Lightning and surge protection for wind turbines

Information from DEHN

Due to their vast exposed surface and height, wind turbines are vulnerable to direct lightning strikes. Since the risk of lightning striking a wind turbine increases quadratically with its height, it can be estimated that a multi-megawatt wind turbine will be hit by a direct lightning strike roughly every 12 months. High investment costs must be amortised within a few years, meaning that downtime as a result of lightning and surge damage and associated repair costs must be avoided. For this reason, comprehensive lightning and surge protection measures are essential.

When planning a lightning protection system for wind turbines, earth-to-cloud flashes as well as cloud-to-cloud flashes must be considered for objects with a height of more than 60 m in exposed locations. The high electrical charge of these upward leaders must be taken into account for the protection of the rotor blades and for selecting lightning current arresters.

Standardisation

The protection concept should be based on the international standards IEC 61400-24:2010 and IEC 62305 standard series and the guidelines of Germanischer Lloyd (e.g. GL 2010 IV – Part 1: Guideline for the certification of wind turbines).

Protection measures

The IEC 61400-24 standard recommends selection of all subcomponents of the lightning protection system of a wind turbine according to lightning protection level (LPL) 1 unless a risk analysis demonstrates that a lower LPL is sufficient. A risk analysis may also reveal that different sub-components have different LPLs.

The lightning protection system (LPS) of a wind turbine consists of an external LPS and surge protection measures (SPM). To plan protection measures, it is advisable to subdivide the wind turbine into lightning protection zones (LPZ).

The LPS protects two sub-systems which can only be found in wind turbines, namely the rotor blades and the mechanical power train. The standard describes how to protect these parts of a wind turbine. It is advisable to carry out high-voltage tests to verify the lightning current withstand capability of the relevant systems. This article paper describes the implementation of lightning and surge protection measures for electrical and electronic devices/systems of a wind turbine.

The complex problems of protection of the rotor blades and rotatable mounted parts/bearings must be examined in detail and depend on the component manufacturer and type. The standard provides important information on this.

Lightning protection zone concept

The rolling sphere method may be used to determine LPZ 0A, namely the parts of a wind turbine which may be subjected to direct lightning strikes, and LPZ 0B, the parts of a wind turbine which are protected from direct lightning strikes by external air-termination systems or air-termination systems integrated in parts of a wind turbine (for example in the rotor blade). According to the standard, the rolling sphere method must not be used for rotor blades. For this reason, the design of the air-termination system should be tested according to chapter 8.2.3 of the standard. Fig. 1 shows a typical application of the rolling sphere method, and Fig. 4 the possible division of a wind turbine into different lightning protection zones (LPZ). Division into LPZ depends on the design of the wind turbine.

It is decisive that the lightning parameters injected from outside of the wind turbine into LPZ 0A are reduced by shielding measures and surge protective devices at all zone boundaries.

Shielding measures

The nacelle should be designed as an encapsulated metal shield to achieve a volume with an electromagnetic field that is considerably lower than the field outside of the wind turbine. The tubular steel tower used for large wind turbines can be considered an almost perfect Faraday cage. The switchgear and control cabinets in the nacelle in the operation building should also be made of metal. The connecting cables should feature an external shield that is capable of carrying lightning currents. Shielded cables are only resistant to EMC interference if the shields are connected to the equipotential bonding on both ends.

Magnetic shielding and cable routing should be performed as per section 4 of IEC 62305-4. For this reason, the general guidelines for an EMC-compatible installation practice according to IEC/TR 61000-5-2 should be used.

Shielding measures include for example:
- Installation of a metal braid on GRP-coated nacelles
- Metal tower
- Metal switchgear cabinets
- Metal control cabinets
- Lightning current carrying shielded connecting cables (metal cable duct, shielded pipe or the like)
- Cable shielding

External lightning protection measures

These include:
- Air-termination and down-conductor systems in the rotor blades
- Air-termination systems for protecting nacelle superstructures, the nacelle and the hub
Wind Power

- Using the tower as air-termination system and down conductor
- Earth-termination system consisting of a foundation earth electrode and a ring earth electrode

The function of the external LPS is to intercept direct lightning strikes and to discharge the lightning current from the point of strike to the ground. The potential points of strike for a wind turbine (except the rotor blades) can be determined by means of the rolling sphere method (see Fig. 1). For wind turbines, it is advisable to use class of LPS I. Therefore, a rolling sphere with a radius \( r = 20 \) m is rolled over the wind turbine to determine the points of strike. Air-termination systems are required where the sphere contacts the wind turbine.

