LIGHTNING *PROTECTION* *GUIDE*

2nd updated edition

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Preface

Since its foundation in 1980, the IEC TC 81 "Lightning Protection" of the International Electrotechnical Commission (IEC) has drawn up diverse standards for the protection of buildings from lightning, for the protection of electronic systems, for risk analysis and for the simulation of the effects of lightning. These standards were compiled one after the other as they were required, and published under different numbers with no recognisable system. The standards work therefore became more and more unsystematic to the user. In September 2000, the IEC TC 81 therefore decided to introduce a new, clearly arranged structure for lightning protection standards (series: IEC 62305). Revised and new standards will be integrated into this new structure.

The new International Lightning Protection Standards IEC 62305 (Parts 1 to 4) were published at the beginning of 2006. Almost at the same time they came into force as new European Lightning Protection Standards EN 62305-1 to 4.

The standards IEC 62305 and EN 62305 provide compact information as required for the protection of electrical and electronic systems in buildings and structures. So, this complex protection successfully has been subdivided into a number of concrete individual protective measures which the designer and installer can compose to an overall system adjusted and specific to the respective target of protection.

When signing new contracts on designing and installation of lightning protection systems, in future the contractor has to follow the series of standards IEC 62305 or EN 62305 to work in compliance with the State of the Art.

For this to be possible, the contractor must familiarise himself with the contents of the new lightning protection standards.

With this completely revised LIGHTNING PROTECTION GUIDE, we would like to support you as the specialists in this field, regardless of whether you are involved in design or executing, in becoming familiar with the new series of lightning protection standards.

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Contents

Signs and symbols

Symbol*	Description	Symbol*	Description	Symbol*	Description
	PEN conductor		Gas discharge tube (basic)		Local equipotential bonding Surge arrester
	N conductor		Resistor, Decoupling element (general)		Lightning equipotential bonding Lightning current arrester
	PE conductor		Transformer		Lightning equipotential bonding Lightning current arrester Yellow/Line TYPE 1
	Movable conductor, e.g. expansion piece		Zener diode, unipolar		Local equipotential bonding Surge arrester Yellow/Line TYPE 2 - 4
	Expansion loop (at concrete joints)		Capacitor		Lightning equipotential bonding Lightning current arrester (SPD Type 1)
	Adjustable resistor		Isolating point/ Measuring point		Local equipotential bonding Surge arrester (SPD Type 2, SPD Type 3)
	Thermistor, adjustable		Interface		Isolating spark gap
	Socket (of a socket outlet or a plug-in connection)		Clamp External lightning protection		Varistor
	Suppressordiode, bipolar		Enclosure with terminals		Combined surge protective device for power supply and IT systems
	Earth (general)	**LPZ**	Lightning protection zone		Surge arrester for hazardous/explosive areas
	Signal lamp	**Ex Zone**	Explosive area		Equipotential bonding bar
	Semiconductor	**LEMP**	Lightning electromagnetic pulse		LifeCheck arrester testing
	Fuse (general)	**SEMP**	Switching electromagnetic pulse		Inductor

* according to IEC 62305-3 (EN 62305-3): 2006 and EN 60617: 1997-08

The symbols of the Yellow/Line SPD Classes

Characteristic	Symbol	Legend
Discharge capacity of an SPD (acc. to categories of IEC 61643-21)	TYPE 1	Impulse D1 (10/350 µs), lightning impulse current ≥ 2.5 kA/line or ≥ 5 kA/total • exceeds the discharge capacity of TYPE 2 – TYPE 4
	TYPE 2	Impulse C2 (8/20 µs), increased impulse load ≥ 2.5 kA/line or ≥ 5 kA/total • exceeds the discharge capacity of TYPE 3 – TYPE 4
	TYPE 3	Impulse C1 (8/20 µs), impulse load ≥ 0.25 kA / line or ≥ 0.5 kA / total • exceeds the discharge capacity of TYPE 4
	TYPE 4	Load < TYPE 3
Protective effect of an SPD (limitation below the test levels acc. to EN 61000-4-5)	P1	Test level required for the terminal device: 1 or higher
	P2	Test level required for the terminal device: 2 or higher
	P3	Test level required for the terminal device: 3 or higher
	P4	Test level required for the terminal device: 4
Energy coordination (with another Yellow/Line arrester)	⊕	SPD has a decoupling impedance and is suitable for coordination with an arrester labelled ⊐
	⊐	SPD suitable for coordination with an arrester having a decoupling impedance ⊕

Abbreviations

a.c.	Alternating Current		MEBB	Main Equipotential Bonding Bar
ADSL	Asymmetric Digital Subscriber Line		MOEB	Meshed Operational Equipotential Bonding
ATM	Asynchronous Transfer Mode		MSC	Mobile Switching Centre
BA	Building Automation		NTBA	Network Termination for ISDN Basic Rate Access
BTS	Base Transceiver Station			
CHP	Combined Heat and Power Unit		NTPM	Network Termination for Primary Rate Multiplex Access
d.c.	Direct Current			
DDC	Direct Digital Control		PABX	Private Automatic Branch Exchange
DNO	Distribution Network Operator		PE	Protective Conductor
EB	Equipotential Bonding		PEB	Protective Equipotential Bonding
EBB	Equipotential Bonding Bar		PEN	Protective and Neutral Conductor
EDP	Electronic Data Processing		PEX	Polymerised Polyethylene
EMC	Electromagnetic Compatibility		PSU	Power Supply Unit
ERP	Earthing Reference Point		PV	Photovoltaic
FEM	Finite Elements Method		PVC	Polyvinyl Chloride
GDT	Gas Discharge Tube		RBS	Radio Base Station
GDV	Gesamtverband der Deutschen Versicherungswirtschaft e.V. (German Insurance Association)		RCD	Residual Current Protective Device
			SAK	Shield Terminal (**S**chirm**a**nschluss**k**lemme)
GPS	Global Positioning System		SD	Sub-Distribution
GRP	Glass-fibre Reinforced Plastic		SDB	Sub-Distribution Board
HVI	High Voltage Resistant Insulating Down Conductor		SEB	Service Entrance Box
			SEMP	Switching Electromagnetic Pulse
ISDN	Integrated Services Digital Network		SLK	Protective Conductor Terminal (**S**chutz**l**eiter**k**lemme)
IT	Information Technology			
KNX	Open standard for home and building control		SPC	Stored Program Control
			SPD	Surge Protective Device
LEMP	Lightning Electromagnetic Pulse		TC	Telecommunication
LPC	Lightning Protection Components		TEI	Terminal Equipment Interface
LPL	Lightning Protection Level		TOV	Temporary Overvoltage
LPMS	LEMP Protection Measures System		UPS	Uninterruptible Power Supply
LPS	Lightning Protection System		VDN	Association of German Network Operators
LPZ	Lightning Protection Zone			
l.v.	Low Voltage		VdS	VdS Schadenverhütung GmbH (VdS Loss Prevention)
MDB	Main Distribution Board			
MEB	Main Equipotential Bonding Bar		WT	Wind Turbine

1. State of the art for the installation of lightning protection systems

1.1 Installation standards

At the beginning of 2006, the new IEC standards on lightning protection, Parts 1 to 4 of the series IEC 62305 were published. Almost at the same time they became effective as new European Lightning Protection Standards EN 62305-1 to 4.

The new standards of the series EN 62305 specify the state of the art in the field of lightning protection on a uniform and up-to-date European basis. The actual protection standards (EN 62305-3 and -4) are preceded by two generally valid standard parts (EN 62305-1 and -2) (**Table 1.1.1**).

IEC 62305-1 (EN 62305-1):
General principles
This section contains information about the risk posed by lightning, lightning characteristics, and the parameters derived therefrom for the simulation of the effects of lightning. In addition, an overall view of the IEC 62305 (EN 62305) series of standards is given. Procedures and protection principles which form the basis of the following sections are explained.

IEC 62305-2 (EN 62305-2):
Risk management
Risk management in accordance with IEC 62305-2 (EN 62305-2) uses risk analysis to first establish the necessity for lightning protection. The optimum protective measure from a technical and economic point of view is then determined. Finally, the remaining residual risk is ascertained. Starting with the unprotected state of the building, the remaining risk is reduced and reduced until it is below the tolerable risk. This method can be used both for a simple determination of the class of lightning protection system in accordance with IEC 62305-3 (EN 62305-3), and also to establish a com-

plex protection system against lightning electromagnetic impulse (LEMP) in accordance with EN 62305-4.

IEC 62305-3 (EN 62305-3):
Physical damage to structures and life hazard
This section deals with the protection of buildings and structures and persons from material damage and life-threatening situations caused by the effect of lightning current or by dangerous sparking, especially in the event of direct lightning strikes. A lightning protection system comprising external lightning protection (air-termination system, down-conductor system and earth-termination system) and internal lightning protection (lightning equipotential bonding and separation distance) serves as a protective measure. The lightning protection system is defined by its class, Class I being more effective than Class IV. The class required is determined with the help of a risk analysis carried out in accordance with IEC 62305-2 (EN 62305-2), unless otherwise laid down in regulations (e.g. building regulations).

IEC 62305-4 (EN 62305-4):
Electrical and electronic systems within structures
This section deals with the protection of buildings and structures with electrical and electronic systems against the effects of the lightning electromagnetic impulse. Based on the protective measures according to IEC 62305-3 (EN 62305-3), this standard also takes into consideration the effects of electrical and magnetic fields, and induced voltages and currents, caused by direct and indirect lightning strikes. Importance and necessity of this standard derives from the increasing use of diverse electrical and electronic systems which are grouped together under the heading information systems. For the protection of information systems, the building or structure is divided up into lightning protection zones (LPZ). This allows local differences in the number, type and sensitivity of the electrical and electronic devices to be taken into consideration when choosing the protective measures. For each lightning protection zone, a risk analysis in accordance with IEC 62305-2 (EN 62305-2) is used to select those

Classification	Title
IEC 62305-1: 2006-01 **(EN 62305-1)**	Protection against lightning Part 1: General principles
IEC 62305-2: 2006-01 **(EN 62305-2)**	Protection against lightning Part 2: Risk management
IEC 62305-3: 2006-01 **(EN 62305-3)**	Protection against lightning Part 3: Physical damage to structures and life hazard
IEC 62305-4: 2006-01 **(EN 62305-4)**	Protection against lightning Part 4: Electrical and electronic systems within structures

Table 1.1.1   Lightning protection standard valid since January 2006

protective measures which provide optimum protection at minimum cost.

These standards can be applied to the design, installation, inspection and maintenance of lightning protection systems for buildings and structures, their installations, their contents and the persons within.

1.2 Work contracts

A work contractor is fundamentally liable for ensuring that his service is free of deficiencies. Compliance with the recognised engineering rules is the decisive starting point for work and service free of deficiencies. Relevant national standards are used here in order to fill the factual characteristic of the "recognised engineering rules" with life. If the relevant standards are complied with, it is presumed that the work and service is free from deficiencies. The practical significance of such a prima facie evidence lies in the fact that a customer who lodges a complaint of non-conform service by the work contractor (for example for the installation of a lightning protection system) has basically little chance of success if the work contractor can show that he complied with the relevant technical standards. As far as this effect is concerned, standards and prestandards carry equal weight. The effect of the presumption of technical standards is removed, however, if either the standards are withdrawn , or it is proven that the actual standards no longer represent the state of the art. Standards cannot statically lay down the state of the recognised engineering rules in tablets of stone, as technical requirements and possibilities

are continually changing. So, if standards are withdrawn and replaced with new standards or prestandards, then it is primarily the new standards which then correspond to the state of the art.

Contractors and those placing an order for work regularly agree that the work must conform to the general state of the art without the need to make specific mention of this. If the work shows a negative deviation from this general state of the art, it is faulty. This can result in a claim being made against the contractor for material defect liability. The material defect liability only exists, however, if the work was already faulty at the time of acceptance! Circumstances occurring subsequently – such as a further development of the state of the art – do not belatedly make the previously accepted, defect-free work faulty!

For the question of the deficiency of work and service, the state of the recognised engineering rules at the time of the acceptance is the sole deciding factor.

Since, in future, only the new lightning protection standards will be relevant at the time of completion and acceptance of lightning protection systems, they have to be installed in accordance with these standards. It is not sufficient that the service conformed to the engineering rules at the time it was provided, if, between completion of a contract, service provision and acceptance of the construction work, the technical knowledge and hence the engineering rules have changed.

Hence works which have been previously installed and already accepted under the old standards do not become defective because, as a result of the updating of the standards, a "higher technical standard" is demanded.

	Definition acc. to IEC 61643	Definition acc. to EN 61643
SPDs which withstand the partial lightning current with a typical waveform 10/350 µs require a corresponding impulse test current I_{imp} The suitable test current I_{imp} is defined in the Class I test procedure of IEC 61643-1	SPD class I	SPD Type 1
SPDs which withstand induced surge currents with a typical waveform 8/20 µs require a corresponding impulse test current I_n The suitable test current I_n is defined in the Class II test procedure of IEC 61643-1	SPD class II	SPD Type 2
SPDs that withstand induced surge currents with a typical waveform 8/20 µs and require a corresponding impulse test current I_{sc} The suitable combination wave test is defined in the Class III test procedure of IEC 61643-1	SPD class III	SPD Type 3

Table 1.1.2   Equivalents for SPD classifications (In the following the Lightning Protection Guide uses the designation SPD Type 1, SPD Type 2, SPD Type 3)

With the exception of lightning protection systems for nuclear facilities, lightning protection systems have only to conform to the state of the art at the time they are installed, i.e. they do not have to be updated to the latest state of the art. Existing systems are inspected in the course of maintenance tests according to the standards in force at the time they were installed.

1.3 Product standards

Materials, components and units for lightning protection systems must be designed and tested for the electrical, mechanical and chemical stresses which have to be expected during their use. This affects both the components of the external lightning protection as well as units of the internal lightning protection system.

EN 50164-1:
Requirements for connection components

This standard describes inspection and test procedures for metal connecting units. Units falling within the scope of this standard are:

⇒ Clamps

⇒ Connectors

⇒ Terminal components

⇒ Bridging components

⇒ Expansion pieces

⇒ Measuring points

Our clamps and connectors meet the requirements of this standard.

EN 50164-2:
Requirements for conductors and earth electrodes
This standard specifies the requirements on conductors, air-termination rods, lead-in components and earthing electrodes.

EN 61643-11:
Surge protective devices connected to low voltage systems
Since 1 December 2002, the requirements on, and inspections of, surge protective devices in low voltage systems have been governed by EN 61643-11. This product standard is the result of international standardisation as part of IEC and CENELEC.

EN 61643-21: Surge protective devices connected to telecommunications and signalling networks
This standard describes the performance requirements and testing methods for surge protective devices used for the protection of telecommunications and signal processing networks including e.g.

⇒ data networks,

⇒ voice transmission networks,

⇒ alarm systems,

⇒ automation systems.

CLC/TS 61643-22 (IEC 61643-22:2004, modified): 2006-04; Low-voltage surge protective devices, Part 22:
Surge protective devices connected to telecommunications and signalling networks - Selection and application principles

EN 61663-1
Lightning protection - Telecommunication lines - Fibre optic installations

EN 61663-2
Lightning protection - Telecommunication lines - Lines using metallic conductors

2. Characteristics of lightning current

2.1 Lightning discharge and sequence of lightning current

Every year, an average of around 1.5 million lightning strikes discharge over Germany. For an area of 357,042 km² this corresponds to an average flash density of 4.2 lightning discharges per square kilometre per year. The actual lightning density, however, depends to a large extent on geographic conditions. An initial overview can be obtained from the lightning density map contained in **Figure 3.2.3.1**. The higher the resolution of the lightning density map, the more accurate the information it provides about the actual lightning frequency in the area under consideration.

Using the BLIDS Blitzinformationsdienst von Siemens (lightning information service by Siemens), it is now possible to locate lightning to within 200 m in Germany. For this purpose, eighteen measuring outposts are spread throughout the country. They are synchronised by means of the highly accurate time signal of the global positioning system (GPS). The measuring posts record the time the electromagnetic wave produced by the lightning discharge arrives at the receiver. From the differences in the times of arrival of the electromagnetic wave recorded by the various receivers, and the corresponding differences in the times it takes the electromagnetic wave to travel from the location of the lightning discharge to the receivers, the point of strike is calculated. The data determined in this way are filed centrally and made available to the user in form of various packages. Further information about this service can be obtained from www.blids.de.

Thunderstorms come into existence when warm air masses containing sufficient moisture are transported to great altitudes. This transport can occur in a number of ways. In the case of heat thunderstorms, the ground is heated up locally by intense insolation. The layers of air near the ground heat up and rise. For frontal thunderstorms, the invasion of a cold air front causes cooler air to be pushed below the warm air, forcing it to rise. Orographic thunderstorms are caused when warm air near the ground is lifted up as it crosses rising ground. Additional physical effects further increase the vertical upsurge of the air masses. This forms updraught channels with vertical speeds of up to 100 km/h, which create towering cumulonimbus clouds with typical heights of 5 – 12 km and diameters of 5 – 10 km.

Electrostatic charge separation processes, e.g. friction and sputtering, are responsible for charging water droplets and particles of ice in the cloud. Positively charged particles accumulate in the upper part, and negatively charged particles in the lower part of the thundercloud. In addition, there is again a small positive charge centre at the bottom of the cloud. This originates from the corona discharge which emanates from sharp-pointed objects on the ground underneath the thundercloud (e.g. plants), and is transported upwards by the wind.

If the space charge densities, which happen to be present in a thundercloud, produce local field strengths of several 100 kV/m, leader discharges (leaders) are formed which initiate a lightning discharge. Cloud-to-cloud flashes result in charge neutralisation between positive and negative cloud charge centres, and do not directly strike objects on the ground in the process. The lightning electromagnetic impulses (LEMP) they radiate must be taken into consideration, however, because they endanger electrical and electronic systems.

Fig. 2.1.1   Downward flash (cloud-to-earth flash)
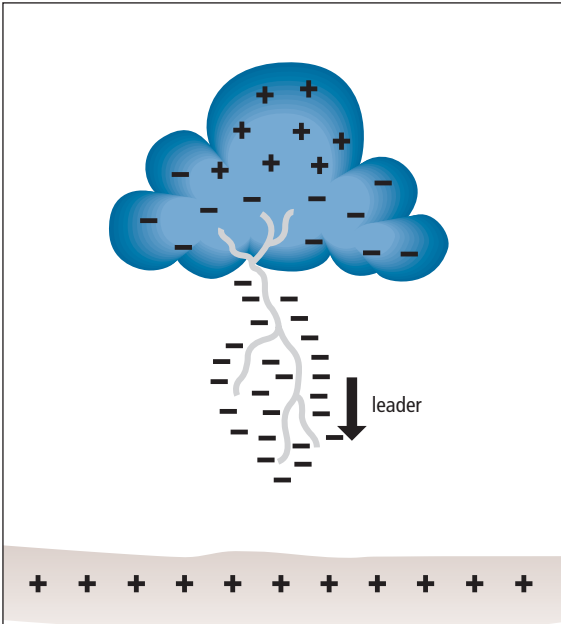
Fig. 2.1.2 Discharge mechanism of a negative downward flash
(cloud-to-earth flash)
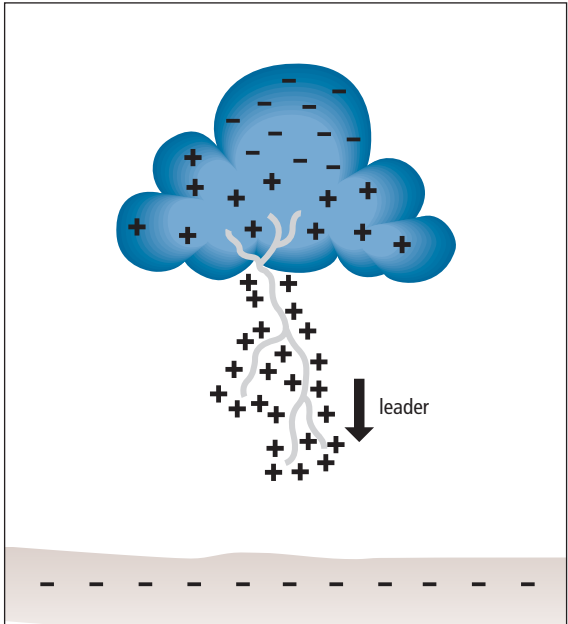
Fig. 2.1.3 Discharge mechanism of a positive downward flash
(cloud-to-earth flash)

Lightning flashes to earth lead to a neutralisation of charge between the cloud charges and the electrostatic charges on the ground. We distinguish between two types of lightning flashes to earth:

⇒ Downward flash (cloud-to-earth flash)

⇒ Upward flash (earth-to-cloud flash)

In the case of downward flashes, leader discharges pointing towards the ground guide the lightning discharge from the cloud to the earth. Such discharges usually occur in flat terrain and near low buildings and structures. Downward flashes can be recognised by the branching (**Figure 2.1.1**) which is directed earthwards. The most common type of lightning is negative lightning flashes to earth, where a leader filled with negative cloud charge pushes its way from the thunder cloud to earth (**Figure 2.1.2**). This leader propagates in a series of jerks with a speed of around 300 km/h in steps of a few 10 m. The interval between the jerks amounts to a few 10 μs. When the leader has drawn close to the earth, (a few 100 m to a few 10 m), it causes the strength of the electric field of objects on the surface of the earth in the vicinity of the leader (e.g. trees, gable ends of buildings) to increase. The increase is great enough to exceed the dielec-

tric strength of the air. These objects involved reach out to the leader by growing positive streamers which then meet up with the leader, initiating the main discharge.

Positive flashes to earth can arise out of the lower, positively charged area of a thundercloud (**Figure 2.1.3**). The ratio of the polarities is around 90 % negative lightning to 10 % positive lightning. This ratio depends on the geographic location.

On very high, exposed objects (e.g. radio masts, telecommunication towers, steeples) or on the tops of mountains, upward flashes (earth-to-cloud

Fig. 2.1.4 Upward flash (earth-to-cloud flash)
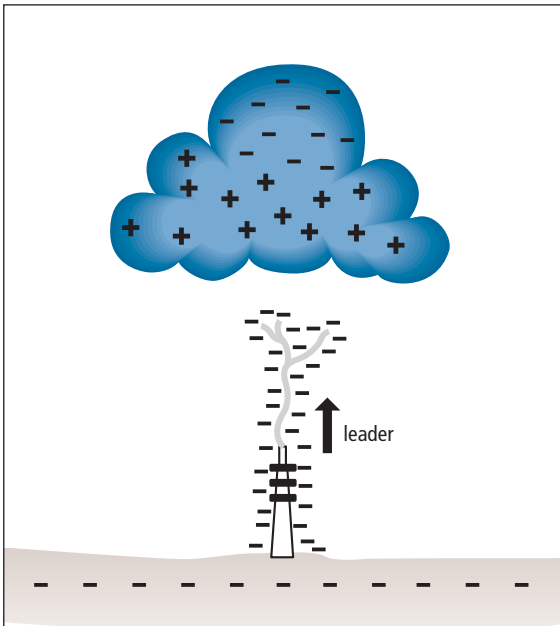
Fig. 2.1.5   Discharge mechanism of a negative upward flash (earth-to-cloud flash)
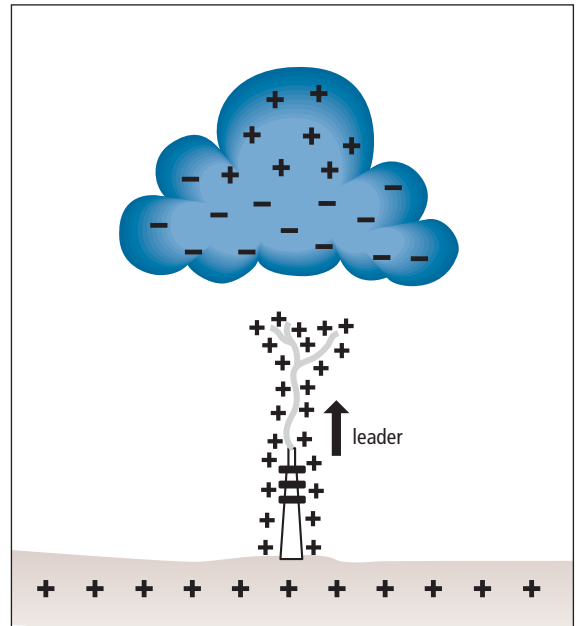
Fig. 2.1.6   Discharge mechanism of a positive upward flash (earth-to-cloud flash)

flashes) can occur. It can be recognised by the upwards-reaching branches of the lightning discharge (**Figure 2.1.4**). In the case of upward flashes, the high electric field strength required to trigger a leader is not achieved in the cloud, but rather by the distortion of the electric field on the exposed object, and the associated high strength of the electric field. From this location, the leader and its charge channel propagate towards the cloud. Upward flashes occur with both negative polarity (**Figure 2.1.5**) and also with positive polarity (**Figure 2.1.6**). Since, with upward flashes, the leaders propagate from the exposed object on the surface of the earth to the cloud, high objects can be struck several times by one lightning discharge during a thunderstorm.

Objects struck by lightning are subject to higher stress by downward flashes (cloud-to-earth flashes) than by upward flashes (earth-to-cloud flashes). The parameters of downward flashes are therefore taken as the basis when designing lightning protection measures.

Depending on the type of lightning flash, each lightning discharge consists of one or more partial strikes of lightning. We distinguish between short strikes with less than 2 ms duration and long strikes with a duration of more than 2 ms. Further

distinctive features of partial lightning strikes are their polarity (negative or positive), and their temporal position in the lightning discharge (first, subsequent or superimposed partial strikes of lightning). The possible combinations of partial lightning strikes are shown in **Figure 2.1.7** for downward flashes, and **Figure 2.1.8** for upward flashes. The lightning currents consisting of both impulse currents and continuing currents are load-independent currents, i.e. the objects struck exert no effect on the lightning currents. Four parameters important for lightning protection technology can be obtained from the lightning current profiles shown in **Figure 2.1.7** and **2.1.8**:

⇒ The peak value of lightning current I

⇒ The charge of the lightning current Q_{flash}, comprising the charge of the short strike Q_{short} and the charge of the long strike Q_{long}

⇒ The specific energy W/R of the lightning current

⇒ The steepness di/dt of the lightning current.

The following chapters show which of the individual efficiency parameters are responsible for which effects, and how they influence the dimensioning of lightning protection systems.
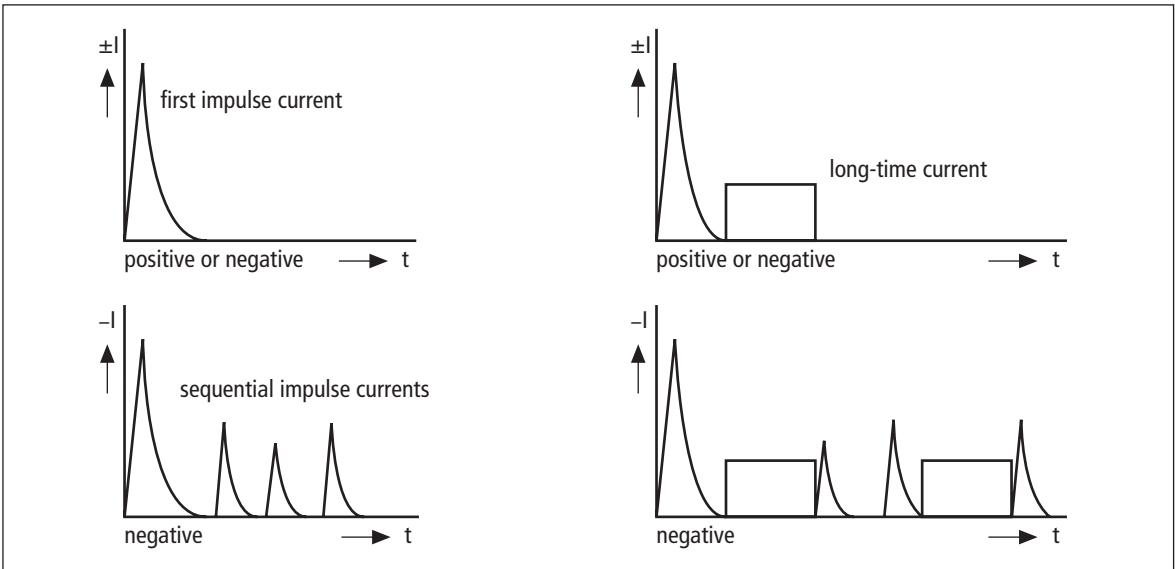
Fig. 2.1.7   Possible components of downward flashes
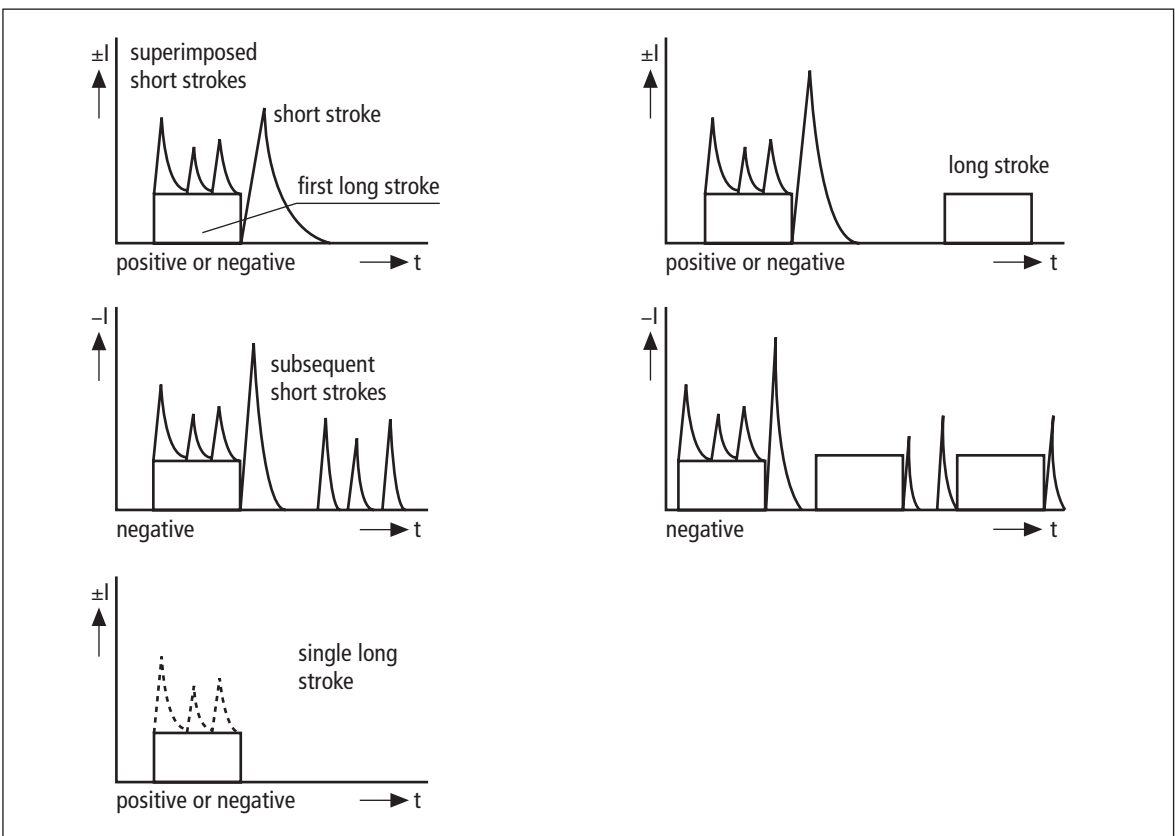
Fig. 2.1.8   Possible components of upward flashes

2.2 Peak value of lightning current

Lightning currents are load-independent currents, i.e. a lightning discharge can be considered an almost ideal current source. If a load-independent active electric current flows through conductive components, the amplitude of the current, and the impedance of the conductive component the current flows through, help to regulate the potential drop across the component flown through by the current. In the simplest case, this relationship can be described using Ohm´s Law.

$$U = I \cdot R$$
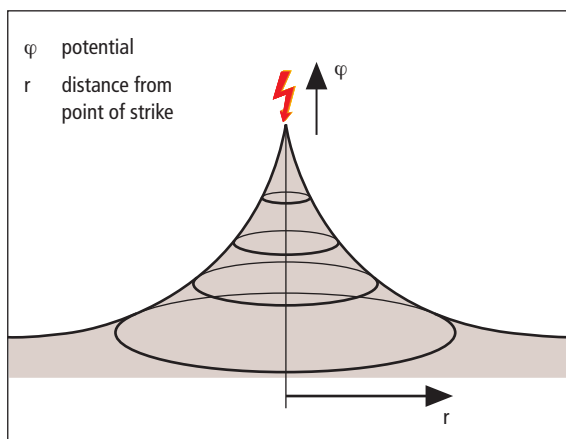
Fig. 2.2.1   Potential distribution of a lightning strike into homogenous soil

Fig. 2.2.2   Animals killed by shock current due to hazardous step voltage

If a current is formed at a single point on a homogeneously conducting surface, the well-known potential gradient area arises. This effect also occurs when lightning strikes homogeneous ground (**Figure 2.2.1**). If living beings (people or animals) are inside this potential gradient area, a step voltage is formed which can cause a shock current to flow through the body (**Figure 2.2.2**). The higher the conductivity of the ground, the flatter the shape of the potential gradient area. The risk of dangerous step voltages is thus also reduced.

If lightning strikes a building which is already equipped with a lightning protection system, the lightning current flowing away via the earth-termination system of the building gives rise to a potential drop across the earthing resistance R_E of the earth-termination system of the building (**Figure 2.2.3**). As long as all conductive objects in the building, which persons can come into contact with, are raised to the same high potential, persons in the building cannot be exposed to danger. This is why it is necessary for all conductive parts in the building with which persons can come into contact, and all external conductive parts entering
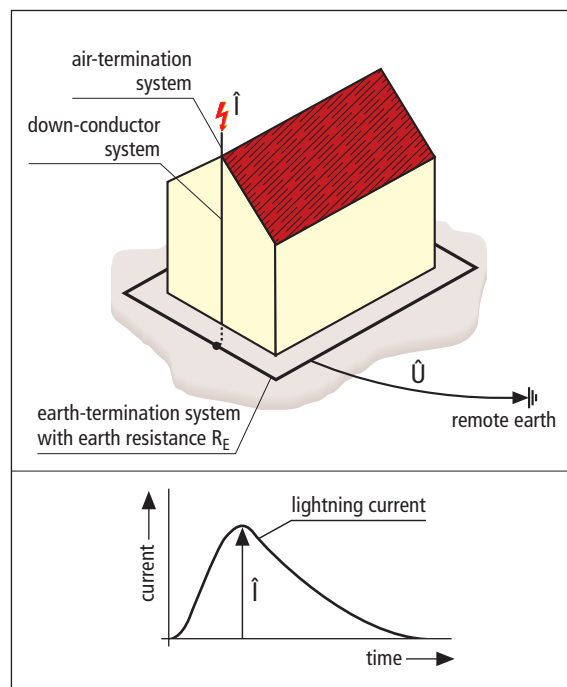
Fig. 2.2.3   Potential rise of the earth-termination system of a building compared to the remote earth due to the peak value of the lightning current
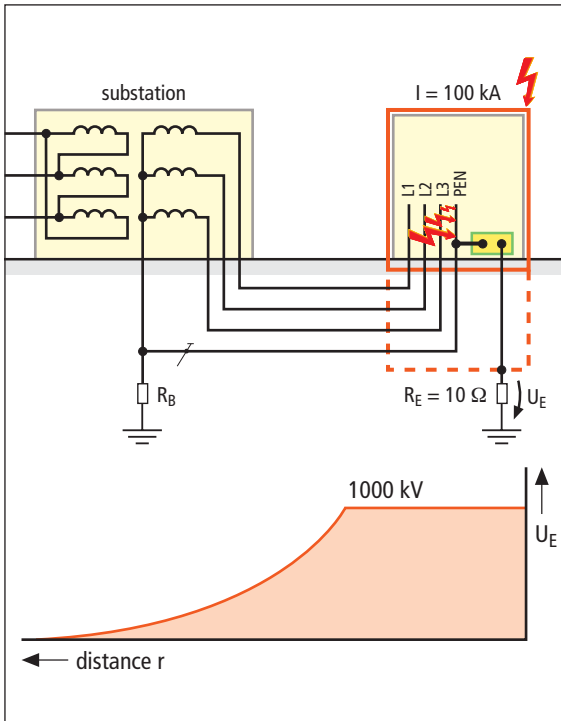
Fig. 2.2.4   Threat to electrical installations by potential rise at the earth-termination system

1 Loop in the down con-
  ductor with potential
  flashover distance s₁

2 Loop in the down con-
  ductor and installation
  cable with potential
  flashover distance s₂

3 Installation loop with
  potential flashover
  distance s₃

Fig. 2.3.1   Induced square-wave voltage in loops via the current steepness Δi/Δt of the lightning current

the building, to have equipotential bonding. If this is disregarded, there is a risk of dangerous shock hazard voltages if lightning strikes.

The rise in potential of the earth-termination system as a result of the lightning current also creates a hazard for electrical installations (**Figure 2.2.4**). In the example shown, the operational earth of the low-voltage supply network is located outside the potential gradient area caused by the lightning current. If lightning strikes the building, the potential of the operational earth R_B is therefore not identical to the earth potential of the consumer system within the building. In the present example, there is a difference of 1000 kV. This endangers the insulation of the electrical system and the equipment connected to it.

2.3 Steepness of lightning current

The steepness of lightning current $\Delta i/\Delta t$, which is effective during the interval Δt, determines the height of the electromagnetically induced voltages. These voltages are induced in all open or closed conductor loops located in the vicinity of conductors through which lightning current is flowing. **Figure 2.3.1** shows possible configurations of conductor loops in which lightning currents could induce voltages. The square wave voltage U induced in a conductor loop during the interval Δt is:

$$U = M \cdot \Delta i / \Delta t$$

M   Mutual inductance of the loop

$\Delta i/\Delta t$ Steepness of lightning current

As already described, lightning discharges comprise a number of partial strikes of lightning. As far as the temporal position is concerned, a distinction is made between first and subsequent short strikes within a lightning discharge. The main difference between the two types of short strikes consists in the fact that, because the lightning channel has to be built, the gradient of the lightning current of the first short strike is not as steep as that of the subsequent short strike, which can use an existing,

Example of calculation
based on an installation loop (e.g. alarm system)

a	10 m
s	3 m
$\frac{\Delta i}{\Delta t}$	$150 \frac{kA}{\mu s}$ (high requirement)

From the above diagram results: $M_2 \approx 4.8\ \mu H$ ①

$U = 4.8 \cdot 150 = 720\ kV$
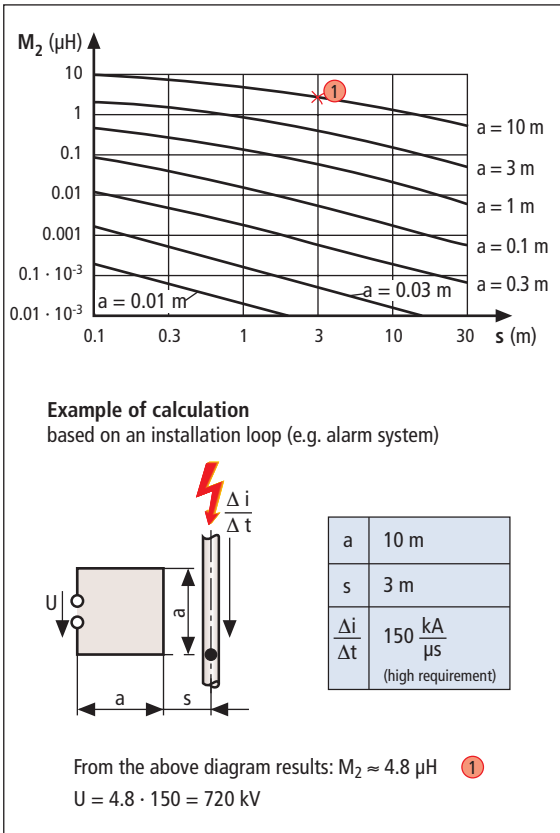
Fig. 2.3.2   Example for calculation of induced square-wave voltages in squared loops

fully conductive lightning channel. The steepness of lightning current of the subsequent lightning strike is therefore used to assess the highest induced voltage in the conductor loops.

An example of how to assess the induced voltage in a conductor loop is shown in **Figure 2.3.2**.

2.4 Charge of lightning current

The charge Q_{flash} of the lightning current is made up of the charge Q_{short} of the short strike and the charge Q_{long} of the long strike. The charge

$$Q = \int i\,dt$$

of the lightning current determines the energy deposited at the precise striking point, and at all points where the lightning current continues in
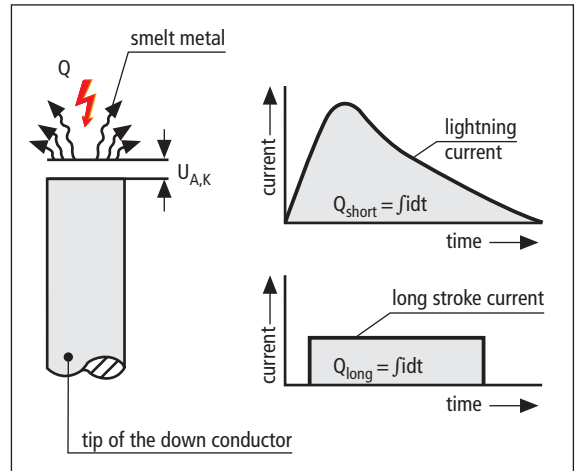
Fig. 2.4.1   Energy deposited at the point of strike by the load of the lightning current

the shape of an electric arc along an insulated path. The energy W deposited at the base of the electric arc is given by the product of the charge Q and the anode-/cathode voltage drop with values in the micrometer range $U_{A,K}$ (**Figure 2.4.1**).

The average value of $U_{A,K}$ is a few 10 V and depends on influences such as the height and shape of the current:

$$W = Q \cdot U_{A,K}$$

Q   Charge of lightning current

$U_{A,K}$ Anode/cathode voltage drop

Hence, the charge of the lightning current causes the components of the lightning protection system struck by lightning to melt down. The charge is also relevant for the stresses on isolating spark gaps and protective spark gaps and by spark-gap based surge protective devices.

Recent examinations have shown that, as the electric arc acts for a longer time, it is mainly the continuing charge Q_{long} of the continuing current which is able to melt or vaporise large volumes of materials. **Figure 2.4.2** and **2.4.3** show a comparison of the effects of the short strike charge Q_{short} and the long strike charge Q_{long}.
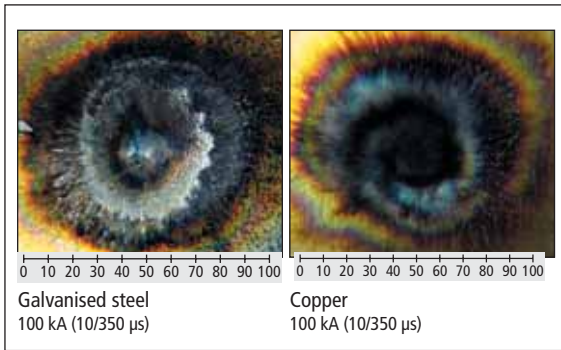
Fig. 2.4.2   Effect of an impulse current arc on a metal surface

Galvanised steel
100 kA (10/350 µs)

Copper
100 kA (10/350 µs)

Aluminium
d = 0.5 mm; 200 A, 350 ms

Copper
d = 0.5 mm; 200 A, 180 ms

Stainless steel
d = 0.5 mm; 200 A, 90 ms

Steel
d = 0.5 mm; 200 A, 100 ms

Galvanised steel
d = 0.5 mm; 200 A, 100 ms
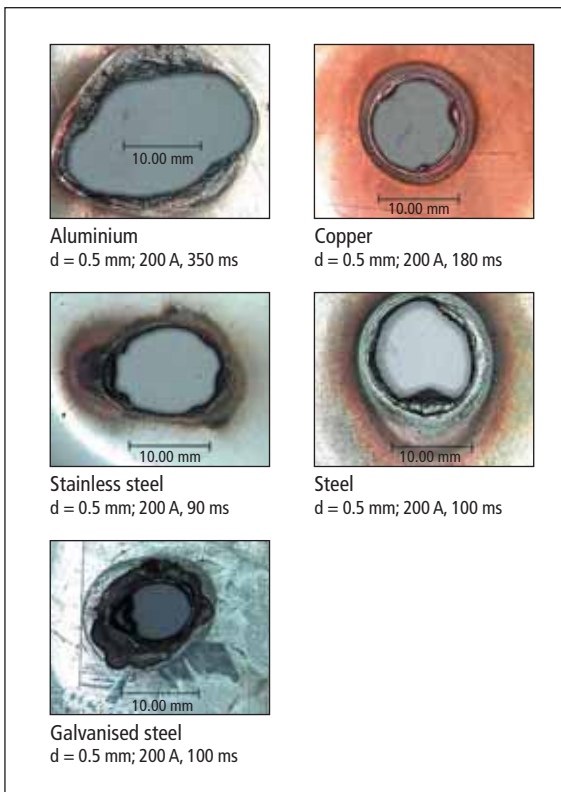
Fig. 2.4.3   Plates perforated by the effects of long-time arcs

2.5 Specific energy

The specific energy W/R of an impulse current is the energy deposited by the impulse current in a resistance of 1 Ω. This energy deposition is the integral of the square of the impulse current over the time for the duration of the impulse current:

$$W / R = \int i^2 dt$$

The specific energy is therefore often called the current square impulse. It is relevant for the temperature rise in conductors through which a lightning impulse current is flowing, as well as for the force exerted between conductors flown through by a lightning impulse current (**Figure 2.5.1**).

For the energy W deposited in a conductor with resistance R we have:

$$W = R \cdot \int i^2 dt = R \cdot W / R$$

R   (Temperature dependent) d.c. resistance of the conductor

W/R Specific energy

The calculation of the temperature rise of conductors through which a lightning impulse current is flowing, can become necessary if the risks to persons, and the risks from fire and explosion, have to be taken into account during the design and installation of lightning protection systems. The calculation assumes that all the thermal energy is generated by the ohmic resistance of the compo-
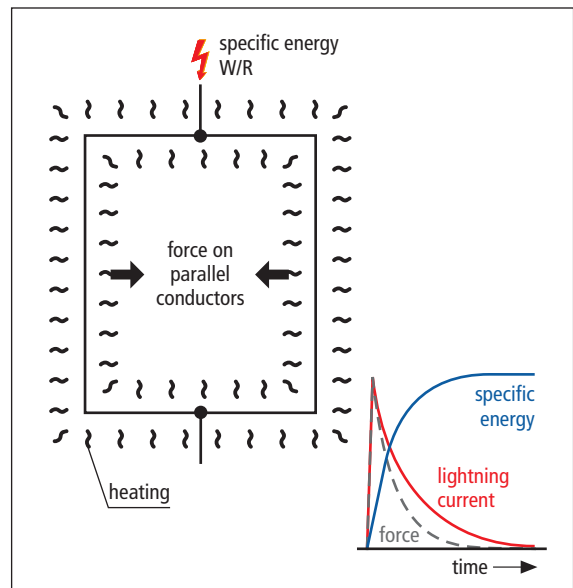
Fig. 2.5.1   Heating and force effects by the specific energy of lightning current

Cross section [mm²]			4	10	16	25	50	100
Material	Aluminium W/R [MJ/Ω]	2.5	–	564	146	52	12	3
		5.6	–	–	454	132	28	7
		10	–	–	–	283	52	12
	Iron W/R [MJ/Ω]	2.5	–	–	1120	211	37	9
		5.6	–	–	–	913	96	20
		10	–	–	–	–	211	37
	Copper W/R [MJ/Ω]	2.5	–	169	56	22	5	1
		5.6	–	542	143	51	12	3
		10	–	–	309	98	22	5
	Stainless steel W/R [MJ/Ω]	2.5	–	–	–	940	190	45
		5.6	–	–	–	–	460	100
		10	–	–	–	–	940	190

Table 2.5.1   Temperature rise ΔT in K of different conductor materials

Fig. 2.5.2   Electrodynamic effect between parallel conductors

The force between the conductors is attractive if the two currents flow in the same direction, and repulsive if the currents flow in opposite directions. It is proportional to the product of the currents in the conductors, and inversely proportional to the distance of the conductors. Even in the case of a single, bent conductor, a force is exerted on the conductor. Here, the force is proportional to the square of the current in the bent conductor.

The specific energy of the impulse current thus determines the load which causes a reversible or irreversible deformation of components and arrays of a lightning protection system. These effects are taken into consideration in the test arrangements of the product standards concerning the requirements made on connecting components for lightning protection systems.

nents of the lightning protection system. Furthermore, it is assumed that, because of the brevity of the process, there is no perceptible heat exchange with the surrounding. **Table 2.5.1** lists the temperature rises of different materials used in lightning protection, and their cross sections, as a function of the specific energy.

The electrodynamic forces F generated by a current i in a wire with a long, parallel section of length I and a distance d (**Figure 2.5.2**) can be calculated as an approximation using the following equation:

$$F(t) = \mu_0 / 2\pi \cdot i^2(t) \cdot l / d$$

F(t)   Electrodynamic force

i   Current

μ_0 Magnetic constant in air ($4\pi \cdot 10^{-7}$ H/m)

l   Length of conductor

d   Distance between the parallel conductors

2.6 Assignment of lightning current parameters to lightning protection levels

In order to define lightning as a source of interference, lightning protection levels I to IV are laid down. Each lightning protection level requires a set of

⇒ maximum values (dimensioning criteria used to design lightning protection components to meet the demands expected to be made of them) and

⇒ minimum values (interception criteria necessary to be able to determine the areas with sufficient protection against direct lightning strikes (radius of rolling sphere)).

Lightning protection level	Maximum values (Dimensioning criteria)	
	Max. lightning current peak value	Probability of the actually upcoming lightning current to be <u>less</u> than the max. lightning current peak value
I	200 kA	99 %
II	150 kA	98 %
III	100 kA	97 %
IV	100 kA	97 %

Table 2.6.1   Maximum values of lightning current parameters and their probabilities

Lightning protection level	Minimum values (Interception criteria)		
	Min. lightning current peak value	Probability of the actually upcoming lightning current to be <u>higher</u> than the min. lightning current peak value	Radius of the rolling sphere
I	3 kA	99 %	20 m
II	5 kA	97 %	30 m
III	10 kA	91 %	45 m
IV	16 kA	84 %	60 m

Table 2.6.2   Minimum values of lightning current parameters and their probabilities

The **Tables 2.6.1** and **2.6.2** show the assignment of the lightning protection levels to maximum and minimum values of the lightning current parameters.

3. Designing a lightning protection system

3.1 Necessity of a lightning protection system – legal regulations

The purpose of a lightning protection system is to protect buildings from direct lightning strikes and possible fire, or from the consequences of the load-independent active lightning current (non-igniting flash of lightning).
If national regulations, e.g. building regulations, special regulations or special directives require lightning protection measures, they must be installed.
Unless these regulations contain specifications for lightning protection measures, a lightning protection system (LPS) Class III meeting the requirements of IEC 62305-3 (EN 62305-3) is recommended as minimum.

Otherwise, the need for protection and the choice of appropriate protection measures, should be determined by risk management.
The risk management is described in IEC 62305-2 (EN 62305-2) (see subclause 3.2.1).

Of course other additional corresponding national standards and legal requirements may be applicable and have to be taken into account. In the following some examples of German directives, standards and legal regulations.

In Germany further information on how to determine the type of lightning protection systems for general buildings and structures can be found in the following directive of the VdS:

⇒ VdS-Richtlinie 2010 "Risikoorientierter Blitz- und Überspannungsschutz, Richtlinien zur Schadenverhütung". [engl.: "Risk orientated lightning and surge protection, guideline for prevention of damage"]

For example, the building regulations of the State of Hamburg (HbauO § 17, Abs. 3) require a lightning protection system to be installed if lightning can easily strike a building because of:

⇒ its length,
⇒ its height or
⇒ the use to which it is put,

or if

⇒ it is expected that a lightning strike would have serious consequences.

This means:
"A lightning protection system must be built even if only one of the requirements is met."

A lightning strike can have particularly **serious consequences** for buildings and structures owing to their location, type of construction or the use to which they are put.
A nursery school, for example, is a building where a lightning strike can have serious consequences because of the use to which the building is put.
The interpretation to be put on this statement is made clear in the following court judgement:

Extract from the Bavarian Administrative Court, decision of 4 July 1984 – No. 2 B 84 A.624.

1. A nursery school is subject to the requirement to install effective lightning protection systems.

2. The legal requirements of the building regulations for a minimum of fire-retardant doors when designing staircases and exits also apply to a residential building which houses a nursery school.

For the following reasons:
According to the Bavarian building regulations, buildings and structures whose location, type of construction or the use to which they are put, make them susceptible to lightning strikes, or where such a strike can have serious consequences, must be equipped with permanently effective lightning protection systems. This stipulates the requirement for effective protective devices in two cases. In the first case, the buildings and structures are particularly susceptible to lightning strikes (e.g. because of their height or location); in the other case, any lightning strike (e.g. because of the type of construction or the use to which it is put) can have particularly serious consequences. The plaintiff´s building falls within the latter category because of its present use as a nursery school. A nursery school belongs to the group of buildings where a lightning strike can have serious consequences because of the use to which the building is put. It is of no consequence that, in the annotations to the Bavarian building regulations, nursery school are not expressly mentioned in the illustrative list of buildings and structures which are particularly at risk, alongside meeting places.

The risk of serious consequences if lightning strikes a nursery school arises because, during the day, a large number of children under school age are present at the same time.

The fact that the rooms where the children spend their time are on the ground floor, and that the children could escape to the outside through several windows – as put forward by the plaintiff – is not a deciding factor. In the event of fire, there is no guarantee that children of this age will react sensibly and leave the building via the windows if necessary. In addition, the installation of sufficient lightning protection equipment is not too much to expect of the operator of a nursery school. A further section of the Bavarian building regulations requires that, amongst other things, staircases must have entrances to the cellar which have self-closing doors which are, at least, fire-retardant. The requirements do not apply to residential buildings with up to two flats. The respondent only made the demand when the plaintiff converted the building, which was previously residential, into a nursery school as well, in accordance with the authorised change of use. The exemption provision cannot be applied to buildings which were built as residential buildings with up to two flats, but which now (also) serve an additional purpose which justifies the application of the safety requirements.

Serious consequences (panic) can also arise when lightning strikes assembly rooms, schools, hospitals.
For these reasons, it is necessary that all buildings and structures which are at risk of such events are equipped with permanently effective lightning protection systems.

Lightning protection systems always required
Buildings and structures where a lightning protection system must always be included because, in these cases, the German law has affirmed the need, are

1. Assembly places with stages or covered stage areas and assembly places for the showing of films, if the accompanying assembly rooms in each case, either individually or together, can accommodate more than 100 visitors;

2. Assembly places with assembly rooms which individually or together can accommodate more than 200 visitors; in the case of schools, museums and similar buildings, this regulation only applies to the inspection of technical installations in assembly rooms which individually can accommodate more than 200 visitors, and their escape routes;

3. Sales areas whose sales rooms have more than 2000 m² of floor space;

4. Shopping centres with several sales areas which are connected to each other either directly or via escape routes, and whose sales rooms individually have less than 2000 m² of floor space but having a total floor space of more than 2000 m²;

5. Exhibition spaces whose exhibition rooms individually or together have more than 2000 m² of floor space;

6. Restaurants with seating for more than 400 customers, or hotels with more than 60 beds for guests;

7. High-rise buildings as defined in the Hamburg building regulations (HbauO);

8. Hospitals and other buildings and structures having a similar purpose;

9. Medium-sized and large-scale garages as defined in the Hamburg regulations for garages (Hamburgisches Gesetz- und Verordnungsblatt);

10. Buildings and structures

10.1 with explosive materials, such as ammunition factories, depots for ammunition and explosives,

10.2 with factory premises which are at risk of explosion, such as varnish and paint factories, chemical factories, larger depots of combustible liquids and larger gas holders,

10.3 particularly at risk of fire, such as
    – larger woodworking factories,
    – buildings with thatched roofs, and
    – warehouses and production plants with a high fire load,

10.4 for larger numbers of people such as
    – schools,
    – homes for the elderly and children´s homes,
    – barracks,

- correctional facilities
- and railway stations,

10.5 with cultural assets, such as
- buildings of historic interest,
- museums and archives,

10.6 towering above their surroundings, such as
- high chimneys,
- towers
- high buildings.

The following list provides an overview of the relevant "General Provisions" in Germany which deal with the issue of requirement, design and inspection of lightning protection systems.

General international and national (German) provisions:

DIN 18384: 2000-12
Contract procedure for building works
Part C: General technical specifications for building works; Lightning protection systems

Lightning protection systems:

Standardleistungsbuch für das Bauwesen (StLB)
Leistungsbereich 050, Blitzschutz- und Erdungsanlagen (Translation: Standard services book for the construction industry, Service sector 050, lightning protection and earth-termination systems)
The purpose of this standard services book is to ensure conformity of the texts used in the service descriptions, and also to facilitate data processing. The texts are used for public tenders by all building authorities, and by federal, state and local governments.

IEC 62305-1: 2006-01
EN 62305-1: 2006-02
Lightning protection – Part 1: General principles

IEC 62305-2: 2006-01
EN 62305-2: 2006-02
Lightning protection – Part 2: Risk management

IEC 62305-3: 2006-01
EN 62305-3: 2006-02
Lightning protection – Part 3: Physical damage to structures and life hazard

IEC 62305-4: 2006-01
EN 62305-4: 2006-02
Lightning protection – Part 4: Electrical and electronic systems within structures

DIN 48805 ... 48828
Components for external lightning protection
This series of standards specifies dimensions and material thicknesses.
It is being replaced step by step by the following standard.

EN 50164-1: 1999-09
Lightning protection components (LPC)
Part 1: Requirements for connection components
Defines the requirements which metal connection components such as connectors, terminals and bridging components, expansion pieces and measuring points for lightning protection systems have to meet.

EN 50164-2: 2002-08
Lightning protection components (LPC)
Part 2: Requirements for conductors and earth electrodes
This standard describes, for example, dimensions and tolerances for metal conductors and earth electrodes as well as the test requirements to the electrical and mechanical values of the materials.

Special standards for earth–termination systems:

DIN 18014: 2007-09
Foundation earth electrode – General planning criteria

DIN VDE 0151: 1986-06
Material and minimum dimensions of earth electrodes with respect to corrosion
This VDE guideline applies to corrosion protection when installing and extending earth electrodes and earthing-termination systems. It provides information on how to avoid or reduce the risk of corrosion to earth electrodes and with earth electrodes of other systems installed. Moreover, it provides information to assist in making the correct choice of earth electrode materials, and also about special anticorrosion measures.

DEHN

EN 50162: 2004-08
Protection against corrosion by stray current from direct current systems
Among others this standard requires that for underground storage tanks being electrically separated from the electrical installation in the house by insulating parts, the connection between the tank and the lightning protection system must be effected via an isolating spark gap.

HD 637 S1: 1999-05
Power installations exceeding 1 kV

EN 50341-1: 2001-10
Overhead electrical lines exceeding a.c. 45 kV – Part 1: General requirements; Common specifications;
Special consideration also is given to the requirements of protection against lightning.
Reference is made to the risk of back flashover, and a relationship is established between the impulse earthing resistance of the mast or framework earthing, the impulse withstand voltage of the insulation and the peak value of the lightning current.
Furthermore attention is drawn to the fact that it is more effective to install several individual earth electrodes (meshed or star-type earth electrodes) than a single, very long earth rod or surface earth electrode.

Special standards for internal lightning and surge protection, equipotential bonding:

IEC 60364-4-41: 2005, mod
HD 60364-4-41: 2007
Erection of power installations – Part 4-41: Protection against electric shock

IEC 60364-5-54: 2002, mod
HD 60364-5-54: 2007
Erection of low voltage installations – Part 5-54: Selection and erection of electrical equipment – earthing arrangements, protective conductors, equipotential bonding.

IEC 60364-5-53/A2: 2001
IEC 64/1168/CDV: 2001-01
Erection of low voltage installations – Part 5: Selection and erection of electrical equipment; Chapter 53: Switchgear and controlgear; Section 534:

Devices for protection against overvoltages; Amendment A2
This standard deals with the use of surge protective devices Type I, II and III in low-voltage consumer's installations in accordance with the protection at indirect contact.

IEC 60364-4-44: 2001 + A1: 2003, mod
HD 60364-4-443: 2006
Erection of low voltage installations – Part 4: Protection for safety; Chapter 44: Protection against overvoltages; Section 443: Protection against overvoltages of atmospheric origin or due to switching.

IEC 109/44/CD: 2005
EN 60664-1: 2003-04
Isolation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests (IEC 60664-1: 1992 + A1: 2000 + A2: 2002)
This standard defines the minimum insulation distances, their selection and the rated impulse voltages for overvoltage categories I to IV.

VDEW Directive: 2004-08
(German Directive)
Surge protective devices Type 1 – Use of surge protective devices (SPD) Type 1 (previously Class B) in the upstream area of the meter.
Describes the use and the installation of surge protective devices Type 1 in the upstream area of the meter.

Especially for electronic systems such as television, radio, data systems technology (telecommunications systems):

IEC 60364-5-548: 1996
Electrical installations of buildings – Part 5: Selection and erection of electrical equipment – Section 548: Earthing arrangements and equipotential bonding for information technology installations.

IEC/DIS 64(CO)1153: 1981
MOD IEC 60364-4-41: 1982
Earthing and equipotential bonding
Part 2 summarises all requirements on the function of a telecommunications system with respect to earthing and equipotential bonding.

DIN VDE 0800-10: 1991-03
(German standard)
Transitional requirements on erection and operation of installations
Part 10 contains requirements for the installation, extension, modification and operation of telecommunications systems. Section 6 of this part lays down the requirements for surge protective measures.

IEC 61643-21: 2000-08 + Corrigendum: 2001
EN 61643-21: 2001-07
Low-voltage surge protective devices – Part 21: Surge protective devices connected to telecommunications and signalling networks; Performance requirements and testing methods.

IEC 60728-11: 2005-01
EN 60728-11: 2005-05
Cable networks for television signals, sound signals and interactive services – Part 11: Safety
Part 11 requires measures to protect against atmospheric discharges (earthing of the antenna mounting, equipotential bonding).

VDE 0855 Part 300: 2002-07
(German standard)
Transmitting / receiving systems for transmitter RF output power up to 1 kW;
Safety requirements
Section 12 of Part 300 describes the lightning and surge protection and the earthing of antenna systems.

IEC 61663-1: 1999-07
EN 61663-1: 1999-11
Lightning protection – Telecommunication lines, Part 1: Fibre optic installations
On this subject, the standard describes a method for calculating the possible number of incidences of damage for selecting the protective measures which can be used, and gives the permissible frequency of incidences of damage. Only primary faults (interruption of operations) and not secondary faults (damage to the cable sheath (formation of holes)), however, are considered.

IEC 61663-2: 2001-03
EN 61663-2: 2001-06
Lightning protection – Telecommunication lines, Part 2: Lines using metallic conductors.

This standard must only be applied to the lightning protection of telecommunication and signal lines with metal conductors which are located outside buildings (e.g. access networks of the landline providers, lines between buildings).

Special installations:

EN 1127-1: 1997-08
Explosive atmospheres – Explosion prevention and protection – Part 1: Basic concepts and methodology
This standard is a guide on how to prevent explosions, and protect against the effects of explosions by employing measures during the drafting and design of devices, protection systems and components.
Part 1 requires also protection against the effects of a lightning strike which put the installations at risk.

pr EN 1127-1: 2004-12
Explosive atmospheres – Explosion prevention and protection – Part 1: Basic concepts and methodology.

IEC 60079-14: 2002
EN 60079-14: 2003-08
Electrical apparatus for explosive gas atmospheres – Part 14: Electrical installations in hazardous areas (other than mines)
Section 6.5 draws attention to the fact that the effects of lightning strikes must be taken into consideration.
Section 12.3 describes the detailed stipulations for installations for the ex zone 0.
Extremely extensive equipotential bonding is required in all ex zones.

IEC 31J/120/CDV: 2006
pr EN 60079-14: 2006-06
Explosive atmospheres – Part 14: Electrical installations design, selection and erection

IEC 61241-17: 2005-01
EN 61241-17: 2005-05
Electrical apparatus for use in the presence of combustible dust – Part 17: Inspection and maintenance of electrical installations in hazardous areas with explosive atmospheres (other than mines)

VDE document series 65: "Elektrischer Explosions-schutz nach DIN VDE 0165"; VDE Verlag Berlin [engl.: "Electrical explosion protection according to DIN VDE 0165"], Annex 9: "PTB-Merkblatt für den Blitzschutz an eigensicheren Stromkreisen, die in Behälter mit brennbaren Flüssigkeiten einge-führt sind" [engl.: "PTB bulletin for protection of intrinsically safe circuits installed in containers with flammable liquids against lightning"]

In Germany standards can be obtained from the following addresses:

VDE VERLAG GMBH
Bismarckstraße 33
10625 Berlin
Germany
Phone: +49 30 34 80 01-0
Fax: +49 30 341 70 93
eMail: vertrieb@vde-verlag.de
Internet: www.vde-verlag.de

or

Beuth-Verlag GmbH
Burggrafenstraße 4-10
10787 Berlin
Germany
Phone: +49 30 2601-2240
Fax: +49 30 2601-1724
Internet: www.din.de/beuth

3.2 Assessment of the risk of damage and selection of protective components

3.2.1 Risk management

Risk management with foresight includes calculating the risks for the company. It provides the basis on which decisions can be made in order to limit these risks, and it makes clear which risks should be covered by insurance. When considering the management of insurances, it should be borne in mind, however, that insurance is not always a suitable means of achieving certain aims (e.g. maintaining the ability to deliver). The probabilities that certain risks will occur cannot be changed by insurance.

Companies which manufacture or provide services using extensive electronic installations (and nowadays this applies to most companies), must also give special consideration to the risk presented by lightning strikes. It must be borne in mind that the damage caused by the non-availability of electronic installations, production and services, and also the loss of data, is often far greater than the damage to the hardware of the installation affected.

In the case of lightning protection, innovative thinking about damage risks is slowly gaining in importance. The aim of risk analysis is to objectify and quantify the risk to buildings and structures, and their contents, as a result of direct and indirect lightning strikes. This new way of thinking has been embodied in the international standard IEC 62305-2: 2006 or the European standard EN 62305-2: 2006.

The risk analysis presented in IEC 62305-2 (EN 62305-2) ensures that it is possible to draw up a lightning protection concept which is understood by all parties involved, and which meets optimum technical and economic requirements, i.e. the necessary protection can be guaranteed with as little expenditure as possible. The protective measures which result from the risk analysis are then described in detail in the later parts of the standard, in the new IEC 62305 (EN 62305) series.

3.2.2 Fundamentals of risk assessment

According to IEC 62305-2 (EN 62305-2), risk R of lightning damage can generally be found using the relationship:
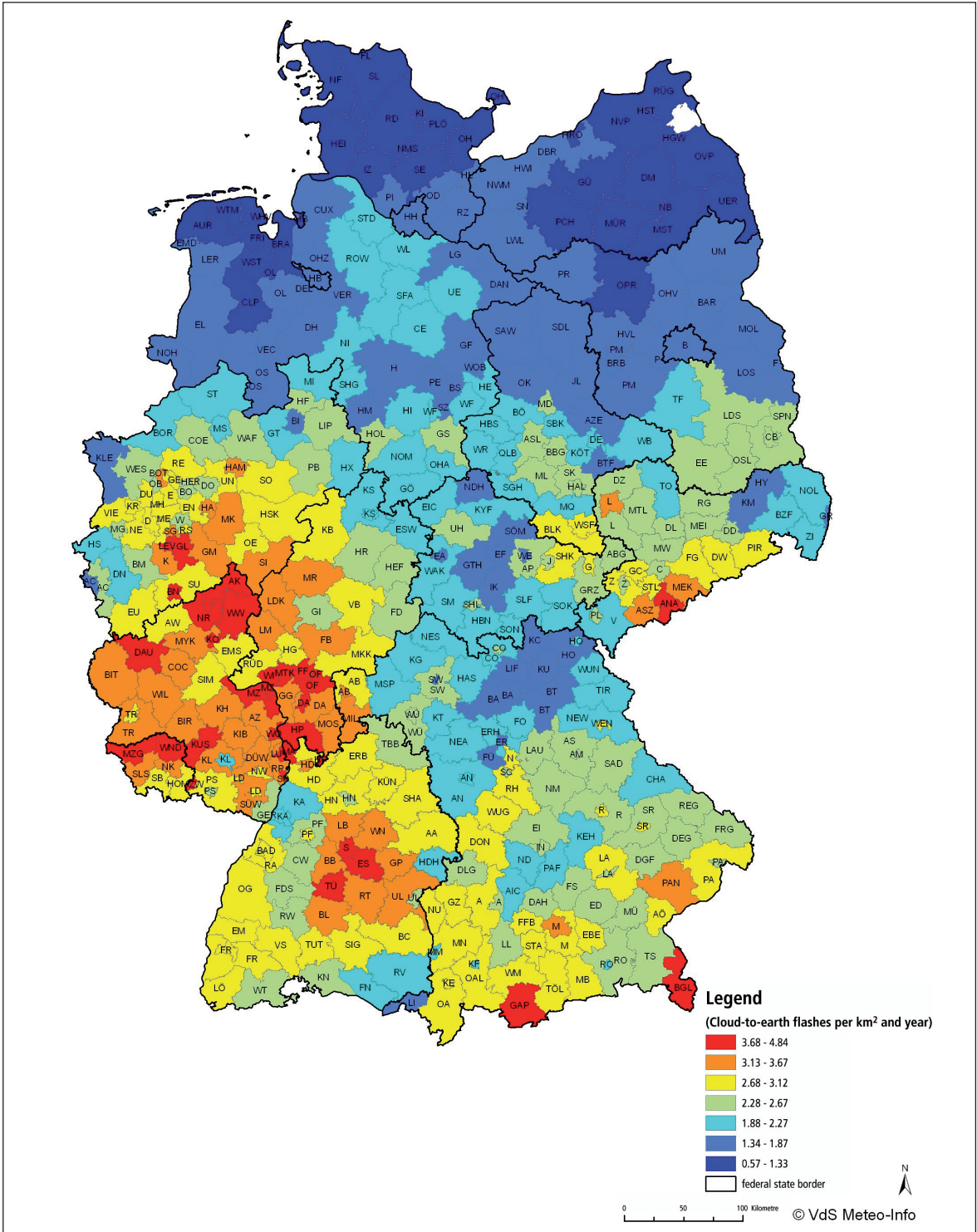
Fig. 3.2.3.1 Lightning density in Germany (average of 1999 – 2005)

Legend
(Cloud-to-earth flashes per km² and year)

■	3.68 - 4.84
■	3.13 - 3.67
■	2.68 - 3.12
■	2.28 - 2.67
■	1.88 - 2.27
■	1.34 - 1.87
■	0.57 - 1.33
▢	federal state border

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$$R = N \cdot P \cdot L$$

N   Number of hazardous events, i.e. frequency of lightning strikes in the area under consideration (How many lightning strikes occur per year in the area under consideration?);

P   Probability of damage (What is the probability that a lightning strike causes a quite specific type of damage?);

L   Loss, i.e. the quantitative evaluation of the damage (What are the effects, amount of loss, extent, and consequences of a very specific type of damage?).

The task of the risk assessment therefore involves the determination of the three parameters N, P and L for all relevant risk components. This involves establishing and determining of many individual parameters. A comparison of the risk R thus established with a tolerable risk R_T then enables a statement to be made about the requirements and the dimensioning of lightning protection measures.

An exception is the consideration of the economic losses. For this kind of damage the protective measures have to be justified strictly by the economical point of view. There is no tolerable risk R_T, but rather a cost-benefit analysis. An exception is the consideration of the economic losses. For this kind of damage the protective measures have to be justified strictly by the economical point of view. There is no tolerable risk R_T, but rather a cost-benefit analysis.

3.2.3 Frequency of lightning strikes

We distinguish between the following frequencies of lightning strikes which can be relevant for a building or structure:

N_D Frequency of direct lightning strikes to the building or structure;

N_M Frequency of close lightning strikes with electromagnetic effects;

N_L Frequency of direct lightning strikes in utility lines entering the building or structure;

N_I Frequency of lightning strikes adjacent to utility lines entering the building or structure.

The calculation of the frequencies of lightning strikes is given in detail in Annex A of IEC 62305-2 (EN 62305-2). For practical calculations it is recommendable to take the annual density of the cloud-to-earth flashes N_g for the region under consideration from **Figure 3.2.3.1**. If a finer grid is used, the local values of the lightning densities can still deviate noticeably from these averages. Owing to the relatively short time of seven years the map has been recorded, and to the large area averaging according to licence plate number areas, the application of a safety factor of 25 % to the values given in **Figure 3.2.3.1** is recommended.

For the frequency of **direct** lightning strikes N_D to the building or structure we have:

$$N_D = N_g \cdot A_d \cdot C_d \cdot 10^{-6}$$

A_d is the equivalent interception area of the isolated building or structure (**Figure 3.2.3.2**), C_d a site factor so that the influence of the surroundings (built-up, terrain, trees, etc.) can be taken into account (**Table 3.2.3.1**).

Similarly, the frequency of close lightning strikes N_M can be calculated:

$$N_M = N_g \cdot A_m \cdot 10^{-6}$$

Relative site of the building or structure	C_d
Object is surrounded by higher objects or trees	0.25
Object is surrounded by objects or trees of the same or lower height	0.5
Free-standing object: no further objects near by (within a distance of 3H)	1
Free-standing object on top of a moutain or a rounded hilltop	2

Table 3.2.3.1   Site factor C_d
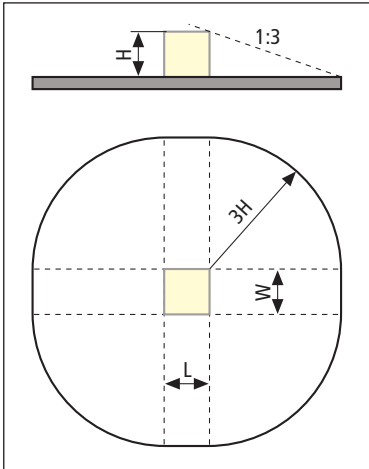
Fig. 3.2.3.2 Equivalent interception area A_d for direct lightning strikes into a stand-alone structure
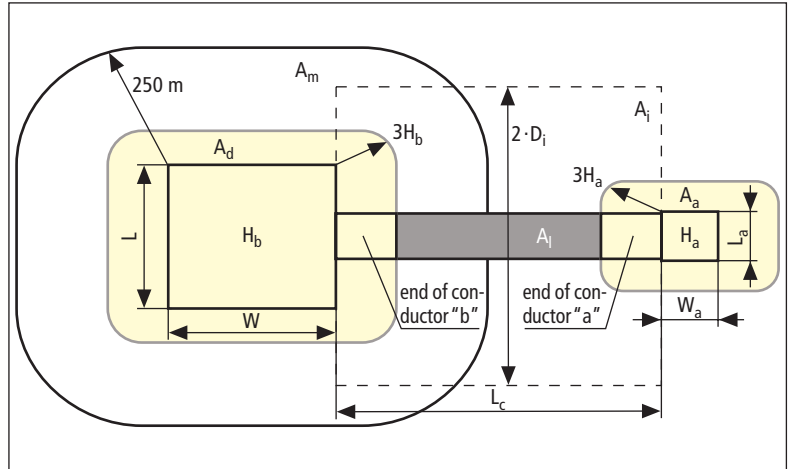
Fig. 3.2.3.3 Equivalent interception areas A_d, A_l, A_a for direct lightning strikes into structures / supply lines and A_m, A_i for indirect lightning strikes near the structures / supply lines

A_m is arrived at by drawing a line at a distance of 250 m around the building or structure (**Figure 3.2.3.3**). The equivalent interception area A_d C_d of the building or structure estimated using the environmental coefficients is then subtracted from the area thus enclosed. Lightning strikes on the area A_m lead exclusively to magnetically induced surges in installation loops in the interior of the building or structure.

The frequency of direct lightning strikes in a utility line entering a building or structure N_L is:

$$N_L = N_g \cdot A_l \cdot C_e \cdot C_t \cdot 10^{-6}$$

The area **A_l** (**Figure 3.2.3.3**) is a function of the type of line (overhead line, cable), the length L_C of the line; in the case of cables, it is a function of the earth resistivity ρ; and for overhead lines it is a function of height H_C of the line above ground level (**Table 3.2.3.2**). If the length of the line is not known, or if it is very time-consuming to ascertain it, then, as a worst-case scenario, a value of L_C = 1000 m can be set.

H_C Height (m) of the line above ground level;

ρ Earth resistivity (Ωm) in, or on, which the line is laid, up to a maximum value of ρ = 500 Ωm;

L_C Length (m) of the line, measured from the building or structure to the first distribution junction, or to the first location where surge protective devices are installed, up to a maximum length of 1000 m;

H Height (m) of the building or structure;

H_b Height (m) of the building or structure;

H_a Height (m) of the neighbouring building or structure connected via the line.

If, within the area A_l there is a medium voltage line rather than a low voltage one, then a transformer reduces the intensity of the surges at the entrance to the building or structure. In such cases, this is taken into account by the correction factor C_t = 0.2. The correction factor C_e (environment factor) is ultimately a function of the building density (**Table 3.2.3.3**).

The frequency N_L must be determined individually for each utility line entering the building or structure. In the building or structure under consideration, lightning strikes within the area A_l lead, as a rule, to a high energy discharge which can generate a fire, an explosion, a mechanical or chemical reaction. The frequency N_L therefore, does not comprise pure surges which result in faults or damage to the electrical and electronic systems, but mechanical and thermal effects which arise when lightning strikes.

Surges to utility lines entering the building or structure are described by the frequency of lightning strikes next to such a utility line N_I:

	Overhead line	Underground cable
A_l	$\left[L_C - 3 \cdot \left(H_a + H_b \right) \right] \cdot 6 \cdot H_C$	$\left[L_C - 3 \cdot \left(H_a + H_b \right) \right] \cdot \sqrt{\rho}$
A_i	$1000 \cdot L_C$	$25 \cdot L_C \cdot \sqrt{\rho}$

Table 3.2.3.2   Equivalent interception areas A_l and A_i in m^2

Environment	C_e
Urban with high buildings or structures (higher than 20 m)	0
Urban (buildings or structures of heights between 10 m and 20 m)	0.1
Suburban (buildings or structures not higher than 10 m)	0.5
Rural	1

Table 3.2.3.3   Environment factor C_e

$$N_l = N_g \cdot A_i \cdot C_t \cdot C_e \cdot 10^{-6}$$

The area A_i (**Figure 3.2.3.3**) is again a function of the type of line (overhead line, underground cable), the length L_C of the line; in the case of cables, it is a function of the earth resistivity ρ; and for overhead lines it is a function of the height H_C of the line above ground level (**Table 3.2.3.3**). The same worst-case scenario applies. The area A_i is usually significantly larger than A_l. This makes allowance for the fact that surges resulting in faults or damage to electrical and electronic systems can also be caused by lightning strikes further away from the line.

The correction factors C_t und C_e correspond to those already stated above. The frequency N_l must then also be determined individually for each utility line entering the building or structure.

3.2.4 Probabilities of damage

The damage probability parameter gives the probability that a supposed lightning strike will cause a quite specific type of damage. It is therefore assumed that there is a lightning strike on the relevant area; the value of the damage probability can then have a maximum value of 1. We differentiate between the following eight damage probabilities:

P_A Electric shock suffered by living beings as a result of a direct lightning strike to the building or structure;

P_B Fire, explosion, mechanical and chemical reactions as a result of a direct lightning strike to the building or structure;

P_C Failure of electrical / electronic systems as a result of a direct lightning strike to the building or structure; $P_C = P_{SPD}$

P_M Failure of electrical / electronic systems as a result of a lightning strike to the ground next to the building or structure;

P_U Electric shock suffered by living beings as a result of a direct lightning strike to the utility lines entering the building or structure;

P_V Fire, explosion, mechanical and chemical reactions as a result of a direct lightning strike to a utility line entering the building or structure;

P_W Failure of electrical / electronic systems as a result of a direct lightning strike to a utility line entering the building or structure;

P_Z Failure of electrical / electronic systems as a result of a lightning strike to the ground next to a utility line entering the building or structure.

This damage probabilities are presented in detail in Annex B of IEC 62305-2 (EN 62305-2). They can be taken either directly from tables or they are the resulting function of a combination of further

Characteristics of building or structure	Class of lightning protection system (LPS)	P_B
Building or structure is not protected by LPS	–	1
Building or structure is protected by LPS	IV	0.2
	III	0.1
	II	0.05
	I	0.02
Building or structure with air-termination system according to class of LPS and a metal facade or a concrete reinforcement as natural down conductor system		0.01
Building or structure with metal roof or with air-termination system, preferably including natural components, which protect all roof superstructes entirely against direct lightning strikes, and a metal facade or concrete reinforcement a natural down conductor system.		0.001

Table 3.2.4.1   Damage factor P_B to describe the protective measures against physical damage

Lightning protection level (LPL)	Damage factor P_{SPD}
No coordinated surge protection	1
III – IV	0.03
II	0.02
I	0.01
Surge protective devices (SPD) having a protective characteristic better than for LPL I (higher lightning current carrying capability, lower protection level, etc.)	0.005 – 0.001

Table 3.2.4.2   Damage factor P_{SPD} to describe the protective measures surge protective devices as a function of the lightning protection level
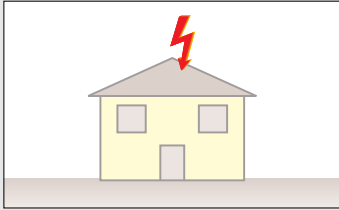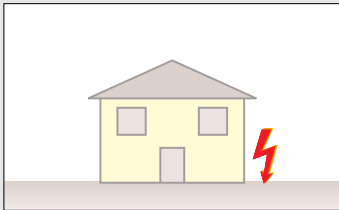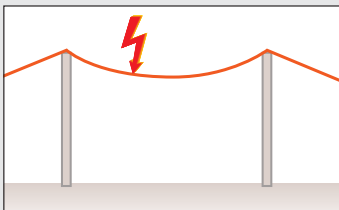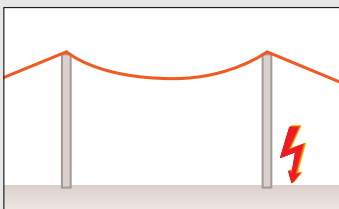
influence factors. There is no more subdivision into simple (basic) probabilities and reduction factors. Some reduction factors now rather have been assigned to the Annex C, i.e. to the losses, for example P_B and P_C representing damage factors. Both parameter values are presented in **Tables 3.2.4.1** and **3.2.4.2**. Attention still is drawn to the fact that also other, deviating values are possible, if based on detailed examinations or estimations.

3.2.5 Types of loss and sources of damage

Depending on the construction, use and substance of the building or structure, the relevant types of damage can be very different. IEC 62305-2 (EN 62305-2) recognises the following four types of damage:

L1 Loss of human life (injury to, or death of, persons);

L2 Loss of services for the public;

L3 Loss of irreplaceable cultural assets;

L4 Economic losses.

The types of loss stated can arise as a result of the different **sources of damage**: The sources of damage thus literally represent the "cause" in a causal relationship, the type of loss the "effect" (see **Table 3.2.5.1**). The possible sources of damage for one type of loss can be manifold. It is therefore necessary to first define the relevant types of damage for a building or structure. It is then subsequently possible to stipulate the sources of damage to be determined.

Point of Strike	Example	Source of damage	Building or structure	
			Type of damage	Type of loss
Building or structure		S1	D1	L1, L4[b]
			D2	L1, L2, L3, L4
			D3	L1[a], L2, L4
Earth next to the structure		S2	D3	L1[a], L2, L4
Entering supply line		S3	D1	L1, L4[b]
			D2	L1, L2, L3, L4
			D3	L1[a], L2, L4
Earth next to the entering supply line		S4	D3	L1[a], L2, L4

[a] For hospitals and buildings or structures with hazard of explosion
[b] For agricultural properties (loss of animals)

Source of damage in relation to the point of strike
S1 Direct lightning strike to the building or structure;
S2 Lightning strike to the earth near the building or structure;
S3 Direct lightning strike to the entering supply line;
S4 Lightning strike to the earth close to the entering supply line.

Type of damage
D1 Electric shock to living beings as a result of contact and step voltage;
D2 Fire, explosion, mechanical and chemical reactions as a result of the physical effects of the lightning discharge;
D3 Failure of electrical and electronic sytems as a result of surges.

Type of loss
L1 Injury to, or death of, persons;
L2 Loss of services for the public;
L3 Loss of irreplaceable cultural assets;
L4 Economic losses.

Table 3.2.5.1   Sources of damage, types of damage and types of loss according to the point of strike

3.2.6 Loss factor

If a particular type of damage has occurred in a building or structure, then the effect of this damage must be assessed. It is possible, for example, for a fault or damage to a DP system (L4 type of loss: economic losses) to have very different consequences. If no data appertaining to the business is lost, then the claim will only be for the damage to the hardware to the value of a few thousand Euro. If, however, the complete business of a company is dependent on the permanent availability of the DP system (call centre, bank, automation engineering) then, in addition to the hardware damage, there is also disproportionately high consequential damage as a result of customer dissatisfaction, customers going to other suppliers, overlooked business processes, loss of production, etc.
The effects of the damage are assessed using the loss factor L.

Basically divided up into the following:

L_t Loss by injury as a result of contact and step voltages;

L_f Loss as a result of physical damage;

L_o Loss as a result of failure of electrical and electronic systems.

Depending on the relevant type of damage, this enables the extent of the damage, its value or the consequences to be assessed. Annex C of IEC 62305-2 (EN 62305-2) gives the fundamentals of the calculation of the loss of the four types of damage. It is frequently the case, however, that it is extremely time-consuming to apply the equations. For usual cases, the aforementioned Annex C therefore also provides suggestions for typical values for the damage factor L, depending on the underlying causes of the damage.

In addition to the actual loss factors Annex C also outlines three reduction factors r_x and an increasing factor h:

r_a Reduction factor for effects of step and contact voltages depending on the kind of ground or floor;

r Reduction factor for measures to mitigate the consequences of fire;

r_f Reduction factor to describe the risk of fire to a building or structure;

h   Factor increasing the relative value of a loss, if there is special hazard (e.g. as a result of panic, potential endangering of the environment by the building or structure).

Although shifted from IEC 62305-2 (EN 62305-2) Annex B (damage factors) to Annex C now, the parameter values, however, remained almost unchanged.

3.2.7 Relevant risk components for different lightning strikes

There is close correlation between the cause of the damage, the type of damage and the resulting relevant risk components. Initially, it serves to represent the dependence on the point of strike of the lightning discharge, and the risk components which are derived from this.
If lightning directly strikes a building or structure, the following risk components arise (**Table 3.2.7.1**):

R_A Risk component for electric shocks to living beings as a result of direct lightning strikes;

R_B Risk component for physical damage as a result of direct lightning strikes;

R_C Risk of malfunctioning of electrical and electronic systems as a result of surges caused by direct lightning strikes.

If lightning strikes the earth near a building or structure, or neighbouring buildings, the following risk component is created:

R_M Risk of malfunctioning of electrical and electronic systems as a result of surges caused by direct lightning strikes to the ground next to the building or structure.

