure 3)
	Probability that a flash to the wind turbine will cause
P_A	shock to living beings
P_B	physical damage
P_C	failure of internal systems
	Probability that a flash near the wind turbine will cause
P_M	failure of internal systems
	Probability that a flash to a service line will cause
P_U	injury to living beings
P_V	physical damage
P_W	failure of internal systems
	Probability that a flash near a service line will cause
P_Z	failure of internal systems
	Loss due to
$L_A = L_U = r_a \cdot L_t$	injury to living beings
$L_B = L_V = r_p \cdot r_f \cdot h_z \cdot L_f$	physical damage
$L_C = L_M = L_W = L_Z = L_o$	failure of internal systems
NOTE Values of loss L_t ; L_f ; L_o ; factors r_p , r_a , r_u , r_f reducing the loss and factor h_z increasing the loss are given in Annex B.	

8 Lightning protection of subcomponents

8.1 General

Unless otherwise shown by risk analysis, all subcomponents should be protected according to LPL-I.

Lifetime compliance with a certain LPL may require maintenance and inspections which may be site specific. Maintenance and inspection requirements for the lightning protection system including the earthing system should be described in the service and maintenance manuals. Maintenance and inspection procedures are outlined in Clause 12.

NOTE A detailed risk assessment may reveal that a protection level less than LPL-I is economically optimal for some wind turbines or wind farms, just as it may be advantageous to differentiate so that for example wind turbine blades are protected to a higher LPL while other parts repairable or replaceable at less costs may be protected to a lower LPL.

8.2 Blades

8.2.1 General

Wind turbine blades are the most exposed parts of the turbine, and would experience the full impact from the electric fields as associated with the lightning attachment process, the lightning currents, and the magnetic field associated with lightning currents. The formal explanation of the attachment process and the following current/charge conduction is described in Annex A.

Wind turbine blades are placed in lightning protection zone O_A according to IEC 62305-1 and shall be protected accordingly.

A general description of the different issues concerning lightning protection of blades is included in Annex C.

8.2.2 Requirements

The lightning protection shall be sufficient to enable the blade to accept LPL I lightning flashes (unless a risk analysis shows that LPL-II or LPL-III is sufficient) without structural damage that would impair the functioning of the blade.

Lightning damage shall be limited to that which can be tolerated until the next scheduled maintenance and inspection.

8.2.3 Verification

The ability of the air-termination system and down-conductor system to intercept lightning flashes and conduct lightning currents shall be verified by one of the following methods:

- a) high-voltage and high-current tests in accordance with 8.2.5;
- b) demonstration of similarity of the blade type (design) with a previously verified blade type, or a blade type with documented successful lightning protection;
- c) using analysis tools previously verified by comparison with test results or with blade protection designs that have had successful service experience.

To claim verification by similarity, the blades must exhibit the same material composition, the same system of lightning protection and have the same structural characteristic dimensions. Significant changes which would affect lightning susceptibility should not be allowed without verification. However, assessments that would be identical to those performed on a previously verified blade design would not have to be repeated.

The blade manufacturer shall produce documentation that describes which of the above methods are used and the results of the verification.

8.2.4 Protection design considerations

The following subclauses describe the issues which are important for design and incorporation of the lightning protection systems associated with the blade.

8.2.4.1 Air-termination system

The lightning air-termination systems are placed in the surface areas on the blade where connection leaders might originate and cause lightning flash attachments or punctures if no air terminations are present. The air-termination systems may be part of the blade structure itself, components added to the blade, or combinations thereof.

The air-termination system positioning tools (rolling sphere, protective angle, etc.) described in IEC 62305-3 do not apply to wind turbine blades. Therefore, the air-termination system design shall be verified according to 8.2.3.

The manufacturer shall ensure that the air termination system is properly fixed in its mountings, and he shall design the air termination system so that it can withstand the expected wear due to wind, moisture, particles, etc. As part of such verification, the lightning protection components shall be present in the final blade design, preceding fatigue tests and other mechanical tests.

All internal parts of the air-termination system, the mounting of the air terminations and the connections to the down conductor shall be designed to minimise the risk of getting internal discharges (i.e. streamers and leaders) forming from these parts.

The manufacturer shall design the air-termination system so that service personnel can repair or replace parts of it that may be damaged or degraded by lightning or other environmental effects. The air terminations will wear over time due to erosion at lightning arc roots. The erosion is related to the charge entering at the lightning arc root(s) and the surface material and geometry of the air termination system. Blades that receive large numbers of lightning flashes may eventually require replacement of the air terminations. The lifetime of the air termination system should be maximised through suitable selection of material and design. The manufacturer shall provide guidance on how to inspect and maintain the air-termination system.

If the air-termination system is covered by, for example, a coating, the function and the reparability over the lifetime of the blade must be maintained. Recommended tests for determining the effectiveness of air terminations are described in Annex D.

The manufacturer shall define a procedure for regular inspection of the air-termination systems so that the estimated design life-time and service/replacement intervals can be established and verified.

Verification of the air-termination system efficiency shall be done as described in 8.2.3.

