

STANDARD

DNVGL-ST-0076

Edition May 2015

Design of electrical installations for wind turbines

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FOREWORD

DNV GL standards contain requirements, principles and acceptance criteria for objects, personnel, organisations and/or operations.

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CHANGES – CURRENT

General

This is a new document.

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SECTION 1 INTRODUCTION

1.1 General

This DNV GL standard provides principles and technical requirements for design and construction of electrical installations for wind turbines onshore and offshore.

The present DNV GL standard can be applied as part of the technical basis for carrying out a DNV GL certification of wind turbines.

Guidance note:

The present DNV GL standard will cover the technical requirements to be applied for the DNV GL certification schemes and it is also intended to cover the requirements implied when using IEC 61400-22 related certification schemes.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

1.2 Objectives

The objectives of this standard are to:

- Provide an internationally acceptable level of safety by defining minimum requirements for electrical installations in wind turbines (in combination with referenced standards, recommended practices, guidelines, etc.).
- Serve as design basis for designers, suppliers, purchasers and regulators.
- Specify requirements for wind turbines subject to DNV GL certification.

1.3 Scope and application

The standard is applicable to all types of wind turbines.

The standard is applicable to the design of electrical components and electrical systems for the complete wind turbine, including main components, cable systems and, control and protection systems.

Electrical installations shall be so designed that:

- the maintaining of normal operational conditions will be ensured without recourse to any emergency source of electrical power
- the operation of emergency equipment required for machinery and personal safety will be ensured under various defined emergency conditions
- the safety of personnel and installations from electrical hazards will be ensured and risks of injury to human life will be reduced to a minimum
- the equipment and installations will reach the expected life times
- sufficiently high reliability is reached for the entire system.

This standard covers:

- rotating electrical machines
- power transformers
- frequency converters
- high voltage switchgear
- back-up power supply systems
- low-voltage switchgear, controlgear and switchboards including safety-related parts
- cables, lines and accessories
- lightning protection, earthing and bonding
- electrical pitch and yaw drives
- selection and interconnection of electrical equipment
- electrical control and protection systems
- installation and maintenance
- corrosion protection

- fire protection
- extreme environmental conditions (-x, +y).

1.4 Normative references

The standards and guidelines in [Table 1-1](#) include provisions, which through reference in this text constitute provisions of this standard.

Table 1-1 Standards and guidelines

<i>Id.</i>	<i>Name</i>	<i>Date</i>	<i>Edition</i>
IEC/CISPR 11	Analogue Standard to EN 55011:2009: <i>Industrial, scientific and medical equipment- Radio- frequency disturbance characteristics Limits and methods of measurement</i>	2011-04	5.0
CISPR 16-1	Analogue Standard to EN 55016-1: <i>Specification for radio disturbance and immunity measurement apparatus and methods - Part 1: Radio disturbance and immunity measuring apparatus</i>	2003-07-01	
CISPR 16-2	Analogue Standard to EN 55016-2: <i>Specification for radio disturbance and immunity measurement apparatus and methods - Part 2: Methods of measurement of disturbances and immunity</i>	2003-07-01	
CISPR 16-3	Analogue Standard to EN 55016-1-3: <i>Specification for radio disturbance and immunity measurement apparatus and methods - Part 3: Reports and recommendations of CISPR</i>	2007-05	
CISPR 16-4	Analogue Standard to EN 55016-2-4: <i>Part 4-1: Uncertainties, statistics and limit modelling — Uncertainties in standardized EMC tests</i>	2005-09	
EN 50160	<i>Voltage characteristics of electricity supplied by public distribution networks</i>	2011-02	
EN 50522	<i>Earthing of power installations exceeding 1 kV a.c.</i>	2011-11	
EN 60909	<i>Short-circuit currents in three-phase a.c. systems</i>	2013-02-25	
EN ISO 12944	<i>Fertilizers and liming materials - Vocabulary</i>	2000-03	
GL-IV-1	<i>Guideline for the Certification of Wind Turbines, Germanischer Lloyd</i>		2010
GL-IV-2	<i>Guideline for the Certification of Offshore Wind Turbines, Germanischer Lloyd</i>		2012
IEC 60034-1	<i>Rotating electrical machines - Part 1: Rating and performance (IEC 60034-1:2010, modified)</i>	2010-02-03	12.0
IEC 60034-5	<i>Rotating electrical machines - Part 5: Degrees of protection provided by the integral design of rotating electrical machines (IP code) – Classification</i>	2006-11	4.1
IEC 60034-16-3	<i>Rotating electrical machines - Part 16: Excitation systems for synchronous machines - Section 3: Dynamic performance</i>	1996-02-14	1.0
IEC 60034-29	<i>Rotating electrical machines - Part 29: Equivalent loading and superposition techniques - Indirect testing to determine temperature rise</i>	2009-01	1.0
IEC 60038	<i>CENELEC standard voltages</i>	2009-06-17	7.0
IEC 60068-2-1	<i>Environmental testing – Part 2-1: Tests</i>	2007-03-13	6.0
IEC 60068-2-27	<i>Environmental testing – Part 2-27: Tests</i>	2008-02-27	4.0
IEC 60068-2-30	<i>Environmental testing – Part 2-30: Tests</i>	2005-08-10	3.0
IEC 60068-2-52	<i>Environmental testing - Part 2: Tests - Test Kb: Salt mist, cyclic (sodium, chloride solution)</i>	1996-02-07	2.0
IEC 60068-2-6	<i>Environmental testing – Part 2-6: Tests</i>	2007-12-13	7.0
IEC 60076-1	<i>Power transformers – Part 1: General</i>	2011-04-20	3.0
IEC 60076-11	<i>Power transformers - Part 11: Dry-type transformers</i>	2004-05-27	1.0
IEC 60076-16	<i>Power transformers - Part 16: Transformers for wind turbine applications</i>	2011-08-25	1.0
IEC 60092-101	<i>Electrical installations in ships - Part 101: Definitions and general requirements</i>	2002-08-22	4.1
IEC 60099-1	<i>Surge arresters – Part 1: Non-linear resistor type gapped surge arresters for a.c. systems</i>	1999-12-22	3.1

Table 1-1 Standards and guidelines (Continued)

<i>Id.</i>	<i>Name</i>	<i>Date</i>	<i>Edition</i>
IEC 60099-4	<i>Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems</i>	2014-06-30	3.0
IEC 60112	<i>Method for the determination of the proof and the comparative tracking indices of solid insulating materials</i>	2009-10-13	4.1
IEC 60204-1	<i>Safety of machinery - Electrical equipment of machines - Part 1: General requirements</i>	2009-02	5.1
IEC 60204-11	<i>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</i>	2000-07-31	1.0
IEC 60227-4	<i>Standard series Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V</i>	1997-12-19	2.1
IEC 60228	<i>Conductors of insulated cables</i>	2004-11-02	3.0
IEC 60287	<i>Standard series Electric cables - Calculation of the current rating</i>	2006-12-13	2.0
IEC 60364-4-44	<i>Low-voltage electrical installations - Part 4-44: Protection for safety - Protection against voltage disturbances and electromagnetic disturbances</i>	2007-08-14	2.0
IEC 60364-5-52	<i>Low-voltage electrical installations - Part 5-52: Selection and erection of electrical equipment - Wiring systems</i>	2009-10-20	3.0
IEC 60364-5-53	<i>Electrical installations of buildings - Part 5-53: Selection and erection of electrical equipment - Isolation, switching and control</i>	2002-06-24	3.1
IEC 60364-6	<i>Low-voltage electrical installations - Part 6: Verification</i>	2006-02-23	1.0
IEC 60502	<i>Standard series Power cables with extruded insulation and their accessories for rated voltages from 1 kV ($U_m = 1.2 \text{ kV}$) up to 30 kV ($U_m = 36 \text{ kV}$)</i>	2004-04-14	2.0
IEC 60529	<i>Degrees of protection provided by enclosures (IP Code)</i>	2014-09	3.0
IEC 60664-1	<i>Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests</i>	2007-04-26	2.0
IEC 60695	<i>Standard series Fire hazard testing</i>		
IEC 60721	<i>Standard series Classification of environmental conditions</i>		
IEC 60721-3-3	<i>Classification of environmental conditions - Part 3-3: Classification of groups of environmental parameters and their severities - Stationary use at weatherprotected locations</i>	2002-10-22	2.2
IEC 60721-3-6	<i>Classification of environmental conditions. Part 3: Classification of groups of environmental parameters and their severities. Ship environment</i>	1987-04-15	1.0
IEC 60825-1	<i>Safety of laser products – Part 1: Equipment classification and requirements</i>	2014-07-31	4.0
IEC 60840	<i>Power cables with extruded insulation and their accessories for rated voltages above 30 kV ($U_m = 36 \text{ kV}$) up to 150 kV ($U_m = 170 \text{ kV}$) – Test methods and requirements</i>	2011-11-23	4.0
IEC 60947-1	<i>Low-voltage switchgear and controlgear – Part 1: General rules</i>	2011-03-30	5.1
IEC 61000-4-30	<i>Electromagnetic compatibility (EMC) - Part 4-30: Testing and measurement techniques - Power quality measurement methods</i>	2008-10-13	2.0
IEC 61000-6-1	<i>Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity for residential, commercial and light-industrial environments</i>	2005-03-09	2.0
IEC 61000-6-2	<i>Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments Power station and substation environment</i>	2005-01-27	2.0
IEC 61000-6-3	<i>Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments</i>	2006-07	2.0
IEC 61000-6-4	<i>Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments</i>	2011-02-23	2.1
IEC/TS 61000-6-5	<i>Electromagnetic compatibility (EMC) - Part 6-5: Generic standards - Immunity for power station and substation environments In-door equipment</i>	2001-07-24	1.0

Table 1-1 Standards and guidelines (Continued)

<i>Id.</i>	<i>Name</i>	<i>Date</i>	<i>Edition</i>
IEC 61000-6-6	<i>Electromagnetic compatibility (EMC) - Part 6-6: Generic standards - HEMP immunity for indoor equipment</i>	2003-04-09	1.0
IEC 61010-1	<i>Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 1: General requirements</i>	2010-06-10	3.0
IEC 61082-1	<i>Preparation of documents used in electro technology – Part 1: Rules</i>	2006-04-11	2.0
IEC 61326-1	<i>Electrical equipment for measurement, control and laboratory use – EMC requirements – Part 1: General requirements</i>	2012-07-10	2.0
IEC 61326-3-1	<i>Electrical equipment for measurement, control and laboratory use – EMC requirements – Part 3-1: Immunity requirements for safety-related systems and for equipment intended to perform safety-related functions (functional safety) - General industrial applications</i>	2008-01	1.0
IEC 61378-1	<i>Converter transformers - Part 1: Transformers for industrial applications</i>	2011-07-26	2.0
IEC 61400-1	<i>Wind turbine generator systems – Part 1: Design requirements</i>	2014-04-15	3.1
IEC 61400-21	<i>Wind turbine generator systems – Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines</i>	2008-08-13	2.0
IEC 61400-22	<i>Wind turbines - Part 22: Conformity testing and certification</i>	2010-05-31	1.0
IEC 61400-23	<i>Wind turbines - Part 23: Full-scale structural testing of rotor blades</i>	2014-04-08	1.0
IEC 61400-24	<i>Wind turbine generator systems – Part 24: Lightning protection</i>	2010-06-16	1.0
IEC 61439-1	<i>Low-voltage switchgear and control gear assemblies – Part 1: General rules</i>	2011	1.0
IEC 61558-1	<i>Safety of power transformers, power supplies, reactors and similar products – Part 1: General requirements and tests</i>	2009-04	2.1
IEC 61643-11	<i>Low-voltage surge protective devices – Part 11: Surge protective devices connected to low-voltage power systems – Requirements and tests methods</i>	2012-12-14	2.0
IEC 61643-21	<i>Low-voltage surge protective devices- Part 21: Surge protective devices connected to telecommunications and signalling networks – Performance requirements and testing methods</i>	2012-07-27	1.2
IEC 61800-1	<i>"Adjustable speed electrical power drive systems - Part 1: General requirements - Rating specifications for low voltage adjustable speed d.c. power drive systems"</i>	1997-12-15	1.0
IEC 61800-2	<i>Adjustable speed electrical power drive systems - Part 2: General requirements - Rating specifications for low voltage adjustable frequency a.c. power drive systems</i>	1998-03-20	1.0
IEC 61800-3	<i>Adjustable speed electrical power drive systems - Part 3: EMC requirements and specific test methods</i>	2012-03-08	2.1
IEC 61800-4	<i>Adjustable speed electrical power drive systems - Part 4: General requirements - Rating specifications for a.c. power drive systems above 1 000 V a.c. and not exceeding 35 kV</i>	2002-09-12	1.0
IEC 61800-5-1	<i>Adjustable speed electrical power drive systems - Part 5-1: Safety requirements - Electrical, thermal and energy</i>	2007-07-16	2.0
IEC 61800-6	<i>Adjustable speed electrical power drive systems - Part 6: Guide for determination of types of load duty and corresponding current ratings</i>	2003-03-31	1.0
IEC 61936-1	<i>Power installations exceeding 1 kV a.c. - Part 1: Common rules</i>	2014-02-26	2.1
IEC 62271	<i>Standard series High-voltage switchgear and controlgear</i>		
IEC 62305-1	<i>Protection against lightning – Part 1: General principles</i>	2010-12-09	2.0
IEC 62305-3	<i>Protection against lightning – Part 3: Physical damage to structures and life hazard</i>	2010-12-09	2.0
IEC 62305-4	<i>Protection against lightning – Part 4: Electrical and electronic systems within structures</i>	2010-12-09	2.0
IEC 62477-1	<i>Safety requirements for power electronic converter systems and equipment - Part 1: General</i>	2012-07-24	1.0
ISO 13849-1	<i>Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design</i>	2006-11-01	2.0

Table 1-1 Standards and guidelines (Continued)

<i>Id.</i>	<i>Name</i>	<i>Date</i>	<i>Edition</i>
ISO 1940-1	<i>Mechanical vibration - Balance quality requirements for rotors in a constant (rigid) state - Part 1: Specification and verification of balance tolerances</i>	2004-04	
ISO/IEC 17025	<i>General requirements for the competence of testing and calibration laboratories</i>	2005-05	2.0
ISO 281	<i>Rolling bearings - Dynamic load ratings and rating life</i>	2010-10	
ISO 7010-W001	<i>Graphical symbols - Safety colours and safety signs - Registered safety signs</i>	2012-10	
ISO 9000	<i>Quality management systems - Fundamentals and vocabulary</i>	2014-07-25	
ISO 9001	<i>Quality management systems - Requirements</i>	2014-07-25	
ISO 9004	<i>Managing for the sustained success of an organization - A quality management approach</i>	2009-12	
	<i>Technical Note Certification of Grid Code Compliance by GL Renewables Certification</i>	2013-12-04	9

1.5 Informative references

For additional acceptable methods for fulfilling the requirements in this standard see also current service documents published on www.dnvgl.com / MyDNVGL / Rules and Standards. Other recognized codes or standards may be applied provided it is shown that they meet or exceed the level of safety of the actual standard.