If lightning directly strikes utility lines entering a building or structure, the following risk components arise:

R_U Risk components for electric shocks to living beings in the event of direct lightning strikes to utility lines entering the building or structure;

R_V Risk components for physical damage in the event of direct lightning strikes to utility lines entering the building or structure;

Type of damage	Lightning strike (with regard to the structure)				
	Direct	Indirect			
	S1	S2	S3	S4	
	Direct lightning strike into the structure	Lightning strike into the earth next to the structure	Direct lightning strike into the entering supply line	Lightning strike into the earth next to the entering supply line	
D1 Electric shock to living beings	$R_A = N_D \cdot P_A \cdot r_a \cdot L_t$		$R_U = (N_L + N_{DA}) \cdot P_U \cdot r_a \cdot L_t$		$R_s = R_A + R_U$
D2 Fire, explosions, mechanical and chemical effects	$R_B = N_D \cdot P_B \cdot r \cdot h \cdot r_f \cdot L_f$		$R_V = (N_L + N_{DA}) \cdot P_V \cdot r \cdot h \cdot r_f \cdot L_f$		$R_f = R_B + R_V$
D3 Interferences on electrical and electronic systems	$R_C = N_D \cdot P_C \cdot L_o$	$R_M = N_M \cdot P_M \cdot L_o$	$R_W = (N_L + N_{DA}) \cdot P_W \cdot L_o$	$R_Z = (N_I - N_L) \cdot P_Z \cdot L_o$	$R_o = R_C + R_M + R_W + R_Z$
	$R_d = R_A + R_B + R_C$	$R_i = R_M + R_U + R_V + R_W + R_Z$			

Table 3.2.7.1 In addition to the risk components R_U, R_V and R_W, there is the frequency of direct lightning strikes into the supply line N_L and the frequency of direct lightning strikes into the connected building or structure N_{DA} (compare **Figure 3.2.3.3**). In case of the risk component R_Z, however, the frequency of lightning strikes next to the supply line N_I has to be reduced by the frequency of direct lightning strikes into the supply line N_L.

R_W Risk of failure of electrical and electronic systems as a result of surges caused by direct lightning strikes to utility lines entering the building or structure.

If lightning eventually strikes the ground next to the utility lines entering a building or structure, the following risk component is created:

R_Z Risk of failure of electrical and electronic systems as a result of surges caused by direct lightning strikes to the ground next to the utility lines entering the building or structure.

The eight risk components in total (which basically must be determined individually for each type of damage) can now be combined according to two different criteria: the point of strike of lightning and the cause of the damage.

If the combination according to the point of strike is of interest, i.e. the evaluation of **Table 3.2.7.1** according to columns, then the risk

⇒ as a result of a direct lightning strike to the building or structure is:

$$R_d = R_A + R_B + R_C$$

⇒ as a result of an indirect lightning strike next to the building or structure is:

$$R_i = R_M + R_U + R_V + R_W + R_Z$$

If, on the other hand, it is desired to investigate the cause of the damage, then the risks can be combined as follows:

⇒ For electric shock to humans or animals as a result of contact and step voltages:

$$R_s = R_A + R_U$$

Types of loss		R_T
L1	Loss of human life (injury to, or death of, persons)	10^{-5}/year
L2	Loss of services for the public	10^{-3}/year
L3	Loss of irreplaceable cultural asset	10^{-3}/year

Table 3.2.8.1   Typical values for the tolerable risk R_T

⇒ For fire, explosion, mechanical and chemical reaction, caused by mechanical and thermal effects of a lightning strike:

$$R_f = R_B + R_V$$

⇒ For failure of electrical and electronic systems due to surges:

$$R_o = R_C + R_M + R_W + R_Z$$
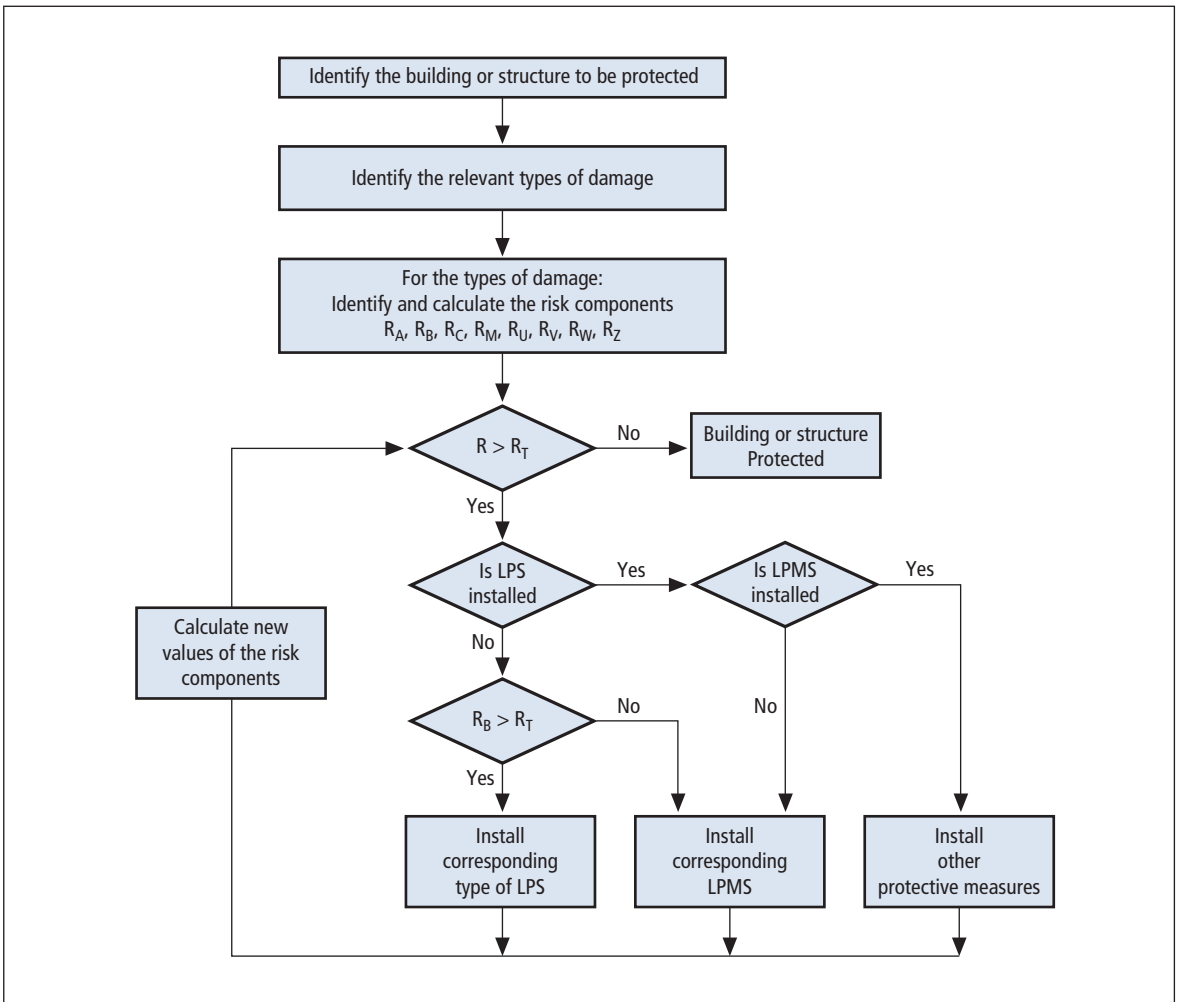
Fig. 3.2.9.1   Flow chart for selection of protective measures for the types of loss L1 ... L3

3.2.8 Tolerable risk of lightning damage

When making a decision on the choice of lightning protection measures, one has to examine whether the damage risk R determined for each relevant type of damage exceeds a tolerable (i.e. a still acceptable) value R_T or not. This, however, is only applicable for the three types of loss L1 – L3, which are of so-called public interest. For a building or structure which is sufficiently protected against the effects of lightning, then must hold:

$$R \leq R_T$$

R represents the sum over all risk components which are relevant for the respective type of loss L1 – L3:

$$R = \sum R_V$$

IEC 62305-2 (EN 62305-2) provides acceptable maximum values R_T for these three types of loss (**Table 3.2.8.1**).

3.2.9 Choice of lightning protection measures

The measures for protection against lightning are intended to lead to the limiting of the damage risk R to values below the tolerable risk of damage R_T. Using a detailed calculation of the damage risks for the types of damage which are relevant to a specific building or structure in each case, i.e. by dividing them into the individual risk components R_A, R_B, R_C, R_M, R_U, R_V, R_W and R_Z, it is possible to choose lightning protection measures in an extremely targeted way.

The flow chart in IEC 62305-2 (EN 62305-2) (**Figure 3.2.9.1**) illustrates the procedure. Starting from the fact that the calculated damage risk R exceeds the tolerable damage risk R_T, the first thing to be examined is whether the risk of physical damage caused by a direct lightning strike to a building or structure R_B exceeds the tolerable damage risk R_T. If this is the case, a complete lightning protection system with suitable external and internal lightning protection must be installed. If R_B is sufficiently small, the second step is to examine whether the risk can be sufficiently reduced by protective mea-

sures against the lightning electromagnetic pulse (LEMP).

Proceeding according to **Figure 3.2.9.1** makes it possible to choose those protective measures which lead to a reduction in the risk components which have relatively high values in each case, i.e. protective measures whose degrees of effectiveness in the case under inspection are comparatively high.

3.2.10 Economic losses / Economic efficiency of protective measures

The type of loss L4, economic losses, is relevant for many buildings or structures. Here it is no longer possible to work with a tolerable risk of damage R_T. One rather has to compare, whether the protective measures are justifiable from an economical point of view. Not an absolute parameter, such as a specified tolerable risk of damage R_T, is standard of comparison, but a relative one: Different states of protection of the building or structure are compared and the optimal solution, i.e. the cost of damage as a result of lightning strikes remaining as low as possible, will be realised. So several variants can and shall be examined.

The basic procedure is represented in **Figure 3.2.10.1**, **Figure 3.2.10.2** shows the corresponding flow chart from IEC 62305-2 (EN 62305-2). At the beginning this new method certainly will arouse new discussions among experts because it allows a (rough) estimation of costs even before the actual designing of lightning protection measures. Here a detailed and administered respective data base can render good service.

Usually not only the type of loss L4, but also one or several of the other types of loss L1 – L3 are relevant for a building or structure. In these cases first of all the proceeding represented in **Figure 3.2.9.1** is applicable, i.e. the damage risk R for the each of the losses L1 – L3 must be lower than the tolerable damage risk R_T. In this case a second step is to examine the efficiency of the planned protective measures according to **Figure 3.2.10.1** and **Figure 3.2.10.2**. Of course, also here again several variants of protection are possible, the most favourable one finally to be realised, however, provided that

Yearly costs as a result of lightning strike

Loss amount x yearly occurrence probability

Where:
Loss amount is the replacement cost plus follow-up costs (e.g. production loss, data loss)

Occurrence probability depends on the protective measures

Yearly costs of the protective measures

Depreciation, maintenance, interest loss (per year)
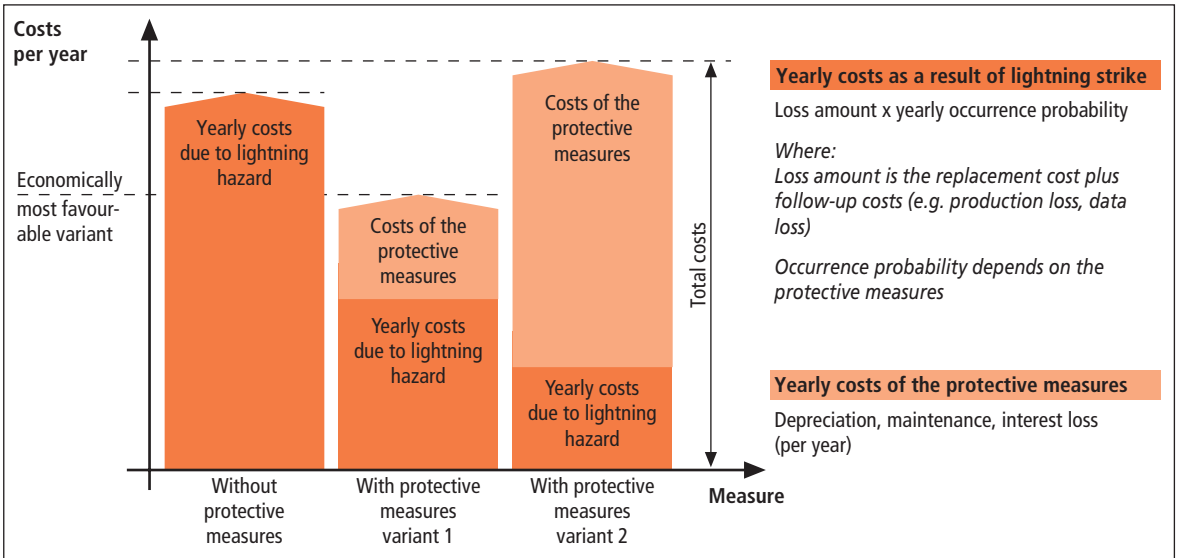
Fig. 3.2.10.1   Basic procedure in case of a purely economic consideration and calculation of the yearly costs

for all relevant types of loss of public interest L1 – L3 is always R < R_T.
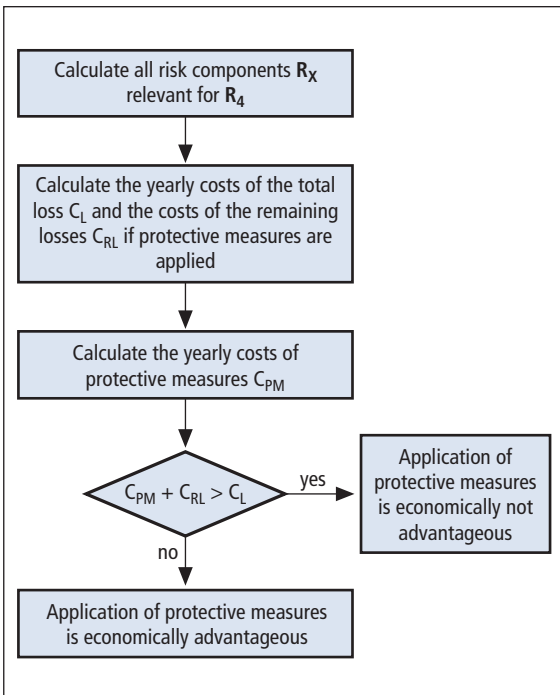
Fig. 3.2.10.2   Flow chart for the choice of protective measures in case of economic losses

3.2.11 Summary

In practice, it is time-consuming and not always easy to apply the procedures and data given. This should not prevent the experts in the field of lightning protection and, in particular, those at the sharp end, from studying this material. The quantitative assessment of the risk of lightning damage for a building or structure is a considerable improvement on the situation often encountered before, where decisions for or against lightning protection measures were frequently made solely on the basis of subjective considerations which were not always understood by all parties.

A quantitative assessment of this type is therefore an important pre-requirement for the decision whether to designate lightning protection measures for a building or structure and, if so, to what extent and which ones. In the long term it will thus make a contribution to the acceptance of lightning protection and damage prevention.

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3.2.12 Designing aids

For practical applications, the time-consuming and not always simple application of the procedure for assessing the risk of damage for buildings and structures can be noticeably improved by the use of a PC-aided solution. In "DEHNsupport" the procedures and date from IEC 62305-2 (EN 62305-2) have been converted into a user-friendly software. With "DEHNsupport" the user has a purposeful assistance for designing. The following designing aids are available:

⇒ Risk analysis according to IEC 62305-2 (EN 62305-2)

⇒ Calculation of the separation distance

⇒ Calculation of the length of earth electrodes

⇒ Calculation of the length of air-termination rods

3.3 Inspection and maintenance

3.3.1 Types of inspection and qualification of the inspectors

Other and additional national standards and legal requirements have to be taken into account.

To guarantee that the building or structure, the persons therein, and the electrical and electronic systems have permanent protection, the mechanical and electrical characteristics of a lightning protection system must remain completely intact for the whole of its service life. To ensure this case, a coordinated programme of inspection and maintenance of the lightning protection system shall be laid down by an authority, the designer of the lightning protection system, or the person installing the lightning protection system, and the owner of the building or structure. If faults are found during the inspection of a lightning protection system, the operator / owner of the building or structure is responsible for the immediate removal of the faults. The inspection of the lightning protection system must be carried out by a lightning protection specialist.

A lightning protection specialist is due to his technical training, knowledge and experience, also with regard to the applicable standards, able to design, install and inspect lightning protection systems.

The criteria – technical training, knowledge and experience – usually are met after several years of practical and professional experience and during an occupational activity in the field of lightning protection. The fields designing, installation and inspection require different skills from the lightning protection specialist.

A lightning protection specialist is a competent person who is familiar with the relevant safety equipment regulations, directives and standards to the extent that he is in a position to judge if technical work equipment is in a safe working condition. Competent persons are, for example, after-sales service engineers. A training course leading to recognition as a competent person for lightning and surge protection, as well as for electrical installations conforming to EMC (EMC approved engineer), is offered by the VdS Loss Prevention, which is part of the Joint Association of German Insurers (GDV e.V.), in cooperation with the Committee for Lightning Protection and Lightning Research of the Association of German Electrical Engineers (ABB of the VDE).

Note: A *competent person* is not an *expert*!

An *expert* has *special* knowledge because of his training and experience in the field of technical work equipment which requires testing. He is familiar with the relevant safety equipment regulations, directives and standards to the extent that he is in a position to judge if complex technical work equipment is in a safe working condition. He shall be able to inspect technical work equipment and provide an expert opinion. An expert is a specially trained, officially approved competent person. Persons who are eligible to be experts are, for example, engineers at the German Technical Inspectorate or other specialist engineers. Installations which are subject to monitoring requirements generally have to be inspected by *experts*.

Regardless of the required inspector's qualifications, the inspections shall ensure that the lightning protection system fulfils its protective function of protecting living beings, stock, technical equipment in the building or structure operational technology, safety technology, and the building or structure, against the effects of direct and indirect lightning strikes when combined with any maintenance and service measures which may be necessary. A design report of the lightning protection system containing the design criteria, design description and technical drawings shall therefore

be available to the inspector. The inspections which need to be carried out are distinguished as follows:

Inspection of the design
The inspection of the design shall ensure that all aspects of the lightning protection system with its components correspond to the state of the art in force at the time the designing is undertaken. It must be carried out before the service is provided.

Inspections during the construction phase
Sections of the lightning protection system which will not be accessible when the building work is complete must be inspected as long as this is possible. These include:

⇒ Foundation earth electrodes
⇒ Earth-termination systems
⇒ Reinforcement connections
⇒ Concrete reinforcements used as room shielding
⇒ Down-conductor systems and their connections laid in concrete

The inspection comprises the control of the technical documentation, and on-site inspection and assessment of the work carried out.

Acceptance inspection
The acceptance inspection is carried out when the lightning protection system has been completed. The following must be thoroughly inspected:

⇒ Compliance with the protection plan conforming to the standards (design),
⇒ the work done (technical correctness)

taking into consideration

⇒ the type of use,
⇒ the technical equipment of the building or structure and
⇒ the site conditions.

Repeat inspection
Regular repeat inspections are the precondition for a permanently effective lightning protection system. In Germany they shall be carried out every 2 to 4 years. **Table 3.3.1.1** contains recommendations for the intervals between the full inspections of a lightning protection system under average environmental conditions. If official instructions or regulations with inspection deadlines are in force, these deadlines have to be considered as minimum requirements. If official instructions prescribe that the electrical installation in the building or structure must be regularly inspected, then the functioning of the internal lightning protection measures shall be inspected as part of this inspection.

Visual inspection
Lightning protection systems Type I or II in buildings and structures, and critical sections of lightning protection systems (e.g. in cases where there is considerable influence from aggressive environmental conditions) have to undergo a visual inspection between repeat inspections (**Table 3.3.1.1**).

Additional inspection
In addition to the repeat inspections, a lightning protection system must be inspected if

⇒ fundamental changes in use,
⇒ modifications to the building or structure,

Type of LPS	Visual inspection (Year)	Complete inspection (Year)	Complete inspection of critical systems (Year)
I and II	1	2	1
III and IV	2	4	1
Note: In buildings or structures with hazard of explosion a visual inspection of the lightning protection system should be carried out every 6 months. Once in a year the electrical installations should be tested. A deviation from these yearly inspection plan is accepted if it makes sense to carry out the tests in intervals of 14 to 15 months in order to measure the conductivity of the ground at different times of the year in order to get knowledge of seasonal changes.			

Table 3.3.1.1   Longest interval between inspections of the LPS acc. to IEC 62305-3, Table E.2

⇒ restorations,

⇒ extensions or

⇒ repairs

on a protected building or structure have been carried out.

These inspections shall also be carried out when it is known that a lightning has struck the lightning protection system.

3.3.2 Inspection measures

The inspection comprises the control of the technical documentation, on-site inspection and measurement.

Control of the technical documentation

The technical documentation must be inspected to ensure it is

⇒ complete and

⇒ in accordance with the standards.

On-site inspection

The on-site inspection shall examine whether

⇒ the complete system corresponds to the technical documentation,

⇒ the complete system of external and internal lightning protection is in an acceptable condition,

⇒ there are any loose connections and interruptions in the lines of the lightning protection system,

⇒ all earthing connections (if visible) are in order,

⇒ all lines and system components are correctly secured, and units with a mechanical protective function are in working order,

⇒ modifications requiring additional protective measures have been made at the protected building or structure,

⇒ the surge protective devices installed in power supply systems and information systems are correctly installed,

⇒ there is any damage, or whether there are any disconnected surge protective devices,

⇒ upstream overcurrent protection devices of surge protective devices have tripped,

⇒ in the case of new supply connections or extensions which have been installed in the interior of the building or structure since the last inspection, the lightning equipotential bonding was carried out,

⇒ equipotential bonding connections within the building or structure are in place and intact,

⇒ the measures required for proximities of the lightning protection system to installations have been carried out.

Note: For existing earth-termination systems which are more than 10 years old, the condition and quality of the earth conductor line and its connections can only be assessed by exposing it at certain points.

Measurements

Measurements are used to inspect the conductivity of the connections and the condition of the earth-termination system.

⇒ **Conductivity of the connections**
Measurements must be made to examine whether all the conductors and connections of air-termination systems, down-conductor systems, equipotential bonding lines, shielding measures etc. have a low-impedance conductivity. The recommended value is < 1 Ω.

⇒ **Condition of the earth-termination system**
The contact resistance to the earth-termination system at all measuring points must be measured to establish the conductivity of the lines and connections (recommended value < 1 Ω).
Further, the conductivity with respect to the metal installations (e.g. gas, water, ventilation, heating), the total earthing resistance of the lightning protection system, and the earthing resistance of individual earth electrodes and partial ring earth electrodes must be measured.

The results of the measurements must be compared with the results of earlier measurements. If they deviate considerably from the earlier measurements, additional examinations must be performed.

3.3.3 Documentation

A report must be compiled for each inspection. This must be kept together with the technical documentation and reports of previous inspections at the installation/system operator´s premises or at the offices of the relevant authority.

The following technical documentation must be available to the inspector when, for example, he carries out his assessment of the lightning protection system:

⇒ Design criteria

⇒ Design descriptions

⇒ Technical drawings of the external and internal lightning protection

⇒ Reports of previous services and inspections

An inspection report shall contain the following information:

⇒ **General**

a) Owner, address

b) Installer of the lightning protection system, address

c) Year of construction

⇒ **Information about the building or structure**

a) Location

b) Use

c) Type of construction

d) Type of roofing

e) Lightning protection level (LPL)

⇒ **Information about the lightning protection system**

a) Material and cross section of the lines

b) Number of down conductors, e.g. inspection joints (designation corresponding to the information in the drawing)

c) Type of earth-termination system (e.g. ring earth electrode, earth rod, foundation earth electrode)

d) Design of the lightning equipotential bonding to metal installations, to electrical installations and to existing equipotential busbars

⇒ **Inspection fundamentals**

a) Description and drawings of the lightning protection system

b) Lightning protection standards and provisions at the time of the installation

c) Further inspection fundamentals (e.g. regulations, instructions) at the time of the installation

⇒ **Type of inspection**

a) Inspection of the design

b) Inspections during the construction phase

c) Acceptance inspection

d) Repeat inspection

e) Additional inspection

f) Visual inspection

⇒ **Result of the inspection**

a) Any modifications to the building or structure and / or the lightning protection system determined

b) Deviations from the standards, regulations, instructions and application guidelines applicable at the time of the installation

c) Defects determined

d) Earthing resistance or loop resistance at the individual inspection joints, with information about the measuring method and the type of measuring device

e) Total earthing resistance (measurement with or without protective conductor and metal building installation)

⇒ **Inspector**

a) Name of inspector

b) Inspector´s company / organisation

c) Name of person accompanying

d) Number of pages in inspection report

e) Date of inspection

f) Signature of the inspector´s company / organisation

3.3.4 Maintenance

The maintenance and inspection of lightning protection systems must be coordinated.

In addition to the inspections, regular maintenance routines should therefore also be established for all lightning protection systems. How frequently the maintenance work is carried out depends on the following factors:

⇒ Loss of quality related to weathering and the ambient conditions

⇒ Effects of direct lightning strikes and possible damage arising therefrom

⇒ Class of lightning protection system required for the building or structure under consideration

The maintenance measures should be determined individually for each lightning protection system and become an integral part of the complete maintenance programme for the building or structure.

A maintenance routine should be drawn up. This allows a comparison to be made between results recorded now, and those from an earlier service. These values can also be used for comparison with a subsequent inspection.

The following measures should be included in a maintenance routine:

⇒ Inspection of all conductors and components of the lightning protection system

⇒ Measuring of the electrical conductivity of installations of the lightning protection system

⇒ Measuring of the earthing resistance of the earth-termination system

⇒ Visual inspection of all surge protective devices (relates to surge protective devices on the lines of the power supply and information system entering the building or structure) to determine if there has been any damage or if any disconnections are present

⇒ Refastening of components and conductors

⇒ Inspection to ascertain that the effectiveness of the lightning protection system is unchanged after installation of additional fixed equipment or modifications to the building or structure

Complete records should be made of all maintenance work. They should contain modification measures which have been, or are to be, carried out.

These records serve as an aid when assessing the components and installation of the lightning protection system. They can be used to examine and update a maintenance routine. The maintenance records should be kept together with the design and the inspection reports of the lightning protection system.

4. Lightning protection system
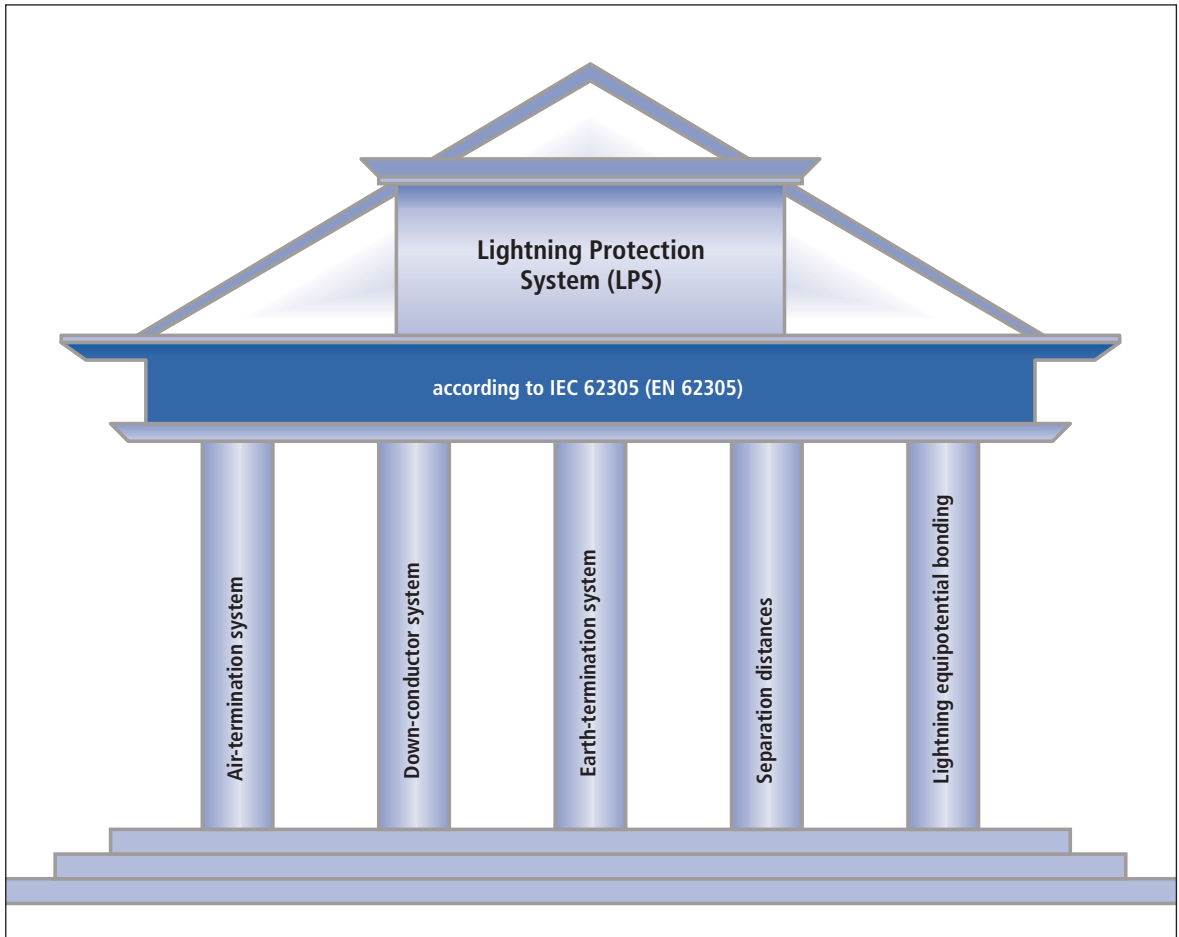
Fig. 4.1   Components of a lightning protection system

Lightning protection systems shall protect buildings and structures from fire or mechanical destruction, and persons in the buildings from injury or even death.
A lightning protection system comprises an external and an internal lightning protection (**Figure 4.1**).

The functions of the external lightning protection are:

⇒ Directing direct lightning strikes into an air-termination system

⇒ Safe conduction of the lightning current to the earth by means of a down-conductor system

⇒ Distribution of the lightning current in the earth via an earth-termination system

The function of the internal lightning protection is

⇒ to prevent hazardous sparking inside the building or structure.
This is achieved by means of equipotential bonding or a safety distance between the components of the lightning protection system and other conductive elements inside the building or structure.

The lightning equipotential bonding reduces the potential drops caused by the lightning current. This is achieved by connecting all separate, conductive parts of the installation directly by means of conductors or surge protective devices (SPDs) (**Figure 4.2**).
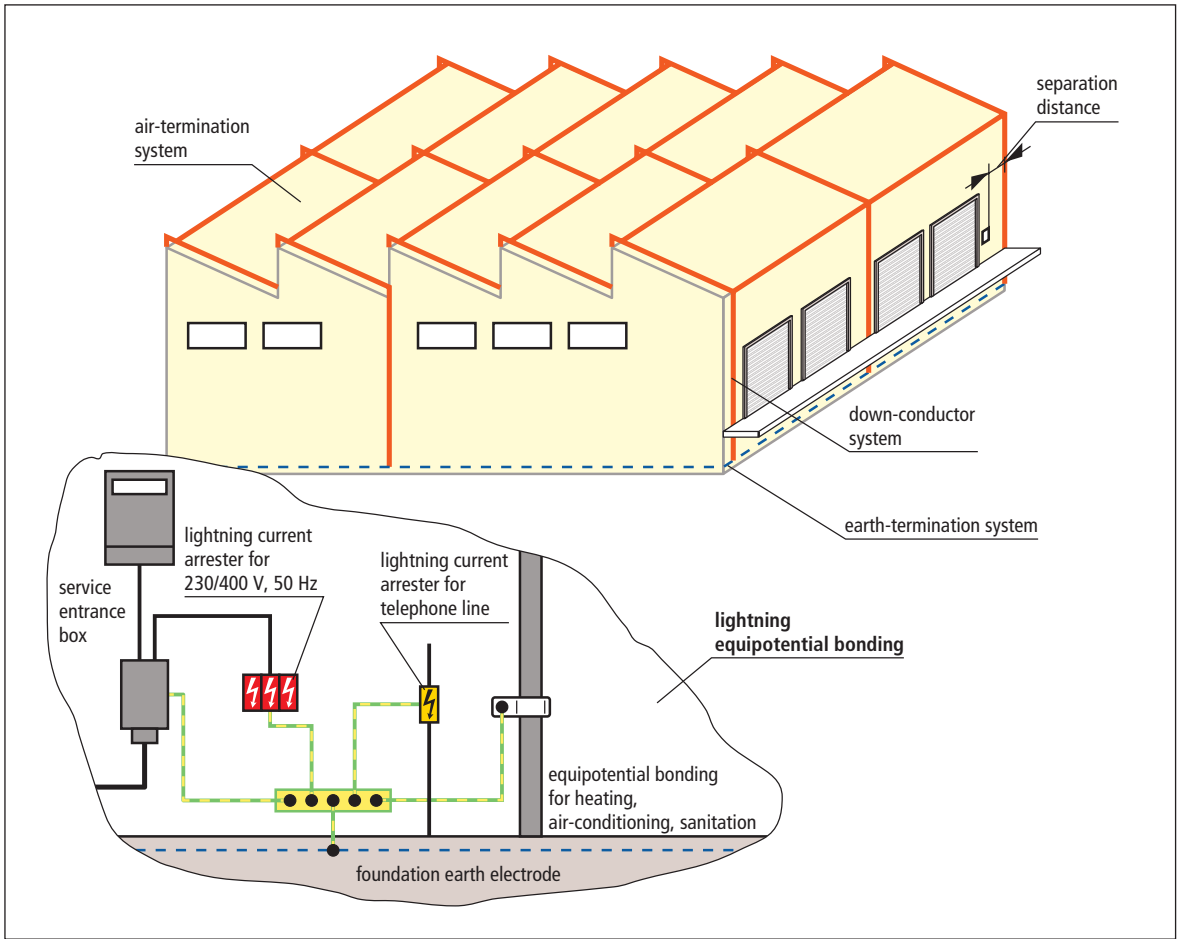
Fig. 4.2   Lightning protection system (LPS)

The four classes of lightning protection systems (LPS) – I, II, III and IV – are determined using a set of construction rules which are based on the corresponding lightning protection level. Each set comprises class dependent (e.g. radius of the rolling sphere, mesh size) and class independent (e.g. cross-sections, materials) construction rules.

To ensure the continuous availability of complex information technology installations even in the event of a direct lightning strike, it is necessary to have continuing measures for the surge protection of electronic installations which supplement the lightning protection system. This extensive catalogue of measures is described in Chapter 7 under the concept of lightning protection zones.

5. External lightning protection

5.1 Air-termination systems

The function of the air-termination systems of a lightning protection system is to prevent direct lightning strikes from damaging the volume to be protected. They must be designed to prevent uncontrolled lightning strikes to the structure to be protected.
By correct dimensioning of the air-termination systems, the effects of a lightning strike to a structure can be reduced in a controlled way.

Air-termination systems can consist of the following components and can be combined with each other as required:

⇒ Rods

⇒ Spanned wires and cables

⇒ Intermeshed conductors

When determining the siting of the air-termination systems of the lightning protection system, special attention must be paid to the protection of corners and edges of the structure to be protected. This applies particularly to air-termination systems on the surfaces of roofs and the upper parts of facades. Most importantly, air-termination systems must be mounted at corners and edges.

Three methods can be used to determine the arrangement and the siting of the air-termination systems (**Figure 5.1.1**):

⇒ Rolling sphere method

⇒ Mesh method

⇒ Protective angle method

The rolling sphere method is the universal method of design particularly recommended for geometrically complicated applications.
The three different methods are described below.

5.1.1 Designing methods and types of air-termination systems

The rolling sphere method – "geometric-electrical model"
For lightning flashes to earth, a downward leader grows step-by-step in a series of jerks from the cloud towards the earth. When the leader has got close to the earth within a few tens, to a few hundreds of metres, the electrical insulating strength of the air near the ground is exceeded. A further "leader" discharge similar to the downward leader begins to grow towards the head of the downward leader: the upward leader. This defines the

Class of LPS	Max. building height	
	Radius of the rolling sphere (r)	Mesh size (M)
I	20 m	5 x 5 m
II	30 m	10 x 10 m
III	45 m	15 x 15 m
IV	60 m	20 x 20 m
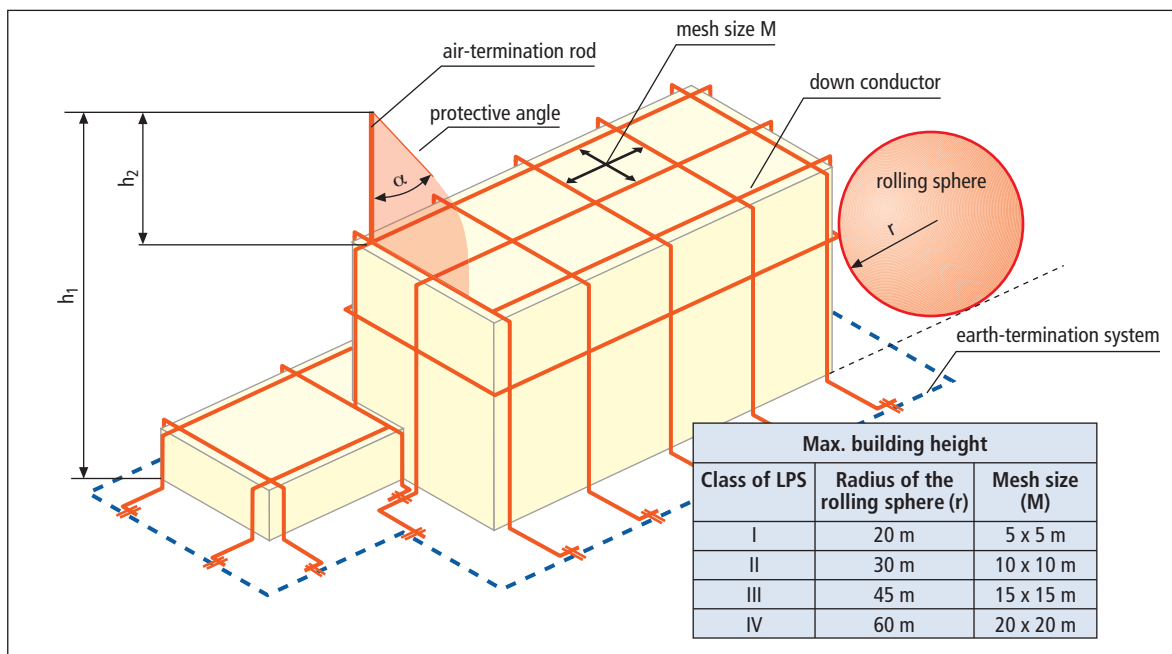
Fig. 5.1.1   Method for designing of air-termination systems for high buildings
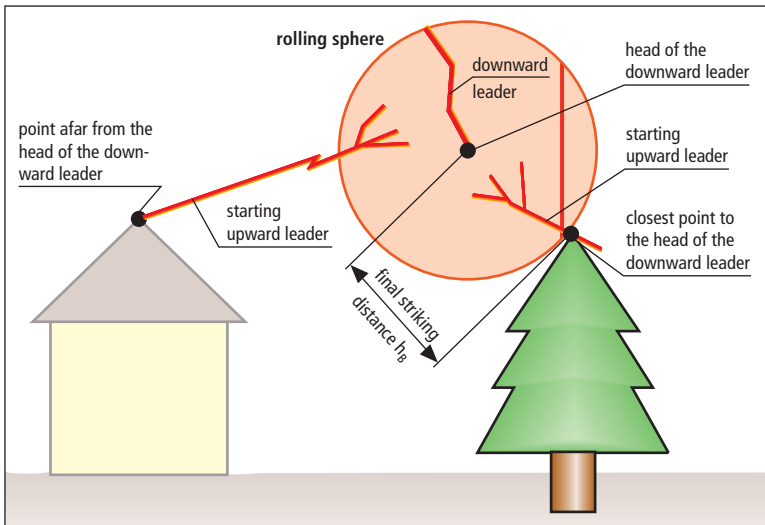
Fig. 5.1.1.1 Starting upward leader defining the point of strike

A rolling sphere can touch not only the steeple, but also the nave of the church at several points. All points touched are potential points of strike.

Fig. 5.1.1.2 Model of a rolling sphere
Ref: Prof. Dr. A. Kern, Aachen

point of strike of the lightning strike (**Figure 5.1.1.1**).

The starting point of the upward leader and hence the subsequent point of strike is determined mainly by the head of the downward leader. The head of the downward leader can only approach the earth within a certain distance. This distance is defined by the continuously increasing electrical field strength of the ground as the head of the downward leader approaches. The smallest distance between the head of the downward leader and the starting point of the upward leader is called the final striking distance h_B (corresponds to the radius of the rolling sphere).

Immediately after the electrical insulating strength is exceeded at one point, the upward leader which leads to the final strike and manages to cross the final striking distance, is formed. Observations of the protective effect of guard wires and pylons were used as the basis for the so-called **"geometric-electrical model"**.

This is based on the hypothesis that the head of the downward leader approaches the objects on the ground, unaffected by anything, until it reaches the final striking distance.

The point of strike is then determined by the object closest to the head of the downward leader. The upward leader starting from this point "forces its way through" (**Figure 5.1.1.2**).

Classification of the lightning protection system and radius of the rolling sphere
As a first approximation, a proportionality exists between the peak value of the lightning current and the electrical charge stored in the downward leader. Furthermore, the electrical field strength of the ground as the downward leader approaches is also linearly dependent on the charge stored in the downward leader, to a first approximation.

Thus there is a proportionality between the peak value I of the lightning current and the final striking distance h_B (= radius of the rolling sphere):

$$r = 10 \cdot I^{0.65}$$

r in m
I in kA

The protection of structures against lightning is described in IEC 62305-1 (EN 62305-1). Among other things, this standard defines the classification of the individual lightning protection system and stipulates the resulting lightning protection measures.

It differentiates between four classes of lightning protection system. A Class I lightning protection system provides the most protection and a Class IV, by comparison, the least. The interception effec-

Lightning protection level LPL	Probabilities for the limit values of the lightning current parameters		Radius of the rolling sphere (final striking distance h_B) r in m	Min. peak value of current I in kA
	< Max. values acc. to Table 5 IEC 62305-1 (EN 62305-1)	> Min. values acc. to Table 6 IEC 62305-1 (EN 62305-1)		
IV	0.84	0.97	60	16
III	0.91	0.97	45	10
II	0.97	0.98	30	5
I	0.99	0.99	20	3

Table 5.1.1.1   Relations between lightning protection level, interception criterion E_i, final striking distance h_B and min. peak value of current I
Ref.: Table 5, 6 and 7 of IEC 62305-1 (EN 62305-1)

tiveness E_i of the air-termination systems is concomitant with the class of lightning protection system, i.e. which percentage of the prospective lightning strikes is safely controlled by the air-termination systems. From this results the final striking distance and hence the radius of the "rolling sphere". The correlations between class of lightning protection system, interception effectiveness E_i of the air-termination systems, final striking distance / radius of the "rolling sphere" and current peak value are shown in **Table 5.1.1.1**.

Taking as a basis the hypothesis of the "geometric-electrical model" that the head of the downward leader approaches the objects on the earth in an arbitrary way, unaffected by anything, until it reaches the final striking distance, a general method can be derived which allows the volume to be protected of any arrangement to be inspected. Carrying out the rolling sphere method requires a scale model (e.g. on a scale of 1:100) of the building / structure to be protected, which includes the external contours and, where applicable, the air-termination systems. Depending on the location of the object under investigation, it is also necessary to include the surrounding structures and objects, since these could act as "natural protective measures" for the object under examination.

Furthermore, a true-to-scale sphere is required according to the class of lightning protection system with a radius corresponding to the final striking distance (depending on the class of lightning protection system, the radius r of the "rolling sphere" must correspond true-to-scale to the radii 20, 30, 45 or 60 m). The centre of the "rolling sphere" used corresponds to the head of the downward leader towards which the respective upward leaders will approach.

The "rolling sphere" is now rolled around the object under examination and the contact points representing potential points of strike are marked in each case. The "rolling sphere" is then rolled over the object in all directions. All contact points are marked again. All potential points of strike are thus shown on the model; it is also possible to determine the areas which can be hit by lateral strikes. The naturally protected zones resulting from the geometry of the object to be protected and its surroundings can also be clearly seen. Air-termination conductors are not required at these points (**Figure 5.1.1.3**).

It must be borne in mind, however, that lightning footprints have also been found on steeples in places not directly touched as the "rolling sphere" rolled over. This is traced to the fact that, among other things, in the event of multiple lightning flashes, the base of the lightning flash moves because of the wind conditions. Consequently, an area of approx. one metre can come up around the
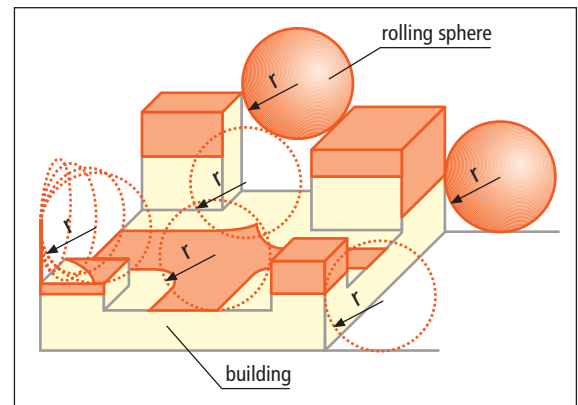
Fig. 5.1.1.3   Schematic application of the "rolling sphere" method at a building with considerably structured surface

point of strike determined where lightning strikes can also occur.

Example 1: New administration building in Munich

During the design phase of the new administration building, the complex geometry led to the decision to use the rolling sphere method to identify the areas threatened by lightning strikes.

This was possible because an architectural model of the new building was available on a scale of 1:100.

It was determined that a lightning protection system Class I was required, i.e. the radius of the rolling sphere in the model was 20 cm (**Figure 5.1.1.4**).

The points where the "rolling sphere" touches parts of the building, can be hit by a direct lightning strike with a corresponding minimum current peak value of 3 kA (**Figure 5.1.1.5**). Consequently, these points required adequate air-termination systems. If, in addition, electrical installations were localised at these points or in their immediate vicinity (e.g. on the roof of the building), additional air-termination measures were realised there.

The application of the rolling sphere method meant that air-termination systems were not installed where protection was not required. On the other hand, locations in need of more protection could be equipped accordingly, where necessary (**Figure 5.1.1.5**).

Example 2: Aachen Cathedral

The cathedral stands in the midst of the old town of Aachen surrounded by several high buildings.

Adjacent to the cathedral there is a scale model (1:100) whose purpose is to make it easier for visitors to understand the geometry of the building.

The buildings surrounding the Aachen Cathedral provide a partial natural protection against lightning strikes.

Therefore, and to demonstrate the effectiveness of lightning protection measures, models of the most important elements of the surrounding buildings were made according to the same scale (1:100) (**Figure 5.1.1.6**).

Figure 5.1.1.6 also shows "rolling spheres" for lightning protection systems Class II and III (i.e. with radii of 30 cm and 45 cm) on the model.

Fig. 5.1.1.4   Construction of a new administration building: Model with "rolling sphere" acc. to lightning protection system Type I
Ref.: WBG Wiesinger

Fig. 5.1.1.5   Construction of a DAS administration building: Top view (excerpt) on the zones threatened by lightning strikes for lightning protection system Class I
Ref.: WBG Wiesinger

Fig. 5.1.1.6   Aachen Cathedral: Model with environment and "rolling spheres" for lightning protection systems Class II and III
Ref.: Prof. Dr. A. Kern, Aachen
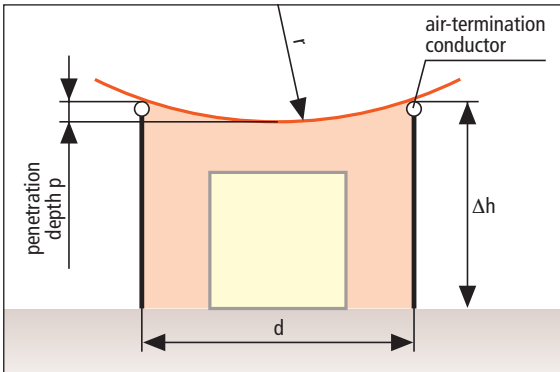
Fig. 5.1.1.7   Penetration depth p of the rolling sphere

	Class of LPS			
	I	II	III	IV
r	20	30	45	60

Cuboidal protective area between four air-termination rods
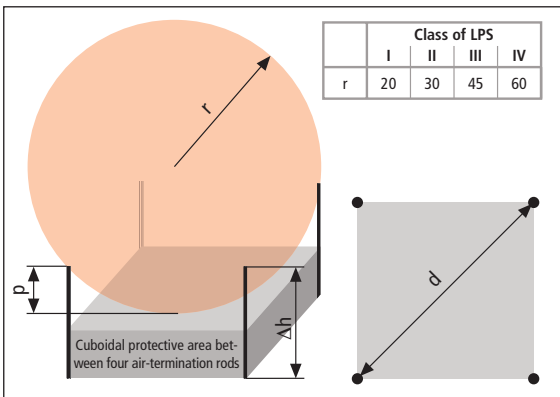
Fig. 5.1.1.8   Air-termination system for installations mounted on the roof with their protective area

domelight installed on the roof
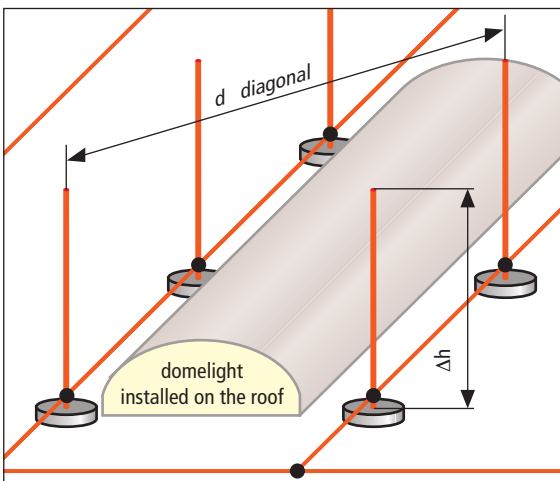
Fig. 5.1.1.9   Calculation Δh for several air-termination rods according to rolling sphere method

The aim here was to demonstrate the increasing requirements on the air-termination systems as the radius of the rolling sphere decreases, i.e. which areas of Aachen Cathedral had additionally to be considered at risk of being hit by lightning strikes, if a lightning protection system Class II with a higher degree of protection was used.

The "rolling sphere" with the smaller radius (according to a class of lightning protection system with a higher lightning protection level) naturally touches also the model at all points already touched by the "rolling sphere" with the larger radius. Thus, it is only necessary to determine the additional contact points.

As demonstrated, when dimensioning the air-termination system for a structure, or a structure mounted on the roof, the sag of the rolling sphere is decisive.

The following formula can be used to calculate the penetration depth p of the rolling sphere when the rolling sphere rolls "on rails", for example. This can be achieved by using two spanned wires, for example.

$$ p = r - \left[r^2 - \left(d / 2 \right)^2 \right]^{\frac{1}{2}} $$

r   Radius of the rolling sphere

d   Distance between two air-termination rods or two parallel air-termination conductors

Figure 5.1.1.7 illustrates this consideration.

Air-termination rods are frequently used to protect the surface of a roof, or installations mounted on the roof, against a direct lightning strike. The square arrangement of the air-termination rods, over which no cable is normally spanned, means that the sphere does not "roll on rails" but "sits deeper" instead, thus increasing the penetration depth of the sphere (**Figure 5.1.1.8**).

The height of the air-termination rods Δh should always be greater than the value of the penetration depth p determined, and hence greater than the sag of the rolling sphere. This additional height of the air-termination rod ensures that the rolling sphere does not touch the structure to be protected.

d	Sag of the rolling sphere [m] (rounded up)			
Distance between air-termniation rods [m]	Class of LPS with rolling sphere radius in meters			
	I (20 m)	II (30 m)	III (45 m)	IV (60 m)
2	0.03	0.02	0.01	0.01
4	0.10	0.07	0.04	0.03
6	0.23	0.15	0.10	0.08
8	0.40	0.27	0.18	0.13
10	0.64	0.42	0.28	0.21
12	0.92	0.61	0.40	0.30
14	1.27	0.83	0.55	0.41
16	1.67	1.09	0.72	0.54
18	2.14	1.38	0.91	0.68
20	2.68	1.72	1.13	0.84
23	3.64	2.29	1.49	1.11
26	4.80	2.96	1.92	1.43
29	6.23	3.74	2.40	1.78
32	8.00	4.62	2.94	2.17
35	10.32	5.63	3.54	2.61

Table 5.1.1.2   Sag of the rolling sphere over two air-termination rods or two parallel air-termination conductors

Another way of determining the height of the air-termination rods is using **Table 5.1.1.2**. The penetration depth of the rolling sphere is governed by the largest distance of the air-termination rods from each other. Using the greatest distance, the penetration depth p (sag) can be taken from the table. The air-termination rods must be dimensioned according to the height of the structures mounted on the roof (in relation to the location of the air-termination rod) and also the penetration depth (**Figure 5.1.1.9**).

If, for example, a total height of an air-termination rod of 1.15 m is either calculated or obtained from the table, an air-termination rod with a standard length of 1.5 m is normally used.

Mesh method
A "meshed" air-termination system can be used universally regardless of the height of the structure and shape of the roof. A reticulated air-termination network with a mesh size according to the class of lightning protection system is arranged on the roofing (**Table 5.1.1.3**).

To simplify matters, the sag of the rolling sphere is assumed to be zero for a meshed air-termination system.
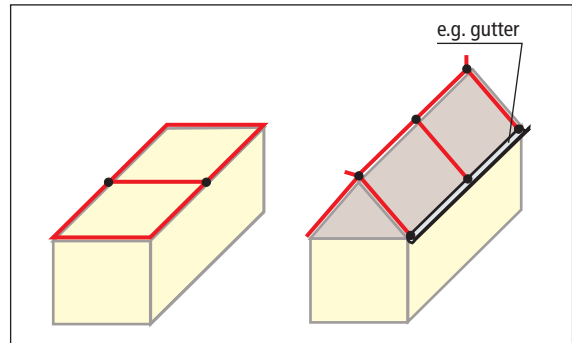
Fig. 5.1.1.10   Meshed air-termination system

By using the ridge and the outer edges of the structure, as well as the metal natural parts of the structure serving as an air-termination system, the individual cells can be sited as desired.

The air-termination conductors on the outer edges of the structure must be laid as close to the edges as possible.
A metal attic can serve as an air-termination conductor and / or a down-conductor system if the required minimum dimensions for natural components of the air-termination system are complied with (**Figure 5.1.1.10**).

Protective angle method
The protective angle method is derived from the electric-geometrical lightning model. The protective angle is determined by the radius of the rolling sphere. The comparable protective angle with the radius of the rolling sphere is given when a slope intersects the rolling sphere in such a way that the resulting areas have the same size (**Figure 5.1.1.11**).
This method must be used for structures with symmetrical dimensions (e.g. steep roof) or roof-mounted structures (e.g. antennas, ventilation pipes).
The protective angle depends on the class of lightning protection system and the height of the air-

Class of LPS	Mesh size
I	5 x 5 m
II	10 x 10 m
III	15 x 15 m
IV	20 x 20 m

Table 5.1.1.3   Mesh size
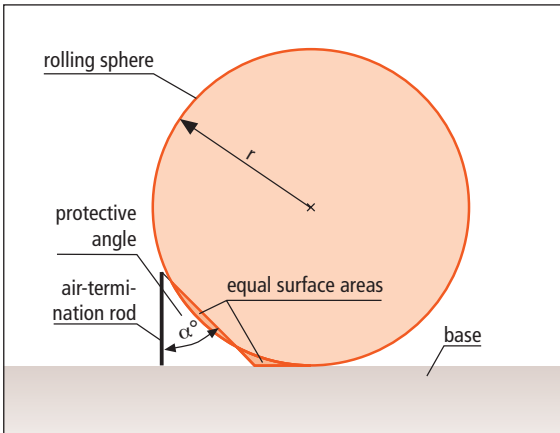
Fig. 5.1.1.11   Protective angle and comparable radius of the rolling sphere
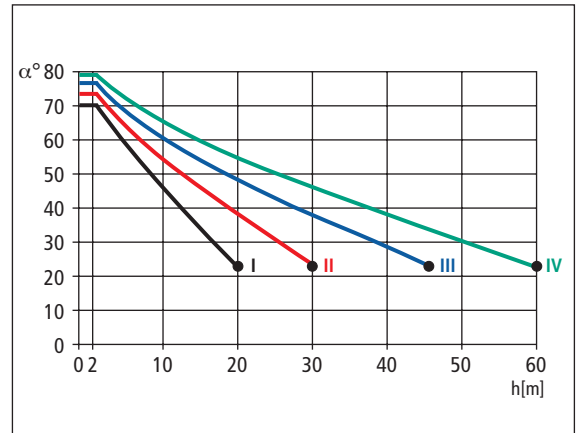
Fig. 5.1.1.12   Protective angle α as a function of height h depending on the class of lightning protection system
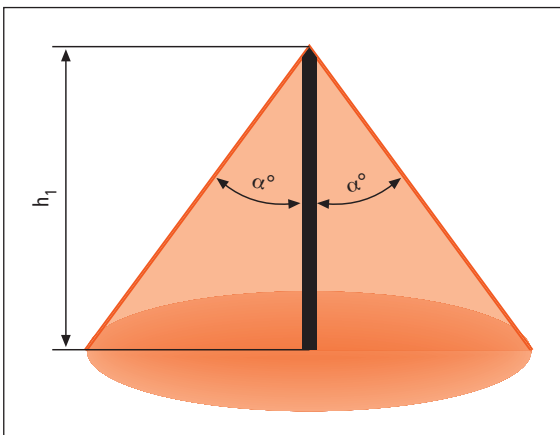
Fig. 5.1.1.13   Cone-shaped protection zone
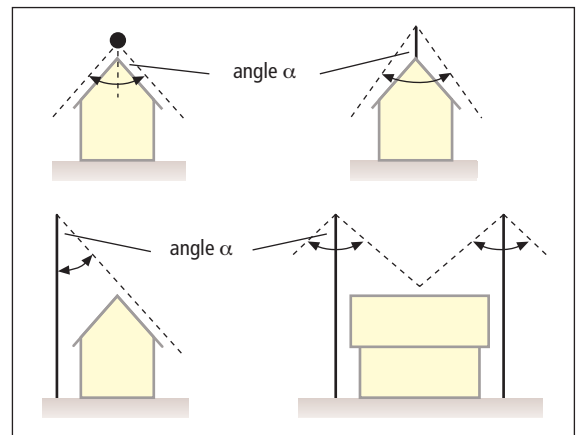
Fig. 5.1.1.14   Example of air-termination systems with protective angle α

Angle α depends on the class of lightning protection system and the height of the air-termination conductor above ground
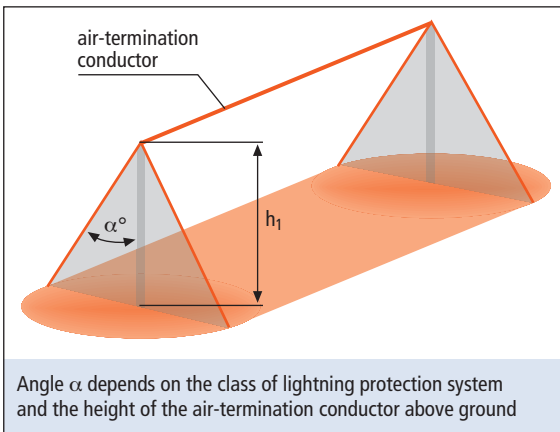
Fig. 5.1.1.15   Area protected by an air-termination conductor

h_1: Physical height of the air-termination rod

Note:
Protective angle α_1 refers to the height of the air-termination system h_1 above the roof surface to be protected (reference plane); Protective α_2 refers to the height $h_2 = h_1 + H$, while the earth surface is the reference plane.
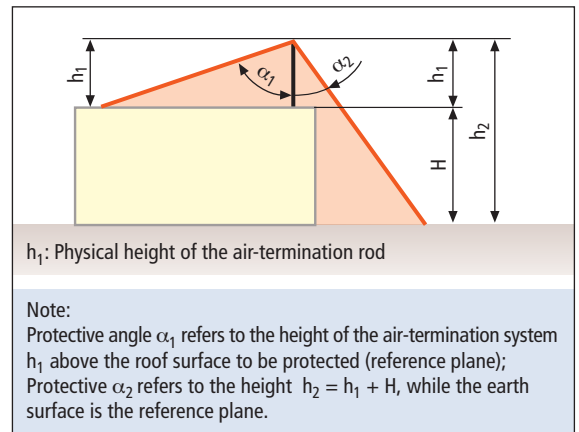
Fig. 5.1.1.16   External lightning protection system, volume protected by a vertical air-termination rod

Height of the air-termination rod h in m	Class of LPS I		Class of LPS II		Class of LPS III		Class of LPS IV	
	Angle α	Distance a in m	Angle α	Distance a in m	Angle α	Distance a in m	Angle α	Distance a in m
1	71	2.90	74	3.49	77	4.33	79	5.14
2	71	5.81	74	6.97	77	8.66	79	10.29
3	66	6.74	71	8.71	74	10.46	76	12.03
4	62	7.52	68	9.90	72	12.31	74	13.95
5	59	8.32	65	10.72	70	13.74	72	15.39
6	56	8.90	62	11.28	68	14.85	71	17.43
7	53	9.29	60	12.12	66	15.72	69	18.24
8	50	9.53	58	12.80	64	16.40	68	19.80
9	48	10.00	56	13.34	62	16.93	66	20.21
10	45	10.00	54	13.76	61	18.04	65	21.45
11	43	10.26	52	14.08	59	18.31	64	22.55
12	40	10.07	50	14.30	58	19.20	62	22.57
13	38	10.16	49	14.95	57	20.02	61	23.45
14	36	10.17	47	15.01	55	19.99	60	24.25
15	34	10.12	45	15.00	54	20.65	59	24.96
16	32	10.00	44	15.45	53	21.23	58	25.61
17	30	9.81	42	15.31	51	20.99	57	26.18
18	27	9.17	40	15.10	50	21.45	56	26.69
19	25	8.86	39	15.39	49	21.86	55	27.13
20	23	8.49	37	15.07	48	22.21	54	27.53
21			36	15.26	47	22.52	53	27.87
22			35	15.40	46	22.78	52	28.16
23			36	16.71	47	24.66	53	30.52
24			32	15.00	44	23.18	50	28.60
25			30	14.43	43	23.31	49	28.76
26			29	14.41	41	22.60	49	29.91
27			27	13.76	40	22.66	48	29.99
28			26	13.66	39	22.67	47	30.03
29			25	13.52	38	22.66	46	30.03
30			23	12.73	37	22.61	45	30.00
31					36	22.52	44	29.94
32					35	22.41	44	30.90
33					35	23.11	43	30.77
34					34	22.93	42	30.61
35					33	22.73	41	30.43
36					32	22.50	40	30.21
37					31	22.23	40	31.05
38					30	21.94	39	30.77
39					29	21.62	38	30.47
40					28	21.27	37	30.14
41					27	20.89	37	30.90
42					26	20.48	36	30.51
43					25	20.05	35	30.11
44					24	19.59	35	30.81
45					23	19.10	34	30.35
46							33	29.87
47							32	29.37
48							32	29.99
49							31	29.44
50							30	28.87
51							30	29.44
52							29	28.82
53							28	28.18
54							27	27.51
55							27	28.02
56							26	27.31
57							25	26.58
58							25	27.05
59							24	26.27
60							23	25.47

angle α

height **h** of the air-termination rod

distance **a**

Table 5.1.1.4   Protective angle α depending on the class of lighting protection system

termination system above the reference plane (**Figure 5.1.1.12**).

Air-termination conductors, air-termination rods, masts and wires should be arranged to ensure that all parts of the building to be protected are situa-

Fig. 5.1.1.17   Protection of small-sized installations on roofs against direct lightning strikes by means of air-termination rods
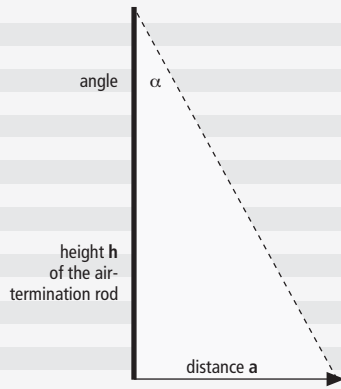

Fig. 5.1.1.18   Gable roof with conductor holder
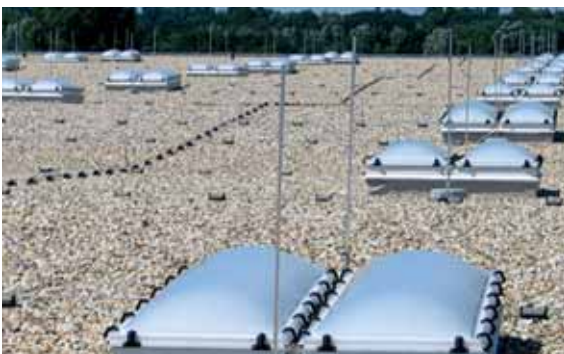
Fig. 5.1.1.19   Flat roof with conductor holders: Protection of the domelights

ted within the volume of protection of the air-termination system.

The protection zone can be "cone-shaped" or "tent-shaped", if a cable, for example, is spanned over it (**Figures. 5.1.1.13** to **5.1.1.15**).

If air-termination rods are installed on the surface of the roof to protect structures mounted thereon, the protective angle α can be different. In **Figure 5.1.1.16**, the roof surface is the reference plane for protective angle α_1. The ground is the reference plane for the protective angle α_2. Therefore the angle α_2 according to **Figure 5.1.1.12** and **Table 5.1.1.4** is less than α_1.

Table 5.1.1.4 provides the corresponding protective angle for each class of lightning protection system and the corresponding distance (zone of protection).

Protective angle method for isolated air-termination systems on roof-mounted structures
Special problems may occur when roof-mounted structures, which are often installed at a later date, protrude from zones of protection, e.g. the mesh. If, in addition, these roof-mounted structures contain electrical or electronic equipment, such as roof-mounted fans, antennas, measuring systems or TV cameras, additional protective measures are required.

If such equipment is connected directly to the external lightning protection system, then, in the event of a lightning strike, partial currents are conducted into the structure. This could result in the destruction of surge sensitive equipment. Direct lightning strikes to such structures protruding above the roof can be prevented by having isolated air-termination systems.

Air-termination rods as shown in **Figure 5.1.1.17** are suitable for protecting smaller roof-mounted structures (with electrical equipment).

They form a "cone-shaped" zone of protection and thus prevent a direct lightning strike to the structure mounted on the roof.

The separation distance s must be taken into account when dimensioning the height of the air-termination rod (see Chapter 5.6).

Isolated and non-isolated air-termination systems
When designing the external lightning protection system of a structure, we distinguish between two types of air-termination system:

⇒ isolated

⇒ non-isolated

The two types can be combined.

The air-termination systems of a **non-isolated** external lightning protection system of a structure can be installed in the following ways:

If the roof is made of non-flammable material, the conductors of the air-termination system can be installed on the surface of the structure (e.g. gable or flat roof). Normally non-flammable building materials are used. The components of the external lightning protection system can therefore be mounted directly on the structure (**Figures 5.1.1.18** and **5.1.1.19**).

If the roof is made of easily inflammable material e.g. thatched roofs, then the distance between the flammable parts of the roof and the air-termination rods, air-termination conductors or air-termination meshes of the air-termination system must not be less than 0.4 m.
Easily inflammable parts of the structure to be protected must not be in direct contact with parts of the external lightning protection system. Neither may they be located under the roofing, which can be punctured in the event of a lightning strike (see also Chapter 5.1.5 Thatched roofs).

With **isolated** air-termination systems, the complete structure is protected against a direct lightning strike via air-termination rods, air-termination masts or masts with cables spanned over them. When installing the air-termination systems, the separation distance s to the structure must be kept (**Figures 5.1.1.20** and **5.1.1.21**).

The separation distance s between the air-termination system and the structure must be kept.

Air-termination systems isolated from the structure are frequently used, when the roof is covered with inflammable material, e.g. thatch or also for ex-installations, e.g. tank installations.

See also Chapter 5.1.5 "Air-termination system for structures with thatched roofs".

s separation distance acc. to IEC 62305-3 (EN 62305-3)
α protective angle acc. to Table 5.1.1.4
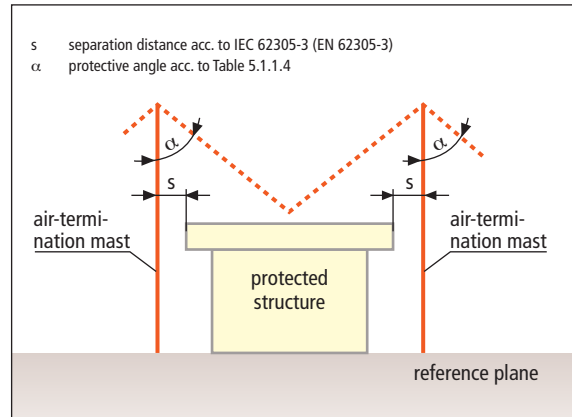
Fig. 5.1.1.20   Isolated external lightning protection system with two separate air-termination masts according to the protective angle method: Projection on a vertical area

s_1, s_2 separation distance acc. to IEC 62305-3 (EN 62305-3)
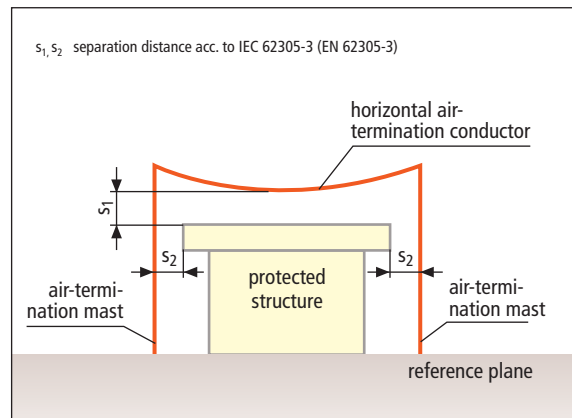
Fig. 5.1.1.21   Isolated external lightning protection system, consisting of two separate air-termination masts, connected by a horizontal air-termination conductor: Projection on a vertical surface via the two masts (vertical section)

A further method of designing isolated air-termination systems consists in securing the air-termination systems (air-termination rods, conductors or cables) with electrically insulating materials such as GRP (glass fibre-reinforced plastic).
This form of isolation can be limited to local use or applied to whole parts of the installation. It is often used for roof-mounted structures such as fan systems or heat exchangers with an electrically conductive connection into the structure (see also Chapter 5.1.8).

Class of LPS	Material	Thickness^a t mm	Thickness^b t` mm
I to IV	Lead	-	2.0
	Steel (stainless, galvanised)	4	0.5
	Titanium	4	0.5
	Copper	5	0.5
	Aluminium	7	0.65
	Zinc	-	0.7
^at prevents from puncturing, overheating, and inflamming			
^bt` only for metal plates, if the prevention of puncturing, overheating, and inflamming is not important			

Table 5.1.1.5   Min. thickness of metal plates

Natural components of air-termination systems
Metal structural parts such as attics, guttering, railings or cladding can be used as natural components of an air-termination system.

If a structure has a steel skeleton construction with a metal roof and facade made of conductive material, these can be used for the external lightning protection system, under certain circumstances.

Sheet metal cladding on the walls or roof of the structure to be protected can be used if the electrical connection between the different parts is permanent. These permanent electrical connections can be made by e.g. brazing, welding, pressing, screwing or riveting, for example.
If there is no electrical connection, a supplementary connection must be made for these elements e.g. with bridging braids or bridging cables.

If the thickness of the sheet metal is not less than the value t' in **Table 5.1.1.5**, and if there is no requirement to take account of a through-melting of the sheets at the point of strike or the ignition of flammable material under the cladding, then such sheets can be used as an air-termination system.

The material thicknesses are not distinguished according to the class of lightning protection system.

If it is, however, necessary to take precautionary measures against through-melting or intolerable heating-up at the point of strike, if the thickness of the sheet metal shall not be less than value t in **Table 5.1.1.5**.

The required thicknesses t of the materials can generally not be complied with, for example, for metal roofs.
For pipes or containers, however, it is possible to meet the requirements for these minimum thicknesses (wall thickness). If, though, the temperature rise (heating-up) on the inside of the pipe or tank represents a hazard for the medium contained therein (risk of fire or explosion), then these must not be used as air-termination systems (see also Chapter 5.1.4).

If the requirements on the appropriate minimum thickness are not met, the components, e.g. conduits or containers, must be situated in an area protected from direct lightning strikes.

A thin coat of paint, 1 mm bitumen or 0.5 mm PVC cannot be regarded as insulation in the event of a direct lightning strike. Such coatings break down when subjected to the high energies deposited during a direct lightning strike.
There must be no coatings on the joints of the natural components of the down-conductor systems.

If conductive parts are located on the surface of the roof, they can be used as a natural air-termination system if there is no conductive connection into the structure.
By connecting, e.g. pipes or electrical conductors into the structure, partial lightning currents can enter the structure and affect or even destroy sensitive electrical / electronic equipment.
In order to prevent these partial lightning currents from penetrating, isolated air-termination systems shall be installed for the aforementioned roof-mounted structures.
The isolated air-termination system can be designed using the rolling sphere or protective angle method. An air-termination system with a mesh size according to the class of lightning protection system used can be installed if the whole arrangement is isolated (elevated) from the structure to be protected by at least the required separation distance s.

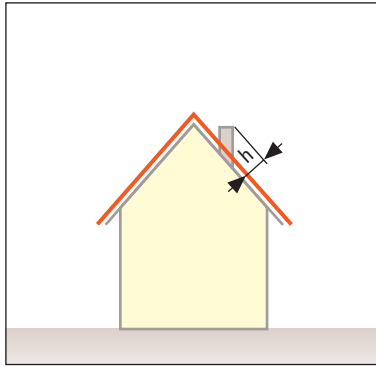Fig. 5.1.2.1   Air-termination system on a gable roof

Fig. 5.1.2.2   Height of a roof superstructure made of electrically non-conductive material (e.g. PVC), h ≤ 0.5 m

Fig. 5.1.2.3   Additional air-termination system for ventilation pipes

A universal system of components for the installation of isolated air-termination systems is described in Chapter 5.1.8.

5.1.2 Air-termination systems for buildings with gable roofs

Air-termination systems on roofs are the metal components in their entirety, e.g. air-termination conductors, air-termination rods, air-termination tips.

The parts of the structure usually hit by lightning strikes, such as the top of the gable, chimneys, ridges and arrises, the edges of gables and eaves, parapets and antennas and other protruding structures mounted on the roof, must be equipped with air-termination systems.

Normally, a reticulated air-termination network is installed on the surface of gabled roofs, said network corresponding to the mesh size of the appropriate class of lightning protection system (e.g. 15 m x 15 m for a lightning protection system Class III) **(Figure 5.1.2.1)**.

By using the ridge and the outer edges of the structure, as well as the metal parts of the structure serving as an air-termination system, the individual meshes can be sited as preferred. The air-termination conductors on the outer edges of the structure must be installed as close to the edges as possible.

Generally, the metal gutter is used for closing the "mesh" of the air-termination system on the roof surface. If the gutter itself is connected so as to be electrically conductive, a gutter clamp is mounted

at the crossover of the air-termination system and the gutter.

Roof-mounted structures made of electrically **non-conductive** material (e.g. PVC vent pipes) are considered to be sufficiently protected if they do not protrude more than h = 0.5 m from the plane of the mesh **(Figure 5.1.2.2)**.

If the protrusion is h > 0.5 m, the structure must be equipped with an air-termination system (e.g. interception tip) and connected to the nearest air-termination conductor. One way of doing this would be to use a wire with a diameter of 8 mm up to a maximum free length of 0.5 m, as shown in **Figure 5.1.2.3**.

Metal structures mounted on the roof without conductive connection into the structure do not need to be connected to the air-termination system if all the following conditions are met:

⇒ Structures mounted on the roof may protrude a maximum distance of 0.3 m from the plane of the mesh

⇒ Structures mounted on the roof may have a maximum enclosed area of 1 m^2 (e.g. dormer windows)

⇒ Structures mounted on the roof may have a maximum length of 2 m (e.g. sheet metal roofing parts)

Only if all three conditions are met, no terminal is required.

Fig. 5.1.2.4   Building with photovoltaic system
Ref.: Wettingfeld Lightning Protection, Krefeld, Germany

Fig. 5.1.2.5   Antenna with air-termination rod

Furthermore, with the conditions stated above, the separation distance to the air-termination conductors and down-conductor systems must be maintained (**Figure 5.1.2.4**).

Air-termination rods for chimneys must be erected to ensure that the whole chimney is in the zone of protection. The protective angle method is applied when dimensioning the air-termination rods.

If the stack is brick-built or constructed with pre-formed sections, the air-termination rod can be mounted directly on the stack.

If there is a metal insert pipe in the interior of the stack, e.g. as found when redeveloping old buildings, the separation distance to this conductive component must be kept. This is an example where isolated air-termination systems are used and the air-termination rods are erected with distance holders. The inserted metal pipe must be connected to the equipotential bonding. The assembly to protect parabolic antennas in particular is similar to that to protect stacks with an internal stainless steel pipe.

In the event of a direct lightning strike to antennas, partial lightning currents can enter the structure to be protected via the shields of the coaxial cables and cause the effects and destruction previously described. To prevent this, antennas are equipped with isolated air-termination systems (e.g. air-termination rods) (**Figure 5.1.2.5**).

Air-termination systems on the ridge have a tent-shaped zone of protection (according to the protective angle method). The angle depends on the height above the reference plane (e.g. surface of

the earth) and the class of lightning protection system chosen.

5.1.3 Air-termination systems for flat-roofed structures

An air-termination system for structures with flat roofs (**Figures 5.1.3.1** and **5.1.3.2**) is designed using the mesh method. A mesh-type air-termination system with a mesh size corresponding to the class of lightning protection system is installed on the roof (**Table 5.1.1.3**).

Figure 5.1.3.3 illustrates the practical application of the meshed air-termination system in combination with air-termination rods to protect the structures mounted on the roof, e.g. domelights, photovoltaic cells or fans. Chapter 5.1.8 shows how to deal with these roof-mounted structures.

Roof conductor holders on flat roofs are laid at intervals of approx. 1 m. The air-termination conductors are connected with the attic, this being a natural component of the air-termination system. As the temperature changes, so does the length of the materials used for the attic, and hence the individual segments must be equipped with "slide plates".

If the attic is used as an air-termination system, these individual segments must be permanently interconnected so as to be electrically conductive without restricting their ability to expand. This can
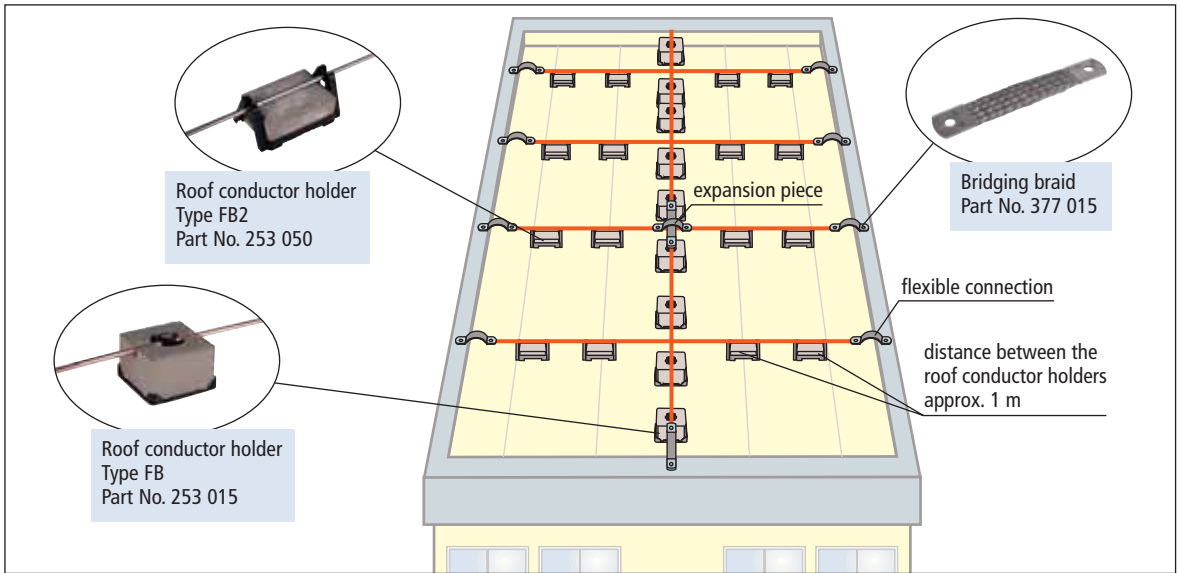
Fig. 5.1.3.1   Air-termination system

Fig. 5.1.3.2   Air-termination system on a flat roof

Fig. 5.1.3.3   Use of air-termination rods

Fig. 5.1.3.4   Bridged attic
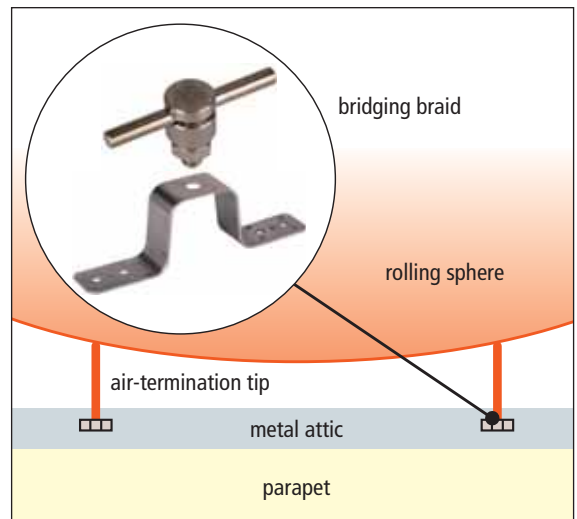
Fig. 5.1.3.5   Example how to protect a metal roof attic, if melting through is unacceptable (front view)

be achieved by means of bridging braids, straps or cables (**Figure 5.1.3.4**).

The changes in length caused by changes in temperature must also be taken into account with air-termination conductors and down-conductor systems (see Chapter 5.4).

A lightning strike to the attic can cause the materials used to melt through. If this is unacceptable, a

Fig. 5.1.3.6   Synthetic flat roof sheetings – Roof conductor holder Type KF / KF2

supplementary air-termination system, e.g. with air-termination tips, must be installed, its location being determined by using the rolling sphere method (**Figure 5.1.3.5**).

Conductor holders for flat roofs, homogeneously welded

In the wind, roof sheetings can move across the roof surface horizontally, if they are only fixed mechanically / laid on the surface. A special position fixing is required for the air-terminat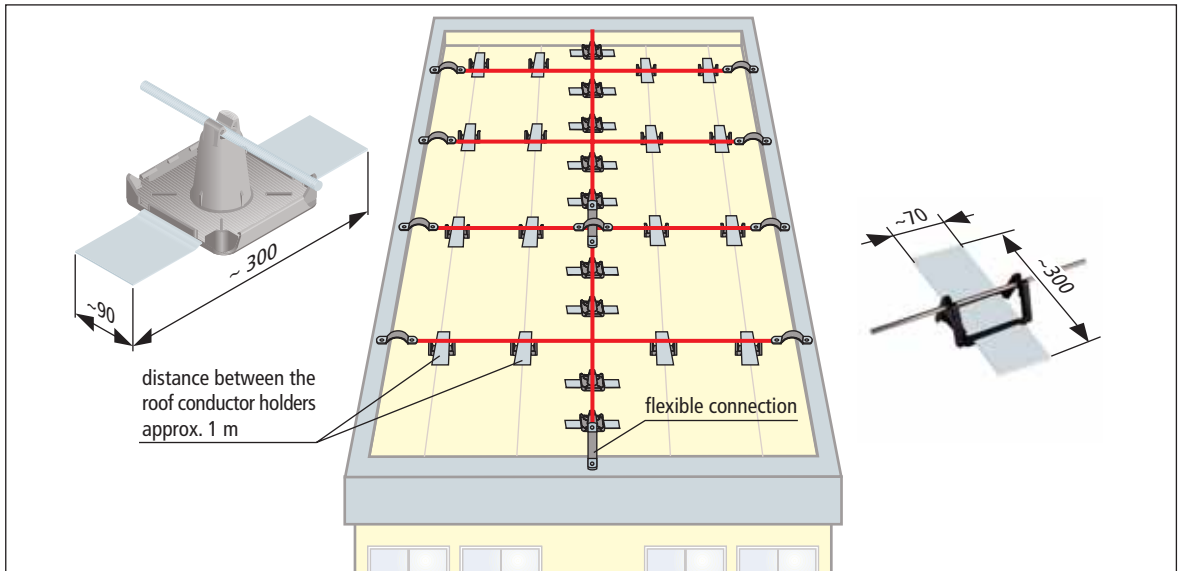ion conductor for preventing the conductor holders for air-termination systems from being displaced on the smooth surface. Conventional roof conductor holders cannot be permanently bonded to roof sheetings since the latter do not usually permit the application of adhesives.

A simple and safe way of fixing the position is to use roof conductor holders Type KF in combination with straps (cut the strips to fit) made of the roof sheeting material. The strap is clamped into the plastic holder and both sides are welded onto the seal. Holder and strap should be positioned immediately next to a roof sheeting joint at a distance of approx. 1 m. The strip of foil is welded to the roof sheeting according to the manufacturer of the roof sheeting. This prevents air-termination conductors on flat roofs from being displaced.

If the slope of the roof is greater than 5 °, each roof conductor holder must be equipped with a position fixing element. If the synthetic roof sheetings are secured by mechanical means, the roof conductor holders must be arranged in the immediate vicinity of the mechanical fixing elements.

When carrying out this work, it must be considered that welding and bonding work on the seal affect the guarantee provided by the roofer.
The work to be carried out must therefore only be done with the agreement of the roofer responsible for the particular roof, or be carried out by him himself (**Figure 5.1.3.6**).

5.1.4 Air-termination systems on metal roofs

Modern industrial and commercial purpose-built structures often have metal roofs and facades. The metal sheets and plates on the roofs are usually 0.7 – 1.2 mm thick.

Figure 5.1.4.1 shows an example of the construction of a metal roof.
When the roof is hit by a direct lightning strike, melting through or vaporisation can cause a hole formed at the point of strike. The size of the hole depends on the energy of the lightning strike and

Fig. 5.1.4.1   Types of metal roofs, e.g. roofs with round standing seam

Detail B

Evaluation: BLIDS – SIEMENS
I = 20400 A

Detail A

residential building

Fig. 5.1.4.2   Example of damage: Metal plate cover

the characteristics of the material, (e.g. thickness). The biggest problem here is the subsequent damage, e.g. water entering at this point. Days or weeks can pass before this damage is noticed. The

Suitable for all classes of lightning protection system	
Distance of the horizontal conductors	Height of the air-termination tip*)
3 m	0.15 m
4 m	0.25 m
5 m	0.35 m
6 m	0.45 m
*) recommended values	

Table 5.1.4.1   Lightning protection for metal roofs – Height of the air-termination tips

rolling sphere with a radius acc. to class of LPS

air-termination tip
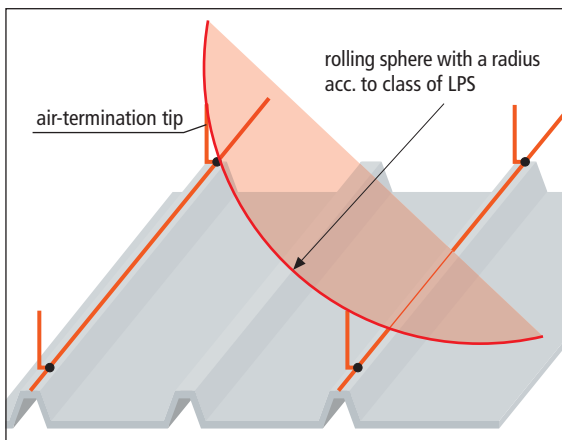
Fig. 5.1.4.3   Air-termination system on a metal roof – Protection against holing

roof insulation becomes damp and / or the ceiling becomes wet and is no longer rainproof.