8.2.4.2 The down conductor system and its connection components

The down conductor system and its connection components is the system for conducting the lightning current from the air-termination system to the termination in the root end of the blade.

The connections to the down conductor system shall be firm and permanent and ensure that the entire system can withstand the combined impact of the electrical, thermal, and electrodynamic effects of the lightning current. The ability of the lightning protection systems

to withstand the mechanical stresses in the blades shall be verified, preferably by installing the system in a blade which is subjected to the tests in IEC/TS 61400-23.

The cross section of the down conductor and natural conductive parts of the blade used as down conductor shall be able to conduct lightning current corresponding to the chosen LPL. Metal conductors shall in general be selected according to IEC 62305-3.

Testing of connection components shall be done in accordance with EN 50164-1 without the conditioning/aging applied. The current test levels should be selected according to the first short stroke of the selected LPL. If non-rigid connections are used, such as rotating links, bearings or spark gaps, then testing should be done with the long stroke current as well. If several paths for the lightning current exist, the test current amplitudes for each path may be scaled according to the distribution of the current between the paths.

All internal parts of the down conductor system and connection components shall be designed to minimise the risk of internal discharges forming from these parts. This aims at impeding the development of electrical discharges from structures elsewhere than the external air termination system; whereby the risk of such internal discharges puncturing the blade skin is limited.

Externally mounted down conductors are defined as air-termination systems, hence the requirements in 8.2.4.1 apply.

The manufacturer shall define a procedure for regular inspection of any parts of the down conductor system and its connection components that may be degraded by service environments so that the condition and estimated design life time and service intervals of these parts can be verified.

Recommended tests for determining the capability of down conductors and connection components are described in Annex D.

Verification of the down conductor system and its connection components shall be done as described in 8.2.3.

8.2.4.3 Additional conductive components

In case additional conductive components (conductive structural components, CFC, weights, tip brake cables, electrical cables for sensors, warning lights, etc.) are present within the blade, these parts shall in general be bonded to the lightning protection system, be designed to conduct their share(s) of lightning current and be designed to prevent flashover between conductive parts.

Alternatively, it shall be documented by testing corresponding to the LPL and/or analysis whether additional conductive components, CFC structures etc. shall be bonded together and to the lightning protection system or not.

Bonding methods for these additional conductive components shall be proven by high-current testing as described in 8.2.5.2.

In case conductors form parallel current paths within the blade, such conductors shall be interconnected according to IEC 62305-1, and attention must be paid to the effects of electrodynamic forces.

8.2.4.4 Electrical field stress impact on composite material design

Due to the elevation and exposure of wind turbine blades, the entire structure of the blade will be exposed to high electric fields many times during its service life. High static and transient electric fields are produced by thunder clouds and electrically applied to the blade structure.

Approaching lightning leaders expose the blade structure to higher electric fields. In both cases, the electric fields may over time degrade the insulating properties of composite materials. Therefore, the lightning protection systems should be designed considering high voltage insulation design principles.

8.2.5 Test methods

The following test methods apply to entire blade designs or sub-sections such as blade tips or laminate coupons.

8.2.5.1 High-voltage tests

Interception effectiveness of the air termination systems on the blade can be evaluated using the initial leader attachment test described in Annex D, Subclause D.2.1.

Development of specific design details surrounding tip receptors, side receptors or similar can gain from the initial leader attachment test described in Annex D, Subclause D.2.1.

Improvement of the ability of the blade laminate to impede internal discharges and prevent them from puncturing the blade skin can be achieved by increasing the electrical breakdown field strength of the materials. The breakdown field strength of insulating composites and coating layers can be evaluated according to IEC 60060-1, IEC 60243-1 (a.c.), IEC 60243-3 (impulse voltage) and IEC 60464-2 (coating).

When electrical activity occurs on insulating surfaces (streamers, surface flashovers, etc.), the surface may deteriorate experienced as tracking and electrical erosion. The impact, in connection with moisture, may change the properties of the insulating surface towards a more conductive nature, and hence increase the risk of direct lightning attachment. The resistance to tracking of various blade and coating materials can be evaluated and compared using IEC 60587.

8.2.5.2 High-current tests

The air termination systems will be largely affected by the impact of the charge in the lightning flash (i.e. the time integral of the lightning current), a phenomenon that can be evaluated by the high-current physical damage test in Annex D, Clause D.3.

Connection components and parts of the down conductor can be tested by the high-current physical damage test in Annex D, Clause D.3, or the EN 50164-1 without the conditioning/aging applied.

The current test waveforms and levels should include the first short stroke and if relevant also the long stroke (continuing current) defined for the selected LPL.

8.3 Nacelle and other structural components

8.3.1 General

Lightning protection of the nacelle and other structural components of the wind turbine should be made using the large metal structures themselves as much as possible for lightning air termination, equipotentialisation, shielding and conduction of lightning current to the earthing system. Additional lightning protection components such as air termination systems for protection of meteorological instruments and air craft warning lights on the nacelle, down conductors and bonding connections shall be made and dimensioned according to IEC 62305-3. The wind turbine should be divided into lightning protection zones, LPZ (see Annex E).

