Chapter 3
Lightning Protection of Domestic, Commercial, and Transport Systems

Abstract This chapter presents a few examples of lightning protection systems for a variety of structures and systems. Particularly, the lightning protection of houses is described. The selection of lightning protections devices, the ratings for different applications, and the graded system protection are discussed for the protection of internal systems of a house. The external protection of the house is also presented. Both basic lightning protection as well as enhanced lightning protection are treated, besides the lightning protection of the following: boats, photovoltaic (PV) installations, frequency converters, network services, wind turbines, and historic buildings.

3.1 General

There are two lightning overvoltage modes. These are the common mode (line-to-neutral or line-to-line surge voltages) and normal mode (line-to-ground or neutral-to-ground surge voltages). Lightning over voltages mostly appears in common mode and enters the internal system at the origin of electrical installation. There are three types of protective wiring. These are the TT, TN, and IT systems. The first of the two letters indicate the earthing conditions of the supplying power source. If the first letter is T, which stands for direct earthing of one point of the power source. If the first letter is I, it indicates the insertion of all live parts from earth or connection of one point of the power source through an impedance. The second letter of the two letters indicates the earthing conditions of the bodies of equipment. If the second letter is T then the body of the equipment is directly earthed. If the second letter is N then the body of the equipment is directly connected to the operational earth electrode, that is the earthing of the power source. A third letter may be added, where S indicates that the neutral and protective conductors are laid separately from each other. If the third letter is C, it indicates that the neutral and protective conductors are combined into one conductor.

The TT system to protect persons is one of the simplest. Here, the exposed conductive parts are earthed and RCDs (residual current devices) are used. Where

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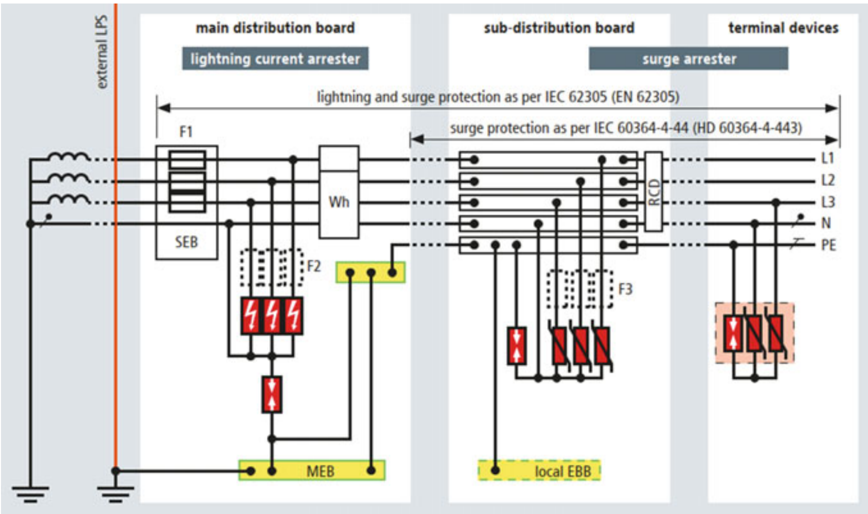


Fig. 3.1 The lightning protection of a TT system

the exposed conductive parts are earthed at a number of points, then each circuit connected to a given earthed electrode must have an RCD installed. Figure 3.1 shows the placements of protective devices in a TT system.

In the TN system, it is essential to have both interconnection and earthing of exposed conductive parts and the neutral. The first fault is interrupted using circuit breakers or fuses as overcurrent protection. In the IT system, the conductive parts are interconnected and earthed. An insulation monitoring device (IMD) is used to indicate the first fault. The second fault is interrupted by overcurrent protectors such as circuit breakers and fuses. The residual current over voltages appears in the TT mode and affects only the sensitive equipment. In the TT mode, when the neutral on the distribution side is linked to a low resistance value earthing system (a few ohms in an installation with earthing electrode resistance of tens of ohms), a phase to neutral protection must be used at each level of the installation. Cascaded protection is used when each level of the installation requires overcurrent protection with ratings appropriate to that level. Several voltage protectors are used in cascade. Spark gap-based protection components with varistors and diodes that limit voltages to compatible levels are used in cascaded protection. For terminal protection close to equipment, proximity voltage surge protectors are used.

When selecting voltage surge protectors, class 1 (Type 1) is compulsory at the origin of the installations and secondary buildings when a lightning conductor is present. In industrial installations and office complexes, high-capacity protection devices such as voltage surge protectors are used when no lightning conductor is used. An increased capacity protection device such as a voltage surge protector is used for smaller installations. At the origin of an installation, an increased capacity protection device or standard main protection device must be coordinated with the main protective device. For very sensitive equipment, a proximity protection device such as a voltage surge protector must be used.

3.2 Lightning Protection of Houses

3.2.1 An Overview

3.2.1.1 Damage from Lightning

A direct lightning strike to a house, rare though it be, poses the greatest threat to the house structure and the contents of the house. Moreover, lightning will be able to damage equipment connected to cables a mile (1.6 km) or more from the location of the strike because the initial lightning impulse is very strong, of the order of 20 kA peak and 1 μs rise time. There are four ways in which that a lightning strike can damage residential equipment. These are strike to power or communication lines, strike to or near equipment outside the house, strike to nearby object, and direct strike to the house structure. These occur in decreasing order of frequency. The four ways by which lightning may pose a threat and damage houses and the electrical and electronic equipment and systems of the house, in detail, are as follows.

(1) Direct lightning strike to power lines and telecommunication and cable television wiring. This is the most common form of lightning threat and damage to houses and home systems. When the network is placed at a higher elevation, it is readily struck by lightning, and the lightning surges travel through the power or communication network into the house. Another route is when lightning strikes the ground close to the house. When this happens, lightning surge currents may travel through underground conductors and piping into the house.

(2) The second most common route is through strikes to neighboring systems that collect lightning surges and may pass them onto the household systems. Examples of these are external electric gate control systems, ground lightning systems, satellite dishes, and security systems. Since all these systems are powered or connected to systems inside the house, lightning surges find a ready route to travel into the home electronic and electrical systems and equipment and cause damage or gradual electric rust.