1.6 Definitions

1.6.1 Terminology and definitions

The verbal forms can and will are used in this Standard when describing DNV GL's actions and activities, whereas the verbal forms shall, should and may are used when referring to actions and activities by other parties than DNV GL.

Table 1-2 Definitions of verbal forms

<i>Term</i>	<i>Definitions</i>
<i>shall</i>	verbal form used to indicate requirements strictly to be followed in order to conform to the document
<i>should</i>	verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required
<i>may</i>	verbal form used to indicate a course of action permissible within the limits of the document

Table 1-3 Definition of terms

<i>Term</i>	<i>Definition</i>
<i>asset</i>	term used in the context of wind farm projects to describe the project or object to be developed, manufactured and maintained The term usually refers either to "wind turbines with support structures", the "offshore substation with topside and support structure" or "power cables".
<i>certification</i>	refers to third-party issue of a statement, based on a decision following review, that fulfilment of specified requirements has been demonstrated related to products, processes or systems (ISO 17000:2004)
<i>conformity statement</i>	IEC term for Conformity Statement
<i>customer</i>	DNV GL's contractual partner
<i>foundation</i>	the part of the support structure for a wind turbine or substation that transfers the loads acting on the structure into the seabed
<i>offshore substation</i>	term referring to transformer platforms and converter platforms, with or without accommodations An offshore substation may be defined as an integral element of the offshore wind farm project or as a separate asset for DNV GL project certification.

Table 1-3 Definition of terms (Continued)

<i>Term</i>	<i>Definition</i>
<i>offshore wind farm project</i>	term referring to the assets of a wind farm including total number of wind turbines, support structures, substations with topside and support structure and power cables
<i>onshore wind farm project</i>	term referring to the assets of a wind farm including total number of wind turbines, support structures, substations with topside and support structure, if relevant and power cables
<i>optional</i>	optional information or recommendations which are not part of the scope which is required in order to obtain conformity statements and project certificates
<i>project certificate</i>	a document signed by DNV GL and affirming that, at the time of assessment, the asset referred to on the certificate met the requirements stated in normative documents
<i>recommendation</i>	non-mandatory advice
<i>stand-alone operation</i>	an isolated operation of a wind turbine requiring stable and temporary operation connected to a discrete part of a power system or after network splitting
<i>verification</i>	verification consists of evaluating and checking information to establish that an object in question meets a technical requirement or standard Multiple verification activities are performed and successfully completed to support the decision to issue a statement of compliance.
<i>wind turbine</i>	system which converts kinetic energy in the wind into electrical energy

1.6.2 Acronyms, abbreviations and symbols

Table 1-4 Acronyms and abbreviations

<i>Short form</i>	<i>In full</i>
AC	alternating current
BGFE	Berufsgenossenschaft der Feinmechanik und Elektrotechnik /
CMP	critical manufacturing process
CTI	comparative tracking index
DC	direct current
dt	delta (of) time, time difference
dU	delta of voltage, voltage difference
EIS	electrical insulation system
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EN	European Norms
FRT	fault ride through
GL	Germanischer Lloyd SE
HVAC	heating, ventilation and air conditioning system
IAC	internal arc classification
IEC	International Electrotechnical Commission
I_k''	initial symmetrical short-circuit current
IP	degree of protection provided by enclosures
ISO	International Organization for Standardization
J	current density
LEMP	lightning electromagnetic impulses
LPL	lightning protection level
LPS	lightning protection system
LPZ	lightning protection zone
M	mechanical torque
M_n	nominal mechanical torque
n_3	maximum operating speed
NDE	non-drive end
n_{\max}	maximum overspeed which may never be exceeded
OVC	overvoltage category

Table 1-4 Acronyms and abbreviations (Continued)

P_r	rated power: maximum continuous electrical power (active power) at the output terminals of the wind turbine
PSCSS	power semiconductor converter systems
RCD	residual current protective device
RCM	residual current monitoring device
Rms	root mean square
SF6	sulfur hexafluoride
SPD	surge protection device
SRP/CS	safety-related parts of the control system
VDE	Verband der Elektrotechnik Elektronik Informationstechnik e.V.
v_{in}	cut-in wind speed of the wind turbine
UV	ultraviolet

1.6.3 Symbols

1.6.3.1 Latin characters

- A Expression of two-dimensional surface [m^2]
- F_{m_3} Force applied to a cable clamp [N]
- I_{p_3} Maximum aperiodic short-circuit current [A]
- a_m cable distance from centre to centre (independent of trefoil or single horizontal layer) [m]
- l Distance between cable clamps [m]

1.6.3.2 Greek characters

- μ_0 Magnetic permeability of free space (constant)

1.6.3.3 Subscripts

- c characteristic value
- d design value
- k characteristic value
- p plastic
- y yield

SECTION 2 OPERATION AND ENVIRONMENT

2.1 Environmental conditions

- 1) All electrical components shall be designed to comply with the operating and environmental conditions expected at the installation site.
- 2) The environmental conditions for the design shall be defined in terms of representative values or by the limits of the variable conditions. The probability of the simultaneous occurrence of environmental conditions shall be taken into account when the design values are selected.
- 3) External environmental condition values which shall be taken into account are defined in GL-IV-2, Edition 2012, Section 4.2.4.
Conditions deviating from these defined environmental conditions need to be specified in the design basis. For IEC 61400-1 standard wind turbine classes the values must not be less onerous than stated in Section 4.2.4 of GL-IV-2, Edition 2012.
- 4) Internal temperature assumptions concerning locations with electrical installations (at least in the hub and at the frequency converter) are to be specified in the design basis or in the design documentation. The internal temperature assumptions shall consider the site specific conditions with respect to duration of power production at different levels and external ambient temperature. For standard wind turbine classes and when site specific data are not available, the below assumptions may be applied without further justification:
 - wind speed above rated wind for 8 hours at maximum ambient temperature
 - grid loss after more than 8 hours of operation at wind speeds with more than rated wind
 - no wind for longer than 8 hours at the minimum outside temperature.

2.2 Grid parallel operation

- 1) With regard to the grid quality expected for wind turbines, reference is made to Section 4.2.4.10 of GL-IV-2, Edition 2012.
- 2) Grid connected wind turbines require approval from the relevant grid operator. In general, the grid code of the relevant grid operators shall be applied for this purpose.
Some countries require Grid Code Compliance (GCC) by law (e.g. Spain and Germany). The Technical Note *Certification of Grid Code Compliance* by GL Renewables Certification can be used for certification with regard to country specific requirements.

2.3 Island operation

- 1) In the absence of specific data, the values given in [Table 2-1](#) shall be assumed for the conditions in island operation:

Table 2-1 Permissible voltage and frequency deviations in stand-alone operation

Parameter	Deviation	
	permanent	short-term
A	Frequency	± 5%
	Voltage	± 10%
B	Voltage	± 20%
A: General		
B: Storage batteries and frequency converters		

For storage devices, [\[7.2.2\]](#) shall be applied as far as applicable.

Guidance note:

Deviations from these values are permissible if the connected consumers are suitable for this.

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- 2) Measures for monitoring and control of the electrical grid frequency shall be implemented in isolated grids.

- 
- 3) If further requirements are missing for the design, EN 50160 should be applied.
 - 4) As a proof of the ability to run in isolated grids, the wind turbine shall be operated for 100 hours during high and low wind speeds with variable and changing loads. This can be proven by testing. The test is accepted if no protection has tripped and the turbine has never overrun the design values for grid frequency and voltage.

SECTION 3 ROTATING ELECTRICAL MACHINES

3.1 General

- 1) Electrical machines in wind turbines (generator, main / auxiliary electrical motors) shall comply with standard IEC 60034-1:2010 "Rotating electrical machines – Part 1: Rating and performance" and other relevant standards of the standard series IEC 60034. This shall be proven by corresponding statements of the electrical machine manufacturer on the rating plate.
- 2) All data on the rating plate shall be provided as required in IEC 60034-1:2010 subclause 10.2. A corresponding rating plate shall be placed at each electrical machine.
- 3) Electrical machines shall be so designed and constructed that the permissible over-temperatures for the class of insulation are not exceeded, irrespective of the operating time. The values listed in IEC 60034-1:2010 should be used as guideline values.
- 4) Electrical machines shall be so designed to withstand the highest rotational speed according to table 18 of IEC 60034-1:2010.
- 5) Direct-drive generators that are more and more utilized for large multi-megawatt wind turbines require special treatment depending on the respective design and their integration to the overall wind turbine structure. Subsequent requirements refer mainly, but are not limited to slotted radial flux machines and shall be considered additionally:
 - The cogging torque of direct-drive machines should be reduced to a minimum. The presence of a cogging torque and its impact on structural parts (generator internal supporting structure but also external) shall be investigated and results shall be considered for the structural design.
 - The influence of generator temperatures on bearings, bearing clearance and lubrication shall be determined in an early design stage. Results shall affect the selection of these components and materials or the definition of maintenance activities and intervals.
 - The structural load path of direct-drive generators shall be of rigid design in order to limit operational variation of the air gap over the circumference. Concepts with magnetic bearing should be considered as an option.
 - Required adoption of test methods to manufacturing processes of a direct-drive generator shall be agreed with DNV GL beforehand. Scaling of test results gained from measurements at generator segments only shall be well documented, if applicable.

3.2 General design conditions

3.2.1 Rating of generators

3.2.1.1 Generators for wind turbines shall be designed for continuous operation (duty type S1 as per IEC 60034-1:2010). Other duty types shall be agreed upon with DNV GL.

3.2.1.2 The power rating according to the generator rating plate may differ from the maximum continuous electrical power (active power) P_r at the output terminals of the wind turbine as defined in GL-IV-2, Edition 2012, Section 2.2.2.7 para 1. This is acceptable, as long as the test reports of the generator tests show compliance with duty type S1 and insulation class as designed, as well as capacity of the generator to operate at P_r (considering the power losses between the generator and the output terminals of the wind turbine).

3.2.1.3 The generator shall be so designed to withstand the highest speed either according to Table 18 of IEC 60034-1:2010 based on the maximum operating speed n_3 of the wind turbine as defined in GL-IV-2, Edition 2012, Section 2.2.2.6 para 1 or with maximum overspeed n_{max} as defined in GL-IV-2, Edition 2012, Section 2.2.2.6 para 6, depending on which value is higher. Additionally, the speed rating of the generator shall take into account the frequency converter rating. The frequency converter system voltage and the level of the corresponding voltage testing depend on the maximum speed n_{max} , too. See [5.2.1.16] for details.

3.2.1.4 The insulation system of the generator (e.g. windings of stator/rotor) must support voltage peaks.

The maximum voltage change rate (dU/dt) shall be in compliance with the maximum value generated by the frequency converter system.

In general the insulation system of the electrical machines shall be in compliance with the requirements given in the subsequent standards of IEC 60034-18, depending on the deployed winding system (form-wound / wire-wound).

3.2.1.5 If the generator is used with a frequency converter system, measures shall be taken to limit the bearing current and shaft voltage. Possible measures are earthing system of the shaft, filters at the machine-side converter, insulated coupling to the gear box (if applicable) and/or bearing insulation.

The deployed measures shall be described (see also [5.2.1.16]). Corresponding calculations shall give the relation between shaft voltage and bearing current as well as shaft current measurements.

If the generator is used with frequency converter systems on the rotor side, the generator shall be equipped with slip rings for shaft earthing. The slip rings for shaft earthing should be installed at the NDE (non-drive end) or at both sides of the generator rotor.

3.2.1.6 The equivalent circuit diagram of the generator including the parameters given in Appendix 1 shall be applied for static and dynamic electrical calculations and simulations.

3.2.1.7 If synchronous generators are equipped with devices or other measures for short-circuit torque limitation, the resulting mechanical torque (M) at the shaft shall be analysed to show their function and efficiency. For a synchronous generator with separate excitation system, the parameters according to IEC 60034-16-3:1996 (Figure 1) shall be considered.

3.2.2 Rating of auxiliary motors

3.2.2.1 Motors shall be designed according to the operating times and temperatures to be expected. The designed duty types shall be given as specified in IEC 60034-1:2010 Part 1 or as per equivalent codes.

3.2.2.2 For motors used for rotor blade pitching and for yaw systems refer to Sec.14 additionally.

3.2.3 Materials

3.2.3.1 The materials for the construction of electrical machines shall be suitable for the expected environmental conditions; particular attention shall be paid to the corrosive effect of a marine atmosphere.

3.2.3.2 If plastics are used for casings, terminal boxes and fan wheels, flame-retardant materials suited for the ambient temperature range at the location of the plastic items shall be used.

3.2.4 Ventilation and cooling

3.2.4.1 In general electrical machines and their ventilation and cooling system shall comply with standard IEC 60034-5:2006 "Rotating electrical machines – Part 5: Degrees of protection provided by the integral design of rotating electrical machines (IP code) – Classification".