One example of damage, assessed using BLIDS (**Bl**itz-**I**nformations **D**ienst von **S**iemens – Siemens Lightning Information Service) illustrates this problem (**Figure 5.1.4.2**). A current of approx. 20,000 A struck the sheet metal and made a hole (**Figure 5.1.4.2: Detail A**). Since the sheet metal was not earthed by a down-conductor system, flashovers to natural metal components in the wall occurred in the area around the fascia (**Figure 5.1.4.2: Detail B**), which also caused a hole.

To prevent such kind of damage, a suitable external lightning protection system with wires and clamps capable of carrying lightning currents must be installed even on a "thin" metal roof. The IEC 62305-3 (EN 62305-3) lightning protection standard clearly illustrates the risk of damage to metal roofs. Where an external lightning protection system is required, the metal sheets must have the minimum values stated in **Table 5.1.1.5**.

The thicknesses t are not relevant for roofing materials. Metal sheets with a thickness t' may only be used as a natural air-termination system if puncturing, overheating and melting is tolerated. The owner of the structure must agree to tolerate this type of roof damage, since there is no longer any guarantee that the roof will offer protection from the rain. Also the Rules of the German Roofing Trade concerning lightning protection on and attached to roofs require the agreement of the owner.

If the owner is not prepared to tolerate damage to the roof in the event of a lightning strike, then a separate air-termination system must be installed

1. **Parallel conector**
   St/tZn   Part No. 307 000
2. **Roof conductor holder**
   for metal roofs, loose conductor leading, DEHNgrip conductor holder
   StSt   Part No. 223 011
   Al   Part No. 223 041
3. **Roof conductor holder**
   for metal roofs fixed conductor leading with clamping frame
   StSt   Part No. 223 010
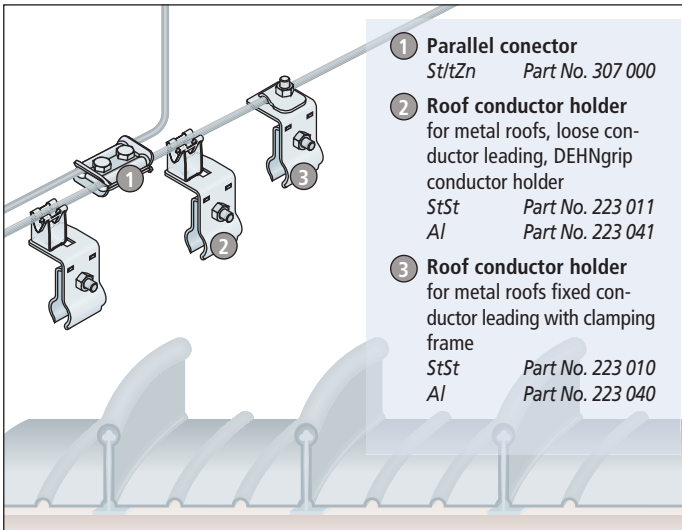   Al   Part No. 223 040

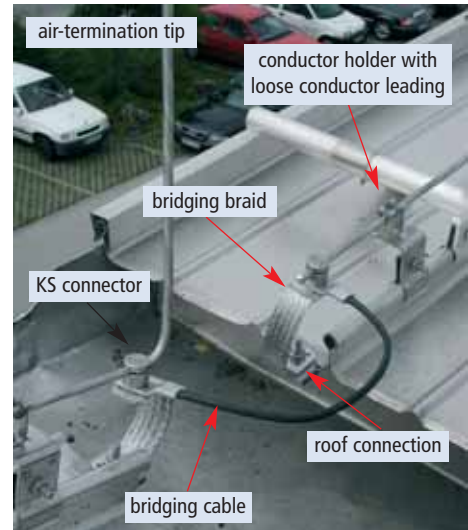Fig. 5.1.4.4a   Conductor holders for metal roofs – Round standing seam

Fig. 5.1.4.4b   Conductor holder for metal roofs – Round standing seam

on a metal roof. The air-termination system must be installed to ensure that the rolling sphere (radius r which corresponds to the class of lightning protection system chosen) does not touch the metal roof (**Figure 5.1.4.3**).

When mounting the air-termination system it is recommended to install a so-called "hedgehog roof" with longitudinal conductors and air-termination tips.

In practice, the heights of air-termination tips according to **Table 5.1.4.1** are tried and tested, regardless of the class of lightning protection system involved.

Holes must not be drilled into the metal roof when fixing the conductors and air-termination tips. Various conductor holders are available for the different types of metal roofs (round standing seam, standing seam, trapezoidal). **Figure 5.1.4.4a** shows one possible design for a metal roof with round standing seam.

When installing the conductors, care must be taken that the conductor holder located at the highest point of the roof must be designed with a fixed conductor leading, whereas all other conductor holders must be designed with a loose conductor leading because of the linear compensation

Fig. 5.1.4.5   Model construction of a trapezoidal sheet roof, conductor holder with clamping frame

Fig. 5.1.4.6   Model construction of a roof with standing seam

Fig. 5.1.4.7   Air-termination rod for a domelight on a roof with round standing seam

caused by changes in temperature (**Figure 5.1.4.4b**).

The conductor holder with fixed conductor leading is illustrated in **Figure 5.1.4.5** using the example of a trapezoidal sheet roof.

Figure 5.1.4.5 also shows an air-termination tip next to the conductor holder. The conductor holder must be hooked into the fixing screw above the covering plate for the drill hole to prevent any entering of water.

Figure 5.1.4.6 uses the example of a round standing seam roof to illustrate the loose conductor leading.
Figure 5.1.4.6 also shows the connection to the roof with round standing seam at the roof edge, which is capable of carrying currents.
Unprotected installations projecting above the roof, e.g. domelights and chimney covers, are exposed points of strike for a lightning discharge. In order to prevent these installations from being struck by a direct lightning strike, air-termination rods must be installed adjacent to the installations projecting above the roof. The height of the air-termination rod results from the protective angle α (**Figure 5.1.4.7**).

5.1.5 Principle of an air-termination system for structures with thatched roof

The design of lightning protection systems Class III generally meets the requirements of such a structure. In particular individual cases, a risk analysis based on IEC 62305-2 (EN 62305-2) can be carried out.

The air-termination conductors on such roofs (made of thatch, straw or rushes) must be fastened across isolating supports to be free to move. Certain distances must also be maintained around the eaves.

In case of subsequent installation of a lightning protection system on a roof, the distances must be increased. This allows to maintain the necessary minimum distances when re-roofing is carried out. For a lightning protection system Class III, the typical distance of the down-conductor system is 15 m.

The exact distance of the down-conductor systems from each other results from calculating the separation distance s in accordance with IEC 62305-3 (EN 62305-3).

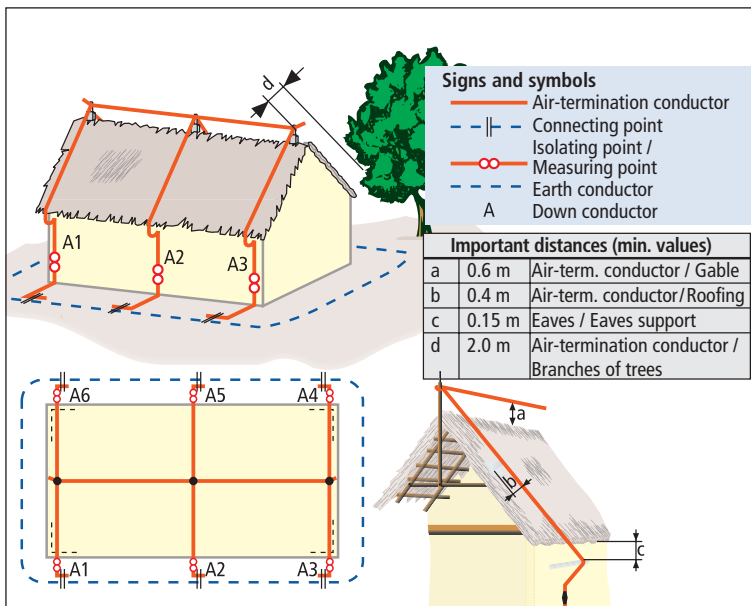Chapter 5.6 explains how to calculate the separation distance.

Ideally, ridge conductors should have spans up to around 15 m, and down-conductor systems up to around 10 m without additional supports.
Fastening posts must be tightly connected to the roof structure (rafters and rails) by means of bolts and washers (**Figures 5.1.5.1** to **5.1.5.3**).

Metal components situated above the roof surface (such as weather vanes, irrigation systems, antennas, metal plates, conductors) must be entirely in the protected volume of isolated air-termination systems.
In such cases, effective protection against lightning can only be achieved with an isolated external lightning protection system with

Signs and symbols	
———	Air-termination conductor
– ‖ –	Connecting point
– ‖ –	Isolating point / Measuring point
– – –	Earth conductor
A	Down conductor

Important distances (min. values)		
a	0.6 m	Air-term. conductor / Gable
b	0.4 m	Air-term. conductor / Roofing
c	0.15 m	Eaves / Eaves support
d	2.0 m	Air-termination conductor / Branches of trees

Fig. 5.1.5.1   Air-termination system for buildings with thatched roofs

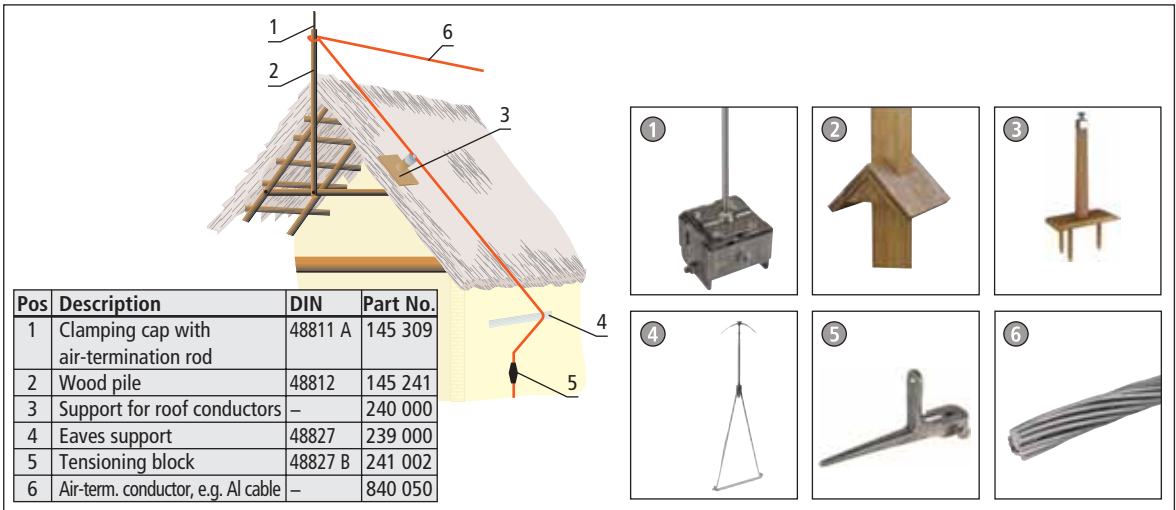| Pos	Description	DIN	Part No.
1	Clamping cap with air-termination rod	48811 A	145 309
2	Wood pile	48812	145 241
3	Support for roof conductors	–	240 000
4	Eaves support	48827	239 000
5	Tensioning block	48827 B	241 002
6	Air-term. conductor, e.g. Al cable	–	840 050

Fig. 5.1.5.2   Components for thatched roofs

air-termination rods near the structure, or air-termination conductors or interconnected air-termination masts adjacent to the structure.

If a thatched roof borders onto metal roofing material, and if the structure has to be equipped with an external lightning protection system, then an electrically non-conductive roofing material at least 1 m wide, e.g. in plastic, must be inserted between the thatched roof and the other roof.

Tree branches must be kept at least 2 m away from a thatched roof. If trees are very close to, and higher than, a structure, then an air-termination conductor must be mounted on the edge of the roof facing the trees (edge of the eaves, gable) and connected to the lightning protection system. The necessary distances must be maintained.

A further way of protecting structures with thatched roofs against a strike of lightning is to erect air-termination masts so that the whole structure is in the protected volume.

This method can be found in Chapter 5.1.8 isolated air-termination system (steel telescopic lightning protection masts).
A new and architecturally very attractive possibility of isolated lightning protection is the use of isolated down conductor systems.
Example for the installation of isolated down conductor systems: Redevelopment of the roof of a historical farmhouse in Lower Saxony (**Figure 5.1.5.4**).

Referring to the building regulations (LBO) of the respective federal state as well as to the model building regulations (MBO), the competent building authority decides about the necessity of a lightning protection system.

Fig. 5.1.5.3   Thatched roof

Fig. 5.1.5.4   Historical farmhouse with external lightning protection (Ref. Photo: Hans Thormählen GmbH & Co.KG)
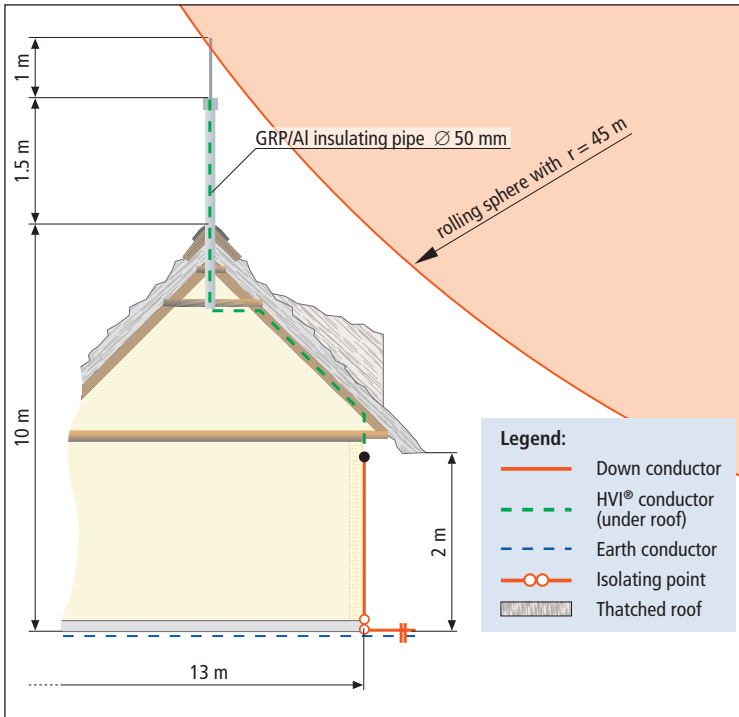
Fig. 5.1.5.5   Sectioning at the central building

The building regulations of Lower Saxony (NBauO) for example stipulate in § 20 (3) that:

"Buildings or structures which due to the location, type of construction or use are particularly susceptible to lightning strikes, or where such a strike can have serious consequences, must be equipped with permanently effective lightning protection systems."

With regard to the increasing damage events caused by lightning strikes and surges, property insurers require that measures of lightning and surge protection are taken prior to the conclusion of new, or adjustment of existing insurance contracts. Basis for the risk assessment is a risk analysis according to IEC 62305-2 (EN 62305-2).

At the historical farmhouse a lightning protection system Class III has been installed, which meets the standard requirements for buildings with thatched roofs IEC 62305-3 (EN 62305-3).
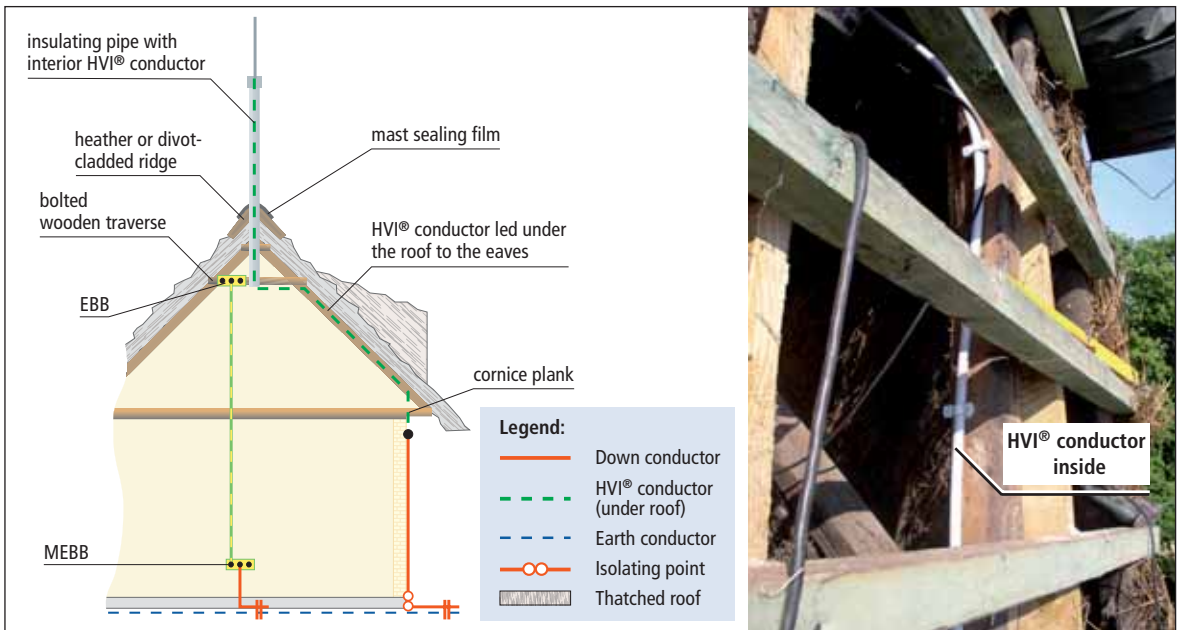

Fig. 5.1.5.6   Schematic diagram and diagram of the down conductor installation at the rafter

Fig. 5.1.5.7   HVI conductor led through the cornice plank

The heather-cladded ridge of the object is protected by a reticulated plastic cover to avoid abrasion by birds.

Before designing of the air-termination system, the protected volumes are to be determined by the rolling sphere method. A rolling sphere radius of 45 m is applicable in case of a lightning protection system Class III according to the standard specifications. The height of the air-termination system was ascertained to be 2.30 m, thus the two stacks at the ridge and the three new dormers at the one side of the roof are within the protected volume (**Figure 5.1.5.5**).

An insulating pipe (Glass Fibre Reinforced Unsaturated Plastic) was chosen to keep the air-termination system correspondingly elevated and to support the isolated down-conductor system. The lower part of the insulating pipe is aluminium to ensure the mechanical stability. Due to the induction of neighbouring components unwanted sparking is possible in this section. To avoid this, there are no earthed parts or electrical equipment within a distance of 1 m from the air-termination system.

The electrical isolation of air-termination systems and down-conductor systems on the one hand and of the metal installations to be protected and the systems of power supply and information techno logy of the building or structure to be protected on the other hand, can be achieved by the separation distance s between these conductive parts. This must be determined according to IEC 62305-3

(EN 62305-3). The isolated HVI conductor is specified with an equivalent separation distance in air of s = 0.75 m or s = 1.50 m for solid building materials. **Figure 5.1.5.6** shows how the down conductor system is arranged.

The HVI conductor is run in an insulating pipe. The construction requires a down leading of the HVI conductor via a central earthing busbar, the equipotential bonding measures being performed by a flexible conductor H07V-K 1 x 16 mm^2. The insulating pipe is fixed at a special construction (wooden traverse) and further down, the down conductors are routed along the rafters of the roof construction underneath the battens (**Figure 5.1.5.6**).

At the eaves, the HVI conductors are led through the cornice plank (**Figure 5.1.5.7**).

For architectural reasons aluminium down conductors are installed further down. Like for the whole installation, the crossover of the HVI conductor to the uninsulated, bare down conductor near the earthing system is effected on the basis of the mounting instructions of the DEHNconductor system. A sealing unit was not necessary.

5.1.6 Walkable and trafficable roofs

It is not possible to mount air-termination conductors (e.g. with concrete blocks) on trafficable roofs. One possible solution is to install the air-termination conductors in either concrete or in the joints between the sections of the roadway. If the air-termination conductor is installed in these joints, mushroom head collectors are installed at the intersections of the mesh as defined points of strike.

The mesh size must not exceed the value according to the class of lightning protection system (see Chapter 5.1.1, **Table 5.1.1.3**).

If it can be guaranteed that no persons will be on this area during a thunderstorm, then it is sufficient to install the measures described above.

Persons who can go onto this storey of the car park must be informed by means of a sign that they must immediately clear this storey when a thunderstorm occurs, and not return for the duration of the storm (**Figure 5.1.6.1**).
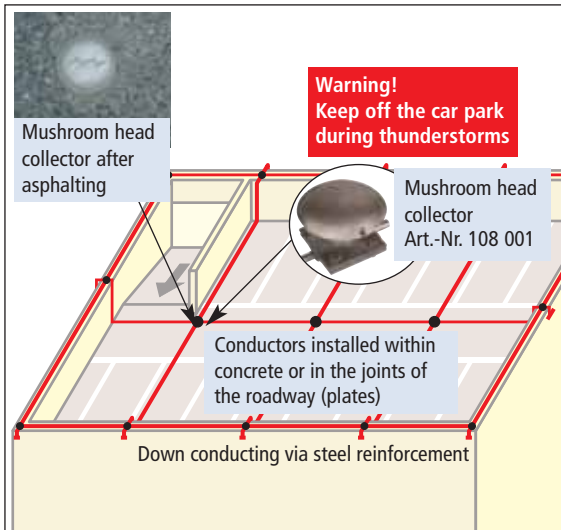
Fig. 5.1.6.1 Lightning protection for car park roofs – Building protection

Fig. 5.1.6.2 Lightning protection for car park roofs – Building and life protection IEC 62305-3 (EN 62305-3); Annex E

If it is also possible that persons are on the roof during a thunderstorm, then the air-termination system must be designed to protect these persons, assuming they have a height of 2.5 m (with outstretched arm) from direct lightning strikes.

The air-termination system can be dimensioned using the rolling sphere or the protective angle method according to the class of lightning protection system (**Figure 5.1.6.2**).

These air-termination systems can also be constructed from spanned cables or air-termination rods. These air-termination rods are secured to structural elements such as parapets or the like, for example.

Furthermore, lightning masts, for example, can also act as air-termination rods to prevent life hazard. With this version, however, attention must be paid to the partial lightning currents which can be conducted into the structure via the power lines. It is imperative to have lightning equipotential bonding measures for these lines.

5.1.7 Air-termination system for green and flat roofs

A planted roof can make economic and ecological sense. This is because it provides noise insulation,
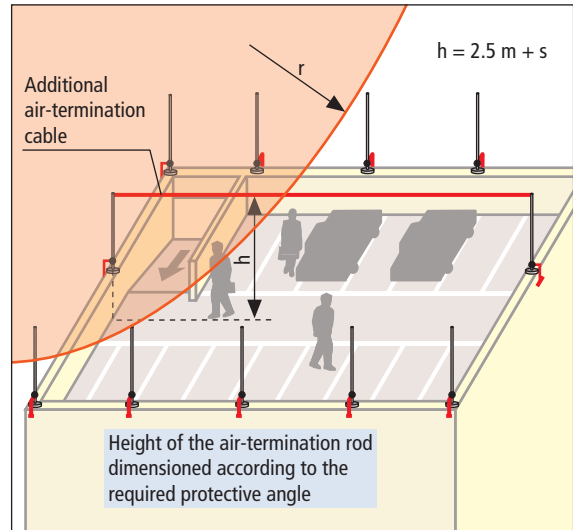
protects the roof skin, suppresses dust from the ambient air, provides additional heat insulation, filters and retains rainwater and is a natural way of improving the living and working conditions. Moreover, in many regions it is possible to obtain grants from public funds for cultivating plants on the roof. A distinction is made between so-called extensive and intensive cultivation. An extensive planted area requires little care, in contrast to an intensive planted area which requires fertiliser, irrigation and cutting. For both types of planted area, either earth substrate or granulate must be laid on the roof.

It is even more expensive if the granulate or substrate has to be removed because of a direct lightning strike.

If there is no external lightning protection system, the roof seal can be damaged at the point of strike.

Experience has shown that, regardless of the type of care required, the air-termination system of an external lightning protection system can, and should, also be installed on the surface of a green roof.

For a meshed air-termination system, the IEC 62305-3 (EN 62305-3) lightning protection stan-

Fig. 5.1.7.1   Green roof

Fig. 5.1.7.2   Air-termination system on a green roof

Fig. 5.1.7.3   Conductor leading on the covering layer

dard prescribes a mesh size which depends on the class of lightning protection system chosen (see Chapter 5.1.1, **Table 5.1.1.3**). An air-termination conductor installed inside the covering layer is difficult to inspect after a number of years because the air-termination tips or mushroom head collectors are overgrown and no longer recognisable, and frequently damaged by maintenance work. Moreover, air-termination conductors installed inside the covering layer are more susceptible to corrosion. Conductors of air-termination meshes installed uniformly on top of the covering layer are easier to inspect even if they become overgrown, and the height of the interception system can be lifted up by means of air-termination tips and rods and "grown" with the plants on the roof. Air-termination systems can be designed in different ways. The usual way is to install a meshed air-termination net with a mesh size of 5 m x 5 m (lightning protection system Class I) up to a max. mesh size of 15 m x 15 m (lightning protection system Class III) on the roof surface, regardless of the height of the structure. It is preferable to determine the installation site of the mesh considering the external edges of the roof and any metal structures acting as an air-termination system.

Stainless steel (Material No. 1.4571) has proven to be a good material for the conductors of air-termination systems on planted roofs.
Aluminium wire must not be used for installing conductors in the covering layer (in the earth substrate or granulate), (**Figures 5.1.7.1** to **5.1.7.3**).
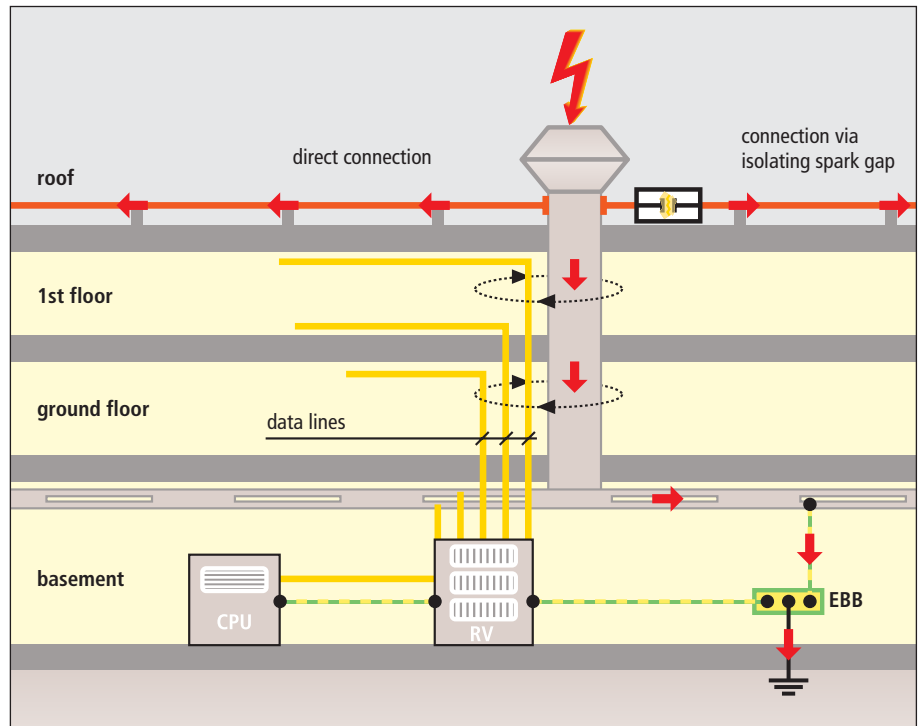

Fig. 5.1.8.1   Connection of roof-mounted structures

Fig. 5.1.8.2 Isolated air-termination system, protection provided by an air-termination rod

Fig. 5.1.8.3 Air-termination rod with distance holder

5.1.8 Isolated air-termination systems

Roof-mounted structures such as air conditioning and cooling systems, e.g. for mainframes, are nowadays used on the roofs of larger office blocks and industrial structures. Antennas, electrically controlled domelights, advertising signs with integrated lightning and all other protruding roof-mounted structures having a conductive connection, e.g. via electrical cables or ducts, into the structure, must be treated in a similar way.

According to the state of the art for lightning protection, such roof-mounted structures are protected against direct lightning strikes by means of separately mounted air-termination systems. This prevents partial lightning currents from entering the structure, where they would affect or even destroy the sensitive electrical/electronic installations.

In the past, these roof-mounted structures were connected directly.

This direct connection meant that parts of the lightning current were conducted into the structure. Later, "indirect connection" via a spark gap was introduced. This meant that direct lightning strikes to the roof-mounted structure could also flow away via the "internal conductors" to some extent, and in the event of a more distant lightning strike to the structure, the spark gap should not operate. The operating voltage of approx. 4 kV was almost always attained and hence partial

lightning current was also carried into the structure via the electrical cable, for example. This can affect or even destroy electrical or electronic installations inside the structure.

The only way of preventing these currents to be carried in is to use isolated air-termination systems which maintain the separation distances.

Figure 5.1.8.1 shows a partial lightning current penetrating the inside of the structure.

These widely different roof-mounted structures can be protected by various designs of isolated air-termination systems.

Air-termination rods

For smaller roof-mounted structures (e.g. small fans) the protection can be achieved by using individual, or a combination of several, air-termination rods. Air-termination rods up to a height of 2.0 m can be fixed with one or two concrete bases piled on top of each other (e.g. Part No. 102 010) as self supporting installation (**Figure 5.1.8.2**).

If air-termination rods are higher than 2.5 m or 3.0 m, they must be fixed at the object to be protected by distance holders made of electrically insulating material (e.g. DEHNiso distance holder) (**Figure 5.1.8.3**).

Angled supports are a practical solution when air-termination rods also have to be secured against

Fig. 5.1.8.4 Angled support for air-termination rods

Fig. 5.1.8.5 Supporting element for the air-termination rod

Fig. 5.1.8.6 Isolated air-termination system for photovoltaic system

the effects of side winds (**Figures 5.1.8.4** and **5.1.8.5**).

If higher air-termination rods are required, e.g. for larger roof-mounted structures, which nothing can be secured to, the air-termination rods can be installed by using special supports.

Self-supporting air-termination rods up to a height of 8.5 m can be installed by using a tripod. These supports are fixed to the floor with standard concrete bases (one on top of another). Additional guy lines are required above a free height of 6 m in order to withstand the stresses caused by the wind.

These self-supporting air-termination rods can be used for a wide variety of applications (e.g. antennas, PV installations). The special feature of this type of air-termination system is its short installation time as no holes need to be drilled and only few elements need to be screwed together (**Figures 5.1.8.6** to **5.1.8.7**).

For protecting complete structures or installations (e.g. PV installations, ammunition depots) with air-termination rods, lightning protection masts are used. These masts are installed in a concrete foun-

dation. Free heights of 19 m above ground level can be achieved, even higher, if custom-made ones are used. It is also possible to span a cable between these masts if they are especially designed for this purpose. The standard lengths of the steel telescopic lightning protection masts are supplied in sections, offering enormous advantages for transportation.

Further information (e.g. installation, assembly) about these steel telescopic lightning protection masts can be found in Installation Instructions No. 1574 (**Figures 5.1.8.8** and **5.1.8.9**).

Spanned over by cables or conductors

According to IEC 62305-3 (EN 62305-3), air-termination conductors can be installed above the structure to be protected.

The air-termination conductors generate a tent-shaped protective space at the sides, and a cone-shaped one at the ends. The protective angle α depends on the class of lightning protection system and the height of the air-termination system above the reference plane.

Fig. 5.1.8.7 Isolated air-termination system for roof-mounted structures

Fig. 5.1.8.8 Additional protection in the transition area by anticorrosive band for underground application

Fig. 5.1.8.9 Installation of a steel telescopic lightning protection mast

Fig. 5.1.8.10   Installed air-termination system
                 Ref.: Blitzschutz Wettingfeld , Krefeld. Germany

The rolling sphere method with its corresponding radius (according to the class of lightning protection system) can also be used to dimension the conductors or cables.

The mesh type of air-termination system can also be used if an appropriate separation distance s between the components of the installation and the air-termination system must be maintained. In such cases, isolating distance holders in concrete bases are installed vertically, for example, for guiding the mesh on an elevated level (**Figure 5.1.8.10**).

DEHNiso-Combi
A user-friendly way of installing conductors or cables in accordance with the three different design methods for air-termination systems (rolling sphere, protective angle, mesh) is provided by the DEHNiso-Combi programme of products.

The aluminium insulating pipes with "isolating distance" (GRP – **G**lass-fibre **R**einforced **P**lastic) which are fixed to the object to be protected, provide a way of guiding the cables. By means of the GRP distance holder, a subsequently separate guiding to the down-conductor system or supplementary air-termination systems (e.g. mesh) is realised.

Further information about the application is contained in the brochures DS 123E, DS 111E and in the set of installation instructions No. 1475.

Fig. 5.1.8.11   Tripod support for self-supporting insulating pipes

Fig. 5.1.8.12   Isolated air-termination systems with DEHNiso-Combi

The types of design described can be combined with each other as desired to adapt the isolated air-termination systems to the local conditions (**Figures 5.1.8.11** to **5.1.8.14**).

Fig. 5.1.8.13   Detail picture of DEHNiso-Combi

Fig. 5.1.8.14   Isolated air-termination system with DEHNiso-Combi

5.1.9 Air-termination system for steeples and churches

External lightning protection system

According to the German standard DIN EN 62305-3, Supplement 2, lightning protection systems Class III meet the normal requirements for churches and steeples. In particular individual cases, for example

in the case of culturally significant structures, a special risk analysis in accordance with IEC 62305-2 (EN 62305-2) must be carried out.

Nave

According to the German standard DIN EN 62305-3, Supplement 2, the nave must have its own lightning protection system and, if a steeple is attached, this system must be connected by the shortest route with a down-conductor system of the steeple. In the transept, the air-termination conductor along the transverse ridge must be equipped with a down-conductor system at each end.

Steeple

Steeples up to a height of 20 m must be equipped with a down-conductor system. If steeple and nave are joined, then this down-conductor system must be connected to the external lightning protection system of the nave by the shortest route (**Figure 5.1.9.1**). If the down-conductor system of the steeple coincides with a down-conductor system of the nave, then a common down-conductor system can be used at this location. According to the German standard DIN EN 62305-3, Supplement 2, steeples above 20 m in height must be provided

Fig. 5.1.9.1   Installing the down-conductor system at a steeple

with at least two down conductors. At least one of these down conductors must be connected with the external lightning protection system of the nave via the shortest route.

Down-conductor systems on steeples must always be guided to the ground on the outside of the steeple. The installation inside the steeple is not allowed (DIN EN 62305-3 Supplement 2). Further, the separation distance s to metal components and electrical installations in the steeple (e.g. clock mechanisms, belfry) and under the roof (e.g. air conditioning, ventilation and heating systems) must be maintained by suitable arrangement of the external lightning protection system. The required separation distance can become a problem especially at the clock. In this case, the conductive connection into the structure can be replaced with an isolating connector (e.g. a GRP pipe) to prevent hazardous sparking in parts of the external lightning protection system.

In more modern churches built with reinforced concrete, the reinforcement steels can be used as down-conductor systems if it can be ensured that they provide a continuous conductive connection. If pre-cast reinforced concrete parts are used, the reinforcement may be used as a down-conductor system if terminals to connect the reinforcement continuously are provided on the pre-cast concrete parts.

In Germany the lightning equipotential bonding with the electronic equipment (power system, telephone and public address system) shall be effected at the entrance to the building and for the bells control and timing system in the steeple and at the control and timing system, in accordance with Supplement 2 of DIN EN 62305-3.

5.1.10 Air-termination systems for wind turbines (WT)

Requirement for protection against lightning
IEC 61400-24 describes measures required to protect wind turbines against lightning. In the certification directives of the German Lloyd, a lightning protection system Class III is required for WT hubs in a height of 60 m and Class II if the hub is in a height of more than 60 m. In case of offshore plants a lightning protection system Class I is required. This can control lightning strikes with currents measuring up to 200,000 A. This requirements are based on the experience made at the operation of WT and on the assessment of the risk of damage according to IEC 62305-2 (EN 62305-2).

Principle of an external lightning protection system for wind turbines
The external lightning protection system comprises air-termination systems, down-conductor systems and an earth termination system and protects against mechanical destruction and fire. Lightning strikes to wind turbines usually affect the rotor blades. Hence, receptors, for example, are integrated to determine defined points of strike (**Figure 5.1.10.1**).

In order to allow the coupled lightning currents to flow to earth in a controlled way, the receptors in the rotor blades are connected to the hub with a metal interconnecting conductor (solid tape conductor St/tZn 30 mm x 3.5 mm or copper cable 50 mm^2). Carbon fibre brushes or air spark gaps then, in turn, bridge the ball-bearings in the head of the nacelle in order to avoid the welding of the revolving parts of the structure.

Fig. 5.1.10.1   WT with integrated receptors in the rotor blades

Fig. 5.1.10.2   Lightning protection for wind speed indicators at WT

Fig. 5.1.11.1   Protection against direct lightning strikes by self-sup-
porting air-termination rods

In order to protect structures on the nacelle, such as anemometers in the event of a lightning strike, air-termination rods or "air-termination cages" are installed (**Figure 5.1.10.2**).

The metal tower or, in case of a prestressed concrete version, the down-conductor systems embedded in the concrete (round conductor St/tZn Ø 8 ...10 mm or tape conductor St/tZn 30 mm x 3.5 mm) is used as the down-conductor system. The wind turbine is earthed by a foundation earth electrode in the base of the tower and the meshed connection with the foundation earth electrode of the operation building. This creates an "equipotential surface" which prevents potential differences in the event of a lightning strike.

5.1.11   Wind load stresses on lightning protection air-termination rods

Roofs are used more and more as areas for technical installations. Especially when extending the technical equipment in the structure, extensive installations are sited more than ever on the roofs of larger office blocks and industrial structures. It is essential to protect roof-mounted structures such as air conditioning and cooling systems, transmitters for cell sites on host buildings, lamps, flue gas vents and other apparatus connected to the electrical low voltage system (**Figure 5.1.11.1**).

In accordance with the relevant lightning protection standards contained in the IEC 62305 (EN 62305) series, these roof-mounted structures can be protected from direct lightning strikes with isolated air-termination systems. This requires an iso-

lation of both the air-termination systems, such as air-termination rods, air-termination tips or air-termination meshes, and the down-conductor systems, i.e. to be installed with sufficient separation distance from the roof-mounted structures within the zone of protection. The construction of an isolated lightning protection system creates a zone of protection in which direct lightning strikes cannot occur. It also prevents partial lightning currents from entering the low voltage system and hence the structure. This is important as the entering of partial lightning currents into the building can affect or destroy sensitive electrical/electronic installations.

Extended roof-mounted structures are also equipped with a system of isolated air-termination systems. These are connected with each other and also with the earth-termination system. Among other things the magnitude of the zone of protection created depends on the number and the height of the air-termination systems installed.

A single air-termination rod is sufficient to provide the protection required by smaller roof-mounted structures. The procedure involves the application of the rolling sphere method in accordance with IEC 62305-3 (EN 62305-3) (**Figure 5.1.11.2**).

With the rolling sphere method, a rolling sphere whose radius depends on the class of lightning

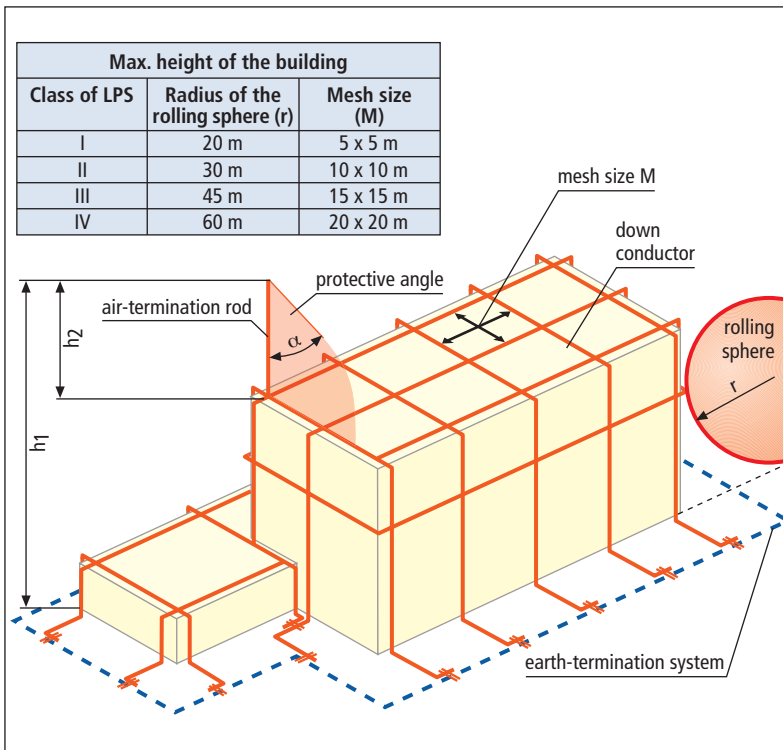| Max. height of the building		
Class of LPS	Radius of the rolling sphere (r)	Mesh size (M)
I	20 m	5 x 5 m
II	30 m	10 x 10 m
III	45 m	15 x 15 m
IV	60 m	20 x 20 m

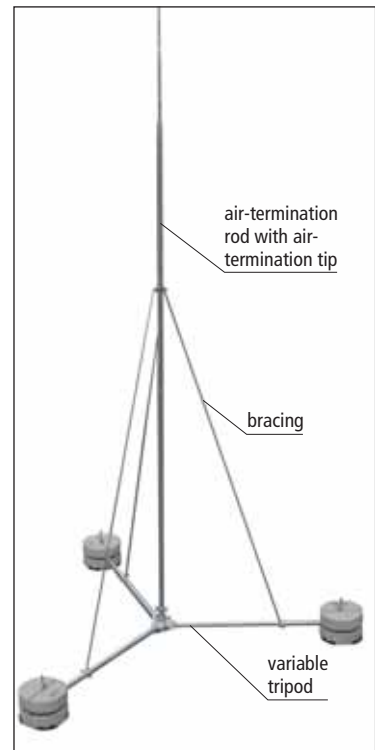Fig. 5.1.11.2   Procedure for installation of air-termination systems according to IEC 62305-3 (EN 62305-3)

Fig. 5.1.11.3   Self-supporting air-termination rod with variable tripod

protection system chosen is rolled in all possible directions on and over the structure to be protected. During this procedure, the rolling sphere must touch the ground (reference plane) and/or the air-termination system only.

This method produces a protection volume where direct lightning strikes are not possible.

To achieve the largest possible volume of protection, and also to be able to protect larger roof-mounted structures against direct lightning strikes, the individual air-termination rods should ideally be erected with a corresponding height. To prevent self-supporting air-termination rods from tilting and breaking a suitably designed base and supplementary braces are required (**Figure 5.1.11.3**).

The requirement for the self-supporting air-termination rods to be built as high as possible must be balanced against the higher stress exerted by the active wind loads. A 40 % increase in wind speed, for example, doubles the active tilting moment. At the same time, from the application point of view,

users demand a lightweight system of "self-supporting air-termination rods", which are easier to transport and install. To ensure that it is safe to use air-termination rods on roofs, their mechanical stability must be proven.

Stress caused by wind loads

Since self-supporting air-termination rods are installed at exposed sites (e.g. on roofs), mechanical stresses arise which, owing to the comparable location and the upcoming wind speeds, correspond to the stresses suffered by antenna frames. Self-supporting air-termination rods must therefore basically meet the same requirements concerning their mechanical stability as set out in the German standard DIN 4131 for antenna frames.

DIN 4131 divides Germany up into 4 wind zones with zone-dependent wind speeds (**Figure 5.1.11.4**).

When calculating the prospective actual wind load stresses, apart from the zone-dependent wind load, the height of the structure and the local con-

ditions (structure standing alone in open terrain or embedded in other buildings) must also be included. From **Figure 5.1.11.4** it can be seen that around 95 % of Germany´s surface area lies within Wind Zones I and II. Air-termination rods are therefore generally designed for Wind Zone II. The use of self-supporting air-termination rods in Wind Zone III and Wind Zone IV must be assessed for each individual case taking the arising stresses into account.

According to DIN 4131 a constant dynamic pressure over the height of a structure can be expected for structures up to a height of 50 m. For the calculations, the maximum height of the structure was considered 40 m, so that a total height (height of the structure plus length of the air-termination rods) is kept below the 50 m mark.

When designing self-supporting air-termination rods, the following requirements must be met for the wind load stress:

⇒ Tilt resistance of the air-termination rods

⇒ Fracture resistance of the rods

⇒ Maintaining the required separation distance to the object to be protected even under wind loads (prevention of intolerable deflections)

Determination of the tilt resistance

The dynamic pressure arising (depends on the wind speed), the resistance coefficient c_w and the contact surface of the wind on the air-termination rod, generate a uniform load q' on the surface which generates a corresponding tilting moment M_T on the self-supporting air-termination rod. To ensure that the self-supporting air-termination rod is stable, the tilting moment M_T must be opposed by a load torque M_O, which is generated by the post. The magnitude of the load torque M_O depends on the standing weight and the radius of the post. If the tilting moment is greater than the load torque, the wind load pushes the air-termination rod over.

The proof of the stability of self-supporting air-termination rods is also obtained from static calculations. Besides the mechanical characteristics of the materials used, the following information is included in the calculation:

⇒ **Wind contact surface of the air-termination rod:** determined by length and diameter of the individual sections of the air-termination rod.

⇒ **Wind contact surface of the bracing:** Very high self-supporting air-termination rods are anchored with 3 braces mounted equidistantly around the circumference. The wind contact surface of these braces corresponds to the area projected by these braces onto a plane in a right angle to the direction of the wind, i.e. the

Zone	Dynamic pressure q [kN/m²]	Wind velocity v [km/h]	Wind strength
I	0.8	126.7	
II	1.05	145.1	12 - 17
III	1.4	161.5	
IV	1.7	184.7	
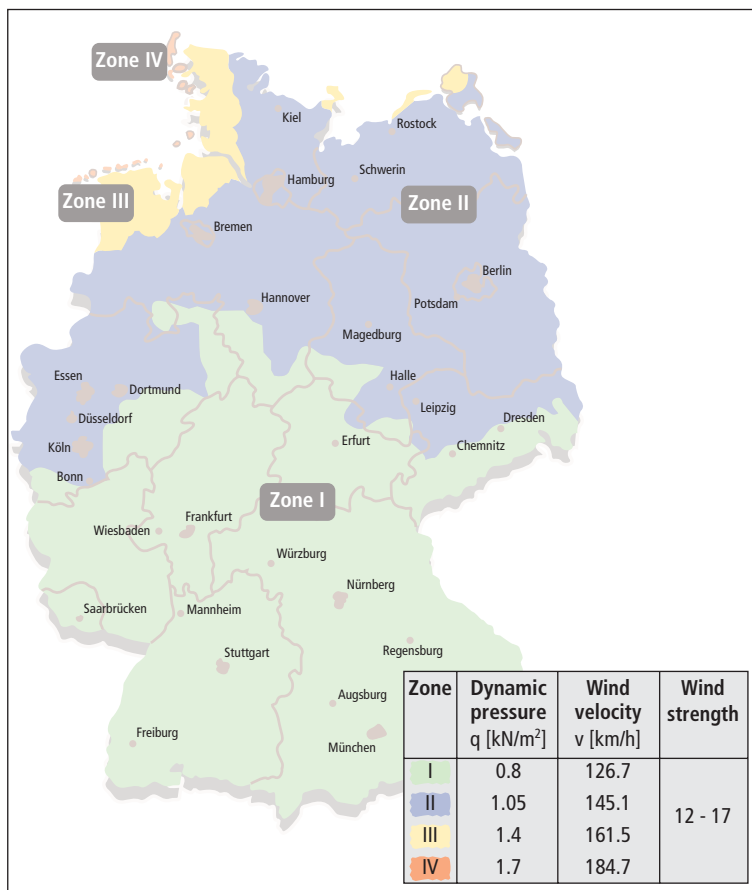
Fig. 5.1.11.4 Division of Germany into wind load zones and corresponding values of dynamic pressure and max. wind speed
Ref.: DIN 4131:1991-11: Steel antenna frames, Berlin: Beuth-Verlag, GmbH

brace lengths are shortened accordingly when considered in the calculation.

⇒ **Weight of the air-termination rod and the bracing:** The dead weight of the air-termination rod and the braces is taken into account in the calculation of the load torque.

⇒ **Weight of the post:** The post is a tripod weighted down with concrete blocks. The weight of this post is made up of the dead weight of the tripod and the individual weights of the concrete blocks used.

⇒ **Tilting lever of the post:** The tilting lever denotes the shortest distance between the centre of the tripod and the line or point around which the whole system would tilt.

The proof of stability is obtained by comparing the following moments:

⇒ **Tilting moment** formed from the wind-load-dependent force on the air-termination rod or the braces and the lever arm of the air-termination rod.

⇒ **Load torque** formed from the weight of the post, the weight of the air-termination rod and the braces, and the length of the tilt lever through the tripod.

Stability is achieved when the ratio of load torque to the tilting moment assumes a value **>1**.
Basically: the greater the ratio of load torque to tilting moment, the greater the stability.
The required stability can be achieved in the following ways:

⇒ In order to keep the wind contact surface of the air-termination rod small, the cross sections used have to be as small as possible. The load on the air-termination rod is reduced, but, at the same time, the mechanical strength of the air-termination rod decreases (risk of breaking). It is therefore crucial to make a compromise between a smallest possible cross section to reduce the wind load and a largest possible cross section to achieve the required strength.

⇒ The stability can be increased by using larger base weights and/or larger post radii. This often conflicts with the limited areas for erection and the general requirement for low weight and easy transport.

Implementation
In order to provide the smallest possible wind contact surface, the cross sections of the air-termination rods were optimised in accordance with the results of the calculation. For easier transportation and installation, the air-termination rod comprises an aluminium tube (in sections, if so desired) and an aluminium air-termination rod. The post to hold the air-termination rod is hinged and is available in two versions. Roof pitches up to 10 ° can be compensated..

Determination of the fracture resistance
Not only the stability of the air-termination rod must be proven, but also the fracture resistance, since the occurring wind load exerts bending stresses on the self-supporting air-termination rod. The bending stress in such cases must not exceed the max. permissible stress. The bending stress occurring is higher for longer air-termination rods. The air-termination rods must be designed to ensure that wind loads as can arise in Wind Zone II cannot cause permanent deformation of the rods.

Since both the exact geometry of the air-termination rod and the non-linear performance of the materials used must be taken into account, the proof of the fracture resistance of self-supporting air-termination rods is obtained using an FEM calculation model. The finite elements method, FEM for short, is a numerical method for calculation of stresses and deformations of complex geometrical structures. The structure under examination is broken down into so-called "finite elements" using imaginary surfaces and lines which are interconnected via nodes.

The calculation requires the following information:

⇒ **FEM-calculation model**

The FEM calculation model corresponds to the simplified geometry of the self-supporting air-termination rod.

⇒ **Material characteristics**

The performance of the material is represented by the details of cross-sectional values, modulus of elasticity, density and lateral contraction.

⇒ **Loads**

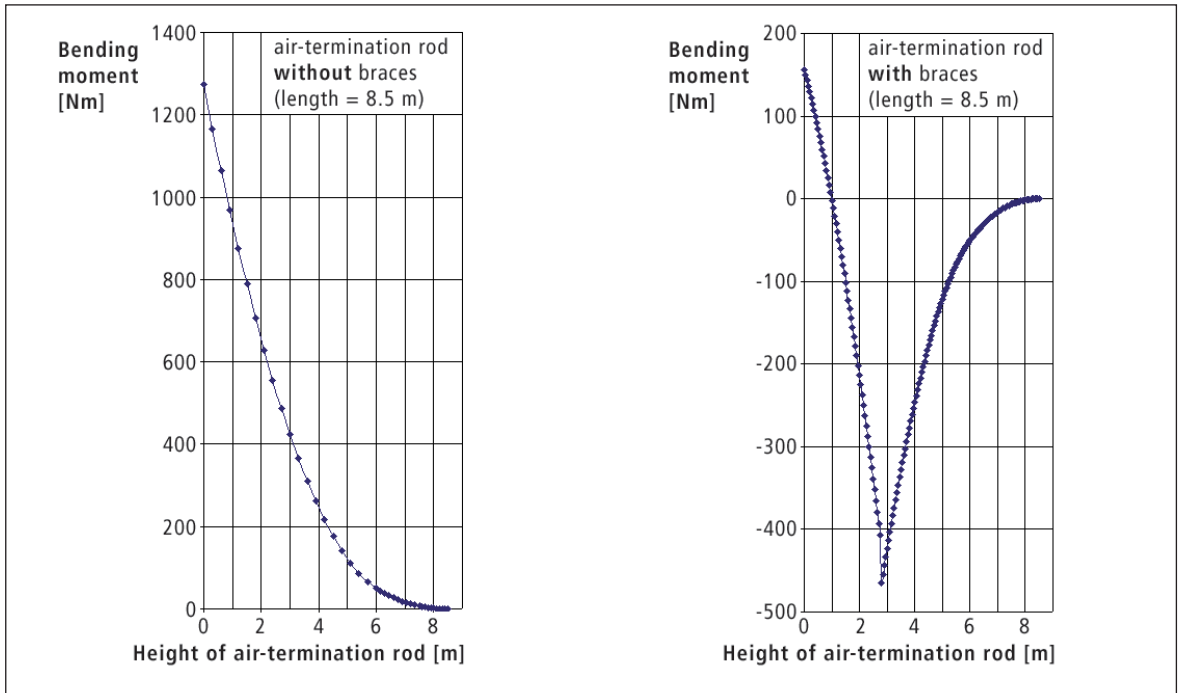The wind load is applied to the geometric model as a pressure load.

Fig. 5.1.11.5   Comparison of bending moment courses at self-supporting air-termination rods with and without braces (length = 8.5 m)

The fracture resistance is determined by comparing the permissible bending stress (material parameter) and the max. bending stress which can occur (calculated from the bending moment and the effective cross section at the point of maximum stress).

Fracture resistance is achieved if the ratio of permissible to actual bending stress is >1. Basically, the same principle also applies here: the greater the ratio of permissible to actual bending stress, the greater the fracture resistance.

Using the FEM calculation model, the actual bending moments for two air-termination rods (length = 8.5 m) were calculated as a function of their height with and without braces (**Figure 5.1.11.5**). This clearly illustrates the effect of a possible brace on the course of the moments. Whereas the max. bending moment of the air-termination rod without a brace in the fixed-end point is around 1270 Nm, the brace reduces the bending moment to around 460 Nm. This brace makes it possible to reduce the stresses in the air-termination rod to such an extent that, for the max. expected wind loads, the strength of the materials used is not

exceeded and the air-termination rod is not destroyed.

Implementation
Braces create an additional "bearing point" which significantly reduces the bending stresses occurring in the air-termination rod. Without supplementary bracing, the air-termination rods would not cope with the stresses of Wind Zone II. Therefore, air-termination rods higher than 6 m are equipped with braces.

In addition to the bending moments, the FEM calculation also provides the tensile forces occurring in the bracing, whose strength must also be proven.

Determination of the wind-load-dependent deflection of the air-termination rod
A further important value calculated with the FEM model is the deflection of the tip of the air-termination rod. Wind loads cause the air-termination rods to bend. The bending of the rod results in a change to the volume to be protected. Objects to be protected are no longer situated in the zone of
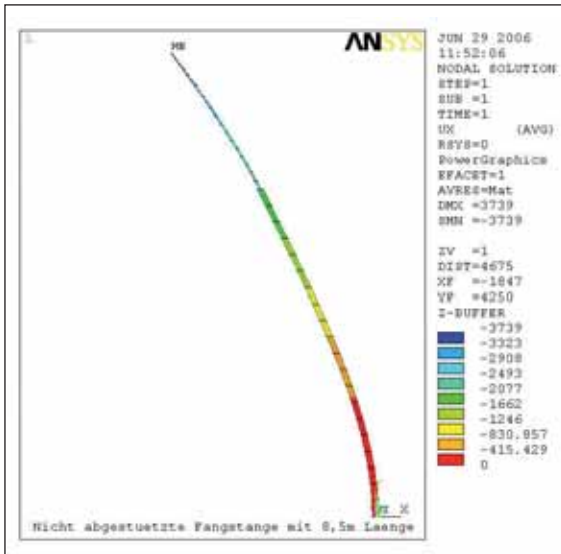
Fig. 5.1.11.6   FEM model of a self-supporting air-termination rod without bracing (length = 8.5 m)
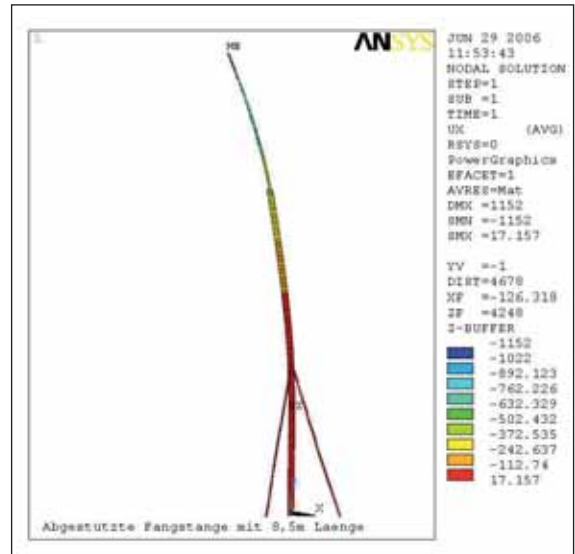
Fig. 5.1.11.7   FEM model of a self-supporting air-termination rod with bracing (length = 8.5 m)

protection and/or proximities can no longer be maintained.

The application of the calculation model on a self-supporting air-termination rod without and with braces produces the following results (**Figures 5.1.11.6** and **5.1.11.7**).

For the example chosen, the calculation gives a displacement of the tip of the air-termination rod with bracing of around 1150 mm. Without bracing there would be a deflection of around 3740 mm, a theoretical value which exceeds the breaking point of the air-termination rod under consideration.

Implementation

Above a certain rod height, supplementary braces reduce this defection significantly. Furthermore, this also reduces the bending load on the rod.

Conclusion

Tilting resistance, fracture resistance and deflection are the decisive factors when designing air-termination rods. Base and air-termination rod must be coordinated to ensure that the loads occurring as a result of the wind speeds of Zone II do not cause a tilting of the rod, nor damage it.

It must still be borne in mind that large deflections of the air-termination rod reduce the separation distance and thus intolerable proximities can arise.

Higher air-termination rods require a supplementary bracing to prevent such intolerable deflections of the tips of the air-termination rods.

The measures described ensure that self-supporting air-termination rods can cope with Zone II wind speeds according to DIN 4131 (German standard).

5.2 Down-conductor system

The down-conductor system is the electrically conductive connection between the air-termination system and the earth-termination system. The function of down-conductor systems is to conduct the intercepted lightning current to the earth-termination system without intolerable temperature rises, for example, to damage the structure.

To avoid damage caused during the lightning current discharge to the earth-termination system, the down-conductor systems must be mounted to ensure that from the point of strike to the earth,

⇒ several parallel current paths exist,

⇒ the length of the current paths is kept as short as possible (straight, vertical, no loops),

⇒ the connections to conductive components of the structure are made wherever required (distance < s; s = separation distance).

5.2.1 Determination of the number of down conductors

The number of down conductors depends on the perimeter of the external edges of the roof (perimeter of the projection on the ground surface).

The down conductors must be arranged to ensure that, starting at the corners of the structure, they are distributed as uniformly as possible to the perimeter.

Depending on the structural features (e.g. gates, precast components), the distances between the various down conductors can be different. In each case, there must be at least the total number of down conductor required for the respective class of lightning protection system.

The IEC 62305-3 (EN 62305-3) standard gives typical distances between down conductors and ring conductors for each class of lightning protection system (**Table 5.2.1.1**).

The exact number of down conductors can only be determined by calculating the separation distance s. If the calculated separation distance cannot be maintained for the intended number of down conductors of a structure, then one way of meeting this requirement is to increase the number of down conductors. The parallel current paths improve the current splitting coefficient k_c. This measure reduces the current in the down conductors, and the required separation distance can be maintained.

Natural components of the structure (e.g. reinforced concrete supports, steel skeleton) can also be used as supplementary down conductors if continuous electrical conductivity can be ensured.

By interconnecting the down conductors at ground level (base conductor) and using ring conductors for higher structures, it is possible to bal-

Class of LPS	Typical distance
I	10 m
II	10 m
III	15 m
IV	20 m

Table 5.2.1.1   Distance between down conductors according to IEC 62305-3 (EN 62305-3)

ance the distribution of the lightning current which, in turn, reduces the separation distance s.

The latest IEC 62305 (EN 62305) series of standards attaches great significance to the separation distance. The measures specified can change the separation distance positively for structures and thus the lightning current can be safely discharged.

If these measures are not sufficient to maintain the required separation distance, it is also possible to use a new type of high voltage-resistant isolated conductors (HVI). These are described in Chapter 5.2.4.

Chapter 5.6 describes how the exact separation distance can be determined.

5.2.2 Down-conductor system for a non-isolated lightning protection system

The down-conductor systems are primarily mounted directly onto the structure (with no distance). The criterion for installing them directly on the structure is the temperature rise in the event of lightning striking the lightning protection system. If the wall is made of flame-resistant material or material with a normal level of flammability, the down-conductor systems may be installed directly on or in the wall.

q mm^2	Ø	Type of lightning protection system											
		Aluminium			Iron			Copper			Stainless steel		
		III + IV	II	I	III + IV	II	I	III + IV	II	I	III + IV	II	I
16		146	454	*	1120	*	*	56	143	309	*	*	*
50	8 mm	12	28	52	37	96	211	5	12	22	190	460	940
78	10 mm	4	9	17	15	34	66	3	5	9	78	174	310
* melting / vaporising													

Table 5.2.2.1   Max. temperature rise ΔT in K of different conductor materials

Owing to the specifications in the building regulations of the German federal states, highly flammable materials are generally not used. This means that the down-conductor systems can usually be mounted directly on the structure.

Wood with a bulk density greater than 400 kg/m^2 and a thickness greater than 2 mm is considered to have a normal level of flammability. Hence the down-conductor system can be mounted on wooden poles, for example.

If the wall is made of highly flammable material, the down conductors can be installed directly on the surface of the wall, provided that the temperature rise when lightning currents flow is not hazardous.

The maximum temperature rise ΔT in K of the various conductors for each class of lightning protection system are stated in **Table 5.2.2.1**. These values mean that, generally, it is even permissible to install down conductors underneath heat insulation because these temperature rises present no fire risk to the insulation materials.

This ensures that the fire retardation measure is also provided.

When installing the down-conductor system in or underneath heat insulation, the temperature rise (on the surface) is reduced if an additional PVC sheath is used. Aluminium wire sheathed in PVC can also be used.

If the wall is made of highly flammable material, and the temperature rise of the down-conductor systems presents a hazard, then the down conductors must be mounted to ensure that the distance between the down-conductor systems and the wall is greater than 0.1 m. The mounting elements may touch the wall. The erector of the structure must state whether the wall, where a down-conductor system is to be installed, is made of flammable material.

In Germany the precise definition of the terms flame-resistant, normal level of flammability and highly flammable can be taken from Supplement 1 of DIN EN 62305-3 (VDE 0185-305-3).

5.2.2.1 Installation of down-conductor systems

The down conductors must be arranged to be the direct continuation of the air-termination conductors. They must be installed straight and vertically
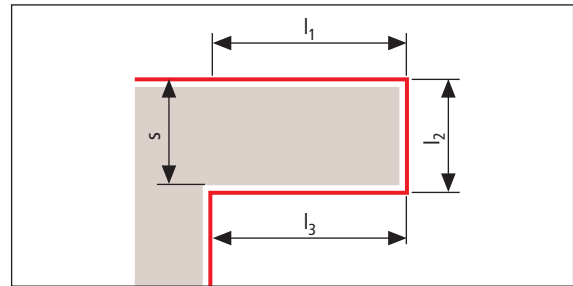
Fig. 5.2.2.1.1   Loop in the down conductor

so as to represent the shortest possible direct connection to the earth.

Loops, e.g. projecting eaves or structures, must be avoided. If this is not possible, the distance measured where two points of a down-conductor system are closest, and the length I of the down-conductor system between these points, must fulfill the requirements on the separation distance s (**Figure 5.2.2.1.1**).

The separation distance s is calculated using the total length $l = l_1 + l_2 + l_3$.

Down-conductor systems must not be installed in gutters and downpipes, even if they are sheathed in an insulating material. The damp in the gutters would badly corrode the down-conductor systems.

If aluminium is used as a down conductor, it must not be installed directly (with no distance) on, in or under plaster, mortar, concrete, neither should it be installed in the ground. If it is equipped with a PVC sheath, then aluminium can be installed in mortar, plaster or concrete, if it is possible to ensure that the sheath will not be mechanically damaged nor will the insulation fracture at low temperatures.

It is recommended to mount down conductors to maintain the required separation distance s to all doors and windows (**Figure 5.2.2.1.2**).

Metal gutters must be connected with the down conductors at the points where they intersect (**Figure 5.2.2.1.3**).

The base of metal downpipes must be connected to the equipotential bonding or the earth-termination system, even if the pipe is not used as a down conductor. Since it is connected to the eaves gutter, through which the lightning current flows, the downpipe also takes a part of the lightning

The connection must be as short as possible, straight and installed vertically

Downpipes may only be used as down conductor, if they are soldered or riveted
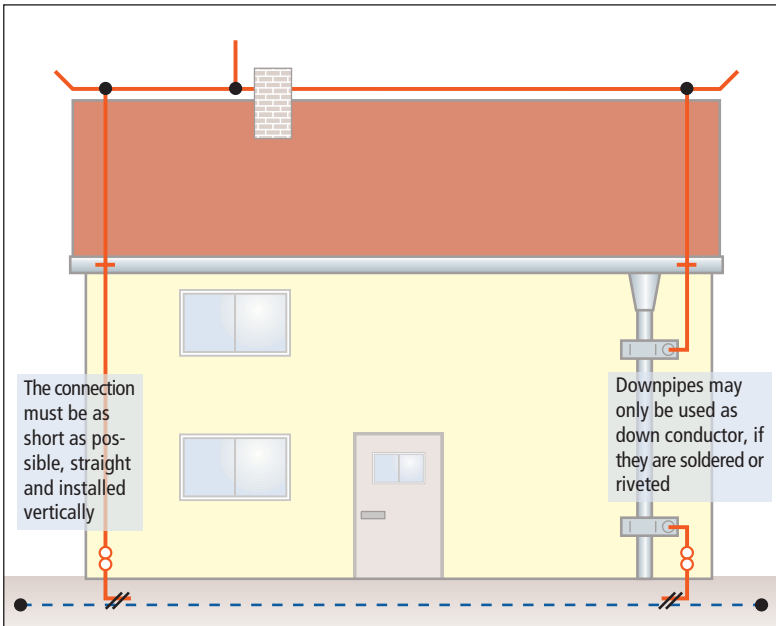
Fig. 5.2.2.1.2 Down-conductor system

Fig. 5.2.2.1.3 Air-termination system with connection to the gutter

StSt wire Ø 10 mm

Fig. 5.2.2.1.4 Earthed downpipe

current which must be conducted into the earth-termination system. **Figure 5.2.2.1.4** illustrates one possible design.

5.2.2.2 Natural components of a down-conductor system

When using natural components of the structure as a down-conductor system, the number of down conductors to be installed separately can be reduced or, in some cases, they can be dispensed with altogether.

The following parts of a structure can be used as "natural components" of the down-conductor system:

⇒ Metal installations, provided that the safe connection between the various parts is permanent and their dimensions conform to the minimum requirements for down conductors. These metal installations may also be sheathed in insulating material. The use of conduits containing flammable or explosive materials as down conductors is not permitted if the seals in the flanges/couplings are non-metallic or the flanges/couplings of the connected pipes

are not otherwise connected so as to be electrically conductive.

⇒ The metal skeleton of the structure

If the metal frame of structures with a steel skeleton or the interconnected reinforced steel of the structure is used as a down-conductor system, then ring conductors are not required since additional ring conductors would not improve the splitting of the current.

⇒ Safe interconnected reinforcement of the structure

The reinforcement of existing structures cannot be used as a natural component of the down-conductor system unless it can be ensured that the reinforcement is safely interconnected. Separate external down conductors must be installed.

⇒ Precast parts

Precast parts must be designed to provide terminal connections for the reinforcement. Precast parts must have an electrically conductive connection between all terminal connections. The individual components must be interconnected on site during installation (**Figure 5.2.2.2.1**).
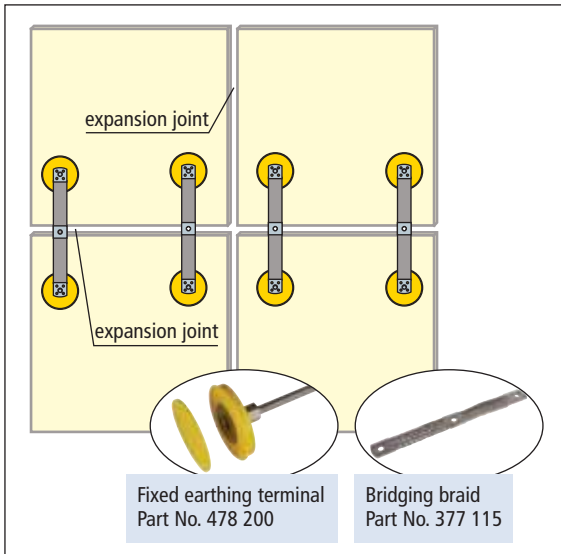
Fig. 5.2.2.2.1   Use of natural components – new buildings made of ready-mix concrete

Fig. 5.2.2.2.2   Metal subconstruction, conductively bridged

Note:

In the case of prestressed concrete, attention must be paid to the particular risk of possible intolerable mechanical effects arising from lightning current and resulting from the connection to the lightning protection system.

For prestressed concrete, connections to tensioning rods or cables must only be effected outside the stressed area. The permission of the person responsible for erecting the structure must be given before using tensioning rods or cables as a down conductor.

If the reinforcement of existing structures is not safely interconnected, it cannot be used as a down-conductor system. In this case, external down conductors must be installed.

Furthermore, facade elements, mounting channels and the metal substructures of facades can be used as a natural down-conductor system, provided that:

⇒ the dimensions meet the minimum requirements of down-conductor systems. For sheet metal, the thickness must not be less than 0.5 mm. Their electrical conductivity in vertical direction must be ensured. If metal facades are used as a down-conductor system, they must be interconnected to ensure that the individual plates are safely interconnected with each
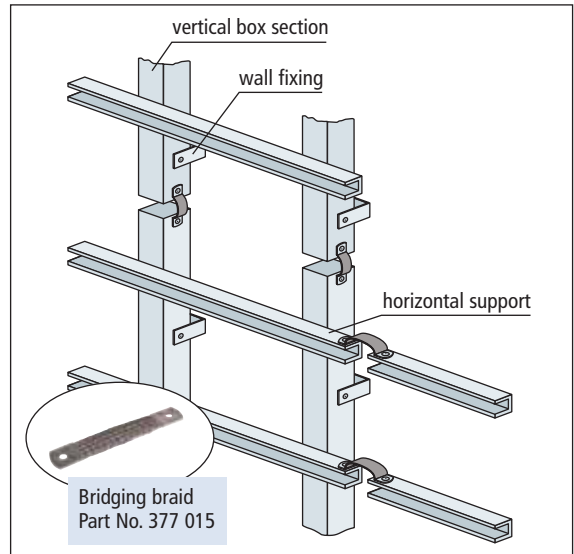
other by means of screws, rivets, or bridging connections. There must be a safe connection capable of carrying currents to the air-termination system and also to the earth-termination system.

⇒ If metal plates are not interconnected in accordance with the above requirement, but the substructure ensures that they are continuously conductive form the connection on the air-termination system to the connection on the earth-termination system, then they can be used as a down-conductor system (**Figures 5.2.2.2.2** and **5.2.2.2.3**).

Fig. 5.2.2.2.3   Earth connection of a metal facade

Metal downpipes can be used as natural down conductors, as long as they are safely interconnected (brazed or riveted joints) and comply with the minimum wall thickness of the pipe of 0.5 mm.

If a downpipe is not safely interconnected, it can serve as a holder for the supplementary down conductor. This type of application is illustrated in **Figure 5.2.2.2.4**. The connection of the downpipe to the earth-termination system must be capable of carrying lightning currents since the conductor is held only along the pipe.

5.2.2.3 Measuring points

There must be a measuring point at every connection of a down conductor with the earth-termination system (above the lead-in, if possible).

Measuring points are required to allow the inspection of the following characteristics of the lightning protection system:

⇒ Connections of the down conductors via the air-termination systems to the next down conductor

⇒ Interconnections of the terminal lugs via the earth-termination system, e.g. in the case of ring or foundation earth electrodes (earth electrode Type B)

⇒ Earth electrode resistance of single earth electrodes (earth electrode Type A)

Fig. 5.2.2.2.4 Down conductor installed along a downpipe

Fig. 5.2.2.3.1 Measuring point with number plate

Measuring points are not required if the structural design (e.g. reinforced concrete structure or steel skeleton) allows no "electrical" disconnection of the "natural" down-conductor system to the earth-termination system (e.g. foundation earth electrode).

The measuring point may only be opened with the help of a tool for the purpose of taking measurements, otherwise it must be closed.

Each measuring point must be able to be clearly assigned to the design of the lightning protection system. Generally, all measuring points are marked with numbers (**Figure 5.2.2.3.1**).

If the separation distance is too short, the conductive parts of the building construction have to be connected to the air-termination system. The effects from the currents have to be taken into account.
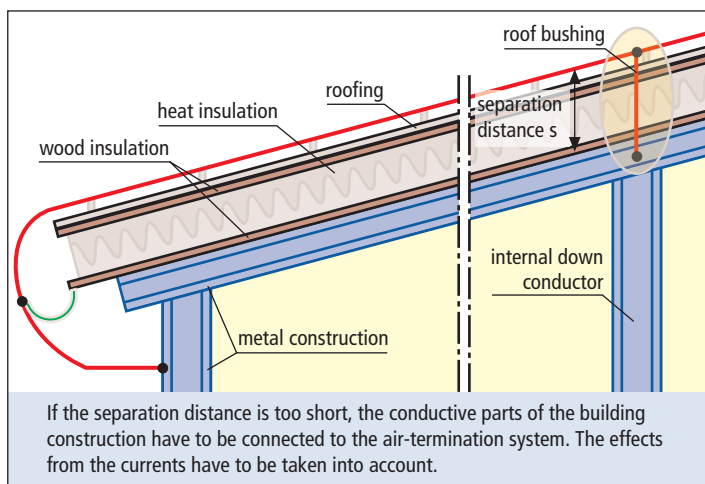
Fig. 5.2.2.4.1 Air-termination system installed on large roofs – Internal down-conductor system

Courtyards with circumference of more than 30 m. Typical distances according to class of LPS
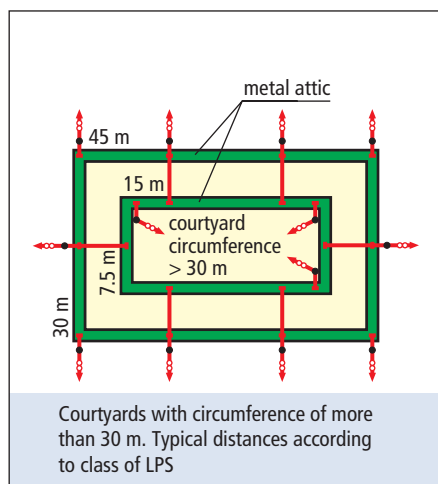
Fig. 5.2.2.5.1 Down-conductor systems for courtyards
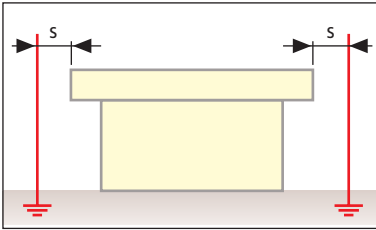
Fig. 5.2.3.1   Air-termination masts isolated from the building
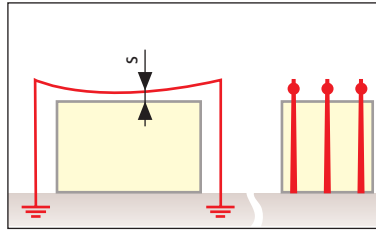
Fig. 5.2.3.2   Air-termination masts spanned with cables
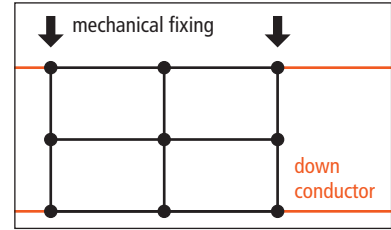
Fig. 5.2.3.3   Air-termination masts spanned with cables with cross connection (meshing)

5.2.2.4 Internal down-conductor systems

If the edges of the structure (length and width) are four times as large as the distance of the down conductors which corresponds to the class of lightning protection system, then supplementary internal down conductors must be installed (**Figure 5.2.2.4.1**).

The grid dimension for the internal down-conductor systems is around 40 m x 40 m.

Large structures with flat roofs, such as large production halls or also distribution centres, frequently require internal down conductors. In such cases, the ducts through the surface of the roof should be installed by a roofer because he is responsible for ensuring that the roof provides protection against rain.

The consequences of the partial lightning currents through internal down-conductor systems within the structure must be taken into account. The resulting electromagnetic field in the vicinity of the down conductor must be taken into consideration when designing the internal lightning protection system (pay attention to inputs to electrical/electronic systems.)

5.2.2.5 Courtyards

Structures with enclosed courtyards having a perimeter greater than 30 m (**Figure 5.2.2.5.1**) must have down-conductor systems installed with the distances shown in **Table 5.2.1.1**.

5.2.3 Down conductors of an isolated external lightning protection system

If an air-termination system comprises air-termination rods on isolated masts (or one mast), then this is both air-termination system and down-conductor system at the same time (**Figure 5.2.3.1**).

Each individual mast requires at least one down conductor. Steel masts or mast with an interconnected steel reinforcement require no supplementary down-conductor system.

For optical reasons, a metal flag pole, for example can also be used as an air-termination system.

The separation distance s between the air-termination and down-conductor systems and the structure must be maintained.

If the air-termination system consists of one or more spanned wires or cables, each end of the cable which the conductors are attached to requires at least one down conductor (**Figure 5.2.3.2**).

If the air-termination system forms an intermeshed network of conductors, i.e. the individual spanned wires or cables are interconnected to form a mesh (being cross-linked), there must be at least one down conductor at the end of each cable the conductors are attached to (**Figure 5.2.3.3**).

5.2.4 High voltage-resistant, isolated down-conductor system – HVI conductor

A multitude of structures is used in order to create an exhaustive network of cell sites. Some of these structures have lightning protection systems. In order to design and implement the mast infrastructure in accordance with the standards, the actual situation must be taken into account during the design phase while the relevant standards have to be strictly differentiated.

For the operator of a mobile phone network there are basically **three different situations**:

- ⇒ Structure has no lightning protection system
- ⇒ Structure is equipped with a lightning protection system which is no longer capable of functioning
- ⇒ Structure is equipped with a functioning lightning protection system

Structure has no lightning protection system

In Germany cell sites are constructed in accordance with DIN VDE 0855-300. This deals with the earthing of the cell site. In accordance with the concept for protection against surges of the mobile phone network operators, supplementary protection against surges is integrated into the meter section.

Structure is equipped with a lightning protection system which is no longer capable of functioning

In Germany cell sites are connected to the external lightning protection system as required by the class of lightning protection system (LPS) determined. The lightning current paths required for the cell site are investigated and assessed. This involves replacing non-functional components of the existing installation which are required to discharge the lightning current, such as air-termination conductor, down-conductor system and connection to the earth-termination system. Any observed defects to parts of the installation which are not required must be notified in writing to the owner of the structure.

Structure is equipped with a functioning lightning protection system

Experience has shown that most lightning protection systems are designed according to LPS Class III. Regular inspections are prescribed for certain structures. It must be planned to integrate the cell site installation in accordance with the class of lightning protection system (LPS) determined. For installations with LPS Class I and II, the surroundings of the installation must be recorded photographically to ensure that, if problems subsequently arise with proximities, the situation at the time of construction can be proven. If a cell site is erected on a structure with a functional external lightning protection system, its erection is governed by the latest lightning protection standard (IEC 62305 (EN 62305)). In this case for example, in Germany the DIN VDE 0855-300 can only be used for the equipotential bonding of the antenna cable. Proximities must be calculated as appropriate to the class of LPS. All mechanical components used must be able to cope with the prospective partial lightning currents. For reasons of standardisation, all the steel fixing elements and structures for holding antennas of many mobile phone network operators must be designed for LPS Class I. The connection should be done via the shortest route, which is not a problem, however, as the air-termination conductors on flat roofs are usually designed to be meshed. If there is a functional lightning protection system on the host building, this has a higher priority than an antenna earthing installation.

Because of how it is designed, the class of lightning protection system to be effected must be laid down at the discussion stage of the project:

- ⇒ If the system technology components are also situated on the roof, it is preferable to install the electrical cable on the exterior side of the structure.
- ⇒ If the system technology components are situated on the roof, and if it is intended to erect a central mast, the installation must be equipped with an isolated lightning protection system.
- ⇒ If the system technology components are located within the structure, it is preferable to have an isolated lightning protection embedment. Care must be taken that the cell site infrastructure is designed to be geometrically small so that the costs of the isolated lightning protection system are economically viable.

Experience has shown that, in many cases, existing lightning protection systems have old defects which adversely affect the effectiveness of the installation. These defects mean that even if the cell site is correctly "tied-in" to the external lightning protection system, damage can still be caused within the structure.

In order to enable a designer of mobile phone networks to erect antenna installations in accordance with the standards even in difficult situations, the only thing available to him used to be the isolated lightning protection system with horizontal distance holders. In such cases, however, the design of the antenna installation, could really not be considered architecturally aesthetic (**Figure 5.2.4.1**).

Fig. 5.2.4.1   Isolated air-termination system with distance holder
Fig. 5.2.4.2   Isolated air-termination system for cell sites –
              Application of DEHNconductor system

Air-termination systems as shown in **Figure 5.2.4.1** are not applicable for locations where the antennas have to be pleasing to look at.

The isolated HVI conductor is an innovative solution which provides the installer of lightning protection systems with novel possibilities for design and for easy maintaining of the separation distance (**Figure 5.2.4.2**).

5.2.4.1 Installation and performance of the isolated down-conductor system HVI

Basic conception of the isolated down-conductor system is to cover the lightning current carrying conductor with an insulating material, allowing the necessary separation distance s to other conductive parts of the structure, to electrical conductors and conduits to be kept. Incorrect proximities must be avoided. Basically the following requirements to the isolated down-conductor system have to be met, if insulating materials are used to avoid inadmissible proximities:

⇒ Possibility of a lightning current proof connection of the down-conductor system with the air-termination system (air-termination rod, air-termination conductor, air-termination tip, etc.) by terminals.

⇒ Compliance with the required separation distance s by sufficient dielectric strength of the down-conductor system in the range of the input point as well as in the course of the down-conductor system.

⇒ Sufficient current carrying capability because of an adequate cross section of the down-conductor system.

⇒ Possibility of connection to the earth-termination system or of equipotential bonding.

Sheathing of the down conductors with insulating materials of high dielectric strength basically allows to reduce the separation distance. Certain high voltage technological requirements, however, have to be met. This being necessary as the dielectric strength of the isolated down-conductor system depends on its positioning and on the occurrence of creeping discharges.

The use of unshielded, isolated down-conductor systems is a fundamental solution to be independent with regard to positioning and laying. A conductor, however, which has only a sheathing of insulating material does not solve the problem. Already relatively low induced impulse voltages will release creeping discharges in the range of the proximities (e.g. between metal, earthed conductor holders and the feeding point), which can result in a total flashover at the surface of long conductor sections. Ranges of insulating material, metal (at high voltage potential or earthed) getting in contact with the air are critical with regard to creeping discharges. This range is subject to a high voltage stressing because of the potential arising of creeping discharges, resulting in a considerably reduced voltage resistance. Creeping discharges have to be taken into account, whenever usual (vertical to the surface of the insulating material) components of electrical field strength E, lead to the tripping voltage of the creeping discharge being exceeded and, field components tangentially enforce the increase of creeping discharges (**Figure 5.2.4.1.1**).

The creeping discharge release-voltage determines the resistance of the whole insulation, being in the magnitude of 250 – 300 kV lightning impulse voltage.
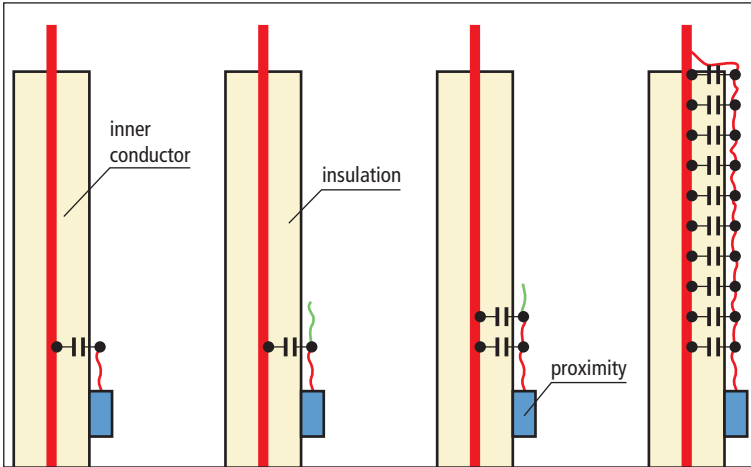
Fig. 5.2.4.1.1   Basic development of a creeping discharge at an isolated down conductor without special coating

By the coaxial single conductor cable – HVI conductor – shown in **Figure 5.2.4.1.2** the occurrence of the creeping discharge is avoided and the lightning current is safely conducted to the earth.
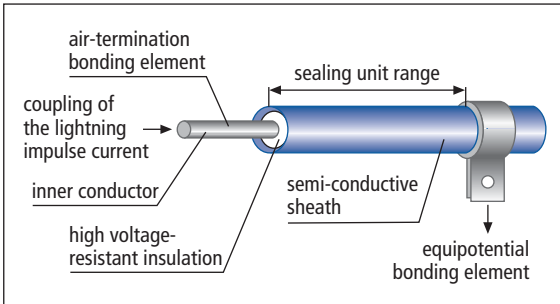
Fig. 5.2.4.1.2   Components of HVI Conductor
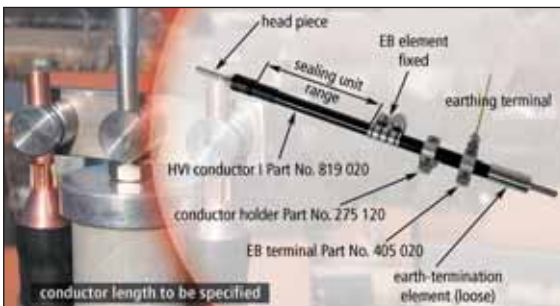
Fig. 5.2.4.1.3   HVI conductor I and components of the DEHNconductor system

Isolated down-conductor systems with field control and semi-conductive shield prevent from creeping discharges by a targeted influencing of the electric field in the range of the input point. They allow the lightning current to be conducted into the special cable, the safe discharge of the lightning current and the required separation distance s to be kept. The semi-conductive shield of the coaxial input cable insulates from the electric field. It has to be minded, however, that the magnetic field surrounding the current carrying inner conductor is not affected.

Optimisation of the field control allows an adjusted cable sealing unit length of 1.50 m to realise the required equivalent separation distance in air of s ≤ 0.75 m and in case of solid construction material of s ≤ 1.50 m (**Figure 5.2.4.1.3**).

This special cable sealing unit is realised by an adjusted connection element to the air-termination system (supply point) and the equipotential bonding terminal in a fixed distance. Compared with a coaxial cable with metal shield, the whole semi-conductive coating of the cable has a clearly higher resistance. Even by a multiple equipotential bonding connection of the cable coating only insignificant partial lightning currents will be dragged into the building.