(3) Pulsed lightning electromagnetic fields, LEMPs, radiated by close by objects including trees and tall structures struck by lightning may travel into the house and induce high voltages and surges in the internal systems. This is so even when the point of strike is not directly connected to home systems and equipment.

Fig. 3.2 Lightning protection of a single-family house without external lightning protection. Credit: DEHN, with permission

(4) The worst case, though rare, is when lightning directly strikes a house. If the house is not provided with a Lightning Protective System (LPS), such a direct strike can cause immense damage to the house structure and to electrical and electronic systems inside it. The LPS system, both external and internal, is presented in the sections to follow.

Figure 3.2 shows the lightning protection of a single-family house without an external lightning protection. Special attention must be given to protect the electronic equipment and systems in increasing use in homes. Referring to Fig. 3.2, the protection arrangements, with reference to the numbers indicated in Fig. 3.2, are as follows:

CHECK CHANGES IN 1–8

1. At the main distribution board. Combined arrester mounted at the entrance of the building. Alternative devices may be used to protect against over-voltages caused by LEMP.
2. For Internet/Telephone Broadband system. Protective device to protect the telecommunication systems at the entrance of the building. Alternatively, other devices may be used to protect broadband connections to PC.
3. For photovoltaic (PV) systems, 3A and 3B in Fig. 3.2 is presented a protection system for PV systems. If the cable length between the PV and the inverter is longer than 10 m, a separate protector is needed at the roof.

4. For sub-distribution board or terminal devices: Protects downstream distribution boards against over voltages from inductive coupling are in order. Alternative devices are available for three-phase terminal devices, for sensitive electric blinds, and for placing directly at the terminal devices.
5. For office/home office/Ethernet devices, computer workstations, and DSL routers.
6. For TV/Satellite systems: For antenna input of TV sets and satellite systems, urge arresters with F sockets, for antenna splitters and multi-switches are recommended.
7. For home automation/heating/air-conditioning/ventilation: Lightning arresters for sensitive equipment are used. These are installed directly at the electronic components of the air conditioners, heat pumps, etc.
8. For smart home: The protective equipment is mounted in the bus terminal slot of KNX components.

External protection systems, such as an air-termination system, are used to protect the house against the effects of lightning directly striking the house, which may result in fire if unprotected. The air-termination is connected to the earth-termination system using a down conductor. Different lightning protection arrangements to that shown in Fig. 3.2 are available for the following: single-family house with external lightning protection, multiple family house with no external lightning protection, and multiple family house with external lightning protection.

3.2.1.2 Basic Protection Against Lightning

In order to conduct lightning currents safely to ground, and prevent them flowing into electronic and electrical systems and equipment, it is pertinent to provide a good grounding system. In order to ensure this and to prevent potential drops developing to cause excess current flows, it is required that a well-grounded electrode (ground electrode) should be connected to metallic structural parts, metallic pipes, cable sheaths, telephone lines, and broadband connections. A well-protected system will have both good bonding and effective grounding.

There are three main features in the basic grounding and protection systems. These are as follows:

(1) One main grounding point with a soundly earthed electrode will serve as the central point to which all lightning currents must be conducted to be dissipated into the ground. All grounding electrodes must be connected to a central ground in order to avoid potential drops between different grounded electrodes. Any potential drop will cause disastrous circulating currents of large magnitudes, which are injected back into the electric system inside the house, often in a reverse direction. This must be avoided.

(2) Whatever lightning surges that seek to enter the building from external electrical, communication, and entertainment networks must be captured and eliminated at the entry point or systematically, stage by stage, eliminated by using

multiple points of surge protection along its route into the household terminals. Electric power cable sheaths as well as external antenna cable sheaths must be connected to the common grounding system of the house. At the point of entry to the building, a special Network Interface Device (NID) is used to eliminate these surges at the point of entry.

(3) By connecting all metal pipes (e.g. water pipes) and building structural metal parts to the common ground point, lightning surges on metal pipes and building metal parts, as well as any danger of potential rise, may be avoided.

These protections greatly reduce shock or electrocution risk to people inside the house and reduce the possibility of a fire caused by lightning. However, they are insufficient to prevent damage to electrical and electronic equipment.

3.2.1.3 Enhanced Protection Against Lightning

To increase protection in high-lightning areas, the following additional systems are important:

(1) Lightning protection system (LPS).
(2) Surge protectors on the AC power wiring.
(3) Additional surge protectors on signal wiring.
(4) Adjacent to electronic and power equipment, a special protection device.

Where the probability of direct lightning strike is high, one or more lightning rods (air terminals) are placed on top of the building and bonded together and connected to the building ground electrode system. The lightning current is safely conducted from the lightning rods to the building's ground system through down conductors. Surge protectors cut down the voltage level of lightning surges before they enter into system and will need to be handled by point-of-use protectors at the equipment. The lightning currents coming on external wiring are conducted to the ground conductor through the use of surge protectors.

3.2.2 Choosing Service Entrance Surge Protectors (SPDs)

Large surge voltages and currents are experienced by the surge protectors used by the AC mains terminal box typically at the entrance to a house. Indirect penetration of lightning surges occurs through utility and electric distribution systems which pick up the lightning surge from lightning strikes to close by soil, electric power lines, and buildings. Less severe than lightning surges are switching surges caused by switching on or off of heavy electric equipment, load, or machines.

When selecting the ratings of SPD surge protectors, the following conditions must be met: (a) capability to prevent damage to service equipment at the power supply entry point to the house and heavy equipment such as air conditioners and other appliances directly connected to entry circuits; (b) provision gradually to cut down surge voltages, using SPDs at critical points, as the surge travels down the connections cables from the main entry into terminal box to various indoor circuits and equipment; and (c) assurance that the electric wiring and other equipment are not damaged by using SPDs at appropriate points.

Lightning surges are carried by two lines, which include the following two modes: line-to-neutral (L-N) or line-to-line (L-L) Normal Mode; or line-to-ground (L-G) or neutral-to-ground (N-G) Common Mode. At the power line entry to the building and right after a transformer, the L-G and L-N modes need protection. Inside the buildings, the L-N, L-G, and N-G modes need protection.