Draught-ventilated machines may be used if the machine is designed to be resistant against incoming air with moisture, oil vapour and dust, or if the incoming air is free from such.

3.2.4.2 Electrical machines for wind turbines shall be designed in fully enclosed form. Machines with a power output exceeding 50 kW shall be provided with drain holes to prevent the accumulation of condensed water. If necessary due to technical reasons also machines with lower power output shall be provided with drain holes.

3.2.4.3 The cooling circuit of the generator shall be monitored in a suitable manner.

3.2.5 Windings and permanent magnets

3.2.5.1 In conjunction with the protective devices provided, electrical machines shall be able to withstand the thermal and mechanical stresses occurring in the event of short-circuit. This shall be proven with a measurement report of the generator short-circuit testing (acc. to IEC 60034-1:2010 subclause 9.9) and/or short-circuit calculations including model description. For testing purposes, original protection devices

are not required. The worst cases defined in Appendix 4.C of GL-IV-2, Edition 2012 shall be tested. The following test values shall be given as a minimum: short-circuit torque at the generator shaft, short-circuit current at rotor and stator, winding temperatures during short-circuit.

3.2.5.2 The winding temperatures shall be monitored with regard to its limiting values. For generators thermistors or equivalent sensors shall be used. The temperature sensors shall be placed in the windings at the hot spots.

For auxiliary motors thermal overcurrent relays with bimetallic elements are also suitable.

3.2.5.3 For generators with permanent magnets installed a calculation or demonstration shall be provided to demonstrate that in the event of short-circuit the permanent magnets are not demagnetized due to high temperatures or high magnetization.

3.2.6 Bearings

3.2.6.1 Bearings shall be designed according to GL-IV-2, Edition 2012, Section 7.3.

3.2.6.2 To avoid damage to bearings, no harmful currents should flow between bearings and the shaft.

The bearing current density J for the bearings of electrical machines shall be less than 0.1 A/mm^2 . This shall be proven by corresponding calculations and/or measurements.

3.2.6.3 The bearing temperature shall be monitored with regard to its limiting values. Thermistors or equivalent sensors shall be used.

3.2.7 Generator testing

3.2.7.1 Generators for wind turbines shall be thermal- and performance-tested according to IEC 60034-1:2010.

3.2.7.2 For the thermal performance test according to IEC 60034-1:2010 chapter 8 the following applies:

If the machines are operated with frequency converters, the increased warming caused by the additional harmonics shall be taken into account during the type test as follows:

- Worst-case operating conditions for voltage and power factor, as normally defined in the design documentation of the wind turbine, shall be applied during the test. This refers to the lowest tolerable operating voltage with the maximum capacitive power factor.
- When carrying out the thermal performance test of the machine, the frequency converter that is used in the wind turbine should be operated at the same time and according to the worst-case operating conditions (see also [5.3.2.4]).
- If a thermal performance test under the above mentioned conditions is not possible for technical reasons, indirect testing methods and corresponding calculations (according to e.g. IEC 60034-29:2008) are permissible as an alternative.

Guidance note:

Expanded operating ranges for power factor and voltage are often the result of local requirements given in so-called grid codes. These requirements may an influence on the turbine design and must therefore be considered at an early design stage.

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3.2.7.3 The overspeed test according to IEC 60034-1:2010 subclause 9.7 shall be performed with each generator type used for wind turbines:

- for 2 minutes
- with the highest rotational speed, see [3.2.1.3]
- vibration measurements before and after the overspeed test (e.g. as per IEC 60034-14:2007 for generators with rated speed $\geq 120 \text{ rpm}$)
- as an alternative, the overspeed test can also be performed during balancing (balancing test before and after overspeed run on the balancing machine).

3.2.7.4 Additional tests:

- withstand voltage test acc. to IEC 60034-1:2010 subclause 9.2
- measurement of shaft currents and voltages (shaft to housing)
- for synchronous machines (optional, see [3.2.5.1]): Short-circuit withstand test acc. to IEC 60034-1:2010 subclause 9.9
- for synchronous machines: Total harmonic distortion (THD) acc. to IEC 60034-1:2010 subclause 9.11.

3.2.7.5 Routine tests shall be performed during the production of the machine, with the minimum scope as given in IEC 60034-1:2010 subclause 9.1.

3.2.8 Earthing

3.2.8.1 Electrical machines shall be provided with an earthing terminal or another connection point for earthing conductors. Requirements are given in IEC 60034-1:2010 subclause 11.1.

3.2.8.2 If generators with rated voltages above 1 kV are used, additional ground bolts shall be installed, to be able to earth correctly during maintenance or repair. Minimum requirements are given in IEC 60204-11:2000 subclause 5.

3.2.9 Carbon brushes

3.2.9.1 The length of the slip ring carbon brushes of the generator shall be monitored continuously (e.g. by a limit switch). Alternatively regular visual checks of the carbon brushes in appropriate intervals shall be included in the maintenance schedule.

3.2.9.2 The brushes have to be exchanged before total wear during maintenance or after alarm indication of the monitoring.

SECTION 4 POWER TRANSFORMERS

4.1 General

- 1) Power transformers with an apparent power greater than 100 kVA shall meet the requirements as set out in this Section.
- 2) Transformers shall comply with the latest version of the IEC 60076 series. This shall be verified through type test and routine test.
- 3) Test conditions and results of these tests shall comply with the requirements given in the respective parts of the IEC 60076 series. An overview of necessary type and routine tests is given in chapter 11 of IEC 60076-1:2011.
- 4) Data and information given on the rating plate shall be in accordance with the requirements of the IEC 60076 series. A corresponding rating plate shall be placed at each transformer.
- 5) When additional air-cooling with fans is provided, the transformer rating plate shall display the nominal power rating both with and without fans.
- 6) Power transformers shall be so designed and constructed that the permissible over-temperatures for the thermal class are not exceeded, irrespective of the operating time. Depending on the wind turbine design, the transformer might be operated at a frequency converter. The increased warming caused by the additional harmonics shall then be taken into account for the temperature-rise test e.g. by applying IEC 61378-1:2011 in addition to para 4.1.2.
- 7) Transformers used for internal power supply, reactors and power supplies shall be in accordance with the requirements given in IEC 61558-1:2009.
- 8) IP rating shall be similar for the transformer and its mounted accessories like gauges and monitoring equipment.

4.2 Installation

- 1) Power transformers shall be installed in separate rooms which can be locked (interlocking with de-energization required) and which are accessible to authorized personnel only. The installation locations for power transformers shall be sufficiently cooled. The access to the transformer room shall only be possible with the power transformer disconnected and earthed on the grid side.
- 2) An exception to the above can be made for power transformers of encapsulated or insulated design (with cable connection terminals being integrated in this design).
- 3) The fastening torque for cable connection terminals of power transformers has to be specified and shall be included in the design, erection and maintenance documentation.
- 4) Power transformers installed in the nacelle or in the tower head section of the wind turbine are exposed to a higher level of vibration compared to other locations. This shall be considered for the design and installation of the transformer.
- 5) Transformer accessories, e.g. external protection devices and monitoring equipment mounted on the transformer, shall be made of environment-resistant materials, when exposed to e.g. sun radiation or salty air. The capabilities shall be proven by application of the IEC 60721 series. Please refer additionally to [Sec.13 \(Offshore\)](#).
- 6) Transformer accessories, e.g. Buchholz, shall be easy accessible from ground level without the need for a ladder.
- 7) Lifting points on transformers should be NDT tested. Additionally, the lifting points should be capable of lifting the transformer with oil filled and all accessories installed in case of a liquid-immersed type. They shall be arranged in a way that no obstruction to lifting/slinging equipment will occur.
- 8) Transformers placed inside the WTG should have their own enclosure to minimize any extended damage in case of failure. For liquid-immersed transformers an enclosure of blast-wall type design is preferred.

Guidance note:

When erecting wind turbines with power transformers contained inside the tower or nacelle, the relevant authority regulations may be taken into account. Reference should be made to e.g. IEC 61936-1:2014 and EN 50522:2011.

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4.3 Protection

- 1) Power transformers shall be protected against short-circuit and overload.
- 2) It shall be possible to switch off power transformers on all sides. Installation shall facilitate disconnection of this equipment on all sides if voltages can be applied on more than one side.
- 3) Power transformers shall be fitted with temperature monitoring.
- 4) Transformers shall be protected against transient overvoltage and electrical stress on the insulation as needed.

4.4 Dry-type power transformers

- 1) In addition to para 4.1.3, IEC 60076-11:2004 shall be applied for the design of dry-type power transformers.
- 2) The transformer shall be able to withstand the conditions at the place of installation without accelerated ageing or weakening of the electrical insulation system (EIS) including the insulation of all transformer terminals, to prevent fire from being caused by the transformer. Such conditions are:
 - salty (and / or wet) air from outside which might come in contact with the EIS
 - pollution on the EIS from moisture, dust, coal powder and brake lining in the concentrations occurring inside the transformer enclosure
 - vibrations.

This can best be achieved by using a protection degree of IP 55 for the transformer including transformer terminals and connection terminals. Transformer cooling shall be implemented accordingly, taking into account possible condensation.

- 3) The power transformer shall be self-extinguishing. The fire class shall be F1 according to IEC 60076-11:2004, where applicable.
- 4) The enclosure of the transformer, including any internal cooling system, shall be designed with protection degree IP 55 or higher. If not:
 - Regular cleaning (from salt and dirt) of the EIS surfaces is required in a way and frequency achieving sufficient surface resistance on the EIS to maintain the electrical integrity during lifetime.
 - Increased surface insulation level of the EIS to withstand the higher voltage of a permanently earthed insulation surface with a permanent and very low surface resistance.
 - The transformer has passed the test E3 according to IEC 60076-16:2011 with humidity of above 95% and water conductivity in the range between 3.6 S/m to 4 S/m.
- 5) Resin-encapsulated or solid-cast design shall be used only.

4.5 Liquid-immersed power transformers

- 1) Liquid-immersed power transformers shall be provided with a collecting pan / oil sump which permits the proper disposal of the liquid and prevents environmental pollution due to leakage. It should be designed to take full oil volume of tank.
- 2) Liquid-immersed power transformers shall be fitted with protection against over-pressure (pressure relief device) and shall not pander to outgassing.
- 3) The liquid temperature shall be monitored. An alarm shall be actuated before the maximum permissible temperature is attained. When the temperature limit is reached, the transformer shall be disconnected.
- 4) The liquid filling level shall be monitored.
- 5) Buchholz relay or adequate electronic relay is required for every non-hermetically sealed power transformer with conservator.
- 6) Hermetically sealed power transformers shall be equipped with high quality tank designs and monitoring of the sealing shall prevent early aging of the transformer.
- 7) If conservator is used a bagged conservator design is a must for transformer breathing.

SECTION 5 FREQUENCY CONVERTERS

5.1 General

- 1) Frequency converters are power semiconductor converter systems (PSCSs) as defined in IEC 62477-1:2012 Edition 1. They are normally used in pairs, one being connected to the rotating electrical machine (machine-side converter) and one to the power transformer and thereby with the grid (grid-side converter). Both are interconnected by a DC bus, backed by power capacitors. Grid-side and machine-side converters can be designed as parallel modules or as one single module.
- 2) Sections [5.1] to [5.4] apply for main frequency converters when used within the wind turbine in connection with the generator. When used in connection with other systems, only [5.5] is applicable.
- 3) For frequency converters with voltages above 1000 V AC or 1500 V DC (medium voltage converter), additional requirements given in IEC 61800-4:2002 shall be applied.
- 4) Power electronics shall be designed in accordance with the electromagnetic immunity requirements and requirements for electro-magnetic emissions (electromagnetic compatibility, EMC). The relevant EMC requirements are given in IEC 61800-3:2012.
- 5) The manufacturer of the frequency converter shall evaluate the results, proving that the EMC requirements are fulfilled based on measurements of a test laboratory, accredited according to ISO/IEC 17025:2005 for IEC 61000-4-30:2008, IEC 61400-21:2008 and IEC 61800-3:2012.
Based on the test results concerning EMC, the manufacturer of the frequency converter shall require corresponding measures that have to be observed during installation or assembly. At a minimum, the shielding of connecting cables shall be defined in detail by the frequency converter manufacturer.
- 6) The frequency converter or its control system may be applied for testing of the Load-Relevant control and safety system Functions (LRF) in a hardware-in-the-loop environment.

5.2 General design conditions

5.2.1 General design and data to be provided

5.2.1.1 Protective earthing shall be designed according to IEC 62477-1:2012 subclause 4.4.4.3 and confirmed by the frequency converter manufacturer.

5.2.1.2 Protective bonding shall be designed according to IEC 62477-1:2012 subclause 4.4.4.2 and tested by the frequency converter manufacturer according to IEC 62477-1:2012 subclause 5.2.3.11 (see also [5.3.2.3]).

5.2.1.3 The design concerning the connections between frequency converter and wind turbine, as defined in IEC 62477-1:2012 subclause 6.3.6 (power conductor type, size, amount of cables etc.), shall be stated by the frequency converter manufacturer.

5.2.1.4 Statement and definition of environmental conditions shall be given according to the standard series IEC 60721. Guidance and minimum scope of documentation can be found in IEC 62477-1:2012 subclause 4.9.

5.2.1.5 Insulation design shall be rated according to IEC 62477-1:2012. For this, the impulse withstand voltages and temporary overvoltages shall be defined and tested for main power circuits. The impulse withstand voltages and the temporary overvoltages shall be determined according to Table 10 in IEC 62477-1:2012 subclause 4.4.7.1.5 (insulation voltages). For this, the system voltages of machine-side converter and grid-side converter have to be defined.

