White Paper SV08/E/0812

Lightning and surge protection for wind turbines

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Due to their vast exposed surface and height, wind turbines are highly vulnerable to the effects of 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 is hit by a direct lightning strike roughly every 12 months. The feed-in compensation must amortise the high investment costs 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, not only cloud-to-earth flashes, but also earth-to-cloud flashes, so-called upward leaders, 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 particularly taken into account for the protection of the rotor blades and selecting suitable 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 to select all sub-components of the lightning protection system of a wind turbine according to lightning protection level (LPL) I 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 IEC 61400-24 standard recommends that the lightning protection system is based on a comprehensive lightning protection concept.
The lightning protection system of a wind turbine consists of an external lightning protection system (LPS) and surge protection measures (SPM) to protect electrical and electronic equipment. In order to plan protection measures, it is advisable to subdivide the wind turbine into lightning protection zones (LPZ).
The lightning protection system of wind turbines protects two sub-systems which can only be found in wind turbines, namely the rotor blades and the mechanical power train. The IEC 61400-24 standard describes in detail how to protect these special parts of a wind turbine and how to prove the effectiveness of the lightning protection measures. According to this standard, it is advisable to carry out high-voltage tests to verify the lightning current withstand capability of the relevant systems with the first stroke and the long stroke, if possible, in a common discharge.
This white paper mainly describes the implementation of lightning and surge protection measures for electrical and electronic devices/systems of a wind turbine.

The complex problems with regard to the protection of the rotor blades and rotably mounted parts/bearings must be examined in detail and depend on the component manufacturer and type. The IEC 61400-24 standard provides important information in this respect.

Lightning protection zone concept

The lightning protection zone concept is a structuring measure to create a defined EMC environment in an object. The defined EMC environment is specified by the immunity of the electrical equipment used. The lightning protection zone concept allows to reduce conducted and radiated interference at the boundaries to defined values. For this reason, the object to be protected is subdivided into protection zones.
The rolling sphere method may be used to determine LPZ 0_A, namely the parts of a wind turbine which may be subjected to direct lightning strikes, and LPZ 0_B, namely 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 IEC 61400-24 standard, the rolling sphere method must not be used for rotor blades themself. For this reason, the design of the air-termination system should be tested according to chapter 8.2.3 of the IEC 61400-24 standard. Figure 1 shows a typical application of the rolling sphere method, Figure 4 the possible division of a wind turbine into different lightning protection zones. The division into lightning protection zones depends on the design of the wind turbine. Therefore, the structure of the wind turbine should be observed. However, it is decisive that the lightning parameters injected from outside of the wind turbine into LPZ 0_A are reduced by suitable shielding measures and surge protective devices at all zone boundaries so that the electrical and electronic devices and systems inside a wind turbine can be operated safely.

Shielding measures

The nacelle should be designed as an encapsulated metal shield. Thus, a volume with an electromagnetic field that is considerably lower than the field outside of the wind turbine is achived in the nacelle. In accordance with IEC 61400-24, a tubular steel tower as predominantly used for large wind turbines can be considered an almost perfect Faraday cage, best suitable for electromagnetic shielding. The switchgear and control cabinets in the nacelle and, if any, 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. The shields must be contacted by means of fully (360 °) contacting terminals without installing EMC-incompatible long connecting cables on the wind turbine.