3.2.3 Surge Current Rating

At the service entry point, typically, a 10 kA (8/20 μs waveform) is defined as the largest surge that can be expected (Note: An 8/20 μs waveform rises to its peak in 8 μs and falls to half that value in 20 μs). SPDs with current ratings of 10–70 kA per phase (for residential systems) and in the range of 40–300 kA (for industrial systems) are available. SPDs are typically tested for 8/20, 4/10, 10/350, or 10/1000 μs impulses. Typically, SPDs with surge current rating of 20–70 kA (8/20 μs) per phase are used for residential or light commercial areas. In order to obtain good lifetime and reliability in areas where lightning incidence is high, SPDs rated in the range of 40–120 kA are used. Those SPDs installed along the circuit from the main entry point need to be coordinated, as the surge voltage is expected to drop significantly as the surge passes through the SPDs. The reduction of the surge voltage, in addition to clipping by the SPD, also depends on the impedance of the circuit between two adjacent SPDs along the stream. When installing SPDs, special attention must be paid to secure low impedance grounding, minimum length leads, twisted SPD wires (to reduce loop impedance) and avoidance of 90-degree bends, which increase lead strength. Over current protection should be provided at the service entrance without an internal fuse. Plug in, point-of-use, or supplementary protectors are used to cover over voltages due to open neutral conductors, utility regulator failures and high voltage power cross.

Telephone cables, CATV/antenna/satellite coaxial cables, and broadband cables that carry power should be protected at their entry point to the building. Bonding of the cable sheath to the building ground where the cable enters the building for coaxial connections is important, and direct connection to the building or power panel ground will deal with the large currents. All ground rods should be connected to the building ground. It is highly recommended that the phone protector and cable are mounted at the entry point, right next to the AC protector/ground. This is to ensure that all points of the grounding system are at the same potential. Where large lightning currents flow through the house grounding system, ground potential rise (GPR) results.

3.2.4 Ground Potential Rise

Voltage drops of the order of 10 kV can develop between two points of a cable sheath, which is grounded for lightning strike toward one end of the cable. This, in turn, can give rise to large potential drops between equipment inside the building, each having its own grounding point connected to the building ground. To prevent the internal GPR from causing damage to equipment, it is important to provide surge protection to all the incoming lines and interconnecting lines between different equipment ports; for instance, two television sets inside the building. Moreover, the surge protection devices of all the utilities (including CATV, telephone, power) should be bonded together and where possible enter the building close to each other. Similarly, equipment outside the building (e.g. emergency generator, spa, well pumps, pool heaters) also experience GPR due to the fact that they are referenced to two grounds. They are referenced to the building ground (the line and neutral connected building ground) and local, equipment ground through the concrete slab on which they may be mounted. For a 20 kA lightning strike and a 30 Ω ground, the potential rise may be of the order of 400 kV. The building ground only experiences a delayed voltage rise due to the cable impedance. This could cause large voltage drops, say of the order of 30 kV between the pad ground and the building ground. In the case of a generator or motor, with the coil referenced to the building ground, there could be an electric flashover between the motor coil and the motor frame referenced to the pad ground. The electric motor/generator insulation could be destroyed. In order to protect such equipment, a surge protector should be installed at the equipment site to bond between all line wires, neutral and ground.

3.2.4.1 Multi-Port Point-of-Use (Plug-In) Protectors

The multi-port point-of-use surge protectors consist of an AC protector and signal-like protectors. They are installed at the equipment connecting to both AC and signal lines. These protectors have a lower effective surge limiting voltage than protectors at the panel, and protect against sustained AC over voltage. These having a lower surge limiting voltage, they protect against very small surge voltages that may slip past the primary signal protector. By bonding the grounds for all protectors, the intersystem voltages are minimized.

3.2.4.2 AC Protection Circuits

Since fast electromechanical relays are available that are fast enough for AC protection circuits. These AC protection systems normally contain circuit breakers, indicator lights, multiple varistors and fuses, besides other voltage-limiting components, and capacitors and inductors, which are used to remove radio frequency interference

(RFI). In case of over voltage, the electronic protection systems quickly disconnect surges when detected. These are called varistors, which provide protection against rapidly changing surges. The current it needs to withstand is close to 10 kA. The plug-in protectors are expected to withstand currents of the order to 20–500 A. Surge arresters with high surge current should be installed at the service entrance.

3.2.5 Signal Protectors

A wide variety of protectors are used depending on the signal service; namely, satellite, computer, phone, and video links. The protectors must allow the signal to go through without significant modifications, while the over voltages must be limited to the safe value of the equipment. They must have a capacity to absorb surge energy without getting damaged. The protectors must be properly coordinated with the main protector at the building entry point. The current flowing into the protector is limited by placing a resistor in series with the signal input line.

3.2.6 Inter-System Bonding

It is preferred that the multi-port protector and its components are mounted in a single unit and the signal protector ground, and the AC grounds should be directly connected. Where needed, hum bars, low voltage MOVs (10–50 V), and ground isolators should be used to handle special problems that may be created by 50 Hz circulating currents.

3.2.7 Special Purpose Protectors

Special purpose protectors are used for power over Ethernet (POW) connections, dog fences, and transceivers for inter-building wireless connections. In general, to protect electronic systems in houses, it is required that proper grounding and bonding be provided, especially at the service entrance. Other installations required are: AC panel and primary signal surge protection at or near the service entrance, and multi-port plug-in protectors near the equipment to be protected.