5.2.1.6 The system voltage of the machine-side converter shall not be less than the rms value of the maximum voltage phase-to-earth at one of the following operational points whichever is the most severe:

- at the highest possible rotational speed n_{\max} (maximum overspeed as defined in GL-IV-2, Edition 2012, Section 2.2.2.6 para 6) with disconnected grid-side converter
- at minimum rotational speed occurring with the generator being connected at wind speeds above v_{in} (cut-in wind speed as defined in GL-IV-2, Edition 2012, Section 2.2.2.8 para 1)
- at maximum voltage at the highest possible electrical power P_A (activation power as defined in GL-IV-2, Edition 2012, Section 2.2.2.7 para 3).

The system voltage of the grid-side converter shall be determined by the manufacturer of the frequency converter according to IEC 62477-1:2012 subclause 4.4.7.1.6.1.

5.2.1.7 The overvoltage category according to IEC 62477-1:2012 shall be OVC III for the machine-side converter and OVC III for the grid-side converter, provided the main frequency converter is installed in Lightning Protection Zone 1 (LPZ 1) or better.

5.2.1.8 Clearance distances shall be designed according to IEC 62477-1:2012 subclause 4.4.7.4, creepage distances according to IEC 62477-1:2012 subclause 4.4.7.5. This shall be documented by a corresponding statement. This statement shall contain the following information:

- CTI (comparative tracking index) according to IEC 62477-1:2012 subclause 4.4.7.5.1 and IEC 60112:2009 for all parts of the main power circuit inside the frequency converter
- pollution degree according to [Table 5-1](#).

Table 5-1 Definitions of pollution degree according to IEC 62477-1:2012, Table 8

Pollution degree	Description
1	No pollution or only dry, non-conductive pollution occurs. The pollution has no influence.
2	Normally, only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation is to be expected.
3	Conductive pollution or dry non-conductive pollution occurs, which becomes conductive due to condensation which is to be expected.
4	The pollution generates persistent conductivity caused, for example by conductive dust or rain or snow.

5.2.1.9 For the main power circuit (including busbars) and inductors, solid insulation material shall be used which has a proven performance according to IEC 62477-1:2012 subclause 4.4.7.8.

5.2.1.10 In the case of plugs or similar devices that can be disconnected without the use of a tool, and in case their withdrawal results in the exposure of conductors (e.g. pins), the discharge time shall not exceed 1 s, otherwise such conductors shall be protected against direct contact as per IPXXB at least. If neither a discharge time of 1 s nor a protection of at least IPXXB can be achieved, disconnecting devices with an appropriate warning shall be applied instead.

5.2.1.11 Cooling shall comply with IEC 62477-1:2012 subclause 4.7.2.2.

5.2.1.12 When the coolant is intentionally in contact with live parts (for example non-earthed heat sinks), the conductivity of the coolant shall be continuously monitored and controlled, in order to avoid hazardous current flow through the coolant.

5.2.1.13 The temperatures of at least the cooling circuits, of the semiconductors and inductors shall be monitored in a suitable manner. The maximum allowed limits shall be stated by the frequency converter manufacturer.

5.2.1.14 The distance between terminals of main power flow and any obstruction toward which the wire is directed upon leaving the terminal shall be at least that specified in [Table 5-2](#).

Table 5-2 Wire bending space from terminals to enclosure according to IEC 62477-1:2012, Table 19

Size of wire mm ²	Minimum bending space, terminal to obstruction [mm]		
	Wires per terminal		
	1	2	3
10 – 16	40	-	-
25	50	-	-
35	65	-	-
50	125	125	180
70	150	150	190
95	180	180	205
120	205	205	230
150	255	255	280
185	305	305	330
240	305	305	380
300	355	405	455
350	355	405	510
400	455	485	560
450	455	485	610

5.2.1.15 If a DC chopper is used to convert excess energy to heat (e.g. to reduce mechanical loads or during Fault Ride Through (FRT) situations), the design shall be described. At a minimum, the following details shall be given: maximum power and maximum operation time at full power, resistance range to be set, cooling time after full-power maximum-time operation, and cooling principle. All trigger values and trigger situations shall be given.

5.2.1.16 The current flowing through generator bearings and generator shaft shall be analysed and possible paths shall be described. This analysis shall consider the measured shaft current and touch current from the converter, to be measured during the joint heat-run type test of the generator and frequency converter (see [5.3.2.4] and [3.2.7]).

5.2.1.17 The maximum value of voltage steepness (dU/dt) at machine-side and at grid-side shall be given and verified by measurement; see [5.3.2.5].

5.2.1.18 Condensation inside the frequency converter shall be avoided. Therefore heating procedures after standstill (e.g. after grid loss) shall be implemented in the converter control and/or wind turbine control system.

5.2.2 Protection equipment

5.2.2.1 All power electronics shall be protected against overload and short-circuit. It shall not be possible for a semiconductor element to be destroyed in the event of a single malfunction outside the element itself. Protection of the installation may be achieved by fuses, circuit breakers or the intervention of the control system.

Guidance note:

Effective protection of the semiconductors against short-circuit currents can be achieved by a fast reacting converter control system by switching off power modules before the peak of short circuit current occurs and following switching of upstream circuit-breaker / fuses.

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5.2.2.2 Single-phase protection equipment is not acceptable for three-phase installations. Exceptions can be made if other mechanisms ensure that three-phase tripping takes place in the case of one-phase faults. If fuses are used, a corresponding mechanism shall be implemented.

5.2.2.3 The protection equipment shall ensure that, in the event of a disconnection, the energy stored in the components and the load circuit cannot have a damaging effect and that, in the event of a failure of essential components, the wind turbine is brought to a standstill in a controlled manner and damaged subsystems are switched off as selectively as possible.

5.2.2.4 Permanent self-test facilities are required for voltage loss, overvoltage and overcurrent protection equipment as well as for communication failure, to safeguard the function of the protection equipment.

5.2.2.5 Sec.8 Low voltage switchgear, controlgear and switchboards shall apply as far as it is relevant.

5.2.2.6 In accordance with IEC 60364-5-53:2002, semiconductor devices shall not be used for the purpose of isolating from power sources.

Guidance note:

For the selection of RCD (residual current-operated protective devices) or RCM (residual current monitoring devices), guidance concerning typical failure current waveforms is given in IEC 62477-1:2012, subclause 4.4.8 and Annex H.

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5.2.2.7 Capacitors within a frequency converter shall be discharged to an energy level of less than 20 J, as set out in IEC 62477-1:2012 subclause 4.5.1.2, within 5 s after the removal of power from the frequency converter.

If capacitors are located behind panels that are removable for service, installation or disconnection no risk of electric energy hazard from charge stored on capacitors shall be present after disconnection of the frequency converter. They shall be discharged to a voltage less than DVC A (given in IEC 62477-1:2012 Table 5), within 5 s after the removal of power from the frequency converter.

If the above mentioned requirements are not achievable for functional or other reasons, then [5.4] item 3 shall apply.

5.2.2.8 If a crowbar is used for the protection of the frequency converter against excessive currents or voltages in the generator rotor, the design shall be described. At a minimum, the trigger values, resistance and maximum operation time shall be given, as well as minimum cooling time after maximum operation time.

5.2.2.9 The frequency converter and the installed power electronics inside shall be protected sufficiently against overvoltages (e.g. due to lightning, grid disturbances). For requirements regarding overvoltage protection please refer to [10.3.10].

5.3 Testing

5.3.1 Routine testing

5.3.1.1 Each frequency converter shall be routine-tested after production. Routine tests shall contain the following items as a minimum:

- visual inspection
- tightness of cooling system, except for air-cooled frequency converters
- plausibility checks of voltage waveform and phase angle
- preloading and discharging of DC capacitors
- test of grid synchronization
- heating test, showing the proper heating behaviour of the power semiconductors with the cooling system running.

5.3.1.2 As part of the routine test the protective bonding impedance shall be measured according to IEC 62477-1:2012 subclause 5.2.3.11.4. The test result shall be compliant with the requirements given in IEC 62477-1:2012 subclause 5.2.3.11.2.2. If the result is not compliant with these requirements, an exception is possible in the following case:

The converter is fully assembled in a closed switchboard by the converter manufacturer and the connection to the protective earthing system of the wind turbine is effected by more than one means (e.g. by two or more protective bonding cables).

5.3.1.3 For each semiconductor module a burn-in test shall be carried out at maximum overload current for maximum overload time. This is to be done typically by the manufacturer of the semiconductor modules. Test reports shall be provided.

5.3.2 Type testing

5.3.2.1 Type testing of the frequency converter shall be performed in order to verify design assumptions for this component. The measurements shall be performed by staff who are independent of the production or design team. The place of testing will usually be the factory of either the frequency converter or the generator.

5.3.2.2 Type testing should be performed in following order immediately after each other: first the heat run, then voltage testing, and finally partial discharge testing.

5.3.2.3 For type testing at least following electrical tests according to IEC 62477-1:2012 subclause 5.2.3 shall be performed:

- impulse voltage test (IEC 62477-1 subclause 5.2.3.2)
- AC or DC voltage test (IEC 62477-1 subclause 5.2.3.4)
- partial discharge test (IEC 62477-1 subclause 5.2.3.5)
- touch current measurement test (IEC 62477-1 subclause 5.2.3.7)
- protective equipotential bonding test (IEC 62477-1 subclause 5.2.3.11)
- temperature rise test (IEC 62477-1 subclause 5.2.3.10).

5.3.2.4 The temperature rise test (see also Section 3.2.7.2) shall be performed together with the generator type under evaluation according to IEC 62477-1:2012 subclause 5.2.3.10 for the operational mode with the highest operating temperature. This operational mode shall be described, giving frequency, voltage and current at a minimum. The test shall be performed together with the generator and all relevant filters.

Subclause 4.6.4.1 and Table 14 of IEC 62477-1:2012 shall be observed. During the temperature rise test, the parameters specified in [5.3.2.5] to [5.3.2.6] and [5.2.1.16] shall be measured additionally.

5.3.2.5 The maximum voltage steepness during normal operation (see [5.2.1.17]) shall be measured at the machine-side and grid-side. The measurement shall be performed together with the filters used.

5.3.2.6 The following values shall be measured between generator and frequency converter:

- current rms values
- currents of frequencies higher than 50 Hz, measured analogously to IEC 61400-21:2008 subclause 7.4: Current harmonics, interharmonics and higher frequency Components (comment: "analogously" is used here because IEC 61400-21:2008 is valid for the entire wind turbine)
- maximum possible current of the machine-side converter
- for reference purposes, the simultaneous voltage on the DC bus.

5.3.2.7 Frequency converter with forced cooling shall be operated at rated load with fan or blower motor or motors made inoperative, singly or in combination with a single fault, by physically preventing their rotation. This shall be done until a reaction of the frequency converter can be seen.

5.3.2.8 If coolants other than air are used, the hydrostatic pressure test according to IEC 62477-1:2012 subclause 5.2.7 and the loss of coolant test according to IEC 62477-1:2012 subclause 5.2.4.9.4 shall be passed successfully as a type test.

5.3.2.9 Vibration test according to IEC 62477-1:2012 subclause 5.2.6.4 with the requirements given in IEC 62477-1:2012 subclause 4.9 shall be performed.

5.4 Installation, commissioning and maintenance

- 1) Manuals shall contain as a minimum the requirements of IEC 62477-1:2012 subclause 6.3.8 for commissioning and subclause 6.5 for maintenance.

- 2) The marking and scope of data to be given on the rating plate and in the manuals shall be in accordance with IEC 62477-1:2012 subclause 6.
- 3) When the requirements of [5.2.2.7] are not met, the warning symbol ISO 7010-W001 (see Annex C of IEC 62477-1:2012) including an indication of the discharge time (e.g. 45 s, 5 min) shall be placed in a clearly visible position on the enclosure, the capacitor protective barrier or at a point close to the capacitor(s) concerned (depending on the construction). The symbol shall be explained and the time required for the capacitors to discharge after the removal of power from the frequency converter shall be stated in the manuals.

Guidance note:

Additionally to the warning symbol ISO 7010-W001 converters can be equipped with display or lamps that indicate when the capacitors are discharged.

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5.5 Frequency converters connected to other systems than generator

- 1) This subsection shall be used for all applications of frequency converters in the turbine, except the main power generator system.
- 2) For frequency converters used for rotor blade pitching and for yaw systems please refer additionally to Sec.14.
- 3) The requirements of [5.1] item 4 applies additionally.
- 4) For frequency converters driving rotating electrical machines supplied by DC voltages, the rating plate and corresponding specifications shall be given according to IEC 61800-1:1997 subclause 8 (product information) plus the maximum voltage change rate dU/dt in kV/ms.
- 5) For frequency converters driving rotating electrical machines supplied by AC voltages, the rating plate and corresponding specifications shall be given according to IEC 61800-2:1998 subclause 8 (product information), plus the maximum voltage change rate dU/dt in kV/ms.

SECTION 6 HIGH-VOLTAGE SWITCHGEAR

6.1 General

- 1) High-voltage switchgear with rated voltages above 1 kV shall meet the requirements as set out in this section.
- 2) High-voltage switchgear shall comply with the IEC 62271 series. This shall be verified through type test and routine test. The scope of type test shall contain at least the following tests:
 - Dielectric tests
 - Short-time withstand current and peak withstand current tests
 - Internal fault

The test reports shall contain the results of these tests and the test conditions. Additionally, the IAC code as result of the internal fault test shall be given in the test reports (see also [6.2.1.2]).

- 3) Information on the nameplate shall be in accordance with the IEC 62271 series. A corresponding nameplate shall be placed on each switchgear.

6.2 General design conditions

6.2.1 Protective measures and tests

6.2.1.1 A risk of personal injury through electrical shock and internal arcs shall be minimized, independently of the necessary protection against foreign matter and water.

6.2.1.2 With reference to the IEC 62271 series, only IAC-qualified high-voltage switchgear shall be installed inside the wind turbine. The test current applied shall be as high as the rated short-time withstand current of the respective type of switchgear used.

6.2.1.3 Installation of the switchgear within the tower or nacelle shall be in accordance with the IAC accessibility type of the switchgear used.