8.3.2 Hub

The hub for large wind turbines is a hollow cast iron sphere of 2 m to 3 m in diameter. Hence the material thickness alone ensures that the hub structure itself is immune to lightning. In most cases, electrical and mechanical control systems and actuators are placed in the hub with circuits going to the outside of the hub, to the blades and to the nacelle. The hub should be made into a Faraday cage by providing magnetic shields in the openings in the hub towards the blades, the front and the nacelle (i.e. the hub should be defined as a LPZ). In many cases, these openings are closed by blade flange plates and the main shaft flange, which can be considered very effective magnetic shields. When the openings are closed with magnetic shields as described above, the contents of the hub require no particular lightning protection. Lightning protection of the hub is then limited to equipotential bonding and transient protection of systems placed outside the hub, such as blade actuator systems, and of electrical and control systems in the hub connected to circuits extending to the outside of the hub.

8.3.3 Spinner

Typically the hub has a glass fibre cover, called the spinner, which is mounted on the hub and rotates with it. As the rolling sphere model would always indicate that there is a possibility of lightning attaching to the front end of the spinner, lightning protection shall be considered. In some wind turbine designs there are also electrical and mechanical control systems and actuators placed outside the hub and covered by the spinner. Such systems shall be shielded from lightning attachment with air termination systems. In case no such systems are placed under the spinner, it may be reasonable to accept the risk of lightning puncturing through the spinner and not have any lightning protection of the spinner. However, in most cases simple and practical lightning protection of the spinner can probably be made using the metal support structure for the spinner as air termination system and connection to the hub.

8.3.4 Nacelle

The nacelle structure should be part of the lightning protection so that it is ensured that lightning attaching to the nacelle will either attach to natural metal parts able to withstand the stress or attach to a lightning air-termination system designed for the purpose. Nacelles with GFRP cover or similar should be provided with a lightning air-termination system and down conductors forming a cage around the nacelle. The lightning air-termination system including exposed conductors in this cage should be able to withstand lightning flashes corresponding to the chosen lightning protection level. Other conductors in the Faraday cage should be dimensioned to withstand the share of lightning currents that they may be exposed to. Lightning air-termination systems for protection of instruments, etc. on the outside of the nacelle should be designed according to the general rules in IEC 62305-3, and down conductors should be connected to the above-mentioned cage.

A metal mesh could be applied to nacelles with GFRP cover to provide shielding against external electric and magnetic fields, and magnetic fields from currents flowing in the mesh. Alternatively, all circuits inside the nacelle could be placed in closed metal conduits or cable trays etc.. An equipotential bonding system shall be established in which the major metal structures in and on the nacelle are included, as it is required in the electrical codes, and as it will provide an efficient equipotential plane to which all earthing and equipotential bonding connections should be made.

Lightning current from lightning attaching to the blades should preferably be conducted directly to the above-mentioned cage thereby completely avoiding lightning current passing through the blade pitch bearings and drive train bearings (see 8.2 and 8.4 for discussion of protection of blades and bearings). Different kinds of brush systems are commonly used for diverting lightning currents away from bearings. However, the efficiency of such discrete brushes may be low, as it is very difficult to construct the brush and earth lead systems with impedance low enough to significantly reduce the current going through the low impedance of the main shaft and bearing systems to the nacelle bed plate.

NOTE A nacelle cover with such a magnetic shield will not be able to protect against effects of magnetic fields from lightning currents flowing inside the nacelle, such as in the main shaft.

8.3.5 Tower

A tubular steel tower, as predominantly used for large wind turbines, usually fulfils the dimensions required for down conductors stated in IEC 62305-3 and can be considered an almost perfect electromagnetic shield Faraday cage, as it is electromagnetically almost closed both at the interface to the nacelle and at ground level. It would therefore in most cases be reasonable to define the inside of the tower as lightning protection zone LPZ1 or LPZ2. In order to keep the tower as electromagnetically closed as possible, there should be direct electrical contact all the way along the flanges between tower sections. The tower and all major metal parts in it should be integrated into the protection earth conductor (PE) and equipotential bonding systems to make the best of the protection offered by the Faraday cage. With regards to bonding of metal structures and systems inside the tower such as ladders, wires and rails, see 9.3.5.

The interface towards the nacelle is usually closed with metal platforms and hatches, which can also serve as an electromagnetic shield closing the tower (see 8.4.2 for discussion of lightning protection of the yaw bearing).

The tower interface to the earthing system is discussed in Clause 9. If the tower is constructed as a Faraday cage as described above, then the contents of the tower require no particular lightning protection. The task of ensuring lightning protection of the tower is thereby limited to equipotential bonding and transient protection of electrical and control circuits extending to other lightning protection zones such as into the nacelle and to the outside of the tower.

Lattice towers naturally cannot be considered a very effective Faraday cage, although there will be some magnetic field attenuation and lightning current reduction inside the lattice tower. It is reasonable to define the inside of a lattice tower as LPZ0_B. Lightning down conduction should be via the lattice tower structural elements, which therefore have to fulfil the dimensions required for down conductors stated in IEC 62305-3 taking current sharing between parallel paths into account. Shields of cables in lattice towers may need to be bonded to the tower at certain interspacing in order to avoid puncture of cable insulation; this is to be assessed by calculation (see IEC 62305-2, Annex D).