Both the satellite dish and the coaxial cable sheath must be bonded to the building ground with at least a #10 wire. The satellite RF cable should come into the building near the service entrance to shorten the bond if possible. A separate ground rod is not an adequate substitute for the ground rod. The NID (network interface device, which contains the primary phone protector, and is normally supplied by the telephone

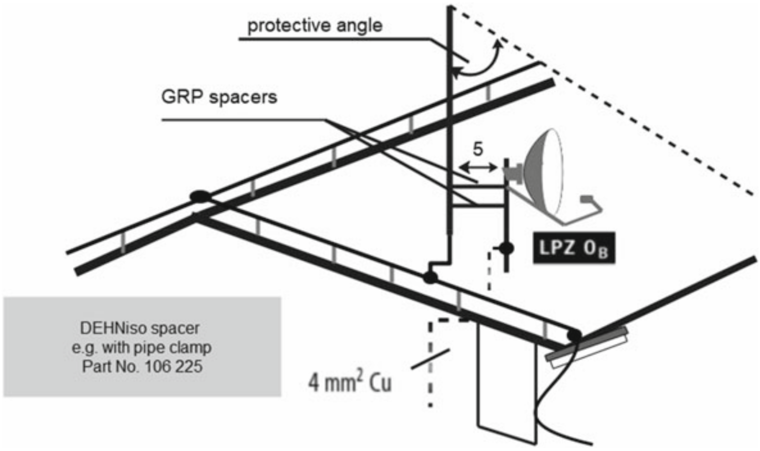


Fig. 3.3 Protection of the microwave dish Antenna (Credit: DEHN)

utility) should be examined, and it should be ensured that its ground terminal is bonded to the building ground. The NID should also be inspected to ensure that there is actually a protector present. The CATV grounding block normally installed at the building entrance should be checked to confirm that it is bonded to the building ground.

Four common types of connections that violate protection integrity are: equipment plugged into an AC outlet, which is not part of the multi-port protector; unprotected rooftop antenna or other signal input connection, bypassing the multi-port protector; downstream signal connections and any ground, unintentional or unintended, to any piece of equipment, bypassing the surge protection.

The rooftop microwave antenna may be protected as shown in Fig. 3.3. It needs to be ensured that the protective angle of the air-termination system covers the antenna as shown in Fig. 3.3. For more details, Cohen (2005) may be consulted.

3.3 Boats

Lightning strikes to ships and boats are higher in number closer to the equator, with higher probability of a lightning strike being closer to shore than at sea. Lightning flash density is higher close to shore than at sea. A typical leisure boat is fixed with electrical wires running down from the top of the mast to the interior of the ship. These include connections to radio antennas, anemometer, and navigation lights. The electrical cables run into various instruments placed inside the interior. There are also underwater sensors such as the depth sounder and log. If the lightning current from a lightning strike to the mast flows down and damages these underwater wiring

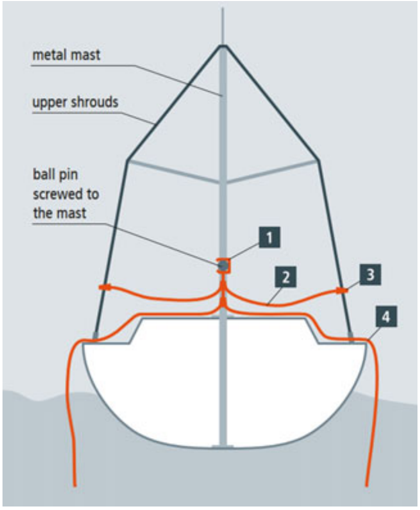


Fig. 3.4 The external lightning protection of the boat. The air-termination system is grounded by dangling the earth electrodes into the seawater. (Numbers in the figure: 1—universal earthing clamp; 2—multipole earthing cable; 3—earthing tongs; 4—braided copper strip.) (Credit: DEHN, with permission.)

systems, it can result in water seeping into the boat. The lightning leader that strikes the top of the mast is conducted into the water through earthing conductors, with the earthing conductors hanging into the water. This is shown in Fig. 3.4. Mobile lightning protection is used with the metal mast, since mobile protection is much cheaper. The earthing connections are two copper braids let into the water to a depth of 1.5 m. The lower part of the mast has a ball pin for the ease of mounting the mobile lightning protection system.

When the boat is harbored, it is supplied from a power supply on the shore. The power supply system has to be protected from corrosion, and the shoreside earth of the power supply system must not be connected to the earthed part of the boat. An isolation transformer protects people inside the boat from shoreside power supply surges when the boat is harbored. Figure 3.5 shows the protection system employed for the internal electric system of a yacht.

In non-metal boats, additional lightning protection measures need to be provided since the body of the boat cannot be depended on to conduct lightning currents into the water. AN air-termination rod of 12 mm thickness is extended above the wooden mast with the air-termination protruding 300 mm above the mast. A copper conductor of 70 mm^2 cross-section connects the air-termination rod to earth plates in the outer area of the boat. In large boats, different earth plates are used for power supply grounding in the seawater and lightning earthing. The two plates for the power supply and lightning earthing are kept at a sufficient distance from each other to prevent lightning flashovers between the earth plates. Copper conductors of 16 mm^2 cross-section are used to connect the mast, shroud, stays, and chain plates to the earth plate. The conductor must be connected using screwing, riveting, and welding.

Equipotential bonding is accomplished connecting all metal parts and electronics to equipotential bonding and the earth-termination system of the power supply. The equipotential bonding helps protect people from touch voltage and sparking. During