Apart from the required separation distance s , the maximum conductor length L_{max} of such an isolated down-conductor system is calculated with

$$L_{\max} = \frac{k_m \cdot s}{k_i \cdot k_c}$$

5.2.4.2 Installation examples

Application for cell sites

Cell site installations are frequently erected on host structures. There is usually an agreement between the operator of the cell site installation and the owner of the structure that the erection of the cell site installation must not increase the risk
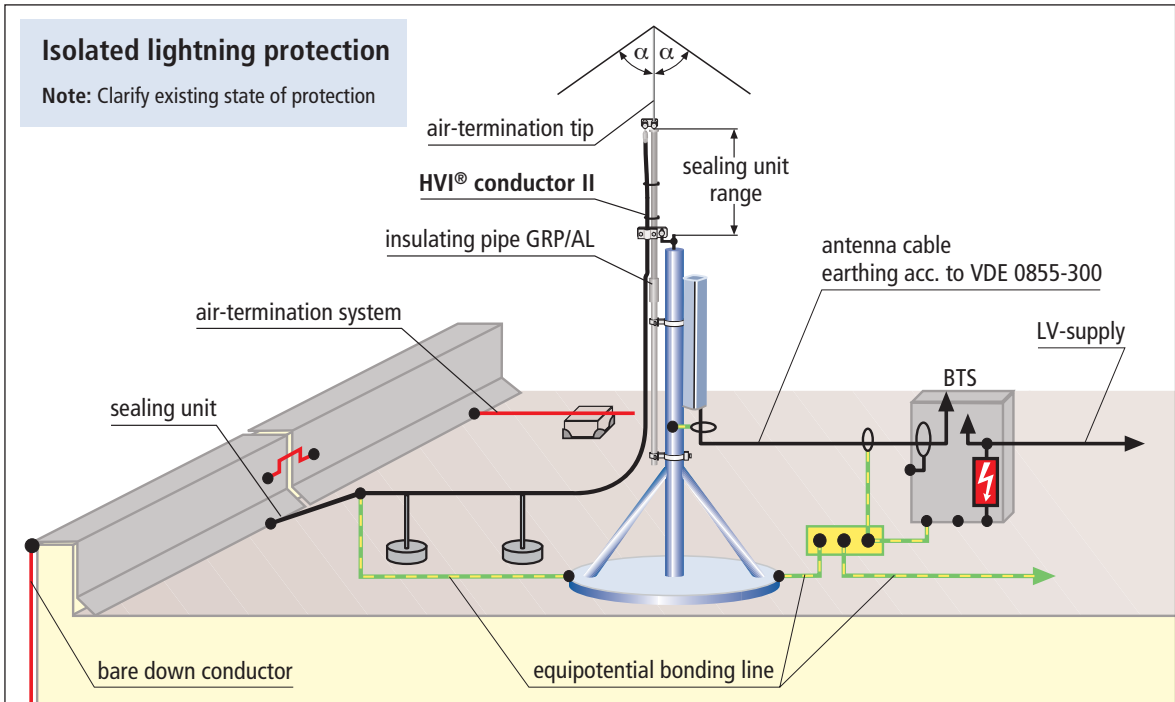
Fig. 5.2.4.2.1   Integration of a new 2G/3G antenna into the existing lightning protection system by using the HVI conductor

Isolated lightning protection

Note: Clarify existing state of protection

air-termination tip

HVI® conductor II

sealing unit range

insulating pipe GRP/AL

antenna cable earthing acc. to VDE 0855-300

air-termination system

LV-supply

BTS

sealing unit

bare down conductor

equipotential bonding line

to the structure. For protection against lightning, this particularly means that no partial lightning currents must enter the structure if there is a lightning strike to the frame structure. A partial lightning current within the structure would especially put the electrical and electronic apparatus at risk.

Figure 5.2.4.2.1 shows one possible solution for the "isolated air-termination system" on the frame structure of an antenna. The air-termination tip must be fixed to the frame structure of the antenna by means of an insulating pipe in non conductive material so that it is isolated. The height of the air-termination tip is governed by the requirement that the structure of the frame and any electrical devices which are part of the cell site installation (BTS – **B**ase **T**ransceiver **S**tation) must be arranged in the zone of protection of the air-termination tip.

Structures with several antenna systems must be equipped with multiple "isolated air-termination systems".

Figures 5.2.4.2.2a and **b** illustrate the installation on an antenna post.

air-termination tip

feeding point

insulating pipe

HVI® conductor

earth connection
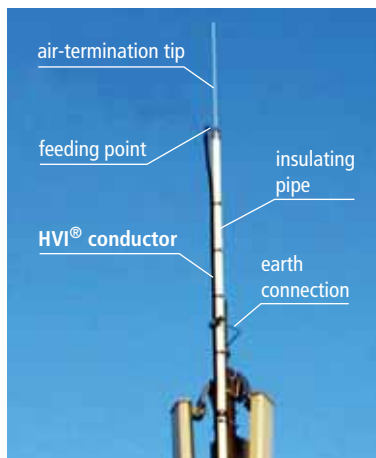
Fig. 5.2.4.2.2a Insulating pipe within the antenna area

HVI® conductor

insulating pipe

earthing clamp

earth connection feeding point
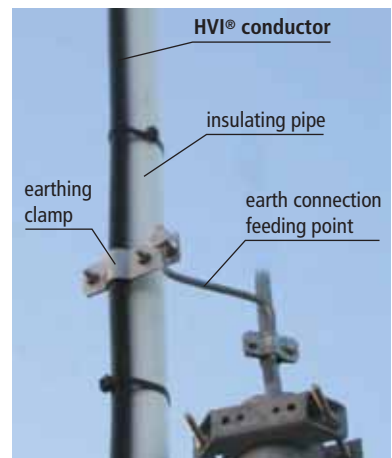
Fig. 5.2.4.2.2b Connection to the antenna frame structure for directing potential

Fig. 5.2.4.2.3a Fan with air-termination rod and spanned cable

Fig. 5.2.4.2.3b Air-termination rod, elevated ring conductor connected to the isolated down-conductor system
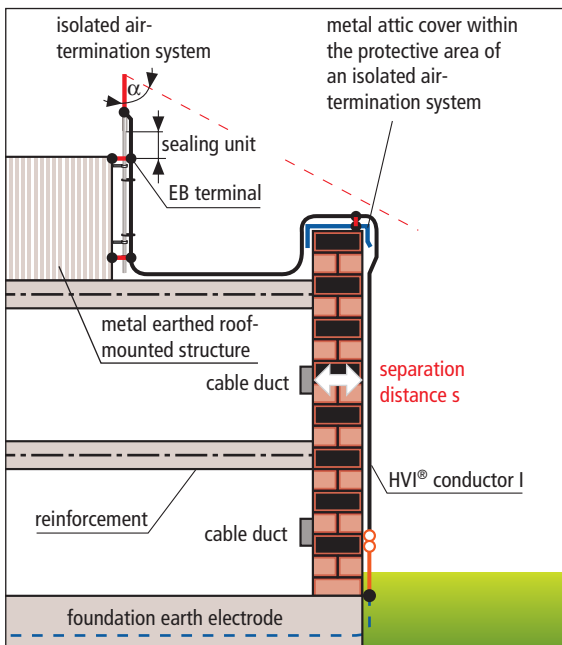
Fig. 5.2.4.2.4 Keeping the required separation distance with voltage-controlled isolated down conductor (HVI)

Roof-mounted structures

Metal and electrical roof-mounted structures protrude above roof level and are exposed points for lightning strikes. The risk of partial lightning currents flowing within the structure is also existing because of conductive connections with conduits and electrical conductors leading into the structure. To prevent this and to set up the necessary separation distance for the complete structure easily, the air-termination system must be installed with a terminal to the isolated down-conductor system, as shown in **Figure 5.2.4.2.3a** and **5.2.4.2.3b**.

Hence all metal and electrical roof-mounted structures protruding above roof level are within the area protected against lightning strikes. The lightning current will be "channeled" along the structure and distributed by the earth-termination system.

If several structures are mounted on the roof then, according to the basic illustration in **Figure 5.2.4.2.4**, several isolated air-termination systems must be installed. This must be done to ensure that all structures protruding above the roof must be arranged in an area protected from lightning strikes (lightning protection zone LPZ 0_B).

Down-conductor system

Especially problematical from the optical point of view often is the integration of a down-conductor system, taking into account the required separation distance s.

The HVI conductor e.g. can be installed or even integrated in the facade (**Figure 5.2.4.2.5**). This new kind of isolated down-conductor system con-
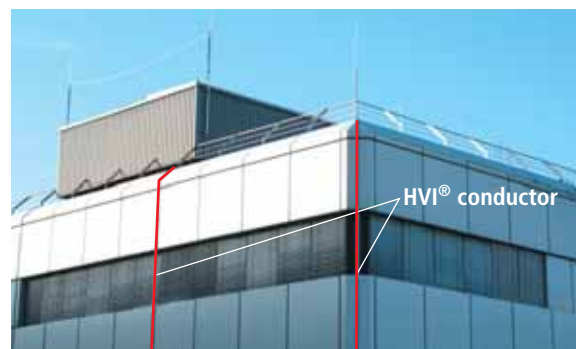
Fig. 5.2.4.2.5 Air termination system with spanned cable and isolated down-conductor system

tributes to an architectural more pleasing structure. Functionality and design can be an entity. Therefore this innovative technology is an important feature of modern architecture.

5.2.4.3 Project example: Training and residential building

Structure

The structure in **Figure 5.2.4.3.1** was built conventionally from the ground floor to the 6th floor. At a later date, the 7th floor was attached to the existing roof surface.

The external facade of the 7th floor consists of metal sheets.

The media centre is situated on the 3rd floor, the ground floor is used for administration. All other floors up to the 7th floor are used for apartments. The roof surface of the 6th and 7th floor was finished off with a metal attic whose components are interconnected so as to be non-conductive.

The complete structure is 25.80 m high (without attic) up to the roof level.

Subsequently, five antenna systems for mobile phone systems and microwaves were installed by different operators of mobile phone networks on the roof surface of the 7th floor. The antennas were erected both in the corners and in the middle of the roof surface.

The cable (coax cables) from the four antennas in the corners of the roof surface were installed in the vicinity of the attic to the south-west corner. From this point, the cables are led through a metal cable duct which is connected to the attic of the roof surfaces of the 7th and 6th floors to the BTS room on the 6th floor.

The cables from the antenna in the middle are also installed by means of a metal cable duct directly to the 2nd BTS room on the north-east side of the structure to the 6th floor. This cable duct is also connected to the surrounding attics.

The structure was equipped with a lightning protection system. The new installation of the external lightning protection system to protect against damage to the structure and life hazards was designed in accordance with the national lightning protection standard DIN V VDE V 0185-3, which was applicable when the building was erected.

During the installation of the antennas, the equipotential bonding and earthing measures of the system were carried out in accordance with German standard DIN VDE 0855 Part 300.

The earthing of the systems, however, was not isolated from the existing external lightning protection system at the earth-termination system at ground level, but directly at the air-termination system.

Hence, in the event of a lightning discharge, partial lightning currents are conducted directly into the structure via the coax cable shields. These partial lightning currents do not only present a life hazard, they also present a hazard to the existing technical equipment of the structure.

New concept

A lightning protection system was required, which prevents partial lightning currents from being conducted directly into the structure via the antenna components (frame structures, cable shields and installation systems). At the same time, the required separation distance s between the frame structures of the antennas and the air-termination system on the roof surface of the 7th floor must be realised.

This cannot be effected with a lightning protection system of a conventional design.
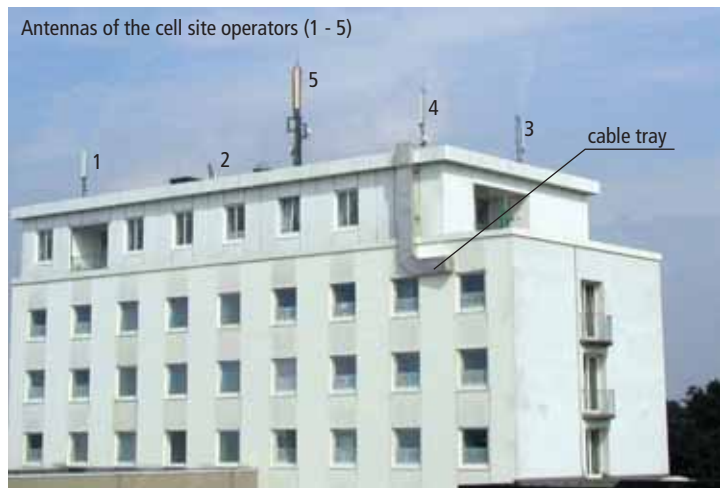
Fig. 5.2.4.3.1   Total view

By installing the HVI conductor, a lightning protection system was constructed with an isolated air-termination system. This required the following components:

⇒ Air-termination tips on insulating pipes in GRP material, secured directly to the antenna pole (**Figure 5.2.4.2.2a**).

⇒ Down conductor from the air-termination tip by means of an HVI conductor with connection to the isolated ring conductor (**Figure 5.2.4.3.2**).

⇒ Sealing end feeding point to ensure the resistance against creeping flashovers at the input (**Figures 5.2.4.2.2a** and **5.2.4.2.2b**).

⇒ Isolated ring conductor on insulating supports made of GRP, supports as high as according to the calculation of the required separation distance

⇒ Down conductors installed separately from the isolated ring conductor via the respective metal attics and metal facade to the bare metal down conductors on the 6th floor with the required separation distance s to the lower attic (**Figure 5.2.4.3.3**).

⇒ Supplementary ring conductor, all down-conductor systems interconnected at a height of approx. 15 m to reduce the required separation distance s of the interception and down-conductor system (**Figures 5.2.4.3.4** and **5.2.4.4.1**).

The various implementation stages explained in detail are summarised in **Figure 5.2.4.3.4**.
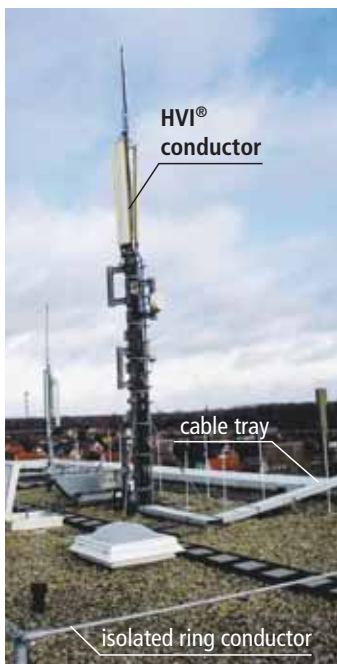
Fig. 5.2.4.3.2   Isolated air-termination system and isolated ring conductor
Ref.: H. Bartels GmbH, Oldenburg, Germany
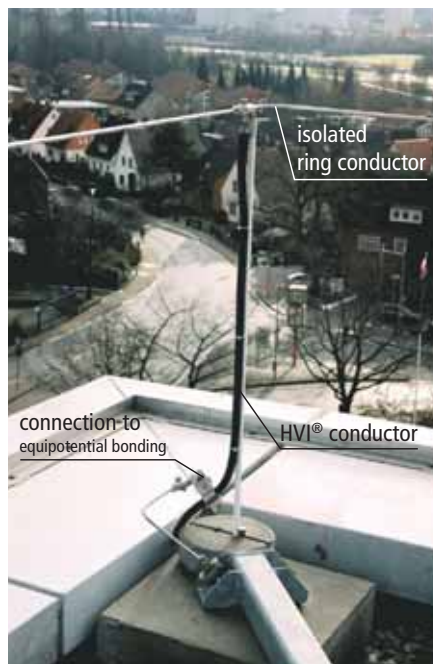
Fig. 5.2.4.3.3   Down conductor of isolated ring conductor

Fig. 5.2.4.3.4   Total view on a newly installed external lightning protection system

It is also important to note that the proposed design concept was discussed in detail with the system erector in order to avoid mistakes when carrying out the work.

When designing the external lightning protection system, care was taken that the deck on the 6th floor (**Figure 5.2.4.3.1**) and the lower attachments (**Figure 5.2.4.3.4**) were also arranged in the zone of protection/protective angle of the air-termination system.

5.2.4.4 Separation distance

When calculating the required separation distance s, not only the height of the structure but also the heights of the individual antennas with the isolated air-termination system had to be taken into consideration.

Each of the four corner antennas protrudes 3.6 m above the surface of the roof. The antenna in the middle protrudes 6.6 m above the roof surface.

Considering the height of the structure, result the following total heights to be taken into account when calculating the installation:

⇒ 4 corner antennas to the base of the air-termination tip + 29.40 m
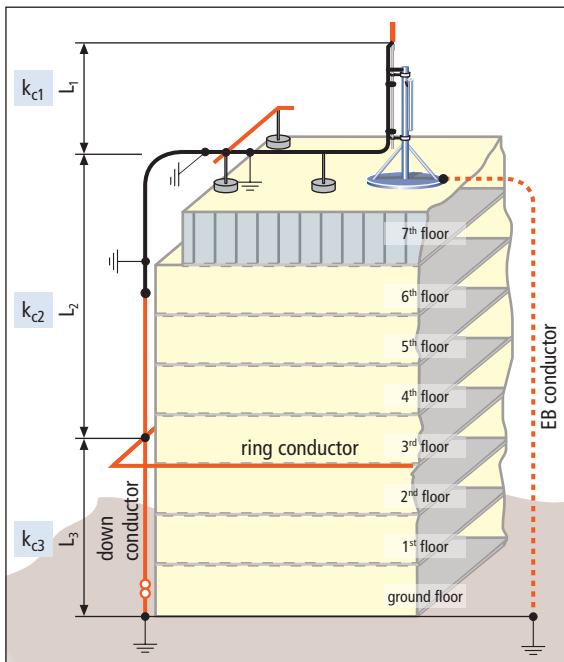
Fig. 5.2.4.4.1 Calculation of the required separation distance

⇒ 1 antenna in the middle of the roof surface to the base of the air-termination tip + 32.40 m

⇒ Three further, isolated separate air-termination rods on the west side of the roof surface and two isolated air-termination masts on the balcony 6th floor, south side, realise the zone of protection of the complete roof surface.

A special cable, DEHNconductor, Type HVI, was used as the isolated down conductor, allowing an equivalent separation distance of s = 0.75 m (air)/ 1.5 m (solid building materials) to be maintained.

The calculation of the required separation distances was done as shown in **Figure 5.2.4.4.1** for three partial areas:

1. Partial area at a level of + 32.4 m and a level of + 29.4 m (antennas) to + 27.3 m (isolated ring conductor) on the roof.

2. Partial area at + 27.3 m to + 15.0 m (isolated ring conductor on roof up to lower supplementary ring conductor).

3. Partial area at + 15.0 to ± 0 m (lower ring conductor to ground level).

The complete down-conductor system comprises six down conductors from the isolated ring conductor at a height of + 27.3 m to the supplementary ring conductor at a level of + 15.0 m. The ring conductor at a level of + 15.0 m is connected with the earthing ring conductor via the six down conductors of the residential structure and four further down conductors on attached parts of the structure.

This produces a different splitting of the current in the individual partial areas which had to be taken into consideration for the design of the lightning protection system.

The equipotential bonding required and the earthing of the antenna components on the roof surface (including the cable ducts, metal facades and the attics on both roof levels) was done using two supplementary earthing cables NYY 1 x 25 mm^2 connected to the equipotential bonding of the individual BTS stations.

The erection of this isolated air-termination system on the surface of the roof and on the antenna systems, as well as the isolated down conductors around metal parts of the structure, prevent partial lightning currents from entering the structure.

Material	Configuration	Min. cross-section mm²	Remarks[10]
Copper	solid flat material solid round material[7] cable solid round material[3, 4]	50[8] 50[8] 50[8] 200[8]	min. thickness 2 mm diameter 8 mm min. diameter each wire 1.7 mm diameter 16 mm
Tin plated copper[1]	solid flat material solid round material[7] cable	50[8] 50[8] 50[8]	min. thickness 2 mm diameter 8 mm min. diameter each wire 1.7 mm
Aluminium	solid flat material solid round material cable	70 50[8] 50[8]	min. thickness 3 mm diameter 8 mm min. diameter each wire 1.7 mm
Aluminium alloy	solid flat material solid round material cable solid round material[3]	50[8] 50 50[8] 200[8]	min. thickness 2.5 mm diameter 8 mm min. diameter each wire 1.7 mm diameter 16 mm
Hot dipped galvanised steel[2]	solid flat material solid round material[9] cable solid round material[3, 4, 9]	50[8] 50 50[8] 200[8]	min. thickness 2.5 mm diameter 8 mm min. diameter each wire 1.7 mm diameter 16 mm
Stainless steel[5]	solid flat material[6] solid round material[6] cable solid round material[3, 4]	50[8] 50 70[8] 200[8]	min. thickness 2 mm min. thickness 8 mm min. diameter each wire 1.7 mm diameter 16 mm

[1] Hot dipped or electroplated, minimum thickniss of the coating 1 μm.

[2] The coating should be smooth, continuous and free of residual flux, minimum thickness 50 μm.

[3] For air-termination rods. For applications where mechanical loads, like wind loads are not critical, a max. 1 m long air-termination rod with a diameter of 10 mm with an additional fixing may be used.

[4] For lead-in earth rods.

[5] Chromium ≥ 16 %, nickel ≥ 8 %, carbon ≤ 0.03 %

[6] For stainless steel in concrete and/or in direct contact with flammable material, the min. cross section for solid round material has to be increased to 78 mm² (10 mm diameter) and for solid flat material to 75 mm² (3 mm thickness).

[7] For certain applications where the mechnical strength is not important, 28 mm² (6 mm diameter) material may be used instead of 50 mm² (8 mm diameter). Then distance of the fixing elements has to be reduced.

[8] If thermal and mechanical requirements are important, the min. cross section for solid flat material can be increased to 60 mm² and for solid round material to 78 mm².

[9] At a specific energy of 10,000 kJ/Ω the min. cross section to prevent from melting is 16 mm² (copper), 25 mm² (aluminium), 50 mm² (steel) and 50 mm² (stainless steel). For further information see Annex E.

[10] Thickness, width and diameter are defined at a tolerance of ± 10 %.

Table 5.3.1   Material, configuration and min. cross sections of air-termination conductors, air-termination rods and down conductors according to IEC 62305-3 (EN 62305-3) Table 6
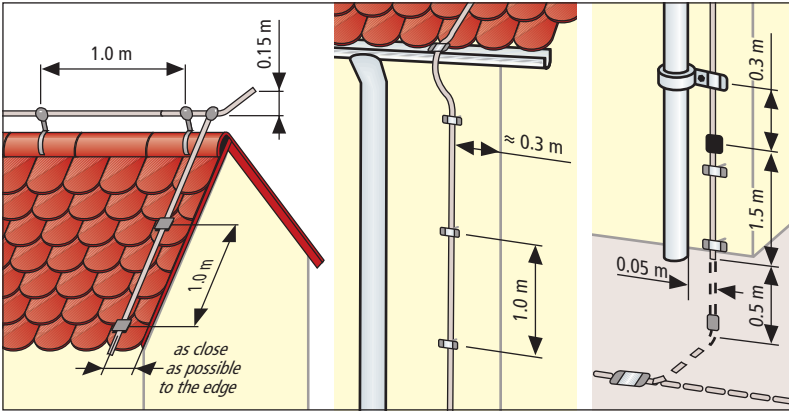
Fig. 5.4.1   Detail examples of an external lightning protection system at a building with a sloped tiled roof
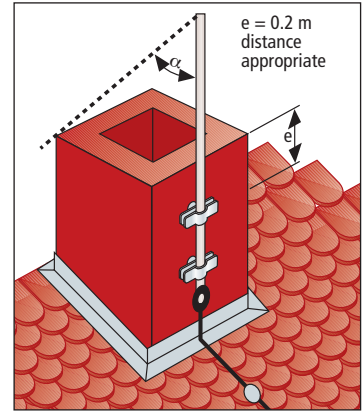
Fig. 5.4.2   Air-termination rod for chimneys

5.3 Materials and minimum dimensions for air-termination conductors and down conductors

Table 5.3.1 gives the minimum cross sections, form and material of air-termination systems.

This requirements arise from the electrical conductivity of the materials to carry lightning currents (temperature rise) and the mechanical stresses when in use.

When using a round conductor Ø 8 mm as an air-termination tip, the max. free height permitted is 0.5 m. The height limit for a round conductor Ø 10 mm is 1 m in free length.

Note:
According to IEC 62305-3 (EN 62305-3) Clause 1, Table 8, the minimum cross section for an interconnecting conductor between two equipotential bonding bars is 14 mm^2 Cu.
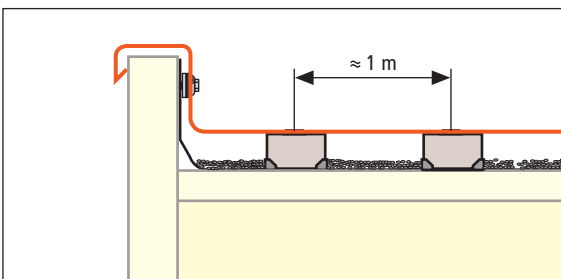
Fig. 5.4.3   Application on a flat roof

Tests with a PVC-insulated copper conductor and an impulse current of 100 kA (10/350 µs) determined a temperature rise of around 56 K. Thus, a cable NYY 1 x 16 mm^2 Cu can be used as a down conductor or as a surface and underground interconnecting cable, for example.

5.4 Assembly dimensions for air-termination and down-conductor systems

The following dimensions (**Figure 5.4.1**) have been tried and tested in practice and are primarily determined by the mechanical forces acting on the components of the external lightning protection system.
These mechanical forces arise not so much as a result of the electrodynamic forces generated by the lightning currents, but more as a result of the compression forces and the tensile forces, e.g. due to temperature-dependent changes in length, wind loads or the weight of snow.
The information concerning the max. distances of 1.2 m between the conductor holders primarily relates to St/tZn (relatively rigid). For using aluminium, distances of 1 m have become the standard in practice.
IEC 62305-3 (EN 62305-3) gives the following assembly dimensions for an external lightning protection system (**Figures 5.4.1** and **5.4.2**).

Figure 5.4.3 illustrates the application on a flat roof.

If possible, the separation distance to windows, doors and other openings should be maintained when installing down conductors.

Further important assembly dimensions are illustrated in **Figures 5.4.3 – 5.4.5**.

Installation of surface earth electrodes (e.g. ring earth electrodes) around the structure at a depth of > 0.5 m and a distance of approx. 1 m from the structure (**Figure 5.4.4**).

For the earth entries or terminals on the foundation earth electrode (ring earth electrodes), corrosion protection must be considered. Measures such as anticorrosive bands or wires with PVC sheath at a min. of 0.3 m above and below the turf (earth entry) must be employed (**Figure 5.4.5**) for protection.

An optically acceptable and noncorrosive connection possibility is provided by a stainless steel fixed earthing terminal set to be laid in concrete.

Moreover, there must also be corrosion protection for the terminal lug for equipotential bonding inside the building in damp and wet rooms.

The material combinations below (within air-termination systems, down conductors and with parts of the structure) have been tried and tested, provided that no particularly corrosive environmental conditions must be taken into consideration. These are values obtained from experience (**Table 5.4.1**).

Fig. 5.4.4   Dimensions for ring earth electrodes
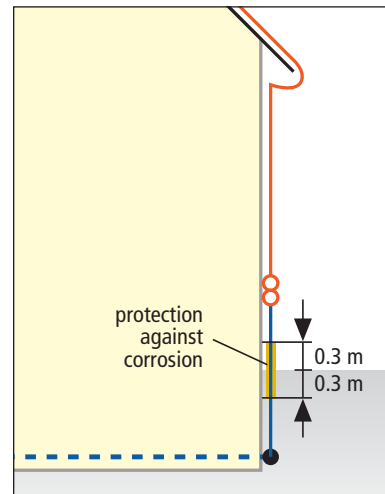
Fig. 5.4.5   Points threatened by corrosion

5.4.1 Change in length of metal wires

In practice, the temperature-dependent changes in length of air-termination and down conductors are often underestimated.

The older regulations and stipulations recommended an expansion piece about every 20 m as a general rule in many cases. This stipulation was based on the use of steel wires, which used to be the usual and sole material employed. The higher values for the coefficients of linear expansion of stainless steel, copper and especially aluminium materials were not taken into account.

In the course of the year, temperature changes of 100 K must be expected on and around the roof. The resulting changes in length for different metal wire materials are shown in **Table 5.4.1.1**. It is noticeable that, for steel and aluminium, the tem-

	Steel (tZn)	Aluminium	Copper	StSt	Titanium	Tin
Steel (tZn)	yes	yes	no	yes	yes	yes
Aluminium	yes	yes	no	yes	yes	yes
Copper	no	no	yes	yes	no	yes
StSt	yes	yes	yes	yes	yes	yes
Titanium	yes	yes	no	yes	yes	yes
Tin	yes	yes	yes	yes	yes	yes

Table 5.4.1   Material combinations

Material	Coefficient of linear expansion α $\dfrac{1}{10^6}\ \dfrac{1}{K}$	ΔL Calculation formula $\quad \Delta L = \alpha \cdot L \cdot \Delta T$ Assumed temperature change on the roof: $\Delta T = 100$ K
Steel	11.5	$\Delta L = 11.5 \cdot 10^{-6} \cdot 100\ cm \cdot 100 = 0.115\ cm \cdot 1.1\ mm/m$
StSt	16	$\Delta L = 16 \cdot 10^{-6} \cdot 100\ cm \cdot 100 = 0.16\ cm = 1.6\ mm/m$
Copper	17	$\Delta L = 17 \cdot 10^{-6} \cdot 100\ cm \cdot 100 = 0.17\ cm = 1.7\ mm/m$
Aluminium	23.5	$\Delta L = 23.5 \cdot 10^{-6} \cdot 100\ cm \cdot 100 = 0.235\ cm \cdot 2.3\ mm/m$

Table 5.4.1.1   Calculation of the temperature-related change in length ΔL of metal wires in lightning protection

Fig. 5.4.1.1   Air-termination system – Compensation of expansion with bridging braid

Material	Surface under the fixing of the air-termination system or down conductor		Distance of expansion pieces in m
	soft, e. g. flat roof with bitumen- or synthetic roof sheetings	hard, e. g. pantiles or brickwork	
Steel	X		≈ 15
		X	≤ 20
StSt/Copper	X		≈ 10
		X	≤ 15
Aluminium	X	X	≤ 10
Use of expansion pieces, if no other length compensation is provided			

Table 5.4.1.2   Expansion pieces in lightning protection – Recommended application

perature-dependent changes in length differ by a factor of 2.

The stipulations governing the use of expansion parts in practice are thus as shown in **Table 5.4.1.2**. When using pieces, care must be taken that they provide flexible length equalisation. It is not sufficient to bend the metal wires into an S shape since these "expansion pieces", handmade on site, are not sufficiently flexible.

When connecting air-termination systems, for example to metal attics surrounding the edges of roofs, care should be taken that there is a flexible connection to suitable components or measures. If this flexible connection is not made, there is a risk that the metal attic cover will be damaged by the temperature-dependent change in length.

To compensate for the temperature-dependent changes in length of the air-termination conductors, expansion pieces must be used to equalise the expansion (**Figure 5.4.1.1**).

5.4.2 External lightning protection system for an industrial structure and a residential house

Figure 5.4.2.1a illustrates the design of the external lightning protection system for a residential house with attached garage and **Figure 5.4.2.1b** that for an industrial structure.

Figures 5.4.2.1a and **5.4.2.1b** and **Tables 5.4.2.1a** and **b** show examples of the components in use today.

No account is taken of the measures required for an internal lightning protection system such as lightning equipotential bonding and surge protection (see also Chapter 6).

Particular attention is drawn to DEHN´s DEHNsnap and DEHNgrip programme of holders.

The DEHNsnap generation of synthetic holders (**Figure 5.4.2.2**) is suitable as a basic component
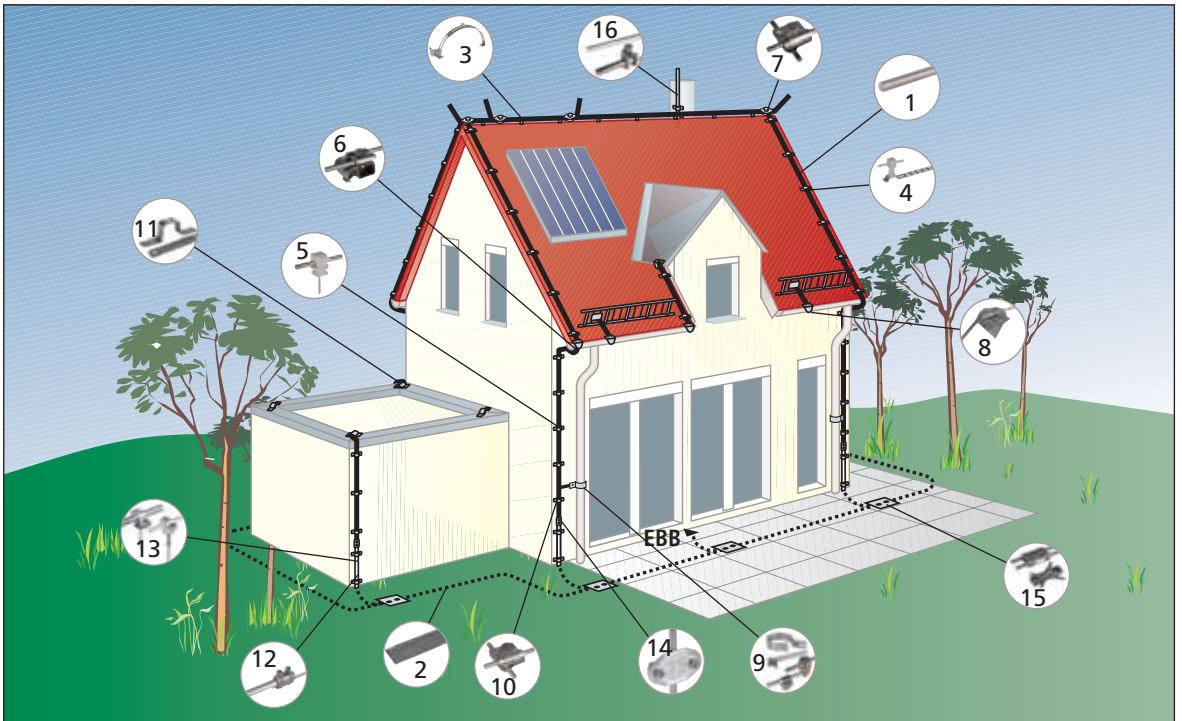
Fig. 5.4.2.1a External lightning protection of a residential building

Pos.	Part description		Part No.
1	Round conductor ø 8 mm - DEHNALU,		840 008
	medium hard soft- twistable		840 018
2	Steel strip 30 x 3.5 mm	St/tZn	810 335
	Round conductor ø 10 mm	StSt V4A	860 010
3	Roof conductor holders	St/tZn	202 020
	for ridge and hip tiles	StSt	204 109
		StSt	204 249
		StSt	204 269
		StSt	206 109
		StSt	206 239
4	Roof conductor holders	StSt	204 149
	for conductors within roof surfaces	StSt	204 179
		St/tZn	202 010
		St/tZn	202 050
		St/tZn	202 080
		StSt	206 209
		St/tZn	206 309
5	DEHNsnap		204 006
	DEHNgrip		207 009
	conductor holder with cleat and flange		275 160
	conductor holder for heat insulation		273 740
6	Gutter clamp for beads	St/tZn	339 050
		StSt	339 059
	Single-screw gutter clamp	St/tZn	339 100
		StSt	339 109

Pos.	Part description		Part No.
7	MV clamp	St/tZn	390 050
	MV clamp	StSt	390 059
8	Gutter board clamp	St/tZn	343 000
9	Downpipe clamp adjustable for ø 60 - 150 mm		423 020
	Downpipe clamp for any cross sections		423 200
	KS connector for connecting conductors		301 000
	KS connector	StSt	301 009
10	MV clamp		390 051
11	Bridging bracket	Aluminium	377 006
	Bridging braid	Aluminium	377 015
12	Lead-in earthing rod ø 16 mm		480 150
	complete		480 175
13	Rod holder with cleat and flange		275 260
	Rod holder for heat insulation		273 730
14	Number plate for marking isolating points		480 006
			480 005
15	Parallel connector		305 000
			306 020
	Cross unit		319 201
	SV clamps	St/tZn	308 220
	SV clamps	StSt	308 229
16	Air-termination rod with forged tab		100 075
	Air-termination rod with rounded ends		483 075
	Rod clamp		380 020

Table 5.4.2.1a Components for external lightning protection of a residential building
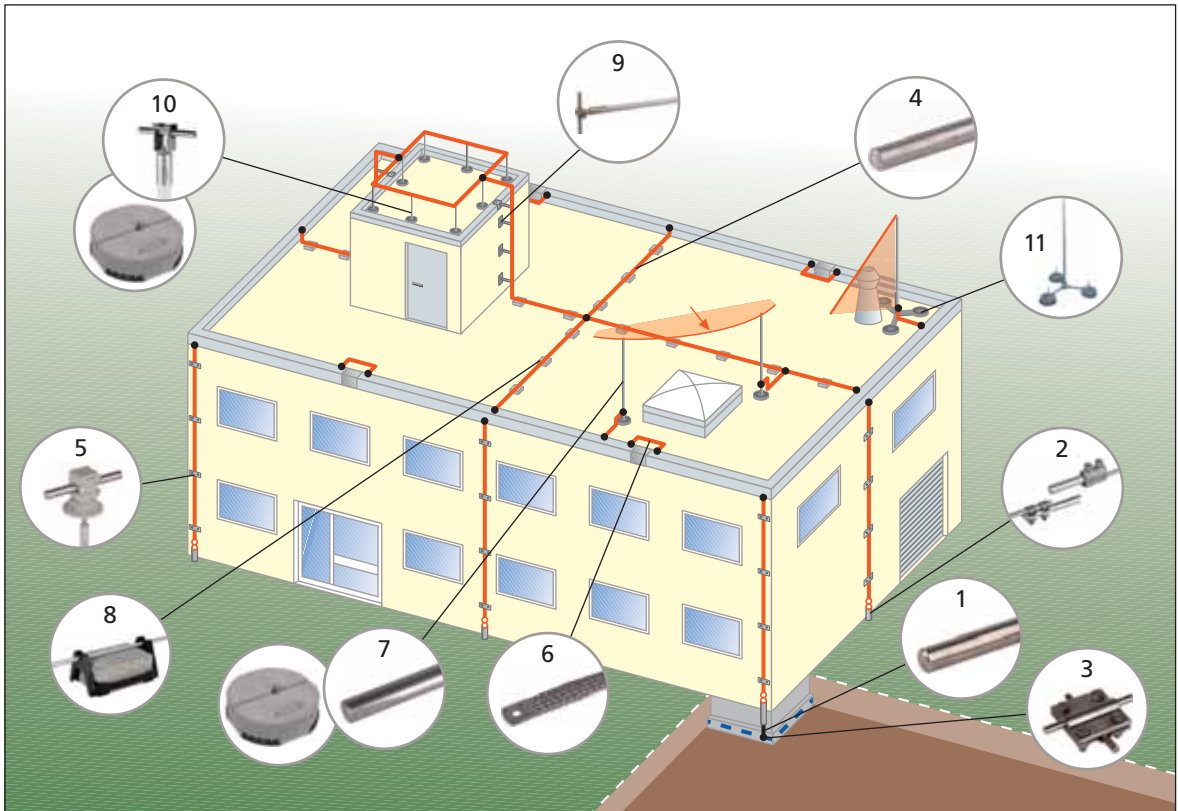
Fig. 5.4.2.1b   External lightning protection of an industrial structure

Pos.	Part description		Part No.
1	Stainless steel conductor ø 10 mm	StSt	860 010
2	Set of lead-in earthing rods	St/tZn	480 150
3	Cross unit	StSt	319 209
4	DEHNALU-DRAHT®	AlMgSi	840 008
5	Conductor holder DEHNsnap®		204 120
6	Bridging braid	Al	377 015
7	Air-termination rod	AlMgSi	104 200
	with concrete base with adapted flat washer		120 340

Pos.	Part description		Part No.
8	Roof conductor holder for flat roofs		253 050
9	DEHNiso distance holder	ZDC-St/tZn	106 100
10	Elevated ring conductor		
	with concrete base with adapted flat washer		102 340
	and distance holder	StSt	106 160
11	Isolated air-termination rod		105 500

Table 5.4.2.1b   Components for external lightning protection of a residential structure

(roof and wall). The cap simply snaps in to fix the conductor in the holder while still being loosely guided. The special snap-in technique exerts no mechanical load on the fastening.

DEHNgrip (**Figure 5.4.2.2**) is a stainless steel system of holders without screws which was put into the programme to supplement the DEHNsnap system of synthetic holders.

This system of holders without screws can also be used as both a roof and a wall conductor holder for Ø 8 mm conductors.

Simply press in the conductors and the conductor is fixed in DEHNgrip (**Figure 5.4.2.2**).

Conductor holder
DEHNsnap

cap

basic component

Conductor holder
DEHNgrip
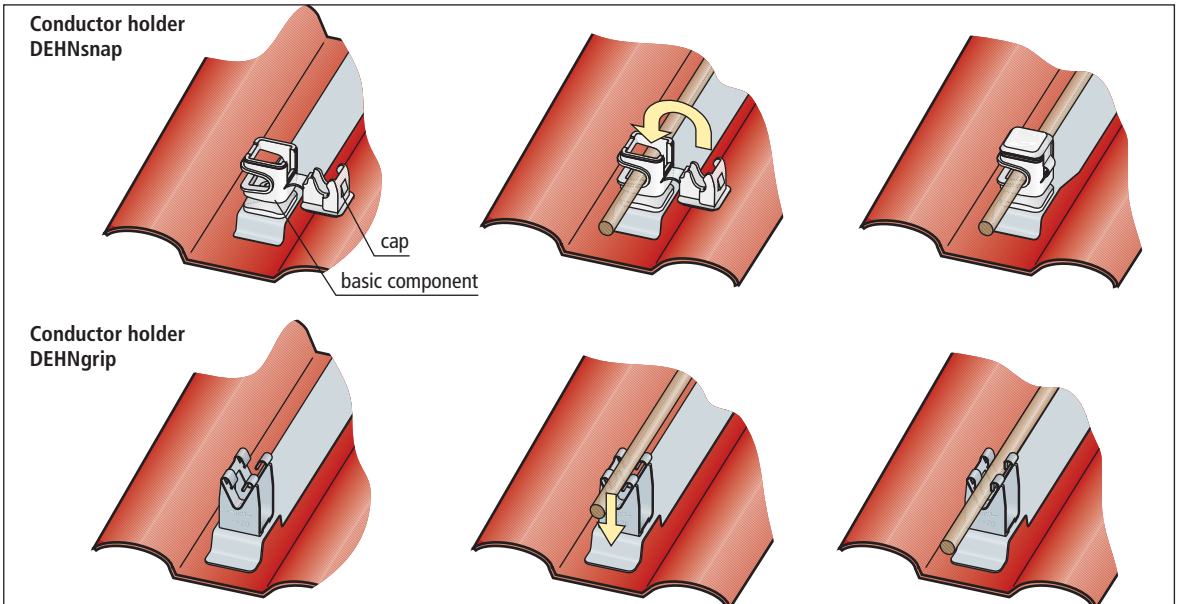
Fig. 5.4.2.2   DEHNsnap and DEHNgrip conductor holders

5.4.3 Application tips for mounting roof conductors holders

Ridge and hip tiles:

Adjust roof conductor holders with adjusting screw to suit the dimension of the ridge tile (**Figure 5.4.3.1**).

The conductor leading can, in addition, be gradually adjusted by means of conductor holders from the top centre to the bottom side.

(Conductor holder can be loosened by either turning the holder or opening the fixing screw.)

⇒ SPANNsnap roof conductor holder with DEHNsnap synthetic conductor holder or DEHNgrip stainless steel conductor holder (**Figure 5.4.3.2**).

Permanent tension due to stainless steel tension spring. Universal tension range from
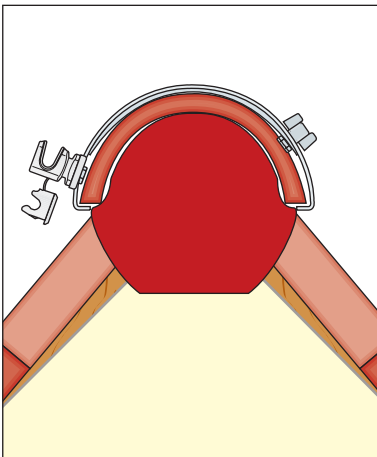
Fig. 5.4.3.1   Conductor holder with DEHNsnap for ridge tiles
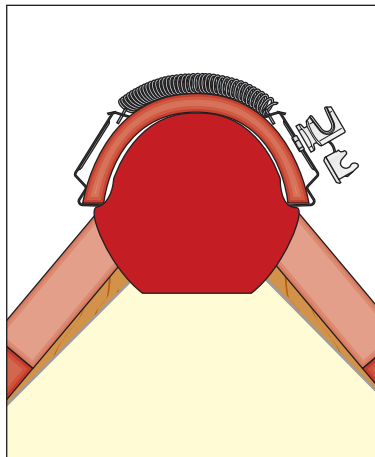
Fig. 5.4.3.2   SPANNsnap with plastic DEHNsnap conductor holder
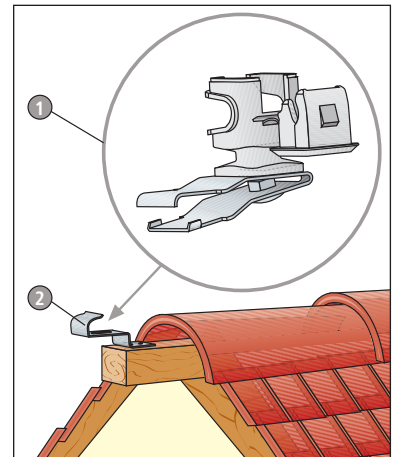
Fig. 5.4.3.3   FIRSTsnap for mounting on existing ridge clamp

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180 – 280 mm with laterally adjustable conductor leading for Rd 8 mm conductors.

⇒ FIRSTsnap conductor holder with DEHNsnap synthetic conductor holder for putting on existing ridge clamps for dry ridges.

For dry ridges, the DEHNsnap conductor holder **(1)** (**Figure 5.4.3.3**) is put on the ridge clamp already on the structure **(2)** and tightened manually (only turn DEHNsnap).

Grooved pantiles:
UNIsnap roof conductor holder with preformed struts is used for the roof surfaces. The conductor holder is bent by hand before being hooked into the battens. Additionally, it can also be secured with nails (**Figure 5.4.3.4**).

Smooth tiles (Figure 5.4.3.5)

Slate roofs:
When using it on slate roofs, the internal hook system is bent (**Figure 5.4.3.6**) or equipped with a supplementary clamp (Part No. 204 089).

Grooved tiles:
⇒ FLEXIsnap roof conductor holder for grooved tiles, for direct fitting on the groove (**Figure 5.4.3.7**).

The flexible stainless steel strut is pushed between the grooved tiles.
By pressing on the top grooved tile, the stainless steel strut is deformed and adapts itself to the shape of the groove.
Thus it is fixed tightly under the tile. This application with an aluminium strut makes it easy to adapt to the shape of the groove.
A notch is provided for an eventually existing window hook. The strut of the holder can also be nailed down (holes in the strut).

⇒ Roof conductor holders with preformed strut, for hooking into the bottom grove for pantile roofs (**Figure 5.4.3.8**).

Flat tiles or slabs:
DEHNsnap conductor holder **(1)** (**Figure 5.4.3.9**) and its clamping device **(2)** is pushed in between the flat tiles **(3)** (e.g. plain tile) or slabs and tightened manually (only turn DEHNsnap).

Overlapped constructions:
In case of overlapped constructions **(3)** (e.g. slabs and natural slates), DEHNsnap conductor holder **(1)** (**Figure 5.4.3.10**) with clamping terminals **(2)** is pushed on from the side and secured with a screw driver when the holder is open.
For slabs laid on a slat, DEHNsnap can also be turned to allow a plumb conductor leading.

angled by hand
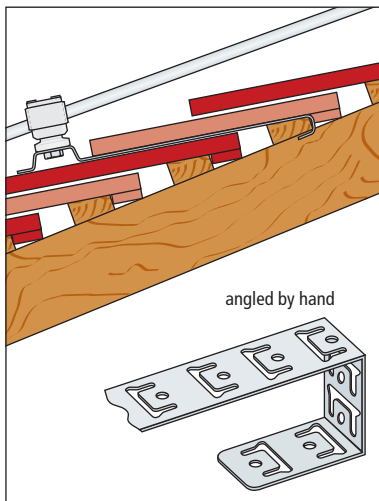
Fig. 5.4.3.4   UNIsnap roof conductor holder with preformed strut – Used on grooved pantiles
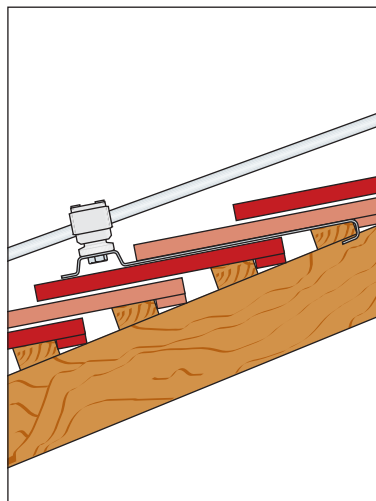
Fig. 5.4.3.5   UNIsnap roof conductor holder with preformed strut – Used on smooth tiles, e.g. plain tiles

angle the inner latching for use on slate roofs
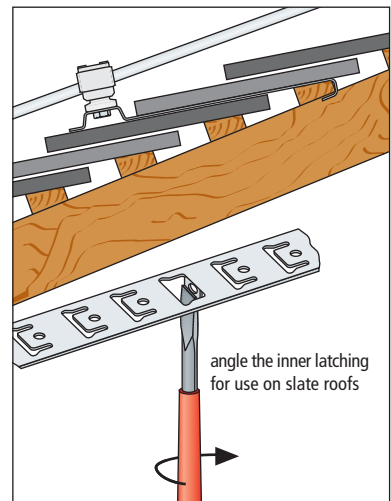
Fig. 5.4.3.6   UNIsnap roof conductor holder with preformed strut – Used on slate roofs
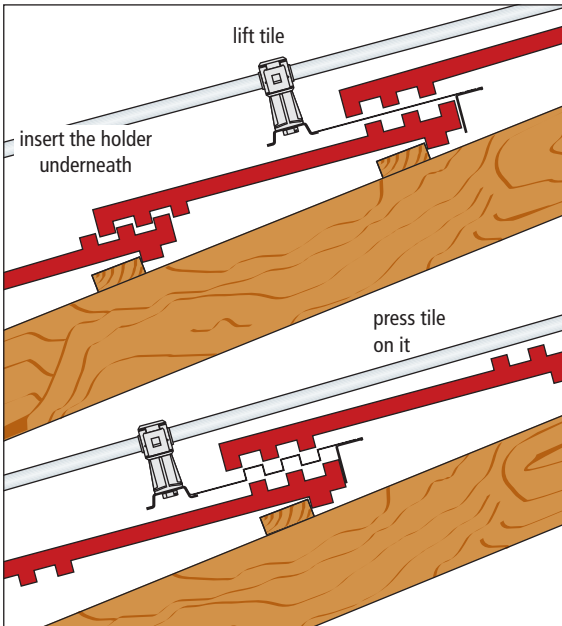
Fig. 5.4.3.7   Conductor holder for direct fitting on the seams
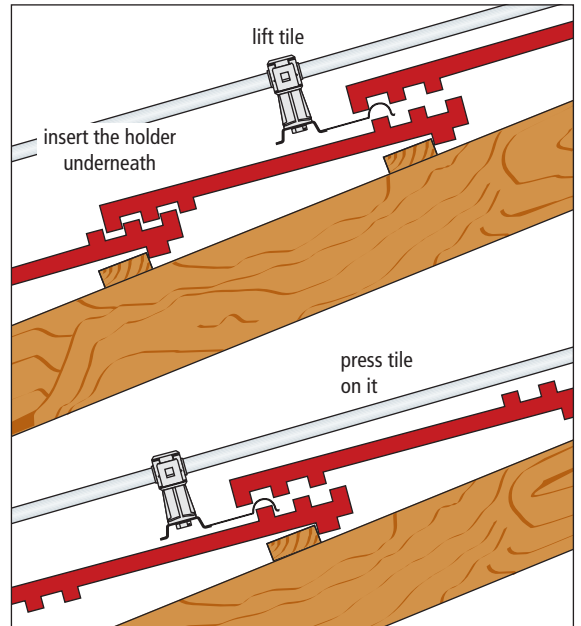
Fig. 5.4.3.8   Roof conductor holder for hanging into the bottom seam of pantile roofs
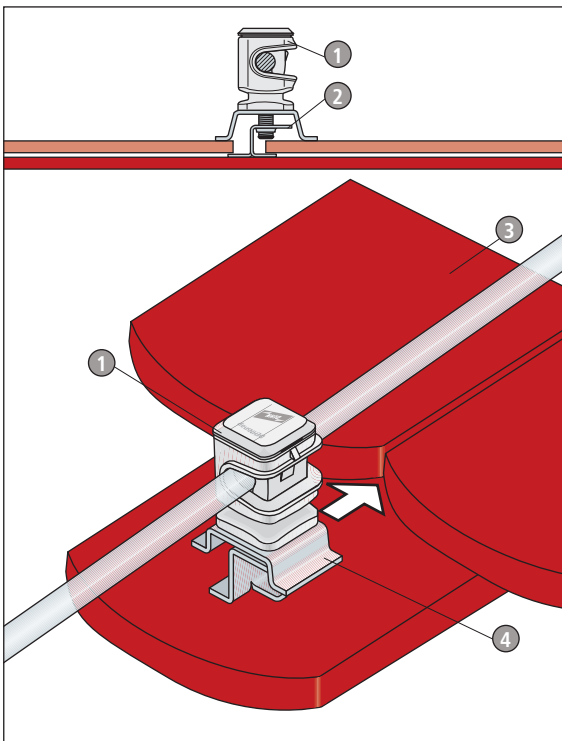
Fig. 5.4.3.9   ZIEGELsnap, for fixing between flat tiles or plates
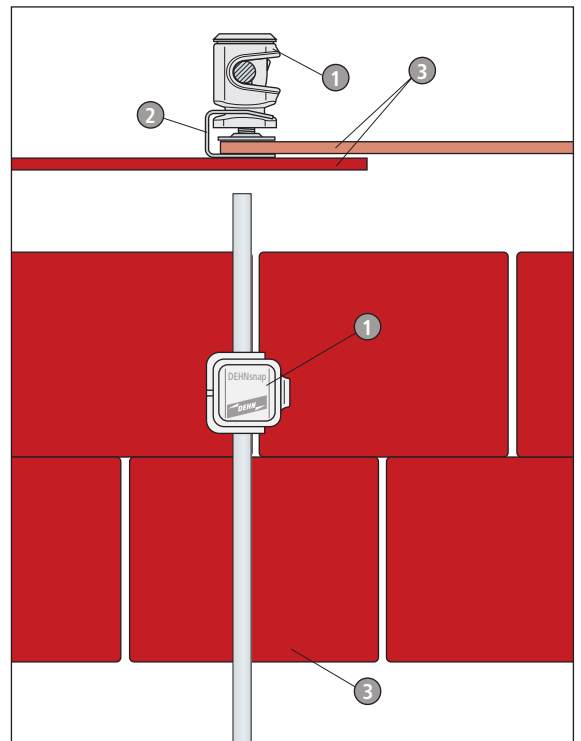
Fig. 5.4.3.10   PLATTENsnap roof conductor holder for overlapped construction

5.5 Earth-termination systems

A detailed explanation of the terms used in earth-termination technology is contained in IEC 62305-3 (EN 62305-3) "Lightning protection – physical damage to structures and life hazard", HD 637 S1 "Power installations exceeding 1 kV", IEC 60050-826 "International electrotechnical vocabulary Part 826: Electrical installations" and IEC 60364-5-54 "Electrical installations of buildings – Part 5-54". In Germany DIN 18014 is additionally applicable for foundation of earth electrodes. Below, we repeat only the terminology which is required to understand the following designs.

Terminology

Earth

is the conductive ground whose electrical potential at each point is set equal to zero as agreed. The word "earth" also the designation for both the earth as a place as well as earth as a material, e.g. the type of soil: humus, loam, sand, gravel and rock.

Reference earth

(neutral earth) is the part of the earth, especially the surface of the earth outside the sphere of influence of an earth electrode or an earth-termination system, in which, between two arbitrary points, no perceptible voltages arising from the earthing current occur (**Figure 5.5.1**).

Earth electrode

is a conductive component or several conductive components in electrical contact with the earth and forming an electrical connection with it (includes also foundation earth electrodes).

Earth-termination system

is a localised entirety of interconnected conductive earth electrodes or metal components acting as such, (e.g. reinforcements of concrete foundations, cable metal sheaths in contact with the earth, etc.).

U_E Earth potential
U_B Touch voltage
U_{B1} Touch voltage without potential control (at the foundation earth electrode)
U_{B2} Touch voltage with potential control (foundation and control earth electrode)
U_S Step voltage
φ Earth surface potential
FE   Foundation earth electrode
CE   Control earth electrode (ring earth electrode)
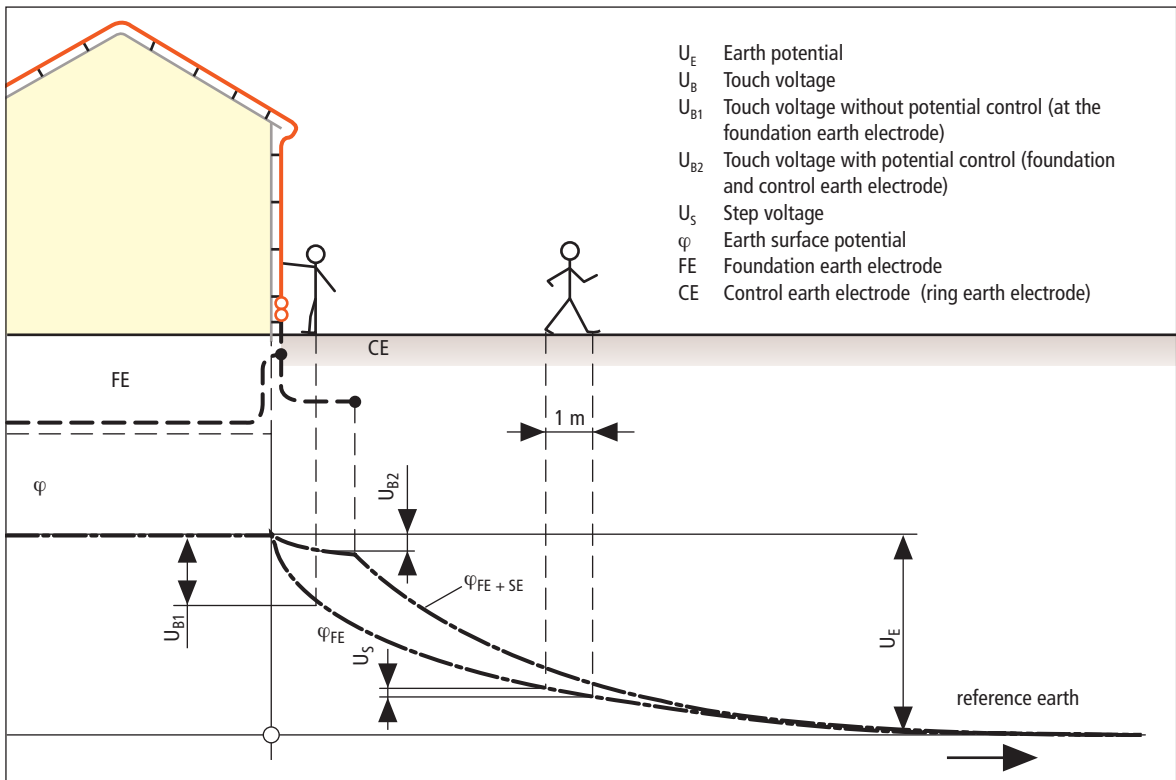
Fig. 5.5.1   Earth surface potential and voltages at a foundation earth electrode FE and control earth electrode CE flown through by currents

Earthing conductor

is a conductor connecting a system component to be earthed to an earth electrode and which is installed above the ground or insulated in the ground.

Lightning protection earthing

is the earthing installation of a lightning protection system to discharge lightning currents into the earth.

Below some types of earth electrodes and their classification are described according to location, form and profile.

Classification according to location

Surface earth electrode

is an earth electrode generally driven in at a shallow depth down to 1 m. It can consist of round material or flat strips and be designed as a star-type, ring or meshed earth electrode or a combination thereof.

Earth rod

is an earth rod generally driven in plumb down to greater depths. It can consist of round material or material with another profile, for example.

Foundation earth electrode

comprises one or more conductors embedded in concrete which is in contact with the earth over a wide area.

Control earth electrode

is an earth electrode whose form and arrangement serves more to control the potential than to maintain a certain earth electrode resistance.

Ring earth electrode

is an an earth electrode underneath or on the surface of the earth, leading as closed ring around the structure.

Natural earth electrode

is a metal component in contact with the earth or with water either directly or via concrete, whose original function is not as an earth electrode but which acts as an earth electrode (reinforcements of concrete foundations, conduits, etc.).

Classification according to form and profile

One distinguishes between:
flat strip earth electrodes, cruciform earth electrodes and earth rods.

Types of resistance

Specific earth resistance

ρ_E is the specific electrical resistance of the earth. It is given in Ωm and represents the resistance between two opposite sides of a cube of earth with edges of 1 m in length.

Earth electrode resistance

R_A of an earth electrode is the resistance of the earth between the earth electrode and reference earth. R_A is practically a resistance.

Impulse earth resistance

R_{st} is the resistance as lightning currents traverse from one point of an earth-termination system to the reference earth.

Voltages at current carrying earth-termination systems, control of potential

Earth potential

U_E is the voltage arising between an earth-termination system and reference earth (**Figure 5.5.1**).

Potential of the earth´s surface

φ is the voltage between one point of the earth´s surface and reference earth (**Figure 5.5.1**).

Touch voltage

U_B is the part of the potential of the earth´s surface which can be bridged by humans (**Figure 5.5.1**), the current path via the human body running from hand to foot (horizontal distance from touchable part around 1 m) or from one hand to the other.

Step voltage

U_S is the part of the potential of the earth´s surface which can be bridged by humans taking one step 1 m long, the current path via the human body running from one foot to the other (**Figure 5.5.1**).

Potential control

is the effect of the earth electrodes on the earth potential, particularly the potential of the earth´s surface (**Figure 5.5.1**).

Equipotential bonding

for lightning protection system is the connection of metal installations and electrical systems to the lightning protection system via conductors, lightning current arresters or isolating spark gaps.

Earth electrode resistance / Specific earth resistance

Earth electrode resistance R_A

The conduction of the lightning current via the earth electrode into the ground does not happen at one point but rather energises a particular area around the earth electrode.

The type of earth electrode and the way it is installed must now be chosen to ensure that the voltages affecting the surface of the earth (touch and step voltages) do not assume hazardous values.

The earth electrode resistance R_A of an earth electrode can best be explained with the help of a metal sphere buried in the ground.

If the sphere is buried deep enough, the current discharges radially to be equally distributed over the surface of the sphere. **Figure 5.5.2a** illustrates this case; as a comparison, **Figure 5.5.2b** illustrates the case of a sphere buried just under the earth´s surface.

The concentric circles around the surface of the sphere represent surface of equal voltage. The earth electrode resistance R_A is composed of the partial resistances of individual layers of the sphere connected in series. The resistance of such a layer of the sphere is calculated using

$$R = \rho_E \cdot \frac{l}{q}$$

where ρ_E is the specific earth resistance of the ground, assuming it is homogeneous,

l   the thickness of an imaginary layer of the sphere

    and

q   the medial surface of this layer of the sphere.

To illustrate this, we assume a metal sphere 20 cm in diameter buried at a depth of 3 m at a specific earth resistance of 200 Ωm.
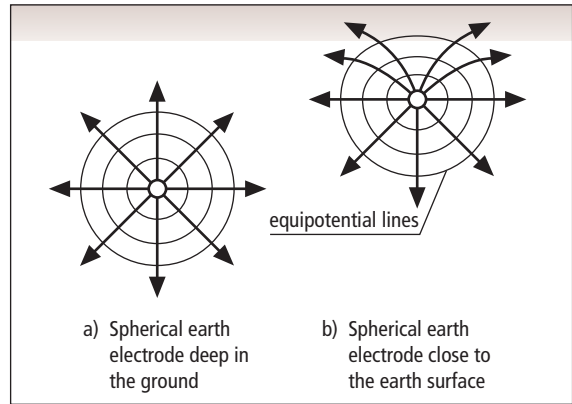
Fig. 5.5.2   Current distribution from the spherical earth electrode

a) Spherical earth electrode deep in the ground

b) Spherical earth electrode close to the earth surface

If now the increase in earth electrode resistance for the different layers of the sphere is calculated, then as a function of the distance from the centre of the sphere, a curve as shown in **Figure 5.5.3**. is obtained.

The earth electrode resistance R_A for the spherical electrode is calculated using:

$$R_A = \frac{\rho_E \cdot 100}{2\pi \cdot r_K} \cdot \frac{1 + \frac{r_K}{2t}}{2}$$

ρ_E Specific earth resistance in Ωm
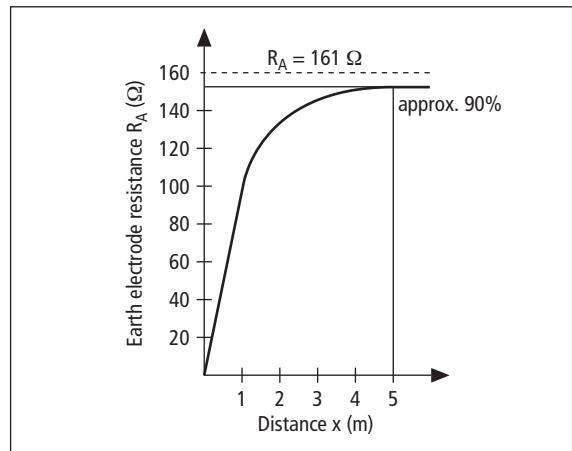
Fig. 5.5.3   Earth electrode resistance R_A of a spherical earth electrode with Ø 20 cm, 3 m deep, at ρ_E = 200 Ωm as a function of the distance x from the centre of the sphere
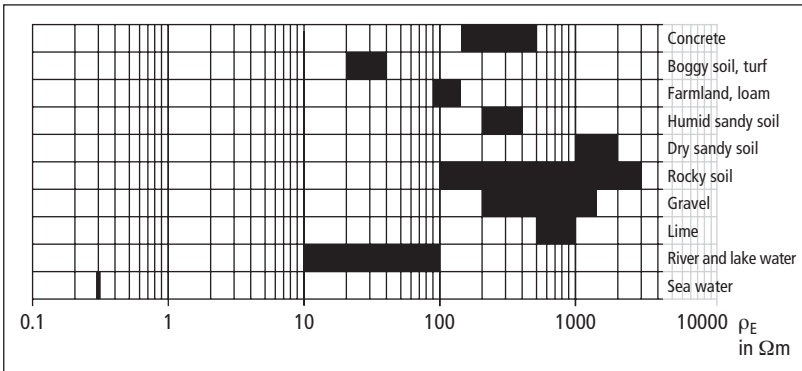
Fig. 5.5.4   Specific earth resistance ρ_E of different ground types

t   Burial depth in cm

r_K Radius of the spherical earth electrode in cm

This formula gives a earth electrode resistance of $R_A = 161\ \Omega$ for the spherical earth electrode.

The trace of the curve in **Figure 5.5.3** shows that the largest fraction of the total earth electrode resistance occurs in the immediate vicinity of the earth electrode. Thus, for example, at a distance of 5 m from the centre of the sphere, 90 % of the total earth electrode resistance R_A has already been achieved.

Specific earth resistance ρ_E
The specific earth resistance ρ_E which determines the magnitude of the earth electrode resistance R_A of an earth electrode, is a function of the composi-

tion of the soil, the amount of moisture in the soil and the temperature. It can fluctuate between wide limits.

Values for various types of soil
Figure 5.5.4 gives the fluctuation ranges of the specific earth resistance ρ_E for various types of soil.

Seasonal fluctuations
Extensive measurements (literature) have shown that the specific earth resistance varies greatly according to the burial depth of the earth electrode. Owing to the negative temperature coefficient of the ground (α = 0.02 ... 0.004), the specific earth resistance attain a maximum in winter and a minimum in summer. It is therefore advisable to convert the measured values obtained from earth electrodes to the maximum prospective values, since even under unfavourable conditions (very low temperatures), permissible values must not be exceeded. The curve of the specific earth resistance ρ_E as a function of the season (ground temperature) can be represented to a very good approximation by a sinus curve having its maximum around the middle of February and its minimum around the middle of August. Investigations have further shown that, for earth electrodes buried not deeper than around 1.5 m, the maximum deviation of the specific earth resistance from the average is around ± 30 % (**Figure 5.5.5**).
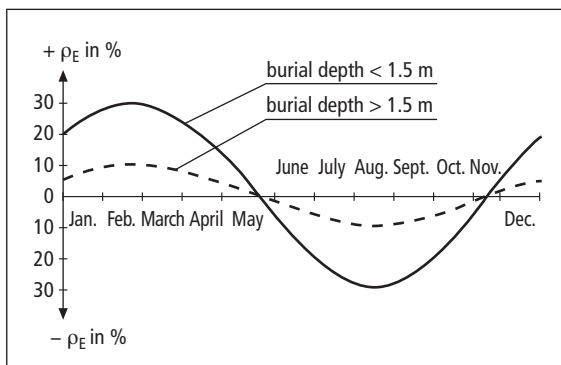
Fig. 5.5.5   Specific earth resistance ρ_E as a function of the seasons without influencing of rainfall (burial depth of the earth electrode < 1.5 m)
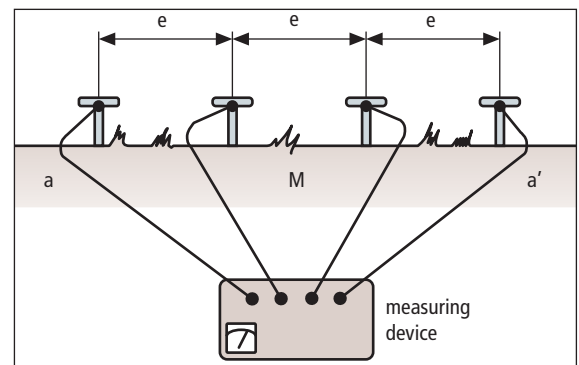
Fig. 5.5.6   Determination of the specific earth resistance ρ_E with a four-terminal measuring bridge acc. to the WENNER method

For earth electrodes buried deeper (particularly for earth rods), the fluctuation is merely ± 10 %. From the sineshaped curve of the specific earth resistance in **Figure 5.5.5**, the earthing electrode resistance R_A of an earth-termination system measured on a particular day can be converted to the maximum prospective value.

Measurement

The specific earth resistance ρ_E is determined using an earthing measuring bridge with 4 clamps which operates according to the null method.

Figure 5.5.6 illustrates the measuring arrangement of this measuring method named after WENNER. The measurement is carried out from a fixed central point M which is retained for all subsequent measurements. Four measuring probes (earthing spikes 30 ... 50 cm long) are driven into the soil along a line a – a' pegged out in the ground. From the measured resistance R one can determine the specific earth resistance ρ_E of the ground:

$$\rho_E = 2\pi \cdot e \cdot R$$

R   measured resistance in Ω

e   probe distance in m

ρ_E average specific earth resistance in Ωm down to a depth corresponding to the probe distance e

By increasing the probe distance e and re-tuning the earthing measuring bridge, the curve of the

Earth electrode	Rough estimate	Auxiliary
Surface earth electrode (star-type earth electrode)	$R_A = \dfrac{2 \cdot \rho_E}{l}$	–
Earth rod	$R_A = \dfrac{\rho_E}{l}$	–
Ring earth electrode	$R_A = \dfrac{2 \cdot \rho_E}{3 \cdot d}$	$d = 1.13 \cdot \sqrt[2]{A}$
Meshed earth electrode	$R_A = \dfrac{\rho_E}{2 \cdot d}$	$d = 1.13 \cdot \sqrt[2]{A}$
Earth plate	$R_A = \dfrac{\rho_E}{4.5 \cdot a}$	–
Hemispherical earth electrode	$R_A = \dfrac{\rho_E}{\pi \cdot d}$	$d = 1.57 \cdot \sqrt[3]{V}$

R_A Earth electrode resistance (Ω)

ρ_E Specific earth resistance (Ωm)

l   Length of earth electrode (m)

d   Diameter of a ring earth electrode, of the area of the equivalent circuit or of a hemispherical earth electrode (m)

A   Area (m²) of the enclosed area of a ring or meshed earth electrode

a   Edge length (m) of a square earth plate, for rectangular plates value: $\sqrt{b \cdot c}$, while b and c are the two sides of the rectangle

V   Content (m³) of a single foundation element

Table 5.5.1   Formulae for calculating the earth electrode resistance R_A for different earth electrodes
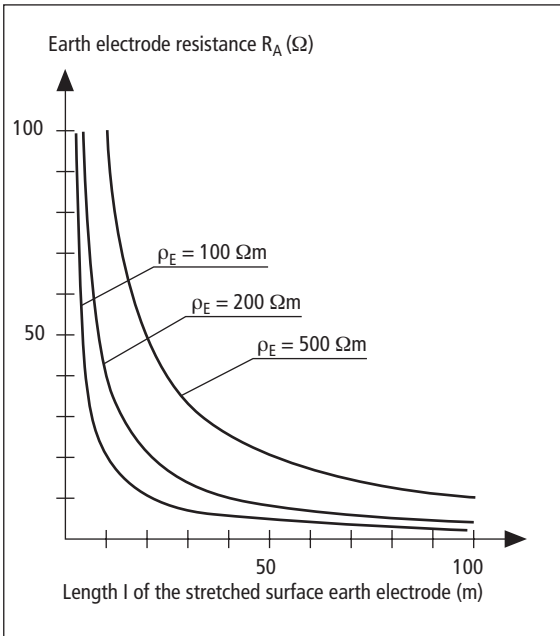
Fig. 5.5.7   Earth electrode resistance R_A as a function of length I of the surface earth electrode at different specific earth resistance ρ_E

Fig. 5.5.8   Earth potential U_E between supply conductor and earth surface as a function of the distance from the earth electrode, at an earth strip (8 m long) in different depths

Fig. 5.5.9   Max. step voltage U_S as a function of the burial depth for a stretched earth strip

specific earth resistance can be determined ρ_E as a function of the depth.

Calculation of earth electrode resistances

Table 5.5.1 gives the formulae for calculating the earth electrode resistances of the most common types of earth electrode. In practice, these approximate formulae are quite sufficient. The precise formulae for the calculations must be taken from the following sections.

Straight surface earth electrode

Surface earth electrodes are generally embedded horizontally in the ground at a depth of 0.5 ... 1 m. Since the layer of soil covering the earth electrode dries out in summer and freezes in winter, the earth electrode resistance R_A of such a surface earth electrode is calculated as if it lays on the surface of the ground:

$$R_A = \frac{\rho_E}{\pi \cdot l} \cdot \ln \frac{l}{r}$$

R_A Earth electrode resistance of a stretched surface earth electrode in Ω

ρ_E Specific earth resistance in Ωm

I   Length of the surface earth electrode in m

r   Quarter width of steel strip in m or diameter of the round wire in m

The earth electrode resistance R_A as a function of the length of the earth electrode can be taken from **Figure 5.5.7**.

Figure 5.5.8 shows the transverse and longitudinal earthing potential U_E for an 8 m long flat strip earth electrode.
The effect of the burial depth on the earthing potential can be clearly seen.

Figure 5.5.9 illustrates the step voltage U_S as a function of the burial depth.

In practice, the calculation is done using the approximate formula in **Table 5.5.1**:

$$R_A = \frac{2 \cdot \rho_E}{l}$$

Earth rod
The earth electrode resistance R_A of a earth rod is calculated using:

$$R_A = \frac{\rho_E}{2\pi \cdot l} \cdot \ln \frac{l}{r}$$

R_A earth electrode resistance in Ω

ρ_E Specific earth resistance in Ωm

l Length of the earth rod in m

r Radius of the earth rod in m

As an approximation, the earth electrode resistance R_A can be calculated using the approximate formula given in **Table 5.5.1**:

$$R_A = \frac{\rho_E}{l}$$

Figure 5.5.10 shows the earth electrode resistance R_A as a function of the rod length l and the specific earth resistance ρ_E.

Combination of earth electrodes
If the soil conditions require several earth rods, the driving down depth of the earth rods is applicable for the corresponding minimum distance of the different earth rods which have to be interconnected.
The earth electrode resistance calculated using the formulae and the measurement results given in the diagrams apply to low frequency d.c. current

and a.c. current provided that the expansion of the earth electrode is relatively small (a few hundred metres). For longer lengths, e.g. for surface earth electrodes, the a.c. current also has an inductive part.
Furthermore, the calculated earth electrode resistances do not apply to lightning currents. This is where the inductive part plays a role, which can lead to higher values of the impulse earthing resistance for larger expansion of the earth-termination system.
Increasing the length of the surface earth electrodes or earth rods above 30 m reduces the impulse earth electrode resistance by only an insignificant amount. It is therefore expedient to combine several shorter earth electrodes. In such cases, because of their interaction, care must be taken that the actual total earth electrode resistance is greater than the value calculated from the individual resistances connected in parallel.

Star-type earth electrodes
Star-type earth electrodes in the form of cruciform surface earth electrodes are important when relatively low earth electrode resistances shall be created in poorly conducting ground at an affordable price.
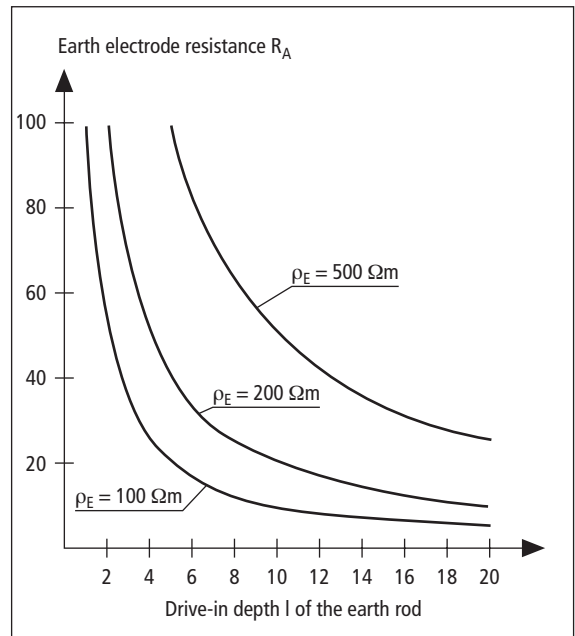
Fig. 5.5.10   Earth electrode resistance R_A of earth rods as a function of their length l at different specific earth resistances ρ_E
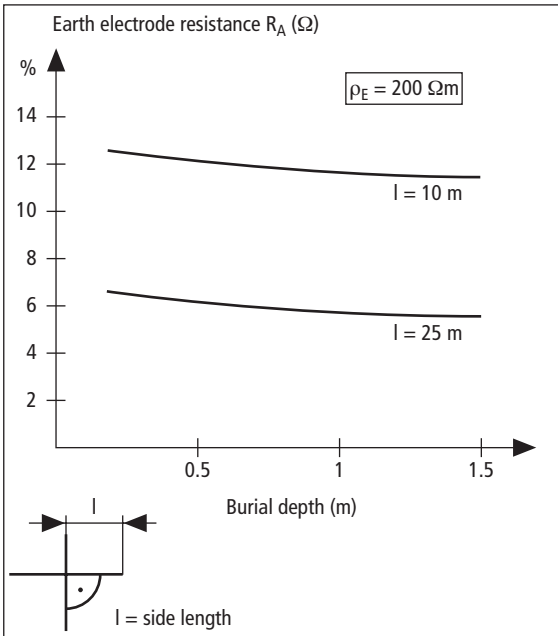
Fig. 5.5.11 Earth electrode resistance R_A of crossed surface earth electrode (90 °) as a function of the burial depth

Fig. 5.5.12 Earth potential U_E between the supply conductor of the earth electrode and earth surface of crossed surface earth electrode (90 °) as a function of the distance from the cross centre point (burial depth 0.5 m)

The earth electrode resistance R_A of a cruciform surface earth electrode whose sides are at 90 ° to each other is calculated using:

$$R_A = \frac{\rho_E}{4\pi \cdot l} \cdot \ln \frac{l}{r} + 1.75$$

R_A Earth electrode resistance of the cruciform surface earth electrode in Ω

ρ_E Specific earth resistance in Ωm

l Side length in m

d Half a bandwidth in m or diameter of the round wire in m

As a rough approximation, for longer lengths of the star arrangement ($l > 10$ m), the earth electrode resistance R_A can be determined using the total length of the star obtained from the equations in **Table 5.5.1**.

Figure 5.5.11 shows the curve of the earth electrode resistance R_A of cruciform surface earth electrodes as a function of the burial depth;

Figure 5.5.12 shows the curve of the earthing voltage.

For star-type earth electrodes, the angle between the individual arms should be greater than 60 °.
According to **Figure 5.5.12** the earth electrode resistance of a meshed earth electrode is given by the formula:

$$R_A = \frac{\rho_E}{2 \cdot d}$$

Where d is the diameter of the analogous circle having the same area as the meshed earth electrode, which is determined as follows:
For rectangular or polygonal dimensions of the meshed earth electrode:

$$d = \sqrt{\frac{4 \cdot A}{\pi}}$$

A Area of the meshed earth electrode
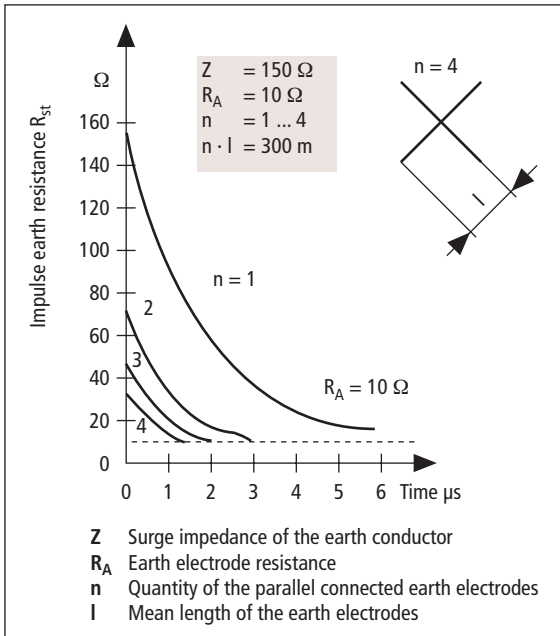
Fig. 5.5.13   Impulse earth resistance R_{st} of single or multiple star-type earth electrodes with equal length
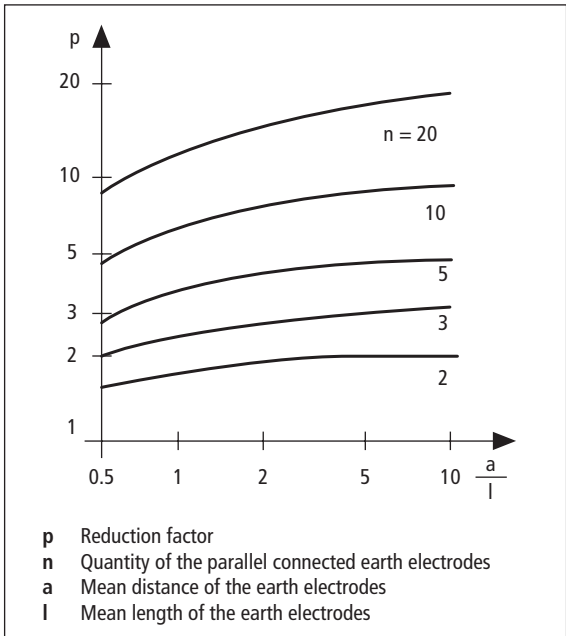
Fig. 5.5.14   Reduction factor p for calculating the total earth electrode resistance R_A of earth rods connected in parallel

For square dimensions (edge length b):

$$d = 1.1 \cdot b$$

Figure 5.5.13 illustrates the curve of the impulse earth electrode resistance of surface earth electrodes with single and multiple star for square-wave voltages.

As can be seen from this diagram, for a given length, it is more expedient to install a radial earth electrode than one single arm.

Foundation earth electrode

The earth electrode resistance of a metal conductor in a concrete foundation can be calculated as an approximation using the formula for hemispherical earth electrodes:

$$R_A = \frac{\rho_E}{\pi \cdot d}$$

Where d is the diameter of the analogous hemisphere having the same volume as the foundation:

$$d = 1.57 \cdot \sqrt[3]{V}$$

V   Volume of the foundation

When calculating the earth electrode resistance, one must be aware that the foundation earth electrode can only be effective if the concrete body has a large contact area with the surrounding ground. Water repellent, isolating shielding significantly increases the earth electrode resistance, or isolate the foundation earth electrode (see 5.5.2).

Earth rods connected in parallel

To keep the interactions within acceptable limits, the distances between the individual earth electrodes and earth rods connected in parallel should not be less than the pile depth, if possible.

If the individual earth electrodes are arranged roughly in a circle and if they all have about the same length, then the earth electrode resistance can be calculated as follows:

$$R_A = \frac{R_{A'}}{p}$$

Where $R_{A'}$ is the average earth electrode resistance of the individual earth electrodes. The reduction factor p as a function of the length of the earth electrode, the distance of the individual earth electrodes and the number of earth electrodes can be taken from **Figure 5.5.14**.

Combination of flat strip earth electrodes and earth rods

If sufficient earth electrode resistance is provided by earth rods, for example from deep water carrying layers in sandy soil, then the earth rod shall be as close as possible to the object to be protected. If a long feed is required, it is expedient to install a radial multiple star-type earth electrode in parallel to this in order to reduce the resistance as the current rises.

As an approximation, the earth electrode resistance of a flat strip earth electrode with earth rod can be calculated as if the flat strip earth electrode were extended by the drive-in depth of the earth rod.

$$R_A \approx \frac{\rho_E}{l_{flat\ strip} + l_{eath\ rod}}$$

Ring earth electrode

For circular ring earth electrodes with large diameters (d > 30 m), the earth electrode resistance is calculated as an approximation using the formula for the flat strip earth electrode (where the circumference $\pi \cdot d$ is used for the length of the earth electrode):

$$R_A = \frac{\rho_E}{\pi^2 \cdot d} \cdot \ln \frac{\pi \cdot d}{r}$$

r   Radius or the round conductor or quarter width of the flat strip earth electrode in m

For non-circular ring earth electrodes, the earth electrode resistance is calculated by using the diameter d of an analogous circle with the same area:

$$R_A = \frac{2 \cdot \rho_E}{3 \cdot d}$$

$$d = \sqrt{\frac{A \cdot 4}{\pi}}$$

A   Area enclosed by the ring earth electrode

Implementation

According to the standards, each installation to be protected must have its own earth-termination system which must be fully functional in itself without requiring metal water pipes or earthed conductors of the electrical installation.

The magnitude of the earth electrode resistance R_A is of only secondary importance for protecting a structure or installation against physical damage. It is important that the equipotential bonding at ground level is carried out systematically and the lightning current is safely distributed in the ground.

The lightning current i raises the structure to be protected to the earthing potential U_E

$$U_E = i \cdot R_A + \frac{1}{2} \cdot L \cdot \frac{di}{dt}$$

with respect to the reference earth.

The potential of the earth´s surface decreases with increasing distance from the earth electrode (**Figure 5.5.1**).

The inductive voltage drop across the earth electrode during the lightning current rise must only be taken into account for extended earth-termination systems (e.g. as required for long surface earth electrodes in poorly conducting soils with bedrock). In general, the earth electrode resistance is determined only by the ohmic part.