6.2.1.4 National and local regulations shall be observed when undertaking the local operation, inspection or maintenance on the high-voltage switchgears. Special attention shall be paid to the work in the pressure-release area. It shall be ensured that all primary (all incoming- and outgoing feeders) and control circuits of the switchgear have been de-energized and grounded and that proper steps have been taken to ensure that they will remain de-energized until all work is completed.

6.2.2 Pressure relief

6.2.2.1 If the gas pressure resulting from internal arcs within the switchboard is to be vented via pressure-release flaps, the installation space shall be as specified by the switchgear manufacturer and shall have an adequate volume. Suitable measures shall be taken to ensure that the overpressure occurring within the space is limited to physiologically acceptable limits. This overpressure shall be taken into account for the structural design of the installation space.

6.2.2.2 If the switchgear is designed that the gas pressure caused by internal arcs is also, or only, released downwards, the floor shall be constructed so that it can withstand this pressure. Care shall be taken to ensure that sufficient volumes of space are available below the floor for the expansion of the internal-arc gases.

6.2.2.3 Combustible materials and low-voltage cables are not admissible in the endangered area.

6.2.2.4 Suitable drawings of the installation place shall be included in the manuals (for installation / operation / commissioning).

6.2.3 SF6 Switchgear

SF6 switchgear shall only be installed in spaces which are adequately ventilated. This might conflict with an overall sealing of the nacelle and / or tower for corrosion protection purposes. In this case, adequate monitoring of the SF6 pressure and short-circuit would be a solution. The design and specific solutions shall generally exclude the risk of hazards to service personnel.

It shall be taken into account that SF6 is heavier than air and the gases escaping in the event of internal arcing have toxic and corrosive effects. For detailed information please refer to national requirements, e.g. for Germany BGV A8 and BGI 753 by BGFE (Berufsgenossenschaft der Feinmechanik und Elektrotechnik).

SECTION 7 BACK-UP POWER SUPPLY SYSTEM

7.1 General

- 1) This section considers electrical back-up power supply systems as a functional unit comprising charging equipment and energy storage systems. It applies to back-up power supply systems installed as an independent source of electrical power for safety systems, braking systems, emergency consumers, control systems and systems which are necessary to regulate the climatic conditions inside the wind turbine.
- 2) Back-up power supply systems within the scope of this section shall be designed to cover failures of the internal or external power supply such as:
 - grid disturbances or grid loss
 - failure of the external power supply (e.g. supply of electricity from the grid, external batteries, diesel generators, etc.).
- 3) For safety related requirements please refer additionally to GL-IV-2, Edition 2012, Sections 2.2.2.12 and 2.2.2.13.

7.2 General design conditions

7.2.1 Charging equipment

7.2.1.1 Only automatic chargers with charging characteristics adapted to the type of energy storage system, such as special battery types etc., shall be used.

7.2.1.2 Overcharging shall be prevented by automatic charger control adapted to the installed battery type or, if necessary, by dump loads which can be switched on.

7.2.1.3 If consumers are supplied while charging is in progress, the consumers shall be designed for operation at the maximum charging voltage.

7.2.1.4 Charging equipment shall be protected against short-circuit and overcurrent on both the input and the output side.

7.2.2 Energy storage system

7.2.2.1 For rating of the energy storage system of back-up power supply systems the internal environmental conditions according to [2.1] shall be considered and the assumptions made for load case definitions shall be taken into account (e.g. pitch system manoeuvres during grid disturbances or grid failure).

7.2.2.2 For rating of the energy storage system of back-up power supply systems intended for braking systems or safety systems, following requirements shall be considered:

- The energy storage system shall be automatically monitored that a sufficient amount of energy is available at least for one emergency braking.
- The accumulator temperature shall be monitored.
- The batteries shall be protected against thermal run away and overheating.
- If the automatic monitoring of the energy storage system cannot be carried out continuously, automatic tests shall be performed at least weekly to show that a sufficient amount of energy is available. The wind turbine shall shut down immediately if the automatic monitoring or test result is out of limits.
- If a failure in the energy storage system is detected and the wind turbine is shut down, an automatic re-start is not permissible.

7.2.2.3 Sufficient rating of the energy storage system of a back-up power supply system shall be proven on the basis of calculations. All design limits, such as maximum load current, temperature limits, discharge limits etc., shall be stated in the calculations.

7.2.2.4 Batteries, capacitor banks or other technologies used for energy storage systems shall permit an adequate number of charge / discharge cycles. The design lifetime, including assumptions and calculations, and the exchange intervals and/or exchange criteria shall be defined by the manufacturer.

7.2.2.5 Warning signs indicating DC voltages higher than 60 V and risks caused by batteries/capacitors, if applicable, shall be provided on the enclosure of the energy storage system. For capacitors an indication of the discharge time (e.g. 45 s, 5 min) shall be placed in a clearly visible position on the enclosure, the capacitor protective barrier or at a point close to the capacitor(s) concerned (depending on the construction). The symbol shall be explained and the time required for the capacitors to discharge after the removal of power shall be stated in the manuals.

7.2.2.6 In case of redundant braking systems the energy storage systems for these shall be located in independent enclosures.

7.2.3 Installation and operation of batteries

7.2.3.1 Environmental conditions shall be determined for the locations of the battery enclosures in accordance with IEC 60721.

7.2.3.2 To avoid sparking, circuits shall be switched off before batteries are connected or disconnected.

7.2.3.3 Batteries mounted in the hub shall be suitable for the special requirements resulting from the rotation.

7.2.3.4 Enclosures for back-up power supply systems shall be resistant against corrosion due to salty and humid sea air, if applicable. They shall in each case have a minimum protection class of IP 54. If they contain batteries and if there is a risk of outgassing, there shall be provision for sufficient air exchange.

7.2.3.5 Back-up power supply systems shall be installed in a way that they are accessible for maintenance work.

7.2.3.6 If capacitor banks are used for energy storage systems, the partial voltages of capacitor groups shall be monitored instead of monitoring the overall voltage of the capacitor bank. No charging shall take place during monitoring.

7.2.4 Back-up power supply for long periods

7.2.4.1 If the wind turbine is out of operation for a longer period due to e.g. absence of the grid connection, a back-up power supply may be intended to supply elementary functions of the wind turbine (e.g. control system, safety system, brake systems). As a rule the period has the duration of 3 months. For this, the requirements as given in [7.2.4.3] to [7.2.4.7] shall be considered.

7.2.4.2 If a system is necessary to control the climatic conditions inside the wind turbine (temperature, humidity, constant overpressure), measures shall be taken to keep the corresponding climate in the wind turbine during a grid outage for up to 3 months. Information according to the requirements given in [7.2.4.3] to [7.2.4.7] shall be documented.

7.2.4.3 The power supply shall be dimensioned in such a way, that it will be able to supply the necessary starting or inrush currents and the energy consumption needed. This shall be documented in a power consumption schedule.

Power consumption management shall be made where necessary to achieve these requirements. The simultaneous power consumption according to this management shall be stated in the power consumption schedule.

7.2.4.4 The energy storage of the back-up power supply has to fit properly on site.

7.2.4.5 The size of the energy storage shall be dimensioned in order to achieve the requirements as given in [7.2.4.3] to [7.2.4.4] depending on the intended application given in [7.2.4.1] and/or [7.2.4.2].

7.2.4.6 The evaluation documents shall contain the size of the storage and the energy consumption calculations of the chosen back-up power supply.

7.2.4.7 The energy level (content of the energy storage) has to be monitored and alarm levels have to be defined.

7.2.4.8 To prevent damage in the gear during grid unavailability the energy needed for fast shaft brake operation and control shall be taken into account were necessary.

7.2.5 Auxiliary power generation for offshore applications

7.2.5.1 In case of grid losses for longer periods (e.g. before grid connection of the offshore wind farm or during problems with the grid connection or inner array connection to the offshore substation) auxiliary diesel generators may be used for the external power supply of the wind turbine.

7.2.5.2 The auxiliary diesel generators are to be installed in suitable engine rooms inside the wind turbine or outside the wind turbine (e.g. outer entrance platform). If installed inside combustion air shall be provided independently out of the wind turbine. If installed outside, the environmental offshore conditions shall be considered.

7.2.5.3 The arrangement shall ensure faultless operation of the diesel generator unit under all ambient conditions for the place of installation, particularly with regard to the supply of fresh air and the removal of exhaust air. The aggregates shall be capable of being started, connected, disconnected and monitored from the remote control room in case of a failure of the normal power supply.

7.2.5.4 The capacity of the generating set shall be dimensioned to fulfil the following requirement: If the wind farm is shut down and neither power supply from the onshore grid nor from the offshore substation are available, sufficient supply shall be possible for those services necessary to maintain normal operating conditions with respect to the functioning and safety of the wind turbine.

7.2.5.5 The apparent power of a three-phase generator shall be such that no inadmissible voltage drops occur in the installation's mains due to the normal starting currents of motors. The start-up of the motor with the greatest starting current shall not give rise to a voltage drop causing other consumers to malfunction.

7.2.5.6 The electric generator of auxiliary diesel generator sets shall comply with IEC 60034 series.

7.2.5.7 Starting-up of the auxiliary generator set shall be possible without external power (from grid or offshore substation). Adequate measures (e.g. batteries or connection to the back-up power supply system of the wind turbine) shall be considered.

7.2.5.8 The auxiliary diesel generator shall be protected against overload and short-circuit.

7.2.5.9 For requirements regarding installation and operation of batteries, please refer to [7.2.3].

SECTION 8 LOW-VOLTAGE SWITCHGEAR, CONTROLGEAR AND SWITCHBOARDS

8.1 General

- 1) The requirements of this section apply to low-voltage switchgear and control gear assemblies with operating voltages of up to 1000 V AC or 1500 V DC.
- 2) Stationary or movable switchboards with or without enclosure shall comply with the standard IEC 61439-1:2011.
- 3) Low-voltage fuses with a rated breaking capacity of at least 6 kA shall comply with the standard IEC 60269-1:2006 + A1:2009.
- 4) All appliances, instruments and operating elements (e.g. sensors, limit switches) shall be permanently labelled in accordance with the corresponding circuit diagrams.

8.2 Protection

8.2.1 General

All components of the electrical installation shall be protected against short-circuit and overload.

8.2.2 Short-circuit

8.2.2.1 The rated breaking capacity of each circuit breaker used for short-circuit protection should not be less than the maximum possible short-circuit current at the point of installation (Otherwise see [8.2.7]).

8.2.2.2 Short-circuit current calculations shall be carried out for the main circuits.

8.2.2.3 The short-circuit calculation shall consider all possible short-circuits. The following types of short-circuits shall be investigated at least:

- short-circuits on the rotor and stator terminals of the generator (except for permanent magnet rotors)
- short-circuits on main busbars.

8.2.2.4 The following values shall be determined according EN 60909:

- peak short-circuit current i_p
- initial symmetrical short-circuit current (I_k'').

8.2.2.5 The short-circuit current calculation shall be accompanied by a list of the switching devices and their characteristic data. The rated making capacity, the rated breaking capacity and the utilization category according to the IEC 60947 series of the switching appliances shall be stated.

8.2.3 Overload

The selection of overload protection devices shall be based on the rated currents in the cable or circuit.

8.2.4 Overcurrent

8.2.4.1 The current-time characteristics of overcurrent protection devices shall be compatible with the system components to be protected and with the requirements of selectivity.

8.2.4.2 The overcurrent protection of the entire circuit (switchgear, switchboard wiring, supply cables and equipment) shall be based on the rated current in of the connected equipment. In the case of grouped supply cables, the protection design shall be based on the evaluated total rated current.

8.2.5 Selectivity

The short-circuit protection of main equipment shall be selective and shall ensure that only the switching device nearest to the fault initiates disconnection of the defective circuit.

8.2.6 Residual current

Residual current protective devices (RCDs) shall be provided for socket-outlets for maintenance purposes with a rated current up to 32 A.

8.2.7 Back-up

Circuit breakers with making / breaking capacities of less than the anticipated maximum short-circuit currents shall be protected by back-up fuses of sufficient breaking capacity.

8.3 Switching devices

8.3.1 General

8.3.1.1 Switching devices shall comply with IEC 60947-1:2011.

8.3.1.2 The making and breaking capacity of switchgear shall be stated by the manufacturer and entered into the documentation.

8.3.1.3 The rated current values of fuses shall be stated in the circuit diagrams. The set values of the adjustable protection equipment shall be stated in the circuit diagrams and permanently marked on the device either on the scales or on plates fixed nearby.

8.3.1.4 Switches and circuit breakers in three-phase circuits shall disconnect all phases simultaneously.

8.3.2 Switches

Switches shall be rated for at least the rated current of the back-up fuse.

8.3.3 Circuit breakers

8.3.3.1 The rated making capacity of a circuit breaker should not be less than the maximum asymmetric short-circuit current which may occur at the point of installation (Otherwise see [8.2.7]).

8.3.3.2 In the case of a fault in the circuit breaker on the low-voltage side of the power transformer, the high-voltage switchgear shall trip.

8.3.4 Fuses

Fuse links shall have an enclosed fusion space.

8.3.5 Motor-circuit switches

8.3.5.1 Motors with a power rating of more than 1 kW shall be individually protected against overloads and short-circuits.

8.3.5.2 Regardless of its rating, every motor shall be protected by a suitable short-circuit protection device.

8.4 Switchgear and controlgear assemblies

8.4.1 General

8.4.1.1 Electrical components mounted in the doors of switchboards for voltages over 50 V shall be safeguarded against accidental contact. Such doors shall be earthed.

8.4.1.2 Electric equipment and fuses shall be safely accessible.

8.4.1.3 For circuit breakers and load-switches, the minimum distances above the arc chutes specified by the manufacturers shall be kept free.

8.4.2 Protection class

8.4.2.1 The degree of protection of an enclosed assembly against contact with live parts shall be at least IP2X according to IEC 60529:2013.