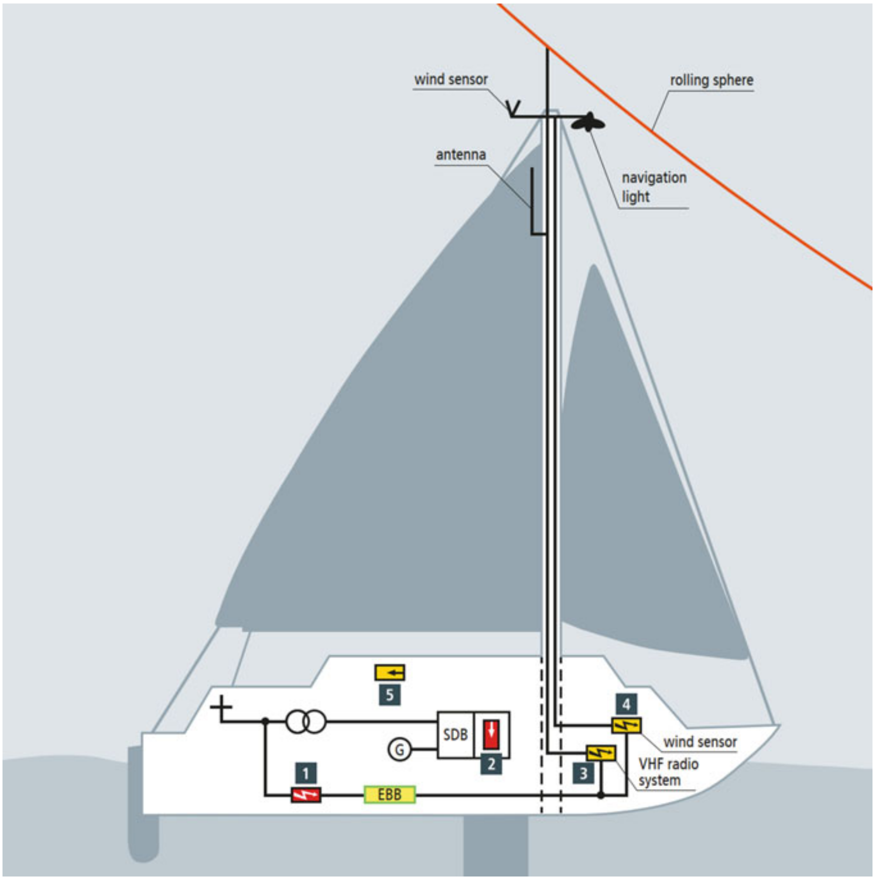


Fig. 3.5 The internal lightning protection of a boat. (Numbers in the figure: Protection for 1—power system; 2—sub-distribution board; 3—VHF radio systems; 4—wind sensor for the navigation system; 5—power supply systems for the navigation system.) (Credit: DEHN, with permission.)

thunderstorm, activity people should not stay outside. Potential differences are generated between the boat metallic parts, wet parts, and the wet skin, which may result in electric flashovers. People should not touch the metal objects, shrouds, or rods. It is important that the lightning protection system should be regularly checked.

3.4 Photovoltaic (PV) Systems

With the year-long availability of solar energy in most countries, it is cheap and clean to use solar radiation to generate electricity. Photovoltaic cells are placed on top of buildings, or larger ground solar farms are constructed by a large collection of solar

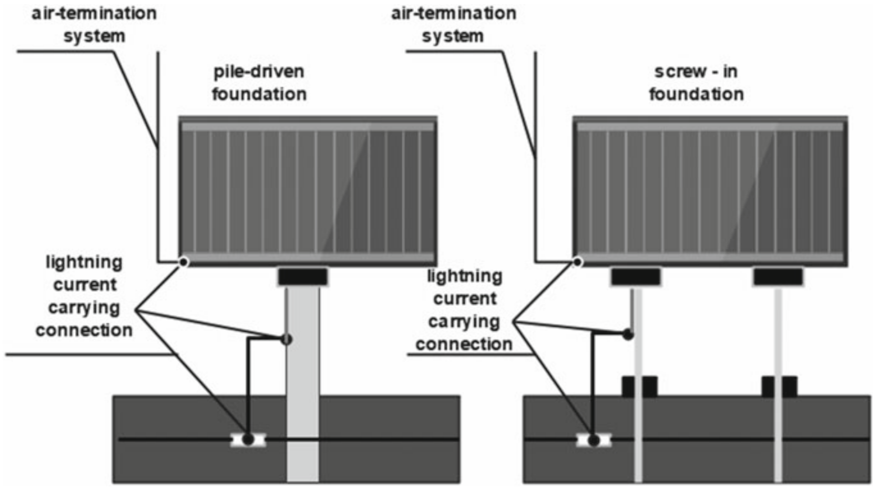
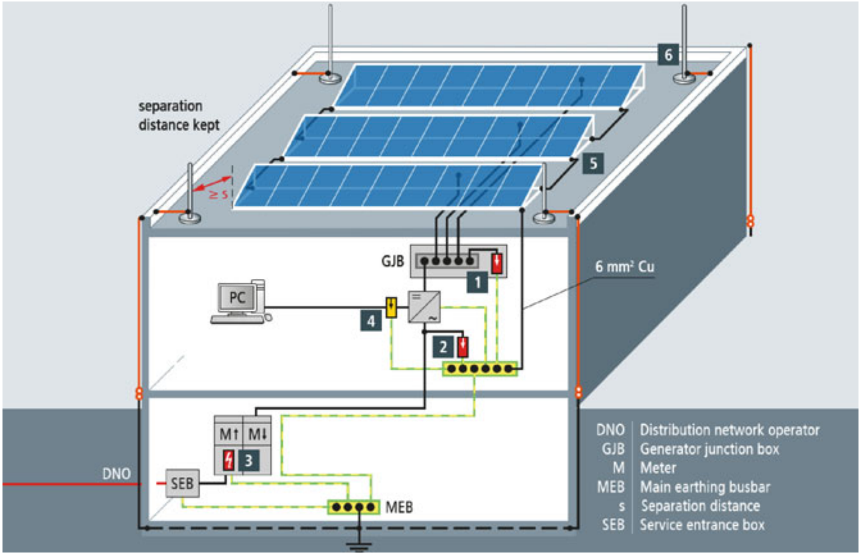


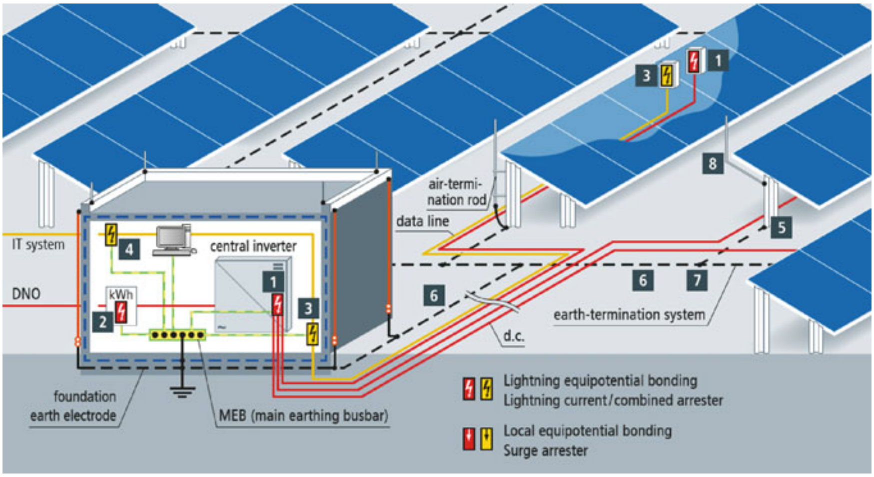
Fig. 3.6 The air-termination protection of photovoltaic (PV) panels (Credit: Adapted from DEHN)