If isolated conductors are led into the structure, the earthing potential U_E has its full value with respect to the conductor.

In order to avoid the risk of punctures and flashovers here, such conductors are connected via isolating spark gaps or with live conductors via surge protective devices (see DEHN main catalogue for Surge Protection) to the earth-termination sys-

tem as part of the lightning equipotential bonding.

In order to keep touch and step voltages as low as possible, the magnitude of the earth electrode resistance must be limited.

The earth-termination system can be designed as a foundation earth electrode, a ring earth electrode and, for structures with large surface areas, as a meshed earth electrode and, in special cases, also as an individual earth electrode.

In Germany foundation earth electrodes must be designed in accordance with DIN 18014.

The foundation earth electrode must be designed as a closed ring and arranged in the foundations of the external walls of the structure, or in the foundation slab, in accordance with DIN 18014. For larger structures, the foundation earth electrode should contain interconnections to prevent an exceeding of the max. mesh size 20 m x 20 m.

The foundation earth electrode must be arranged to be enclosed by concrete on all sides. For steel strips in non-reinforced concrete, the earth electrode must be installed on edge.

In the service entrance room, a connection must be established between foundation earth electrode and equipotential bonding bar. According to IEC 62305-3 (EN 62305-3), a foundation earth electrode must be equipped with terminal lugs for connection of the down-conductor systems of the external lightning protection system to the earth-termination system.

Due to the risk of corrosion at the point where a terminal lug comes out of the concrete, supplementary corrosion protection should be considered (with PVC sheath or by using stainless steel with Material No. 1.4571).

The reinforcement of plate and strip foundations can be used as a foundation earth electrode if the required terminal lugs are connected to the reinforcement and the reinforcements are interconnected via the joints.

Surface earth electrodes must be installed in a depth of at least 0.5 m.

The impulse earthing resistance of earth electrodes is a function of the maximum value of the lightning current and of the specific earth resistance. See also **Figure 5.5.13**. The effective length of the earth electrode for the lightning current is calculated as an approximation as follows:

Surface earth electrode:

$$l_{eff} = 0.28\sqrt{\hat{\imath} \cdot \rho_E}$$

Earth rod:

$$l_{eff} = 0.2\sqrt{\hat{\imath} \cdot \rho_E}$$

l_{eff} Effective length of the earth electrode in m

$\hat{\imath}$ Peak value of the lightning current in kA

ρ_E Specific earth resistance Ωm

The impulse earth resistance R_{st} can be calculated using the formulae in (**Table 5.5.1**), where the effective length of the earth electrode l_{eff} is used for the length I.

Surface earth electrodes are always advantageous when the upper soil layers have less specific resistance than the subsoil.

If the ground is relatively homogeneous (i.e. if the specific earth resistance at the surface is roughly the same as it is deep down) then, for a given earth electrode resistance, the construction costs of surface earth electrodes and earth rods are roughly the same.

According to **Figure 5.5.15**, an earth rod must have only around half the length of a surface earth electrode.
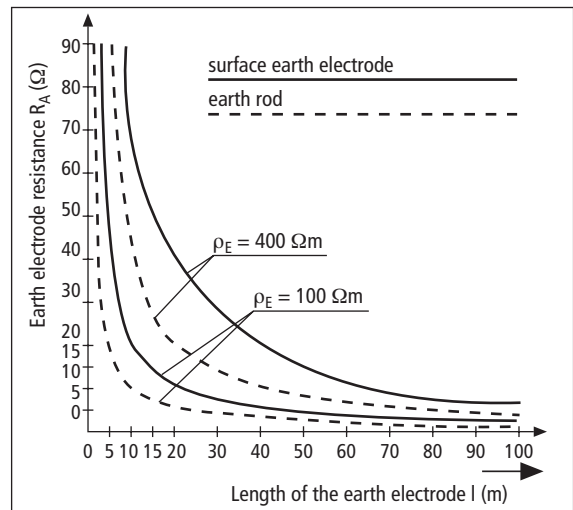
Fig. 5.5.15   Earth electrode resistance R_A of surface and earth rods as a function of the length of the earth electrode I

If the conductivity of the ground is better deep down than it is on the surface, e.g. because of ground water, then an earth rod is generally more cost-effective than the surface earth electrode.

The issue of whether earth rods or surface earth electrodes are more cost-effective in a particular case, can often only be decided by measuring the specific earth resistance as a function of the depth. Since earth rods are easy to assemble and achieve excellent constant earth electrode resistances without the need to dig a trench and without damaging the ground, these earth electrodes are also suitable for improving existing earth-termination system.

5.5.1 Earth-termination systems in accordance with IEC 62305-3 (EN 62305-3)

Earth-termination systems are the continuation of air-termination and down-conductor systems to discharge the lightning current into the earth. Further functions of the earth-termination system are to create equipotential bonding between the down conductors and a potential control in the vicinity of the walls of the structure.

It must be borne in mind that a common earth-termination system for the various electrical systems (lightning protection, low voltage systems and telecommunications systems) is preferable. This earth-termination system must be connected to the equipotential bonding (MEBB – main equipotential bonding bar).

Since IEC 62305-3 (EN 62305-3) assumes a systematic lightning equipotential bonding, no particular value is required for the earth electrode resistance.
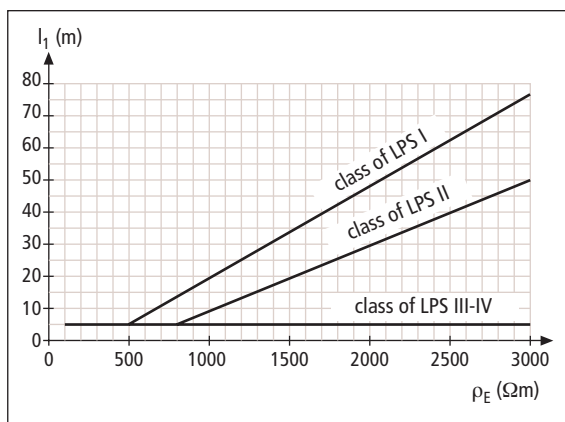
Fig. 5.5.1.1   Minimum lengths of earth electrodes

Generally, however, a low earth resistance (less than 10 Ω, measured with low frequency) is recommended.

The standard classifies earth electrode arrangements into **Type A** and **Type B**.

For both Type A and B earth electrode arrangements, the minimum earth electrode length l_1 of the earthing conductor is a function of the class of lightning protection system (**Figure 5.5.1.1**)

The exact specific earth resistance can only be determined by on-site measurements using the "WENNER method" (four-conductor measurement).

Earth electrode Type A

Earth electrode arrangement Type A describes individually arranged horizontal star-type earth electrodes (surface earth electrodes) or vertical earth electrodes (earth rods), each of which must be connected to a down-conductor system.

There must be at least 2 earth electrodes Type A.

Lightning protection systems Class III and IV require a minimum length of 5 m for earth electrodes. For lightning protection systems, Class I and II the length of the earth electrode is determined as a function of the specific ground resistance. The minimum length for earth electrodes l_1 can be taken from **Figure 5.5.1.1**.

Minimum length of each earth electrode is:

l_1 x 0.5   for vertical or slanted earth electrodes

l_1 for star-type earth electrodes

The values determined apply to each individual earth electrode.

For combinations of the various earth electrodes (vertical and horizontal) the equivalent total length should be taken into account.

The minimum length for the earth electrode can be disregarded if an earth electrode resistance of less than 10 Ω is achieved.

Earth rods are generally driven vertically down to greater depths into natural soil which is generally initially encountered below the foundations. Earth electrode lengths of 9 m have provided the advantage of lying at greater depths in soil layers whose specific resistance is generally lower than in the areas closer to the surface.

area **A₁** to be considered

circular area **A₂**, mean radius r

$A = A_1 = A_2$

$r = \sqrt{\dfrac{A}{\pi}}$

$r \geq l_1$

With respect to ring or foundation earth electrodes, the mean radius *r* of the area enclosed by the earth electrode must not be shorter than *l₁*.
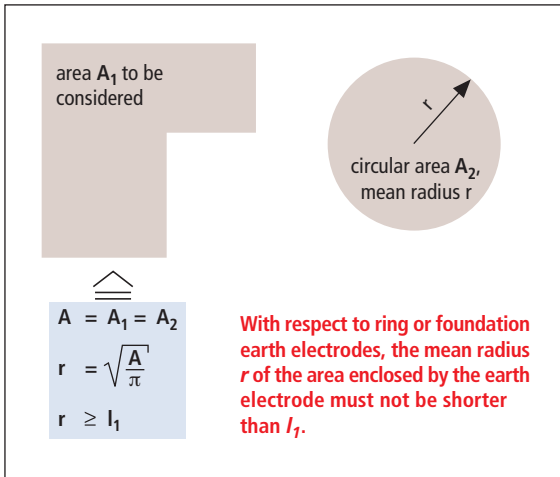
Fig. 5.5.1.2   Earth electrode Type B – Determination of the mean radius – example calculation

12 m

area **A₁** to be considered

5 m

12 m

5 m

7 m

circular area **A₂** mean radius r

7 m

Example: Residential building, LPS Class III, l₁ = 5 m

$A = A_1 = A_2$

$r = \sqrt{\dfrac{A}{\pi}}$

$r \geq l_1$

$A_1 = 109 \ m^2$

$r = \sqrt{\dfrac{109 \ m^2}{3.14}}$

$r = 5.89 \ m$

No further earth electrodes required!

Fig. 5.5.1.3   Earth electrode Type B – Determination of the mean radius

In frosty conditions, it is recommended to consider the first 100 cm of a vertical earth electrode as ineffective.

Earth electrodes Type A do not fulfill the equipotential bonding requirements between the down conductors and the potential control.
Earth electrodes Type A must be interconnected to split the current equally. This is important for calculating the separation distance s. Earth electrodes Type A can be interconnected underground or on surface. When upgrading existing installations the interconnection of the individual earth electrodes can also be realised by laying a conductor in the building or structure.

Earth electrode Type B
Earth electrodes of the Type B arrangement are ring earth electrodes around the structure to be protected, or foundation earth electrodes. In Germany the requirements on these earth electrodes are described in DIN 18014.
If it is not possible to have a closed ring outside around the structure, the ring must be completed using conductors inside the structure. Conduits or other metal components which are permanently electrically conductive can also be used for this purpose. At least 80 % of the length of the earth electrode must be in contact with the earth to ensure that, when calculating the separation distance, the earth electrode Type B can be used as the base.

The minimum lengths of the earth electrodes corresponding to the Type B arrangement are a function of the class of lightning protection system. For lightning protection systems Class I and II, the minimum length for earth electrodes is also determined as a function of the specific ground resistance (see also **Figure 5.5.4**).

For earth electrodes Type B, the average radius r of the area enclosed by the earth electrode must be not less than the given minimum length l₁.

To determine the average radius r, the area under consideration is transferred into an equivalent circular area and the radius is determined as shown in **Figures 5.5.1.2** and **5.5.1.3**.

Below a calculation example:

If the required value of l₁ is greater than the value r corresponding to the structure, supplementary star-type earth electrodes or vertical earth electrodes (or slanted earth electrodes) must be added, their respective lengths l_r (radial/horizontal) and l_v (vertical) being given by the following equations:

$$l_r = l_1 - r$$

$$l_v = \frac{l_1 - r}{2}$$

The number of supplementary earth electrodes must not be less than the number of down conductors, but a minimum of 2. These supplementary earth electrodes shall be connected to the ring earth electrode so as to be equidistant around the circumference.

If supplementary earth electrodes have to be connected to the foundation earth electrode, care must be taken with the materials of the earth electrode and the connection to the foundation earth electrode. It is preferable to use stainless steel with Material No. 1.4571 (**Figure 5.5.2.1**).

The following systems can make additional demands on the earth-termination system, for example:

⇒ Electrical systems – conditions of disconnection from supply with respect to the type of network (TN-, TT-, IT systems) in accordance with IEC 60364-4-41: 2005, mod and HD 60364-4-41: 2007

⇒ Equipotential bonding in accordance with IEC 60364-5-54: 2002 and HD 60364-5-54: 2007

⇒ Electronic systems – data information technology

⇒ Antenna earthing installation in accordance with VDE 0855 (German standard)

⇒ Electromagnetic compatibility

⇒ Substation in or near the structure in accordance with HD 637 S1 and En 50341-1

5.5.2 Earth-termination systems, foundation earth electrodes and foundation earth electrodes for special structural measures

Foundation earth electrodes – Earth electrodes Type B

DIN 18014 (German standard) specifies the requirements on foundation earth electrodes.

Many national and international standards specify foundation earth electrodes as a preferred earth electrode because, when professionally installed, it is enclosed in concrete on all sides and hence corrosion-resistant. The hygroscopic characteristics of concrete generally produce a sufficiently low earth earth electrode resistance.

The foundation earth electrode must be installed as a closed ring in the strip foundation or the bedplate (**Figure 5.5.2.1**) and thus also acts primarily as the equipotential bonding. The division into meshes ≤ 20 m x 20 m and the terminal lugs to the outside required to connect the down conductors of the external lightning protection system, and to the inside for equipotential bonding, must be considered (**Figure 5.5.2.2**).

According to DIN 18014, the installation of the foundation earth electrode is an electrical engineering measure to be carried out or monitored by a recognised **specialist electrical engineer**.

The question of how to install the foundation earth electrode must be decided according to the measure required to ensure that the foundation

Terminal lug
min. 1.5 m long, noticeably marked
– steel strip 30 mm x 3.5 mm
– StSt round steel bar 10 mm
– round steel bar 10 mm with PVC coating
– fixed earthing point

Foundation earth electrode
– steel strip 30 mm x 3.5 mm
– round steel bar 10 mm

Fig. 5.5.2.1   Foundation earth electrode with terminal lug

additional terminal conductor
for forming meshes ≤ 20 m x 20 m

≤ 20 m

20 m

terminal lug

Recommendation:
Several terminal lugs e.g.
in every technical centre

Fig. 5.5.2.2   Mesh of a foundation earth electrode

Fig. 5.5.2.3   Foundation earth electrode

Fig. 5.5.2.4   Foundation earth electrode in use

earth electrode is enclosed on all sides as the concrete is being poured in.

Installation in non-reinforced concrete
Non-reinforced foundations, e.g. strip foundations of residential structures (**Figure 5.5.2.3**), require the use of spacers.
Only by using the spacers at distances of approx. 2 m, is it possible to ensure that the foundation earth electrode is "lifted up" and can be enclosed on all sides by concrete.

Installation in reinforced concrete
When using steel mats, reinforcement cages or reinforcement irons in foundations, it is not only possible to connect the foundation earth electrode to these natural iron components, but this should be done. The function of the foundation earth electrode is thus made even more favourable. There is no need to use spacers. The modern methods of laying concrete and then vibrating it, ensure that the concrete also "flows" under the foundation earth electrode enclosing it on all sides.
Figure 5.5.2.4 illustrates one possible application for the horizontal installation of a flat strip as a foundation earth electrode. The intersections of the foundation earth electrode must be connected so as to be capable of carrying currents. Galvanised steel is sufficient as material of the foundation earth electrode.
Terminal lugs to the outside into the ground must have supplementary corrosion protection at the outlet point. Suitable materials are, for example, plastic sheathed steel wire (owing to the risk of fracture of the plastic sheath at low temperatures, special care must be taken during the installation),

high-alloy stainless steel, Material No. 1.4571, or fixed earthing terminals.
If professionally installed, the earth electrode is enclosed on all sides by concrete and hence corrosion-resistant.
When designing the foundation earth electrode, meshes no bigger than 20 m x 20 m shall be realised. This mesh size bears no relation to the class of lightning protection system of the external lightning protection system.
Modern building techniques employ various types of foundations in a wide variety of designs and sealing versions.
The terminal insulation regulations have also influenced the design of the strip foundations and foundation slabs. For foundation earth electrodes installed in new structures in accordance with DIN 18014, the insulation affects their installation and arrangement.

Perimeter insulation / Base insulation
"Perimeter" is the earth-touching area of the wall and base of a structure. The perimeter insulation is the external heat insulation around the structure. The perimeter insulation seated on the external sealing layer encloses the structure so that there is no heat bridge and protects the sealing additionally against mechanical damage.

The magnitude of the specific resistance of the perimeter insulating plates is a decisive factor when considering the effect of perimeter insulation on the earth electrode resistance of foundation earth electrodes in conventional arrangements in the foundation (strip foundation, foundation slab). Thus, for a polyurethane rigid foam
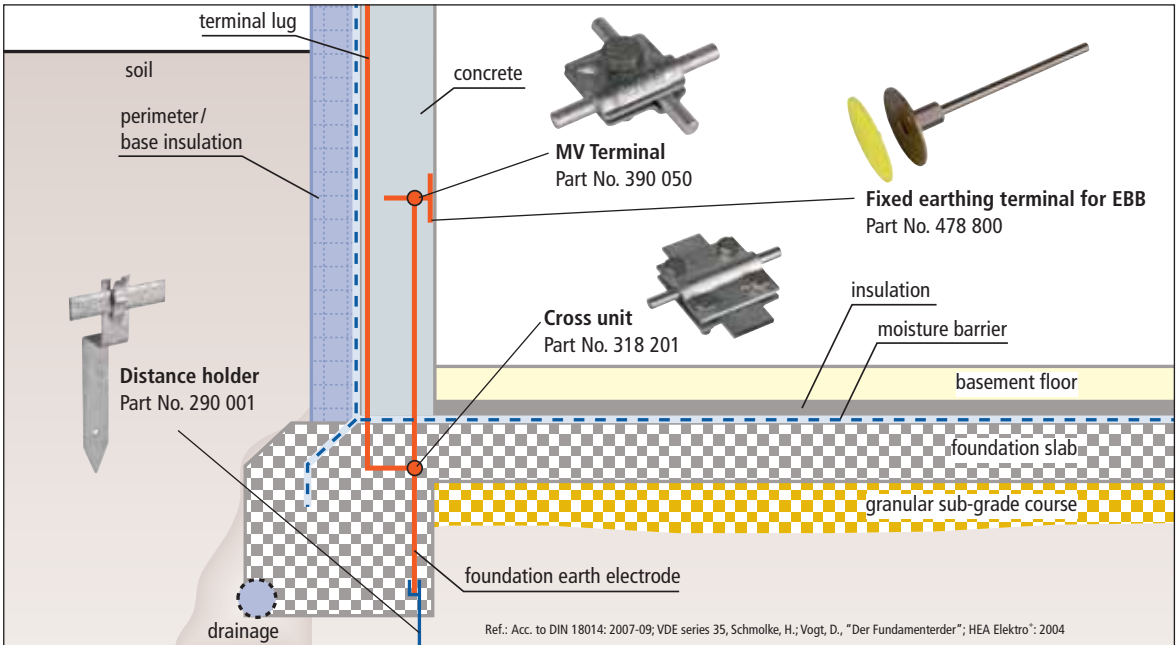
Fig. 5.5.2.5   Arrangement of a foundation earth electrode in a strip foundation (insulated basement wall)
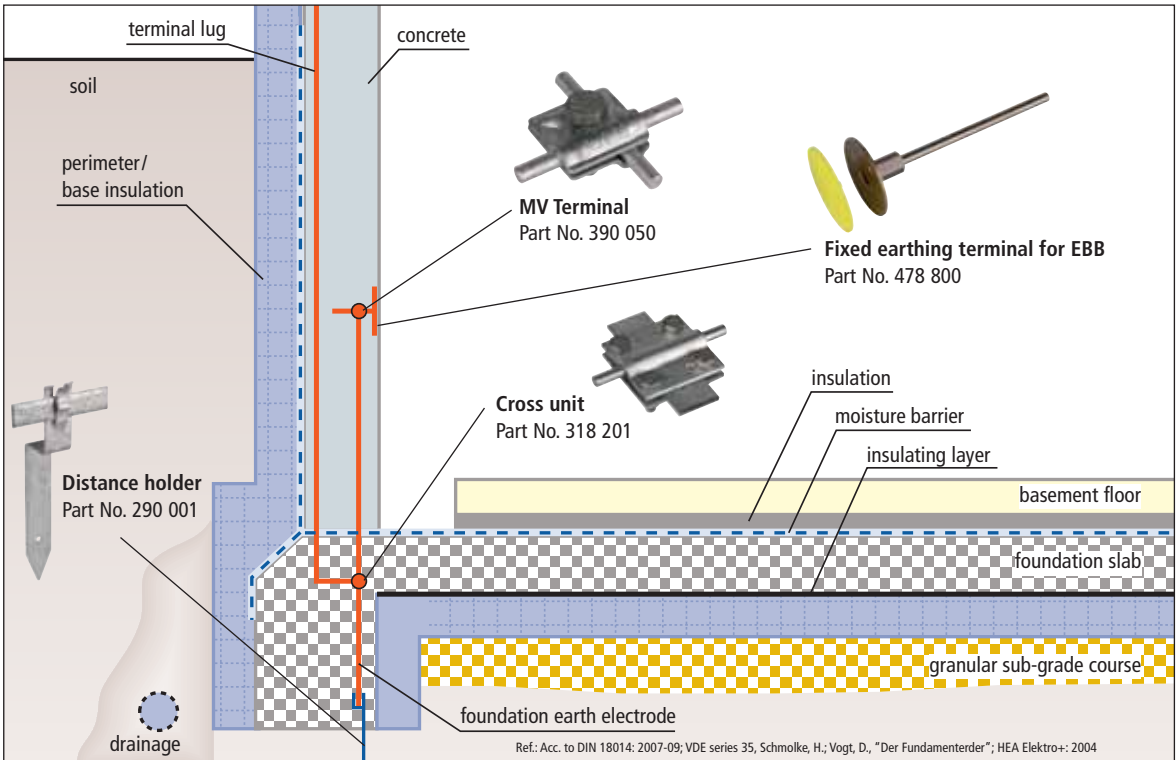
Fig. 5.5.2.6   Arrangement of a foundation earth electrode in a strip foundation (insulated basement wall and foundation slab)
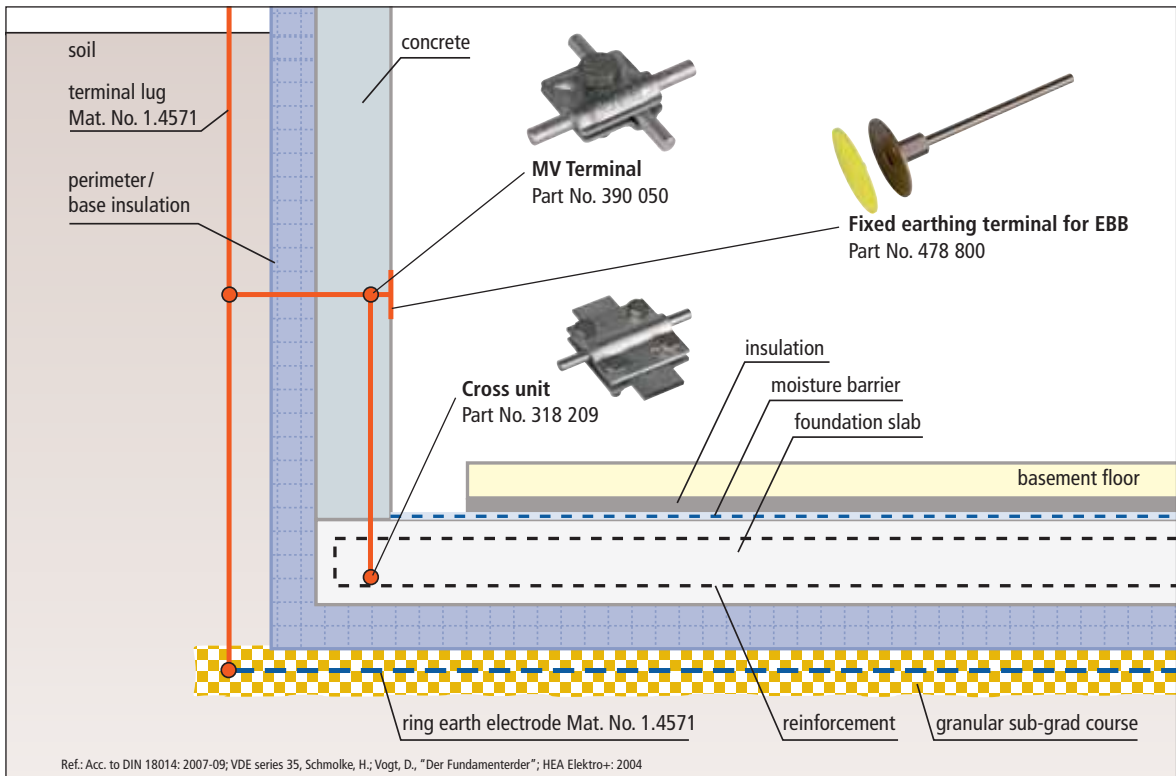
Fig. 5.5.2.7   Arrangement of a foundation earth electrode in case of a closed floor slab (fully insulated)

with bulk density 30 kg/m², for example, a specific resistance of 5.4 · 10¹² Ωm is given. In contrast, the specific resistance of concrete lies between 150 Ωm and 500 Ωm. This alone shows that, in the case of continuous perimeter insulation, a conventional foundation earth electrode arranged in the foundations has practically no effect. The perimeter insulation also acts as an electrical insulator.

The diagrams below illustrate the various ways of insulating the foundations and walls for structures with perimeter and base insulation.

Figures 5.5.2.5 to **5.5.2.7** show the arrangement of the foundation earth electrodes at structures with perimeter and base insulation.

The arrangement of the earth electrode in the strip foundation with insulated sides towards the outside and the bedplate is not regarded as critical (**Figure 5.5.2.5** and **5.5.2.6**).

If the foundation slab is completely insulated, the earth electrode must be installed below the bedplate. Material V4A (Material No. 1.4571) should be used (**Figure 5.5.2.7**).

It is efficient to install fixed earthing terminals, especially for reinforced structures. In such cases, care must be taken that the installation during the construction phase is carried out professionally (**Figure 5.5.2.8**).

Fig. 5.5.2.8   Fixed earthing terminal
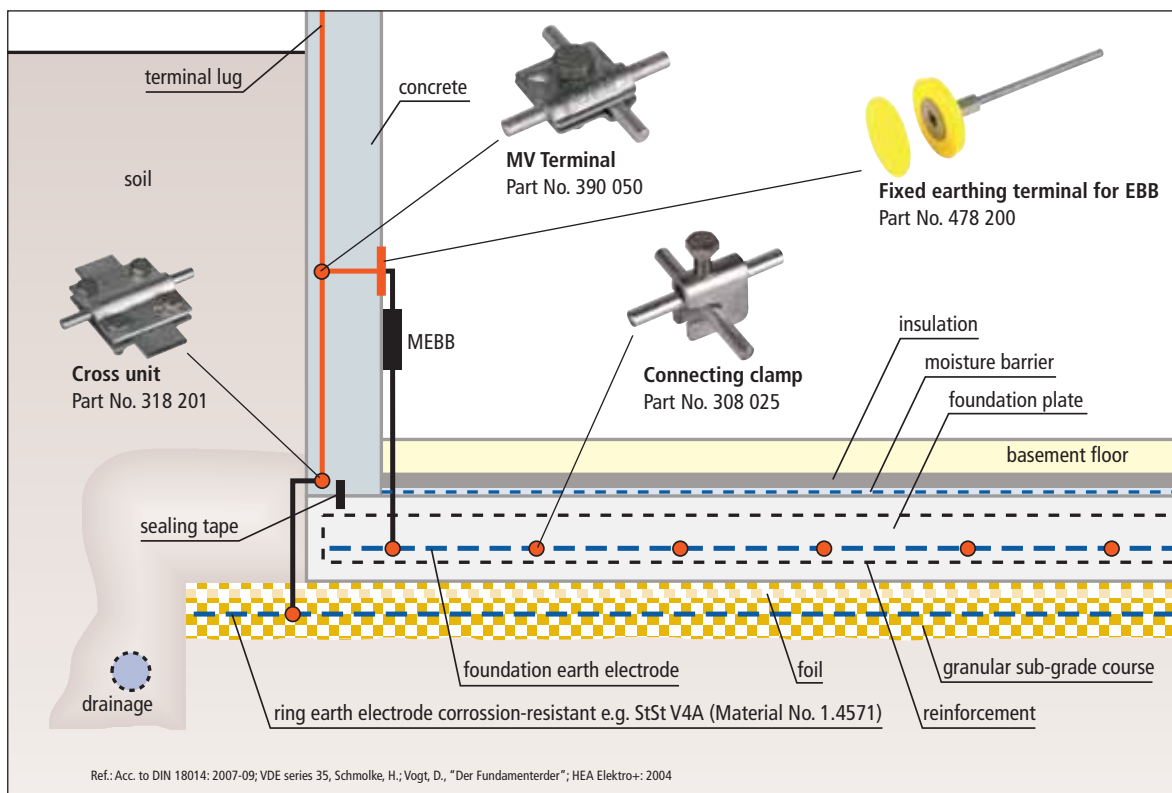
Fig. 5.5.2.9   Arrangement of the foundation earth electrode in case of a closed tank "white tank"

Black tank, white tank

In structures erected in regions with a high groundwater level, or in locations, e.g. on hillsides, with "pressing" water, the cellars are equipped with special measures to prevent moisture penetrating. The outer walls surrounded by earth, and the foundation slab are sealed against the penetration of water to ensure that no troublesome moisture can form on the inside of the wall.

Modern building techniques apply both above mentioned processes for sealing against penetrating water.

One particular issue in this context is whether the efficiency of a foundation earth electrode is still provided for maintaining the measures to protect against life hazards in accordance with IEC 60364-4-41, and as a lightning protection earth electrode in accordance with IEC 62305-3 (EN 62305-3).

Foundation earth electrodes for structures with white tank

The name "white tank" is used to express the opposite of "black tank": a "white tank" receives no additional treatment on the side facing the earth, hence it is "white".

The "white tank" is manufactured from a special type of concrete. Due to the aggregates used at manufacturing of the concrete the concrete body is absolutely waterproof. In contrast to former years there is no risk of humidity penetrating a few centimeters into the tank. Therefore an earth electrode is laid outside of structures with white tank.

Figure 5.5.2.8 shows the designing of an earth connection by a fixed earthing terminal.

Figure 5.5.2.9 illustrates the arrangement of the foundation earth electrode in a white tank.

Earth electrodes for structures with black tank

The name "black tank" derives from the multi-layered strip of black bitumen applied to the sections of the structure which are outside in the ground. The body of the structure is coated with bitumen/tar which is then covered by generally up to 3 layers of bitumen strips.

A ring conductor set into the foundation slab above the seal can act as the potential control in the structure. Due to the high-impedance insulation to the outside, however, the earth electrode is ineffective.

In order to comply with the earthing requirements stipulated in the various standards, an earth electrode, e.g. a ring earth electrode, must be installed externally around the structure or below all seals in the granular sub-grade course.

Wherever possible, the external earth electrode should be led into the structure above the seal of the structure (**Figure 5.5.2.10**), in order to ensure the tightness of the tank also in the long term. A waterproof penetration of the "black tank" is only possible using a special bushing for the earth electrodes.

Fibre concrete foundation slabs

Fibre concrete is a type of concrete which forms a heavy-duty concrete slab with steel fibres added to the liquid concrete before hardening.

The steel fibres are approx. 6 cm long and have a diameter of 1 – 2 mm. The steel fibres are slightly wavy and are admixed equally to the liquid concrete. The proportion of steel fibres is around 20 – 30 kg/m^3 concrete.

The admixture gives the concrete slab both a high compression strength and also a high tensile strength and, compared to a conventional concrete slab with reinforcement, it also provides a considerably higher elasticity.

The liquid concrete is poured on site. This allows to create large areas with a smooth surface and no joints. It is used for bedplates in the foundations of large halls, for example.

Ref.: Acc. to DIN 18014: 2007-09; VDE series 35, Schmolke, H.; Vogt, D., "Der Fundamenterder"; HEA Elektro+: 2004
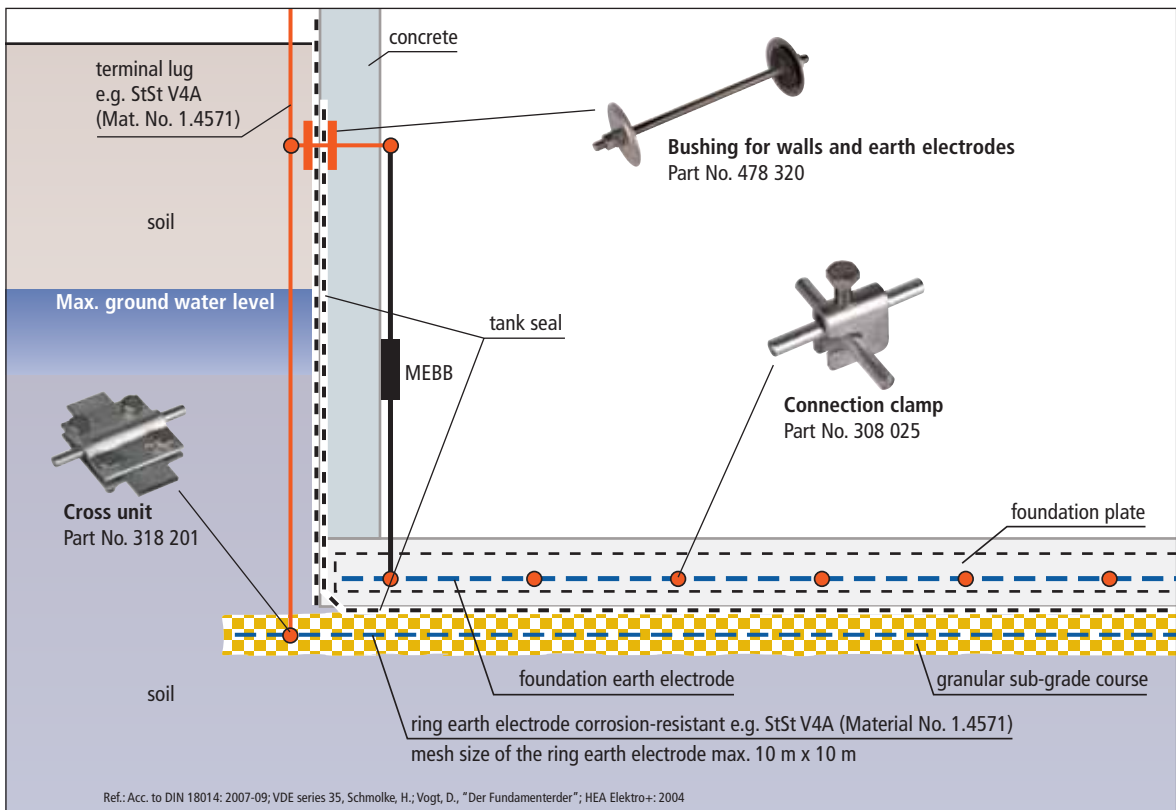
Fig. 5.5.2.10   Arrangement of the earth electrode in case of a closed tank "black tank"

Fibre concrete has no reinforcement. This requires a supplementary ring conductor or a meshed network to be constructed for installing earthing measures. The earthing conductor can be set in the concrete and, if it is made of galvanised material, it must be enclosed on all sides. This is very difficult to do on site.

It is therefore recommended to install a corrosion-resistant high-alloy stainless steel, Material No. 1.4571, below the subsequent concrete bedplate. The corresponding terminal lugs have to be considered.

Note:

A specialist must install the earthing conductors and connecting components in concrete. If this is not possible, the building contractor can undertake the work only if it is supervised by a specialist.

5.5.3 Ring earth electrode – Earth electrode Type B

In Germany the national standard DIN 18014 stipulates that all new structures must have foundation earth electrodes. The earth-termination system of existing structures can be designed in the form of a ring earth electrode (**Figure 5.5.3.1**).

This earth electrode must be installed in a closed ring around the structure or, if this is not possible, a connection to close the ring must be made inside the structure.

80 % of the conductors of the earth electrode shall be installed so as to be in contact with the earth. If this 80 % cannot be achieved, it has to be checked if supplementary earth electrodes Type A are required.

The requirements on the minimum length of earth electrodes according to the class of lightning protection system must be taken into account (see Chapter 5.5.1).

When installing the ring earth electrode, care must be taken that it is installed at a depth > 0.5 m and a distance of 1 m from the structure.

If the earth electrode is driven in as previously described, it reduces the step voltage and thus acts as a potential control around the structure.

This earth electrode should be installed in natural soil. Setting it in gravel or ground filled with construction waste worsens the earth electrode resistance.

When choosing the material of the earth electrode with regard to corrosion, the local conditions must be taken into consideration. It is advantageous to use stainless steel. This earth electrode material does not corrode nor does it subsequently require the earth-termination system to be refurbished with time-consuming and expensive measures such as removal of paving, tar coatings or even steps, for installing a new flat strip.

In addition, the terminal lugs must be particularly protected against corrosion.
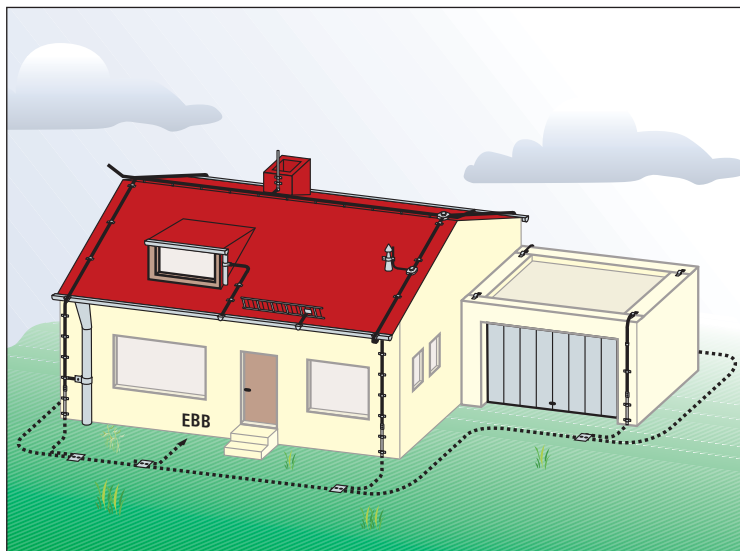
Fig. 5.5.3.1   Ring earth electrode around a residential building
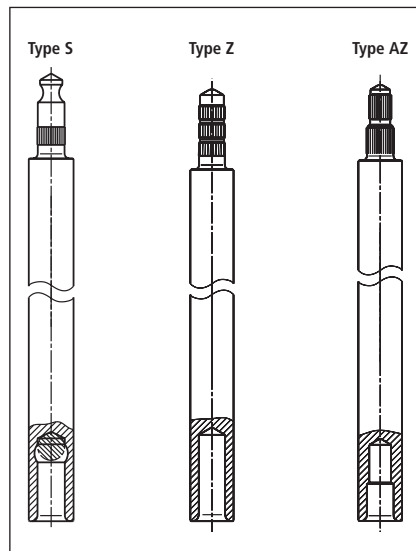
Fig. 5.5.4.1   Couplings of DEHN earth rods

5.5.4 Earth rod – Earth electrode Type A

The sectional earth rods, System DEHN, are manufactured from special steel and hot-dip galvanised, or they consist of high-alloy stainless steel with Material No. 1.4571 (the high-alloy stainless steel earth electrode is used in areas especially at risk from corrosion). The particular feature of these earth rods is their coupling point, which allows the earth rods to be connected without increasing their diameter.

Each rod has a bore at its lower end, while the other end of the rod has a corresponding spigot (**Figure 5.5.4.1**).

With DEHN earth electrode Type "S", the soft metal insert deforms as it is driven into the bore, creating an excellent electrical and mechanical connection.

With DEHN earth electrode Type "Z", the high coupling quality is achieved with a multiply knurled spigot.

With DEHN earth electrode Type "AZ", the high coupling quality is achieved with a multiply knurled and shouldered spigot.

Fig. 5.5.4.2   Driving the earth rod in with a work scaffolding and a vibrating hammer

The advantages of the DEHN earth rods are:.

⇒ Special coupling:

⇒ no increase in diameter so that the earth rod is in close contact with the ground along the whole of its length

⇒ Self-closing when driving in the rods

⇒ Simple to drive in with vibration hammers (**Figure 5.5.4.2**) or mallets

⇒ Constant resistance values are achieved since the earth rods penetrate through the soil layers which are unaffected by seasonal changes in moisture and temperature

⇒ High corrosion resistance as a result of hot-dip galvanising (zinc coating 70 μm thick)

⇒ Galvanised earth rods also provide hot-galvanised coupling points

⇒ Easy to store and transport since individual rods are 1.5 or 1 m long.

5.5.5 Earth electrodes in rocky ground

In bedrock or stony ground, surface earth electrodes such as ring earth electrodes or star-type earth electrodes are often the only way of creating an earth-termination system.

When installing the earth electrodes, the flat strip or round material is laid on the stony ground or on the rock. The earth electrode should be covered with gravel, wet-mix slag aggregate or similar.

It is advantageous to use stainless steel Material No. 1.4571 as earth electrode material. The clamped points should be installed with particular care and be protected against corrosion (anticorrosive band).

5.5.6 Intermeshing of earth-termination systems

An earth-termination system can serve a wide variety of purposes.

The purpose of protective earthing is to safely connect electrical installations and equipment to earth potential and to prevent life hazard and physical damage to property in the event of an electrical fault.

The lightning protection earthing system takes over the current from the down conductors and discharges it into the ground.

The functional earthing installation serves to ensure that the electrical and electronic installations operate safely and trouble-free.

The earth-termination system of a structure must be used for all earthing tasks together, i.e. the earth-termination system deals with all earthing tasks. If this were not the case, potential differences could arise between the installations earthed on different earth-termination systems.

Previously, a "clean earth" was sometimes applied in practice for functional earthing of the electronic equipment, separately from the lightning protection and the protective earth. This is extremely disadvantageous and can even be dangerous. In the event of lightning effects, great potential differences up to a few 100 kV occur in the earth-termination system. This can lead to destruction of electronic installations and also to life hazards. Therefore, IEC 62305-3 and -4 (EN 62305-3 and -4) require continuous equipotential bonding within a structure.

The earthing of the electronic systems can be constructed to have a radial, central or intermeshed 2-dimensional design within a structure, (**Figure 5.5.6.1**). This depends both on the electromagnetic environment and also on the characteristics of the electronic installation. If a larger structure comprises more than one building, and if these are connected by electrical and electronic conductors, then combining the individual earthing systems can reduce the (total) earth resistance. In addition, the potential differences between the structures are also reduced considerably. This diminishes noticeably the voltage load of the electrical and electronic connecting cables. The interconnection of the individual earth-termination systems of the structure should produce a meshed network. The meshed earthing network should be constructed to contact the earth-termination systems at the point where the vertical down conductors are also connected. The smaller the mesh size of the network of the earthing installation, the smaller the potential differences between the structures in the event of a lightning strike. This depends on the total area of the structure. Mesh sizes from 20 m x 20 m up to 40 m x 40 m have proved to be cost-effective. If, for example, high vent stacks (preferred points of strike) are existing, then the connections around this part of the plant should be made closer, and, if possible, radial with circular interconnections (potential control) When choosing the material for the conductors of the meshed earthing network, the corrosion and material compatibility must be taken into account.
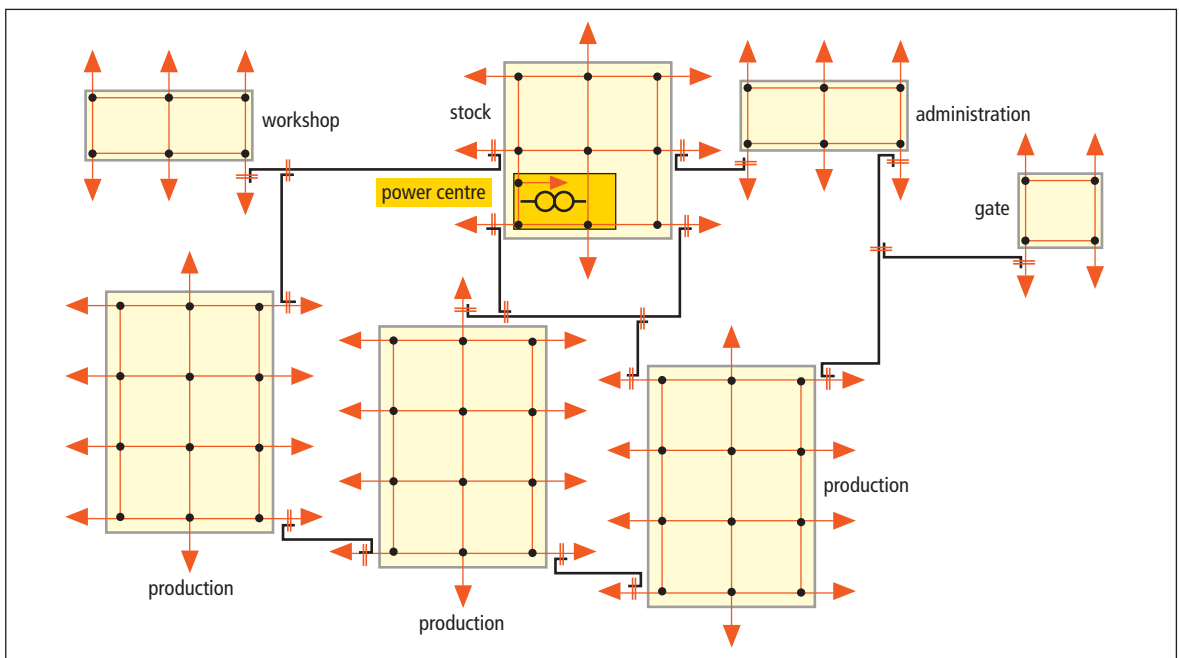
Fig. 5.5.6.1   Intermeshed earth-termination system of an industrial facility

5.5.7 Corrosion of earth electrodes

5.5.7.1 Earth-termination systems with particular consideration of corrosion

Metals in immediate contact with soil or water (electrolytes) can be corroded by stray currents, corrosive soils and the formation of voltaic cells. It is not possible to protect earth electrodes from corrosion by completely enclosing them, i.e. by separating the metals from the soil, since all the usual sheaths employed until now have had a high electrical resistance and therefore negate the effect of the earth electrodes.

Earth electrodes made of a uniform material can be threatened by corrosion from corrosive soils and the formation of concentration cells. The risk of corrosion depends on the material and the type and composition of the soil.

Corrosion damage due to the formation of voltaic cells is being increasingly observed. This cell formation between different metals with widely different metal/electrolyte potentials has been known for many years. What is not widely realised, however, is that the reinforcements of concrete foundations can also become the cathode of a cell and hence cause corrosion to other installations.

With the changes to the way buildings are constructed – larger reinforced concrete structures and smaller free metal areas in the ground – anode/cathode surface ratio is becoming more and more unfavourable, and the risk of corrosion of the more base metals is inevitably increasing.

An electrical isolation of installations acting as anodes to prevent this cell formation is only possible in exceptional cases. The aim nowadays is to integrate all earth electrodes including those metal installations connected to the earth in order to achieve equipotential bonding and hence maximum safety against touch voltages at faults or lightning strikes.

In high voltage installations, high voltage protective earth electrodes are increasingly connected to low voltage operating earth electrodes in accordance with HD 637 S1. Furthermore IEC 60364-4-41, mod and HD 60364-4-41 requires the integration of conduits and other installations into the shock hazard protective measures. Thus, the only way of preventing or at least reducing the risk of corrosion for earth electrodes and other installations in contact with them is choosing suitable materials for the earth electrodes.

In Germany, the national standard DIN VDE 0151 "Material and minimum dimensions of earth electrodes with respect to corrosion" has been available since June 1986 as a white paper. Apart from decades of experience in the field of earthing technology, the results of extensive preliminary examinations have also been embodied in this standard. Many interesting results are available which are important for the earth electrodes, including those of lightning protection systems.

The fundamental processes leading to corrosion are explained below.

Practical anticorrosion measures especially for lightning protection earth electrodes shall be derived from this and from the wealth of material already acquired by the VDE task force on "Earth electrode materials".

Terms used in corrosion protection and corrosion protection measurements

Corrosion

is the reaction of a metal material to its environment which leads to impairment of the characteristics of the metal material and/or its environment. The reaction is usually of electrochemical character.

Electrochemical corrosion

is corrosion during which electrochemical processes occur. They take place exclusively in the presence of an electrolyte.

Electrolyte

is an ion-conducting corrosive medium (e.g. soil, water, fused salts).

Electrode

is an electron-conducting material in an electrolyte. The system of electrode and electrolyte forms a half-cell.

Anode

is an electrode from which a d.c. current enters the electrolyte.

Cathode

is an electrode from which a d.c. current leaves the electrolyte.

1 Electrolyte copper bar with hole for measurements
2 Rubber plug
3 Ceramic cylinder with porous base
4 Glaze
5 Saturated Cu/CuSO$_4$ solution
6 Cu/CuSO$_4$ crystals
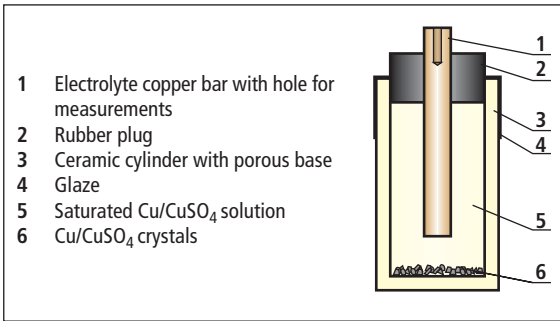
Fig. 5.5.7.1.1 Application example of a non-polarisable measuring electrode (copper/copper sulphate electrode) for tapping a potential within the electrolyte (cross-sectional view)

Reference electrode
is a measuring electrode for determining the potential of a metal in the electrolyte.

Copper sulphate electrode
is a reference electrode which can hardly be polarised, made of copper in saturated copper sulphate solution.
The copper sulphate electrode is the most common form of reference electrode for measuring the potential of subterranean metal objects (**Figure 5.5.7.1.1**).

Corrosion cell
is a voltaic cell with different local partial current densities for dissolving the metal. Anodes and cathodes of the corrosion cell can be formed

⇒ **on the material**
due to different metals (contact corrosion) or different structural components (selective or intercrystalline corrosion).

⇒ **on the electrolyte**
caused by different concentrations of certain materials having stimulatory or inhibitory characteristics for dissolving the metal.

Potentials

Reference potential
Potential of a reference electrode with respect to the standard hydrogen electrode.

Electropotential
is the electrical potential of a metal or an electron-conducting solid in an electrolyte.

5.5.7.2 Formation of voltaic cells, corrosion

The corrosion processes can be clearly explained with the help of a voltaic cell. If, for example, a metal rod is dipped into an electrolyte, positively charged ions pass into the electrolyte and conversely, positive ions are absorbed from the electrolyte from the metal band. In this context one speaks of the "solution pressure" of the metal and the "osmotic pressure" of the solution. Depending on the magnitude of these two pressures, either more of the metal ions from the rod pass into the solution (the rod therefore becomes negative compared to the solution) or the ions of the electrolyte collect in large numbers on the rod (the rod becomes positive compared to the electrolyte). A voltage is thus created between two metal rods in the electrolyte.

In practice, the potentials of the metals in the ground are measured with the help of a copper sulphate electrode. This consists of a copper rod dipped into a saturated copper sulphate solution (the reference potential of this reference electrode remains constant).

Consider the case of two rods made of different metals dipping into the same electrolyte. A voltage of a certain magnitude is now created on each rod in the electrolyte. A voltmeter can be used to
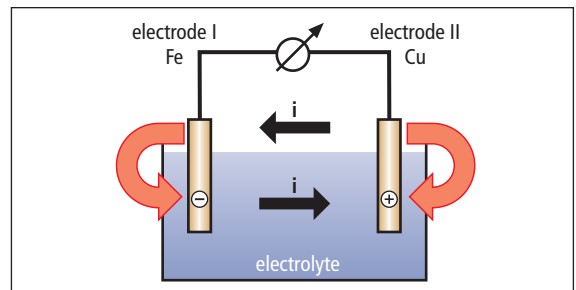
Fig. 5.5.7.2.1 Galvanic cell: iron/copper
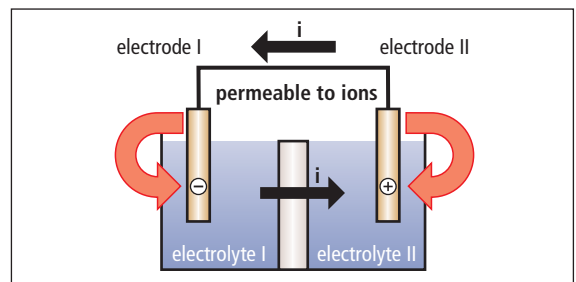
Fig. 5.5.7.2.2 Concentration cell

measure the voltage between the rods (electrodes); this is the difference between the potentials of the individual electrodes compared with the electrolyte.

How does it now come that current flows in the electrolyte and hence that material is transported, i.e. corrosion occurs?
If, as shown here, the copper and iron electrodes are connected via an ammeter outside the electrolyte, for example, the following (**Figure 5.5.7.2.1**) is ascertained: in the outer circuit, the current i flows from + to –, i.e. from the "nobler" copper electrode according to **Table 5.5.7.2.1** to the iron electrode.

In the electrolyte, on the other hand, the current i must therefore flow from the "more negative" iron electrode to the copper electrode to close the circuit. As a generalisation, this means that the more negative pole passes positive ions to the electrolyte and hence becomes the anode of the voltaic cell, i.e. it dissolves. The dissolution of the metal occurs at those points where the current enters the electrolyte.
A corrosion current can also arise from a concentration cell (**Figure 5.5.7.2.2**). In this case, two electrodes made of the same metal dip into different electrolytes. The electrode in electrolyte II with the higher concentration of metal ions becomes electrically more positive than the other. Connecting

	Definition	Symbol(s)	Copper	Lead	Tin	Iron	Zinc
1	Free corrosion potential in the soil[1] [V]	$U_{M\text{-}Cu/CuSO_4}$	0 to −0.1	−0.5 to −0.6	−0.4 to −0.6[2]	−0.5 to −0.8[3]	−0.9 to −1.1[5]
2	Cathodic protective potential in the soil[1] [V]	$U_{M\text{-}Cu/CuSO_4}$	−0.2	−0.65	−0.65[2]	−0.85[4]	−1.2[5]
3	Electrochemical equivalent [kg/(A · year)]	$K = \dfrac{\Delta m}{I\,t}$	10.4	33.9	19.4	9.1	10.7
4	Linear corrosion rate [mm/year] at J = 1 mA/dm²	$W_{lin} = \dfrac{\Delta s}{t}$	0.12	0.3	0.27	0.12	0.15

[1] Measured to saturated copper/copper sulphate electrode (Cu/Cu SO_4).

[2] Values are verified in presently performed tests. The potential of tin-coated copper depends on the thickness of the tin coating. Common tin coatings up to now have amounted up to a few µm and are thus between the values of tin and copper in the soil.

[3] These values do also apply to lower alloyed types of iron. The potential of steel in concrete (reinforcing iron of foundations) depends considerably on external influences. Measured to a saturated copper/copper sulphate elctrode it generally amounts −0.1 to −0.4 V. In case of metal conductive connections with wide underground installations made of metal with more negative potential, it is cathodically polarised and thus reaches values up to approximately −0.5 V.

[4] In anaerobic soils the protective potential should be −0.95 V.

[5] Hot-dip galvanised steel, with a zinc coating according to the above mentioned table, has a closed external pure zinc layer. The potential of hot-dip galvanised steel in the soil corresponds therefore to approximately the stated value of zinc in the soil. In case of a loss of the zinc layer, the potential gets more positive. With its complete corresion it can reach the value of steel.

The potential of hot-dip galvanised steel in concrete has approximately the same initial values. In the course of time, the potential can get more positive. Values more positive than approx. −0.75 V, however, have not been found yet.

Heavily hot-dip galvanised copper with a zinc layer of min. 70 µm has also a closed external pure zinc layer. The potential of hot-dip galvanised copper in soil corresponds therefore to approx. the stated value of zinc in soil. In case of a thinner zinc layer or a corrosion of the zinc layer, the potential gets more positive. Limit values have still not been defined yet.

Table 5.5.7.2.1   Potential values and corrosion rates of common metal materials
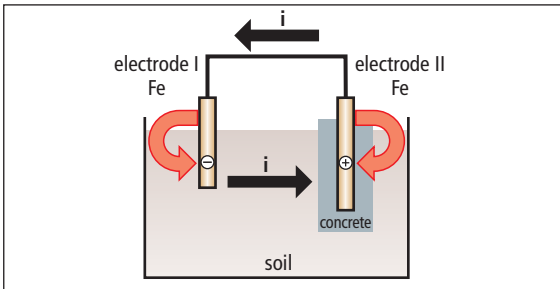
Fig. 5.5.7.2.3   Concentration cell: Iron in soil / iron in concrete
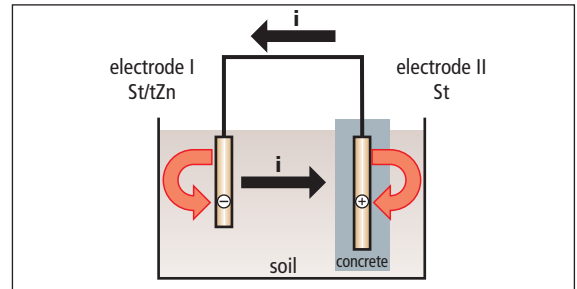
Fig. 5.5.7.2.4   Concentration cell: Galvanised steel in soil / steel (black) in concrete

the two electrodes enables the current i to flow and the electrode, which is electrochemically more negative, dissolves.

A concentration cell of this type can be formed, for example, by two iron electrodes, one of which is fixed in concrete while the other lies in the ground (**Figure 5.5.7.2.3**).

Connecting these electrodes, the iron in the concrete becomes the cathode of the concentration cell and the one in the ground becomes the anode; the latter is therefore destroyed by ion loss.

For electrochemical corrosion it is generally the case that, the larger the ions and the lower their charge, the greater the transport of metal associated with the current flow i, (i.e. i is proportional to the atomic mass of the metal).

In practice, the calculations are carried out with currents flowing over a certain period of time, e.g. over one year. **Table 5.5.7.2.1** gives values which express the effect of the corrosion current (current density) in terms of the quantity of metal dissolved. Corrosion current measurements thus make it possible to calculate in advance how many grammes of a metal will be eroded over a specific period.

Of more practical interest, however, is the prediction if, and over which period of time, corrosion will cause holes or pitting in earth electrodes, steel tanks, pipes etc. So it is important whether the prospective current attack will take place in a diffuse or punctiform way.

For the corrosive attack, it is not solely the magnitude of the corrosion current which is decisive, but also, in particular, its density, i.e. the current per unit of area of the discharge area.

It is often not possible to determine this current density directly. In such cases, this is managed with potential measurements the extent of the avail-

able "polarisation" can be taken from. The polarisation behaviour of electrodes is discussed only briefly here.

Let us consider the case of a galvanised steel strip situated in the ground and connected to the (black) steel reinforcement of a concrete foundation (**Figure 5.5.7.2.4**). According to our measurements, the following potential differences occur here with respect to the copper sulphate electrode:

steel, (bare) in concrete: – 200 mV
steel, galvanised, in sand: – 800 mV

Thus there is a potential difference of 600 mV between these two metals. If they are now connected above ground, a current i flows in the outer circuit from reinforced concrete to the steel in the sand, and in the ground from the steel in the sand to the steel in the reinforcement.

The magnitude of the current i is now a function of the voltage difference, the conductance of the ground and the polarisation of the two metals.

Generally, it is found that the current i in the ground is generated by changes in the material.

But a change to the material also means that the voltage of the individual metals changes with respect to the ground. This potential drift caused by the corrosion current i is called polarisation. The strength of the polarisation is directly proportional to the current density. Polarisation phenomena now occur at the negative and positive electrodes. However, the current densities at both electrodes are mostly different.

For illustration, we consider the following example:

A well-insulated steel gas pipe in the ground is connected to copper earth electrodes.

If the insulated pipe has only a few small spots where material is missing, there is a higher current density at these spots resulting in rapid corrosion of the steel.

In contrast, the current density is low over the much larger area of the copper earth electrodes where the current enters.

Thus the polarisation is greater at the more negative insulated steel conductor than at the positive copper earth electrodes. The potential of the steel conductor is shifted to more positive values. Thus, the potential difference across the electrodes decreases as well. The magnitude of the corrosion current is therefore also a function of the polarisation characteristics of the electrodes.

The strength of the polarisation can be estimated by measuring the electrode potentials for a split circuit. The circuit is split in order to avoid the voltage drop in the electrolyte. Recording instruments are usually used for such measurements since there is frequently a rapid depolarisation immediately after the corrosion current is interrupted.

If strong polarisation is now measured at the anode (the more negative electrode), i.e. if there is an obvious shift to more positive potentials, then there is a high risk that the anode will corrode.

Let us now return to our corrosion cell-steel (bare) in concrete/steel, galvanised in the sand (**Figure 5.5.7.2.4**). With respect to a distant copper sulphate electrode, it is possible to measure a potential of the interconnected cells of between −200 mV and −800 mV. The exact value depends on the ratio of the anodic to cathodic area and the polarisability of the electrodes.

If, for example, the area of the reinforced concrete foundation is very large compared to the surface of the galvanised steel wire, then a high anodic current density occurs at the latter, so that it is polarised to almost the potential of the reinforcement steel and destroyed in a relatively short time.

High positive polarisation thus always indicates an increased risk of corrosion.

In practice it is, of course, now important to know the limit above which a positive potential shifting means an acute risk of corrosion. Unfortunately, it is not possible to give a definite value, which applies in every case; the effects of the soil conditions alone are too various. It is, however, possible to stipulate fields of potential shifting for natural soils.

Summary:
A polarisation below +20 mV is generally non-hazardous. Potential shifts exceeding +100 mV are definitely hazardous. Between 20 and 100 mV there will always be cases where the polarisation causes considerable corrosion phenomena.

To summarise, one can stipulate:
The precondition for the formation of corrosion cells (voltaic cells) is always the presence of metal and electrolytic anodes and cathodes connected to be conductive.

Anodes and cathodes are formed from:
⇒ **Materials**
  • different metals or different surface conditions of a metal (contact corrosion),
  • different structural components (selective or intercrystalline corrosion),
⇒ **Electrolytes**
  • different concentration (e.g. salinity, ventilation).

In corrosion cells, the anodic fields always have a more negative metal/electrolyte potential than the cathodic fields.

The metal/electrolyte potentials are measured using a saturated copper sulphate electrode mounted in the immediate vicinity of the metal in or on the ground. If there is a metal conductive connection between anode and cathode, then the potential difference gives rise to a d.c. current in the electrolyte which passes from the anode into the electrolyte by dissolving metal before entering again the cathode.

The "area rule" is often applied to estimate the average anodic current density J_A:

$$ J_A = \frac{U_C - U_A}{\varphi_C} \cdot \frac{A_C}{A_A} \text{ in A/m}^2 $$

J_A Average anodic current density

U_A, U_C Anode or cathode potentials in V

φ_C Specific polarisation resistance of the cathode in Ωm^2

A_A, A_C Anode or cathode surface m^2

The polarisation resistance is the ratio of the polarisation voltage and the total current of a mixed electrode (an electrode where more than one electrode reaction takes place).

In practice, it is indeed possible to determine the driving cell voltages $U_C - U_A$ and the size of the areas A_C and A_A as an approximation for estimating the rate of corrosion. The values for φ_A (specific polarisation resistance of the anode) and φ_C, however, are not available to a sufficient degree of accuracy. They depend on the electrode materials, the electrolytes and the anodic and cathodic current densities.

The results of examinations available until now allow the conclusion that φ_A is much smaller than φ_C.

To φ_C applies:

steel in the ground	approx. 1 Ωm^2
copper in the ground	approx. 5 Ωm^2
steel in concrete	approx. 30 Ωm^2

From the area rule, however, it is clear, that powerful corrosion phenomena occur both on enclosed steel conductors and tanks with small spots in the sheath where material is missing, connected to copper earth electrodes, and also on earthing conductors made of galvanised steel connected to extended copper earth-termination systems or extremely large reinforced concrete foundations.

By choosing suitable materials it is possible to avoid or reduce the risk of corrosion for earth electrodes. To achieve a satisfactory service life, material minimum dimensions must be maintained (**Table 5.5.8.1**).

5.5.7.3 Choice of earth electrode materials

Table 5.5.8.1 is a compilation of the earth electrode materials and minimum dimensions usually used today.

Hot-dip galvanised steel

Hot-dip galvanised steel is also suitable for embedding in concrete. Foundation earth electrodes, earth electrodes and equipotential bonding conductors made of galvanised steel in concrete may be connected with reinforcement iron.

Steel with copper sheath

In the case of steel with copper sheath, the comments for bare copper apply to the sheath material. Damage to the copper sheath, however, creates a high risk of corrosion for the steel core, hence a complete closed copper layer must always be present.

Bare copper

Bare copper is very resistant due to its position in the electrolytic insulation rating. Moreover, in combination with earth electrodes or other installations in the ground made of more "base" materials (e.g. steel), it has additional cathodic protection, albeit at the expense of the more "base" metals.

Stainless steels

Certain high-alloy stainless steels according to EN 10088 are inert and corrosion-resistant in the ground. The free corrosion potential of high-alloy stainless steels in normally aerated soils is mostly close to the value of copper.

The surface of stainless steel earth electrode materials passivating within a few weeks, they are neutral to other (more inert and base) materials.

Stainless steels shall contain at least 16 % chrome, 5 % nickel and 2 % molybdenum.

Extensive measurements have shown that only a high-alloy stainless steel with the Material No. 1.4571, for example, is sufficiently corrosion-resistant in the ground.

Other materials

Other materials can be used if they are particularly corrosion-resistant in certain environments or are at least equally as good as the materials listed in **Table 5.5.8.1**.

5.5.7.4 Combination of earth electrodes made of different materials

The cell current density resulting from the combination of two different metals installed in the earth to be electrically conductive, leads to the corrosion of the metal acting as the anode (**Table 5.5.7.4.1**). This essentially depends on the ratio of the magnitude of the cathodic area A_C to the magnitude of the anodic area A_A.

The "Corrosion behaviour of earth electrode materials" research project has found the following with respect to the choice of earth electrode materials, particularly regarding the combination of different materials:

A higher degree of corrosion is only to be expected if the ratio of the areas is

$$\frac{A_C}{A_A} > 100$$

Generally, it can be assumed that the material with the more positive potential will become the cathode. The anode of a corrosion cell actually present can be recognised by the fact that it has the more negative potential when opening the metal conductive connection.

Connecting steel installations in the ground, the following earth electrode materials always behave as cathodes in (covering) soils:

– bare copper,
– tin-coated copper,
– high-alloy stainless steel.

Steel reinforcement of concrete foundations

The steel reinforcement of concrete foundations can have a very positive potential (similar to copper). Earth electrodes and earthing conductors connected directly to the reinforcement of large reinforced concrete foundations should therefore be made of stainless steel or copper.

This also applies particularly to short connecting cables in the immediate vicinity of the foundations.

Installation of isolating spark gaps

As already explained, it is possible to interrupt the conductive connection between systems with very different potentials installed in the ground by integrating isolating spark gaps. Normally, then it

Material with small area	Material with great area			
	Galvanised steel	Steel	Steel in concrete	Copper
Galvanised steel	+	+ zinc removal	–	–
Steel	+	+	–	–
Steel in concrete	+	+	+	+
Steel with Cu coating	+	+	+	+
Copper/StSt	+	+	+	+
+ combinable – not combinable				

Table 5.5.7.4.1 Material combinations of earth-termination systems for different area ratios (A_C > 100 x A_A)

is no longer possible for corrosion currents to flow. At upcoming surges, the isolating spark gap operates and interconnects the installations for the duration of the surges. However, isolating spark gaps must not be installed for protective and operating earth electrodes, since these earth electrodes must always be connected to the plant.

5.5.7.5 Other anticorrosion measures

Galvanised steel connecting cables from foundation earth electrodes to down conductors

Galvanised steel connecting cables from foundation earth electrodes to down conductors shall be laid in concrete or masonry up to above the surface of the earth.

If the connecting cables are led through the ground, galvanised steel must be equipped with concrete or synthetic sheathing or, alternatively,

terminal lugs with NYY cable, stainless steel or fixed earthing terminals must be used.

Within the masonry, the earth conductors can also be led upwards without corrosion protection.

Earth entries made of galvanised steel

Earth entries made of galvanised steel must be protected against corrosion for a distance of at least 0.3 m above and below the surface of the earth.

Generally, bitumen coatings are not sufficient. Sheathing not absorbing moisture offers protection, e.g. butyl rubber strips or heat-shrinkable sleeves.

Underground terminals and connections

Cut surfaces and connection points in the ground must be designed to ensure that the corrosion resistance of the corrosion protection layer of the earth electrode material is the same for both. Connection points in the ground must therefore be equipped with a suitable coating, e.g. sheathed with an anticorrosive band.

Corrosive waste

When filling ditches and pits to install earth electrodes, pieces of slag and coal must not come into immediate contact with the earth electrode material; the same applies to construction waste.

Material	Configuration	Min. dimensions			Notes
		Earth rod Ø mm	Earth conductor	Earth plate mm	
Copper	stranded[3]		50 mm²		min. diameter of each strand 1.7 mm
	solid round material[3]		50 mm²		diameter 8 mm
	solid flat material[3]		50 mm²		min. thickness 2 mm
	solid round material	15[8]			
	pipe	20			min. wall thickness 2 mm
	solid plate			500 x 500	min. thickness 2 mm
	grid-type plate			600 x 600	section 25 mm x 2 mm, min. length of grid construction: 4.8 m
Steel	galvanised solid round material[1, 2]	16[9]	diameter 10 mm		
	galvanised pipe[1, 2]	25			min. wall thickness 2 mm
	galvanised solid flat material[1]		90 mm²		min. thickness 3 mm
	galvanised solid plate[1]			500 x 500	min. thickness 3 mm
	galvanised grid-type plate[1]			600 x 600	section 30 mm x 3 mm
	copper-plated solid round material[4]	14			min. 250 µm coating with 99.9 % copper
	bare solid round material[5]		diameter 10 mm		
	bare or galvanised solid flat material[5, 6]		75 mm²		min. thickness 3 mm
	galvanised cable[5, 6]		70 mm²		min. diameter of every wire 1.7 mm
Stainless Steel[7]	solid round material	15	diameter 10 mm		
	solid flat material		100 mm²		min. thickness 2 mm

[1] The coating must be smooth, continuous and free of residual flux, mean value 50 µm for round and 70 µm for flat material.

[2] Threads must be tapped before galvanising.

[3] Can also be tin-coated.

[4] The copper must be connected unresolvably with the steel.

[5] Only permitted, if embedded completely in concrete.

[6] Only permitted for the part of the foundation in contact with the earth, if connected safely with the reinforcement every 5 m.

[7] Chrome ≥ 16 %, nickel ≥ 5 %, molybdenum ≥ 2 %, carbon ≤ 0,08 %.

[8] In some countries 12 mm are permitted.

[9] Some countries require earth lead-in rods to connect down conductor and earth electrode.

Table 5.5.8.1   Material, configuration and min. dimensions of earth electrodes according to IEC 62305-3 (EN 62305-3) Table 7

5.5.8 Materials and minimum dimensions for earth electrodes

Table 5.5.8.1 illustrates the minimum cross sections, shape and material of earth electrodes.

5.6 Electrical isolation of the external lightning protection system – Separation distance

There is a risk of uncontrolled flashovers between components of the external lightning protection system and metal and electrical installations within the structure, if there is insufficient distance between the air-termination or down-conductor system on one hand, and metal and electrical installations within the structure to be protected, on the other.

Metal installations such as water and air conditioning pipes and electric power lines, produce induction loops in the structure which are induced by impulse voltages due to the rapidly changing magnetic lightning field. These impulse voltages must be prevented from causing uncontrolled flashovers which can also possibly cause a fire.
Flashovers on electric power lines, for example, can cause enormous damage to the installation and the connected consumers. **Figure 5.6.1** illustrates the principle of separation distance.
The formula for calculating the separation distance is difficult for the practitioner to apply.

The formula is:

$$s = k_i \ \frac{k_c}{k_m} \ \cdot \ l(m)$$

k_i is a function of the class of lightning protection system chosen (induction factor),

k_c is a function of the geometric arrangement (current splitting coefficient),

k_m is a function of the material in the point of proximity (material factor) and

l (m)   is the length of the air-termination system or down-conductor system from the point at which the separation distance shall be determined to the next point of equipotential bonding.

The coefficient k_i (induction factor) of the corresponding class of lightning protection system represents the threat from the steepness of the current.

Factor k_c takes into consideration the splitting of the current in the down-conductor system of the external lightning protection system. The standard gives different formulae for determining k_c. In order to achieve the separation distances which still can be realised in practice, particularly for higher structures, it is recommended to install ring conductors, i.e. to intermesh the down conductors. This intermeshing balances the current flow, which reduces the required separation distance.
The material factor k_m takes into consideration the insulating characteristics of the surroundings. This calculation assumes the electrical insulating characteristics of air to be a factor of 1. All other solid materials used in the construction industry (e.g. masonry, wood, etc.) insulate only half as well as air.

Further material factors are not given. Deviating values must be proved by technical tests. A factor of 0.7 is specified for the GRP material (glass-fibre reinforced plastic) used in the products of the isolated air-termination systems from DEHN + SÖHNE (DEHNiso distance holder, DEHNiso Combi). This
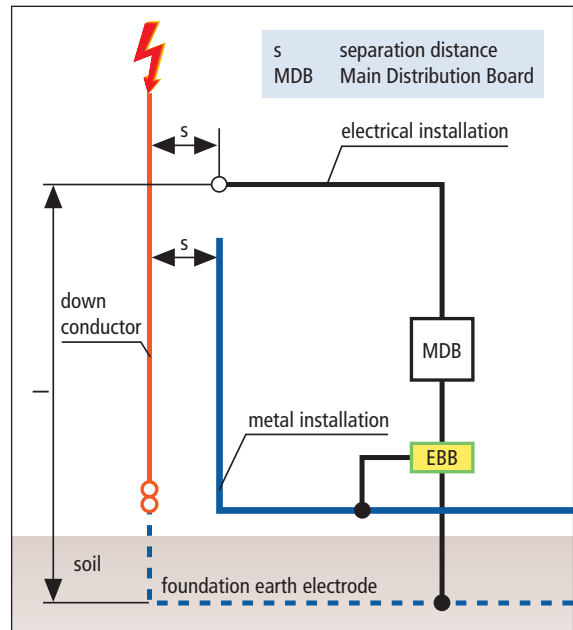
Fig. 5.6.1   Illustration – Separation distance
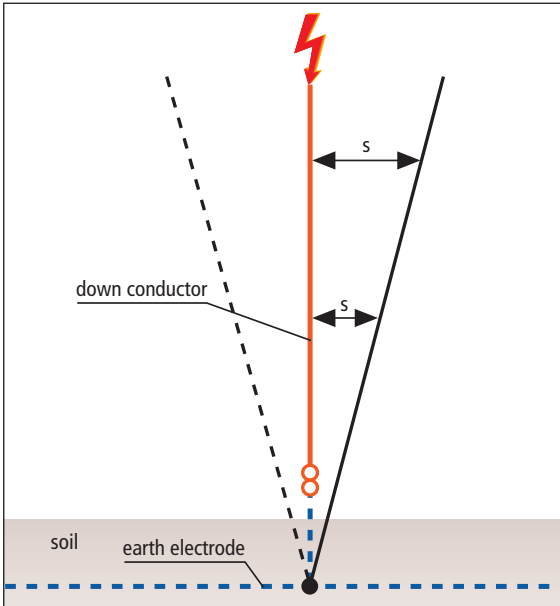
Fig. 5.6.2   Potential difference with increasing height

Fig. 5.6.3   Air-termination mast with $k_c = 1$

factor can be used for calculation in the same way as the other material factors.

Length l is the actual length along the air-termination system or down-conductor system from the point at which the separation distance to the next point of equipotential bonding or the next lightning equipotential bonding level shall be determined.

Each structure with lightning equipotential bonding has an equipotential surface of the foundation earth electrode or earth electrode near the surface of the earth. This surface is the reference plane for determining the distance l.

If a lightning equipotential bonding level is to be created for high structures, then for a height of 20 m, for example, the lightning equipotential bonding must be carried out for all electrical and electronic conductors and all metal installations. The lightning equipotential bonding must be realised by using **surge protective devices Type I**.

Otherwise, even for high structures, the equipotential surface of the foundation earth electrode/earth electrode shall be used as reference point and basis for the length l. Higher structures

are making it more and more difficult to maintain the required separation distances.

The potential difference between the structure's installations and the down conductors is equal to zero near the earth's surface. The potential difference increases with increasing height. This can be imagined as a cone standing on its tip (**Figure 5.6.2**).

Hence, the separation distance to be maintained is greatest at the tip of the building or on the surface of the roof and becomes less towards the earth-termination system.

This requires a multiple calculation of the distance from the down conductors with a different distance l.

The calculation of the current splitting coefficient k_c is often difficult because of the different structures.

If a single air-termination rod is erected next to the structure, for example, the total lightning current flows in this one air-termination conductor and down conductor. Factor k_c is therefore equal to 1.

The lightning current cannot split here. Therefore it is often difficult to maintain the separation dis-

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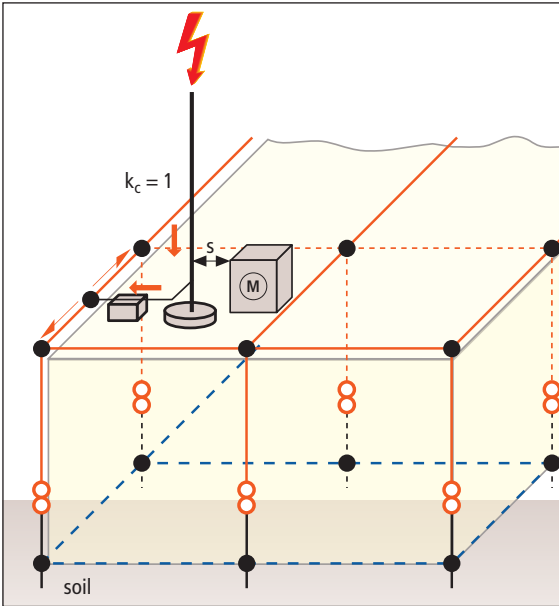
Fig. 5.6.4 Flat roof with air-termination rod and ventilation outlet

tance. In **Figure 5.6.3**, this can be achieved by erecting the mast further away from the structure. Almost the same situation occurs for air-termination rods e.g. for roof-mounted structures. Until it reaches the next connection of the air-termination rod to the air-termination or down conductor. This defined path carries 100 % ($k_c = 1$) of the lightning current (**Figure 5.6.4**).

If two air-termination rods or air-termination masts have a cable spanned between them, the lightning current can split between two paths (**Figure 5.6.5**). Owing to the different impedances, however, the splitting is not always 50 % to 50 %, since the lightning flash does not always strike the exact centre of the arrangement but can also strike along the length of the air-termination system.
The most unfavourable case is taken into account by calculating the factor k_c in the formula.
This calculation assumes an earth-termination system Type B. If single earth electrodes Type A are existing, these must be interconnected.

$$k_c = \frac{h + c}{2h + c}$$

h   length of the down conductor
c   mutual distance of the air-termination rods or air-termination masts

The following example illustrates the calculation of the coefficient for a gable roof with two down conductors (**Figure 5.6.6**). An earth-termination system Type B (ring or foundation earth electrode) is existing.

$$k_c = \frac{9 + 12}{2 \cdot 9 + 12} = 0.7$$

Fig. 5.6.5 Determination of k_c with two masts with overspanned cable and an earth electrode Type B
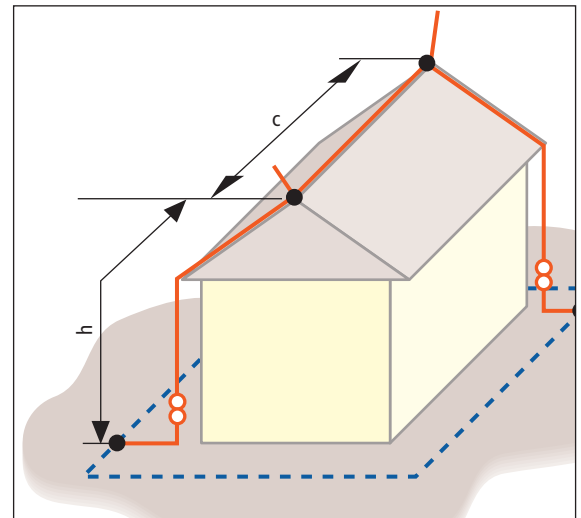
Fig. 5.6.6 Determination of k_c for a gable roof with 2 down conductors
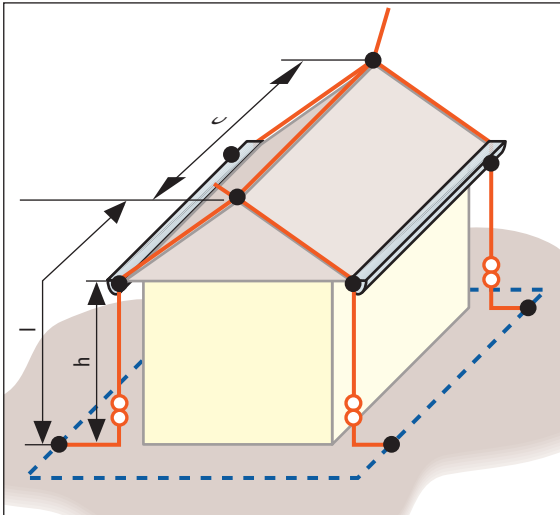
Fig. 5.6.7 Gable roof with 4 down conductors

The arrangement of the down-conductor system shown in **Figure 5.6.6** should no longer be installed, not even on a detached house either. The current splitting coefficient is significantly improved by using two further down conductors, i.e. a total of 4 (**Figure 5.6.7**). The following formula is used in the calculation:

$$k_c = \frac{1}{2n} + 0.1 + 0.2 \sqrt[3]{\frac{c}{h}}$$

h   length of the down conductor up to the eaves gutter of the building as worst point for a lightning input

c   mutual distance of the down conductors

n   is the total number of down conductors

$$k_c = \frac{1}{2 \cdot 4} + 0.1 + 0.2 \sqrt[3]{\frac{12}{4}}$$

Result: **k_c ≈ 0.51**

For structures with flat roofs, the current splitting coefficient is calculated as follows. In this case, an earth electrode arrangement Type B is a precondition (**Figure 5.6.8**).

$$k_c = \frac{1}{2n} + 0.1 + 0.2 \sqrt[3]{\frac{c}{h}}$$

h   plumb distance, height of the building

c   mutual distance of the down conductors

n   the total number of down conductors

The distances of the down conductors are assumed to be equal. If not, c is the greatest distance.

If electrical structures or domelights are located on the flat roof (**Figure 5.6.9**), then two current splitting coefficients must be taken into account when calculating the separation distance. For the air-termination rod, k_c = 1 to the next air-termination/down conductor.
The calculation of the current splitting coefficient k_c for the subsequent course of the air-termination system and down conductors is performed as explained above. For illustration, the separation distance s for a flat roof with roof-mounted structures is determined below.

Example:
Domelights were installed on a structure with a lightning protection system Class III. They are controlled electrically.

Structure data:

⇒   Length 40 m
    Width 30 m

    Height 14 m

⇒   Earth-termination system, foundation earth electrode Type B

⇒   Number of down conductors: 12

⇒   Distance of the down conductors:
    min. 10 m
    max. 15 m

⇒   Height of the electrically controlled domelights: 1.5 m

The calculation of the current splitting coefficient k_c for the structure is:

$$k_c = \frac{1}{2 \cdot 12} + 0.1 + 0.2 \sqrt[3]{\frac{15}{14}}$$

Result: **k_c ≈ 0.35**
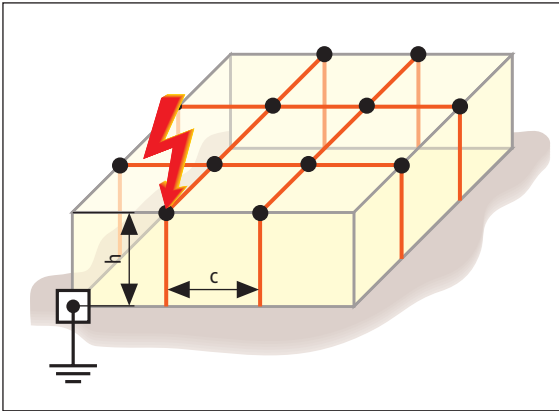
Fig. 5.6.8 Value of coefficient k_c in case of a meshed network of air-termination conductors and an earthing Type B

Fig. 5.6.9 Material factors of an air-termination rod on a flat roof

It is not necessary to calculate the factor k_c for the air-termination rod k_c = 1.

For the calculation of the current splitting the air-termination rod is assumed to be positioned at the edge of the roof and not within the mesh of the air-termination system. If the air-termination rod is within the mesh, the current splitting and the shortest length in the mesh has to be considered additionally.

Calculation of the separation distance for the top edge of the roof of the structure:

The material factor k_m is set as for solid building material k_m = 0.5.

$$ s = 0.04 \; \frac{0.35}{0.5} \; 14 (m) $$

Result: **s ≈ 0.39 m**

Calculation of the separation distance for the air-termination rod:

The material factor is k_m = 0.5 because of the position of the air-termination rod on the flat roof.

$$ s = 0.04 \; \frac{1}{0.5} \; 1.5 (m) $$

Result: **s = 0.12 m**

This calculated separation distance would be correct if the air-termination rod were erected on the surface of the earth (lightning equipotential bonding level).

In order to obtain the separation distance completely and correctly, the separation distance of the structure must be added.

S_{tot} = $s_{structure}$ + $s_{air-termination\ rod}$
       = 0.39 m + 0.12 m

S_{tot} = 0.51 m

This calculation states that a separation distance of 0.51 m must be maintained at the uppermost point of the domelight. This separation distance was determined using the material factor 0.5 for solid materials.

Erecting the air-termination rod with a concrete base, the "full insulating characteristics" of the air are not available at the foot of the air-termination rod (**Figure 5.6.9**). At the foot of the concrete base a separation distance of $s_{structure}$ = 0.39 (solid material) is sufficient.

If lightning equipotential bonding levels are created for high structures at different heights by integrating all metal installations and all electrical and electronic conductors by means of lightning current arresters (SPD Type I), then the following calculation can be carried out. This involves calculating distances to conductors installed on only one lightning equipotential bonding level, and also to those installed over several levels.
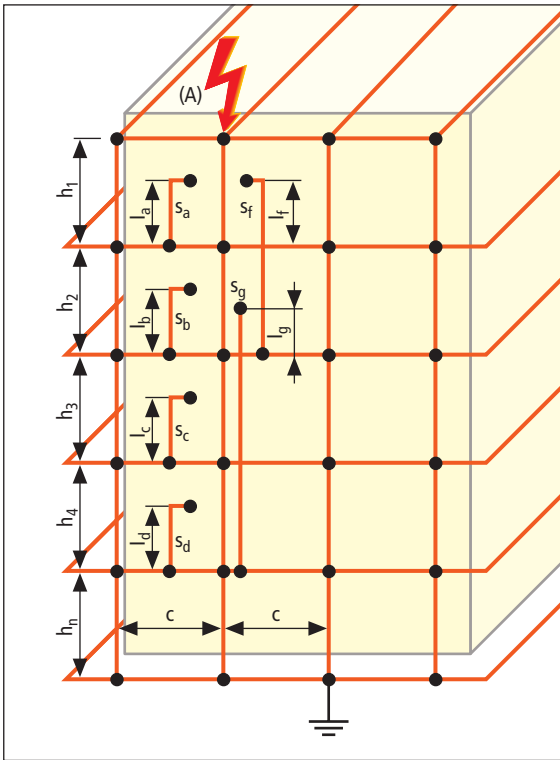
Fig. 5.6.10   Value of coefficient k_c in case of an intermeshed network of air-termination, ring conductors interconnecting the down conductors and an earthing Type B

This assumes an earth-termination system in form of a foundation or ring earth electrode (Type B) or a meshed network (**Figure 5.6.10**).