In steel reinforced concrete towers, the reinforcement can be used for lightning down conduction by ensuring 2 to 4 parallel vertical connections with sufficient cross section which connect horizontally at top, bottom and for every 20 m in between. The steel reinforcement will provide quite effective magnetic field attenuation and lightning current reduction inside the tower if bonded in this way.

8.3.6 Testing methods

Preliminary testing methods are included in Annex D.

8.4 Mechanical drive train and yaw system

8.4.1 General

The wind turbine will in general have a number of bearings for blade pitching, main shaft rotation, gearbox, generator, and yawing systems.

Hydraulic or electrical actuator systems are used for control and operation of main components.

Bearings and actuator systems have moving parts that directly or indirectly bridge different parts of the wind turbine where lightning current may flow.

All bearings and actuator systems that may be in a lightning current path shall be protected as necessary to reduce the level of current passing through the component to a tolerable level.

8.4.2 Bearings

Bearings are difficult to monitor, and it is not acceptable that bearings have to be inspected after lightning attachment to a wind turbine. Systems for protecting bearings therefore shall be well proven and documented.

Protection can be a part of the bearing structure itself or it can be an external system installed across the bearing to bypass the current.

If bearings are operated without protection, it shall be demonstrated that the bearing itself can operate for the whole design lifetime, after being exposed to the expected number of lightning current penetrations. If the bearing is not able to operate for the whole design life time, protection shall be applied (see 8.4.4).

8.4.3 Hydraulic systems

If hydraulic systems are in the lightning current path, it shall be ensured that lightning current penetration will not affect the system. With hydraulic systems, it is necessary to consider the risk of fluid leaks due to damage at fittings and ignition of the hydraulic oil.

Protection measures such as sliding contacts or bonding straps can be used to make the current bypass actuator cylinders.

Hydraulic tubes exposed to lightning current shall be protected to avoid current penetration of the tubes. If hydraulic tubes have mechanical armour, it shall be bonded to the steel structure of the machinery at both ends of the tube. It shall also be ensured that the armour has sufficient cross section to conduct the parts of the lightning current which it may be exposed to.

Similar considerations may apply to water cooling systems.

8.4.4 Spark gaps and sliding contacts

For bypassing bearings and actuator systems, it shall be considered to use spark gaps or sliding contacts. Such bypassing systems including their connecting leads must in order to be effective have less impedance than the direct natural current path through the component.

Spark gaps and sliding contacts shall be able to conduct the lightning current it may be exposed to at the place of use in the wind turbine.

Both spark gaps and sliding contacts shall be designed to maintain the required performance regardless of environmental effects such as rain, ice, pollution with salt, dust, etc.

If spark gaps or sliding contacts are used, these must be considered to be wear parts and the service lifetime of these devices shall be calculated and documented. Spark gaps and sliding contacts shall be inspected regularly in accordance with the service and maintenance manuals.

8.4.5 Testing

All systems for protection of bearings and actuator systems shall have a documented functionality. It is recommended to perform tests with impulse current representing the natural lightning current.

It is recommended to perform impulse current tests on full-scale test objects where the important parts of the system are represented in a test mock-up.

It shall be demonstrated that the protection system can withstand the damaging effect of the first lightning stroke combined with the long stroke current.

If sliding contacts are used as part of the system, mechanical tests shall be performed in order to document the stability of the system with special focus on wear of the contact with and without the erosion effects of lightning current. The wear has to be low enough to allow unaffected operation between the planned service intervals.

Tests can be done on scaled models, but calculations shall demonstrate the scaling factors and effects.

Informative testing methods are included in Annex D, Subclause D.3.4.

8.5 Electrical low-voltage systems and electronic systems and installations

8.5.1 General

This clause deals with the protection of the electrical and control systems of a wind turbine against the effects of

- lightning flashes attaching to the wind turbine;
- leader currents developing from the wind turbine;
- indirect lightning flashes (i.e. effect through LEMP of lightning flashes not affecting the wind turbine directly).

NOTE 1 Transient overvoltages and surges caused by switching operations in electrical systems (switching electromagnetic impulse, SEMP) must be considered as well. However, it is outside the scope of this standard. For general information, the reader is referred to IEC 62305-2 Annex F for discussion of switching overvoltages. Subclause 8.5.6.9 and Clause F.7 of this standard give some information on the selection of SPDs with regard to overvoltages created within wind turbines.

All types of lightning flashes generate lightning electromagnetic impulses (LEMP).

NOTE 2 The general requirements for electrical equipment on machines described in IEC 60204-1 should be observed.

8.5.2 LEMP protection measures (LPMS)

Electrical and control systems are subject to damage from the LEMP. Therefore LEMP protection measures (LPMS) shall be provided to avoid failure of these systems. The effective protection of the electrical and control system of a wind turbine against LEMP requires the systematic approach of the lightning protection zones (LPZ) concept according to IEC 62305-4. LPMS is part of the lightning protection zone (LPZ) concept for the complete wind turbine, described in 8.5.3. Examples of the application of the lightning protection zones (LPZ) concept in a wind turbine are given in Annex E.