panels connected together in a field. The PV panels are placed outside in the open to expose it to sunlight, either on top of tall buildings or out in open fields. In both cases, whether on top of buildings or in the open fields, they are exposed to lightning strikes. The electric cables connected to the PV panels are taken into the buildings to DC to AC converter electronics and other electronic apparatus and control systems. Figure 3.6 shows the air-termination protection used for the exposed PV panels for both screw-in and pile-driven foundations.

Lightning surges that travel from the PV panels to electronic inverters, electronic apparatuses, and instrument and electrical systems are all exposed to lightning voltage surges that come into the building from the outdoor PV panel system to the systems inside the building. It is important that large voltage loops be avoided to prevent lightning electromagnetic pulses inducing voltage surges in electric loops. The PV systems should be earthed at the point of their installation, with the PV panels mounted on metal mountings. Moreover, air-terminations should be placed adjacent to the PV systems at a distance of 1.08 m (why this odd-looking number?), each with a 10 mm diameter. If the air-terminations are placed too close to the PV panels, shadows cast by the air-termination conductors will reduce the efficiency of the PV electric output. Large PV electricity generators could have currents up to 1000 A and need lightning arresters that combine lightning arresters and surge arresters. (Are these not the same?) PV systems with micro converters should have additional protection systems. The PV systems placed outside in a field require SPDs with high current ratings. Fuses are used to protect the installation from reverse currents. Figure 3.7 shows the general arrangement used for the protection of incoming lines from a PV site on rooftop (Fig. 3.7a). The protection for an open field PV installation, outside the building, with the lightning protection systems, is as shown in Fig. 3.7b.



(a)



(b)

Fig. 3.7 **a** Lightning protection of a rooftop mounted photovoltaic system with external protection. (Numbers on the figure: SPDs for 1—the inverter DC input; 2—the inverter AC input; 3—low voltage system; 4—data interface; 5—functional equipotential bonding; 6—air-termination systems.) **b** Lightning protection of DC lines from the PV lines and data lines to the computer from a PV electric generator installed in a field (Numbers on the figure: Protection for 1—the DC input of the inverter; 2—AC side of the grid connection; 3—data interface; 4—remote maintenance ISDN or DSL, earth-termination systems; 5—equipotential bonding; 6—earthing conductor; 7—connection element; 8—air-termination system.) (Credit: DEHN, with permission)

3.5 Frequency Converter Protection

The frequency converter contains a rectifier, DC link, an inverter, and control electronics. These need to be protected from lightning surges. The rectifier generates a pulsating DC voltage. The DC link has residual current protective devices (RCDs), which may experience problems caused by short-time fault currents of the frequency converter, which are high enough to trip the RCD circuit breakers. These RCDs have a discharge capacity of 3 kA for an 8/20 μs waveform. The tripping current is about 30 mA. The inverter has a pulsed output voltage with the pulsed frequency depending on the pulse frequency of the control electronics of the pulsed width modulation (PWM) circuit. A peak pulse is generated with each peak voltage on the fundamental wave. Higher frequencies are used to get a better sinusoid, but these can cause electric field interference. Hence, the electric motor cable must be shielded and earthed at both ends; that is at the frequency converter end and at the motor end. The connections must be made with large area contacts. To reduce voltage drops, earth-terminations that are intermeshed need to be used in order to prevent equalizing currents through the shields. All communication and computer interfaces must be protected by surge protection devices. A suitable protection system for the frequency converter is shown in Fig. 3.8.

Over voltages from system operation such as switching are less severe. But switching surges are more frequent than lightning surges. Although switching surges have lower energy levels than lightning surges, they can still cause large damage. Radiated electromagnetic pulses from inductive and capacitive switching surges radiate in the range of 1–5 MHz. Repetitive starting of welding stations, high-pressure washers, heaters can cause damage as well as age electronic equipment. Filters are used to control high-frequency interference. Voltage rises should be kept below tolerated values of voltage surge protection. Over-voltages should be avoided between protection circuits and exposed metal conductor parts. Equipotential bonding systems

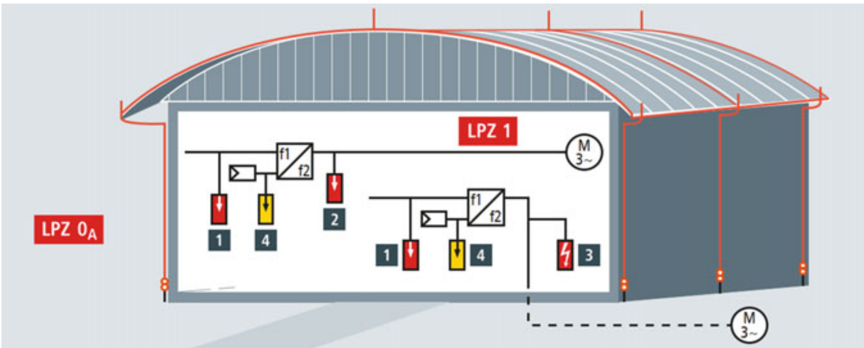


Fig. 3.8 Lightning and surge protection of a frequency converter. (Numbers on the figure: SPDs 1 to 4.) Credit: DEHN, used with permission

should be used. Induction effects due to electric fields should be minimized. Appropriate wiring method and correct location of equipment are essential. In protecting both networks and internal equipment, common fuses and circuit breakers are too slow in operation. Hence, voltage surge protectors should be used for active protection. The protection system must be designed and installed carefully and effectively, particularly including care over the position of the protectors and connections made. Passive protection, seals, equipotentiality, earthing system, and separation of circuits must all be done with proper care.