As previously explained, supplementary ring conductors can be installed around the structure (truss) to balance the lightning current. This has a positive effect on the separation distance. **Figure 5.6.10** illustrates the principle of ring conductors around the structure, without installing a lightning equipotential bonding level by using lightning current arresters at the height of the ring conductors.

The individual segments are assigned different current splitting coefficients k_c. If the separation distance for a roof-mounted structure shall now be determined, the total length from the equipotential surface of the earth electrode to the uppermost tip of the roof-mounted structure must be used as the base (sum of the partial lengths). If the

total separation distance s_{tot} is to be determined, the following formula must be used for the calculation:

$$ s_{tot} = \frac{k_i}{k_m} \left(k_l \cdot l_{tot} + k_{c3} \cdot l_3 + k_{c4} \cdot l_4 \right) $$

With this design of supplementary ring conductors around the structure, it is still the case that no partial lightning currents whatsoever are conducted into the structure.

Even if the numerous down conductors and supplementary ring conductors do not allow a maintaining of the separation distance for the complete installation, it is possible to define the upper edge of the structure as the lightning equipotential bonding surface (+/–0). This roof-level lightning equipotential bonding surface is generally implemented for extremely high structures where it is physically impossible to maintain the separation distance.

This requires the integration of all metal installations and all electrical and electronic conductors into the equipotential bonding by means of lightning current arresters (SPD Type I). This equipotential bonding is also directly connected to the external lightning protection system. These previously described measures allow to set the separation distances on the upper edge of the structure to 0. The disadvantage of this type of design is that all conductors, metal installations, e.g. reinforcements, lift rails and the down conductors as well, carry lightning currents. The effect of these currents on electrical and electronic systems must be taken into account when designing the internal lightning protection system (surge protection).
It is advantageous to split the lightning current over a large area.

5.7 Step and touch voltages

IEC 62305-3 (EN 62305-3) draws attention to the fact that, in special cases, touch or step voltages outside a structure in the vicinity of the down conductors can present a life hazard even though the lightning protection system was designed according to the latest standards.
Special cases are, for example, the entrances or canopies of structures frequented by large num-

bers of people such as theatres, cinemas, shopping centres, where bare down conductors and earth electrodes are present in the immediate vicinity.

Structures which are particularly exposed (at risk of lightning strikes) and freely accessible to members of the public may also be required to have measures preventing intolerably high step and touch voltages.
These measures (e.g. potential control) are primarily applied to steeples, observation towers, mountain huts, floodlight masts in sports grounds and bridges.

Gatherings of people can vary from place to place (e.g. in shopping centre entrances or in the staircase of observation towers). Measures to reduce step and touch voltages are therefore only required in the areas particularly at risk.
Possible measures are potential control, isolation of the site or the additional measures described below. The individual measures can also be combined with each other.

Definition of touch voltage
Touch voltage is a voltage acting upon a person between his position on the earth and when touching the down conductor.
The current path leads from the hand via the body to the feet (**Figure 5.7.1**).

For a structure built with a steel skeleton or reinforced concrete, there is no risk of intolerably high touch voltages provided that the reinforcement is safely interconnected or the down conductors are installed in concrete.
Moreover, the touch voltage can be disregarded for metal facades if they are integrated into the equipotential bonding and/or used as natural components of the down conductor.

If there is a reinforced concrete with a safe tying of the reinforcement to the foundation earth electrode under the surface of the earth in the areas outside the structure which is at risk, then this measure already improves the curve of the gradient area and acts as a potential control. Hence step voltage can be left out of the considerations.

The following measures can reduce the risk of someone being injured by touching the down conductor:

⇒ The down conductor is sheathed in insulating material (min. 3 mm crosslinked polyethylene with an impulse withstand voltage of 100 kV 1.2/50 µs).

⇒ The position of the down conductors can be changed, e.g. not in the entrance of the structure.

⇒ The probability of people accumulating can be reduced with information or prohibition signs; barriers can also be used.

⇒ The specific resistance of the surface layer of the earth at a distance of up to 3 m around the down conductor must be not less than 5000 Ωm.

A layer of asphalt with a thickness of 5 cm, generally meets this requirement.

⇒ Compression of the meshed network of the earth-termination system by means of potential control.

Note
A downpipe, even if it is not defined as a down conductor, can present a hazard to persons touch-

U_E	Earth potential
U_t	Touch voltage
U_S	Step voltage
φ	Potential of earth surface
FE	Foundation earth electrode
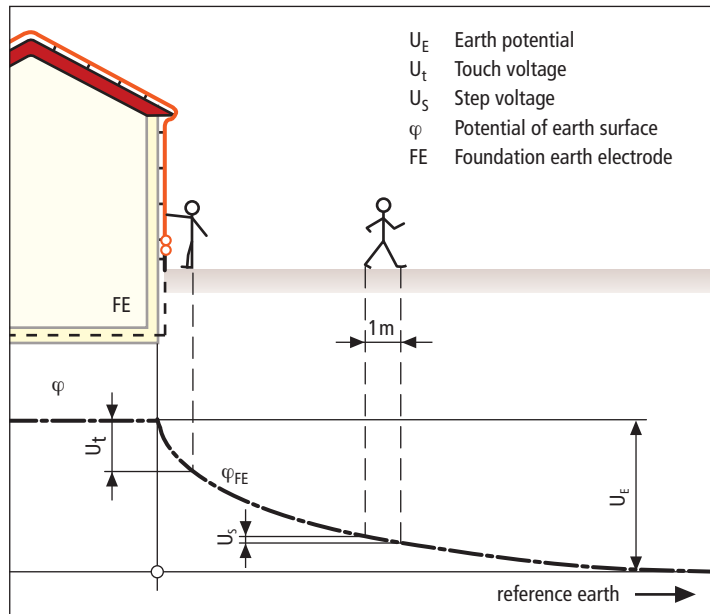
Fig. 5.7.1   Illustration of touch voltage and step voltage
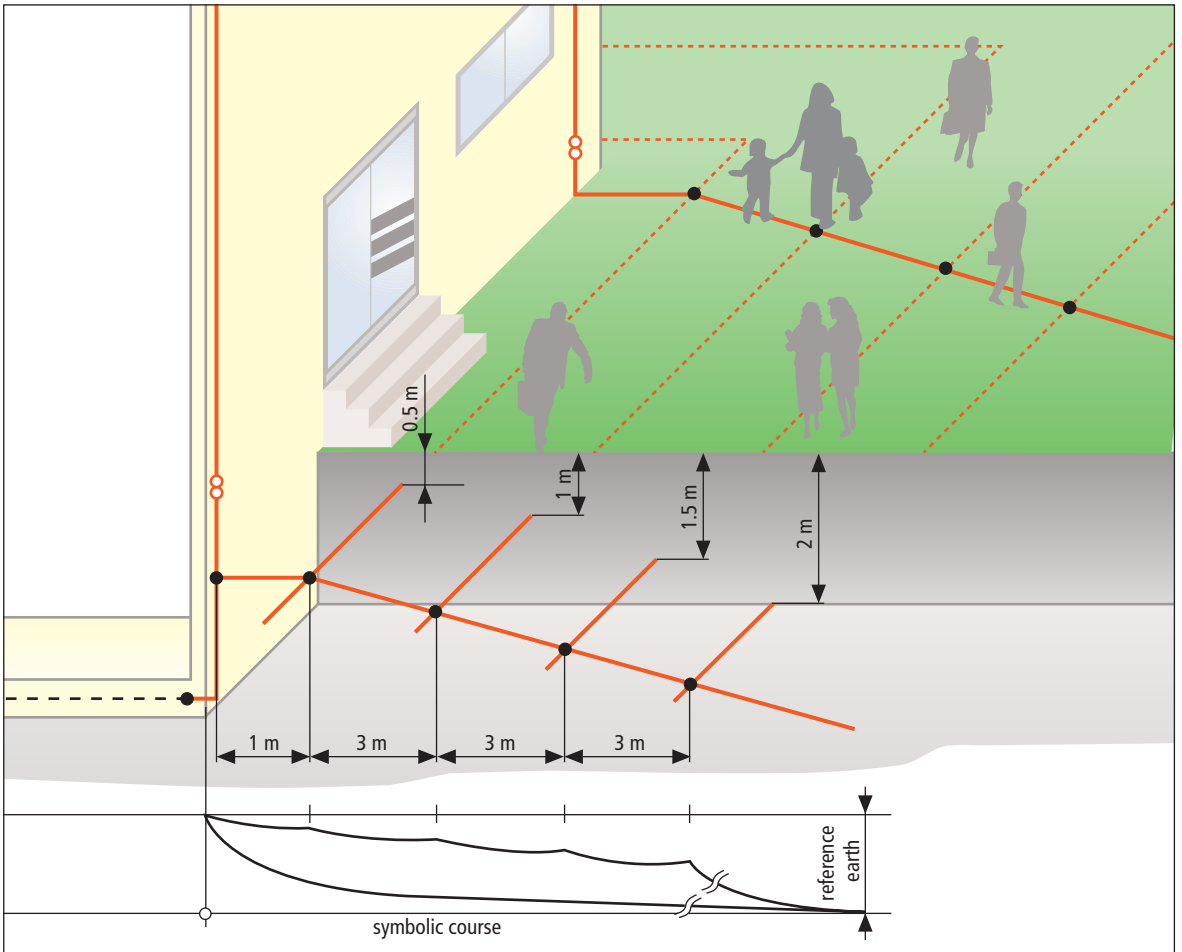
Fig. 5.7.2   Potential control – Illustration and symbolic course of the gradient area

ing it. In such a case, one possibility is to replace the metal pipe with a PVC one (height: 3 m).

Definition of step voltage

Step voltage is a part of the earthing potential which can be bridged by a person taking a step over 1 m. The current path runs via the human body from one foot to the other (**Figure 5.7.1**).

The step voltage is a function of the form of the gradient area.

As is evident from the illustration, the step voltage decreases as the distance from the structure increases. The risk to persons therefore decreases the more they are away from the structure.

The following measures can be taken to reduce the step voltage:

⇒   Persons can be prevented from accessing the hazardous areas (e.g. by barriers of fences)

⇒   Reducing the mesh size of the earthing installation network – potential control

⇒   The specific resistance of the surface layer of the earth at a distance of up to 3 m around the down-conductor system must be not less than 5000 Ωm.

A layer of asphalt with a thickness of 5 cm, or a 15 cm thick bed of gravel generally meets this requirement
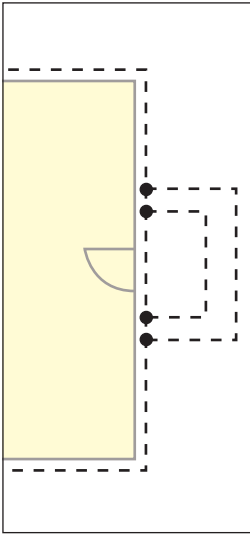
Fig. 5.7.3 Possible potential control in entrance area of the building
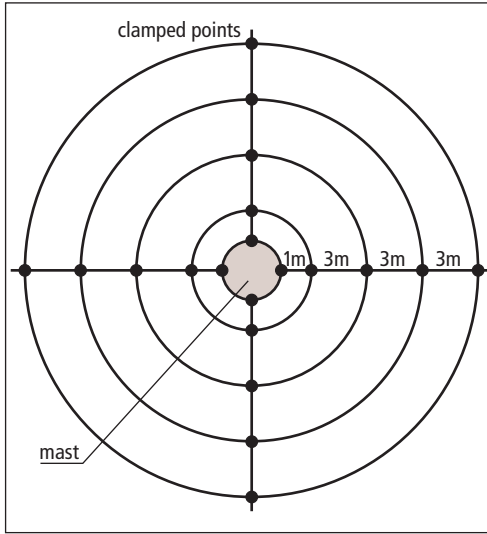
Fig. 5.7.4 Potential control performance for a flood light or cell site mast
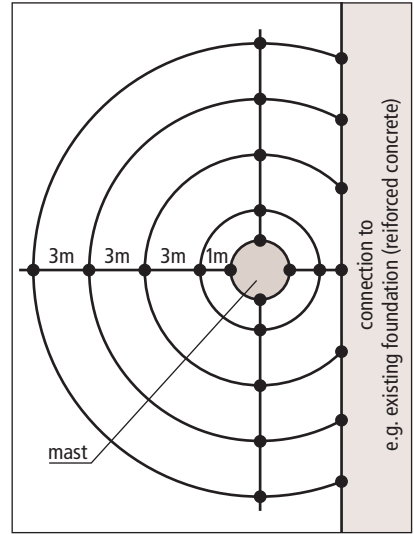
Fig. 5.7.5 Connection control at the ring/foundation earth electrode

If a large number of people frequently congregate in a hazardous area near to the structure to be protected, then a potential control must be provided to protect them.

The potential control is sufficient if the resistance gradient on the surface of the earth in the field to be protected does not exceed 1 Ω/m.
To achieve this, an existing foundation earth electrode should be supplemented by a ring earth electrode installed at a distance of 1 m and a depth of 0.5 m. If the structure already has an earth-termination system in form of a ring earth electrode, this is already "the first ring" of the potential control.

Additional ring earth electrodes should be installed at a distance of 3 m from the first one and

	Distance from the building	Depth
1st ring	1 m	0.5 m
2nd ring	4 m	1.0 m
3rd ring	7 m	1.5 m
4th ring	10 m	2.0 m

Table 5.7.1 Ring distances and depths of the potential control

the subsequent ones. The depth of the ring earth electrode shall be increased (in steps of 0.5 m) the more it is away from the structure (see **Table 5.7.1**).

If a potential control is implemented for a structure, it must be installed as follows (**Figure 5.7.2** and **5.7.3**):
The down conductors must be connected to all the rings of the potential control.
The individual rings must be connected at least twice, however (**Figure 5.7.4**).

If ring earth electrodes (control earth electrodes) cannot be designed to be circular, their ends must be connected to the other ends of the ring earth electrodes. There should be at least two connections within the individual rings (**Figure 5.7.5**).

When choosing the materials for the ring earth electrodes, attention must be paid to the possible corrosion load (Chapter 5.5.7).

Stainless steel V4A (Material No. 1.4571) has proved to be a good choice for taking the formation of voltaic cells between foundation and ring earth electrodes into account.

Cables Ø 10 mm or flat strips 30 mm x 3.5 mm can be installed as ring earth electrodes.

5.7.1 Control of the touch voltage at down conductors of lightning protection systems

The hazardous area of touch and step voltages for persons outside of a building is within the distance of 3 m to the building and up to a height of 3 m. This height of the area to be protected corresponds to the level which a person can reach with his hand plus an additional separation distance s (**Figure 5.7.1.1**).

Special measures of protection are required, for example, for the entrances or canopies of structures highly frequented such as theatres, cinemas, shopping centres, kindergartens where non-insulated down conductors and earth electrodes are nearby.

Structures which are particularly exposed (at risk of lightning strikes) and freely accessible to members of the public, for example mountain huts, may also be required to have measures preventing intolerably high touch voltages. Moreover life hazard is considered as parameter L1 (injury or death of persons) in the risk analyse of a structure according to IEC 62305-2 (EN 62305-2).

The following measures can reduce the risk of touch voltage:

⇒ The down conductor is sheathed in insulating material (min. 3 mm polymerised polyethylene with an impulse withstand voltage of 100 kV (1.2/50 μs).

⇒ The position of the down conductors is changed, (e.g. down conductors are not installed in the entrance of the structure).

⇒ The specific resistance of the surface layer of the earth at a distance of up to 3 m around the down conductor is at least 5 kΩm.

⇒ The probability of people accumulating can be reduced by information or prohibition signs; barriers can also be used.

The measures of protection against touch voltage may be insufficient with regard to an effective protection of people. The required high-voltage resistant coating of an exposed down conductor, for example is not enough if there are no additional measures of protection against creep-flashovers at the surface of the insulation. This is particularly important if environmental influences such as rain (humidity) are to be considered.

Just like at a bare down conductor, high voltages occurs at an insulated down conductor in case of a lightning strike. This voltage, however, is separated from people by the insulation. The human body being a very good conductor compared with the insulator, the insulating layer is stressed by almost the whole touch voltage. If the insulation does not cope with the voltage, part of the lightning current might flow to the earth via the human body as in case of the bare down conductor. Safe protection against life hazard due to touch voltage requires to prevent from flashover through the insulation and from creep-flashovers along the insulation.

A balanced system solution as provided by the CUI conductor meets these requirements of electric
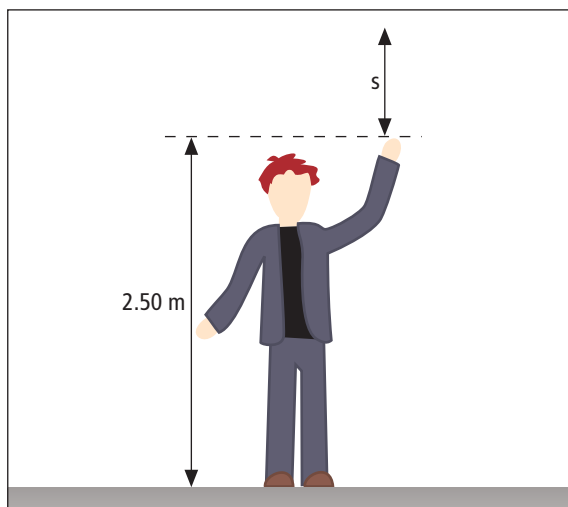
Fig. 5.7.1.1   Area to be protected for a person
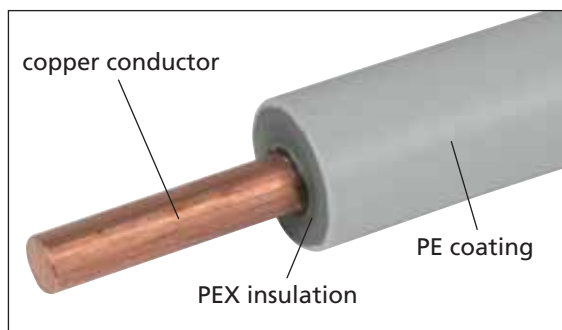
Fig. 5.7.1.2   Structure of the CUI conductor

Fig. 5.7.1.3   Withstand voltage test under sprinkling

strength and creep-flashover insulation to protect against touch voltage.

Structure of the CUI conductor

A copper conductor with a cross section of 50 mm^2 is coated with an insulating layer of surge proof cross-linked polyethylene (PEX) of approx. 6 mm thickness (**Figure 5.7.1.2**).

The insulated conductor has an additional thin polyethylene (PE) layer for protection against external influences. The insulated down conductor CUI is installed vertically in the whole hazard area,
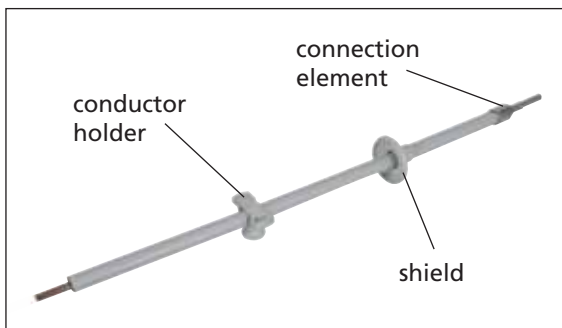
Fig. 5.7.1.4   CUI conductor

i.e. from the earth surface level up to a height of 3 m. The upper end of the conductor is connected to the down conductor coming from the air-termination system, the lower end to the earth-termination system.

Not only the electric strength of the insulation but also the risk of creep-flashovers between the terminal point at the bare down conductor and the hand of the touching person has to be considered. This problem of creeping discharges, well-known in high voltage engineering, is getting worse in case of rain, for example. Tests have shown that under sprinkling the flashover distance can be more than 1 m at an insulated down conductor without additional measures. A suitable shield on the insulated down conductor keeps the CUI conductor dry enough to avoid a creep-flashover along the insulating surface. The operating safety of the CUI conductor with regard to the electric strength and the resistance against creep-flashovers at impulse voltages up to 100 kV (1.2/50 μs) has been tried and tested in withstand voltage tests under sprinkling conditions according to IEC 60060-1. At these sprinkling tests water of a certain conductivity and quantity is sprinkled on the conductor in an angle of approx. 45 ° (**Figure 5.7.1.3**).

The CUI conductor is prefabricated with connection element to be connected to the down conductor (inspection joint) and can be shortened on site if necessary for being connected to the earth-termination system. The product is available in lengths of 3.5 m or 5 m and with the necessary plastic or metal conductor holders (**Figure 5.7.1.4**). By the special CUI conductor the touch voltage at down conductors can be controlled with easy measures and little installation work. Hence the damage risk for persons in special areas will be considerably reduced.

Inductive coupling at a very great steepness of current

Regarding the damage risk for persons also the magnetic field of the arrangement with its influence on the closer surrounding of the down conductor has to be considered. In extended installation loops, for example, voltages of several 100 kV can occur near the down conductor which can result in high economic losses. Also the human body, due to its conductivity, together with the down conductor and the conductive earth, forms a

loop having a mutual inductance of M where high voltages U_i can be induced (**Figures 5.7.1.5a and 5.7.1.5b**). In this case the system arrester-person has the effect of a transformer.

This coupled voltage arises at the insulation, the human body and the earth being primarily considered as conductive. The voltage load becoming too high it results in a puncture or creeping flashover. The induced voltage then drives a current through this loop, the magnitude of which depends on the resistances and the self-inductance of the loop and means life hazard for the person concerned. Hence the insulation must withstand this voltage load. The normative specification of 100 kV at 1.2/50 µs includes the high but very short voltage impulses which are only applied as long as the current rises (0.25 µs in case of a negative subsequent lightning strike). The deeper the insulated down conductors are buried, the greater is the loop and thus the mutual inductance. Hence the induced voltage and the loading of the insulation increases correspondingly which also has to be taken into account with regard to the inductive coupling.

$$M = 0.2 \cdot h \cdot \ln\left(\frac{a}{r_{conductor}}\right)$$

$$U_i = M \cdot \frac{\Delta i}{\Delta t}$$
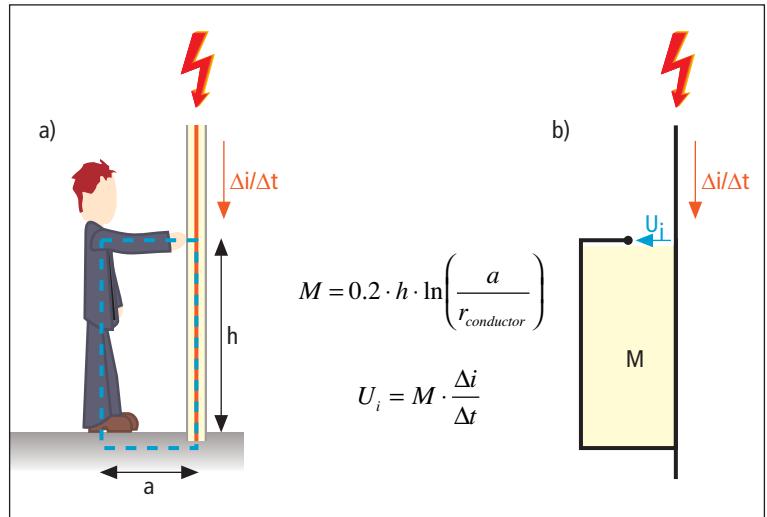
Fig. 5.7.1.5   (a) Loop formed by conductor and person
               (b) Mutual inductance M and induced voltage U_i

6. Internal lightning protection

6.1 Equipotential bonding for metal installations

Equipotential bonding according to IEC 60364-4-41 and IEC 60364-5-54

Equipotential bonding is required for all newly installed electrical power consumer's installations. Equipotential bonding according to IEC 60364 series removes potential differences, i.e. prevents hazardous touch voltages between the protective conductor of the low voltage electrical power consumer's installations and metal, water, gas and heating pipes, for example.

According to IEC 60364-4-41, equipotential bonding consists of the **main equipotential bonding (in future: protective equipotential bonding)** and the **supplementary equipotential bonding (in future: supplementary protective equipotential bonding)** Every building must be given a main equipotential bonding in accordance with the standards stated above (**Figure 6.1.1**).

The supplementary equipotential bonding is intended for those cases where the conditions for disconnection from supply cannot be met, or for special areas which conform to the IEC 60364 series Part 7.
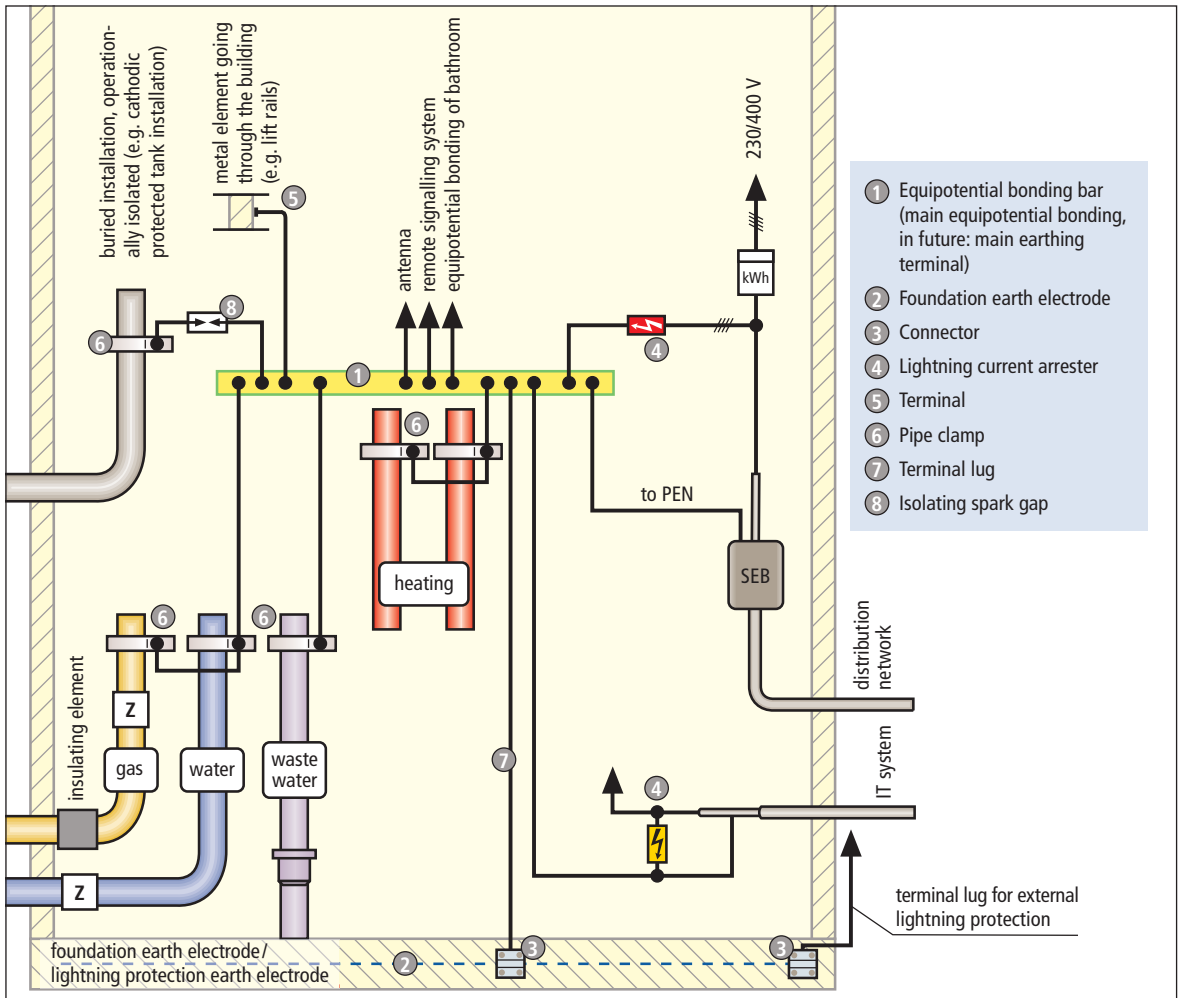
Fig. 6.1.1   Principle of lightning equipotential bonding consisting of lightning and main equipotential bonding (in future: protective equipotential bonding)

Main equipotential bonding

The following extraneous conductive parts have to be **directly** integrated into the main equipotential bonding:

⇒ main equipotential bonding conductor in accordance with IEC 60364-4-41 (in future: earthing conductor)

⇒ foundation earth electrodes or lightning protection earth electrodes

⇒ central heating system

⇒ metal water supply pipe

⇒ conductive parts of the building structure (e.g. lift rails, steel skeleton, ventilation and air conditioning ducting)

⇒ metal drain pipe

⇒ internal gas pipe

⇒ earthing conductor for antennas (in Germany in DIN VDE 0855-300)

⇒ earthing conductor for telecommunication systems (in Germany in DIN VDE 0800-2)

⇒ protective conductors of the electrical installation in accordance with IEC 60364 series (PEN conductor for TN systems and PE conductors for TT systems or IT systems)

⇒ metal shields of electrical and electronic conductors

⇒ metal cable sheaths of high-voltage current cables up to 1000 V

⇒ earth termination systems for high-voltage current installations above 1 kV according to HD 637 S1, if no intolerably high earthing voltage can be dragged.

Normative definition in IEC 60050-826 of an extraneous conductive component:

A conductive unit not forming part of the electrical installation, but being able to introduce electric potential including the earth potential.

Note: Extraneous conductive components also include conductive floors and walls, if an electric potential including the earth potential can be introduced via them.

The following installation components have to be integrated **indirectly** into the main equipotential bonding via isolating spark gaps:

⇒ installations with cathodic corrosion protection and stray current protection measures in accordance with EN 50162

⇒ earth-termination systems of high-voltage current installations above 1 kV in accordance with HD 637 S1, if intolerably high earthing potentials can be transferred

⇒ railway earth for electric a.c. and d.c. railways in accordance with EN 50122-1 (railway lines of the Deutsche Bahn may only be connected upon written approval)

⇒ measuring earth for laboratories, if they are separate from the protective conductors

Figure 6.1.1 shows the terminals and the respective components of the main equipotential bonding.

Design of the earth-termination system for equipotential bonding

The electrical low-voltage consumer's installation requiring certain earthing resistances (disconnection conditions of the protective elements) and the foundation earth electrode providing good earthing resistances at cost-effective installation, the foundation earth electrode is an optimal and effective complement of the equipotential bonding. The design of a foundation earth electrode is governed in Germany by DIN 18014, which, for example requires terminal lugs for the earthing busbar. More exact descriptions and designs of the foundation earth electrode can be found in Chapter 5.5.

If a foundation earth electrode is used as lightning protection earth electrode, additional requirements may have to be considered; they can be taken from Chapter 5.5.

Equipotential bonding conductors (in future: protective bonding conductors)

Equipotential bonding conductors should, as long as they fulfil a protective function, be labelled the same as protective conductors, i.e. green/yellow.

Equipotential bonding conductors do not carry operating currents and can therefore be either bare or insulated.

The decisive factor for the design of the main equipotential bonding conductors in accordance with IEC 60364-5-54 and HD 60364-5-54 is the cross section of the main protective conductor. The main protective conductor is the one coming from the source of current or from the service entrance box or the main distribution board.

	Main equipotential bonding	Supplementary equipotential bonding	
Normal	0.5 x cross section of the largest protective conductor of the installation	between two bodies	1 x cross section of the smaller protective conductor
		between a body and an extraneous conductive part	0.5 x cross section of the protective conductor
Minimum	6 mm^2	with mechanical protection	2.5 mm^2 Cu or equivalent conductivity
		without mechanical protection	4 mm^2 Cu or equivalent conductivity
Possible limit	25 mm^2 Cu or equivalent conductivity	–	–

Table 6.1.1   Cross sections for equipotential bonding conductors

In any case, the minimum cross section of the main equipotential bonding conductor is at least 6 mm^2 Cu. 25 mm^2 Cu has been defined as a possible maximum.

The supplementary equipotential bonding (**Table 6.1.1**) must have a minimum cross section of 2.5 mm^2 Cu for a protected installation, and 4 mm^2 Cu for an unprotected installation.

For earth conductors of antennas (according to IEC 60728-11 (EN 60728-11)), the minimum cross section is 16 mm^2 Cu, 25 mm^2 Al or 50 mm^2 steel.

Equipotential bonding bars
Equipotential bonding bars are a central component of equipotential bonding which must clamp all the connecting conductors and cross sections occurring in practice to have high contact stability; it must be able to carry current safely and have sufficient corrosion resistance.

DIN VDE 0618-1: 1989-08 (German standard) contains details of the requirements on equipotential bonding bars for the main equipotential bonding. It defines the following connection possibilities as a minimum:

⇒ 1 x flat conductor 4 x 30 mm or round conductor Ø 10 mm

⇒ 1 x 50 mm^2

⇒ 6 x 6 mm^2 to 25 mm^2

⇒ 1 x 2.5 mm^2 to 6 mm^2

These requirements on an equipotential bonding bar are met by K12 (**Figure 6.1.2**).

This standard also includes the requirements for the inspection of clamping units of cross sections above 16 mm^2 with regard to the lightning current ampacity. Reference is made therein to the testing of the lightning protection units in accordance with EN 50164-1.

If the requirements in the previously mentioned standard are met, then this component can also be used for lightning equipotential bonding in accordance with IEC 62305-1 to 4 (EN 62305-1 to 4).

Terminals for equipotential bonding
Terminals for equipotential bonding must provide a good and permanent contact.

Fig. 6.1.2   K12 Equipotential bonding bar, Part No. 563 200

Fig. 6.1.3   Pipe earthing clamp,
            Part No. 408 014

Fig. 6.1.4   Pipe earthing clamp,
            Part No. 407 114
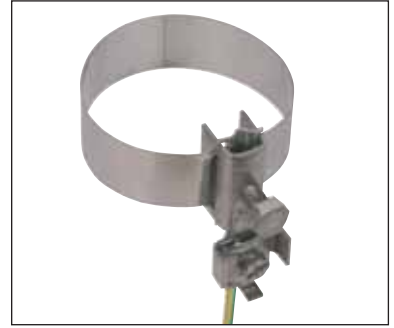
Fig. 6.1.5   Pipe earthing clamp,
            Part No. 540 910

Integrating pipes into the equipotential bonding

In order to integrate pipes into the equipotential bonding, earthing pipe clamps corresponding to the diameters of the pipes are used (**Figures 6.1.3** and **6.1.4**).

Pipe earthing clamps made of stainless steel, which can be universally adapted to the diameter of the pipe, offer enormous advantages for mounting (**Figure 6.1.5**).

These pipe earthing clamps can be used to clamp pipes that are made of different materials (e.g. steel, copper and stainless steel). These components allow also a straight-through connection.

Figure 6.1.6 shows equipotential bonding of heating pipes with straight-through connection.

Test and inspection of the equipotential bonding

Before commissioning the electrical consumer's installation, the connections must be inspected to ensure their faultless condition and effectiveness.

A low-impedance conductance to the various parts of the installation and to the equipotential bonding is recommended. A guide value of $< 1\,\Omega$ for the connections at equipotential bonding is considered to be sufficient.

Fig. 6.1.6   Equipotential bonding with straight-through connection

Supplementary equipotential bonding

If the disconnection conditions of the respective system configuration can not be met for an installation or a part of it, a supplementary local equipotential bonding is required. The reason behind is to interconnect all simultaneously accessible parts as well as the stationary operating equipment and also extraneous conductive parts. The aim is to keep any touch voltage which may occur as low as possible.

Moreover, the supplementary equipotential bonding must be used for installations or parts of installations of IT systems with insulation monitoring.

The supplementary equipotential bonding is also required if the environmental conditions in special installations or parts of installations mean a particular risk.

The IEC 60364 series Part 7 draws attention to the supplementary equipotential bonding for operational facilities, rooms and installations of a particular type.

These are , for example,

⇒   IEC 60364-7-701 Rooms with bathtub or shower

⇒   IEC 60364-7-702 Swimming pools and other basins

⇒   IEC 60364-7-705 For agricultural and horticultural premises

The difference to the main equipotential bonding is the fact that the cross sections of the conductors can be chosen to be smaller (**Table 6.1.1**), and also this supplementary equipotential bonding can be limited to a particular location.
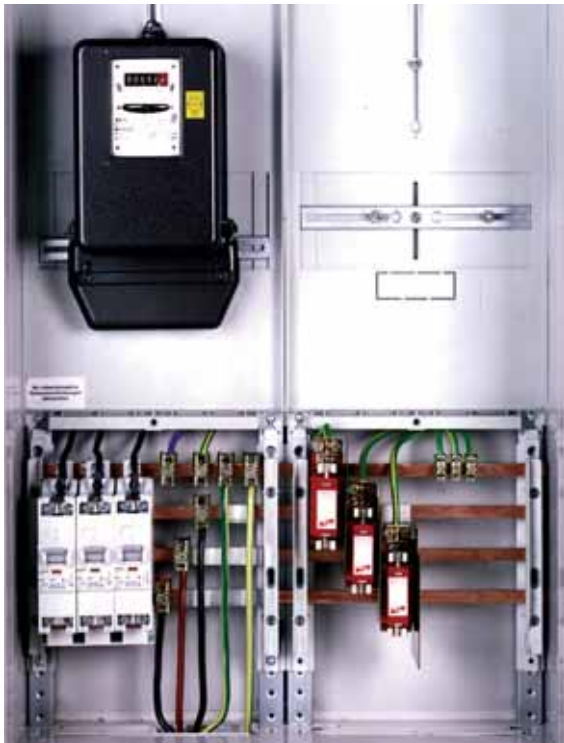
Fig. 6.2.1   DEHNbloc NH lightning current arrester installed in a bus-bar terminal field of a meter installation (refer to Fig. 6.2.2)

Fig. 6.2.2   DEHNventil ZP combined arrester directly snapped on the busbars in the terminal field of the meter cabinet

6.2 Equipotential bonding for low voltage consumer's installations

Equipotential bonding for low voltage consumer's installations as part of the internal lightning protection, represents an extension of the main equipotential bonding (in future: protective equipotential bonding) according to IEC 60364-4-41 (**Figure 6.1.1**).

In addition to all conductive systems, this also integrates the supply conductors of the low voltage consumer's installation into the equipotential bonding. The special feature of this equipotential bonding is the fact that a tie-up to the equipotential bonding is only possible via suitable surge protective devices. The demands on such surge protective devices are described more detailed in Annex E subclause 6.2.1.2 of IEC 62305-3 (EN 62305-3) as well as in subclause 7 and Annexes C and D of IEC 62305-4 (EN 62305-4).

Analogous to the equipotential bonding with metal installations (see Chapter 6.1), the equipotential bonding for the low voltage consumer's installation shall also be carried out immediately at the point of entry into the object. The requirements governing the installation of the surge protective devices in the unmetered area of the low voltage consumer's installation (main distribution system) are described in the directive of the VDN (Association of German Network Operators) "Surge protective devices Type 1. Directive for the use of surge protective equipment Type 1 (up to now Class B) in main distribution systems" (see subclauses 7.5.2 and 8.1) (**Figures 6.2.1** and **6.2.2**).

6.3 Equipotential bonding for information technology installations

Lightning equipotential bonding requires that all metal conductive components such as cable lines and shields at the entrance to the building shall be incorporated into the equipotential bonding so as to cause as little impedance as possible. Examples of such components include antenna lines, (**Figure 6.3.1**) telecommunication lines with metal conductors, and also fibre optic systems with metal elements. The lines are connected with the help of elements capable of carrying lightning current (arresters and shielding terminals). A convenient installation site is the point where cabling going
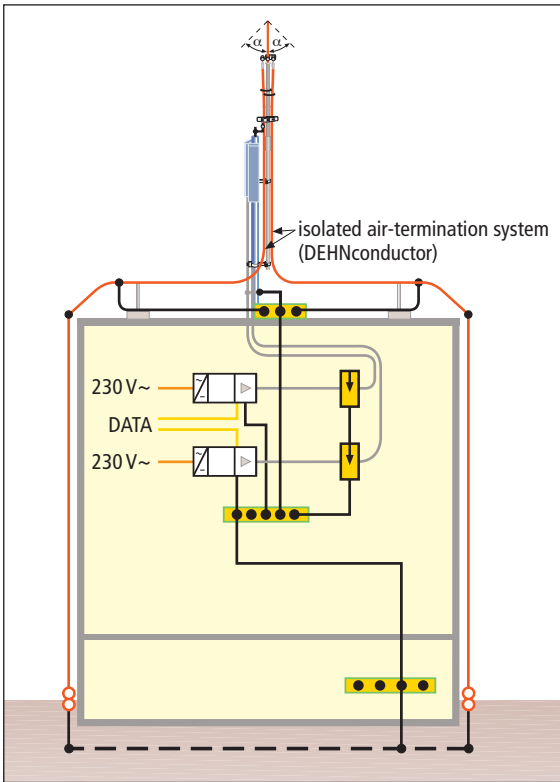
Fig. 6.3.1   Lightning equipotential bonding with isolated air-termination system, type DEHNconductor, for professional antenna systems according to IEC 62305-3 (EN 62305-3)
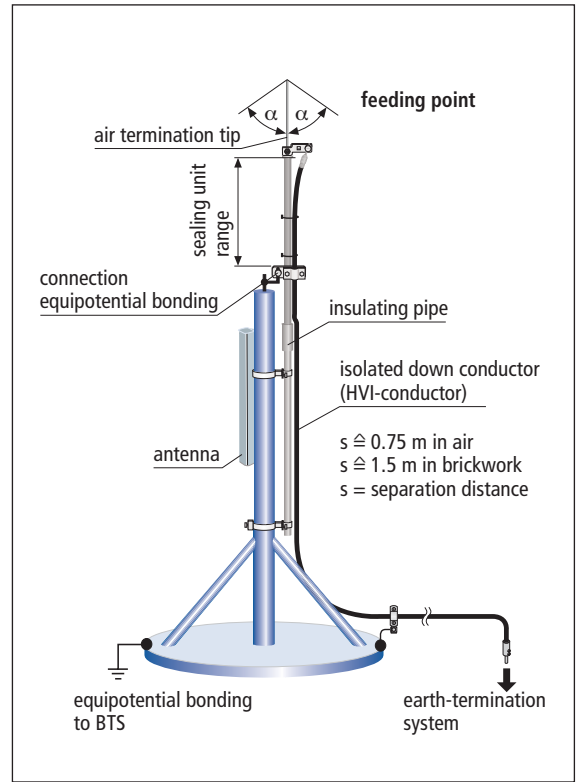
Fig. 6.3.2   Isolated construction of a lightning protection system at a cell site

outside the building transfers to cabling inside the building. Both the arresters and the shielding terminals must be chosen to be appropriate to the lightning current parameters to be expected.

In order to minimise induction loops within buildings, the following additional steps are recommended:

⇒   cables and metal pipes shall enter the building at the same point

⇒   power lines and data lines shall be laid spatially close but shielded

⇒   avoiding of unnecessarily long cables by laying lines directly

Antenna installations:

For reasons connected with radio engineering, antenna installations are generally mounted in an exposed location. Therefore they are more affected by surges, especially in the event of a direct lightning strike. In Germany they must be integrat-

ed into the equipotential bonding in accordance with DIN VDE 0855 Part 300 (German standard) and must reduce the risk of being affected through their design, (cable structure, connectors and fittings) or suitable additional measures. Antenna elements that are connected to an antenna feeder and cannot be connected directly to the equipotential bonding, as this would affect their functioning, should be protected by arresters.

Expressed simply, it can be assumed that 50 % of the direct lightning current flows away via the shields of all antenna lines. If an antenna installation is dimensioned for lightning currents up to 100 kA (10/350 µs) (Lightning Protection Level III (LPL III)), the lightning current splits so that 50 kA flow through the earth conductor and 50 kA via the shields of all antenna cables. Antenna installations not capable of carrying lightning currents must therefore be equipped with air-termination systems in whose protection area the antennas are

located. Choosing a suitable cable, the respective partial lightning current share must be determined for each antenna line involved in down conducting. The required cable dielectric strength can be determined from the coupling resistance, the length of the antenna line and the amplitude of the lightning current.

According to the current standard IEC 62305-3 (EN 62305-3), antenna installations mounted on buildings can be protected by means of

⇒ air-termination rods

⇒ elevated wires

⇒ or spanned cables

In each case the separation distance s must be maintained in the areas protected against lightning strikes.
The electrical isolation of the lightning protection system from conductive components of the building structure (metal structural parts, reinforcement etc.), and the isolation from electric lines in the building, prevent partial lightning currents from penetrating into control and supply lines and hence protect sensitive electrical and electronic devices from being affected or destroyed (**Figure 6.3.1** and **Figure 6.3.2**).

Fibre optic installations:
Fibre optic installations with metal elements can normally be divided into the following types:

⇒ cables with metal-free core but with metal sheath (e.g. metal vapour barrier) or metal supporting elements

⇒ cables with metal elements in the core and with metal sheath or metal supporting elements

⇒ cables with metal elements in the core, but without metal sheath.

For all types of cable with metal elements, the minimum peak value of the lightning current, which adversely affects the transmission characteristics of the optical fibre, must be determined. Cables capable of carrying lightning currents must be chosen, and the metal elements must be connected to the equipotential bonding bar either directly or via an SPD.

⇒ Metal sheath: termination by means of shield terminals e.g. SAK, at the entrance of the building

⇒ Metal core: termination by means of earthing clamp e.g. SLK, near splice box

⇒ Prevention of potential equalising currents: connect indirectly via spark gap e.g. DEHNgap CS, base part BLITZDUCTOR CT, rather than directly

Telecommunication lines:
Telecommunication lines with metal conductors normally consist of cables with balanced or coaxial cabling elements of the following types:

⇒ cables with no additional metal elements

⇒ cables with metal sheath (e.g. metal damp-proofing) and/or metal supporting elements

⇒ cables with metal sheath and additional lightning protection reinforcement

The splitting of the partial lightning current between IT lines can be determined using the procedures in Annex E of IEC 62305-1 (EN 62305-1). The individual cables must be integrated into the equipotential bonding as follows:

a) Unshielded cables must be connected by SPDs which are capable of carrying partial lightning currents. Partial lightning current of the line divided by the number of individual wires = partial lightning current per wire.

b) If the cable shield is capable of carrying lightning currents, the lightning current flows via the shield. However, capacitive/inductive interferences can reach the wires and make it necessary to use surge arresters. Requirements:

⇒ The shield at both ends must be connected to the main equipotential bonding to be capable of carrying lightning currents (**Figure 6.3.3**).

Fig. 6.3.3   SAK shield connection system capable of carrying lightning currents
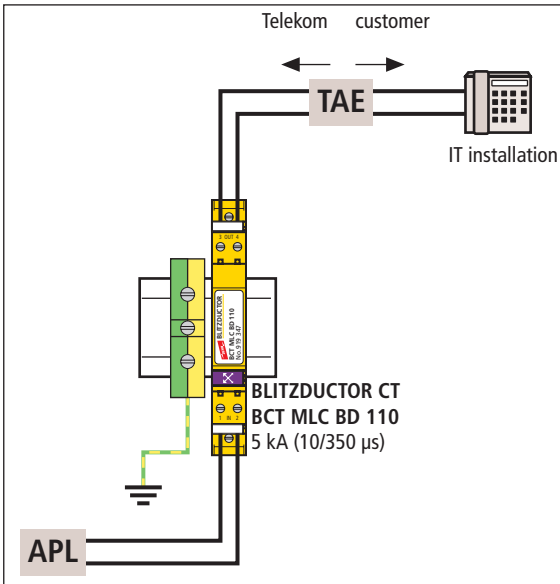
Fig. 6.3.4   Lightning equipotential bonding for connection of a telecommunications device BLITZDUCTOR CT (application permitted by Deutsche Telekom)

Fig. 6.3.5   DEHN equipotential bonding enclosures (DPG LSA) for LSA-2/10 technology, capable to carry lightning current

⇒ In both buildings where the cable ends, the lightning protection zone concept must be applied, and the active wires must be connected in the same lightning protection zone (usually LPZ 1)

⇒ If an unshielded cable is laid in a metal pipe, this must be treated like a cable with a cable shield which is capable of carrying lightning currents.

c)   If the cable shield is not capable of carrying lightning currents, then:

⇒ for the terminal connected at both ends, the procedure is the same as for a signal wire in an unshielded cable. Partial lightning current of the cable divided by the number of individual wires + 1 shield = partial lightning current per wire

⇒ if the shield is not connected at both ends, it has to be treated as if it were not there; partial lightning current of the line divided by the number of individual wires = partial lightning current per wire

If it is not possible to determine the exact wire load, it is recommendable to take the threat parameters from IEC 61643-22. For a telecommunications line hence results a maximum load per wire of 2.5 kA (10/350 µs).

Of course not only the used SPD must be capable of withstanding the expected lightning current load, but also the discharge path to the equipotential bonding.

By means of a multi-core telecommunications line for example this can be demonstrated:

⇒ A telecommunications cable with 100 double wires coming from LPZ 0_A is connected in an LSA building distribution case and shall be protected by arresters.

⇒ The lightning current load of the cable was assumed to be 30 kA (10/350 µs)

⇒ The resulting symmetrical splitting of lightning current to the individual wire is 30 kA/200 wires = 150 A/wire.

At first this means no special requirements to the discharge capacity of the protective elements to be used. After the discharge elements have flown through, the partial currents of all wires add up to 30 kA again to load in the downstream discharge path, for example clamping frames, earthing clamps or equipotential conductors. To be safe from any damage in the discharge path lightning current tested enclosure systems can be used (**Figure 6.3.5**).

7. Protection of electrical and electronic systems against LEMP

7.1 Lightning protection zones concept

A lightning protection system (LEMP Protection Measures System (LPMS)) according to IEC 62305-3 (EN 62305-3) protects persons and material assets of value in the buildings, but it does not protect the electrical and electronic systems in the buildings which are sensitive to transient high-energy surges resulting from the lightning discharge. It is precisely such systems – in the form of building management, telecommunications, control and security systems – which are rapidly becoming common in practically all areas of residential and functional buildings. The owner/operator places very high demands on the permanent availability and reliability of such systems.

The protection of electrical and electronic systems in buildings and structures against surges resulting from the lightning electromagnetic pulse (LEMP) is based on the principle of Lightning Protection Zones (LPZ). According to this principle, the build-

ing or structure to be protected must be divided into internal lightning protection zones according to the level of threat posed by LEMP (**Figure 7.1.1**). This enables areas with different LEMP risk levels to be adjusted to the immunity of the electronic system.

With this flexible concept, suitable LPZs can be defined according to the number, type and sensitivity of the electronic devices/systems. From small local zones to large integral zones which can encompass the whole building. Depending on the type of threat posed by lightning, the following lightning protection zones are defined:

External zones

⇒ **LPZ 0$_A$** – at risk from direct lightning strikes, from impulse currents up to the whole lightning current and from the whole electromagnetic field of the flash of lightning.

⇒ **LPZ 0$_B$** – protected against direct lightning strikes, at risk from the whole electromagnetic
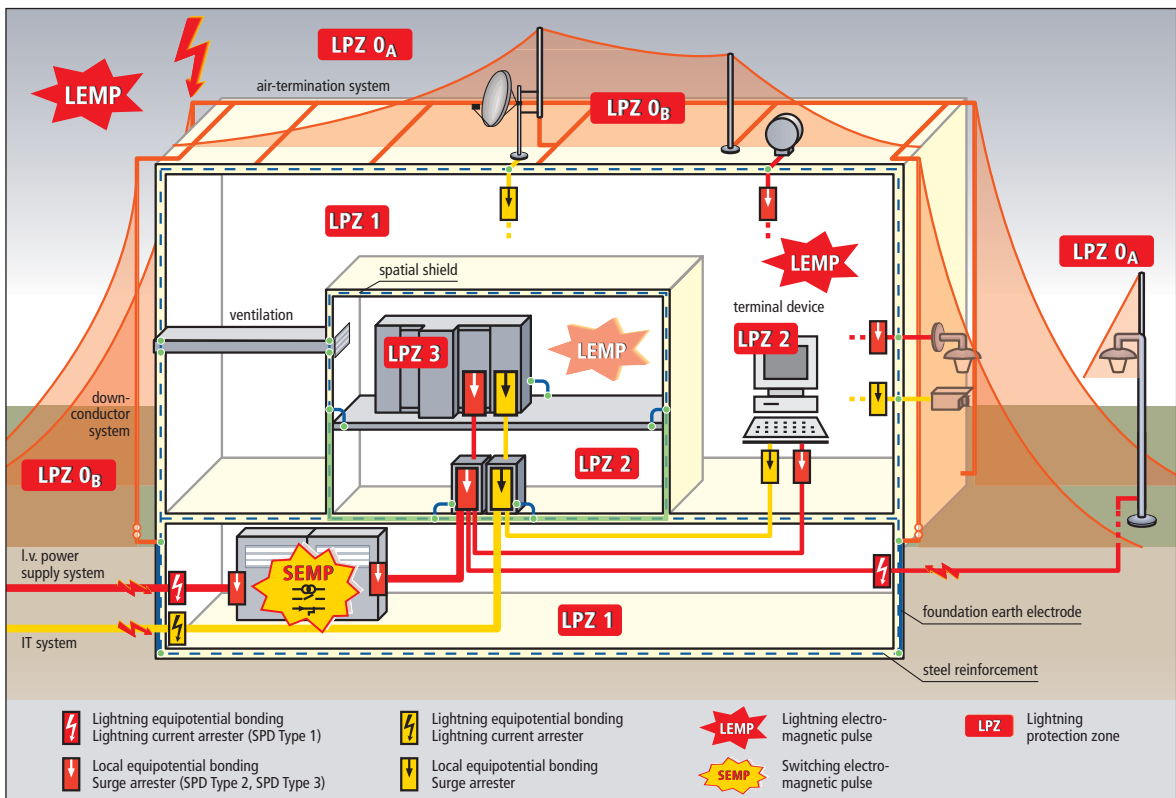
Fig. 7.1.1   Lightning protection zones concept according to IEC 62305-4 (EN 62305-4)
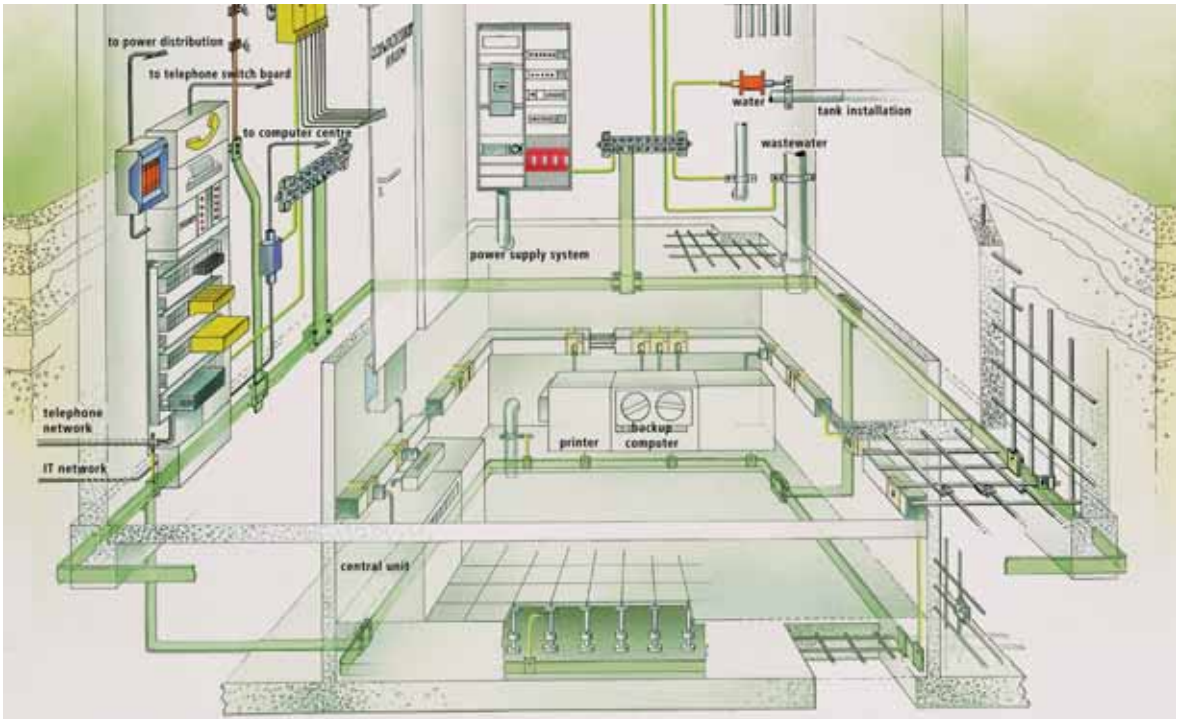
Fig. 7.1.2   Example for realisation of the lightning protection zones concept

field of the flash of lightning. Internal systems can be exposed to (partial) lightning currents.

Internal zones

⇒ **LPZ 1** – impulse currents limited by the splitting of the current and by surge protective devices (SPDs) at the zones boundaries. The electromagnetic field of the lightning flash can be attenuated by spatial shielding.

⇒ **LPZ 2 ... n** – impulse currents further limited by the splitting of the current and by surge protective devices (SPDs) at the zone boundaries. The electromagnetic field of the lightning flash is usually attenuated by spatial shielding.

The requirements on the internal zones must be defined according to the immunity of the electrical and electronic systems to be protected.

At the boundary of each internal zone, the equipotential bonding must be carried out for all metal components and utility lines entering the building or structure. This is done directly or with suitable SPDs. The zone boundary is formed by the shielding measures.

Figure 7.1.2 illustrates an example of how to realise the measures described for the lightning protection zones concept.

7.2 LEMP protection management

For new buildings and structures, optimum protection of electronic systems can only be achieved with a minimum of expense if the electronic systems are designed together with the building and before its construction. In this way, building components such as the reinforcement, the metal girders and metal buttresses can be integrated into the LEMP protection management.

For existing buildings and structures, the cost of the LEMP protection is usually higher than for new buildings and structures. If, however, the LPZs are chosen appropriately and existing installations are used or upgraded, the costs can be reduced.

If the risk analysis in accordance with IEC 62305-2 (EN 62305-2) shows that LEMP protection is required, this can only be achieved if:

Step	Aim	Measure must be taken by (if relevant)
Initial risk analysis [a]	Assessing of the necessity of an LEMP protection. If necessary an appropriate LEMP Protection Measures System (LPMS) based on a risk assessment has to be chosen.	• Lightning protection specialist [b] • Owner
Final risk analysis [a]	The cost/benefit ratio of the chosen protection measures should be optimised again by a risk assessment. Accordingly to be determined: • Lightning protection level (LPL) and the lightning parameters • LPZ and their boundaries	• Lightning protection specialist [b] • Owner
Design of LEMP Protection Measures System (LPMS)	Definition of the LPMS: • Measures of spatial shielding • Equipotential bonding networks • Earth-termination systems • Leading and shielding of conductors • Surge protective devices system	• Lightning protection specialist [b] • Owner • Architect • Designer of the electronic systems • Designer of the important installations
Design of the LPMS	General drawings and descriptions Preparation of the tender documentation Detailed drawings and schedules for the installation	• Engineering office or equivalent
Installation and inspection of the LPMS	Quality of the installation Documentation Possible revision of detailed drawings	• Lightning protection specialist [b] • Installer of the LPMS • Engineering office • Inspection representative
Acceptance of the LPMS	Inspection and documentation of the system	• Independent lightning protection expert [b] • Authorised inspector
Repeat inspections	Ensuring of an appropriate LPMS	• Lightning protection specialist [b] • Authorised inspector
[a] see IEC 62305-2 (EN 62305-2) [b] with profound knowledge of EMC and installation practice		

Table 7.2.1 LEMP protection management for new buildings and for comprehensive modifications of the construction or the utilisation of building according to IEC 62305-4 (EN 62305-4)

⇒ the measures are designed by a lightning protection specialist having profound knowledge of EMC,

⇒ there is close coordination on all aspects of the work between the building experts (e.g. civil and electrical engineers) and those experts in LEMP protection and

⇒ the management plan according to **Table 7.2.1** (IEC 62305-4 (EN 62305-4) Subclause 8.1) is adhered to.

A concluding risk analysis must prove that the residual risk is less than the tolerable risk.
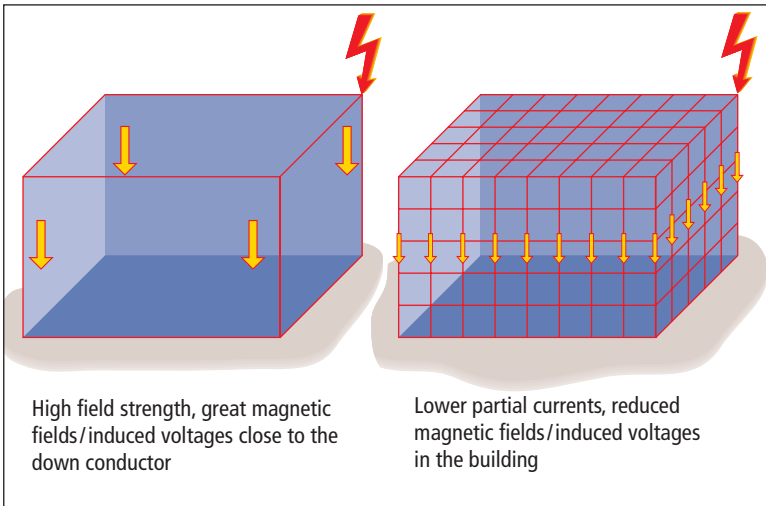
Fig. 7.3.1 Reduction of the magnetic field by means of lattice shields

$$H_1 = k_H \cdot i_o \cdot \frac{w}{d_w \cdot \sqrt{d_r}} \quad [A/m]$$

i_o = lightning current in LPZ 0_A
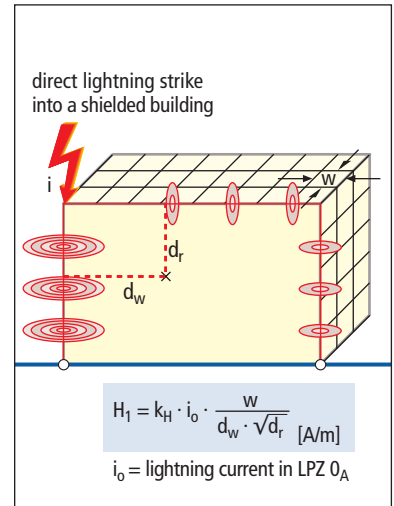
Fig. 7.3.2 Magnetic field at a lightning strike (LEMP) IEC 62305-4 (EN 62305-4)

7.3 Calculation of the magnetic shield attenuation of building / room shielding

Lightning current and the associated electromagnetic field represent the primary source of interference for devices and installations requiring protection in a property. **Figure 7.3.1** shows the principle of how lattice structures work. The fundamentals of the calculation are described in the IEC 62305-4 (EN 62305-4) standard.

The fundamentals of the calculation are based on assumptions and estimates. The complex distribution of the magnetic field inside lattice-shaped shields is determined with a first approximation. The formulae for the determination of the magnetic field are based on numerical calculations of the magnetic field. The calculation takes into account the magnetic field coupling of each rod in the lattice-shaped shield with all other rods, including the simulated lightning channel.

To consider whether it is the effect of the electromagnetic field of the first partial lightning strike or the subsequent lightning strike which is the more critical interference variable for the electric installation requiring protection, the calculations must be done with the maximum value of the current of the short strike ($i_{f/max}$) and the maximum value of the current of the long strike ($i_{s/max}$) corresponding to the lightning protection level derived from Table 5, IEC 62305-1 (EN 62305-1).

The shielding effect of lattice-shaped shields in the event of direct lightning strikes can be calculated using the formula shown in **Figure 7.3.2**. This view is based on the fact that the lightning strike can happen at any point on the roof.

The values calculated for the magnetic field apply to the safety volume V_s inside lattice-shaped shields, which are defined by the separation distance $d_{s/...}$ (**Figure 7.3.3**).

This safety volume takes into account maximum values of the magnetic field strength directly at the lattice structure, a factor which the approximation formula does not sufficiently take into account. IT devices may only be installed inside of volume V_s.
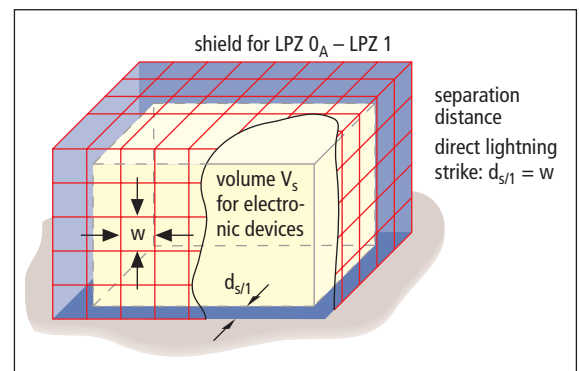
Fig. 7.3.3 Volume for electronic devices within LPZ 1

The fundamentals of the calculation of the shielding effect of lattice-shaped shields for nearby lightning strikes are explained more in detail by **Figures 7.3.4** and **7.3.5**.

Figure 7.3.4 shows the formation of the electromagnetic field whose reduction in field strength is indirectly proportional to the distance s_a. The magnitude of the magnetic field inside a protected volume, e.g. lightning protection zone LPZ 1 (**Figure 7.3.5**), can be described by the quality of the shielding.

The shielding factor SF can be calculated as shown in **Table 7.3.1**.

The results of this calculation of the magnetic field are valid for a safety volume V_s (**Figure 7.3.3**), located within the lightning protection zone with a separation distance $d_{s/1}$ from the shielding.

The separation distance $d_{s/1}$ (for SF < 10) results in:

$$d_{s/1} = w \ [m]$$

w corresponds to the mesh size of the lattice-shaped shield in metres

Implementation of the magnetic shield-attenuation of building / room shielding

Particularly important when shielding against magnetic fields, and hence for the installation of lightning protection zones, are extended metal components, e.g. metal roofs and facades, steel reinforcements in concrete, expanded metals in walls, lattices, metal supporting structures and pipe systems existing in the building. The meshed connection creates an effective electromagnetic shield.

Figure 7.3.6 shows the principle how a steel reinforcement can be developed into an electromagnetic cage (hole shield). In practice, however, it will not be possible to weld or clamp together every junction in large buildings and structures. The usual practice is to install a meshed system of conductors into the reinforcement, said system typically having a size of a ≤ 5 m. This meshed network is connected in an electrically safe way at the cross-points, e.g. by means of clamps. The reinforcement is "electrically hitched" onto the meshed network at a typical distance of b ≤ 1 m. This is done on the building side, for example by means of tie connections.

Mats made of construction steel in concrete are suitable

Fig. 7.3.4 Magnetic field at a lightning strike (LEMP) IEC 62305-4 (EN 62305-4)

$$H_0 = \frac{i}{2\pi S_a} \ [A/m]$$
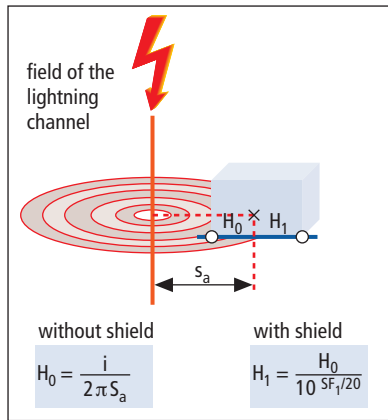
Fig. 7.3.5 Magnetic field at a distant lightning strike (LEMP) IEC 62305-4 (EN 62305-4)

without shield
$$H_0 = \frac{i}{2\pi S_a}$$

with shield
$$H_1 = \frac{H_0}{10^{SF_1/20}}$$

Material	Shielding factor SF (dB)		w = mesh size (m)
	25 kHz (first short strike)	**1 Mhz** (subsequent strike)	(w ≤ 5 m)
Copper Aluminium	$20 \cdot \log (8.5/w)$	$20 \cdot \log (8.5/w)$	r = rod radius (m)
Steel	$20 \cdot \log \dfrac{(8.5 / w)}{\sqrt{1+18\cdot 10^{-6} / r^2}}$	$20 \cdot \log (8.5/w)$	$\mu_r \approx 200$ (permeability)

Example: Steel lattice

w (m)	r (m)	dB at 25 kHz	dB at 1 MHz
0.012	0.0010	44	57
0.100	0.0060	37	39
0.200	0.0090	32	33
0.400	0.0125	26	27

Table 7.3.1 Magnetic attenuation of lattices at a nearby lightning strike acc. to IEC 62305-4 (EN 62305-4)

for shielding purposes. When upgrading existing installations, such steel mats are also laid later. For this type of design, the steel mats must be galvanised to protect them from corrosion.

These galvanised steel mats are then laid on roofs, for example, so that they overlap, or applied either externally or internally to the exterior wall to provide shielding for the building.

Figures 7.3.7a and **7.3.7b** show the subsequent installation of galvanised steel mats on the roof of a building.

To bridge expansion joints, connect the reinforcement of precast concrete components, and for terminals on the external earth-termination system or the internal equipotential bonding system, the building must already be equipped with sufficient fixed earthing points.

Figure 7.3.8 shows an installation of this type, which must be taken into consideration for designing the preliminary building works.

The magnetic field inside the building or structure is reduced over a wide frequency range by means of reduction loops, which arise as a result of the meshed equipotential bonding network. Typical mesh sizes are a ≤ 5 m. The interconnection of all metal components both inside, as well as on the buildings and structures results in a three-dimensional meshed equipotential bonding network.

Figure 7.3.9 shows a meshed equipotential bonding network with appropriate terminals.

If an equipotential bonding network is installed in the lightning protection zones, the magnetic field calculated according to the formulae stated above is typically further reduced by a factor of 2 (corresponds to 6 dB).

(Typical dimension: a ≤ 5 m, b ≤ 1 m)

1 Metal cover of the attic
2 Steel reinforcing rods
3 Intermeshed conductors, superimposed of the reinforcement
4 Connection of the air-termination system
5 Internal equipotential bonding bar
6 Connection capable of carrying lightning currents
7 Connection, e.g. tie connection
8 Ring earth electrode (if existing)
9 Foundation earth electrode

Fig. 7.3.6   Use of reinforcing rods of a building or structure for shielding and equipotential bonding

Fig. 7.3.7a   Galvanised construction steel mats for shielding the building

Fig. 7.3.7b   Use of galvanised construction steel mats for shielding, e.g. in case of planted roofs
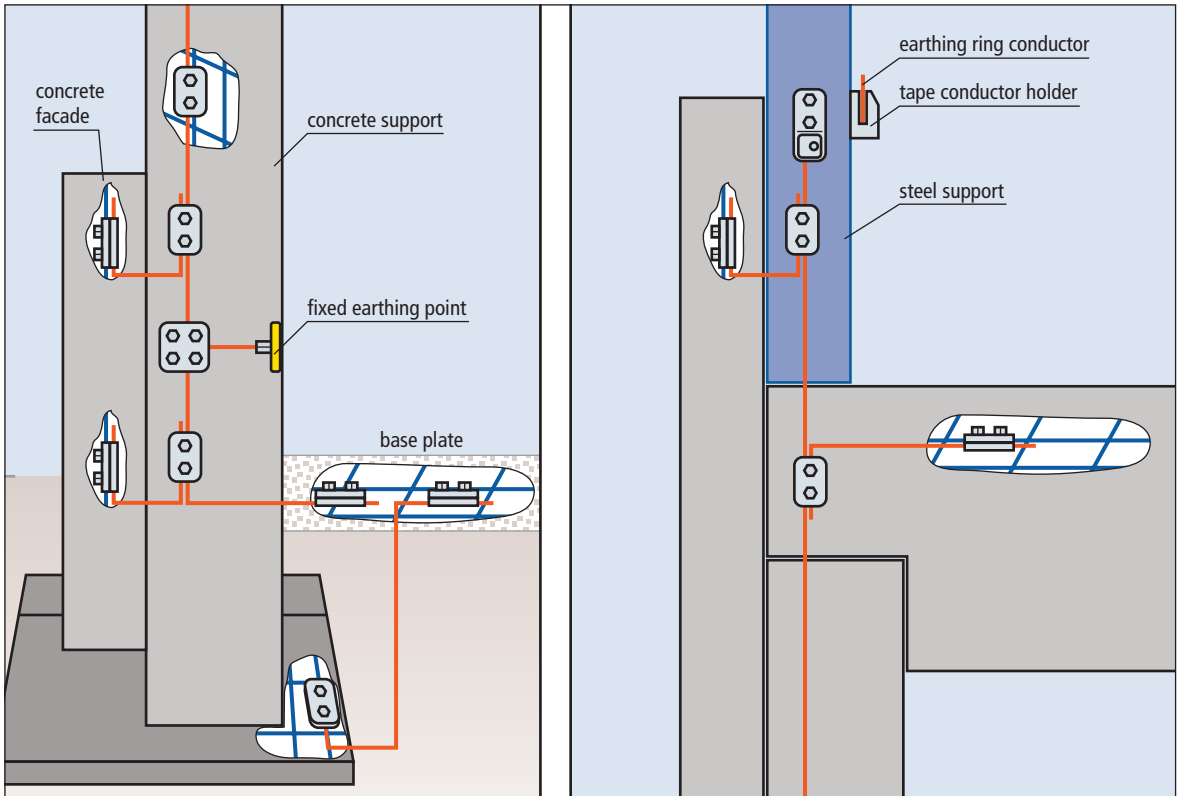
Fig. 7.3.8   Shielding of a structure or building

concrete facade

concrete support

fixed earthing point

base plate

earthing ring conductor

tape conductor holder

steel support
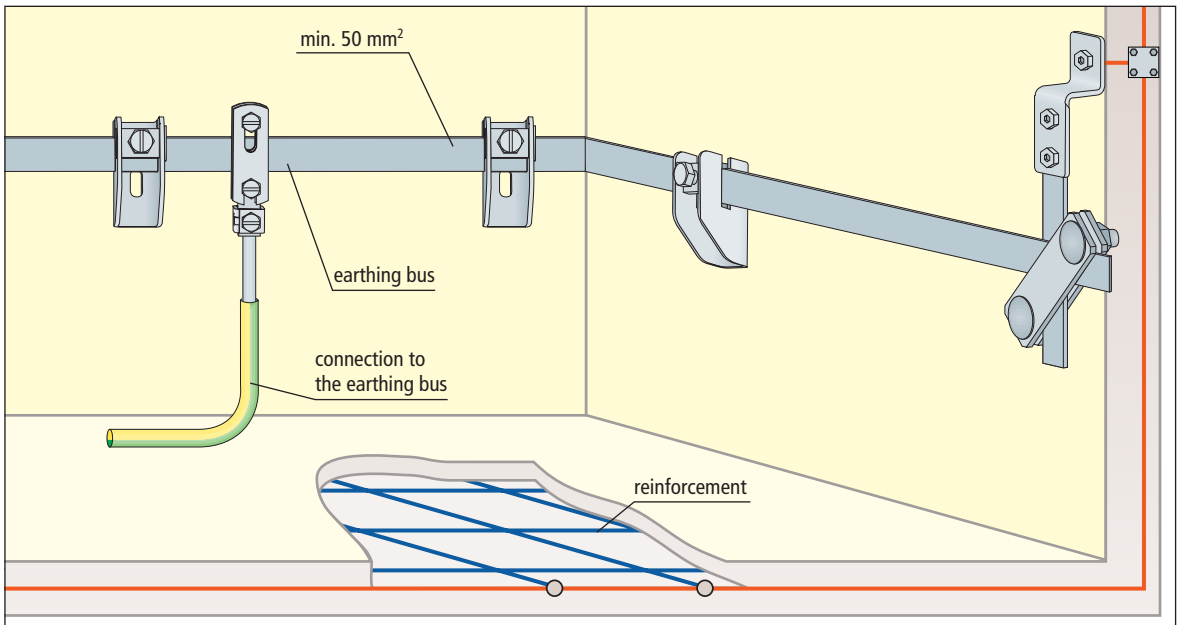
Fig. 7.3.9   Earthing bus according to DIN VDE 0800-2 (German standard)

min. 50 mm²

earthing bus

connection to
the earthing bus

reinforcement

7.3.1 Cable shielding

Cable shields are used to reduce the effect of the interference on the active lines, and the interference emitted from the active lines to neighbouring systems. From the point of view of lightning and surge protection, attention must be paid to the following applications of shielded lines:

⇒ **No shield earthing**

Some installation systems recommend a shielded cable but, at the same time, forbid shield earthing, (e.g. KNX). If there is no shielding terminal, the shield is not effective against interferences and must therefore be considered as non-existing (**Figure 7.3.1.1**).

⇒ **Double-ended shield earthing**

A cable shield must be continuously connected along the whole of its length for good conducting performance, and earthed at least at both ends. Only a shield used at both ends can reduce inductive and capacitive inputs. Cable shields entering a building or structure must have a certain minimum cross section to avoid the risk of sparking. Otherwise the shields are not considered being capable of carrying lightning current. The minimum cross section of a cable shield (S_{cmin}) laid isolated from earth or air, depends on its specific shield resistance (ρ_c) (**Table 7.3.1.1**) on the lightning current flowing (I_f), on the impulse withstand voltage of the system (U_w), and on the cable length (L_c).

$$S_{cmin} = (I_f \cdot \rho_c \cdot L_c \cdot 10^6 / U_w)[mm^2]$$

I_f can be calculated in accordance with IEC 62305-1 (EN 62305-1). The shield connection technology usually being tested up to 10 kA (10/350 µs), this value, as a first approximation, can be drawn on as maximum value.

U_w can be interpreted quite differently. If the cable shield away from the internal system is interrupted at the building entry then the electric strength of the cable is decisive. The cable shield, however, being uninterrupted up to the terminal device, the electric strength of the terminal device is the important (**Table 7.3.1.2**).

Two examples shall illustrate the difference:

TC cable shield up to the building entry, Al, loaded with 10 kA, length 100 m : $S_{cmin} \approx 6$ mm². It also has to be minded, that the shield terminals at the MEBB must be capable of carrying lightning current.

Shielding material	ρ_c in Ωm
Copper	$17.241 \cdot 10^{-9}$
Aluminium	$28.264 \cdot 10^{-9}$
Lead	$214 \cdot 10^{-9}$
Steel	$138 \cdot 10^{-9}$

Table 7.3.1.1   Specific shield resistance ρ_c for different materials

Examples	Electric strength
LV cable	15 kV
TC cable	5 kV
TC subscriber's side	1.5 kV
Measuring and control equipment	0.5 – 1 kV

Table 7.3.1.2   Electric strength

Bus conductor shield up to the terminal device, Cu, loaded with 5 kA, length 100 m : $S_{cmin} \approx 17$ mm². Such cable shields for bus conductors, however, being not convenient for the practice the described conductor has to be considered as not capable of carrying lightning current.

⇒ **Single-ended and indirect shield earthing**

For operational reasons, cable shields are sometimes earthed at only one end. In fact, a certain attenuation of capacitive interference fields is given. Protection against the electromagnetic induction arising with lightning strikes, however, is not provided. The reason for the single-ended shield earthing is the fear of low frequency equalising currents. In extended installations, a bus cable, for example, can often stretch many hundreds of metres between buildings. Especially with older installations, it can happen that one part of the earth-termination systems is no longer in operation, or that no meshed equipotential bonding is existing. In such cases, interferences can occur as a result of multiple shield earthing. Potential differences of the different building earthing systems can allow low frequency equalising currents (n x 50 Hz), and the transients superimposed thereon, to flow. At the same time, currents measuring up to a few amperes are possible which, in extreme cases, can cause cable fires. In addition, crosstalk can cause signal interference if the signal frequency is in a similar frequency range to the interference signal.

The aim, however, must be to virtually implement the requirements of EMC and prevent equalising
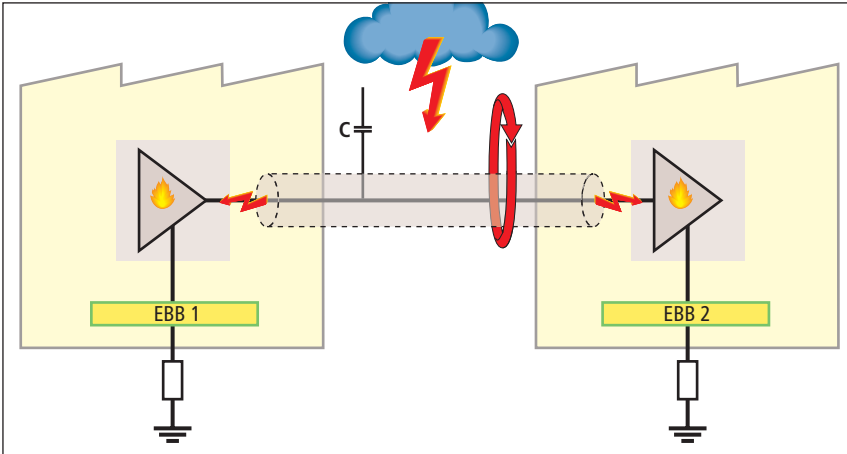
Fig. 7.3.1.1   No shield connection – No shielding from capacitive/inductive couplings

the impulse transfer
impedance of the
shield has to be
considered!
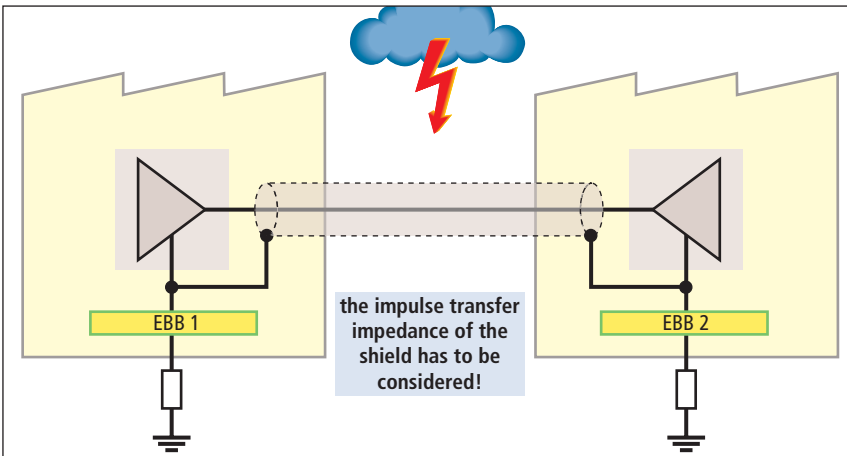
Fig. 7.3.1.2   Shield connection at both ends – Shielding from capacitive/inductive couplings

direct earthing

indirect earthing via
gas discharge tube
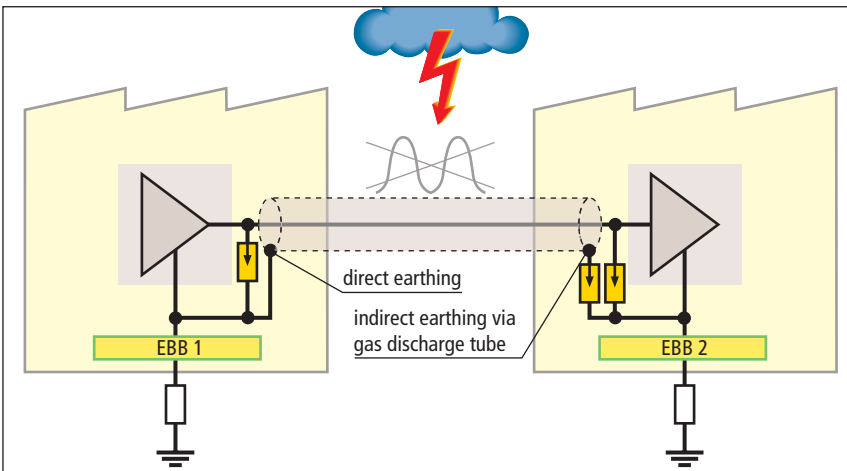
Fig. 7.3.1.3   Shield connection at both ends – Solution: Direct and indirect shield earthing

currents. This can be achieved by combining single-ended and indirect shield earthing. All shields are directly connected with the local equipotential bonding at a central point such as the control room. At the far ends of the cable, the shields are indirectly connected to the earth potential via isolating spark gaps. Since the resistance of a spark gap is around 10 GΩ, equalising currents are prevented in surge-free operation. Should EMC interferences such as lightning strikes occur, the spark gap ignites and discharges the interference pulse without consequential damage to the equipment. This reduces the residual impulse on the active lines and the terminal devices are subject to even less stress. The BLITZDUCTOR CT arrester is equipped with an insert which can take a gas discharge tube, if necessary. This switches between the cable shield and the local earth. The gas discharge tube can be inserted or removed during upgrading or maintenance work in order to change between direct and indirect shield earthing (**Figure 7.3.1.3**).

⇒ **Low impedance shield earthing**

Cable shields can conduct impulse currents of up to several kA. During the discharge, the impulse currents flow through the shield and the shield ter-

minals to earth. The impedance of the cable shield and the shielding terminal creates voltage differences between shield potential and earth. In such a case, voltages of up to some kV can develop and destroy the insulation of conductors or connected devices. Coarse-meshed shields and the twisting of the cable shield (pig tail) to the terminal in a rail clamp are particularly critical. The quality of the cable shield used affects the number of shield earthings required. Under certain circumstances, an earthing is required every 10 metres in order to achieve an efficient shielding effect. Suitable large contacting clamps with slipping spring elements are recommended for the shielding terminal. This is important to compensate for the yield of the synthetic insulation of the conductor (**Figure 7.3.1.4**).

⇒ **Maximum length of shielded cables**

Cable shields have a so-called coupling resistance which roughly corresponds to the d.c. resistance provided by the cable manufacturer. An interference pulse flowing through the resistance creates a potential drop on the cable shield. The permissible coupling resistance for the cable shield can be determined as a function of the dielectric strength of the terminal device and the cable, as well as the cable length. It is crucial that the potential drop is less than the insulation strength of the system. If this is not the case, arresters must be used (**Figure 7.3.1.5**).

⇒ **Extension of LPZs with the help of shielded cables**

IEC 62305-4 (EN 62305-4) states that using a shielded cable between two equal LPZs obviates the need for arresters. This statement applies to interferences to be expected from the spatial surroundings of the shielded cable (e.g. electromagnetic fields) and for meshed equipotential bonding conforming to the standard. But beware. Depending on the conditions the installation is set up in, hazards can still arise and make the use of arresters necessary. Typical potential hazards are: the feeding of the terminal devices from different low voltage main distribution boards (MDB), TN-C systems, high coupling resistances of the cable shields or insufficient earthing of the shield. Further caution must be exercised with cables with poor shield cover, which are often used for economic reasons. The result is residual interferences on the signal lines. Interferences of this type can be controlled by using a high-quality shielded cable or surge protective devices.