The wind turbine manufacturer shall provide a LEMP protection measures system (LPMS) according to IEC 62305-4 for the complete electrical system.

NOTE It can be assumed that effective LEMP protection measures also provide effective protection against the effects of indirect lightning flashes.

Basic protection measures in an LPMS according to IEC 62305-4 include:

- bonding – see Subclause 8.5.4;
- magnetic and electrical shielding of cables and line routing (system installation) – see Subclause 8.5.5;

- coordinated SPD protection – see Subclause 8.5.6;
- earthing – see Clause 9.

Additional methods include:

- isolation, circuit design, balanced circuits, series impedances, etc.

For the LPMS, the following basic information shall be documented (see also Clause 11):

- definition of lightning protection level (LPL) according to IEC 62305-1;
- drawings of the wind turbine defining LPZ and their boundaries;
- circuit diagrams showing SPDs, cable shields and cable shield bonding points.

Figures E.5 and E.6 provide basic examples of such documentation.

8.5.3 Lightning protection zones (LPZ)

A wind turbine can be divided into physical areas which roughly define the level of the influence of a lightning flash on components in that zone. The division of the wind turbine into lightning protection zones is a tool to ensure systematic and sufficient protection of all components of the wind turbine. These lightning protection zones (LPZ) are defined depending on whether or not direct lightning attachment is possible and on the magnitude of the lightning current and associated magnetic and electrical fields expected in that zone (see Table E.1). Lightning protection methods are then applied to ensure that components, for example machinery, electrical systems or control systems, can withstand the magnetic and electrical fields and lightning current that may enter the zone in which the components are placed. For instance, protection against overvoltages is only necessary for cables passing from one zone into a zone with more sensitive components (i.e. from a lower LPZ number to a higher LPZ number), whereas internal connections within the zone may be unprotected. This approach is detailed further in IEC 62305-4, Clause 4 “Design and installation of a LEMP protection measures system (LPMS)”, and it is discussed in Annex E.

Further guidance on how to fulfil these requirements is given in Annex E.

8.5.4 Equipotential bonding within the wind turbine

Equipotential bonding according to IEC 62305-4 shall be used within a wind turbine to ensure that potentially dangerous sparking cannot take place between conducting parts of the wind turbine. These equipotential bonds provide protection against touch and step voltages during a lightning attachment. Equipotential bonds play an important role in reducing the probability of damage to electrical and control systems. Low impedance bonding connections prevent dangerous potential differences between equipment inside the wind turbines.

In order to be most effective, the bonding connections shall make maximum use of the large metal structures of the wind turbine (i.e. mainly tower, nacelle bed plate, nacelle frame and hub). Such bonding conductors may additionally reduce the magnetic field levels caused by lightning. For example, if bonding connections are placed between metal platforms and the tower wall at several positions distributed around the platform-tower interface, it will effectively provide electromagnetic shielding of the inside of the tower.

Much of the damage experienced in wind turbine control systems can be prevented by means of effective bonding and shielding. Some further considerations about the bonding needed in a wind turbine are discussed in Annex G.

8.5.5 Shielding and line routing

Shielding is the means by which electromagnetic field levels are attenuated. The reduction of electromagnetic fields can substantially reduce levels of voltages induced into circuits.

The magnetic field caused inside an LPZ by lightning flashes to the structure or the nearby ground may be reduced by spatial shielding of the LPZ only. Surges induced into the control system via the connecting cabling can be minimised either by spatial shielding, or by line routing and shielding (e.g. shielded cables bonded at both ends), or by a combination of both methods.

Magnetic shielding and line routing according to IEC 62305-4, Clause 4 should be used, and the general guidelines on EMC-correct installation practices described in IEC/TR 61000-5-2 should be followed.

When lightning currents flow through a wind turbine, large magnetic fields are produced. If these changing magnetic fields pass through a loop formed by wiring or formed by wiring and the wind turbine structure, they will induce surge voltages and currents within that loop. The magnitude of the surges is related to the rate of change of the magnetic field and the area of the loop in question. The designer shall consider the magnitude of induced voltages and make sure that such surges do not exceed the withstand level of the cabling and connected equipment.

The use of shielding and line routing should be documented by analysis and/or testing.

Some further considerations about the shielding required in a wind turbine are discussed in Annex G.

8.5.6 Coordinated SPD protection

8.5.6.1 General

Coordinated SPD protection consists of a set of SPDs properly selected, coordinated and installed to reduce failures of electrical and electronic systems.

NOTE Coordination of SPD protection must include the connecting circuits to provide insulation coordination of complete systems.

Coordinated SPD protection limits the effects of lightning surges and internally generated switching surges. The protection of the electrical and control systems requires a systematic approach of coordinated SPDs for both electrical low-voltage power systems and control systems. The recommendations for coordinated SPD protection within wind turbines are given in Annex F.