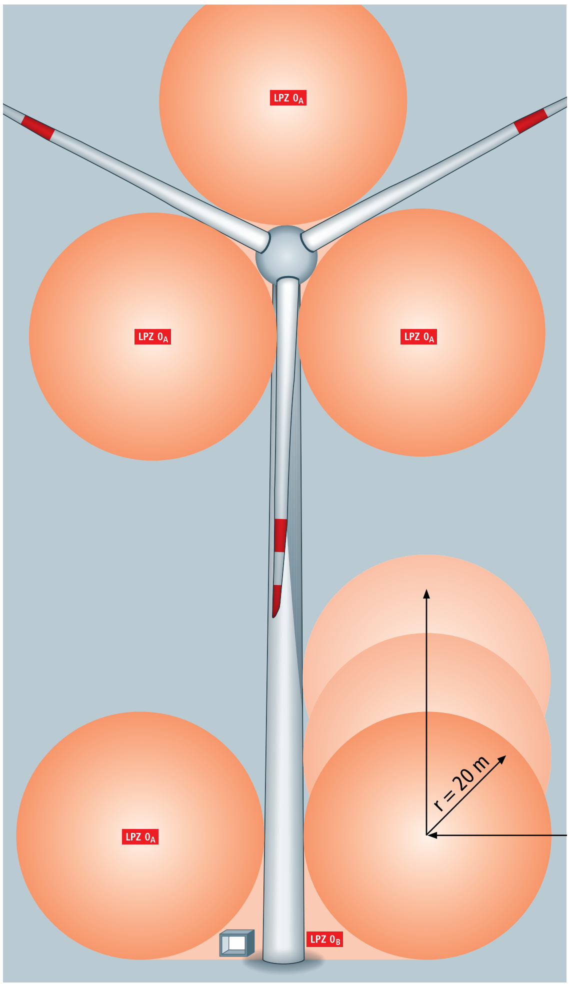


Figure 1 Rolling sphere method

Magnetic shielding and cable routeing 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
- 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 lightning protection system (LPS) is to intercept direct lightning strikes including lightning strikes into the tower of the wind turbine and to discharge the lightning current from the point of strike to the ground. It is also used to distribute the lightning current in the ground without thermal or mechanical damage or dangerous sparking which may cause fire or explosion and endanger persons.

The potential points of strike for a wind turbine (except the rotor blades) can be determined by means of the rolling sphere method (see Figure 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). The air-termination system including the bare conductors in this cage should be capable of withstanding lightning strikes according to the lightning protection level selected. Further conductors in the Faraday cage should be designed in such a way that they withstand the share of lightning current to which they may be subjected. 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 described above.

"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 fulfil the requirements for an external lightning protection system of class of LPS I according to IEC 62305.

This requires that the lightning strike is safely intercepted by the lightning protection system of the rotor blades so that it can be discharged to the earth-termination system via natural components such as bearings, mainframes, the tower and/or bypass systems (e.g. open spark gaps, carbon brushes).

Air-termination system/down conductor

As can be seen in Figure 1, the

- Rotor blades,
- Nacelle including superstructures (Figure 2, Table 1),
- Rotor hub and
- 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 to discharge it to the earth-termination system, they can be used as "natural components" of the air-termination system of the wind turbine's external lightning protection system.
Metallic receptors, which represent defined points of strike for lightning strikes, are frequently installed along the GRP blade to protect the rotor blades against damage due to lightning. A down conductor is routed from the receptor to the blade root. In case of a lightning strike, 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 (Figure 3) is essential to distribute lightning currents and to prevent that the wind turbine is destroyed. Moreover, the earth-termination system must protect humans and animals against electric shock. In case of a lightning strike, the earth-termination system must discharge high lightning currents to the ground and distribute them in the ground without dangerous thermal and/or electrodynamic effects.
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.

Note: Electrical high-voltage regulations such as CENELEC HO 637 S1 or applicable national standards specify how to design an earth-termination system to prevent high touch and step voltages caused by short-circuits in high or medium-voltage systems. With regard to the protection of persons, the IEC 61400-24 standard refers to IEC//TS 60479-1 and IEC 60479-4.

Arrangement of earth electrodes

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

Type A: According to the informative Annex I of IEC 61400-24, 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 connection to a 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: According to the informative Annex I of IEC 61400-24, 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 gain an earth-termination system ranging over as large an area as possible. To prevent excessive step voltages as a result of a lightning strike, potential controlling and corrosion-resistant ring earth electrodes (made of stainless steel, e.g. material AISI/ASTM 316 TI) must be installed around the tower base to ensure protection of persons (Figure 3).