7.4 Equipotential bonding network

The main function of the equipotential bonding network is to prevent hazardous potential drops between all devices/installations in the inner LPZs, and to reduce the magnetic field of the lightning.
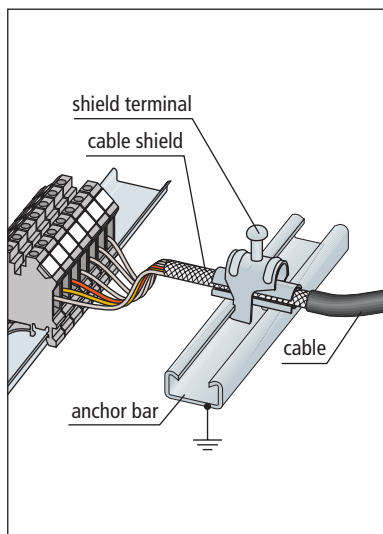
Fig. 7.3.1.4 Shield connection

I = 5 kA

l = 200 m

dielectric strength U_{iso} = 2 kV

to be calculated: max. permissible coupling impedance R_{Kh} of the cable shielding

$$R_{Kh} = \frac{U_{iso}}{I} = \frac{2000\ V}{5000\ A} = 0.4\ \Omega$$

$$l = 200\ m: \implies R_{Kh} = \frac{0.4\ \Omega}{200\ m} = 2\frac{10^{-3}\ \Omega}{m}$$
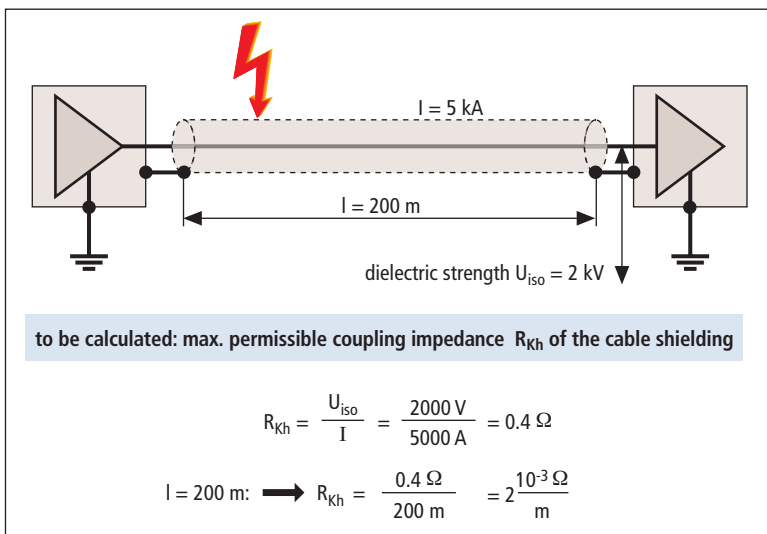
Fig. 7.3.1.5 Shield connection at both ends – Shielding from capacitive/inductive coupling

The low inductance equipotential bonding network required is achieved by means of interconnections between all metal components aided by equipotential bonding conductors inside the LPZ of the building or structure. This creates a three-dimensional meshed network (**Figure 7.4.1**). Typical components of the network are:

⇒ all metal installations (e.g. pipes, boilers),
⇒ reinforcements in the concrete (in floors, walls and ceilings),
⇒ gratings (e.g. intermediate floors),
⇒ metal staircases, metal doors, metal frames,
⇒ cable ducts,
⇒ ventilation ducts,
⇒ lift rails,
⇒ metal floors,
⇒ supply lines.

Ideally, a lattice structure of the equipotential bonding network would be around 5 m x 5 m. This would typically reduce the electromagnetic lightning field inside an LPZ by a factor of 2 (corresponding to 6 dB).

Enclosures and racks of electronic devices and systems should be integrated into the equipotential bonding network with short connections. This requires sufficient numbers of equipotential bonding bars and/or ring equipotential bonding bars (**Figure 7.4.2**) in the building or structure. The busbars, in turn, must be connected to the equipotential bonding network (**Figure 7.4.3**).

Protective conductors (PE) and cable shields of the data links of electronic devices and systems must be integrated into the equipotential bonding network in accordance with the instructions of the system manufacturer. The connections can be made as a mesh or in the shape of a star (**Figure 7.4.4**).
When using a star point arrangement S, all metal components of the electronic system must be suitably insulated against the equipotential bonding network. A star-shaped arrangement is therefore usually limited to applications in small, locally confined systems. In such cases, all lines must enter the building or structure, or a room within the building or structure, at a single point. The star point arrangement S must be connected to the equipo-
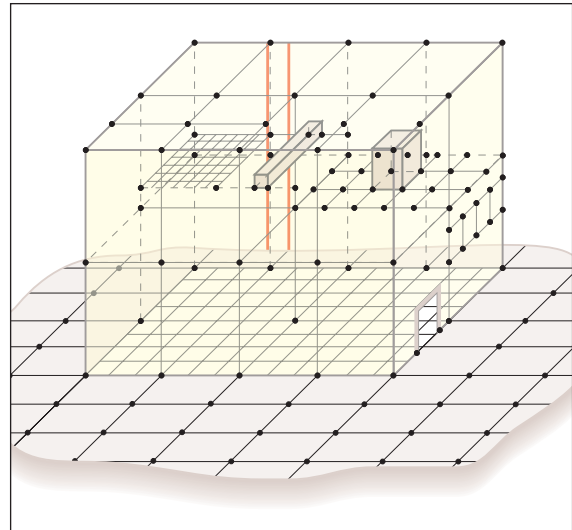
Fig. 7.4.1   Equipotential bonding network in a structure or building

Fig. 7.4.2   Ring equipotential bonding bar in a computer facility

Fig. 7.4.3   Connection of the ring equipotential bonding bar with the equipotential bonding network via fixed earthing point

	Star shape arrangement S	Mesh shape arrangement M	Legend to 7.4.4 and 7.4.5
Basic arrangement	S	M	——— Equipotential bonding network — Equipotential bonding conductor ▭ Device ● Termination point to the equipotential bonding network ERP Earthing reference point S_s Star shape arrangement integrated via a neutral point M_m Mesh shape arrangement integrated via a meshed lattice M_s Mesh shape arrangement integrated via a neutral point
Integration into the equipotential bonding network	S_s — ERP	M_m	

Fig. 7.4.4   Integration of electronic systems into the equipotential bonding network

Combination 1	Combination 2
S_s — ERP — M_m	M_s — ERP — M_m
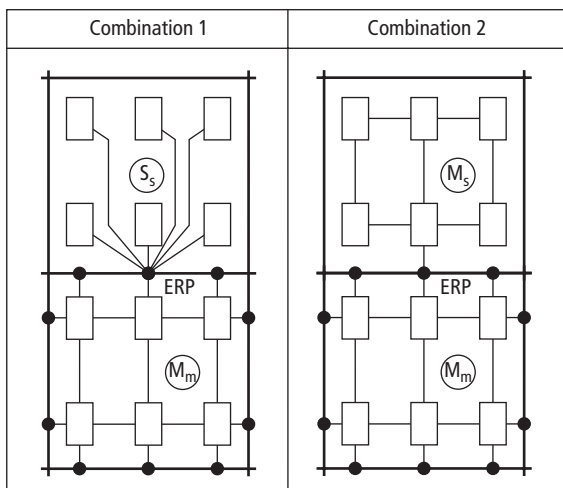
Fig. 7.4.5   Combination of the integration methods according to Figure 7.4.4

tential bonding network at one single earthing reference point (ERP) only. This produces the arrangement S_s.

When using the meshed arrangement M, all metal components of the electronic system do not have to be insulated against the equipotential bonding network. All metal components shall be integrated into the equipotential bonding network at as many equipotential bonding points as possible. The resulting arrangement M_m is used for extended and open systems with many lines between the individual devices. A further advantage of this arrangement is the fact that the lines of the system can enter a building, structure or room at different points.

Complex electronic systems, also allow combinations of star point and meshed arrangements (**Figure 7.4.5**) in order to combine the advantages of both arrangements.

7.5 Equipotential bonding on the boundary of LPZ 0_A and LPZ 1

7.5.1 Equipotential bonding for metal installations

At the boundaries of the EMC lightning protection zones, measures to reduce the radiated electromagnetic field must be realised, and all metal and electrical lines/systems passing through the sectional area must be integrated into the equipotential bonding without exception.

This requirement on the equipotential bonding basically corresponds to that on the main equipotential bonding bar in accordance with IEC 60364-4-41 and IEC 60364-5-54, HD 60364-5-54.

Further towards the main equipotential bonding bar, the lightning equipotential bonding must also be implemented for cables of electrical and electronic systems (see also Chapter 7.5.2) at this boundary of the zones.

This equipotential bonding must be installed as close as possible to the location where the lines and metal installations enter the building or structure. The equipotential bonding conductor should be designed to be as short (low impedance) as possible.

For equipotential bonding, the following minimum cross sections for tying in the equipotential bonding bar to the earth-termination system, interconnecting the different equipotential bonding bars, and tying in the metal installations to the equipotential bonding bar, must be taken into account:

Material	Cross section
Cu	14 mm^2
Al	22 mm^2
Fe	50 mm^2

The following metal installations have to be incorporated into the equipotential bonding:

⇒ Metal cable ducts

⇒ Shielded cables and lines

⇒ Building reinforcement

⇒ Metal water supply pipes

⇒ Metal conduits for lines

⇒ Other metal pipe systems or conductive components (e.g. compressed air)

A corrosion-free earth connection can be easily constructed by using fixed earthing points. During this process, the reinforcement can be connected to the equipotential bonding at the same time (**Figure 7.5.1.1**).

The procedure of tying in the equipotential bonding bar to the fixed earthing point, and connecting the conduits to the equipotential bonding, is shown below (**Figure 7.5.1.1**).

Chapter 7.3 illustrates the tying in of cable shields to the equipotential bonding.

7.5.2 Equipotential bonding for power supply installations

In analogy to metal installations, all electrical power lines and data links at the entrance of the building (lightning protection zone boundary LPZ 0_A to LPZ 1) must be integrated into the equipotential bonding. Whereas the design of data links is described in Section 7.5.3, the following section will look at the design of equipotential bonding with electrical power lines in more detail. The intersections for the equipotential bonding at the LPZ boundary LPZ 0_A to LPZ 1 are defined with the help of the specific design of the property which requires protection. For installations fed by low voltage systems, the LPZ boundary LPZ 0_A/ LPZ 1 is usually taken to be the boundary of the building (**Figure 7.5.2.1**).

Fig. 7.5.1.1   Connection of EBB with fixed earthing point
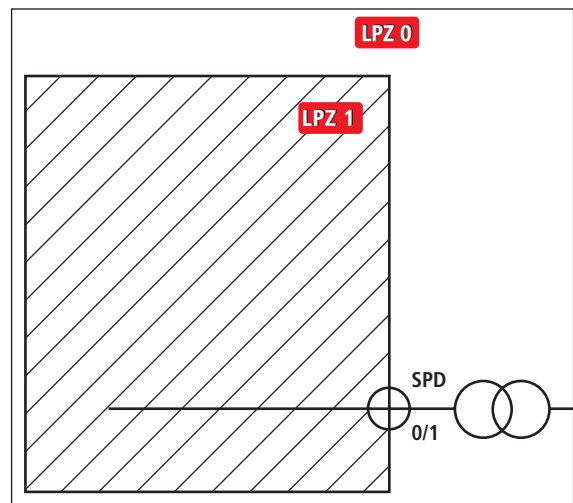
Fig. 7.5.2.1   Transformer outside the structure or building
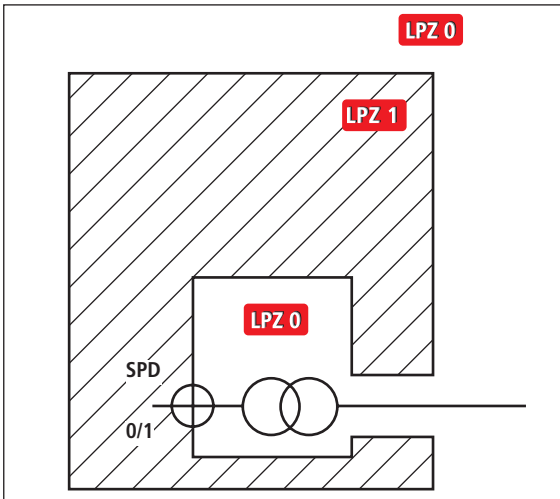
Fig. 7.5.2.2   Transformer inside the structure or building (LPZ 0 integrated in LPZ 1)

For properties fed directly from the medium voltage network, the lightning protection zone LPZ 0_A is extended up to the secondary side of the transformer. The equipotential bonding is carried out on the 230/400 V side of the transformer (**Figure 7.5.2.2**).

To avoid damage at the transformer the additional use of surge protective devices on the high voltage side of the transformer is recommended.

To prevent the flow of partial lightning currents in LPZ 0 from affecting parts of the installation/systems in LPZ 1, additional shielding measures are required for the medium voltage line entering the building or structure.

To prevent equalising currents from occurring between the various equipotential bonding points in an electrical installation, it is recommended to carry out the lightning equipotential bonding of all metal lines and electrical power lines and data links entering the build-

ing or structure centrally at one point. If local circumstances do not permit this, the use of a ring equipotential bonding bar (**Figures 7.5.2.3** and **7.5.2.4**) is recommended.

The ability of the lightning current arrester used (SPD, Class 1) to discharge the current must correspond to the loads at the location where it is employed, based on the lightning protection system level used for the property. The lightning protection system level appropriate for the building or structure under consideration must be chosen on the basis of a risk assessment. If no risk assessment is available, or if it is not possible to make detailed statements about the splitting of the lightning current at the LPZ boundary LPZ 0_A to LPZ 1, it is recommended to use the class of lightning protection system with the highest requirements (lightning protection level I) as a basis. The resulting lightning current load of the individual discharge paths is shown in **Table 7.5.2.1**.

When installing lightning current arresters on the LPZ boundary LPZ 0_A to LPZ 1, it must still be borne in mind that, if the recommended installation site is directly at the service entrance box, this can frequently only be done with the agreement of the power supplier (new: distribution network operator). The requirements on lightning current arresters in main distribution systems are laid down in the directive of the Association of the

1 Reinforcement of the outer walls and the foundation
2 Other earth electrodes, e.g. intermeshing to neighbouring buildings
3 Connection to the reinforcement
4 Internal (potential) ring conductor
5 Connection to external conductive parts, e.g. water pipeline
6 Earth electrode Type B, ring earth electrode
7 Surge protective device
8 Equipotential bonding bar
9 Electrical power or telecommunications line
10 Connection to supplementary earth electrodes, earth electrode Type A

Fig. 7.5.2.3   Example for equipotential bonding in a structure or building with several entries or the external conductive parts and with an internal ring conductor as a connection between the equipotential bonding bars
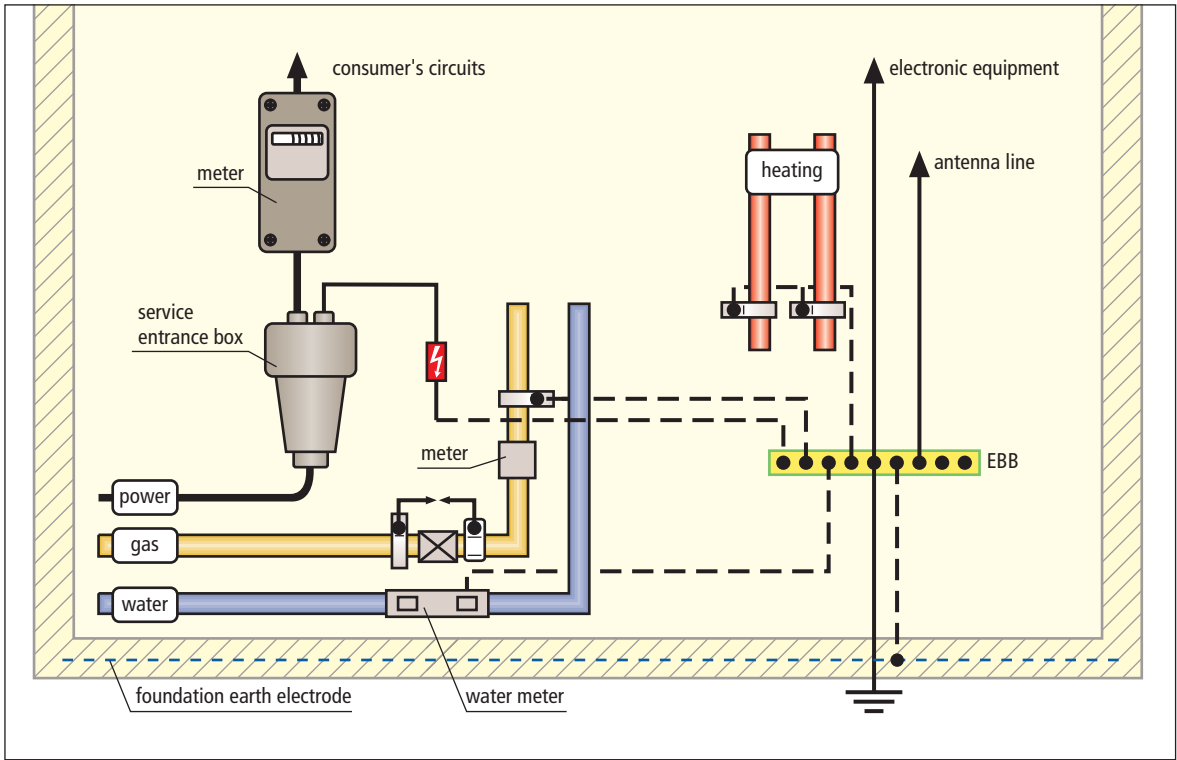
Fig. 7.5.2.4   Internal lightning protection with a common entry of all supply lines

German network operators (VDN) 2004-08: "Surge protective devices Type 1. Directive for the use of surge protective equipment Type 1 (up to now Class B) in main distribution systems" and IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001). When choosing lightning current arresters for the LPZ boundary LPZ 0_A to LPZ 1 then, besides the rating of the discharge capability, the prospective short circuit current to be expected at the installation site must also be taken into account. According to IEC 62305-3 (EN 62305-3) Annex E, Subclause 6.2.1.2, lightning current arresters based on spark gaps should have a high self-quenching capacity and a good ability to limit follow currents, in order to ensure that follow currents at the mains frequency are switched off automatically, and to prevent overcurrent protective devices, e.g. fuses, from false tripping (**Figures 7.5.2.5 – 7.5.2.7**).

The special issues relating to the choice, installation and assembly of lightning current arresters (SPD Type 1) are described in more detail in Chapter 8.1.

Lightning protection level LPL (former: Type of LPS)	Lightning impulse current carrying capability		
	in TN systems	in TT systems (L – N)	in TT systems (N – PE)
I	≥ 100 kA / m	≥ 100 kA / m	≥ 100 kA
II	≥ 75 kA / m	≥ 75 kA / m	≥ 75 kA
III / IV	≥ 50 kA / m	≥ 50 kA / m	≥ 50 kA
m: Quantity of conductors, e.g. for L1, L2, L3, N and PE; m = 5			

Table 7.5.2.1   Required lightning impulse current carrying capability of surge protective devices SPDs Type 1 according to the lightning protection level LPL and the type of low voltage consumer's installation

Fig. 7.5.2.5   DEHNventil combined lightning current and surge arrester
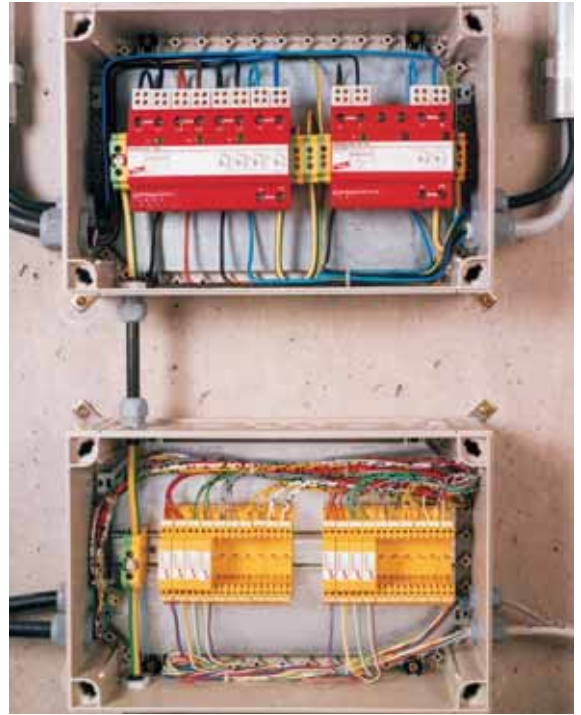
Fig. 7.5.2.6   Lightning equipotential bonding for power supply and information technology systems situated centrally at one point

Fig. 7.5.2.7   Lightning current arrester at LPZ boundary LPZ 0_A – LPZ 1

7.5.3 Equipotential bonding for information technology installations

LPZ 0 – LPZ 1

The lightning equipotential bonding from LPZ 0 to LPZ 1 must be carried out for all metal systems entering a building. IT lines must be connected as close as possible to the point where they enter the building or structure with lightning current arresters providing a suitable discharge capacity. For IT lines a general discharge capability of 2.5 kA (10/350 µs) each wire is required for the boundary from LPZ 0_A to LPZ 1. The generalised approach is not used, however, when designing the discharge capability for installations with a large number of IT lines. After calculating the partial lightning current to be expected for an IT cable (see IEC 62305-3 (EN 62305-3)), the lightning current must then be
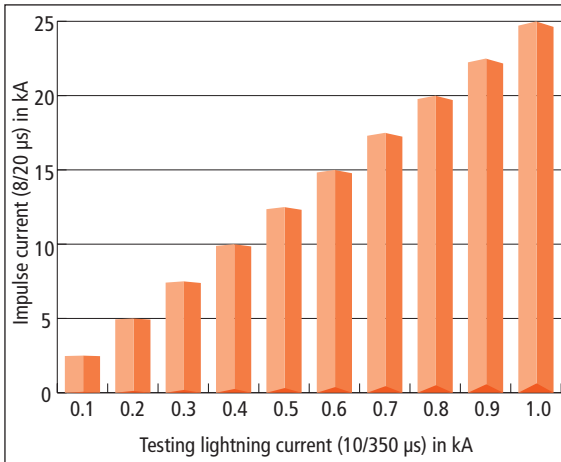
Fig. 7.5.3.1   Comparison of the amplitudes of test currents wave form 10/350 µs and 8/20 µs, each at equal loads
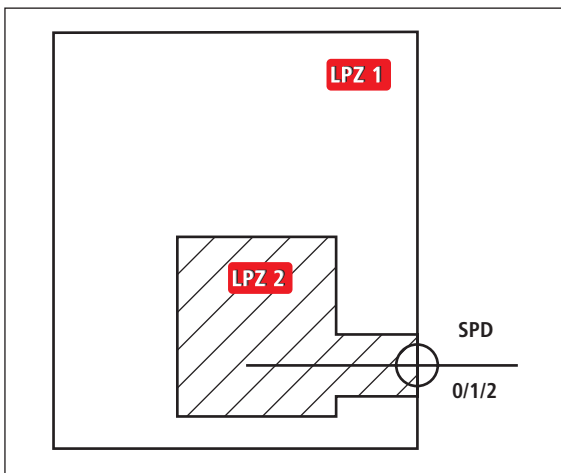
Fig. 7.6.2.1   Only one SPD (0/1/2) required (LPZ 2 integrated in LPZ 1)

divided by the number of individual cores in the cable actually used, in order to arrive at the impulse current per core. The partial lightning current load is lower for multi-core cables than it is for cables with fewer individual cores. For further information please see Chapter 6.3.

The following surge protective devices can therefore be used:

1.   Arresters designed for a discharge current of (10/350 µs)

2.   Arresters designed for a discharge current of (8/20 µs) if

⇒   they have no inductance as a decoupling element

⇒   the specified nominal discharge current is (8/20 µs) > 25 x the required discharge current (10/350 µs) per core (**Figure 7.5.3.1**).

If the equipotential bonding is carried out for lines on the LPZ boundary 0_B to LPZ 1, it is sufficient to use surge protective devices with a discharge capacity of 20 kA (8/20 µs) since no electrically coupled partial lightning currents flow.

7.6   Equipotential bonding on the boundary of LPZ 0_A and LPZ 2

7.6.1   Equipotential bonding for metal installations

See Chapter 7.5.1.

7.6.2   Equipotential bonding for power supply installations

LPZ 0_A – LPZ 2
Depending on the design of the building or structure, it is often unavoidable to realise a LPZ boundary from LPZ 0_A to LPZ 2, especially with compact installations (**Figure 7.6.2.1**).

Putting such an LPZ transition into practice makes high demands on the surge protective devices employed, and the surroundings of the installation. Besides the parameters previously described in Section 7.5.2, a protection level must be achieved which ensures the safe operation of equipment and systems of LPZ 2. A low voltage protection level and high limiting of the interference energy still transmitted by the arrester, form the basis here for a safe energy coordination to surge protective devices in LPZ 2, or to surge suppressing components in the input circuits of the equipment to be protected. The combined lightning current and surge arresters of the DEHNventil M family are designed for such applications and enable the user to combine lightning equipotential bonding and coordinated terminal device protection in a single device (**Figure 7.6.2.2**).

Since, for the LPZ boundary from LPZ 0 to LPZ 2, it is inevitable for both lightning protection zones to

Fig. 7.6.2.2   DEHNventil M TT 255

border directly on each other, a high degree of shielding at the zone boundaries is absolutely imperative. As a matter of principle, it is recommended to design the area of the lightning protection zones LPZ 0 and LPZ 2, which border directly on each other, to be as small as possible. Provided that the building or structure will permit it, LPZ 2 should be equipped with an additional zone shield which is constructed at the zone boundary LPZ 0,

separately from the zone shield flown through by a lightning current, so that, as can be seen in **Figure 7.6.2.1**, LPZ 1 is assembled for a further area of the installation. The attenuation of the electromagnetic field in LPZ 2 this measure brings about, obviates the need for systematic shielding of all lines and systems within LPZ 2, which would otherwise be necessary.

7.6.3 Equipotential bonding for information technology installations

LPZ 0_A – LPZ 2

Generally, a lightning current arrester from LPZ 0 to LPZ 1 acts like a kind of of wave breaker. It conducts a large part of the interference energy away, thus protecting the installation in the building from damage. However, it is frequently the case that the level of residual interference is still too high to protect the terminal devices. In a further step, additional surge protective devices are then installed at the LPZ boundary from LPZ 1 to LPZ 2 to make available a low level of residual interfer-
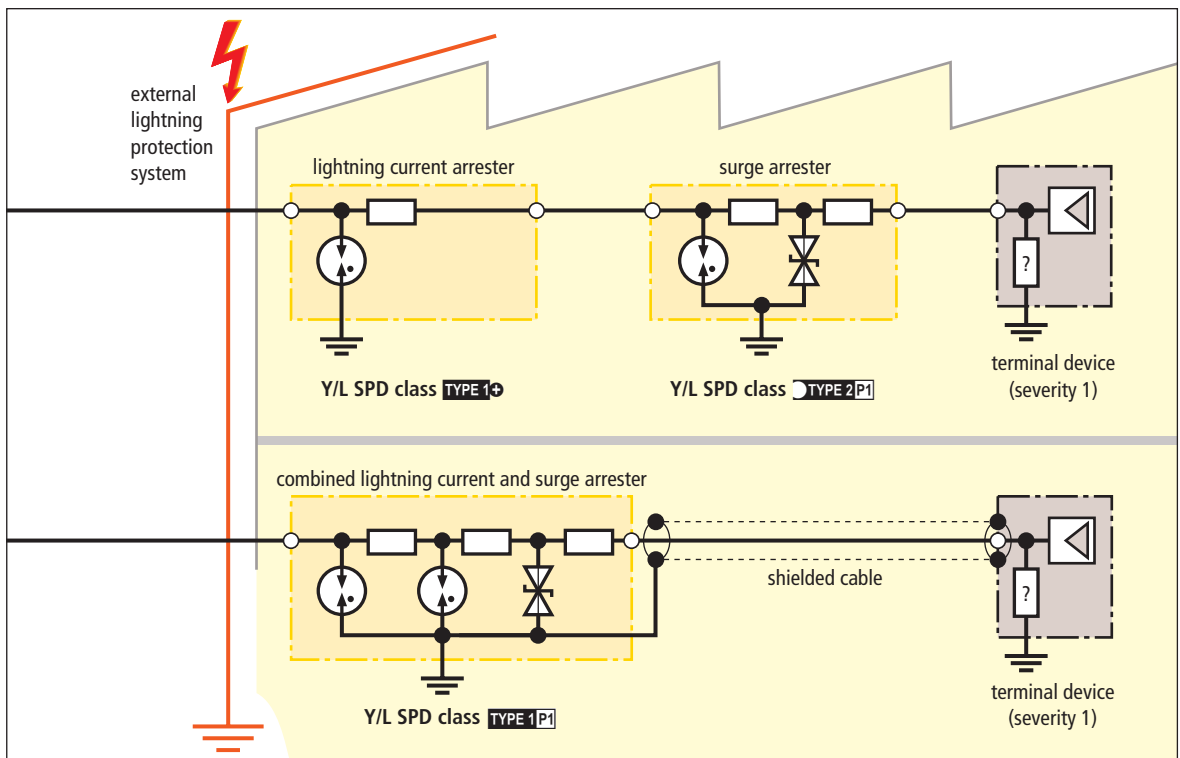
Fig. 7.6.3.1   Combination aid for Yellow/Line SPD classes (see also Figure 7.8.2.2)

ence adjusted to the immunity of the terminal device.

When the equipotential bonding from LPZ 0 to LPZ 2 is carried out, the first thing is to choose the installation site, and determine the partial lightning current of the individual lines and shields, precisely as described in Chapter 6.3.

However, the requirements on an SPD to be installed changes at the LPZ boundary, as do the requirements on the wiring after this boundary. The protective device must be designed as a combined lightning current and surge arrester and its energy must be coordinated with that of the terminal device (**Figure 7.6.3.1**). Combined lightning current and surge arresters have, on the one hand, an extremely high discharge capacity and, on the other, a low level of residual interference to protect the terminal devices. Furthermore, care must be taken that the outgoing line from the protective device to the terminal device is shielded, and that both ends of the cable shield are integrated into the equipotential bonding.

Combined lightning current and surge arresters are recommended

⇒ if the terminal devices are near to the location where the cables enter the building

⇒ if low impedance equipotential bonding from protective device to terminal device can be created

⇒ if the line from the protective device to the terminal device is continuously shielded and earthed at both ends

⇒ if a particularly cost-effective solution is sought.

The use of lightning current arresters and surge arresters is recommended

⇒ if there are long cable distances from the protective device to the terminal device

⇒ if the SPDs for power systems and IT surge protective devices are earthed via different equipotential bonding bars

⇒ if unshielded lines are used

⇒ if large interferences can occur inside LPZ 1.

7.7   Equipotential bonding on the boundary of LPZ 1 and LPZ 2 and higher

7.7.1 Equipotential bonding for metal installations

This equipotential bonding must be done as close as possible to the location where the lines and metal installations enter the zone.

All systems and conductive components must also be connected as described in Chapter 7.5.1.

The equipotential bonding conductors should be designed to be as short (low impedance) as possible.

Ring equipotential bonding in these zones facilitates a low impedance tie-in of the systems into the equipotential bonding.
Figure 7.7.1.1 illustrates the preparation for tying-in a cable trough to the ring equipotential bonding at the zone transition.

The following metal installations have to be integrated into the equipotential bonding:

⇒ metal cable ducts

⇒ shielded cables and lines

⇒ building reinforcement

⇒ metal water supply pipes

⇒ metal conduits for lines

⇒ other metal pipe systems or conductive components (e.g. compressed air)

Fig. 7.7.1.1   Ring equipotential bonding and fixed earthing point for connection of metal installations
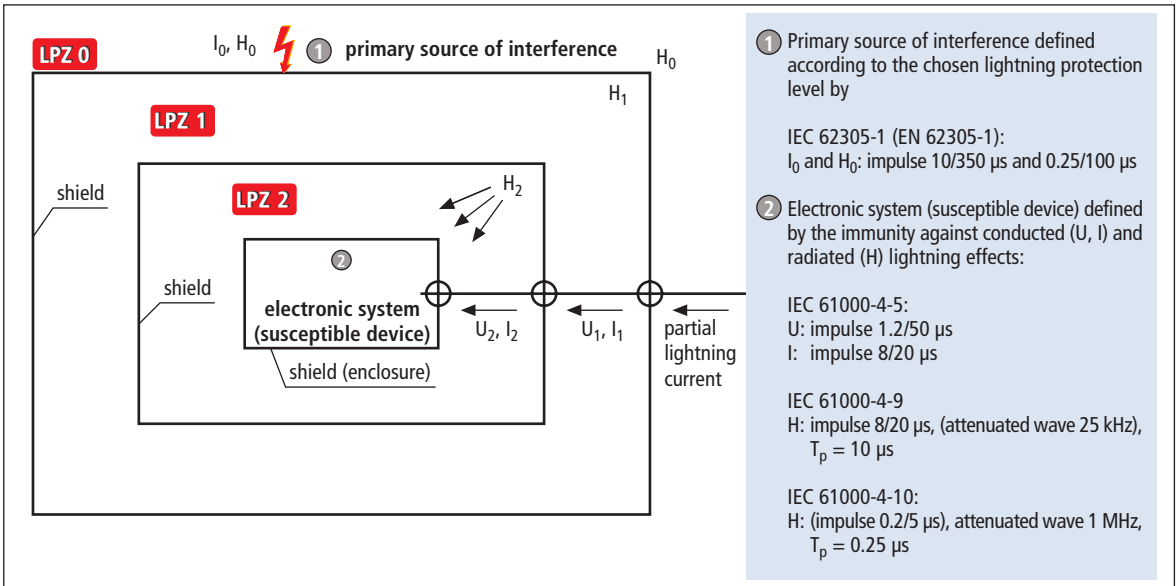
Fig. 7.7.2.1   Electromagnetic compatibility in case of a lightning strike

The cross sections described in Chapter 7.5.1 must again be used for equipotential bonding conductors combining the equipotential bonding bar and the earth-termination systems as well as other equipotential bonding bars.

For the tie-ins of the metal installations to the equipotential bonding, reduced cross sections can be used for these zone boundaries:

Material	Cross section
Cu	5 mm^2
Al	8 mm^2
Fe	16 mm^2

7.7.2 Equipotential bonding for power supply installations

LPZ 1 – LPZ 2 and higher

For LPZ boundaries LPZ 1 to LPZ 2 and higher, as well, surge limitation and field attenuation is achieved by systematical integration of the electrical power lines and data links, also, into the equipotential bonding at each LPZ boundary, as is done with all metal systems (**Figure 7.7.2.1**). Shielding the rooms and devices leads to the attenuation of the electromagnetic effect.

The function of the surge protective devices employed at the LPZ boundaries LPZ 1 to LPZ 2, or at the higher LPZ boundaries, is to minimise the residual values of upstream surge protective devices yet further. They must reduce induced surges affecting the lines laid in the LPZ, and surges generated in the LPZ itself. Depending on the location where the protective measures are taken, they can be either assigned to a device (device protection) (**Figure 7.7.2.2**) or represent the infrastructural basis for the functioning of a device or system in the installation (**Figure 7.7.2.3**).

Fig. 7.7.2.2   Surge protective device for terminal circuits DEHNflex M

Fig. 7.7.2.3   Multi-pole surge arrester DEHNguard M TT

Fig. 7.7.3.1   Protection of industrial electronic equipment (e.g. an SPC) by BLITZDUCTOR CT and SPS Protector

The embodiments of the surge protection at the LPZ boundaries LPZ 1 to LPZ 2 and higher can thus be designed in very different ways.

7.7.3   Equipotential bonding for information technology installations

LPZ 1 – LPZ 2 and higher
At the LPZ boundaries inside buildings, further measures must be taken to reduce the level of interference (**Figure 7.7.3.1**). Since, as a rule, terminal devices are installed in LPZ 2 or higher, the protective measures must ensure that the level of residual interference, lies below values the terminal devices can cope with.

⇒ Use of surge protective devices in the vicinity of terminal devices

⇒ Integration of the cable shields into the equipotential bonding

⇒ Low impedance equipotential bonding of the SPD for IT installations to terminal device and SPD for power installations

⇒ Paying attention to the energy coordination of SPD and terminal device

⇒ Telecommunications lines and gas discharge lamps must be installed at least 130 mm apart

⇒ The distribution boards of electrical installations and data should be located in different cabinets

⇒ Low voltage lines and telecommunications lines must cross at an angle of 90 °

⇒ Cable intersection must be carried out using the shortest route

7.8   Coordination of the protective measures at various LPZ boundaries

7.8.1   Power supply installations

Whereas surge protection in the terminal device, or immediately upstream of it, expressly fulfils the function of protecting the device, the function of surge protective devices in the surrounding installation is twofold. On the one hand, they protect the installation, and, on the other, they form the protective link between the threat parameters of the complete system and the immunity of the device of the equipment and systems requiring protection. The threat parameters of the system, and the immunity of the device to be protected, are thus dimensioning factors for the protective cascade to be installed. To ensure that this protective cascade, beginning with the lightning current arrester and ending with the terminal device protection, is able to function, one must ensure that individual protective devices are selectively effective, i.e. each protection stage only takes on the amount of interference energy which it is designed for. The synchronisation between the protective stages is generally termed coordination and is explained more detailed in IEC 62305-4 (EN 62305-4) Chapter 7. In order to achieve the described selectivity as the protective device operates, the parameters of the individual arrester stages must be coordinated in such a way that, if one protection stage is faced with the threat of an energy overload, the upstream more powerful arrester "responds" and thus takes over the discharge of the interference energy. When designing the coordination, one must be aware that the
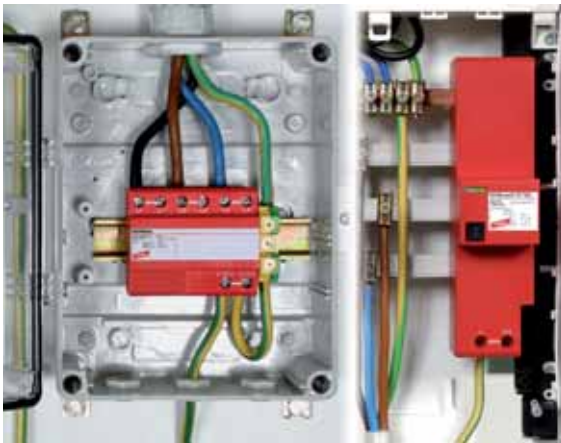
Fig. 7.8.1.1 DEHNbloc 3-pole – Lightning current arrester and DEHNventil ZP – Combined arrester

Fig. 7.8.1.2 DEHNguard TT H LI – Multi-pole surge arrester with service life indication
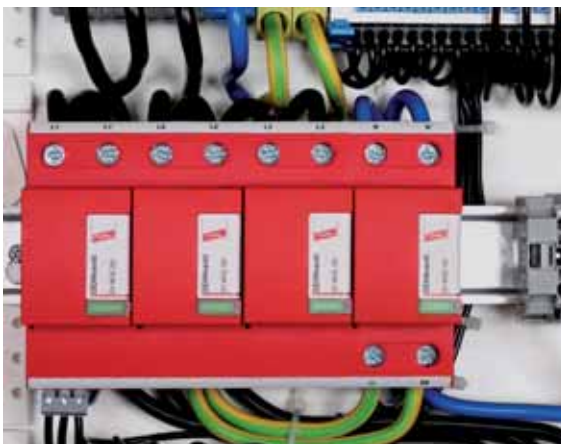
Fig. 7.8.1.3 DEHNventil M TNS – Modular combined arrester

pulse waveform with the greatest pulse length must be assumed to be a threat for the complete arrester chain. Even though surge protective devices, by definition, are only tested with pulse waveforms of 8/20 µs, for the coordination between surge arrester and lightning current arrester, and also for the surge protective device, it is imperative to determine the ability of the device to carry an impulse current of the partial lightning currents with the waveform 10/350 µs. The Red/Line family of energy-coordinated products, was created to avert the dangers arising from defective coordination and the resulting overloading of low-energy protective stages . These surge protective devices, which are coordinated both with each other and also with the device to be protected, provide the user with high safety. By designing them as lightning current arresters, surge arresters and combined lightning current and surge arresters, they are ideally matched to the requirements of the corresponding LPZ boundaries (**Figures 7.8.1.1 – 7.8.1.3**).

7.8.2 IT installations

When implementing measures to protect against disturbance variables from nearby, distant and direct lightning strikes within buildings, it is recommended to apply a concept of protective devices with several protective stages. This reduces the high energy interference (partial lightning current) in stages because an initial energy absorbing stage prevents the main part of the interference from reaching the downstream system. The subsequent stages serve to reduce the interference to values which the system can cope with. Depending on the conditions of the installation, several protective stages can also be integrated into one surge protective device using a combined protective circuit.

The relevant interfaces where the protective devices are employed as part of a cascade are, for example, the zone boundaries (LPZ) of a lightning protection zone concept which conforms to IEC 62305-4 (EN 62305-4).

A cascading of the surge protective devices must be carried out with due regard to the coordination criteria.
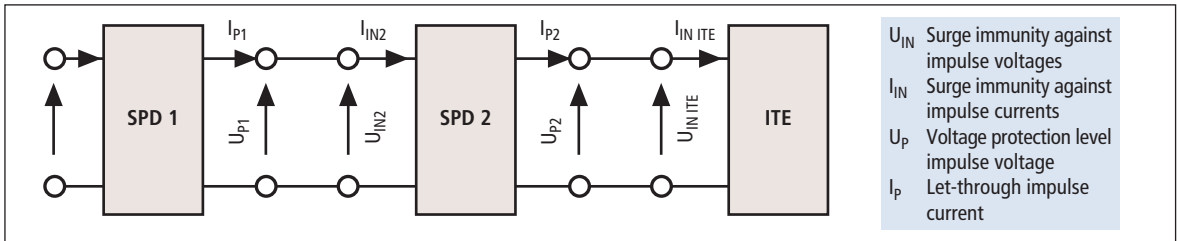
Fig. 7.8.2.1 Coordination according to let-through method of 2 SPDs and one terminal device (according to IEC 61643-21)
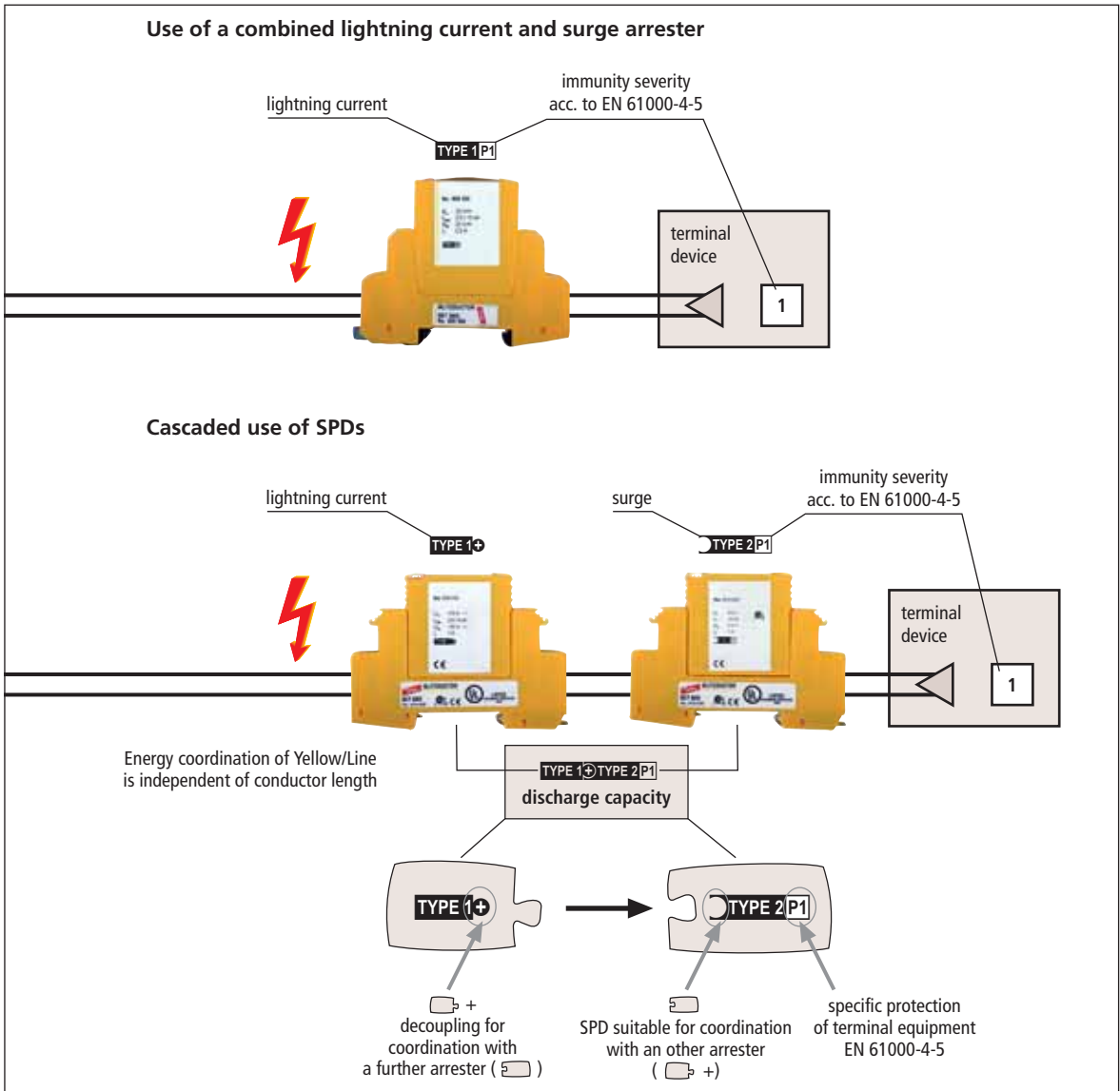
Fig. 7.8.2.2 Examples for the energy coordinated use of arresters according to the Yellow/Line TYPE of arresters and structure of the Yellow/Line-TYPE of arresters symbol

Characteristic	Symbol	Legend
Discharge capacity of an SPD (acc. to categories of IEC 61643-21)	**TYPE 1**	Impulse D1 (10/350 µs), lightning impulse current ≥ 2.5 kA / line or ≥ 5 kA / total • exceeds the discharge capacity of **TYPE 2** – **TYPE 4**
	TYPE 2	Impulse C2 (8/20 µs), increased impulse load ≥ 2.5 kA / line or ≥ 5 kA / total • exceeds the discharge capacity of **TYPE 3** – **TYPE 4**
	TYPE 3	Impulse C1 (8/20 µs), impulse load ≥ 0.25 kA / line or ≥ 0.5 kA / total • exceeds the discharge capacity of **TYPE 4**
	TYPE 4	Load < **TYPE 3**
Protective effect of an SPD (limitation below the test levels acc. to EN 61000-4-5)	**P1**	Test level required for the terminal device: 1 or higher
	P2	Test level required for the terminal device: 2 or higher
	P3	Test level required for the terminal device: 3 or higher
	P4	Test level required for the terminal device: 4
Energy coordination (with another Yellow/Line arrester)	⊕	SPD has a decoupling impedance and is suitable for coordination with an arrester labeled ⊐
	⊐	SPD suitable for coordination with an arrester having a decoupling impedance ⊕

Table 7.8.2.1   Symbol of the SPD class

Cabling	SPD	Exemplified assignment of SPD classes to LPZ boundaries		
		to LPZ 1	to LPZ 2	to LPZ 3
From LPZ 0$_A$	Combined SPD	**TYPE 1 P1**		
	Cascading	**TYPE 1** ⊕	⊐ **TYPE 2 P1**	
		TYPE 1 ⊐	⊕ **TYPE 3 P1**	
From LPZ 0$_B$	Same solution as from LPZ 0$_A$	s. a.		
	Surge arrester	**TYPE 2 P1** or ⊐ **TYPE 2 P1**		
	Cascading	**TYPE 2** ⊐	⊕ **TYPE 3**	
From LPZ 1	Combined arrester	–	**TYPE 1 P1**	
	Surge arrester	–	**TYPE 2 P1** or ⊐ **TYPE 2 P1**	
From LPZ 2	Same solution as from LPZ 1	–	s. a.	
	Surge arrester	–	–	**TYPE 2 P1**
		–	–	**TYPE 3 P1**
		–	–	**TYPE 4 P1**

Table 7.8.2.2   Assignment of the Yellow/Line class of the SPDs at the LPZ boundaries

To determine the coordination conditions acc. to IEC 61643-22, various methods are available (IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001)), some of which require certain knowledge about the structure of the protective devices. A "black box" method is the so-called "Let-Through-Energy Method", which is based on standard pulse parameters and hence can be understood from both a mathematical and a practical point of view.

All parts of the cascade are considered to be coordinated if the residual values I_p for a short-circuited output, and U_p for an open-circuit output, are smaller than the input values I_{in}/U_{in}.

These methods are, however, difficult for the user to carry out because they are very time-consuming. In order to save time and work, the standard permits the use of information supplied by the manufacturers for the coordination (**Figure 7.8.2.1**).

Lightning current arresters at LPZ 0/1 or higher are, as a rule, specified with a discharge capacity of waveform 10/350 μs. Surge arresters, by contrast, are only specified with a waveform of 8/20 μs. This originates from the fact that surge arresters were developed primarily for interferences of inductive and capacitive inputs. If, however, a line passing out of the building is connected to a cascade comprising lightning current arrester and surge arrester, it follows from the coordination conditions that

⇒ the most sensitive element responds first – the surge arrester

⇒ the surge arrester must also be able to carry part of the partial lightning current with the waveform 10/350 μs, albeit a small one

⇒ before the surge arrester is overloaded, the lightning current arrester must trip and take over the discharge process.

The surge protective devices of the Yellow/Line family are coordinated sequentially and safely with each other and with the terminal devices. Therefore they provide markings indicating the symbol of their SPD class (**Figure 7.8.2.2, Tables 7.8.2.1** and **7.8.2.2**).

7.9 Inspection and maintenance of the LEMP protection

The fundamentals and pre-conditions governing the inspection and maintenance of the LEMP protection are the same as those governing the inspection and maintenance of lightning protection systems, as previously described in Chapter 3.4.

The inspections carried out during the construction phase are particularly important for the inspection of the LEMP protection, since many components of the LEMP protection are no longer accessible when the building work has been completed. The necessary measures (e.g. connecting the reinforcement) must be documented photographically and included with the inspection report.

Inspections shall be carried out:

⇒ during the installation of the LEMP protection,

⇒ after the installation of the LEMP protection,

⇒ periodically,

⇒ after each modification to components which are relevant for the LEMP protection,

⇒ after a lightning strike to the building or structure, if necessary.

After completion of the inspection, all defects found must be corrected forthwith. The technical documentation must be updated as and where necessary.

A comprehensive inspection of the LEMP protection should be carried out at least every four years as part of the inspection of the electrical installation in accordance with workplace regulations.

8. Selection, installation and assembly of surge protective devices (SPDs)

8.1 Power supply systems (within the scope of the lightning protection zones concept according to IEC 62305-4 (EN 62305-4))

The installation of a lightning and surge protection system for electrical installations represents the latest state of the art and is an indispensable infrastructural condition for the trouble-free operation of complex electrical and electronic systems without consequential damage. The requirements on SPDs needed for the installation of this type of lightning and surge protection system as part of the lightning protection zones concept according to IEC 62305-4 (EN 62305-4) for power supply systems are stipulated in IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001).

SPDs employed as part of the structure's fixed installation are classified according to the requirements and loads on the installation sites as surge protective devices Type 1, 2 and 3 and tested according to IEC 61643-1 (EN 61643-11).

The highest requirements with respect to the discharge capacity are made on SPDs Type 1. These are employed within the scope of the lightning and surge protection system at the boundary of lightning protection zone LPZ 0$_A$ to LPZ 1 and higher, as shown in **Figure 8.1.1**. These protective devices must be capable of carrying partial lightning currents, waveform 10/350 µs, many times without consequential damage to the equipment. These SPDs Type 1 are called lightning current arresters. The function of these protective devices is to prevent destructive partial lightning currents from penetrating the electrical installation of a structure.

At the boundary of lightning protection zone LPZ 0$_B$ to LPZ 1 and higher, or lightning protection zone LPZ 1 to LPZ 2 and higher, SPDs Type 2 are employed to protect against surges. Their discharge capacity is around some 10 kA (8/20 µs).

The last link in the lightning and surge protection system for power supply installations is the protection of terminal devices (boundary from lightning protection zone LPZ 2 to LPZ 3 and higher). The main function of a protective device Type 3 used at this point is to protect against surges arising between L and N in the electrical system. These are particularly switching surges. The different functions, arrangements and requirements of arresters is given in **Table 8.1.1**.
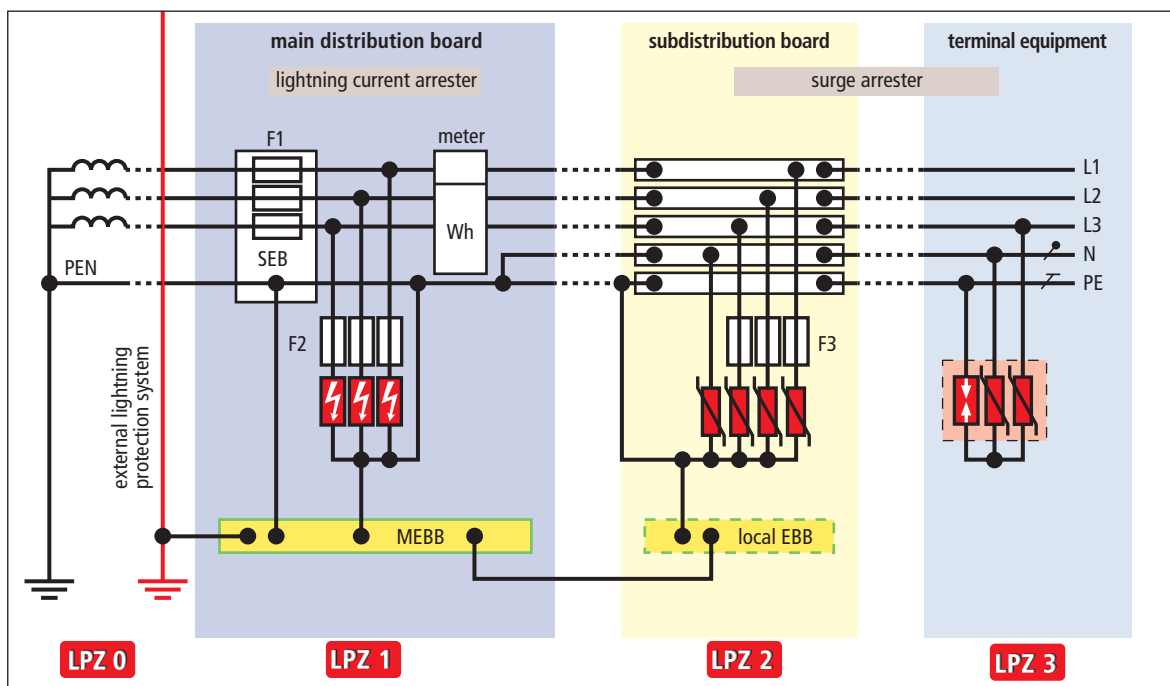
Fig. 8.1.1   Use of SPDs in power supply systems (schematic diagram)

Type/Description	Standard	E DIN VDE 0675-6 with A1, A2 (already withdrawn)	IEC 61643-1: 2005	EN 61643-11: 2002
Lightning current arrester; Combined lightning current and surge arrester		Class B	SPD class I	SPD Type 1
Surge arrester for distribution boards, subdistribution boards, fixed installations		Class C	SPD class II	SPD Type 2
Surge arrester for socket outlets/ terminal units		Class D	SPD class III	SPD Type 3

Table 8.1.1   Classification of SPDs according to VDE, IEC and EN

8.1.1 Technical characteristics of SPDs

Maximum continuous voltage U_c

The maximum continuous voltage (equal to: rated voltage) is the root mean square (rms) value of the max. voltage which may be applied to the correspondingly marked terminals of the surge protective device during operation. It is the maximum voltage on the arrester in the defined non-conductive state which ensures that this state is regained after it has responded and discharged.

The value of U_c shall be selected in accordance with the nominal voltage of the system to be protected and the requirements of the installation provisions (IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001)). Taking into account a 10 % voltage tolerance for TN and TT systems, the maximum continuous voltage U_c is 253 V for 230/400 V systems.

Lightning impulse current I_{imp}

This is a standardised impulse current curve with a 10/350 µs waveform. Its parameters (peak value, charge, specific energy) simulate the load caused by natural lightning currents.

Lightning impulse currents (10/350 µs) apply to SPDs Type 1. They must be able to discharge such lightning impulse currents several times without consequential damage to the equipment.

Nominal discharge current I_n

The nominal discharge current I_n is the peak value of the current flowing through the surge protective device (SPD). It has an 8/20 µs impulse current waveform and is rated for classifying the test of SPDs Type 2 and also for conditioning the SPDs for Type 1 and 2 tests.

Voltage protection level U_p

The voltage protection level of an SPD denotes the maximum instantaneous value of the voltage on the terminals of an SPD while at the same time characterising their capacity to limit surges to a residual level.

Depending on the type of SPD, the voltage protection level is determined by means of the following individual tests:

⇒ Lightning impulse sparkover voltage 1.2/50 µs (100 %)

⇒ Residual voltage for nominal discharge current (in accordance with EN 61643-11: U_{res})

The surge protective device appropriate to the installation site is chosen in accordance with the overvoltage categories described in IEC 60664-1 (EN 60664-1). It must be noted that the required minimum value of 2.5 kV for a 230/400 V three-phase system only applies to equipment belonging to the fixed electrical installation. Equipment in the terminal circuits supplied by the installation require a voltage protection level which is much lower than 2.5 kV.

IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001) also requires a minimum voltage protection level of 2.5 kV for a 230/400 V low-voltage consumers' installation. This minimum voltage protection level can be realised by means of a coordinated system of SPDs Type 1 and SPDs Type 2, or by employing a Type 1 combined lightning current and surge arrester.

Short-circuit withstand capability

This is the value of the prospective power-frequency short circuit current controlled by the surge protective device in case it is furnished with an upstream backup fuse (backup protection).

Follow current extinguishing capability U_c (I_{fi})

The follow current extinguishing capability, also termed breaking capacity, is the unaffected

(prospective) rms value of the mains follow current which can automatically be extinguished by the surge protective device when U_c is applied.

According to IEC 62305-3 (EN 62305-3) and IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001) the follow current extinguishing capability of the SPDs should correspond to the maximum prospective short circuit current at the SPD's installation site. For distributions in industrial plants with very high short circuit currents a corresponding backup fuse has to be chosen for the protective device which interrupts the mains follow current through the protective device.

According to both IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001) and EN 61643-11, SPDs connected between neutral conductors and PE conductors, where a follow current with mains frequency can arise after the SPD has responded (e.g. spark gaps), must have a follow current extinguishing capability of $I_{fi} \geq 100 \ A_{rms}$.

Follow current limiting (for spark-gap based SPDs Type 1)

Follow current limiting is the capability of a spark-gap based SPD to limit any mains follow currents arising to such a degree that the current actually flowing is noticeably smaller than the possible short circuit current at the installation site.

A high degree of follow current limiting prevents upstream protective elements (e.g. fuses) from tripping because of a too high mains follow current.

The follow current limiting is an important parameter for the availability of the electrical installation, particularly for spark-gap based SPDs with a low voltage protection level.

Coordination

In order to ensure a selective functioning of the various SPDs, an energy coordination among the individual SPDs is absolutely essential. The basic principle of energy coordination is characterised by the fact that each protective stage must only discharge the amount of interference energy the SPD is designed for. If higher interference energies occur, the protective stage upstream of the SPD, e.g. SPD Type 1, must take over the discharge of the impulse current and relieve the downstream protective devices. This type of coordination must take into account all possible incidences of interference such as switching surges, partial lightning currents, etc.. According to IEC 62305-4

(EN 62305-4) the manufacturer must prove the energy coordination of its SPDs.

The devices in the Red/Line family are coordinated with each other and tested with reference to their energy coordination.

TOV

TOV (**T**emporary **O**ver**V**oltage) is the term used to describe temporary surges which can arise as a result of faults within the medium and low-voltage networks.

To TN systems as well as the L-N path in TT systems and for a measuring time of 5 seconds applies: $U_{TOV} = 1.45 \times U_0$, where U_0 represents the nominal a.c. voltage of the line to earth.

At 230/400 V systems the TOV to be taken into consideration for the SPDs between L and N is $U_{tov} = 333.5 \ V$. For TOVs arising in low-voltage systems as a result of earth faults in the high-voltage system, $U_{TOV} = 1200 \ V$ for the N-PE path in TT systems has to be taken into consideration for 200 ms. IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001) requires a TOV withstand capability for SPDs installed in low voltage consumer's installations.

The devices of the Red/Line family of products must be rated for TOVs according to EN 61643-11 and meet th requirements of IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001).

8.1.2 Use of SPDs in various systems

Measures to ensure protection against life hazards always take priority over surge protective measures. Since both measures are directly linked to the type of power supply systems and hence also with the use of surge protective devices (SPDs), the following describes TN, TT and IT systems and the variety of ways in which SPDs can be used. Electric currents flowing through the human body can have hazardous consequences. Every electrical installation is therefore required to incorporate protective measures to prevent hazardous currents flowing through the human body. Components being energised during normal operation must be insulated, covered, sheathed or arranged to prevent from being touched if this could result in hazardous currents flowing through the body. This protective measure is termed "protection against electric shock under normal conditions". Moreover, it goes without saying, of course, that a hazard must not be caused either by current flowing

through the body if, as the result of a fault, e.g. a faulty insulation, the voltage is transferred to the metal enclosure (body of a piece of electrical equipment). This protection against hazards which, in the event of a fault, can result from touching bodies or extraneous conductive components, is termed "protection against electric shock under fault conditions".

Generally, the limit of the permanently permissible touch voltage U_L for a.c. voltages is 50 V and for d.c. 120 V.

In electrical circuits containing socket outlets and in electrical circuits containing Class I mobile equipment normally held permanently in the hand during operation, higher touch voltages, which can arise in the event of a fault, must be disconnected automatically within 0.4 s. In all other electrical circuits, higher touch voltages must be automatically disconnected within 5 s.

IEC 60364-4-41: 2005-12 describes protective measures against indirect shock hazard with protective conductors. These protective measures operate in the event of a fault by means of automatic disconnection or message. When setting up the measures for the "protection against electric shock under fault conditions", they must be assigned according to the system configuration and the protective device.

According to IEC 60364-4-41: 2005-12, a low voltage distribution system in its entirety, from the power source of the electrical installation to the last piece of equipment, is essentially characterised by:

⇒ earthing conditions at the power source of the electrical installation (e.g. low voltage side of the local network transformer)

and

⇒ earthing conditions of the body of the equipment in the electrical consumer´s installations.

Hence, essentially, three basic types are defined as distribution systems:

TN system, **TT** system and **IT** system.

The letters used have the following significance:

The **FIRST LETTER** describes the earthing conditions of the supplying power source of the electrical installation:

T direct earthing of one point of the power source (generally the neutral point of the transformer),

I Insulation of all active components from the earth or connection of one point of the power source to earth via an impedance.

The **SECOND LETTER** describes the earthing conditions of the bodies of the equipment of the electrical installation:

T Body of the equipment is earthed directly, regardless of any possible existing earthing of one point of the power supply,

N Body of the electrical equipment is directly connected to the power system earthing (earthing of the power source of the electrical installation).

SUBSEQUENT LETTERS describe the arrangement of the neutral conductor and the protective conductor:

S Neutral conductor and protective conductor are separate from each other,

C Neutral conductor and protective conductor are combined (in one conductor).

There are therefore three possible options for the TN system:

TN-S system, **TN-C** system and **TN-C-S** system.

The protective devices which can be installed in the various systems are:

⇒ overcurrent protective device,

⇒ residual current device,

⇒ insulation monitoring device,

⇒ fault-voltage-operated protection device (special cases).

As previously mentioned, the system configuration must be assigned to the protective device. This results in the following assignments:

TN system

⇒ Overcurrent protective device,

⇒ Residual current device.

TT system

⇒ Overcurrent protective device,

⇒ Residual current device,

⇒ Fault-voltage-operated protective device (special cases).

IT system

⇒ Overcurrent protective device,

⇒ Residual current device,

⇒ Insulation monitoring device,

These measures to protect against life hazards have top priority when installing power supply systems. All other protective measures such as lightning and surge protection of electrical systems and installations are secondary to the protective measures taken against indirect contact with protective conductors under consideration of the system configuration and the protective device. The latter must not be overridden by the use of protective devices for lightning and surge protection. The occurrence of a fault in an SPD, unlikely as it may be, shall also be taken into account. This has particular significance because the surge protective devices are always used to the protective conductor.

In the following sections we therefore describe the use of SPDs in various system configurations. These circuit proposals are taken from IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001).

The concepts shown illustrate the use of lightning current arresters mainly in the area of the service entrance box, i.e. upstream of the meter. IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001) defines the installation site of lightning current arresters as "close to the origin of the installation".

In Germany the use of lightning current arresters upstream the meter is regulated by the VDN-Richtlinie 2004-08 [engl.: Directive of the Association of the German Network Operators]: "Überspannungs-Schutzeinrichtungen Typ 1. Richtlinie für den Einsatz von Überspannungs-Schutzeinrichtungen (ÜSE) Typ 1 (bisher Anforderungsklasse B) in Hauptstromversorgungssystemen." [engl: "Surge protective devices Type 1. Directive for the use of surge protective equipment Type 1 (up to now Class B) in main distribution systems"

This directive, compiled by the VDN defines basic requirements which, depending on the Distribution Network Operator (DNO) can lead to different technical designs.

The preferred kind of supply (network configuration) must be ascertained from the responsible operator of the distribution network

8.1.3 Use of SPDs in TN Systems

For "protection against electric shock under fault conditions" in TN systems, overcurrent and residual current devices have been approved. For the use of SPDs this means that these protective devices may only be arranged downstream of the devices for "protection against electric shock under fault conditions" in order to ensure that the measure to protect against life hazards also operates in the event of a failure of an SPD.

If an SPD Type 1 or 2 is installed downstream of a residual current device, it has to be expected that, because of the discharged impulse current to PE, this process will be interpreted as residual current by a residual current device (RCD), and it interrupts the circuit.

Moreover, if an SPD Type 1 is loaded with partial lightning currents it must be assumed that the high dynamics of the lightning current will cause mechanical damage on the residual current device (**Figure 8.1.3.1**). This would override the protective measure "protection against electric shock under fault conditions".

Of course, this must be avoided. Therefore both lightning current arresters Type 1 and SPDs Type 2 should be used upstream of the residual current device. Hence, for SPDs Type 1 and 2, the only possible measure for "protection against electric shock under fault conditions" is using overcurrent protective devices. The use of SPDs must therefore always be considered in conjunction with a fuse as the overcurrent protective device. Whether or not a supplementary separate backup fuse must be designated for the arrester branch, depends on the size of the next upstream supply fuse and the backup fuse approved for the SPD. The following maximum continuous voltages apply to SPDs Type 1, 2 and 3 when used in TN systems (**Figures.8.1.3.2** and **8.1.3.3a** to **b**):

Figure 8.1.3.4 illustrates an example of the connections for use of lightning current arresters and surge protective devices in TN-C-S systems. It can be seen that SPDs Type 3 are used downstream of the residual current device (RCD). In this context, please note the following:

As a result of the frequency of switching surges in the terminal circuits, SPDs Type 3 are primarily employed to protect against differential mode voltages. These surges generally arise between L and N. A surge limitation between L and N means
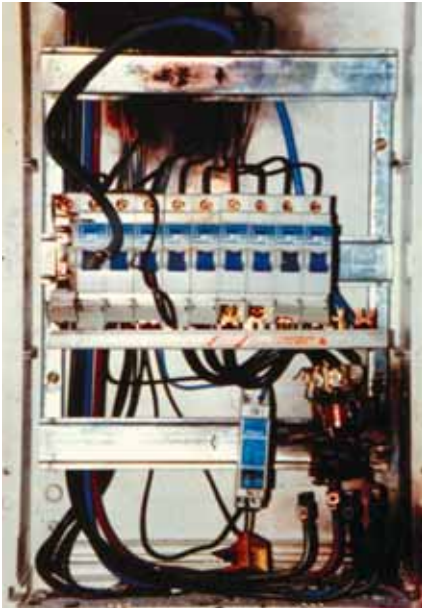
Fig. 8.1.3.1 RCD destroyed by lightning impulse current

that no impulse current is discharged to PE. Thus, this process can also not be interpreted as residual current by the RCD. In all other cases, SPDs Type 3 are designed for a nominal discharge capacity of 1.5 kA. These values are sufficient in the sense that upstream protective stages of SPDs Type 1 and 2 take over the discharge of high energy impulses. When using an RCD capable of withstanding impulse currents, these impulse currents are not able to trip the RCD or cause mechanical damage. The **Figures 8.1.3.5** to **8.1.3.9** illustrate the use of SPDs as part of the lightning protection zones concept, and the required lightning and surge protective measures for a TN-C-S system.

8.1.4 Use of SPDs in TT systems

For "protection against electric shock under fault conditions" in TT systems, the overcurrent protective devices, residual current devices (RCD) and, in special cases, fault-voltage-operated

$U_0 = 230$ V a.c.
$U_c \geq 1.1$ x 230 V = 255 V a.c.
=> 3 x SPD with $U_c \geq 255$ V a.c.

$U_0 =$ Nominal a.c. voltage of the phase conductors to earth
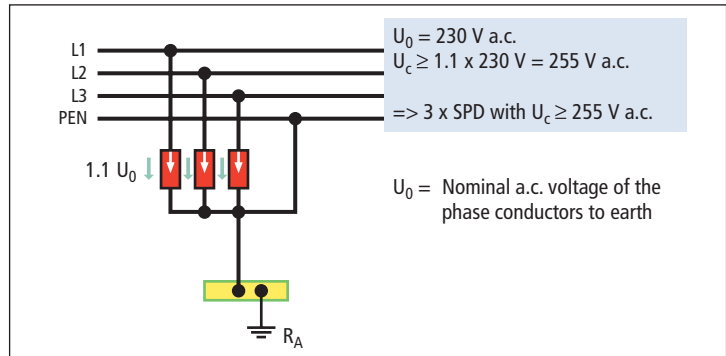
Fig. 8.1.3.2 "3-0" circuit in TN-C systems

$U_0 = 230$ V a.c.
Phase conductor to PE:
$U_c \geq 1.1$ x 230 V = 255 V a.c.
Neutral conductor to PE:
$U_c \geq 230$ V a.c.

3 x SPD with $U_c \geq 255$ V a.c.
1 x SPD with $U_c \geq 230$ V a.c.

The values of U_0 between neutral conductor and PE already refer to most unfavourable operating conditions. A tolerance of 10 % was therefore not considered

$U_0 =$ Nominal a.c. voltage of the phase conductors to earth

Fig. 8.1.3.3a "4-0" circuit in TN-S systems

$U_0 = 230$ V a.c.
Phase conductor to PE:
$U_c \geq 1.1$ x 230 V = 255 V a.c.
Neutral conductor to PE:
$U_c \geq 230$ V a.c.

3 x SPD with $U_c \geq 255$ V a.c.
1 x SPD with $U_c \geq 230$ V a.c.

The values of U_0 between neutral conductor and PE already refer to most unfavourable operating conditions. A tolerance of 10 % was therefore not considered.

$U_0 =$ Nominal a.c. voltage of the phase conductors to earth

Fig. 8.1.3.3b "3+1" circuit in TN-S systems

Fig. 8.1.3.4   Use of SPDs in TN-C-S systems

Fig. 8.1.3.5   Use of SPDs in TN-S systems

L1 L2 L3 N PE

Socket Outlet

SPD Type 3
(Surge arrester)

1 x DSA 230 LA   Part No. 924 370
for cable ducts

SPD Type 3
(Surge arrester)

1 x DFL M 255   Part No. 924 396
for flush-mounted systems

SPD Type 3
(Surge arrester)

1 x STC 230   Part No. 924 350
for existing socket outlets

Subdistribution Board

Cable length ≥ 5 m

16 A

125 A ①

1 x DG M TNS 275   Part No. 952 400

SPD Type 2
(Surge arrester)

125 A ①

fault signal

or with remote signalling contact:
1 x DG M TNS 275 FM   Part No. 952 405

SPD Type 2
(Surge arrester)

Cable length ≥ 15 m

DEHNbloc® Maxi
Coordinated to DEHNguard®
without additional cable length.

DEHNventil®
Directly coordinated to
Red/Line SPDs Type 2 and 3
without additional cable length.

Main Distribution Board

SPD Type 1
(Lightning current arrester)

315 A ①

1 x DB 3 255 H   Part No. 900 120
alt. 3 x DB 1 255 H   Part No. 900 222
1 x MVS 1 8   Part No. 900 611

SPD Type 1
(Coordinated lightning
current arrester)

315 A ①

3 x DBM 1 255 L   Part No. 900 026
1 x MVS 1 8   Part No. 900 611
alt. 3 x DBM 1 255   Part No. 900 025
1 x MVS 1 8   Part No. 900 611

SPD Type 1
(Combined lightning current
and surge arrester)

315 A ①

1 x DV M TNC 255   Part No. 951 300
alt. 1 x DV M TNC 255 FM Part No. 951 305
also available as
1 x DV M TNS 255   Part No. 951 400
alt. 1 x DV M TNS 255FM Part No. 951 405

EBB

1) Only required, if a fuse of the same or a lower nominal value is not already provided in the upstream power supply.

Fig. 8.1.3.6   SPDs used in TN systems – Example: Office Building – Separation of the PEN in the main distribution board

L1 L2 L3 N PE

Socket Outlet

SPD Type 3
(Surge arrester)

1 x NSM PRO EW Part No. 924 342

SPD Type 3
(Surge arrester)

1 x SF PRO Part No. 909 820
1 x S PRO Part No. 909 821

SPD Type 3
(Surge arrester)

1 x SFL PRO Part No. 912 260

Cable length ≥ 5 m

16 A

Subdistribution Board

125 A 1

1 x DG M TNC 275 Part No. 952 300

SPD Type 2
(Surge arrester)

125 A 1

fault signal

or with remote signalling contact:
1 x DG M TNC 275 FM Part No. 952 305

SPD Type 2
(Surge arrester)

Cable length ≥ 15 m

DEHNbloc® Maxi
Coordinated to DEHNguard®
without additional cable length.

DEHNventil®
Directly coordinated to
Red/Line SPDs Type 2 and 3
without additional cable length.

Main Distribution Board

SPD Type 1
(Lightning current arrester)

315 A 1

1 x DB 3 255 H Part No. 900 120
alt. 3 x DB 1 255 H Part No. 900 222
1 x MVS 1 8 Part No. 900 611

SPD Type 1
(Coordinated lightning
current arrester)

315 A 1

3 x DBM 1 255 L Part No. 900 026
1 x MVS 1 8 Part No. 900 611
alt. 3 x DBM 1 255 Part No. 900 025
1 x MVS 1 8 Part No. 900 611

SPD Type 1
(Combined lightning current
and surge arrester)

315 A 1

1 x DV M TNC 255 Part No. 951 300
alt. 1 x DV M TNC 255 FM Part No. 951 305

EBB

1) Only required, if a fuse of the same or a lower nominal value is not already provided in the upstream power supply.

Fig. 8.1.3.7 SPDs used in TN systems – Example: Office Building – Separation of the PEN in the subdistribution board

L1 L2 L3 N PE

SPD Type 3
(Surge arrester)

3 A 1

PLC

Cable length ≥ 5 m

1 x **SPS PRO** Part No. 912 253

SPD Type 3
(Surge arrester)

25 A also
permissible
without NF 10

NETZFILTER

PLC

10 A 1

1 x **DR M 2P 255 FM** Part No. 953 205
1 x **NF 10** Part No. 912 254

SPD Type 3
(Surge arrester)

16 A 1

electronic
equipment

1 x **DR 230 3N FML** Part No. 901 130

16 A

125 A 1

3 x **V NH00 280** Part No. 900 261

2

SPD Type 2
(Surge arrester)

1 x **DG M TNC 275** Part No. 952 300
or with remote signalling contact:
1 x **DG M TNC 275 FM** Part No. 952 305

SPD Type 2
(Surge arrester)

Cable length ≥ 15 m

DEHNbloc® Maxi
Coordinated to DEHNguard®
without additional cable length.

DEHNventil®
Directly coordinated to
Red/Line SPDs Type 2 and 3
without additional cable length.

SPD Type 1
(Lightning current arrester)

315 A 1

EBB

3 x **DB NH00 255 H** Part No. 900 273
alt. 3 x **DB 1 255 H** Part No. 900 222
1 x **MVS 1 8** Part No. 900 611

SPD Type 1
(Coordinated lightning
current arrester)

315 A 1

fault signal

3 x **DBM 1 255 L** Part No. 900 026
1 x **MVS 1 8** Part No. 900 611
alt. 3 x **DBM 1 255 S** Part No. 900 220

SPD Type 1
(Combined lightning current
and surge arrester)

315 A 1

fault signal

1 x **DV M TNC 255 FM** Part No. 951 305
alt. 1 x **DV M TNC 255** Part No. 951 300

1) Only required, if a fuse of the same or a lower nominal value is not already provided in the upstream power supply.
2) Without separate backup fuse in case of earth-fault- and short-circuit-proof installation.

Fig. 8.1.3.8   SPDs used in TN systems – Example: Industry – Separation of the PEN in the subdistribution board

L1 L2 L3 N PE

**SPD Type 3
(Surge arrester)**

heating

Heating Control

16 A

1 x **DR M 2P 255**   **Part No. 953 200**

**SPD Type 3
(Surge arrester)**

S-PROTECTOR

Socket Outlet

1 x **S PRO**   **Part No. 909 821**
1 x **SF PRO**   **Part No. 909 820**
1 x **SFL PRO**   **Part No. 912 260**

KW h

**SPD Type 1
(Combined lightning current
and surge arrester)**

Note:
As an alternative, surge arresters can also be used
(e.g. **DG M TNC 275**   **Part No. 952 300**),
if no
- lightning protection system,
- electrical power supply by the service entry mast,
- antenna on the roof
is available.

1 x **DV ZP TNC 255**   **Part No. 900 390**
also available for 5-wire systems
1 x **DV ZP TT 255**   **Part No. 900 391**

PEN

L1

L2

L3

315 A gL/gG

EBB

PEN
L1
L2
L3

**Central Main and
Subdistribution Board**

Fig. 8.1.3.9   SPDs used in TN systems – Example: Residential building

protective devices have been approved. This means that, in TT systems, lightning current and surge arresters may only be arranged downstream of the above described protective devices in order to ensure the "protection against electric shock under fault conditions" in the event of an SPD failure.

As previously described in Section 8.1.3, in case of an arrangement of an SPD Type 1 or 2 downstream of an RCD, it has to be expected that, because of the impulse current discharged to PE, this discharge process will be

L1
L2
L3
N
PE

$1.1\ U_0$

U_0

R_A

$U_0 = 230$ V a.c.

Phase conductor to neutral conductor
$U_c \geq 1.1 \times 230$ V = 255 V a.c.

Neutral conductor to PE:
$U_c \geq 230$ V a.c.

3 x SPD with $U_c \geq 255$ V a.c.

1 x N-PE arrester with $U_c \geq 230$ V a.c.

The values of U_0 between neutral conductor and PE already refer to the most unfavourable operating conditions.
A tolerance of 10 % has therefore not been considered.

$U_0 =$ Nominal a.c. voltage of the phase conductors to earth

Fig. 8.1.4.1   TT system (230/400 V); "3+1" circuit

DEHN
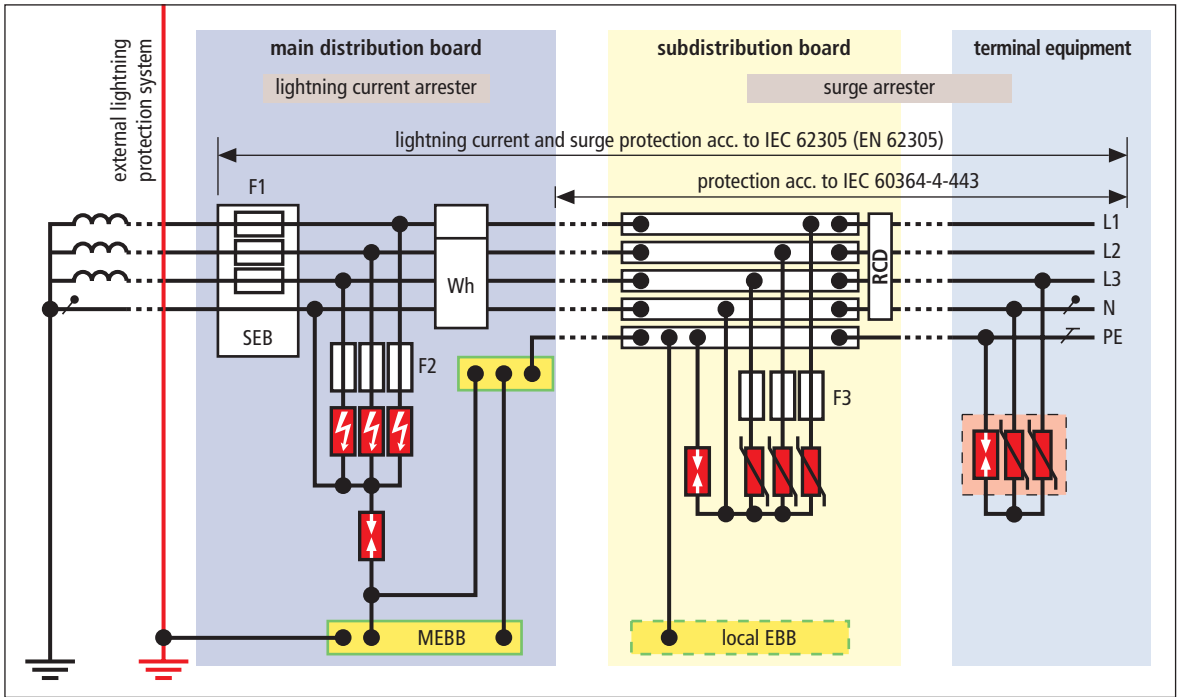
Fig. 8.1.4.2   Use of SPDs in TT systems

interpreted by the RCD as residual current, and then the circuit is interrupted by the same. If SPDs Type 1 are used, it must further be assumed that the dynamics of the discharged partial lightning current would cause mechanical damage to the RCD as the SPD Type 1 responds as is the case with TN systems. This would damage the protective device for "protection against electric shock under fault conditions" and override the protective measure. This type of state, which can result in life hazard, must of course be avoided. Hence, both SPDs Type 1 and SPDs Type 2 must always be installed upstream of the residual current device in TT systems. SPDs Type 1 and 2 must be arranged in TT systems to meet the conditions for the use of overcurrent protective devices for "protection against electric shock under fault conditions".

In the event of a failure, i.e. a faulty SPD, short circuit currents must flow to initiate an automatic disconnection of the overcurrent protective devices within 5 s. If the arresters in the TT system were arranged as shown in **Figures 8.1.3.4** and **8.1.3.5** for TN systems then, in the event of a fault, only earth fault currents would arise instead of

short circuit currents. In certain circumstances, however, these earth fault currents do not trip an upstream overcurrent protective device within the time required.

SPDs Type 1 and 2 in TT systems are therefore arranged between L and N. This arrangement shall ensure that, in the event of a faulty protective device in the TT system, a short circuit current can develop and cause the next upstream overcurrent protective device to respond. However, since lightning currents always occur to earth, i.e. PE, a supplementary discharge path between N and PE must be provided.

These so-called "N-PE arresters" must meet special requirements since here, on the one hand, the sum of the partial discharge currents from L1, L2, L3 and N must be carried and, on the other, there must be a follow current extinguishing capability of 100 A_{rms} because of a possible shifting of the neutral point.

The following maximum continuous voltages apply to the use of SPDs in TT systems between L and N (**Figure 8.1.4.1**):
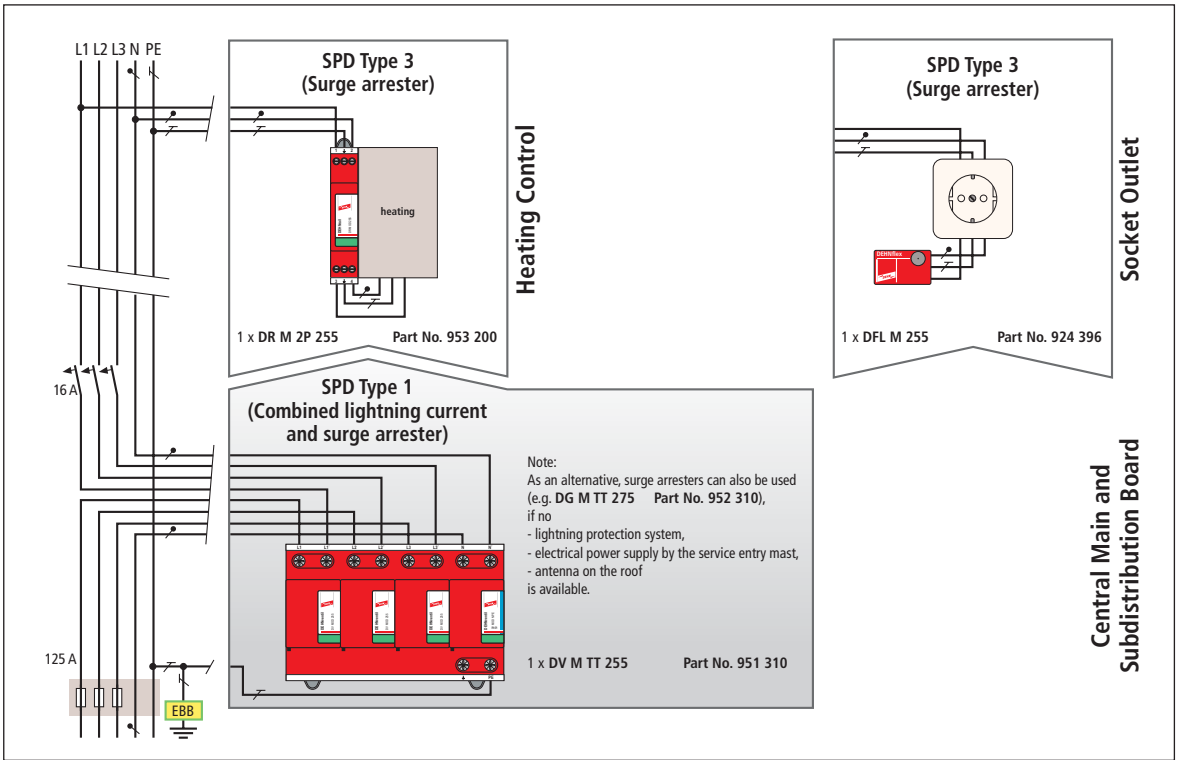
Fig. 8.1.4.3   SPDs used in TT systems – Example: Residential Building

The lightning current carrying capability of the SPDs Type 1 must be designed to conform to lightning protection levels I, II, III/IV, as per IEC 62305-1 (EN 62305-1).

For the lightning current carrying capability of the SPDs between N and PE, the following values must be maintained:

Lightning protection level:
I $I_{imp} \geq$ 100 kA (10/350 µs)
II $I_{imp} \geq$ 75 kA (10/350 µs)
III/IV $I_{imp} \geq$ 50 kA (10/350 µs).

The SPDs Type 2 are also connected between L and N and between N and PE. For the SPD between N and PE, in combination with SPDs Type 2, the discharge capacity must be at least $I_n \geq$ 20 kA (8/20 µs) for three-phase systems and $I_n \geq$ 10 kA (8/20 µs) for single-phase systems.

Since coordination is always performed on the basis of the worst-case conditions (10/350 µs waveform), the N-PE Type 2 arrester from the Red/Line family is based on a value of 12 kA (10/350 µs).

Figure 8.1.4.2 to **8.1.4.6** shows examples of the connections for use of SPDs in TT systems. As is the case in TN systems, surge protective devices Type 3 are installed downstream of the RCD. Generally, the impulse current discharged by this SPD is so low that the RCD does not recognise this process as a residual current.

However, it is still important to use an RCD capable of withstanding impulse currents.

8.1.5 Use of SPDs in IT systems

For "protection against electric shock under fault conditions" in IT systems, overcurrent protective devices, residual current devices (RCD) and insulation monitoring devices have been approved.

Whereas in TN or TT systems, the "protection against electric shock under fault conditions" in the event of the first fault is ensured by the appropriate automatic disconnection from supply

SPD Type 3 (Surge arrester)	**SPD Type 3** (Surge arrester)	**SPD Type 3** (Surge arrester)

L1 L2 L3 N PE

Socket Outlet

1 x **DSA 230 LA**   **Part No. 924 370**
for cable ducts

1 x **DFL M 255**   **Part No. 924 396**
for flush-mounted systems

1 x **STC 230**   **Part No. 924 350**
for existing socket outlets

Cable length ≥ 5 m

16 A

RCD

125 A ①

125 A ①

fault signal

1 x **DG M TT 275**   **Part No. 952 310**

or with remote signalling contact:
1 x **DG M TT 275 FM**   **Part No. 952 315**

SPD Type 2
(Surge arrester)

SPD Type 2
(Surge arrester)

Subdistribution Board

Cable length ≥ 15 m

DEHNbloc® Maxi
Coordinated to DEHNguard®
without additional cable length.