The nacelle construction should be integrated in the lightning protection system to ensure that lightning strikes in the nacelle hit either natural metal parts that are capable of withstanding this load or an air-termination system designed for this purpose. Nacelles with GRP coating or the like should be fitted with an air-termination system and down conductors forming a cage around the nacelle (metal braid). In compliance with IEC 61400-24, air-termination systems for protecting measurement equipment and the like mounted outside of the nacelle should be designed in compliance with the general requirements of IEC 62305-3 and down conductors should be connected to the cage. “Natural components” made of conductive materials which are permanently installed in/on a wind turbine and remain unchanged (e.g. lightning protection system of the rotor blades, bearings, mainframes, hybrid tower, etc.) may be integrated in the LPS. If wind turbines are a metal construction, it can be assumed that they fulfill the requirements for an external lightning protection system of class of LPS I according to IEC 62305.

Air-termination system/down conductor

As can be seen in Fig. 1, the
- Rotor blades
- Nacelle including superstructures (Fig. 2, Table 1)
- Rotor hub
- The tower of the wind turbine

may be hit by lightning. If they are capable of safely intercepting the maximum lightning impulse current of 200 kA and discharging it to the earth-termination system, they can be used as “natural components” of the

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**Fig. 2:** Example of an air-termination system for the weather station (anemometer) and the aircraft warning light.

**Fig. 3:** Earth-termination system of a wind turbine.

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<table>
<thead>
<tr>
<th>No.</th>
<th>Part No.</th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>472 209</td>
<td>Equivalent bonding bar for industrial use</td>
</tr>
<tr>
<td>2</td>
<td>80 010</td>
<td>Wire, stainless steel (AISI ASTM 316 Ti)</td>
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<tr>
<td>3</td>
<td>478 011</td>
<td>Fixed earthing terminal, stainless steel (AISI ASTM 316 Ti)</td>
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<td>4</td>
<td>319 209</td>
<td>Cross unit, stainless steel (AISI ASTM 316 Ti)</td>
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<td>5</td>
<td>810 335</td>
<td>Tape, 30 mm x 3.5 mm (StZn)</td>
</tr>
<tr>
<td>6</td>
<td>308 031</td>
<td>Pressure U-clamp</td>
</tr>
<tr>
<td>7</td>
<td>308 060</td>
<td>MAXI hV clamp, UL4678-approved</td>
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</table>
wind turbine's external lightning protection system.

Metallic receptors, which represent defined points of lightning strike, are frequently installed along the GRP blade to protect against lightning damage. A down conductor is routed from the receptor to the blade root. It can be assumed that the lightning strike hits the blade tip (receptor) and is then discharged via the down conductor inside the blade to the earth termination system via the nacelle and the tower.

**Earth-termination system**

The earth-termination system of a wind turbine must perform several functions such as personal protection, EMC protection and lightning protection. An effective earth-termination system (Fig. 3) is essential to distribute lightning currents and to prevent damage to the wind turbine. Moreover, the earth-termination system must protect humans and animals against electric shock. In general, it is important to establish an earth-termination system for a wind turbine which is used to protect the wind turbine against lightning strikes and to earth the power supply system.

**Arrangement of earth electrodes**

The IEC 62305-3 standard describes two basic types of earth electrode arrangements for wind turbines:

**Type A:** This arrangement must not be used for wind turbines, however, it can be used for annexes (for example, buildings containing measurement equipment or office sheds in the wind farm). Type A earth electrode arrangements consist of horizontal or vertical earth electrodes connected by at least two down conductors on the building.

**Type B:** This arrangement must be used for wind turbines. It either consists of an external ring earth electrode installed in the ground or a foundation earth electrode. Ring earth electrodes and metal parts in the foundation must be connected to the tower construction.

In any case, the reinforcement of the tower foundation should be integrated in the earthing concept of a wind turbine. The earth-termination system of the tower base and the operation building should be connected by means of a meshed network of earth electrodes. To prevent excessive step voltages as a result of a lightning strike, potential controlling and corrosion-resistant ring earth electrodes must be installed around the tower base (Fig. 3).

**Foundation earth electrodes**

Foundation earth electrodes make technical and economic sense, are part of the electrical installation and fulfill essential safety functions.

For this reason, they must be installed by electrically skilled persons or under supervision of an electrically skilled person.

Metals used for earth electrodes must...
comply with the materials listed in Table 7 of IEC 62305-3. The corrosion behaviour of metal in the ground must always be observed.