Foundation earth electrodes

Foundation earth electrodes make technical and economic sense and are e.g. required in the German Technical Connection Conditions (TAB) of power supply companies. Foundation earth electrodes are part of the electrical installation and fulfil essential safety functions. For this reason, they must be

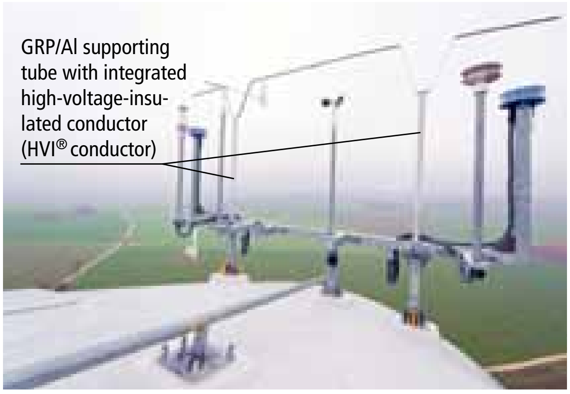
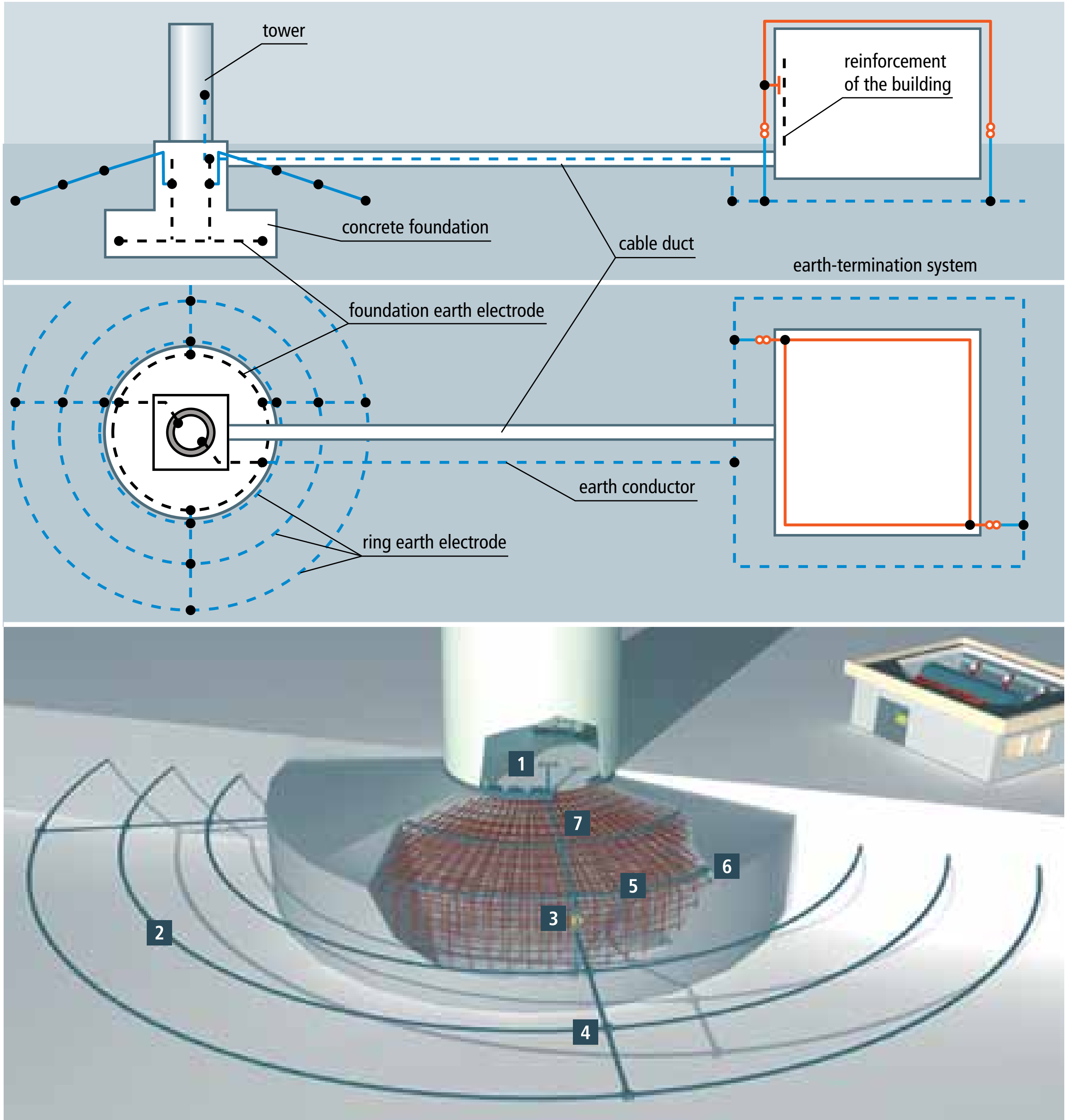


