

INTERNATIONAL STANDARD

**Wind turbines –
Part 24: Lightning protection**





THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2010 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester.

If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

- Catalogue of IEC publications: www.iec.ch/searchpub

The IEC on-line Catalogue enables you to search by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, withdrawn and replaced publications.

- IEC Just Published: www.iec.ch/online_news/justpub

Stay up to date on all new IEC publications. Just Published details twice a month all new publications released. Available on-line and also by email.

- Electropedia: www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 20 000 terms and definitions in English and French, with equivalent terms in additional languages. Also known as the International Electrotechnical Vocabulary online.

- Customer Service Centre: www.iec.ch/webstore/custserv

If you wish to give us your feedback on this publication, or need further assistance, please visit the Customer Service Centre FAQ or contact us:

Email: csc@iec.ch
Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00



IEC 61400-24

Edition 1.0 2010-06

INTERNATIONAL STANDARD

**Wind turbines –
Part 24: Lightning protection**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE **XG**

ICS 27.180

ISBN 978-2-88910-969-2

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 – Microwind generation.....	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 – Definition of short stroke parameters (typically $T_2 < 2$ ms).....	58
Figure A.4 – Definitions of long stroke parameters (typically 2 ms $< T_{\text{long}} < 1$ 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 μ s 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 SPV 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 2006 [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)	66
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_i 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

INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND TURBINES –

Part 24: Lightning protection

FOREWORD

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

International Standard IEC 61400-24 has been prepared by IEC technical committee 88: Wind turbines.

This first edition replaces IEC/TR 61400-24, published in 2002. It constitutes a technical revision. It is restructured with a main normative part, while informative information is placed in an annex.

The text of this standard is based on the following documents:

FDIS	Report on voting
88/366/FDIS	88/369/RVD

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

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

A list of all parts of the IEC 61400 series, under the general title: *Wind turbines*, can be found on the IEC website.

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

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

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

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*