8.5.6.2 Location of SPDs

According to IEC 62305-4, in an LPMS, SPDs shall be located at the line entrance into each LPZ:

- as close as possible to the boundary of LPZ 1, SPDs tested with I_{imp} (Class I test), as classified in IEC 61643-1, shall be installed;
- as close as possible to the boundary of LPZ 2 and higher, and if necessary as close as possible to the equipment to be protected, SPDs tested with I_n (Class II test), as classified in IEC 61643-1, shall be installed.

NOTE If the length of the circuit between the SPD and the equipment is too long (i.e. in general when longer than 10 m), propagation of surges can lead to an oscillation phenomenon – see IEC 62305-4, Subclause D.2.3 and D.2.4.

8.5.6.3 Selection of SPDs

SPDs which shall withstand a partial lightning current with the typical waveform 10/350 μs require a corresponding impulse test current I_{imp} . For power lines, a suitable test current I_{imp} is defined in the Class I test procedure of IEC 61643-1.

SPDs which shall withstand induced surge currents with the typical waveform 8/20 μs require a corresponding impulse test current I_n . For power lines, a suitable test current I_n is defined in the Class II test procedure of IEC 61643-1.

SPDs shall comply with

- IEC 61643-1 for power systems;
- IEC 61643-21 for telecommunication and signalling systems.

8.5.6.4 Installation of SPDs

SPDs shall comply with the installation rules given in

- IEC 60364-4-44, IEC 60364-5-53 and IEC 61643-12 for the protection of power systems;
- IEC 61643-22 for the protection of the control and communication systems.

The installation locations of the SPDs shall be documented e.g. by means of drawings and wiring diagrams according to the LPMS. For the SPDs installed at the different LPZ boundaries and possible surge protection components installed inside equipment, the requirements for energy coordination according to IEC 62305-4 and IEC 61643-12 shall be fulfilled.

According to IEC 62305-4, considerations shall be made regarding the coordination of SPDs in the electrical and control systems. Sufficient information shall be provided in the documentation on how coordination between SPDs is achieved.

Further guidelines for the bonding (earthing) and cabling of electrical and control systems and installations are given in 8.5.4 and 8.5.5 and exemplified in Annex G.

8.5.6.5 Environmental stresses

SPDs shall withstand the environmental stresses characterising the installation place such as:

- ambient temperature;
- humidity;
- corrosive atmosphere;
- vibration and mechanical shock.

Depending on conditions at the point of installation within the wind-turbine, additional and specific requirements on the performance and installation of SPDs might arise. If necessary, the manufacturer of the wind turbine should take into account the environmental conditions for specific points of installation, e.g. nacelle and hub.

8.5.6.6 Maintenance

Maintenance and replacement of SPDs shall be done according to a maintenance plan.

SPDs shall be installed in such a way that they can be inspected.

NOTE The SPD manufacturer can provide information on SPD service life time.

8.5.6.7 SPD monitoring

SPD protection of critical parts of the electrical and control systems of wind turbines may require monitoring.

8.5.6.8 Selection of SPDs with regard to protection level (U_p) and system immunity

In order to identify the required protection level U_p in an LPZ, it is necessary to establish the immunity levels of the equipment in the LPZ, e.g. of

- power lines and equipment terminals according to IEC 61000-4-5 and IEC 60664-1;
- telecom lines and equipment terminals according to IEC 61000-4-5, ITU-T K.20 and ITU-T K.21;
- other lines and equipment terminals according to information obtained from the manufacturer.

Manufacturers of electrical and electronic components should be able to supply the necessary immunity level information according to the EMC standards. Otherwise the wind turbine manufacturer should have tests performed to establish the immunity level.

The established immunity level of components in an LPZ directly defines the necessary protection level to be achieved at the LPZ boundaries.

System immunity shall be verified including all SPDs installed and equipment to be protected, if applicable. Possible testing methods are described in Annex H.

8.5.6.9 Overvoltages created within wind turbines

Specific requirements might apply to SPDs due to large voltage variations and temporary overvoltages within the electrical system of a wind turbine. In such cases, the relevant parts of the electrical systems and voltage levels, current levels and duration shall be identified by analysis and/or testing and SPDs selected accordingly. Examples hereof are given in Annex F.

Evidence shall be provided that the selected SPDs can withstand these specific stress levels.

8.5.6.10 Selection of SPDs with regard to discharge current I_n and impulse current I_{imp}

An analysis of the lightning current distribution within the wind turbine according to IEC 62305-4 is recommended. Based on these calculations, SPDs can be selected with regard to discharge current I_n and impulse current I_{imp} .

SPDs for particularly exposed circuits may require higher rating as compared to the levels given in IEC 60364-5-53 or such circuits could be shielded. Such circuits particularly exposed to either high stresses or repeated stresses should be identified by analysis. If applicable,

such exposed circuits within the electrical and control systems of a wind turbine shall be documented in the wiring diagrams by the wind turbine manufacturer. Further information hereof is given in Annex F.

8.5.6.11 Selection of SPDs with regard to short-circuit current, the follow current interrupt rating and duty cycle (service lifetime) of the SPDs

The short-circuit withstand current rating of the combination of the SPD and the overcurrent protective device (OCPD – e.g. a fuse) and the follow current interrupting rating of the SPD as declared by the SPD manufacturer shall be equal to or higher than the maximum short-circuit current expected at the point of installation. In addition, when a follow current interrupting rating is declared for the SPD, it shall be confirmed by either calculation or testing that the actual OCPD installed in the specific power circuit does not operate.