Figure 2 Example of an air-termination system for the weather station (anemometer) and the aircraft warning light



No.		Part No.
1	Equipotential bonding bar for industrial use	472 209
2	Wire, stainless steel (AISI/ASTM 316 TI)	860 010
3	Fixed earthing terminal, stainless steel (AISI/ASTM 316 TI)	478 011

No.		Part No.
4	Cross unit, stainless steel (AISI/ASTM 316 TI)	319 209
5	Tape, 30 mm x 3.5 mm (St/tZn)	810 335
6	Pressure U-clamp	308 031
7	MAXI MV clamp, UL467B-approved	308 040

Figure 3 Earth-termination system of a wind turbine

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.
Foundation earth electrodes must be made of galvanised or non-galvanised steel (round or strip steel). Round steel must have a minimum diameter of 10 mm. Strip steel must have minimum dimensions of 30 mm x 3.5 mm. It must be observed that this material must be covered with at least 5 cm concrete (corrosion protection). The foundation earth electrode must be connected with the main equipotential bonding bar in the wind turbine. Corrosion-resistant connections must be established via fixed earthing points of terminal lugs made of stainless steel (AISI/ASTM 316 TI). Moreover, a ring earth electrode made of stainless steel (AISI/ASTM 316 TI) must be installed in the ground.

Internal lightning protection measures

- 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 0_A to LPZ 1 and higher

To ensure safe operation of electrical and electronic devices, the boundaries of the lightning protection zones (LPZ) must be shielded against radiated interference and protected against conducted interference (Figures 4 and 5). Surge protective devices that are capable of discharging high lightning currents without destruction must be installed at the transition from LPZ 0_A 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 0_B 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.
According to the lightning protection zone concept, all incoming cables and lines must be integrated in the lightning equipotential bonding without exception by means of class I lightning current arresters at the boundary from LPZ 0_A to LPZ 1 or from LPZ 0_A to LPZ 2. Another local equipotential bonding, in which all cables and lines entering this boundary must be inte-

No. in Fig. 4	Area to be protected	Surge protective device	Part No.
1	Voltage supply of the hub Signal lines between the nacelle and the hub	DEHNguard TN 275 FM BLITZDUCTOR XT BE 24 * DENHpatch DPA M CAT6 RJ45S48	952 205 920 324 929 121
2	Protection of the aircraft warning light	DEHNguard M TN 275 FM	952 205
3	Signal line of the weather station	BLITZDUCTOR XT ML4 BE 24 * BLITZDUCTOR XT ML2 BE S 24 *	920 324 920 224
4	Control cabinet in the nacelle 230/400 V voltage supply	DEHNguard M TNC 275 FM DEHNguard M TNC CI 275 FM	952 305 952 309
5	Protection of the stator side	DEHNguard M WE 600 FM	952 307
6	Protection of the rotor	"Neptune" arrester combination: 3+1 (DG 1000 FM 3x, TFS SN1638 1x)	989 405/ SN 1673
7	Voltage supply of the control cabinet in the tower base, 230/400 V TN-C system	DEHNguard M TNC 275 FM DEHNguard M TNC CI 275 FM	952 305 952 309
8	Main incoming supply, 400/690 V TN system	3x DEHNbloc M 1 440 FM	961 145
9	Protection of the inverter	DEHNguard M WE 600 FM	952 307
10	Protection of the signal lines in the control cabinet of the tower base	BLITZDUCTOR XT ML4 BE 24 * BLITZDUCTOR XT ML2 BE S 24 *	920 324 920 224
11	Protection of the nacelle superstructures	Air-termination rods Pipe clamp for air-termination rods	103 449 540 105

Table 1 Protection of a wind turbine (lightning protection zone concept according to Figure 4) * Associated base part: BXT BAS, No. 920 300