**Internal lightning protection measures**

These include:

- Earthing and equipotential bonding measures
- Spatial shielding and separation distance
- Cable routing and cable shielding
- Installation of coordinated surge protective devices

**Protection of the lines at the transition from LPZ 0A to LPZ 1 and higher**

Boundaries of the lightning protection zones (LPZ) must be shielded against radiated interference and protected against conducted interference (Figs. 4 and 5). Surge protective devices that are capable of discharging high lightning currents without destruction must be installed at the transition from LPZ 0A to LPZ 1 (also referred to as lightning equipotential bonding). These surge protective devices are referred to as class I lightning current arresters and are tested by means of impulse currents of 10/350 μs waveform. At the transition from LPZ 0B to LPZ 1 and LPZ 1 and higher only low-energy impulse currents caused by voltages induced outside the system or surges generated in the system must be coped with. These surge protective devices are referred to as class II surge arresters and are tested by means of impulse currents of 8/20 μs waveform.

All incoming cables and lines must be integrated in the lightning equipotential bonding by means of class I lightning current arresters at the boundary from LPZ 0A to LPZ 1 or from LPZ 0A to LPZ 2. Another local equipotential bonding, in which all cables and lines entering this boundary must be integrated, must be installed for every further zone boundary within the volume to be protected. Type 2 surge arresters must be installed at the transition from LPZ 0B to LPZ 1 and from LPZ 1 to LPZ 2, whereas class III surge arresters must be installed at the transition from LPZ 2 to LPZ 3. The function of class II and class III surge arresters is to reduce the residual interference of the upstream protection stages and to limit the surges induced or generated within the wind turbine.

**Selection of SPDs based on the voltage protection level \( U_p \) and the immunity of the equipment**

To describe the required voltage protection level \( U_p \) in an LPZ, the immunity levels of the equipment within an LPZ must be defined, e.g. for power lines and connections of equipment according to IEC 61000-4-5 and IEC 60664-1, for telecommunication lines and connections of equipment according to IEC 61000-4-5, ITU-T K.20 and ITU-T K.21 and for other lines and connections of equipment according to manufacturer’s instructions. Manufacturers of electrical and electronic components or devices should...
be able to provide the required information on the immunity level according to EMC standards. The defined immunity level of components in an LPZ directly defines the required voltage protection level for the LPZ boundaries.

**Protection of power supply systems**

The transformer of a wind turbine may be installed at different locations (in a separate distribution station, in the tower base, in the tower, in the nacelle). In case of large wind turbines, for example, the unshielded 20 kV cable in the tower base is routed to the medium-voltage switchgear installations. The medium-voltage cables are routed from the medium-voltage switchgear installation in the tower of the wind turbine to the transformer situated in the nacelle. The transformer feeds the control cabinet in the nacelle and the pitch system in the hub by means of a TN-C system (L1, L2, L3, PEN conductor; 3PhY, 3W+G). The switchgear cabinet in the nacelle supplies the electrical equipment in the nacelle with an AC voltage of 230/400 V.

According to IEC 60364-4-44, all pieces of electrical equipment installed in a wind turbine must have a specific rated impulse withstand voltage according to the nominal voltage of the wind turbine (see IEC 60664-1; Table 1, insulation coordination). This means that the surge arresters to be installed must have at least the specified voltage protection level depending on the nominal voltage of the system. Surge arresters used to protect 400/690 V power supply systems must have a minimum voltage protection level $U_p \leq 2.5$ kV, whereas surge arrester used to protect 230/400 V power supply systems must have a voltage protection level $U_p \leq 1.5$ kV to ensure protection of sensitive electrical/electronic equipment. To fulfill this requirement, surge protective devices for 400/690 V power supply systems which are capable of conducting lightning currents of 10/350 μs waveform without destruction and ensure a voltage protection level $U_p \leq 2.5$ kV must be installed.

**230/400 V power supply systems**

The voltage supply of the control cabinet in the tower base, the switchgear cabinet in the nacelle and the pitch system in the hub by means of a 230/400 V TN-C system (3PhY, 3W+G) should be protected by class II surge arresters, for example DEHNguard M TNC 275 FM (Fig. 6).

**Protection of the aircraft warning light**

The aircraft warning light on the sensor mast in LPZ 0B should be protected by means of a class II surge arrester at the relevant zone transitions (LPZ 0B → 1, LPZ 1 → 2) (Table 1).

**400/690 V power supply systems**

Coordinated single-pole lightning current arresters with a high follow current limitation for 400/690 V power supply systems, for example DEHNbloc M 1440 FM (Fig. 7), must be installed to protect the 400/690 V transformer, inverters, mains filters and measurement equipment.