NOTE The SPD manufacturer can provide information on SPD service life time.

8.5.6.12 Behaviour of SPDs in case of multiple lightning flashes

Due to the relatively high frequency of lightning flashes to wind turbines and the critical nature of the installation of SPDs within wind turbines, SPDs shall be able to withstand multiple lightning flashes.

8.5.7 Testing methods for system immunity tests

Preliminary testing methods are included in Annex H.

8.6 Electrical high-voltage (HV) power systems

Large wind turbines are usually connected via a high-voltage (HV) transformer to an underground HV cable system which may connect an array of wind turbines either directly to the grid or to a transformer station stepping up the voltage to that of the sub-transmission system at for example 132 kV.

The wind turbine HV transformer may be placed in the back of the nacelle, in the bottom of the tower or next to the wind turbine tower.

HV surge protection devices are usually referred to as surge arresters. In a wind turbine application, surge arresters serve to protect the transformer and the high-voltage system in general against earth potential rise due to lightning currents passing through the wind turbine earthing system, and to protect against transients entering the wind turbines from the HV cable system outside the wind turbine. The need for surge arresters on the HV side of the transformer should be evaluated based on the principles in IEC 62305-2 (see Clause 7 and Annex B).

Assessment of the levels of transients coming from the HV cable system outside the wind turbine requires special transient electrical network simulations. The studies should be made according to IEC 60071 series. In case such studies are not performed, HV surge arresters are advisable as a general precaution.

HV surge arresters should be metal-oxide surge arresters without gaps in accordance with IEC 60099-4 and should be selected and applied in accordance with IEC 60099-5.

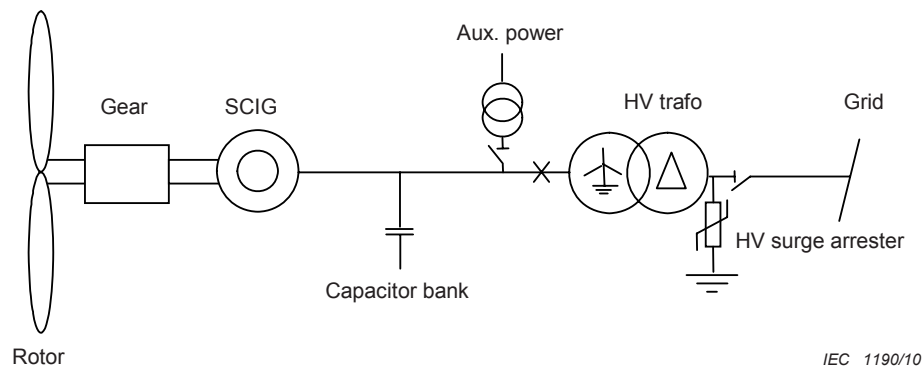


Figure 4a – Squirrel cage induction generator (SCIG)

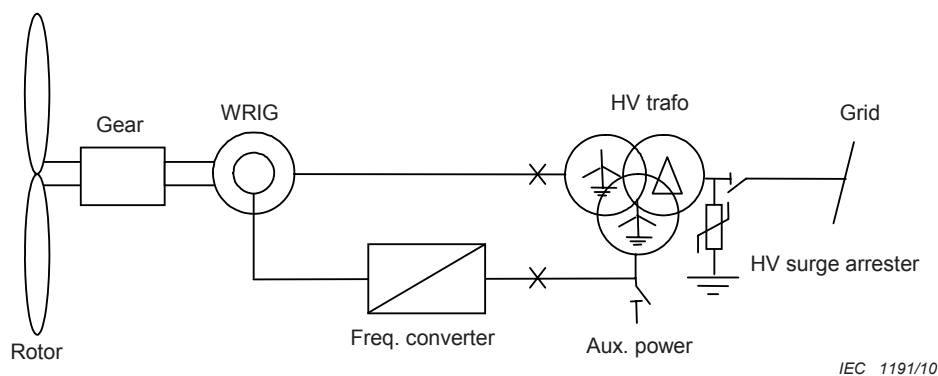


Figure 4b – Wound rotor induction generator (WRIG)

Figure 4 – Examples of placement of HV arresters in two typical main electrical circuits of wind turbines

High-voltage surge arresters should preferably be placed at the HV transformer terminals as shown in Figure 4 thereby providing maximum protection for the transformer. However, it may be convenient to place surge arresters at the switchgear. In general, a distance of 10 m to 40 m between arrester and component to be protected is possible depending on the insulation level of the component, if the distance is larger, a closer study is necessary to decide if for instance arresters at the bottom of the tower can provide the needed protection for a transformer placed in the nacelle. If the transformer is placed outside the tower, it is important that the transformer earthing system is connected to the wind turbine earthing system, and preferably it should be one earthing system.