8.4.2.2 The degree of protection according to IEC 60529:2013 of an enclosed assembly against water shall be at least:

- IPX1 in the tower
- IPX2 in the nacelle
- IPX4 in the hub.

8.4.2.3 Unless specified otherwise, the degree of protection indicated by the manufacturer applies to the complete assembly when installed in accordance with the manufacturer's instructions, for example sealing of the open mounting surface of an assembly, if necessary.

8.4.3 Corrosion protection

In order to insure effective corrosion protection of steel structures, every low-voltage switchgear, control gear and switchboard shall be protected by paint coatings. The painting material used shall be suitable for the environmental requirements specified in [2.1].

8.4.4 Climate

8.4.4.1 During operation, the air temperature in enclosed switchboards shall not exceed +45 °C and shall not fall below -5 °C, otherwise all components shall be verified concerning their operation conditions.

8.4.4.2 At longer periods of grid loss all electrical components will be exposed to the ambient temperature. Therefore the withstand temperatures of the components have to correspond with the applicable ambient temperatures as specified in [2.1].

8.4.5 Tests

To verify the characteristics of a switchboard, type tests shall be performed according to IEC 61439-1:2011. The measurements shall be performed by staff who are independent of the production or design team. The complete test reports shall be submitted to the certification body.

8.5 Electrical apparatus

8.5.1 Terminal bars

8.5.1.1 All screws and other connections shall be safeguarded against mechanical stress by vibration. Small screws up to M4 may be locked using varnish.

8.5.1.2 To prevent conductors being squeezed off, terminals shall have backing plates or the conductors shall be fitted with protective sleeves or equivalent protection for the wires.

8.5.1.3 Protective earthing shall be provided by means of earth terminals or earth bars. Earth terminals shall be clearly marked as such.

8.5.1.4 Screws carrying electrical current shall be tightened with proper torque. Tightening torque shall be stated in the turbine manuals. It is recommended to mark the screws to indicate that proper torque was applied.

8.5.1.5 Live parts that are under voltage after the main circuit breaker has been switched off shall be insulated and marked with a warning plate at the terminals.

8.5.2 Conductors

8.5.2.1 All conductors shall be fixed so that they are vibration-proof and shall be kept away from sharp edges.

8.5.2.2 Conductors leading to equipment mounted in doors shall be laid in a tension-free manner.

8.5.3 Busbars

Busbars shall be mounted in such a way that they withstand the mechanical stresses caused by short-circuit currents or vibrations and maintain the required clearance and creepage distances relative to other voltage-carrying or earthed components.

8.6 Control, measuring and indicating circuits

- 1) Control circuits shall generally be equipped with separate short-circuit protection up to a maximum of 10 A. Joint fuse protection of control and load circuits is permissible if the joint back-up fuse has a maximum rating of 10 A.
- 2) Measuring and indicating devices shall generally be provided with their own circuits, to be protected by separate fuses against short-circuits.

8.7 Control, and safety-related parts

- 1) The scope of this Section is based on the listing of all components and systems (electric, electronic, hydraulic or other) of the control and safety system that take part in performing a protection function. Please refer additionally to GL-IV-2, Edition 2012, Section 2.1.4.

Guidance note:

Protection functions are functions of the control system and / or safety system that ensure that the wind turbine remains within the design limits (e.g. limit states as defined in ISO 2394 "General principles on reliability for structures"). This is achieved by ensuring that the prerequisites for load assumptions are always met with respect to the wind turbine's conditions (e.g. rotational speed, pitch, angles, etc.).

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- 2) The design of the safety-related parts within the electrical installations shall be analysed and documented under consideration of:
 - the related parts in circuit diagram
 - the ability of the responsible parts detecting or tolerating faults
 - redundancy, robustness, diversity and monitoring.

SECTION 9 CABLES, LINES AND ACCESSORIES

9.1 General

- 1) Cables, lines and accessories shall be selected in accordance with the environmental conditions expected at the installation site.
- 2) Cables, lines and accessories installed in the tower or nacelle outside of enclosures shall be resistant to operating fluids such as oil and grease.
- 3) In the case of cables, lines and accessories installed and laid outdoors or installed within lattice towers, UV resistance and resistance to salty moist air shall be ensured.
- 4) All power and control cables should preferably be of low smoke, zero halogen type in order to reduce the amount of toxic and corrosive gas emitted during a possible fire.
- 5) The standardized voltage of cables, lines and accessories shall not be below the rated operating voltage of the circuit involved. For circuits with variable voltage, the maximum voltage occurring during operation is decisive.
- 6) The manufacturers' technical documentation shall state the cables and lines used, together with their standard designation and current-carrying capacities.

9.2 General selection of cables, lines and accessories

- 1) Cables, lines and accessories shall comply with the latest edition of IEC standards listed in item 2 and item 3 below. Other cables or lines may be used if their material and construction complies with equivalent standards (e.g. German VDE) and if verification of their suitability for the application is provided.
- 2) Low-voltage installations:
 - IEC 60227 series
 - IEC 60228.
- 3) High-voltage installations:
 - IEC 60502 series
 - IEC 60840.
- 4) Proof of the current-carrying capacity of main power cables shall be given with consideration of the laying method and installation. IEC 60287 series or IEC 60364-5-52:2011 shall be applied while considering worst-case operating conditions, such as the minimum tolerable operating voltage and worst case power factor.
- 5) Cables and lines shall be protected against short-circuit and overcurrent. If overcurrent protection is already provided in the circuit for the equipment, short-circuit protection shall be added. This shall be designed in accordance with the short-circuit loads at the point of installation.
- 6) For the rating of cables and lines, consideration shall be given to the loads expected during operation corresponding to the consumer demand, taking into account the duty of the electrical units connected. Values on the rating plates of generators and consumers shall be considered as a basis. For cables and lines subjected to twisting during operation, a control device shall be provided which protects against exceeding permissible limits.
- 7) Panel and cabinet wiring shall be of single core type with a minimum heat resistance of 70°C.
- 8) If the connected consumers in a part of the system are not in operation simultaneously, a diversity factor may be used for determining the cross section of the group supply cable. A diversity factor is the ratio of the highest operating load expected under normal operating conditions to the sum of rated loads of all connected consumers.

9.3 Installation of cables

- 1) Multi-core cables or lines shall preferably be used for AC systems. If single-core cabling is provided instead, the following points shall be observed:
 - the cables shall not be armoured with or sheathed in magnetic material
 - non-magnetic clamps shall be provided
 - the cables of a given circuit shall be laid contiguously and shall be arranged in the same tube or cable duct
 - single-core parallel cables shall be of the same type, length and cross-section.
- 2) Cables and lines shall be secured in such a manner that no unacceptable tensile, flexural, compressive or crushing stresses arise. Corrosion-proof or permanently corrosion-protected clips or mounts shall be used for weather-unprotected and outdoor installations.
- 3) Extraordinary mechanical demands, such as increased tensile or torsion stress, operationally required mobility and increased risk of mechanical damage, shall also be taken into account.
- 4) Cable clamps utilized for systems having a voltage over 1 kV shall withstand forces applied during short-circuit in order to avoid cable damage. A 3-phase short-circuit shall be basis for design and calculation of forces, which are expressed by following equation:

$$Fm_3 = \frac{\mu_0}{2\pi} \cdot \frac{\sqrt{3}}{2} \cdot ip_3^2 \cdot \frac{l}{a_m}$$

Fm_3 : Force applied to a cable clamp [N]

μ_0 : Magnetic permeability

ip_3 : Maximum current (first peak of short circuit current) [A]

a_m : cable distance from centre to centre (independent of tre-foil or single horizontal layer) [m]

l : Distance between cable clamps [m].

- 5) For cables suspended freely without additional strain relief, the suitability of the type of cable used shall be verified. The possibility of ice loading shall be taken into account in this context.
- 6) If cables or lines are laid in metal tubes or ducts, these shall be earthed effectively. Warming of such cables shall be considered during design and selection.
- 7) The tubes shall be smooth on the inside and so protected at the ends that there is no risk of damage to the cable sheathing.
- 8) Where there is a risk of mechanical damage, cables and lines shall be effectively protected by coverings or heat shrinks, protection tubes or equivalent.
- 9) Strain relief devices of exposed cables shall be permanently protected against corrosion.
- 10) Suspended cables shall be properly protected against damage and unacceptable constriction of the cable sheath.
- 11) The minimum specified bending radius of cables shall be observed for installation.
- 12) Under normal service conditions, the voltage drop between the busbars (main/emergency switchboard) and the consumers shall not exceed 6%, or 10% in the case of battery-supplied networks of 50 V or less.
- 13) Power and control cables shall be routed separately, e.g. on different cable trays or ladders.

SECTION 10 LIGHTNING PROTECTION

10.1 General

- 1) The lightning protection system shall comply with IEC 61400-24:2010 insofar as this section does not deviate from the IEC document. National requirements in excess thereof and any additional requirements of the grid operators shall be observed.
- 2) Any measurements shall be performed by staff who are independent of the production or design team. A testing laboratory accredited for these measurements is recommended. The complete test reports described herein shall be submitted to the certification body.

10.2 Basic design criteria

10.2.1 Lightning protection level

The wind turbine and its sub-components shall be protected according to the lightning protection level (LPL) I. A corresponding set of maximum and minimum lightning current parameters is to be found in IEC 62305-1:2010, tables 3 and 4.

10.2.2 Lightning protection zone

10.2.2.1 The wind turbine manufacturer shall establish a lightning protection zone (LPZ) concept following the principles given in IEC 62305-4:2010, Clause 4 and discussed in the context of lightning protection of wind turbines in IEC 61400-24:2010, Annex E.

10.2.2.2 The definition of the lightning protection zones is given in IEC 62305-4:2010, subclause 4.3. Each lightning protection zone has the task of reducing the electromagnetic field and the conducted emission disturbances to the stipulated values. The requirements for choosing one or the other lightning protection zone depend on the electromagnetic disturbance immunity of the equipment installed in the higher lightning protection zone. Thus, the manufacturer shall state the voltage protection level, the discharge current and the impulse current of each LPZ and additionally the equipment with the lowest immunity level within each zone and the corresponding immunity level.

10.2.2.3 At each zone boundary, it must be ensured that cables and wires crossing the boundary do not conduct large parts of the lightning current or voltage transients into the lightning protection zone with the higher number. This is achieved by means of proper bonding and shielding practices and surge protection devices (SPD) of all cables and wires at the zone boundary.

10.2.2.4 Lightning protection zones can be interconnected via shielded cables (with the shield connected to the bonding system at both ends) or metallic conduits. Also, a lightning protection zone can be extended with a shielded cable to include external metal sensor housing. The measures for connection and extension of lightning protection zones taken by the designer shall be stated in the lightning protection documentation of the wind turbine and additionally all shielding measures shall be shown in the wiring diagrams. Examples for connected zones or extended zones can be found in IEC 62305-4:2010, modified "Protection against lightning – Part 4: Electrical and electronic systems within structures" subclause 4.2.

10.2.2.5 The lightning protection zones LPZ 0_A and LPZ 0_B typically include the following areas:

- rotor blades including the rotor hub cover and the internals (sensors, actuators etc.)
- the outer part of the nacelle cover
- if there is no metallic housing nor mesh or metallic reinforcement, then all facilities in the nacelle (generator, auxiliary drives, cables, sensors and actuators), the outer parts of metallic switch cabinets, and the inner parts of non-metallic switch cabinets
- measurement sensors outside the wind turbine (if no further protection is provided, otherwise see [10.2.2.7])
- inside of lattice tower
- cable connections outside of the wind turbine or foundation between the wind turbine and the operation buildings
- transformer substations, if no shielding measures are provided.

10.2.2.6 The lightning protection zone LPZ 1 typically includes the following areas:

- Internals of the rotor hub (sensors, actuators etc.), provided that effective lightning-conducting, shielding and SPD are installed.
- The interiors of completely metal-clad nacelle housings or sufficient metal shielding mesh with the corresponding lightning-conducting and SPD measures.
- The interior of all metal-clad equipment, insofar as they are connected in a suitable manner to an equipotential bonding system (e.g. the machine foundation as the bonding level) and SPDs.
- Shielded cables, or cables which are laid in metallic pipes, whereby mesh shields or metallic pipes shall be connected to the equipotential bonding of LPZ 1 zones on both sides.
- The sensors of wind measurement facilities, insofar as these are fitted with lightning cages, appropriate conductors sheathed in a metal shield with both sides of the shield bonded to the turbine earthing system and SPDs.
- The interior of tubular steel towers or reinforced concrete towers, if designed according to applicable standards and connected to the earth electrode, equipotential bonding and protected by SPDs.

10.2.2.7 The lightning protection zone LPZ 2 includes facilities within lightning protection zone LPZ 1, if additional protection measures have to be taken for a further reduction in the effects of electromagnetic fields and overvoltages.

10.3 Lightning protection of sub-components

10.3.1 Rotor Blade

10.3.1.1 The lightning protection system of the rotor blade shall be sufficient to enable the blade to withstand lightning flashes according to LPL 1 without structural damages that would impair the function of the blade. This has to be proven according to the measures set out in IEC 61400-24:2010 subclause 8.2.3.

10.3.1.2 The down-conductor system and the air-termination system have to withstand the operational demands of the blade. This shall be proven by mechanical- and electrical testing of the blade with the fully assembled lightning protection system (see IEC 61400-24:2010 subclause 8.2.4.1 and 8.2.4.2).

This shall be done by installing the lightning protection system in the rotor blade before testing according to IEC 61400-23:2014.

Before and after the tests, the condition of the lightning protection system (if present) shall be visually inspected and electrical conductor resistance shall be measured and documented in the report. A corresponding test plan shall be created before the tests start.

10.3.1.3 The air-termination system shall be designed according to IEC 61400-24:2010, subclause 8.2.4.1.

10.3.1.4 The down-conductor system shall be designed according to IEC 61400-24:2010, subclause 8.2.4.2. If HV-cable is used as down conductor it shall be insulated to reduce the risk of sparking.