**Protection of the generator lines**

Class II surge arresters ("Neptune" arrester combination: 3+1; see Fig. 8) for nominal voltages up to 1000 V must be installed to protect the rotor winding of the generator and the supply line of the inverter. An additional spark-gap-based arrester with a rated power frequency withstand voltage $U_{wac} = 2.2$ kV (50 Hz) is used for potential isolation and to prevent that the varistor based arresters operate prematurely due to voltage fluctuations which may occur during the operation of the inverter. A modular three-pole class II surge arrester of type DEHNguard M WE 600 FM with an increased rated voltage of the varistor for 690 V systems is installed on each side of the stator of the generator (see Fig. 9).

Modular three-pole class II surge arresters of type DEHNguard M WE 600 FM are specifically designed for wind turbines. They have a rated voltage of the varistor $U_{var} = 750$ V AC, thus considering voltage fluctuations which may occur during operation.

**Surge arresters for information technology systems**

Surge arresters for protecting electronic equipment in ITC networks are described in IEC 61643-21 and are installed at the zone boundaries in conformity with the lightning protection zone concept (Fig. 4, Table 1). Multi-stage arresters must be designed without blind spots. This means that it must be ensured that the different protection stages are coordinated with one another. In the majority of cases, fibre optic cables are used for routeing information technology lines into a wind turbines and for connecting the control cabinets from the tower base to the nacelle. The cabling between the actuators and sensors and the control cabinets is implemented by shielded copper cables. In general, the following shielded signal lines connecting the actuators and sensors with the control cabinets must be protected by surge protective devices:

- Signal lines of the weather station on the sensor mast
- Signal lines routed between the nacelle and the pitch system in the hub
- Signal lines for the pitch system

**Signal lines of the weather station**

The signal lines (4 – 20 mA interfaces) between the sensors of the weather station and the switchgear cabinet are routed from LPZ 0B to LPZ 2 and can be protected by means of XT ML4 BE 24 or XT ML2 BE S 24.
combined arresters (Fig. 10). These arresters protect two or four single lines with common reference potential as well as unbalanced interfaces and are available with direct or indirect shield earthing. Two flexible spring terminals for permanent low-impedance shield contact with the protected and unprotected side of the arrester are used for shield earthing.

If the wind measurement equipment (anemometer) is fitted with a heating system, BVT ALD 36 combined arresters may be installed. BVT ALD combined arresters are energy coordinated with the surge protective devices of unearthed DIN rail mounted d.c. power supply systems.

**Signal lines for the pitch system**

If information between the nacelle and the pitch system is exchanged via industrial ethernet data lines, the universal M CLE RJ45 48 arrester can be used. This arrester is specifically designed for industrial Ethernet and similar applications in structured cabling systems according to class E up to 250 MHz for all data services up to 48 V DC for protecting four pairs (see Fig. 11).

Alternatively, a DPA M CAT6 RJ45S48 arrester can be installed to protect the 100 MB Ethernet data lines. This surge protective device is a prewired standard patch cable with integrated surge arrester. The connection of the signal lines for the pitch system depends on the sensors used which may have different parameters depending on the manufacturer. If, for example, sensors are used which are supplied by 24 VDC or lower voltages, XT ML4 BE 24 surge arresters are ideally suited to protect these signal lines. These arresters can be installed in conformity with the lightning protection zone concept at the boundaries from LPZ 0A to LPZ 2 and higher.

**Condition monitoring**

Availability of wind turbines, especially of offshore wind turbines, increasingly gains importance. This requires monitoring of lightning current and surge arresters for signs of pre-damage (condition monitoring).

Arresters with integrated monitoring feature for information technology systems are an easy and ideal monitoring system that detects pre-damage in advance and allows replacement of pre-damaged arresters in the next service cycle. The feature permanently monitors the status of the arrester. The status can be easily read out via contactless RFID technology.

Two systems are available:

**DRC MCM XT (Fig. 11): Compact DIN rail mounted multiple condition monitoring system for condition-based maintenance**

- Condition monitoring of equipped arresters
- Cascaded system permanently monitors up to 150 arresters (600 signal wires)
- Minimal wiring
- Remote signalling via RS485 or remote signalling contacts (1 break and 1 make contact)

**DRC SCM XT: Single condition monitoring system ideally suited for small-sized installations with max. 10 arresters**

- Condition monitoring of equipped arresters
- Monitoring of up to 10 arresters (40 signal wires)
- Minimal wiring
- Remote signalling via remote signalling contact (1 break contact)

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