SV08/E/0812

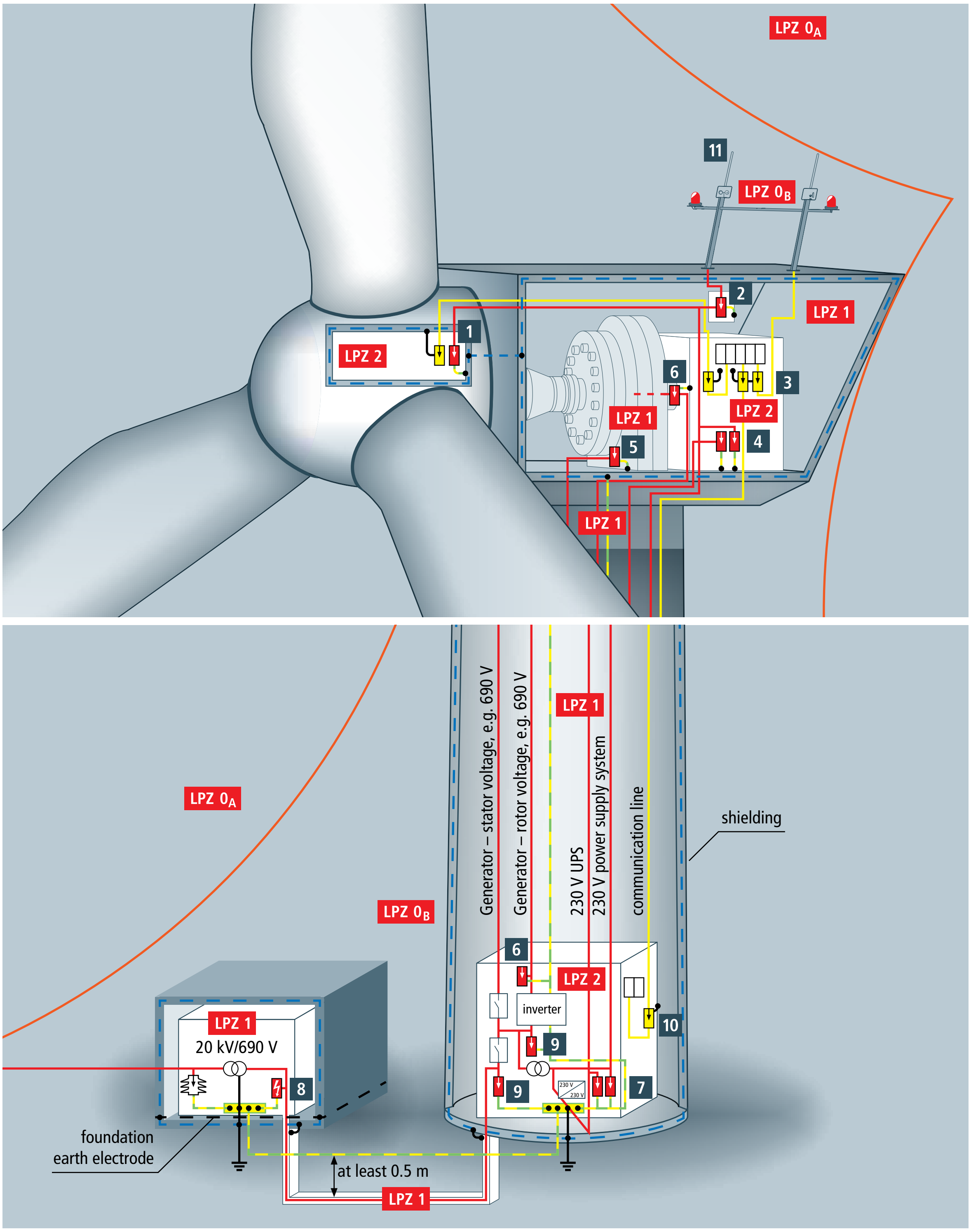


Figure 4 Lightning and surge protection for a wind turbine

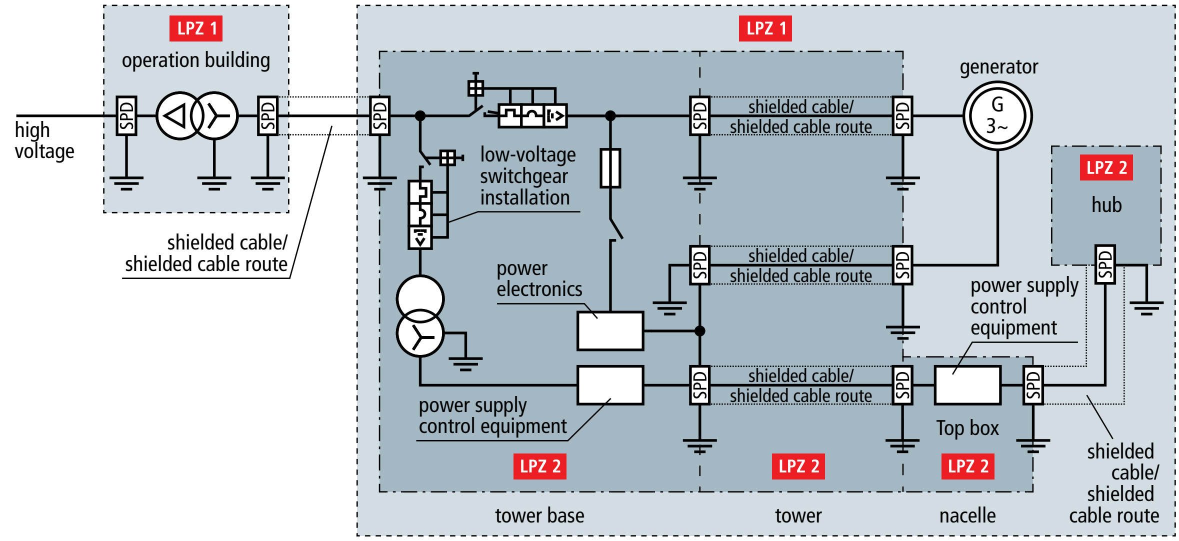


Figure 5 Example of arresters installed at the zone boundaries of a wind turbine according to IEC 61400-24

grated, 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 0_B 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 the EMC standards. Otherwise the wind turbine manufacturer should perform tests to determine the immunity level. The defined immunity level of components in an LPZ directly defines the required voltage protection level for the LPZ boundaries. The immunity of a system must be proven, where applicable, with all SPDs installed and the equipment to be protected.

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 consisting of vacuum circuit breaker, mechanically locked selector switch disconnector, outgoing earthing switch and protective relay. 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 tower base, the switchgear 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 a.c. 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 230/400V power supply systems must have a voltage protection level $U_p \leq 1.5$ kV to ensure protection of sensitive electrical/electronic equipment. To fulfil 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.

SV08/E/0812

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 (Figure 6).

Protection of the aircraft warning light

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