10.3.1.5 Cross-sectional areas of the air-termination system and the down-conductor system shall be dimensioned in accordance with IEC 62305-3:2010, Table 6:

- for conductors of copper or aluminium alloys: at least 50 mm²
- for conductors of stainless steel tape: at least 50 mm with a minimum thickness of 2 mm
- for round conductors of stranded stainless steel: at least 70 mm² with a minimum diameter for each strand of 1.7 mm.

10.3.1.6 When carbon fibre composites are used in a rotor blade design, sufficient measures shall be implemented to protect the carbon fibre composites from direct or indirect lightning strike damages (e.g. by applying mesh or other conductive systems at the rotor blade surface).

If the air-termination system or down-conductor system is integrated in the blade surface (no discrete system) or if the blade surface itself is used as an air-termination system or down-conductor system (e.g. when using carbon fibre composites), then high-voltage and high-current testing shall be performed

according to IEC 61400-24:2010, Annex D. The testing shall prove the ability of the lightning protection system to attract the lightning flashes and to withstand the lightning current according to the assigned lightning protection level.

10.3.1.7 The temperature rise of components in case of a lightning strike shall not harm the integrity of the lightning protection system or the rotor blade itself. This shall be proven by calculations or laboratory testing.

10.3.1.8 Rotor blades shall be fitted with drainage holes to minimize the danger of cracking caused by vaporization in case of a lightning strike.

10.3.2 Nacelle

10.3.2.1 The nacelle structure shall be part of the lightning protection system and must be able to withstand lightning flashes according to the assigned lightning protection level.

10.3.2.2 Metallic nacelle covers or metallic reinforcements shall be connected to the down-conductor system.

10.3.2.3 The air-termination system of non-metallic nacelle covers and of electrical instrumentation mounted outside the nacelle shall be designed according to IEC 62305-3:2010, subclause 5.2 (Air-termination systems) and connected to the down-conductor system.

10.3.2.4 Cables connecting electrical instrumentation mounted outside the nacelle should be routed through closed metallic conduits as long as they are routed outside the nacelle. These metallic conduits shall be connected to the down-conductor system. If shielded cables are used the shields shall be connected to the bonding system at both ends. The cables shall not be wrapped around the metallic conduits or lightning rods.

10.3.2.5 Alternatively to [10.3.2.4], cables connecting electrical instrumentation mounted outside the nacelle may be designed according to IEC 62305-3:2010, subclause 6.3 (Electrical insulation of the external lightning protection system), provided no direct lightning strike is possible.

10.3.3 Spinner

In case of electrical installations and actuators mounted outside the hub and covered by the spinner, lightning protection of these components shall be provided. A typical measure is the placement of an air-termination system and surge protection of the connection at entry of the hub.

10.3.4 Tower

10.3.4.1 Tubular steel towers are especially suited for lightning protection measures, because they can be considered to be an almost perfect Faraday cage. Thus it is reasonable to assign lightning protection zone LPZ 1 if SPDs are installed.

10.3.4.2 The flanges of tubular steel towers between two tower sections shall be in direct electrical contact. The manufacturer shall describe the measures he has taken.

10.3.4.3 Lattice towers shall not be considered to be efficient Faraday cages; they satisfy lightning protection zone LPZ 0B.

10.3.4.4 The structural elements of lattice towers may be used for lightning down conduction if these elements provide a cross-sectional area in compliance with IEC 62305-3:2010, Table 6.

10.3.4.5 The reinforcement of steel reinforced concrete towers may be used for lightning down conduction by ensuring 2 – 4 vertical connections with cross-sectional areas in compliance with IEC 62305-3:2010, Table 6.

10.3.4.6 The steel structure or the reinforcement of the tower, as applicable, shall be connected to the foundation earth with at least 3 points.

10.3.5 Bearings

10.3.5.1 Bearings which are in the lightning current path, such as pitch, yaw, main bearings and gear, shall be protected as necessary to reduce the level of current passing through the bearing to a tolerable level.

10.3.5.2 If the protection is part of the bearing structure itself, 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. The bearing manufacturer must be involved in the demonstration and his final conclusion is required in the corresponding documentation.

10.3.5.3 If the protection is not part of the bearing structure itself, an external protection system installed across the bearing shall bypass the lightning current.

Guidance note:

It is strongly recommended that the lightning protection system be designed in such a way that the lightning current bypasses the bearings.

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10.3.6 Hydraulic systems

Hydraulic systems exposed to lightning current shall be protected according to IEC 61400-24:2010, subclause 8.4.3.

10.3.7 Bypass systems

10.3.7.1 Spark gaps, sliding contacts, brushes, rollers and related technologies providing a bypass for bearings may function as the lightning protection of bearings. They shall be considered as wearing parts and their service lifetime and service measures shall be documented.

10.3.7.2 If the protection of bearings is to be achieved by spark gaps, sliding contacts, brushes, rollers or related technologies, the effectiveness of the bypass system shall be demonstrated by testing according to IEC 61400-24:2010, subclause 8.4.5, or alternatively by calculations.

Guidance note:

If the down conductor between rotor blade and wind turbine is interrupted (e.g. with a spark gap) and there is no parallel earthing connection, measures have to be taken for personal safety to avoid accidents due to electrostatic discharges coming from the rotor blade.

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10.3.8 Connection of generator and gearbox

10.3.8.1 Normally, the generator and the gearbox are satisfactorily linked to the earthing system through the connecting bolts with the main frame. However, if the gearbox or generator is connected to the main frame by means of flexible damping elements, all damping elements should be bridged over with flat copper bands of sufficient cross-section. In case of fewer bonds corresponding calculation shall be provided for verification.

10.3.8.2 The coupling between gearbox and generator shall be insulated in such a way that the lightning current is not conducted via the generator shaft into the generator bearings.

10.3.8.3 As gearbox bearings and other bearings are generally endangered by lightning currents, bypassing the main shaft completely is strongly recommended. This can be done by connecting the down conductor of the rotor blade to the earthing by other means than the main shaft, e.g. using sliding contacts or spark gaps outside the nacelle and tower. This necessitates insulation between the rotor blade roots and the main shaft.

10.3.9 Offshore application

10.3.9.1 Outside equipment (e.g. lightning rods, earthing connection, etc.) shall be of copper or other corrosion-resistant material and, where necessary, protected against galvanic corrosion. Where dissimilar metals are involved, the joint shall be made completely water proof (e.g. by wrapping it in self-amalgamating tape). It also has to be checked by the maintenance personnel at least every two years.

10.3.9.2 The equipment installed inside the offshore wind turbine (e.g. earthing connections, overvoltage protection etc.) shall be designed with regard to the environmental conditions mentioned in [2.1].

10.3.10 Electrical systems and installations

Electrical systems and installations have to be protected against the effects of lightning current, overvoltage and lightning electromagnetic impulses (LEMP). This shall be done by means of equipotential bonding, magnetic and electrical shielding of cables and line routing, coordinated surge protection devices and earthing.

10.3.11 Surge arresters

10.3.11.1 Surge arresters for low-voltage applications shall comply with

- IEC 61643-11:2011 for power systems
- IEC 61643-21:2012 for telecommunication and signalling systems.

This shall be verified on the basis of product data sheets.

10.3.11.2 The energy coordination of surge arresters shall be in compliance with IEC 62305-4:2010, Annex C. Proof shall be given by testing, calculations or selection of coordinated surge arrester families. In each case, a description of the measures taken and the results achieved or protection levels achieved is required.

10.3.11.3 Surge arresters for high-voltage or medium-voltage applications shall comply with

- IEC 60099-1:1999 for gapped surge arresters
- IEC 60099-4: 2014 for metal-oxide arresters

This shall be verified on the basis of product data sheets.

10.3.11.4 The selection criteria for high-voltage and medium-voltage surge arresters shall be given and will be checked for plausibility.

10.3.11.5 Surge arresters should be monitored.

10.3.11.6 Maintenance and replacement of surge arresters shall be performed according to the manufacturer's maintenance plan.

10.3.12 Equipotential bonding system

10.3.12.1 Equipotential bonding shall be achieved by interconnecting the lightning protection system with:

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

10.3.12.2 The bonding conductors shall be kept as short as possible and shall have a cross-sectional area according to IEC 62305-3:2010, Tables 8 and 9.

10.3.12.3 In each lightning protection zone, local bonding bars shall be installed and shall be connected to each other.

Guidance note:

Conductive structural components can be used for the connection of local bonding bars.

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10.3.12.4 Where possible, incoming cables should enter the lightning protection zone at the same location and be connected to the same bonding bar. If incoming cables enter the lightning protection zone at different locations, each cable shall be connected to a bonding bar and the respective bonding bars of the zone shall be connected (see IEC 62305-3:2010, subclause 5.4).

10.3.12.5 The equipotential bonding system shall be designed on the basis of an equipotential bonding plan for all bonding and earthing in the wind turbine, showing the general equipotential bonding system including the locations of the bonding bars within the different lightning protection zones, the bonding conductors with their cross-sectional areas as well as further relevant data.

10.3.13 Earthing system

10.3.13.1 The earthing system of the wind turbine shall be designed to provide sufficient protection against damage due to lightning flashes corresponding to the lightning protection level LPZ 1.

10.3.13.2 The earthing system shall be based on a type B arrangement according to IEC 62305-3:2010 subclause 5.4.2.2, which 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.

10.3.13.3 From the earth electrode, terminal lugs shall be routed into the inside of the tower and connected to the steel structure or reinforcement of the tower with at least three points.

10.3.13.4 Materials used for the earth electrodes of the wind turbine and the corresponding cross-sectional areas shall be in accordance with the values listed in IEC 62305-3:2010, Table 7.

10.3.13.5 All transitions from the foundation earth electrode or from the reinforcement of the concrete into the air shall be with insulated cable to reduce the risk of corrosion.

10.3.13.6 Sufficient corrosion protection shall be applied to earthing cables, lugs, tapes and their connections to different materials. For inspection reasons, it shall be possible to locate and to disconnect each connection.

Guidance note:

The complete lightning protection system, as well as the earthing system, is to be checked by a qualified expert according to the scope laid down in IEC 61400-24:2010 "Wind turbine generator systems – Part 24: Lightning protection" clause 12, as a visual inspection at yearly intervals and as a full inspection at intervals not exceeding 2 years.

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SECTION 11 ELECTRICAL EQUIPMENT FOR MEASUREMENT AND CONTROL USE AND ITS ACCESSORIES

11.1 General

- 1) This section considers electrical equipment for measurement and control use and its accessories. It applies to equipment which by electrical means tests, measures, indicates or records one or more electrical or non-electrical quantities such as sensors and detectors, etc. Also non-measuring equipment such as signal generators, power supplies, transducers, etc. is considered in this section.
- 2) The electrical equipment shall comply with IEC 61010-1:2013.
- 3) Outside equipment, sensors etc. shall be protected against corrosion according to class C5-M (ISO 12944 series).

11.2 Environmental and operating tests

- 1) All measurements as per [11.2] shall be carried out and documented by a testing laboratory accredited for these measurements.
- 2) Electrical equipment for measurement and control use and its accessories for wind turbine applications shall comply with:
 - IEC 60068-2-1:2007
 - IEC 60068-2-30:2005
 - IEC 60068-2-6:2007
 - IEC 60068-2-27:2008
 - IEC 61326-1:2012.

The parameters of the tests required for a specific product shall be determined on a case by case basis depending on the product and its use.

11.3 Additional tests and standards

All measurements as per [11.3] shall be carried out and documented by a testing laboratory accredited for these measurements.

11.3.1 Offshore application

If the electrical equipment is to be exposed to salty environment such as offshore applications additional salt mists tests according to IEC 60068-2-52:1996 shall be performed. These tests serve to demonstrate that under the influence of a saline atmosphere no damage (corrosion) is caused to the components of the equipment under test and no functional affections occur.

11.3.2 Fire hazard

For some specific products it might be necessary to comply with the IEC 60695 series. This requirement shall be determined by the certification body.

11.3.3 Laser products

Laser based measurement equipment shall be evaluate according to IEC 60825-1:2014.

11.3.4 Lightning protection

For protection of measurement equipment (especially outside installations) against hazards of lightning and surge, reference is made to Sec.10.

11.3.5 Safety-related parts

11.3.5.1 If the electrical equipment is designed as a safety-related part of the control system (SRP/CS) additional documentation according to [8.7] shall be submitted to the certification body.

11.3.5.2 The EMC test for the electrical equipment of SRP/CS shall be performed according to IEC 61326-3-1:2008.

11.4 Test results

A test is deemed to have been passed if the specified functions are demonstrated, the results fall within the specified tolerance limits and no damage to the equipment under test is detected. The specimen shall continue to operate as intended after the test.

SECTION 12 ELECTRICAL CHARACTERISTICS

12.1 Power quality

Wind turbines shall be designed in such a way that their subsystems or single components do not generate disturbing electric current, voltage and frequencies at a given point in an electric power system. Generated power characteristics shall be in compliance with applicable parts of series IEC 61000-3 at the respective installation site.

12.2 Electromagnetic compatibility

12.2.1 General

Wind turbines are tall structures with high energy and high frequency electrical installations inside. With regard to the safety functions and the environmental behaviour of a wind turbine the electromagnetic compatibility (EMC) of the complete wind turbine system and of the single components installed inside the wind turbine becomes more and more important.

12.2.2 Wind turbine systems

12.2.2.1 Basically all electrical components installed in and at the wind turbine shall be designed according to the EMC requirements stated in the corresponding product standards of the components. For components which do not have a product standard or no EMC requirements are stated in the product standard the generic EMC requirements have to be applied.

12.2.2.2 Emissions of conducted disturbances shall meet the requirements of IEC 61000-6-4.

12.2.2.3 At a minimum, the immunity for radiated and conducted disturbances shall meet the requirements of IEC 61000-6-2 in case no product standard exists.

12.2.2.4 For immunity to radiated and conducted disturbances of power stations and substations shall meet the requirements of IEC 61000-6-5.