3.6 Networks and Interactive Services

A lightning and surge protection system for an M-bus (meter-bus) is shown in Fig. 3.9. It is necessary to ensure that antennas on rooftops are earthed. The equipotential bonding of LPS cable networks and shields must be established. The earth-terminations may use one of the following four techniques: a foundation earth electrode, two horizontal earth electrode strips of 2.5 m length and at 60° to each other, a

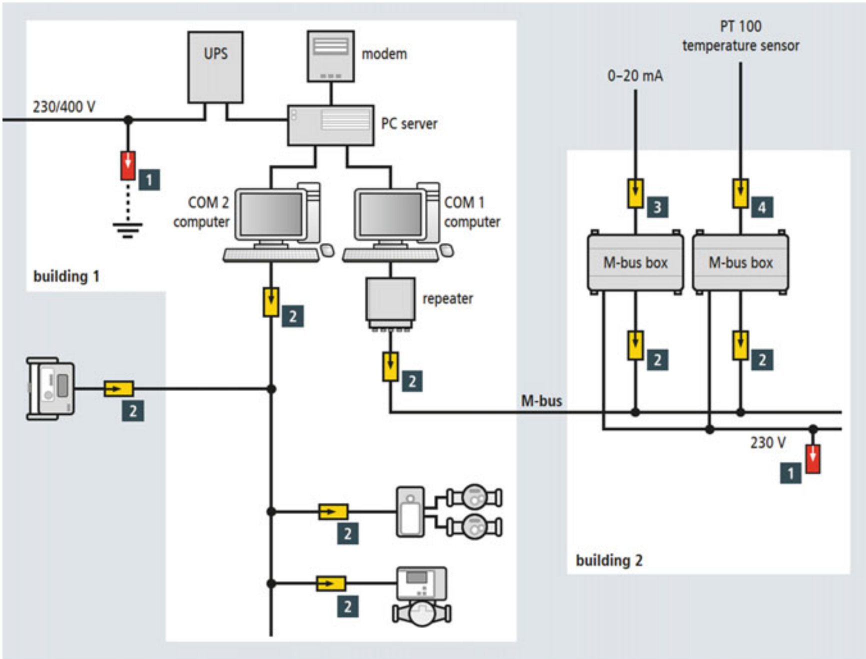


Fig. 3.9 Use of data surge protectors and power surge protectors for M-bus (meter-bus) system without external protection. (Numbers in figure: 1—SPDs for the voltage supply; 2 to 4—SPDs for signal interfaces.) Credit: DEHN, with permission

single 2.5 m long earth electrode or two vertical electrodes of 1.5 m depth and separated from each other by 3 m. The earth-termination must be connected to the main earthing busbar (MEB). The connections must use a 50 mm^2 copper conductor, or 90 mm^2 galvanized steel or a flat strip of 30 × 35 mm giving a cross-section of 105 mm^2. The cable network must be part of the equipotential bonding. Discharge currents are injected into the network from the device. All cables entering the building must be connected to protective equipment bonding. The lightning equipotential bonding inside the building is done through 4 mm^2 copper conductors. In order to avoid sparking, surge protection devices need to be installed between the inner and outer conductors. At the head end, surge protection is installed. Preventive measures are undertaken as well to avoid inductive coupling. Antennas that are placed under the roofs should be installed 2 m under the roof and must not protrude more than 1.5 m from the wall. These antennas must be positioned within the protective zone.

3.7 Wind Turbines

Since wind turbines are very much exposed to direct lightning strikes, they need to be well protected. In Europe, for instance, about ten direct lightning strikes to wind turbines may be expected each year.Both upward and downward flashes may be expected from wind turbines that are taller than 60 m. Lightning protection of both the rotor blades and the mechanical drive train must be provided. These must be tested for lightning current withstand. The wind turbine tower that is of tubular shape affords good Faraday cage protection for all installations inside the tower from direct lightning strikes. Concrete towers provide a galvanic cage. Connecting cables must have external shields that are able to carry lightning currents. External bonding must be done at both ends of the cables.

Magnetic shielding must be provided along the cable route. Installation of a metal braid on GRP-coated nacelles (that is, DEFINE), metal tower, metal switchgear cabinet, metal control cabinet, and current-carrying cable shields must be ensured. For the external wind turbine structure, lightning protecting air-termination and down conductors inside rotor blades are provided. A lightning protection system arrangement for the wind turbine is shown in Fig. 3.10. The tower foundation must be used as earth-termination with foundation earth electrode and ring earth electrode. A rolling sphere of 20 m radius should be used to determine the strike points that need to be covered by the LPS. Direct lightning strikes with currents up to 200 kA may be expected to the rotor blades, nacelle, sputter structure, rotor hub, or the tower. This current must be safely discharged to ground. A metallic receptor attached to the tip of GRP blade is used to protect the rotor blades. Down conductors from the receptor to the blade root, and down conductor inside the nacelle and tower must be connected to the ground. Meshed earthed terminations are used to distribute the lightning current around the earth at the base of the tower. For this, corrosion resistant ring earth electrodes are used, preventing step voltages.