400/690V 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 1 440 FM (Figure 7), must be installed to protect the 400/690 V transformer, inverters, mains filters and measurement equipment.

Protection of the generator lines

Considering high voltage tolerances, class II surge arresters ("Neptune" arrester combination: 3+1, see Figure 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 $U_{N/AC}$ = 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 Figure 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_{mov} of 750 V a.c., thus considering voltage fluctuations which may occur during operation.

Surge arresters for information technology systems

Surge arresters for protecting electronic equipment in telecommunication and signalling networks against the indirect and direct effects of lightning strikes and other transient surges are described in IEC 61643-21 and are installed at the zone boundaries in conformity with the lightning protection zone concept (Figure 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. Otherwise not all protection stages will be activated, thus causing faults in the surge protective device. In the majority of cases, glass fibre cables are used for routeing information technology lines into a wind turbine and for connecting

Figure 6 Modular class II surge arrester for protecting 230/400 V power supply systems

Figure 7 Coordinated class I surge arrester

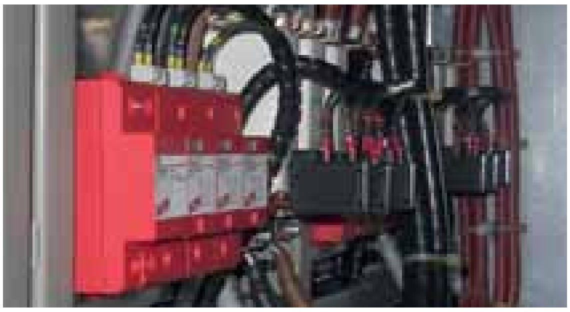
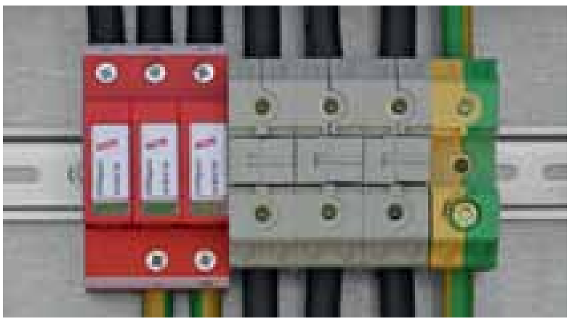