12.2.3 Measures to reduce electromagnetic interferences

12.2.3.1 In IEC 60364-4-44:2011, chapter 444 measures against electromagnetic influences are stated and can be useful for the development of an EMC compliant electrical system. For wind turbines the following requirements have to be fulfilled and documented:

- Metal sheaths of cables shall be bonded at both ends to the common bonding network. Exception is made to short high voltage cables for which a specific analysis of the free end shield voltage shall be made. This has to be documented in the corresponding circuit diagrams and earthing and bonding plans.
- Inductive loops should be avoided by selection of separate routes for power, signal and data circuits wiring (e.g. in cabinets, switchgears, etc.).
- Power and signal cables shall be kept separate and should, wherever practical, cross each other at right-angles. This has to be stated in the design documentation.
- The use of signal and data cables shall be done according to the EMC requirements and, if applicable, additionally to further manufacturer's instructions of the electrical devices (e.g. controls, safety devices, etc.). For example signal and data cables shall have shields. This has to be stated in the design documentation for EMC relevant installations.
- Equipotential bonding connections should have an impedance as low as possible:
 - by being as short as possible
 - by having a cross-section shape that results in low inductive reactance and impedance per metre of route, e.g. a bonding braid with a width to thickness ratio of five to one. This has to be stated in the earthing and bonding plans of the wind turbine
 - where a lightning protection system is installed
 - power and signal cables shall be separated from the down conductors of lightning protection

systems (LPS) by either a minimum distance or by use of screening. The minimum distance shall be determined by the designer of the LPS in accordance with IEC 62305-3

- metallic sheaths or shields of power and signal cables should be bonded in accordance with the requirements for lightning protection given in IEC 62305-3 and IEC 62305-4.

12.2.3.2 Based on these measures against EMI the manufacturer of the wind turbine shall design his turbine taking these measures into account and document this in corresponding circuit diagrams and lightning protection documentation.

12.2.4 Circuit diagrams

The connections of the cable shieldings shall be defined. The installation of filters and capacitors has to be implemented. This shall be stated in the circuit diagrams.

12.2.5 Rotating electrical machines

Rotating electrical machines shall fulfil the requirements according to IEC 60034-1:2010 subclause 13 (Electromagnetic compatibility (EMC)). As far as required there, emission type tests shall be carried out in accordance with CISPR 11 and CISPR 16 as applicable.

12.2.6 Frequency converters

12.2.6.1 Power electronics shall be designed in accordance with the electromagnetic immunity requirements and requirements for electromagnetic emissions. The relevant EMC requirements are given in IEC 61800-3:2012.

12.2.6.2 The manufacturer of the frequency converter shall evaluate the results proving that the EMC requirements are fulfilled. This shall be stated by the manufacturer of the frequency converter in the documentation of the frequency converter.

12.2.6.3 Based on the test results concerning EMC, the manufacturer of the frequency converter shall require corresponding measures that have to be observed during installation or assembly.

12.2.7 Low-voltage switchgear, controlgear and switchboards (voltages of up to 1000 V AC or 1500 V DC)

Low-voltage switchgear, controlgear and switchboards shall be designed and tested according to IEC 61439-1:2011, Annex J. The EMC tests have to be documented including the test setup. Also the installation requirements in the wind turbine have to be documented.

12.2.8 Safety related parts

Safety related parts shall be tested regarding immunity and shall fulfil the performance criterion A defined in IEC 61000-6-2. They shall meet the requirements of IEC 61000-6-2 in case no product standard exists.

12.2.9 Lightning protection

The lightning protection system of the wind turbine is part of EMC. This is covered by the requirements of Sec.10.

SECTION 13 OFFSHORE APPLICATION

13.1 General

- 1) The selection, layout and arrangement of all machinery, equipment and appliances shall be such as to ensure faultless continuous operation under the ambient conditions where applicable.
- 2) The environmental conditions at offshore locations, especially salty air, moisture/wetness, humidity and sun radiation shall be considered when planning and designing the wind turbine and its electrical installations.
- 3) Design parameters may be determined based on environmental conditions applicable to certain types of equipment at the location. If not specified differently, same conditions can be used as for onshore turbines.
- 4) Environmental conditions at offshore locations which shall be taken into account are defined in IEC 61400-3:2009, subclause 6.5.
- 5) Corrosion protection measures (see [13.2.2]) and adequate ventilation shall be ensured for all inside and outside equipment depending on the location. Further guidance and representative conditions can be found in IEC 60721-3-6:1996.
- 6) Major electrical equipment, such as switchgears, power transformers, frequency converters should be installed in controlled atmosphere, wherever possible.
- 7) It shall be clearly identifiable on the rating plate and within the design documentation if such equipment is intended for outdoor installation or not.
- 8) Control and switchgear cabinets shall be protected against the outside environment (offshore atmosphere).
- 9) The heating, ventilation and air conditioning system (HVAC) including air flow concept, applicable filter techniques and air dryer systems of the offshore wind turbines shall be described by e.g. drawings, functional description, data sheets.
- 10) Wave frequency and wave forces can have a significant influence on the structure leading to acceleration and movement of the wind turbine installations. Using data gained from the wind turbine load calculations and/or measurements, the equipment shall be designed and installed in a way assuring long-term integrity. Assumptions and maximum permissible vibration / acceleration values of main power equipment shall be documented.
- 11) The fastening concept of components shall be clarified in this manner, too. Usage of vibration absorbers shall be considered for at least (if applicable):
 - generators
 - transformers
 - switchgears
 - cabinets
 - fans.
- 12) For requirements regarding the auxiliary power generation for offshore applications, please refer to [7.2.5].
- 13) For requirements regarding the earthing system for offshore applications, please refer to [10.3.9].
- 14) The submarine cable part routed from hang-off to switchgear terminals (located in transition piece or in tower) shall be fixed / mounted in a way that there is potentiality for thermal expansion and short circuit force absorption. There shall be no exposure of the cable weight to the switchgear terminals. Supporting structures shall be rigid enough to facilitate the above mentioned.

13.2 Materials and insulation

13.2.1 General

13.2.1.1 Material used for electrical machines, cables and apparatus shall be resistant to sea air containing moisture and salt, and to oil vapours. They shall not be hygroscopic and shall generally be flame-retardant and self-extinguishing.

13.2.1.2 The evidence of flame-retardation and moisture-resistance of insulation and materials shall be according to, e.g., IEC 60092-101:2002 or other equivalent standards.

13.2.1.3 The usage of halogen-free materials is strongly recommended.

13.2.1.4 Units of standard industrial type may be used in areas not liable to be affected by salty sea air subject to appropriate proof of suitability.

13.2.1.5 Materials like stainless steel or UV resistant plastic shall be utilized for all subassemblies and equipment installed outside.

13.2.1.6 Metal parts exposed to harsh and salty environment shall be protected according to the stipulations in [13.2.2] below.

13.2.2 Corrosion protection

For requirements regarding the corrosion protection of offshore applications, please refer to Sections 3.5 and 7.11.4 within GL-IV-2, Edition 2012.

SECTION 14 ELECTRICALLY DRIVEN ROTOR BLADE PITCH AND YAW SYSTEMS

14.1 General

- 1) This section applies to the blade pitching systems and yaw systems of wind turbines as described below. In the event of other designs, the wording shall apply with the necessary changes.
- 2) In systems with electric blade angle actuation, the torque needed for the pitching of the rotor blades is applied by a motor with the associated rotary drive and pitch gearbox. The torque is transmitted by the pitch teeth to the blade bearing fixed to the rotor blade. The motor may be driven by a frequency converter.
- 3) For electric yaw systems the torque necessary to align the nacelle with the wind direction is provided by an adequate quantity of yaw motors with the associated yaw gearboxes (rotary drive). The torque is transmitted by the yaw teeth from the yaw pinion to the yaw bearing. The motor may be driven by a frequency converter.
- 4) Please refer to Section 7.2 *Blade Pitching System* and to Section 7.8 *Yaw System* in GL-IV-2, Edition 2012 additionally.

14.2 Rating of blade pitching and yaw motors

- 1) Motors in wind turbines shall on principle comply with IEC 60034 series. This shall be proven by corresponding statements of the motor manufacturer on the rating plate.
- 2) All data on the rating plate shall be provided as required in IEC 60034-1:2010 subclause 10.2. A corresponding rating plate shall be placed at each electrical machine.
- 3) Motors shall be so designed and constructed that the permissible over-temperatures for the class of insulation are not exceeded, irrespective of the operating time. The values listed in IEC 60034-1 shall be used as guideline values.
- 4) Motors shall be designed according to the operating times and temperatures to be expected. The designed duty types shall be given as specified in IEC 60034-1 or as per equivalent codes.
- 5) Electrical machines shall be so designed to withstand the highest speed according to IEC 60034-1:2010, Table 18.
- 6) The nominal torque (M_n) and the equivalent torque (reference torque) of the motors for the blade pitching system shall be in compliance with the corresponding load calculations.

14.3 Frequency converters connected to blade pitching and yaw systems

- 1) For frequency converters driving rotating electrical machines supplied by DC voltages, the rating plate and corresponding specifications shall be given according to IEC 61800-1:1997 chapter 8 (product information) plus the maximum voltage change rate dU/dt .
- 2) For frequency converters driving rotating electrical machines supplied by AC voltages, the rating plate and corresponding specifications shall be given according to IEC 61800-2:1998 chapter 8 (product information) plus the maximum voltage change rate dU/dt .
- 3) It shall be proven by the manufacturer that the specifications according to Section 14.2 fit with the corresponding components the frequency converter is connected to.
- 4) Frequency converters shall be designed in accordance with the electromagnetic immunity requirements and requirements for electromagnetic emissions (electromagnetic compatibility, EMC). The relevant EMC requirements are given in IEC 61800-3.
- 5) The manufacturer of the frequency converter shall evaluate the results proving that the EMC requirements are fulfilled based on measurements of a testing laboratory (accredited according to ISO/IEC 17025 for IEC 61000-4-30, IEC 61400-21 and IEC 61800-3).
- 6) Based on the test results concerning EMC, the manufacturer of the frequency converter shall require corresponding measures that have to be observed during installation or assembly. As a minimum the shielding of connecting cables has to be defined in detail by the frequency converter manufacturer.

14.4 Verification of the blade pitching system

- 1) The basis for thermal rating of an electrical drive shall be the most severe torque-time simulation run with the highest-torque rms value. The averaging time shall be 600 seconds, or the overall time of the simulation run to be used.
- 2) The thermal rating of an electrical drive shall be determined by using IEC 61800-6 or IEC 60034-1.
- 3) The parameters to be set in the frequency converter shall limit the operational range of the drive to the design values concerning thermal, mechanical and electrical capacity.
- 4) The design values of an electrical drive shall be provided for the full operational range of rotational speed and torque, e.g. as figures for the following cases:
 - i) as set by the control parameters
 - ii) for all operational modes used (in the case of the field weakening range, the maximum rotational speed shall be given additionally)
 - iii) emergency braking run, e.g. by back-up power supply in the case of worst environmental conditions and lowest possible charging status
 - iv) emergency braking run, e.g. by back-up power supply in the case of optimum environmental conditions and maximum possible charging status.

14.5 Back-up power supply systems for blade pitching systems

Back-up power supply systems for blade pitching systems shall be designed according to [7.2.2] and [7.2.3].

14.6 Requirements for control and safety system(s) for blade pitching and yaw systems

Back-up power supply systems within the scope of this section shall be designed for events specified in [7.1] item 2. They shall be designed according to [7.2.2.2].

APPENDIX A GENERATOR PARAMETERS FOR ELECTRICAL CALCULATIONS AND SIMULATIONS

A.1 Generator parameters - general

Generator parameters are required for static and dynamic electrical calculations and simulations. The values shall be applied in accordance with the information supplied by the generator manufacturer. The tables below exemplify the main synchronous and asynchronous generator parameters.

A.2 Generator parameters - synchronous machine

The synchronous machine parameters are:

Variable	Description	Unit
S_n	Nominal power	kVA
M_n	Nominal torque	kNm
U_n	Nominal voltage	V
P	Number of poles	-
f_n	Nominal frequency	Hz
x_1	Leakage reactance	p.u.
r_a	Armature resistance	p.u.
x_d	d-axis synchronous reactance	p.u.
x_d'	d-axis transient reactance	p.u.
x_d''	d-axis subtransient reactance	p.u.
T_{d0}'	d-axis open circuit transient time constant	s
T_{d0}''	d-axis open circuit subtransient time constant	s
x_q	q-axis synchronous reactance	p.u.
x_q'	q-axis transient reactance	p.u.
x_q''	q-axis subtransient reactance	p.u.
T_{q0}'	q-axis open circuit transient time constant	s
T_{q0}''	q-axis open circuit subtransient time constant	s
$T_a = 2H$	Mechanical starting time (2 x inertia constant)	kWs/kVA
D	Damping coefficient	-
$S(1.0)*$	1st saturation factor	-
$S(1.2)*$	2nd saturation factor	-

)* optional parameter

The generator manufacturer shall indicate whether the generator parameters given are of a saturated or non-saturated type.

A.3 Generator parameters - asynchronous machine

The asynchronous machine parameters are:

Variable	Description	Unit
S_n	Nominal power	kVA
M_n	Nominal torque	kNm
M_k	Breakdown torque	kNm
s_k	Breakdown slip	-
U_n	Nominal voltage	V
f_n	Nominal frequency	Hz
r_s	Stator resistance	p.u.

<i>Variable</i>	<i>Description</i>	<i>Unit</i>
x_s	Stator reactance	p.u.
r_{r1}	Rotor resistance (single cage)	p.u.
x_{r1}	Rotor reactance (single cage)	p.u.
r_{r2}	Rotor resistance (double cage)	p.u.
x_{r2}	Rotor reactance (double cage)	p.u.
x_m	Magnetization reactance	p.u.
H_m	Inertia constant	kWs/kVA

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