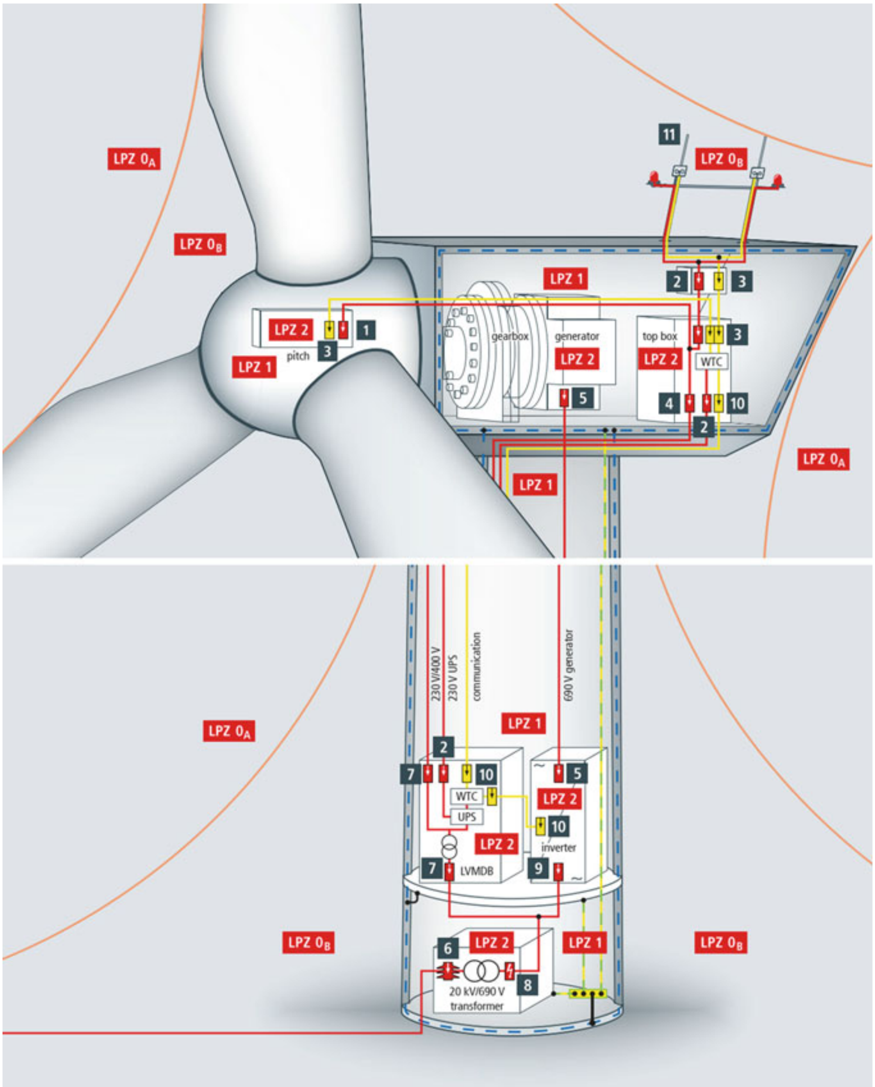


Fig. 3.10 Lightning protection of wind turbine. LPZ—lightning protection zones. Numbers in the figure: areas to be protected: 1—voltage supply of the hub and signal lines between the hub and nacelle; 2—aircraft warning light; 3—signal lines for the weather station and the control cabinet in the nacelle; 4—230/400 voltage supply; 5—protection of the generator; 6—protection of the transformer; 7—protection of tower base voltage supply; 8—main incoming supply; 9—protection of the inverter; 10—protection of the tower base signal lines; 11—protection of the nacelle superstructure.) Credit: DEHN, with permission

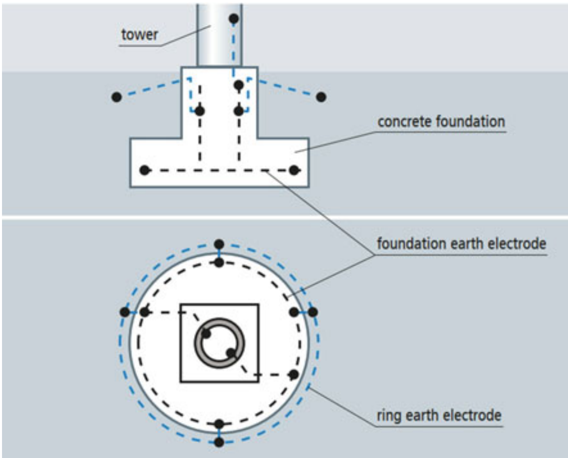


Fig. 3.11 Earthing system for a wind turbine. Credit: DEHN, with permission

Earthing is an essential element of the LPS. For the wind turbine, the earthing arrangement is shown in Fig. 3.11. The earthing resistance should be 10 Ω. At the earth end, more than three conductors could be arranged in a crow's feet-like geometry and buried 0.5 m under the ground. An alternative is to have the earth rods in a triangular layout. The earthing down conductor should be interconnected with the bonding system of the main equipotential link (Fig. 3.11).

3.8 Historic Buildings

Places of worship like churches and buildings of high cultural value should be equipped with permanent and reliable lightning protection systems. Adequate separation must be maintained between lightning current carrying down conductors and the building electric wiring, especially in the steeple. In order to minimize induced voltage surges due to magnetic coupling, short conductors must be used, loops must be minimized, and where necessary surge protectors installed to protect against surges induced due to the indirect effects of lightning radiated electromagnetic pulses LEMP. Equipotential bonding must be done between all metallic pipes and electric cables. The typical lightning protection of a church is shown in Fig. 3.12.

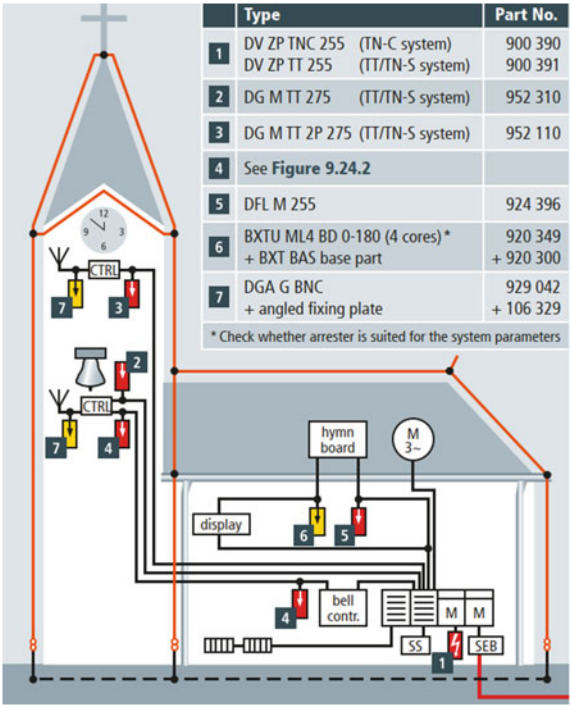


Fig. 3.12 Lightning protection of churches and buildings of cultural value. (Numbers in the figure: SPDs for each section of the electric network, 1–7.) Credit: DEHN, with permission

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