Figure 8 Protection of the rotor winding of the generator ("Neptune" circuit)



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. Since interference by an electromagnetic environment is excluded, the glass fibre cables do not have to be protected by surge arresters unless the glass fibre cable has a metallic sheath which must be directly integrated into the equipotential bonding or by means of surge protective devices.
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 0_B to LPZ 2 and can be protected by means of BLITZDUCTOR XT ML4 BE 24 or BLITZDUCTOR XT ML2 BE S 24 combined arresters (Figure 10). These space-saving combined arresters with LifeCheck feature 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, BLITZDUCTOR 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 DEHNpatch M CLE RJ45B 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 d.c. for protecting four pairs (see Figure 11).
Alternatively, a DEHNpatch DPA M CAT6 RJ45S48 arrester can be installed to protect the 100MB 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 V d.c. or lower voltages, BLITZDUCTOR XT ML4 BE 24 surge arresters are ideally suited

Figure 10 Protection of the weather station (anemometer)

Figure 11 Example of surge protective devices in a pitch system

to protect these signal lines. These arresters can be installed in conformity with the lightning protection zone concept at the boundaries from LPZ 0_A to LPZ 2 and higher.

Condition monitoring

Availability of wind turbines, especially of offshore wind turbines, increasingly gains importance. This requires to monitor lightning current and surge arresters for signs of pre-damage (condition monitoring).
The specific use of condition monitoring allows to plan service work, thus reducing costs.
BLITZDUCTOR arresters with integrated LifeCheck feature for information technology systems are an easy and ideal monitoring system that detects pre-damage in advance and allows to replace pre-damaged arresters in the next service cycle. LifeCheck permanently monitors the status of the arrester. Like an early warning system, LifeCheck reliably detects potential electrical and thermal overload of the protection components. The LifeCheck status can be easily read out via contactless RFID

SV08/E/0812

Figure 12 Customer-specific testing in an impulse current laboratory

technology. A stationary condition monitoring system allows condition-based maintenance of 10 BLITZDUCTOR arresters. Two systems are available:

1. DRC MCM XT (Figure 11) – Compact DIN rail mounted multiple condition monitoring system for condition-based maintenance
   - Condition monitoring of LifeCheck-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)
2. DRC SCM XT – Single condition monitoring system ideally suited for small-sized installations with max. 10 arresters
   - Condition monitoring of LifeCheck-equipped arresters
   - Monitoring of up to 10 arresters (40 signal wires)
   - Minimal wiring
   - Remote signalling via remote signalling contact (1 break contact)

Laboratory tests according to IEC 61400-24

IEC 61400-24 describes two basic methods to perform system-level immunity tests for wind turbines:

- During impulse current tests under operating conditions, impulse currents or partial lightning currents are injected in the individual lines of a control system while supply voltage is present. In doing so, the equipment to be protected including all SPDs is subjected to an impulse current test.
- The second test method simulates the electromagnetic effects of the LEMP. To this end, the full lightning current is injected into the structure which discharges the lightning current and the behaviour of the electrical system is analysed by means of simulating the cabling under operating conditions as realistic as possible. The lightning current steepness is a decisive test parameter.

DEHN offers engineering and test services (Figure 12) for wind turbine manufacturers and supplying industry such as:

- Lightning current tests for bearings and gearboxes of the mechanical power train
- High current tests for the receptors and down conductors of rotor blades
- System-level immunity tests for important control systems such as pitch systems, wind sensors or aircraft warning lights
- Tests for customer-specific connection units

The IEC 61400-24 standard recommends to carry out such system tests for important control systems.

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SV08/E/0812