SPDs on the low-voltage (LV) side of the HV transformer are probably an appropriate general precaution, particularly if significant transients may pass through the transformer from the high-voltage side, in which case a type of SPD for transformer application should be chosen (i.e. SPDs with high energy absorption capability). The transient capacitive and inductive coupling between HV and LV sides of a transformer, and therefore also the transient levels transferred to the LV side, depend very much on the design of the transformer and particularly on the earthing connection of the LV winding (refer to IEC 60071-2, Annex E for further information). It is therefore advisable as a general precaution to install SPDs on the LV side of the transformer, or alternatively to obtain a sufficiently detailed transformer model from the manufacturer for transient studies in order to decide if SPDs are required on the LV side of the transformer.

NOTE The general requirements for high-voltage systems on machinery in IEC 60204-11 should be observed.

9 Earthing of wind turbines and wind farms

9.1 General

To disperse lightning currents and prevent damage to a wind turbine, an efficient earthing system for the machine is essential. The earthing system shall furthermore protect people and livestock against electric shock. When faults occur in the electrical grid, it is necessary to keep the touch and step voltages and the overall earth potential rise to a safe level until protection devices have tripped and safely interrupted the flow of fault current. For lightning flashes, the earthing system must disperse and conduct high frequency and high energy lightning current into the earth without any dangerous thermal and/or electrodynamic effects.

It is generally recommended that one earthing system is established for a wind turbine to be used for lightning protection as well as for power system earthing purposes. Furthermore, it is recommended to include metal parts in the foundation structures in the earthing system, because using the metal parts of the large foundation structures will result in the lowest possible earthing resistance, and because attempting to separate an earthing system from the metal parts of the foundation would represent a structural hazard, particularly for concrete foundations.

Concerning the design of the earthing system to prevent high step and touch voltages due to failures in high-voltage components, please refer to high-voltage electrical codes such as CENELEC HD637 S1 or relevant national standards. In relation to human safety, please refer to IEC/TS 60479-1 and IEC 60479-4.

9.1.1 Basic requirements

The earthing system of the wind turbine shall be designed to provide sufficient protection against damage due to lightning flashes that correspond to the LPL for which the wind turbine protection system is designed.

The earthing system shall be designed to meet four basic design requirements:

- a) ensure personal safety with regard to the step and touch voltages which appear during earth faults;
- b) prevent damage to equipment;
- c) withstand the thermal and electrodynamic forces it will be subjected to during a fault;
- d) have sufficient long-term mechanical strength and corrosion resistance.

9.1.2 Earth electrode arrangements

Two basic types of earth electrode arrangements that are described in IEC 62305-3 apply to wind turbines:

- type A arrangement: This arrangement is not recommended for wind turbines, but can be used for minor buildings (for example buildings containing measurement equipment or office sheds that are connected to a wind turbine farm). Type A earthing arrangements are made with horizontal or vertical electrodes connected to not less than two down conductors on the structures;

NOTE For further information on type A arrangements, see IEC 62305-3, Subclause 5.4.2.1.

- type B arrangement: The type B arrangement is recommended for use with wind turbines. This type of arrangement comprises either an external ring earth electrode in contact with the soil for at least 80 % of its total length or a foundation earth electrode. The ring electrodes and metal parts in the foundation shall be connected to the tower structure.

9.1.3 Earthing system impedance

The conventional earthing impedance of the earthing system does not affect the efficiency of the air termination system and down conducting system. The earthing system shall be designed to have as low an impulse impedance as possible to reduce the total voltage drop (i.e. minimise the earth potential rise), to reduce the partial lightning current flowing into the service lines connecting the wind turbine and to reduce the risk of sparks to other service lines close to the earthing system.

The embedded depth and the type of the earth electrodes shall minimise the effects of corrosion, soil drying and freezing and thereby stabilise the conventional earthing resistance. It is recommended that the first metre of a vertical earth electrode should not be regarded as being effective under frost conditions.

The earthing system components shall be able to withstand lightning currents as well as power system fault currents. This is ensured by selecting earthing system components according to IEC 62305-3. The earthing system shall be constructed to disperse the lightning current into earth without thermal or electrodynamic damage, and the length of the conductors shall be as short as possible.

Additional information is included in Annex I, Subclause I.2.2.

9.2 Equipotential bonding

9.2.1 General

Equipotentialisation is achieved by interconnecting the LPS with

- structural metal parts;
- metal installations;
- internal systems;
- external conductive parts and service lines connected to the structure.

When lightning equipotential bonding is established to internal systems, part of the lightning current may flow into such systems and this effect shall be taken into account.

The manner in which lightning equipotential bonding of service lines such as telecommunication and power lines is achieved is important and shall be discussed with the operator of the telecommunication network, the electric power system operator and other operators or authorities concerned, as there may be conflicting requirements.

9.2.2 Lightning equipotential bonding for metal installations

Lightning equipotential bonding connections shall be made as direct and as straight as possible.

The minimum values of the cross section of the bonding conductors connecting different bonding bars/points and of the conductors connecting the bars/points to the earth termination system are listed in Table 5.

The minimum values of the cross section of the bonding conductors connecting internal metal installations to the bonding bars/points are listed in Table 6.