DEHNventil®
Directly coordinated to
Red/Line SPDs Type 2 and 3
without additional cable length.

SPD Type 1
(Lightning current arrester)

SPD Type 1
(Coordinated lightning
current arrester)

SPD Type 1
(Combined lightning current
and surge arrester)

Main Distribution Board

315 A ①

315 A ①

315 A ①

fault signal

EBB

1 x **DB 3 255 H** **Part No. 900 120**	3 x **DBM 1 255 L** **Part No. 900 026**	1 x **DV M TT 255 FM** **Part No. 951 315**
alt. 3 x **DB 1 255 H** **Part No. 900 222**	alt. 3 x **DBM 1 255** **Part No. 900 025**	alt. 1 x **DV M TT 255** **Part No. 951 310**
1 x **DGP BN 255** **Part No. 900 132**	1 x **DGPM 255** **Part No. 900 055**	
1 x **DK 35** **Part No. 900 699**	1 x **MVS 1 8** **Part No. 900 611**	
1 x **MVS 1 4** **Part No. 900 610**		

1) Only required, if a fuse of the same or a lower nominal value is not already provided in the upstream power supply.

Fig. 8.1.4.4 SPDs used in TT systems – Example: Office building

Switchgear/Machine

SPD Type 3 (Surge arrester)

3 A 1

PLC

DEHN SPD
SPS PRO
function
OUT / FM

1 x SPS PRO   Part No. 912 253

SPD Type 3 (Surge arrester)

25 A also permissible without NF 10

NETZFILTER

PLC

10 A 1

1 x DR M 2P 255 FM   Part No. 953 205
1 x NF 10   Part No. 912 254

SPD Type 3 (Surge arrester)

16 A 1

electronic equipment

DEHNrail 230/3N FML

1 x DR 230 3N FML   Part No. 901 130

Cable length ≥ 5 m

16 A
RCD

Subdistribution Board

125 A 1

1 x DG M TT 275   Part No. 952 310

SPD Type 2 (Surge arrester)

125 A 1

fault signal

or with remote signalling contact:
1 x DG M TT 275 FM   Part No. 952 315

SPD Type 2 (Surge arrester)

Cable length ≥ 15 m

DEHNbloc® Maxi
Coordinated to DEHNguard®
without additional cable length.

DEHNventil®
Directly coordinated to
Red/Line SPDs Type 2 and 3
without additional cable length.

Main Distribution Board

SPD Type 1 (Lightning current arrester)

315 A 1

3 x DB NH00 255 H   Part No. 900 273
1 x DGP B NH00 N 255   Part No. 900 269

SPD Type 1 (Coordinated lightning current arrester)

315 A 1

indication of interference

DEHNsignal
DG DV
DEHNbloc® Maxi
DBM 1 255 L
DEHNbloc® Maxi
DBM 1 255 L
DEHNbloc® Maxi
DBM 1 255 L
DEHNgap Maxi
DGP M255

3 x DBM 1 255 L   Part No. 900 026
alt. 3 x DBM 1 255   Part No. 900 025
1 x DGPM 255   Part No. 900 055
1 x MVS 1 8   Part No. 900 611

SPD Type 1 (Combined lightning current and surge arrester)

315 A 1

fault signal

1 x DV M TT 255 FM   Part No. 951 315
alt. 1 x DV M TT 255   Part No. 951 310

EBB

1) Only required, if a fuse of the same or a lower nominal value is not already provided in the upstream power supply.

Fig. 8.1.4.5   SPDs used in TT systems – Example: Industry

through the overcurrent protective devices or RCDs, the first fault in an IT system only creates an alarm. An excessive shock hazard voltage cannot occur because the first fault in the IT system simply creates an earth connection of the system. The operating state of the IT system then becomes a TN or TT system. Hence, an IT system can be further operated at no risk after the first fault. Thus, work or production processes already begun (e.g. chemical industry) can still be completed. For the first fault, the protective conductor adopts the potential of the faulty external conductor, which, however, does not create a risk, because all bodies and metal components which persons can come into contact with, adopt this potential via the protective conductor. Hence, no hazardous potential differences can be bridged either. When the first fault occurs, however, it must be noted, that the voltage of the IT system of the intact conductors to earth corresponds to the voltage between the external conductors. Hence, in a 230/400 V IT system, in the event of a faulty SPD there is a voltage of 400 V across the non-faulty SPD. This possible operating state must be taken into account when choosing the SPDs with respect to their maximum continuous voltage.

When considering IT systems, a distinction is made between IT systems with neutral conductors entering the building with the others, and IT systems without such neutral conductors. For IT systems with the latter configuration, the SPDs in the so-called "3-0" circuit must be installed between each external conductor and the PE conductor. For IT systems with neutral conductors entering the building with the others, both the "4-0" and the "3+1" circuit can be used. When using the "3+1" circuit, it must be noted that, in the N-PE path, an SPD must be employed with a follow current extinguishing capability appropriate to the system conditions.

The following maximum continuous operating voltages apply to the use of SPDs Type 1, 2 and 3 in IT systems with and without neutral conductors entering the building with the others (**Figures 8.1.5.1a – c**).

A second fault in an IT system must then cause a tripping of a protective device. The statements about TN and TT systems made in Sections 8.1 and 8.2 apply to the use of SPDs in IT systems in connec-
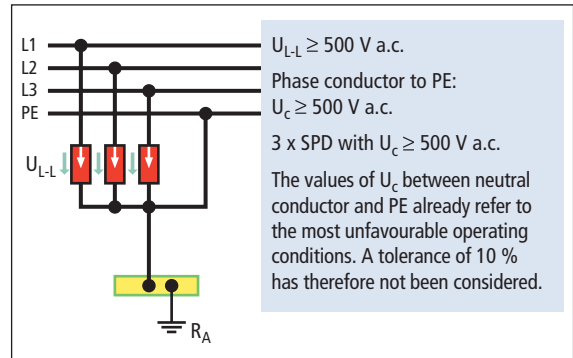
Fig. 8.1.5.1a   IT system without neutral conductor; "3-0" circuit
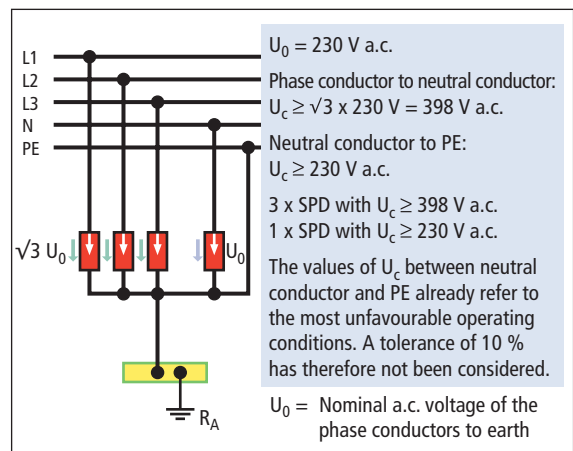
Fig. 8.1.5.1b   IT system with neutral conductor; "4-0" conductor
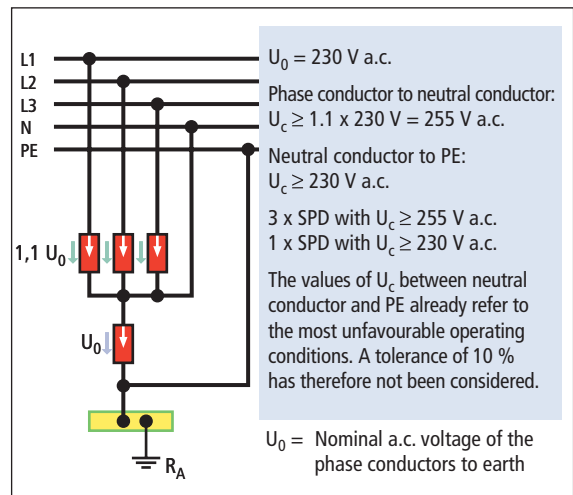
Fig. 8.1.5.1c   IT system with neutral conductor; "3+1" circuit
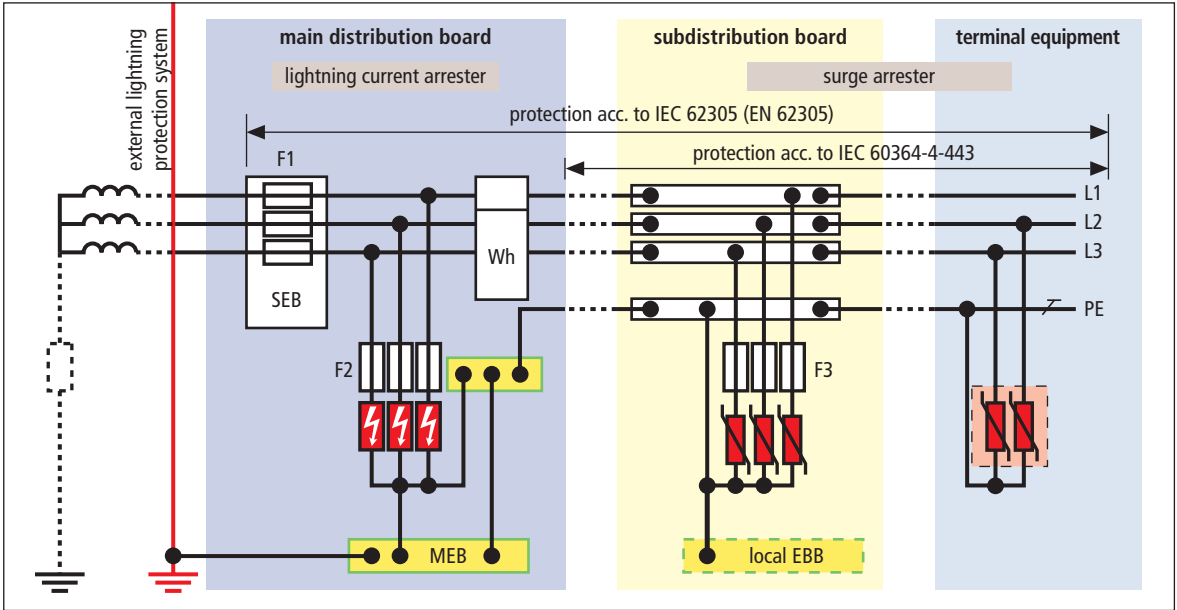
Fig. 8.1.5.2   Use of SPDs in IT systems without neutral conductor

tion with a protective device for "protection against electric shock under fault conditions".

The use of SPDs Type 1 and 2 upstream of the RCD is therefore also recommended for IT systems. A connection example for the use of SPDs in IT systems without neutral conductors entering the building with the others is shown in **Figure 8.1.5.2** and **8.1.5.3**.

Figure 8.1.5.4 shows the use of SPDs in IT systems with neutral conductor.
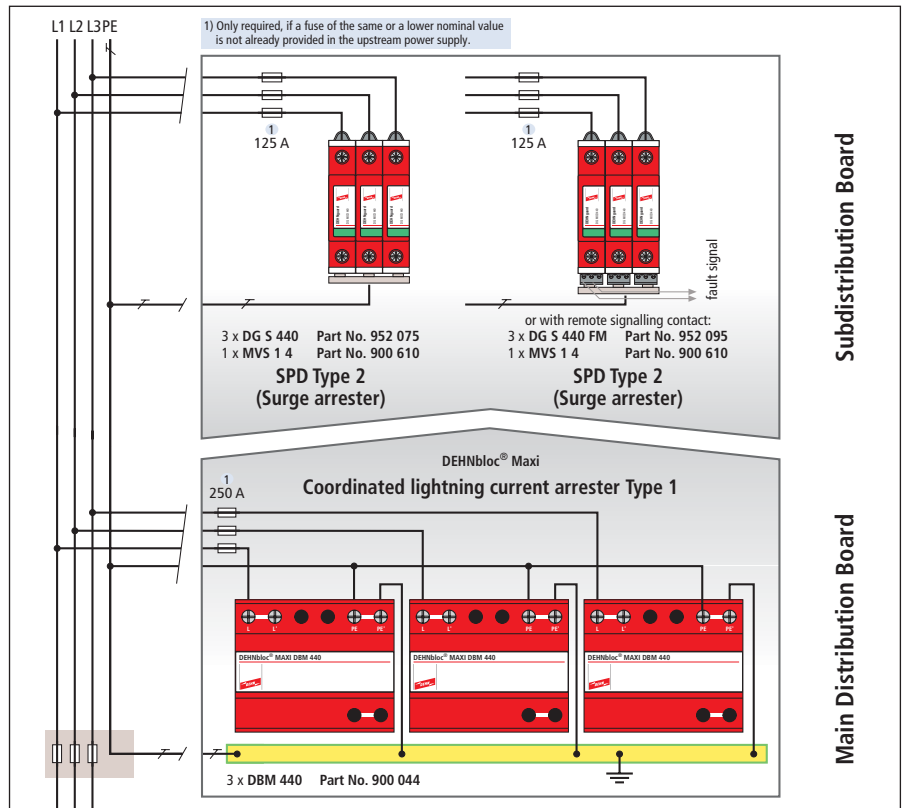
Fig. 8.1.5.3   Use of SPDs in 400 V IT systems – Example without neutral conductor
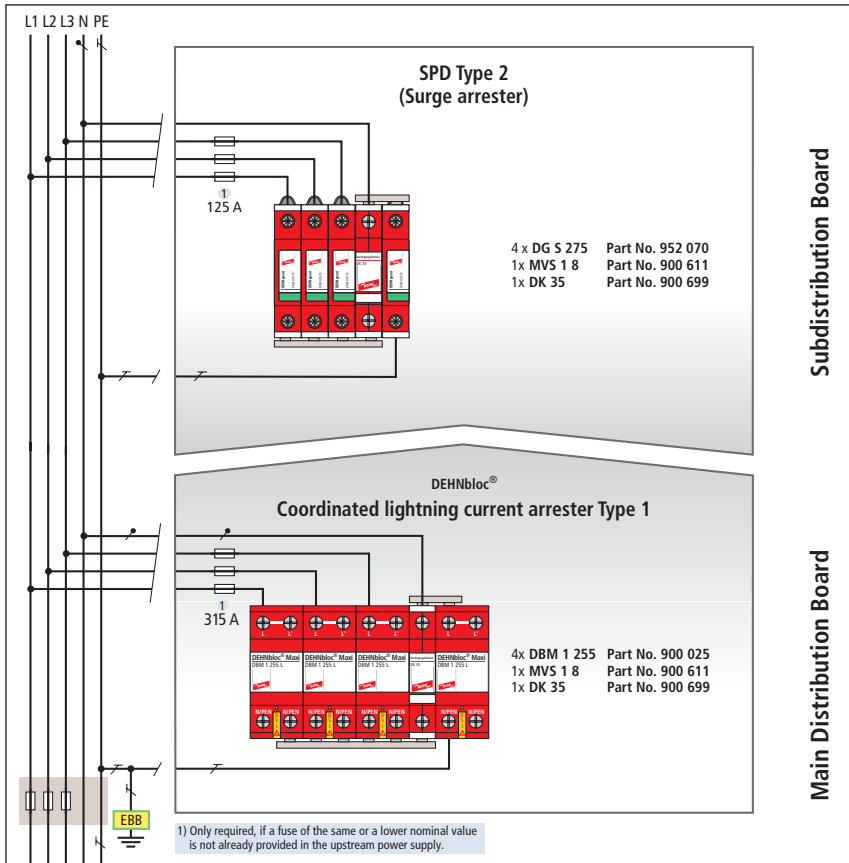
Fig. 8.1.5.4   Use of SPDs in 230/400 V IT systems – Example with neutral conductor

In the figure:

L1 L2 L3 N PE

SPD Type 2
(Surge arrester)

Subdistribution Board

1
125 A

4 x DG S 275   Part No. 952 070
1x MVS 1 8   Part No. 900 611
1x DK 35   Part No. 900 699

DEHNbloc®
Coordinated lightning current arrester Type 1

Main Distribution Board

1
315 A

4x DBM 1 255   Part No. 900 025
1x MVS 1 8   Part No. 900 611
1x DK 35   Part No. 900 699

EBB

1) Only required, if a fuse of the same or a lower nominal value
   is not already provided in the upstream power supply.

8.1.6 Rating the lengths of the connecting leads for SPDs

Rating the lengths of connecting leads of surge protective devices is a significant part of the IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001) installation regulations.

The aspects stated below are also frequently the reason for complaints through experts, members of technical inspectorates, etc. inspecting the structure.

Series connection (V-shape) in accordance with IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001)

Crucial for the protection of systems, equipment and consumers is the actual level of impulse voltage across the installations to be protected. The optimum protective effect is then achieved when the impulse level across the installation to be protected matches the voltage protection level pro-

vided by the surge protective device. Therefore, IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001) suggests a series connection system (V-shape) as shown in **Figure 8.1.6.1** to be used for connecting surge protective devices. This requires no separate conductor branches for connecting the surge protective devices.

Parallel connection system in accordance with IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001)

The optimum series connection system cannot be used under all system conditions.

Nominal currents carried via the double terminals on the surge protective device as part of the series wiring are limited by the thermal loadability of the double terminals. For this reason, the manufacturer of the surge protective device prescribes a certain

max. permissible value of the backup fuse which, in turn, means that series wiring can sometimes not be used for systems with higher nominal operating currents.

Meanwhile, the industry provides so-called two-conductor terminals to solve this problem. Thus, the cable lengths can still be kept short, even if the nominal operating current is increased. When using the two-conductor terminals, however, it must be ensured that the value of the backup fuse stated by the manufacturer for this particular application is always observed (**Figures 8.1.6.2** and **8.1.6.3**).

If series connection is definitely no option, surge protective devices must be integrated into a separate branch circuit. If the nominal value of the next upstream installation fuse exceeds the nominal current of the max. permissible backup fuse of the surge protective device, the branch must be equipped with a backup fuse for the surge protec-
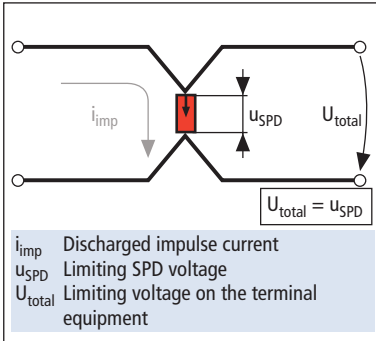
Fig. 8.1.6.1 Surge protective devices in V-shape series connection
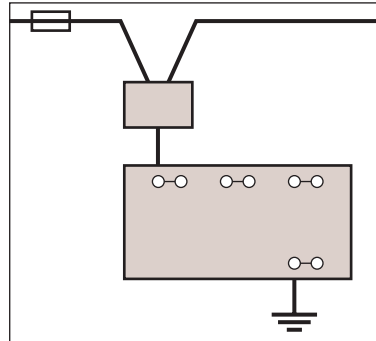
Fig. 8.1.6.2 Principle of "two-conductor terminals (TCT)" – Illustration of a single-pole unit

Fig. 8.1.6.3 Pin connection terminal (PCT) 2 x 16

tive device (**Figure 8.1.6.4**), or SPDs with integrated backup fuse are used (**Figures 8.1.6.5** and **8.1.6.6**).

When the surge protective device in the conductor branch responds, the discharge current flows through further elements (conductors, fuses) causing additional dynamic voltage drops across these impedances.

It can be stated here that the ohmic component is negligible compared to the inductive component.

Taking into account the relation

$$u_{dyn} = i \cdot R + \left(\frac{di}{dt}\right) L$$

and the rate of current change (di/dt) for transient processes of a few 10 kA/μs, the dynamic voltage drop U_{dyn} is considerably determined by the inductive component.

In order to keep this dynamic voltage drop low, the electrician carrying out the work must keep the inductance of the connecting cable and hence its length as low as possible. IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001) therefore recommends to design the total cable length of surge protective devices in branch circuits to be not longer than 0.5 m (**Figure 8.1.6.7**).

Design of the connecting lead on the earth side
This requirement, which is seemingly difficult to realise, shall be explained with the help of the
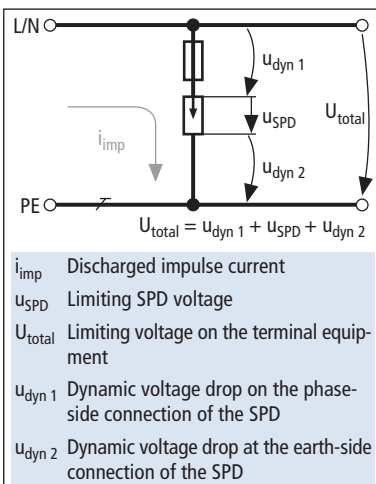
Fig. 8.1.6.4 Connection of surge protective devices in cable branches

Fig. 8.1.6.5 DEHNbloc Maxi S: coordinated lightning current arrester for the busbar with integrated backup fuse

Fig. 8.1.6.6 Surge protective device Type 2 V NH for use in NH fuse bases

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Fig. 8.1.6.7   Recommended max. cable lengths of surge protective devices in branch circuits

unfavourable

Fig. 8.1.6.8a   Unfavourable conductor routing from the "consumer's point of view"

favourable

Fig. 8.1.6.8b   Favourable conductor routing from the "consumer's point of view"

Thus, the effective cable length (l_a) for the surge protective devices corresponds to the distance between the installation site of the surge protective devices (e.g. service entrance box, main distribution board) to the equipotential bonding bar. A connection configuration of this type mostly achieves minimum effective protection of the installation. Without great expenses, however, it is possible to use a conductor leading as shown in **Figure 8.1.6.8b** to reduce the effective cable length of the surge protective devices ($l_b < 0.5$ m).

This is achieved by using a "bypass" conductor (y) from the terminal of the earth side of the arrester to the PEN. The connection from the terminal of the earth side of the arrester to the equipotential bonding bar (x) remains as it was.

According to the VDN-Richtlinie 2004-08 [engl.: Directive of the Association of the German Network Operators]: "Überspannungs-Schutzeinrichtungen Typ 1. Richtlinie für den Einsatz von Überspannungs-Schutzeinrichtungen (ÜSE) Typ 1 (bisher Anforderungsklasse B) in Hauptstromversorgungssystemen." [engl: "Surge protective devices Type 1. Directive for the use of surge protective equipment Type 1 (up to now Class B) in main distribution systems."], the bypass conductor (y) may only be omitted if the surge protective device is installed in the immediate vicinity (≤ 0.5 m) of the service entrance box and hence also in the immediate vicinity of the equipotential bonding.

When installing the connection y, the distance between service entrance box or main distribution board and equipotential bonding bar is thus insignificant. The solution for this problem referred only to the design of the connecting cable on the earth side of the surge protective devices.

example shown in **Figures 8.1.6.8a** and **b**. These show the main equipotential bonding (in future: protective equipotential bonding) of a low voltage consumer's installation in accordance with IEC 60364-4-41 and IEC 60364-5-54. Here, the use of surge protective devices Type 1 extends the equipotential bonding to become a lightning equipotential bonding.

In **Figure 8.1.6.8a**, both measures are installed separately. In this case, the PEN was connected to the equipotential bonding bar and the earthing connection of the surge protective devices was performed via a separate equipotential bonding conductor.

Fig. 8.1.6.9   Arrangement of surge protective devices in a system and the resulting effective cable length

l_1:   Total cable length at installation site 1
l_2:   Total cable length at installation site 2
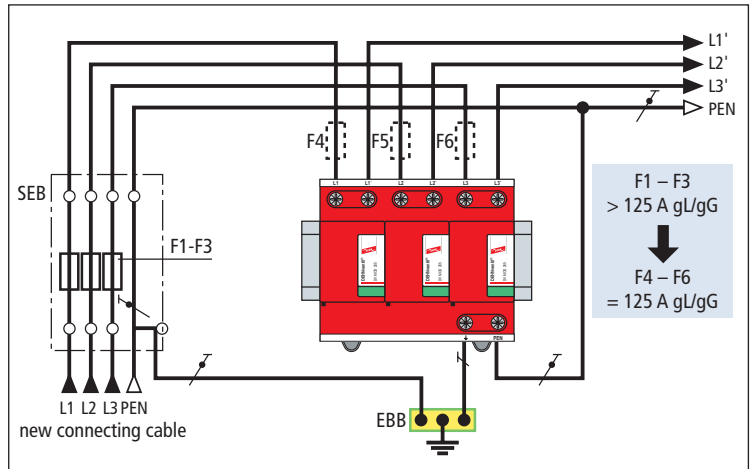
Fig. 8.1.6.10   Series connection V-shape

Design of the phase-side connecting cable

The cable length on the phase side must also be taken into consideration. The following case study shall illustrate this:

In expanded control systems, surge protection must be provided for the busbar system and the circuits attached thereto (A to D) with their consumers (**Figure 8.1.6.9**).

For the use of the surge protective devices in this case, installation sites 1 and 2 are taken as alternatives. Installation site 1 is located directly at the supply of the busbar system. This ensures the same level of protection against surges for all consumers. The effective cable length of the surge protective device at installation site 1 is l_1 for all consumers. If there is not enough space, the installation site of the surge protective devices is sometimes chosen at a position along the busbar system. In extreme cases, installation site 2 can be chosen for the arrangement shown in **Figure 8.1.6.9**. For circuit A results the effective cable length l_2. Busbar systems in fact have a lower inductance compared to cables and conductors (approx. 1/4) and hence a lower inductive voltage drop. However, the length of the busbars must not be disregarded.

The design of the connecting cables has considerable influence on the effectiveness of surge protective devices and must therefore be taken into consideration at the design stage of the installation!

The contents of IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001) described above were important guidelines for the development of the new DEHNventil combined lightning current and surge arrester which was supposed to combine the requirements on lightning current and surge arresters in accordance with the IEC 62305 Part 1 – 4 (EN 62305 Part 1 – 4) standard series in a single device.

This allows to realise a series connection directly via the device. **Figure 8.1.6.10** shows such a series connection in form of an operating circuit diagram.

Fig. 8.1.6.11   V-shape series connection of the DEHNventil M TNC combined lightning current and surge protective device by means of a busbar
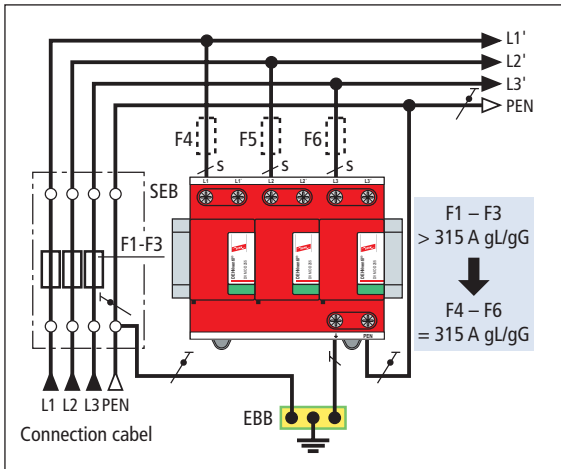
Fig. 8.1.6.12   Parallel wiring

Fig. 8.1.6.13   Cable routing

From **Figure 8.1.6.11** it can be taken how advantageous it is to implement a series connection with the aid of a busbar.

Because of the thermal loading capacity of the double terminals employed, a v-shape series connection (also called through-wiring) can be used up to 125 A.

For load currents > 125 A, the surge protective devices are connected in the conductor branch (so-called parallel wiring). The maximum cable lengths according to IEC 60364-5-53/A2 (IEC 64/1168/CDV: 2001) must be observed. The parallel wiring can be implemented as shown in **Figure 8.1.6.12**.

In this context, it should be ensured that the connecting cable on the earth side still benefits from the double terminal for the earth connection. As shown in **Figure 8.1.6.12**, it is often possible, without great effort, to achieve an effective cable length of the order of magnitude l < 0.5 m with a conductor leading from terminal component "PE" of the earth-side double terminal to PEN.

At the installation of surge protective devices in distributions it must generally be considered that conductors loaded by impulse currents and those not loaded by impulse currents are routed as separately as possible. In any case, a parallel routing of both conductors has to be avoided (**Figure 8.1.6.13**).
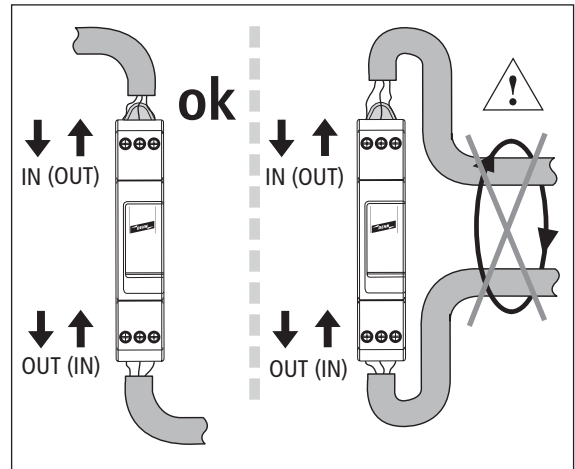
8.1.7 Rating of the terminal cross-sections and the backup protection of surge protective devices

Connecting leads of arresters can be subjected to loads from impulse currents, operating currents and short circuit currents. The individual loads depend on various factors:

⇒ Type of protective circuit: one-port (**Figure 8.1.7.1**)/two-port (**Figure 8.1.7.2**)

⇒ Type of arrester: lightning current arrester, combined lightning current and surge arrester, surge protective devices
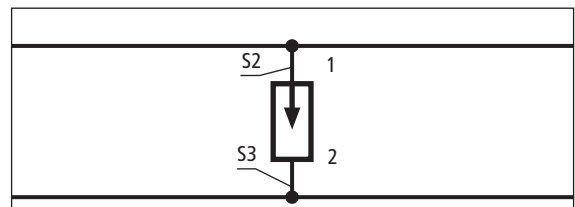
Fig. 8.1.7.1   One-port protective circuit
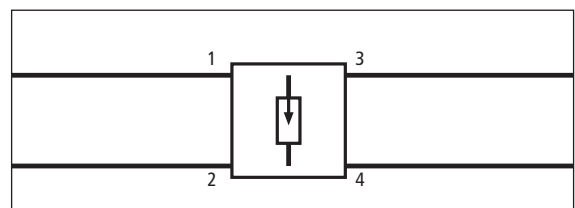
Fig. 8.1.7.2   Two-port protective circuit

Conductor material	Insulating material		
	PVC	EPR / XLPE	Rubber
Cu	115	143	141
Al	76	94	93

Table 8.1.7.1 Material coefficient k for copper and aluminium conductors with different insulating material
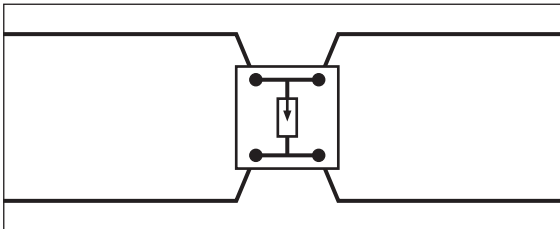
Fig. 8.1.7.3 SPD with through-wiring

⇒ Performance of the arrester on follow currents: follow current extinction/follow current limitation

If surge protective devices are installed as shown in **Figure 8.1.7.1**, the S2 and S3 connecting cables must only be rated upon the criteria of short circuit protection according to IEC 60364-4-43 and the impulse current carrying capability. The data sheet of the protective device provides the maximum permissible overcurrent protection which can be used in this application as backup protection for the arrester.

When installing the devices, it must be ensured that the short circuit current actually flowing is able to trip the backup protection. The rating of the cross-sectional area or of the conductor is then given by the following equation:

DEHNventil DV M TNC 255		Fuse F1 A gL / gG	S2 / mm²	S3 / mm²	Fuse F2 A gL / gG
	F1 > 315 A gL / gG	25	10	16	---
		35	10	16	---
		40	10	16	---
		50	10	16	---
		63	10	16	---
F1		80	10	16	---
	F2 ≤ 315 A gL / gG	100	16	16	---
		125	16	16	---
	F1 ≤ 315 A gL / gG	160	25	25	---
F2		200	35	35	---
		250	35	35	---
		315	50	50	---
	F2	> 315	50	50	≤ 315
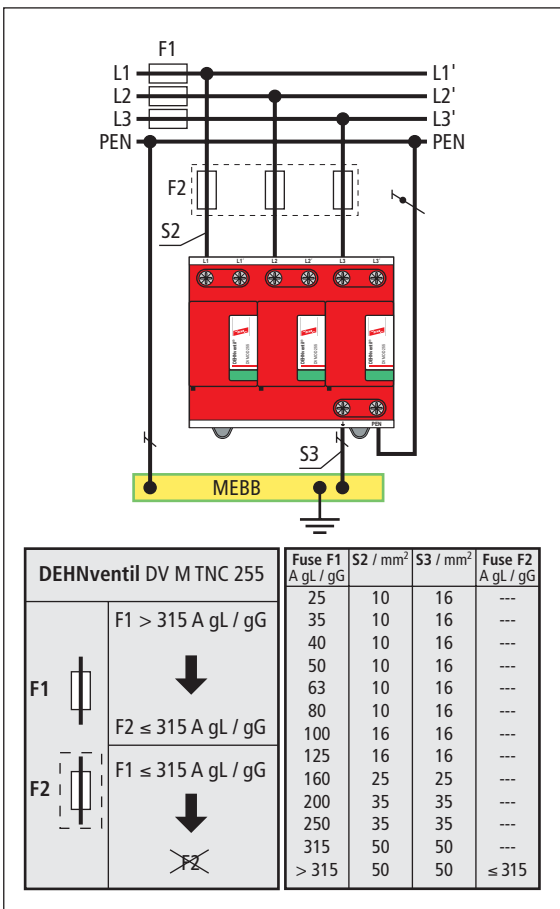
Fig. 8.1.7.4 Example: DEHNventil, DV TNC 255

DEHNguard M TNC 275 DEHNguard M TNS 275 DEHNguard M TT 275		Fuse F1 A gL / gG	S2 / mm²	S3 / mm²	Fuse F2 A gL / gG
	F1 > 125 A gL / gG	35	4	6	---
		40	4	6	---
		50	6	6	---
F1		63	10	10	---
		80	10	10	---
	F2 ≤ 125 A gL / gG	100	16	16	---
		125	16	16	125
	F1 ≤ 125 A gL / gG	160	25	16	125
F2		200	35	16	125
		250	35	16	125
	F2	315	50	16	125
		400	70	16	125
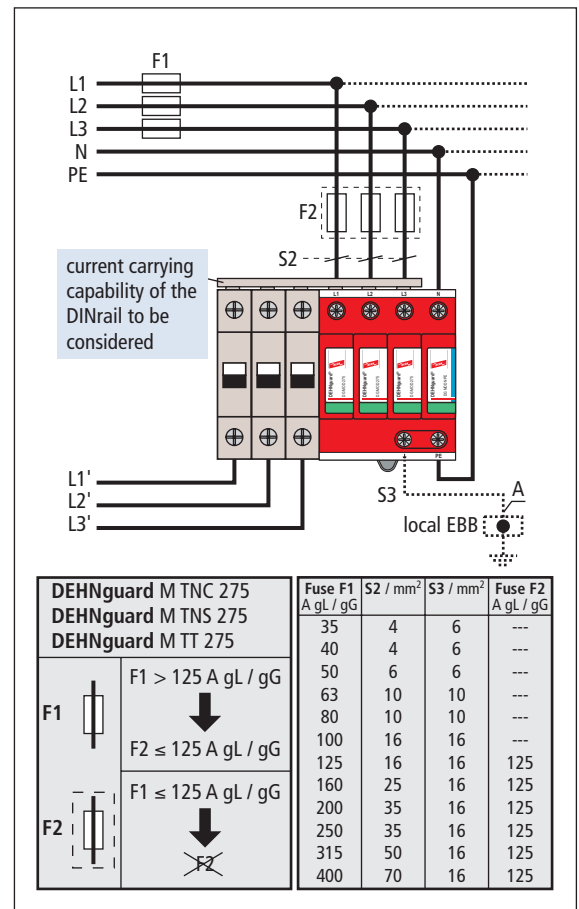
Fig. 8.1.7.5 Example: DEHNguard (M) TNC/TNS/TT
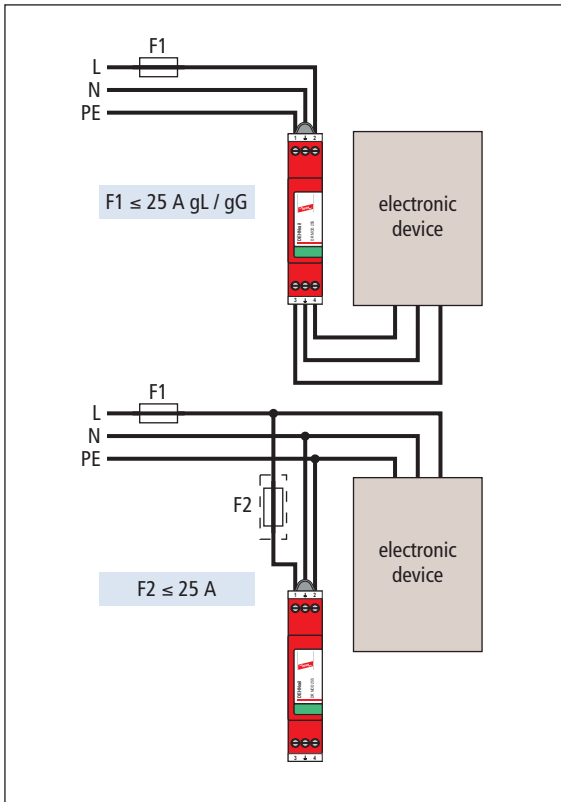
Fig. 8.1.7.6   Example: DEHNrail
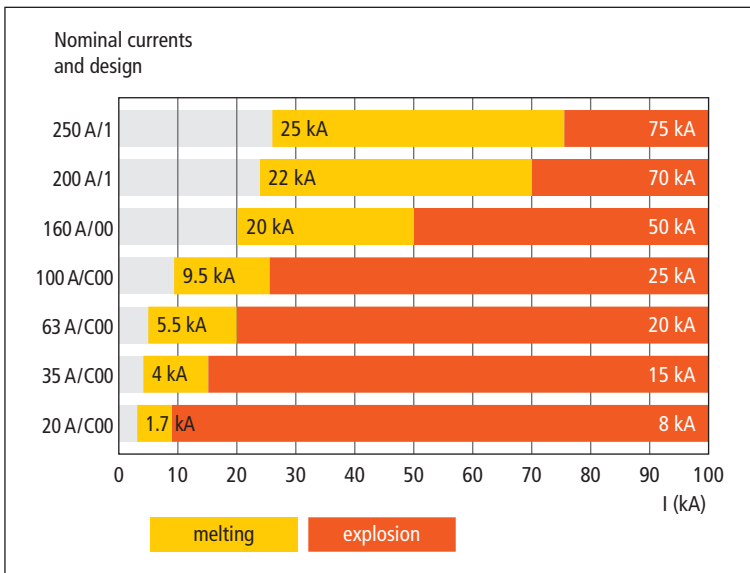
$$k^2 \cdot S^2 = I^2 \cdot t$$

t   Permissible time for disconnection in the event of a short circuit in s

S   Conductor cross section in mm^2

I   Current at complete short circuit in A

k   Material coefficient in A · s/mm^2 according to **Table 8.1.7.1**

Furthermore, it must be ensured that the information concerning the maximum permissible overcurrent protection circuits in the data sheet of the surge protective device is only valid up to the value of the stated short-circuit withstand capability of the protective device. If the short circuit current at the installation site is greater than the stated short-circuit withstand capability of the protective device, a backup fuse must be chosen which is smaller than the maximum backup fuse stated in the data sheet of the arrester by a ratio of 1:1.6.

For surge protective devices installed as shown in **Figure 8.1.7.2**, the maximum operating current must not exceed the nominal load current stated for the protective device. To protective devices which can be connected in series, applies the maximum current for through-wiring (**Figure 8.1.7.3**).

Figure 8.1.7.4 shows examples of cross-sectional areas and backup protection for lightning current arresters and combined lightning current and surge arresters Type 1.

Figure 8.1.7.5 shows examples of cross-sectional areas and backup protection for surge protective devices Type 2. **Figure 8.1.7.6** shows the same for surge protective devices Type 3.

The behaviour of the impulse current must be taken into consideration when rating the backup fuses for surge protective devices. There is a noticeable difference in the way fuses disconnect short circuit currents compared to the way they disconnect loads with impulse currents, particularly with lightning impulse currents, waveform 10/350 µs.

The performance of fuses was determined as a function of the rated current of the lightning impulse current (**Figure 8.1.7.7**).

Fig. 8.1.7.7   Performance of NH fuses bearing impulse current loads
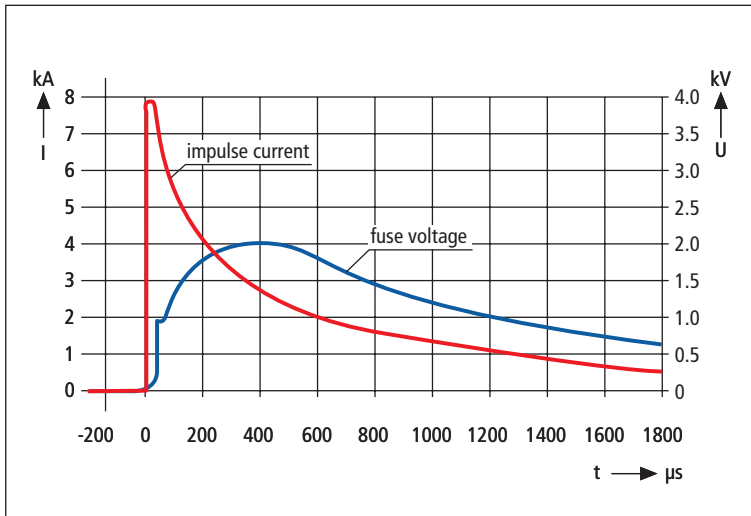
Fig. 8.1.7.8   Current and voltage of a blowing 25 A NH fuse being charged with lightning impulse currents (10/350 µs)
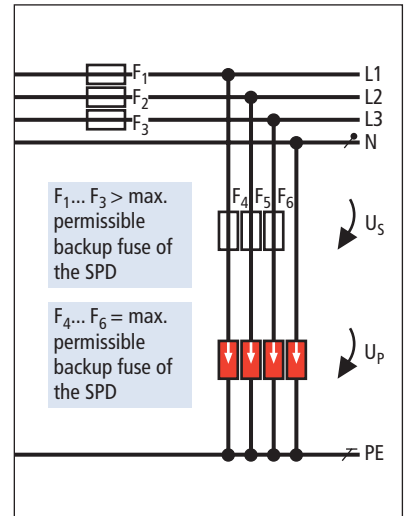
Fig. 8.1.7.9   Use of a separate backup fuse for surge protective devices

Field 1: No melting

The energy brought into the fuse by the lightning impulse current is too low to cause a melting of the fuse.

Field 2: Melting

The energy of the lightning impulse current is sufficient to melt the fuse and hence interrupt the current path through the fuse (**Figure 8.1.7.8**).

It is characteristical for the performance of the fuse that the lightning impulse current, since it is injected, continues to flow, unaffected by the performance of the fuse. The fuse disconnects only after the lightning impulse current has decayed. The fuses are therefore not selective with respect to the disconnection of lightning impulse currents. Therefore it must be ensured that, because of the behaviour of the impulse current, the maximum permissible backup fuse as per the data sheet and/or installation instructions of the protective device is always used.

From **Figure 8.1.7.8** it can also be seen that, during the melting process, a voltage drop builds up across the fuse which in part can be significantly above 1 kV. For applications as illustrated in **Figure 8.1.7.9**, a melting of the fuse can also result in the voltage protection level of the installation being significantly higher than the voltage protection level of the surge protective device employed.

Field 3: Explosion

If the energy of the lightning impulse current is so high to be much higher than the pre-arcing of the fuse, then the fuse strip can vaporise explosively. This often results in a bursting fuse box. Apart from the mechanical consequences, it must be noted that the lightning impulse current continues to flow through the bursting fuse in the form of an electric arc; the lightning impulse current can thus not be interrupted nor, linked to this, can the required impulse current carrying capability of the employed arrester be reduced.

Selectivity to the protection of the installation

When using spark-gap based surge protective devices, care must be taken that any starting mains follow current is limited to the extent that overcurrent protective devices such as fuses and/or arrester backup fuses cannot trip. This characteristic of the protective devices is called follow current limitation or follow current suppression. Only by using technologies such as the RADAX Flow technology allows to develop arresters and combinations of arresters which, even for installations with high short circuit currents, are able to reduce and extinguish the current to such a degree that upstream fuses for lower rated currents do not trip (**Figure 8.1.7.10**).
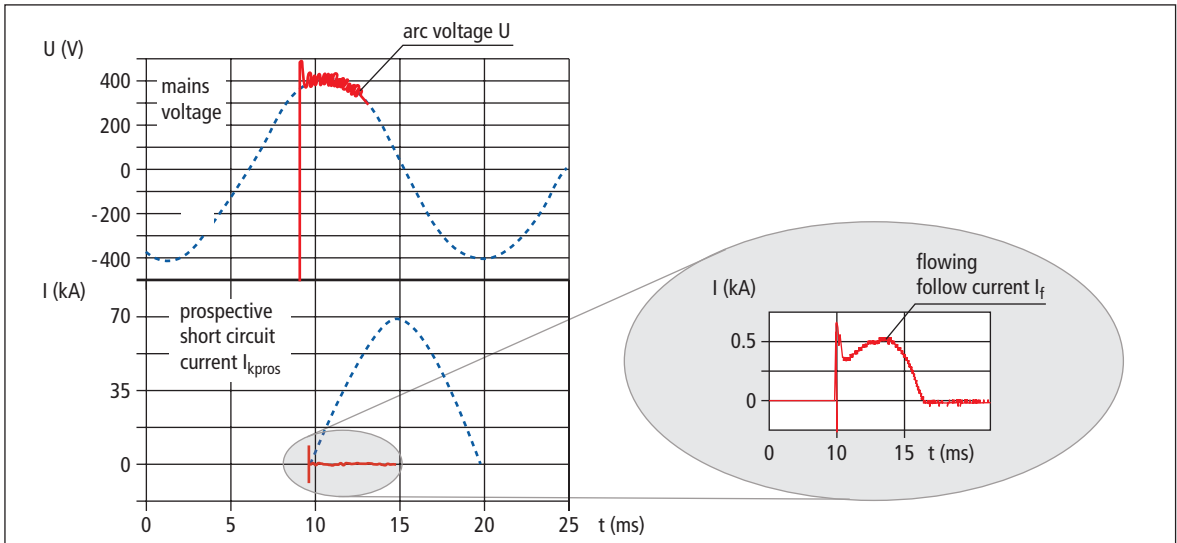
Fig. 8.1.7.10 Reduction of the follow current with the patented RADAX Flow principle
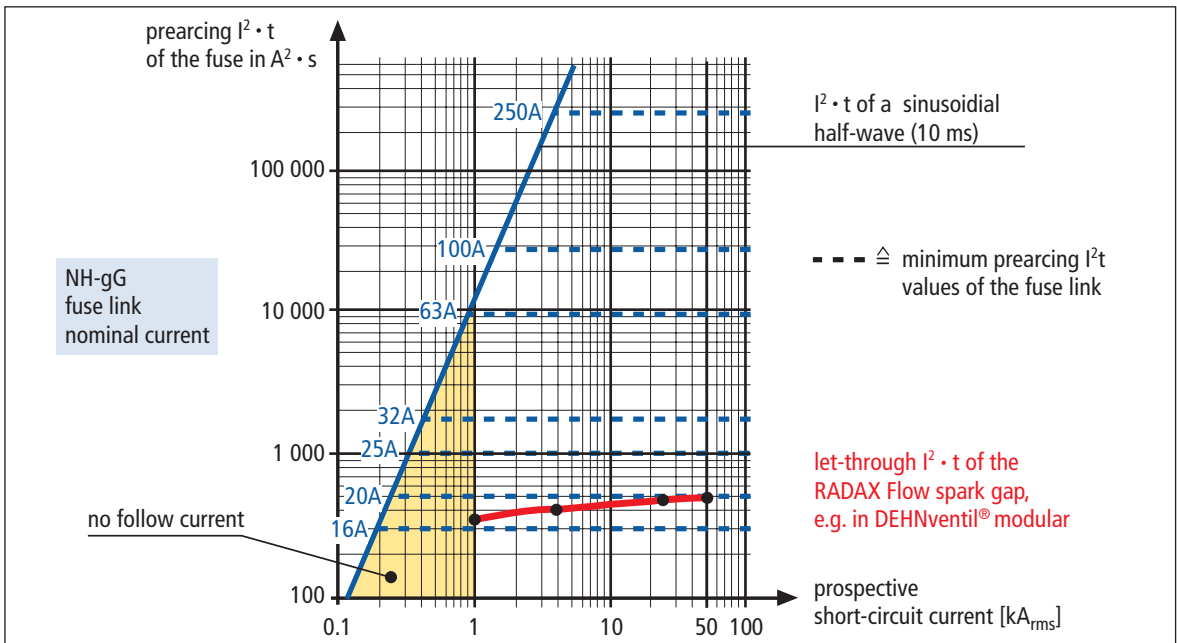
Fig. 8.1.7.11 Disconnection selectivity of DEHNventil to NH fuse holders with different rated currents

The system availability required by EN 60439-1, even in the event of responding surge protective devices, can be fulfilled by the aforementioned "follow current suppression" characteristic of the device. For surge protective devices with low sparkover voltage, in particular, designed to not only take on the function of the lightning equipotential bonding but also that of surge protection in the installation, the performance of the follow current limitation is more important than ever for the availability of the electrical installation (**Figure 8.1.7.11**).

8.2 Information technology systems

The primary function of arresters is to protect downstream terminal devices. They also reduce the risk of cables from being damaged.

The choice of arresters depends, among other things, on the following considerations:

⇒ Lightning protection zones of the installation site, if existing

⇒ Energies to be discharged

⇒ Arrangement of the protective devices

⇒ Immunity of the terminal devices

⇒ Protection against differential-mode and/or common-mode interferences

⇒ System requirements, e.g. transmission parameters

⇒ Compliance with product or user-specific standards, where required

⇒ Adaption to the environmental conditions/installation conditions

Protective devices for antenna cables are classified according to their suitability for coaxial, balanced or hollow conductor systems, depending on the physical design of the antenna cable.

In the case of coaxial and hollow conductor systems, the outer conductor can generally be connected directly to the equipotential bonding. Earthing couplings specially adapted to the respective cables are suitable for this purpose.

Procedure for selection and installation of arresters: Example BLITZDUCTOR CT

Opposite to choosing surge protective devices for power supply systems (see Chapter 8.1), where uniform conditions can be expected with respect to voltage and frequency in 230/400 V systems, the types of signals to be transmitted in automation systems differ with respect to their

⇒ voltage (e.g. 0 – 10 V)

⇒ current (e.g. 0 – 20 mA, 4 – 20 mA)

⇒ signal reference (balanced, unbalanced)

⇒ frequency (DC, NF, HF)

⇒ type of signal (analogue, digital).
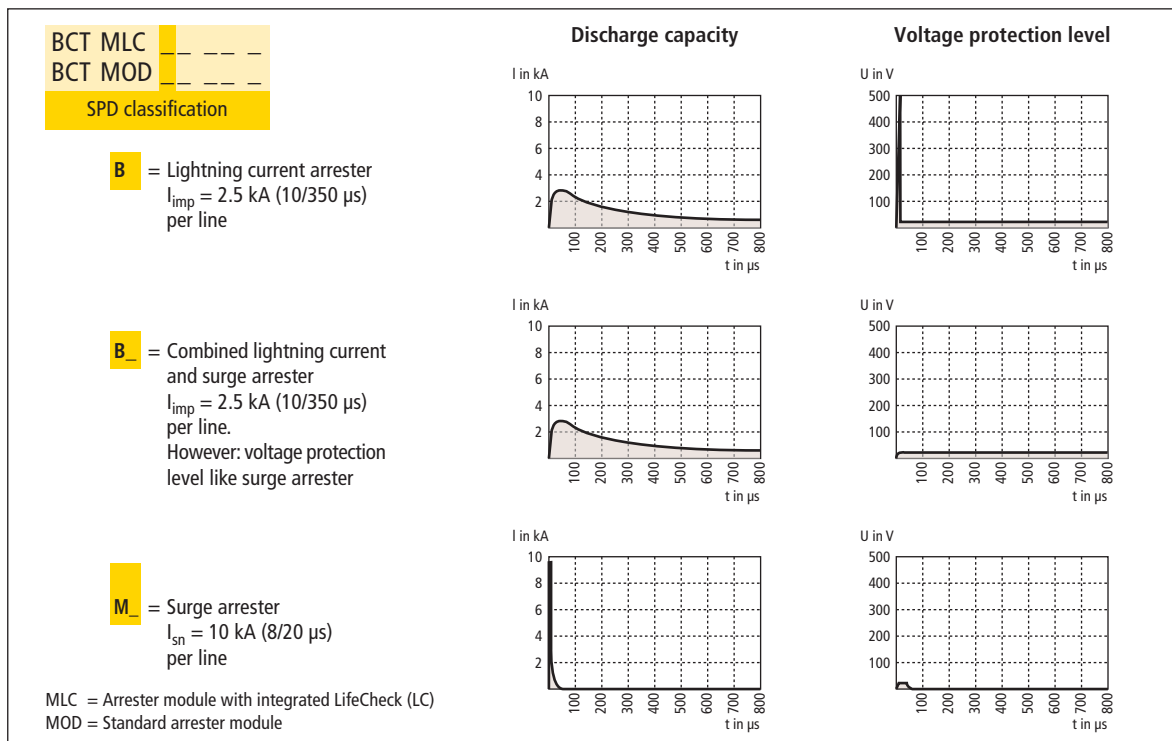
Fig. 8.2.1   SPD classification
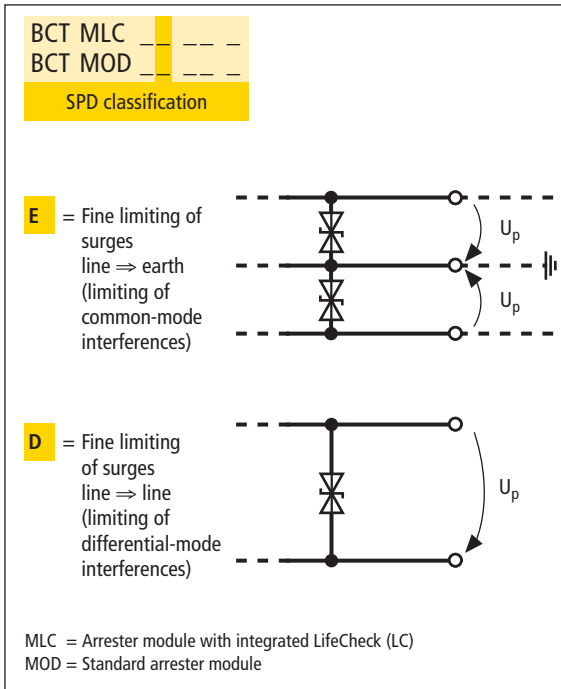
Fig. 8.2.2   Limiting performance

Each of these electrical characteristics for the signal to be transmitted can contain the actual information to be transferred.

Therefore, the signal must not be influenced intolerably by the use of lightning current and surge arresters in measuring and control installations. Several points must be taken into account when choosing protective devices for measuring and control systems. They are described below for our universal BLITZDUCTOR CT protective devices and illustrated by means of application examples (**Figures 8.2.1 – 8.2.4** and **Table 8.2.1**).

Type designation of the protective modules

C   Supplementary limiting of differential-mode interferences and supplementary decoupling resistors in the BLITZDUCTOR CT output for decoupling the BLITZDUCTOR protective diodes from any diodes possibly present at the input of the device to be protected (e.g. clamping diodes, optocoupler diodes)

HF Design for protection of high frequency transmission paths (use of a diode matrix for fine limiting of surges), limiting of common-mode and differential-mode interferences
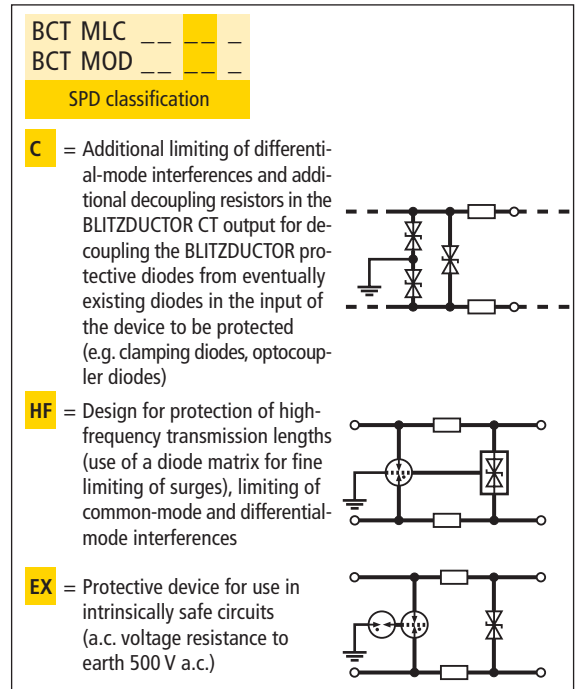
Fig. 8.2.3   Note on special applications
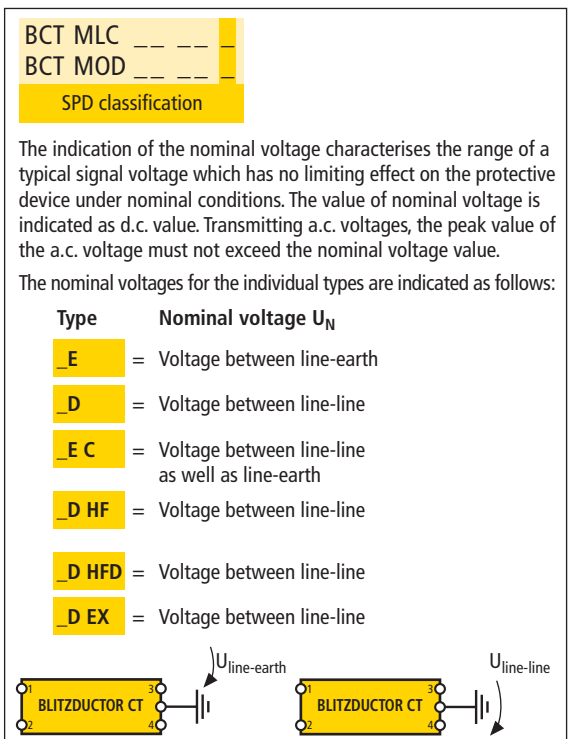
Fig. 8.2.4   Nominal voltage

MLC B	110	MOD B	110
MLC BE	5	MOD ME	5
MLC BE	12	MOD ME	12
MLC BE	15	MOD ME	15
MLC BE	24	MOD ME	24
MLC BE	30	MOD ME	30
MLC BE	48	MOD ME	48
MLC BE	60	MOD ME	60
MLC BE	110	MOD ME	110
MLC BD	5	MOD MD	5
MLC BD	12	MOD MD	12
MLC BD	15	MOD MD	15
MLC BD	24	MOD MD	24
MLC BD	30	MOD MD	30
MLC BD	48	MOD MD	48
MLC BD	60	MOD MD	60
MLC BD	110	MOD MD	110
MLC BD	250	MOD MD	250
MLC BE C	5	MOD ME C	5
MLC BE C	12	MOD ME C	12
MLC BE C	24	MOD ME C	24
MLC BE C	30	MOD ME C	30
MLC BD HF	5	MOD MD HF	5
MLC BD HFD	5	MOD MD HFD	5
MLC BD HFD	24	MOD MD HFD	24
		MOD MD EX	24
		MOD MD EX	30
		MOD MD EX HFD	6

Table 8.2.1   Type designation of the protection modules

EX Protective device for use in intrinsically safe circuits approved by, ATEX and FISCO (a.c. voltage resistance to earth 500 V a.c.)

Technical Data:
Voltage protection level U_p
The voltage protection level is a parameter that characterises the performance of a surge protective device in limiting the voltage at its terminals. The voltage protection level must be higher than the maximum limiting voltage measured.

The measured limiting voltage is the maximum voltage measured at the terminals of the surge protective device when exposed to a surge current and/or surge voltage of a certain waveform and amplitude.

Measured limiting voltage with a steepness of the applied test voltage waveform of 1 kV/µs
This test is to determine the response characteristics of gas discharge tubes (GDT). These protective elements have a "switching characteristic". The mode of functioning of a GTD can be compared to a switch whose resistance can "automatically"
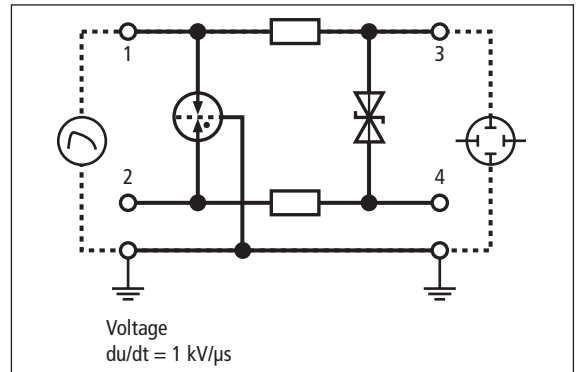
Voltage
du/dt = 1 kV/µs

Fig. 8.2.5   Test arrangement for determining the limiting voltage at a rate of voltage rise of du/dt = 1kV/µs
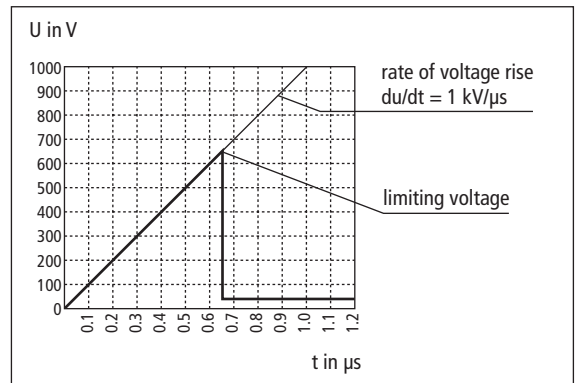
Fig. 8.2.6   Sparkover performance of an SPD at du/dt = 1kV/µs

B	1 A		
BE	1 A	ME	1 A
BD	1 A	MD	1 A
BE C	0.1 A	ME C	0.1 A
BD HF	0.1 A	MD HF	0.1 A
BD HFD	0.1 A	MD HFD	0.1 A
		MD EX	0.5 A
		MD EX HFD	4.8 A

Table 8.2.2   Nominal currents of the protection modules BCT

switch from > 10 GΩ (in non-ignited state) to values < 0.1 Ω (in ignited state) when a certain voltage value is exceeded and the surge applied is nearly short circuited. The response voltage of the GDT depends on the steepness of the incoming voltage (du/dt).

Generally applies:

The higher the steepness du/dt, the higher is the response voltage of the gas discharge tube. The
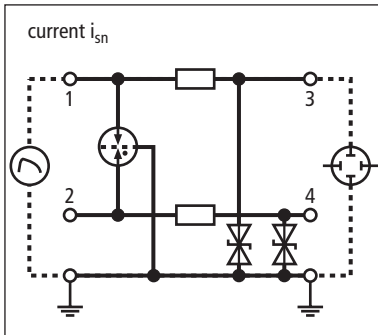
Fig. 8.2.7 Test arrangement for determining the limiting voltage at nominal discharge current
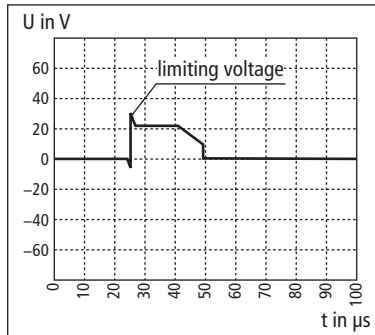
Fig. 8.2.8 Limiting voltage at nominal discharge current
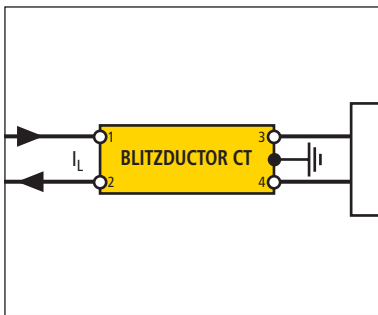
Fig. 8.2.9 Nominal current of BLITZDUCTOR CT
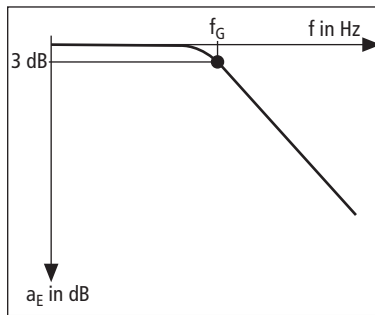
Fig. 8.2.10 Typical frequency response of a BLITZDUCTOR CT

To the different types of protection modules of BLITZDUCTOR CT apply the nominal currents according to **Table 8.2.2**:

Cut-off frequency f_G

The cut-off frequency describes the performance of an SPD depending on the frequency. It is that frequency which gives an insertion loss (a_E) of 3 dB under certain test conditions (see EN 61643-21)

If there is no other indication in the catalogue, this frequency stated applies to a 50 Ohm system (**Figure 8.2.10**).

Selection features (SF)

1. Which discharge capacity is required?

The rating of the discharge capacity of BLITZDUCTOR CT is determined by the protective task to be fulfilled. For easy selection, the following cases a to d are explained.

comparability of different gas discharge tubes is made possible by applying a voltage rise of 1 kV/μs at the gas discharge tube for determination of the dynamic response voltage (**Figures 8.2.5** and **8.2.6**).

Measured limiting voltage at nominal discharge current

This test is carried out to determine the limiting behaviour of protective elements with constant limiting characteristics (F**igures 8.2.7** and **8.2.8**).

Nominal current I_L

The nominal current of BLITZDUCTOR CT characterises the permissible continuous operating current. The nominal current of BLITZDUCTOR CT is determined by the current carrying capability and the insertion loss of the impedances used for decoupling of gas discharge tubes and fine protection elements as well as by the follow current extinguishing capability. The value is stated as d.c. value (**Figure 8.2.9**).

Case a: In this case the terminal equipment to be protected is located in a building structure with an external lightning protection system or the roof of the building is equipped with metal roof structures exposed to lightning (e.g. antenna masts, air-conditioning systems). The measuring and control or telecommunications cable connecting the terminal equipment (**Figure 8.2.11**) to the transformer is mounted outside the building structure. Due to the fact that the building structure is fitted with an external lightning protection, the installation of a lightning current arrester TYPE 1 is necessary. The **modules BCT MLC B...** or **B...** of the BLITZDUCTOR CT family can be used for this purpose.

Case b: Case b is similar to case a, only the building structure, where the terminal equipment to be protected is located, has no external lightning protection system: The arising of lightning currents or partial lightning currents is not assumed here. The installation of a lightning current carrying capable
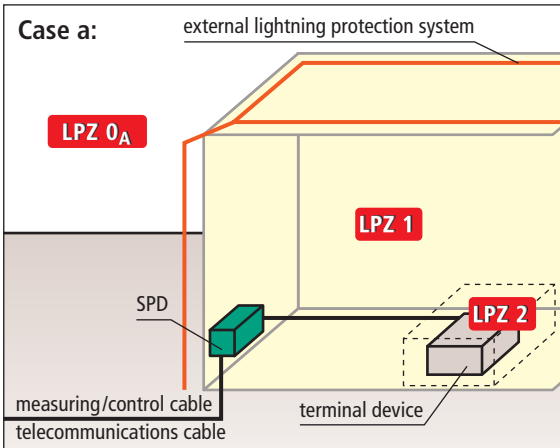
Fig. 8.2.11   Building with external lightning protection system and cables installed between buildings
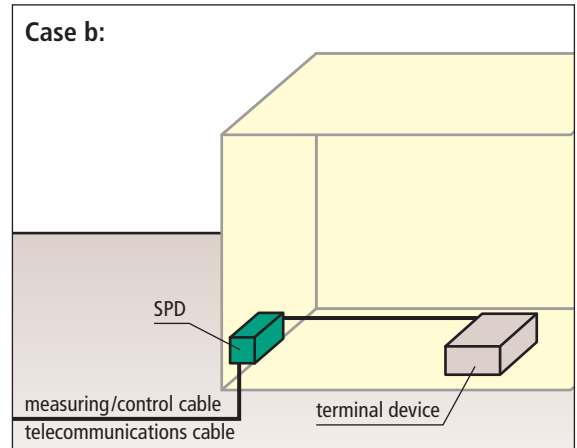
Fig. 8.2.12   Building without external lightning protection system and cables installed between buildings
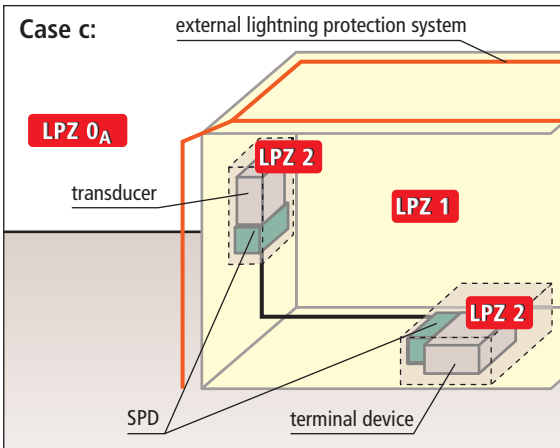
Fig. 8.2.13   Building with external lightning protection system and cables installed inside of the building
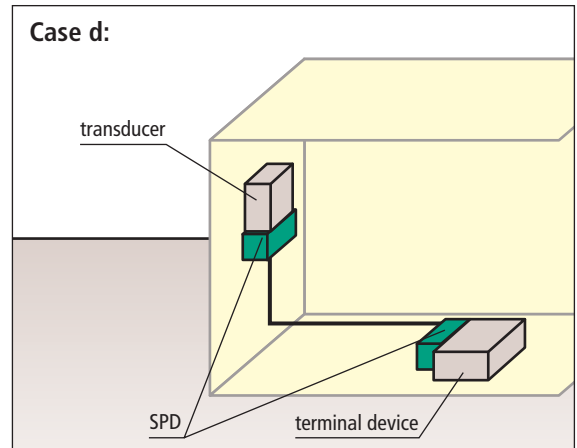
Fig. 8.2.14   Building without external lightning protection system and cables installed inside of the building

Type 1 arresters is only necessary if the measuring and control cable can be influenced by lightning striking adjacent building structures. If this can be excluded, BLITZDUCTOR CT module **BCT MOD M...** as surge protective device TYPE 2 is used (**Figure 8.2.12**).

Case c: In case c, no cable of the data and telecommunications system is mounted outside the building. Although the building structure is fitted with an external lightning protection system, direct lightning currents cannot be injected into this part of the telecommunications system. Therefore,

surge protective devices **BCT MOD M...** of the BLITZDUCTOR CT family are installed here (**Figure 8.2.13**).

Case d: The difference between case d and case c is that the building structure concerned has neither an external lightning protection system nor are cables of the data and telecommunications system mounted outside the building structure. Therefore only the installation of surge arresters is necessary for protection of the equipment. As in cases b and c, protection modules **BCT MOD M...** of the BLITZ-DUCTOR CT family are installed (**Figure 8.2.14**).

2. Which kinds of interferences have to be controlled?

Basically, interferences are classified into **common-mode and differential-mode interferences. Common-mode interferences** always arise **between the signal line and earth** whereas **differential-mode interferences** only arise **between two signal lines.** The majority of interferences arising in communication/signalling systems are common-mode interferences. Therefore protective surges devices limiting between signal line and earth (**Type ...E)** should normally be chosen. Some input modules of devices, as e.g. isolating transformers, do not need fine protection of the line-to-earth connection against surges. Only gas discharge tubes protect them against common-mode interferences. Due to their different response characteristics, the response of gas discharge tubes might cause a common-mode interference to change to a differential-mode interference. Therefore, fine protection elements are integrated between the signal lines (**Type ...D)**.

3. Are there special requirements to adopt the protection circuit to the input circuit of the equipment to be protected?

In some cases it is necessary to protect the equipment against common-mode and differential-mode interferences. The input modules of such electronic equipment are normally fitted with their own protection circuit or contain optocoupler inputs for control-to-load isolation of signalling circuit and internal circuit of the automation equipment. Therefore additional measures are required for decoupling BLITZDUCTOR CT and input circuit of the equipment to be protected. This decoupling is realised with additional decoupling elements between the fine protection elements and output terminals of BLITZDUCTOR CT.

4. How high is the signal frequency/data transmission rate to be transmitted?

As every transmission system, the protection circuit of BLITZDUCTOR CT has certain low-pass characteristics. The cut-off frequency indicates the frequency value from which the frequency to be transmitted is attenuated in its amplitude (above 3 dB). In order to keep the feedback effects of BLITZDUCTOR CT on the communication/signalling system in the limits, the signal frequency of the signalling circuit must be below the cut-off frequency of BLITZDUCTOR CT. The cut-off frequency is indicat-

ed for sinusoids. However, sinusoid signals are not very common in data transmissions. With respect to this fact, a BLITZDUCTOR is to be chosen with a higher cut-off frequency than the nominal frequency of the signalling circuit. When transmitting waveshape signals evaluating the rising or sinking pulse edge, it must be considered that this edge changes from L to H or from H to L within the appropriate interval. This time interval is important for the identification of an edge and for passing "restricted areas". This signal therefore requires a frequency bandwidth which is considerably higher than the fundamental of this wave. That is why the frequency of the protective device must be rated that high. As a general rule applies that the cut-off frequency must not be lower than five times the fundamental wave.

5. How high is the operating current of the installation to be protected?

Due to the electrical features of the components used in the protection circuit of BLITZDUCTOR CT, the signal current which can be transmitted by the protective device is limited. For practical applications this means that the operating current of a signalling system has to be lower than or equal to the nominal current of the protective device.

6. Which maximum continuous operating voltage can arise in the installation to be protected?

The maximum continuous operating voltage in signalling systems must be lower than or equal to the nominal voltage of BLITZDUCTOR CT, so that the protective device has no limiting effects with normal operating conditions.

The maximum continuous operating voltage in signalling systems is normally the nominal voltage of a transmission system regarding also tolerances. When current loops (e.g. 0 – 20 mA) are used, the open circuit voltage of the installation is to be applied to the maximum continuous operating voltage.

7. Which reference has the maximum continuous operating voltage?

Different signal current circuits have different signal references (balanced/unbalanced). On one hand, the continuous operating voltage of the installation can be stated as line/line voltage, on the other hand, as line/earth voltage. This is to be

considered when choosing the protective devices: Different nominal voltages are stated on the basis of the different circuit of the fine protection elements in the protection module of BLITZDUCTOR CT.

These are shown in **Figure 8.2.4** and **Table 8.2.1**.

8. Do the integrated decoupling elements of BLITZDUCTOR CT affect the signal transmission?

Decoupling elements are used inside of BLITZDUCTOR CT in order to coordinate the energy load of the integrated protection elements. They are mounted directly in the signalling circuit and may influence it. Especially with current loops (0 ... 20 mA, 4 ... 20 mA), the operation of a BLITZDUCTOR CT can cause the overrange of the permissible load of the signalling circuit when it is already operated with its maximum load. This has to be considered before use!

9. Which protection level is required?

Basically it is possible to dimension the protective level of a surge protective device to be lower than the immunity level of an automation/telecommunications equipment. However, the problem is that this level is often unknown. Therefore it is necessary to use other means of comparison. In the tests for electromagnetic compatibility (EMC), electrical and electronic equipment must have a certain immunity level against line-conducted interferences. The requirements for testing and test set-up are stipulated in IEC 61000-4-5: 2005. Different test levels are determined with respect to the immunity to pulse-shaped interferences for the various devices used under varying electromagnetic environmental conditions. These test levels bear the designation 1 to 4, whereby test level 1 contains the lowest immunity requirements (on the devices to be protected) and test level 4 ensures the highest immunity requirements of a device.

With regard to the protection provided by the surge protective devices this means that the "let-through energy" must be below the immunity level of the equipment to be protected. Therefore the Yellow/Line devices were classified according to certain characteristics allowing a coordinated installation of the SPDs for protection of automation engineering equipment. The surge immunity test of this equipment was taken as a basis of

determining Yellow/Line SPD class symbols (**Table 7.8.2.1**). If, for example, automation engineering equipment is tested according to test level 1, the equipment may only have a let-through energy corresponding to this test level. In practice this means that an equipment tested with level 4 can only discharge overvoltages without damaging the equipment if the output of the surge protective device corresponds to a let-through energy of 1, 2, 3, or 4. This makes it very easy for the user to choose suitable protective devices.

10. Shall there be one or two stages of protection?

Depending on the building structure and the protection requirements stipulated by the Lightning Protection Zones Concept it may be necessary to install lightning current and surge arresters locally separated from each other or at one point of the installation. In the first case, the protection module Type BCT MLC B of BLITZDUCTOR CT is installed as lightning current arrester and the protection module Type BCT MOD M... as surge arrester. If lightning and surge protective measures are required at one point of the installation, the use of a combined lightning current and surge arrester BLITZDUCTOR CT, Type B... is required.

Remark:

The following examples show the choice of surge protective devices of the BLITZDUCTOR CT family in accordance with the 10 selection features described in **Table 8.2.3**. The result of each single stage is indicated in the column "intermediate result".

The column "final result" shows the influence of the intermediate result on the total result.

Surge protection for electrical temperature control systems

The electrical temperature control of media in technological processes is applied in all branches of industry. The branches differ a lot from each other: They stretch from food industry via chemical processes up to ventilation systems of building structures and building services control systems. However, they have something in common: the distance between measuring sensor and indicator or measured-value processing is long. Due to the long connection cables, overvoltages can be coupled which are not only caused by atmospheric discharges. Therefore a possible protection concept

SF	Application	Intermediate result	Final result
1	The measuring sensor is situated at a process framework in a production hall and the measuring transducer is installed in a control room inside of the production building. The building has no external lightning protection system. The measuring lines are inside the building. This example corresponds to **case d** (**Figure 8.2.14**).	BLITZDUCTOR CT BCT MOD M...	BLITZDUCTOR CT BCT MOD M...
2	The threat to the measuring sensor Pt 100 as well as the measuring transducer Pt 100 by surges arises between signal line and earth. This requires a **fine limiting of common-mode interferences**.	BLITZDUCTOR CT BCT MOD ME	BLITZDUCTOR CT BCT MOD ME
3	There are no special requirements on the adjustment of the protective circuit to the input circuit of the devices to be protected (Pt 100, Pt 100 measuring transducer).	no influence	BLITZDUCTOR CT BCT MOD ME
4	The temperature measuring equipment is a system supplied by d.c. current. The temperature-related measuring voltage is also a d.c. voltage variable. Thus no signal frequencies have to be considered.	no influence	BLITZDUCTOR CT BCT MOD ME
5	The operating current of the supply circuit is limited to 1 mA due to the physical measuring principle of Pt 100. The operating current of the measuring signal amounts to some µA due to the very high impedance measurement tapping.	I_L type ME = 1 A 1 mA < 1 A ⇒ ok µA < 1 A ⇒ ok	BLITZDUCTOR CT BCT MOD ME
6	The maximum arising operating voltage in this system results from the following consideration: According to IEC 60751, Pt 100 measuring resistors are designed for a maximum temperature of up to 850 °C. The respective resistance is 340 Ω. Considering the load-independent measuring current of 1 mA, results a measuring voltage of **approx. 340 mV.**	BLITZDUCTOR CT BCT MOD ... 5 V	BLITZDUCTOR CT BCT MOD ME 5
7	The operating voltage of the system arises **from line to line**.	BCT MOD ME 5 V has nominal voltage 5 V d.c. line ⇒ earth, this allows line ⇒ line 10 V d.c. ⇒ no influence on the measuring signal	BLITZDUCTOR CT BCT MOD ME 5
8	Using the four-wire circuit for measuring the temperature with Pt 100, the influence of the cable resistance and its temperature-related fluctuations on the measuring result are completely eliminated. This also applies to the increasing of the cable resistance by the decoupling impedances of BLITZDUCTOR CT.	no influence	BLITZDUCTOR CT BCT MOD ME 5
9	The Pt 100 measuring transducer has an immunity against conducted interferences according to test level 2 according to IEC 61000-4-5: 2005. The "transmitted energy" being related to the voltage protection level of the surge protective device may correpond to max. test level 2 of IEC 61000-4-5: 2005.	BLITZDUCTOR CT BCT MOD ME 5 TYPE 2 P1 "transmitted energy" corresponds to level 1 "transmitted energy" of the protective device is less than immunity of the terminal device ⇒ TYPE 2 P1 is ok	BLITZDUCTOR CT BCT MOD ME 5
10	The surge protection shall be performed in **one** stage.	BLITZDUCTOR CT BCT MOD ME 5 ⇒ surge arrester	BLITZDUCTOR CT BCT MOD ME 5
		Result of selection:	**BLITZDUCTOR CT BCT MOD ME 5**

Table 8.2.3   Selection features for an electrical temperature measuring equipment
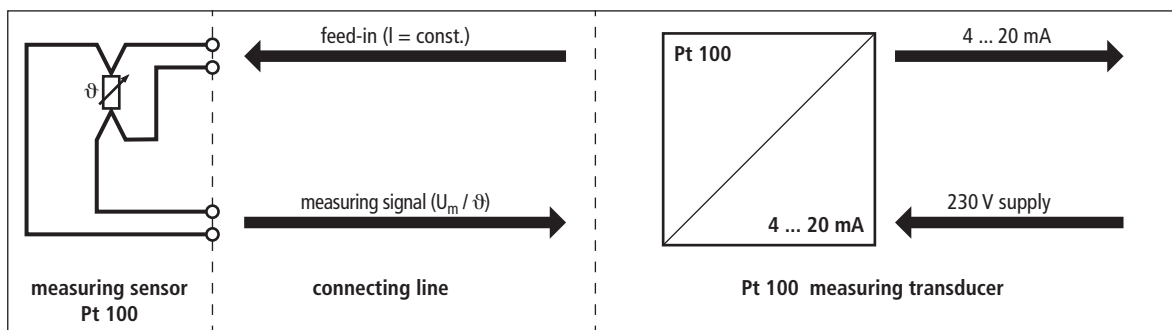
Fig. 8.2.15   Block diagram of temperature measuring

of temperature measurements against surges by a standard type Pt 100 shall be worked out in the following. The building structure where the measuring instrument is located has no external lightning protection system.

The temperature is controlled indirectly by measuring the electrical resistance. The resistance thermometer Pt 100 has a resistance of 100 Ω at 0 °C. This value varies by around 0.4 Ω/K depending on the temperature. The temperature is controlled by injecting a constant current causing a voltage drop proportional to the temperature rise at the resistance thermometer. In order to prevent the the self-heating of the resistance thermometer, the current is limited to 1 mA. In this case, a voltage drop of 100 mV appears at the Pt 100 at 0 °C. This measured voltage must now be transmitted to the indicator or receiver (**Figure 8.2.15**). Out of many various connections of Pt 100 measuring sensors to the measuring transformer, the four-wire configuration is chosen. It represents the best connection for resistance thermometers. By this configuration, the interfering effects of the conductor resistance and its temperature sensitivity on the measured result are excluded. The Pt 100 sensor is supplied with an injected current. Alternations of the conductor resistance are compensated by automatic adjustment of the supply voltage. If the conductor resistance does not alter, the measured voltage U_m remains unchanged. This measured voltage is only influenced by the alternation of the measuring resistance depending on the temperature. It is measured at the transformer using a high-resistance voltage detector. Line compensation is therefore not necessary with this configuration. (**Table 8.2.3**)

Remark:

For ease of assembly, power supply and measuring lines of the temperature control system are fitted with the same type of surge protective device. In practice it has proved that the balanced lines for supply, compensation and measurement are allocated to one protected device each (**Table 8.2.3**).

Surge protection of the 230 V power supply of the Pt 100 receiver as well as the 4 ... 20 mA current loop coming from the receiver is also necessary but not shown here in order to retain clearness.

8.2.1 Measuring and control systems

The large separations between the measuring sensor and the evaluation unit in measuring and control systems allow a coupling of surges. The consequential destruction of components and the breakdown of complete control units can severely interfere with a process technology procedure. The extent of a surge damage caused by a lightning strike often becomes apparent only some weeks later because more and more electronic components have to be replaced because they no longer operate safely. Such kind of damage can have serious consequences for the operator who uses a so-called field bus system because all intelligent field bus components together in one segment can break down simultaneously.

The situation can be improved by installing lightning and surge protective devices (SPDs) which have to be chosen to suit the specific interface.

Typical interfaces and the protective devices appropriate to the system can be found in our "Surge Protection" product catalogue or at www.dehn.de.
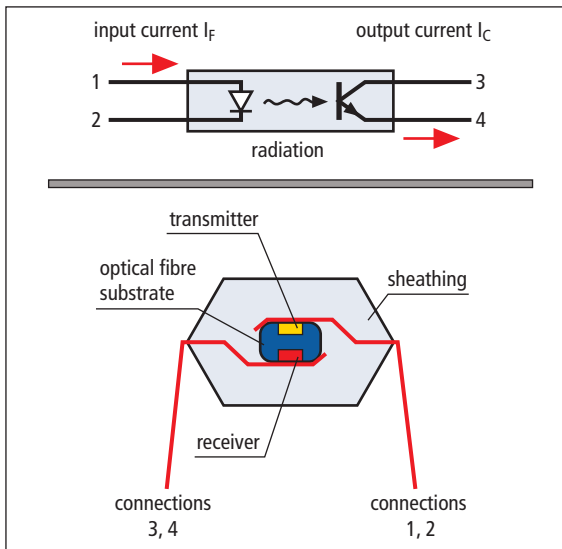
Fig. 8.2.1.1   Optocoupler – Schematic diagram

Electrical isolation using optocouplers:

Optoelectronic components (**Figure 8.2.1.1**), which typically produce a dielectric strength between the input and output of a few 100 V to 10 kV, are frequently installed to transmit signals in process technology systems in order to isolate the field side electrically from the process side. Thus their function is similar to that of transmitters and they can primarily be installed to block low common-mode interferences. However, they cannot provide sufficient protection against arising common-mode and differential-mode interferences. When being affected by a lightning strike (> 10 kV) above their transmitter/receiver surge withstand capability.

Many designers and operators of such installations misleadingly assume that this also realises lightning and surge protection. At this point it is expressly emphasised that this voltage only provides the insulating resistance between input and output (common-mode interference). This means that, when installed in transmission systems attention must be paid not only to the limitation of common-mode interferences but also to sufficient limitation of differential-mode interferences. Furthermore, the integration of supplementary decoupling resistors at the output of the SPD achieves an energy coordination with the optocoupler diode.

Hence, in this case, common-mode and differential-mode interference limiting SPDs, e.g. BLITZ-DUCTOR XT Type BXT ML BE C 24, must be installed.

Detailed designs for the application-specific choice of protective devices for measuring and control systems can be found in Chapter 9.

8.2.2 Technical property management

The pressure of rising costs is forcing the owners and operators of buildings in both the public and the private sector to look more and more for cost saving opportunities for building services management. Technical property management can help to reduce costs on a permanent basis. Technical property management is a comprehensive instrument to make technical equipment in buildings continuously available, to keep it operative and to adapt it to changing organisational requirements. This facilitates optimum management which increases the profitability of a property.

Building automation (BA) has grown out of measuring and control systems on the one hand, and central control systems on the other. The function of building automation is to automate the technical processes within the building in their entirety. This involves networking the complete installation comprising room automation, the M-bus measuring system and the heating-ventilation-air-conditioning and alarm systems via powerful computers on the management level (**Figure 8.2.2.1**), where also data archiving takes place. Long term data storage allows evaluations concerning the energy consumption and the adjustment of the installations in the building to be obtained.

The actual control devices are at the automation level. DDC stations (Direct Digital Control) are increasingly being installed. They implement the complete control and switching functions from a software point of view. All operating modes, control parameters, nominal values, switching times and alarm trigger levels and the corresponding software is filed at the automation level.

Process field devices such as actuators and sensors are located at the lowest level, the field level. They represent the interface between the electrical control and the process. Actuators transform an electrical signal into another physical value (engines, valves, etc.). Sensors transform a physical value
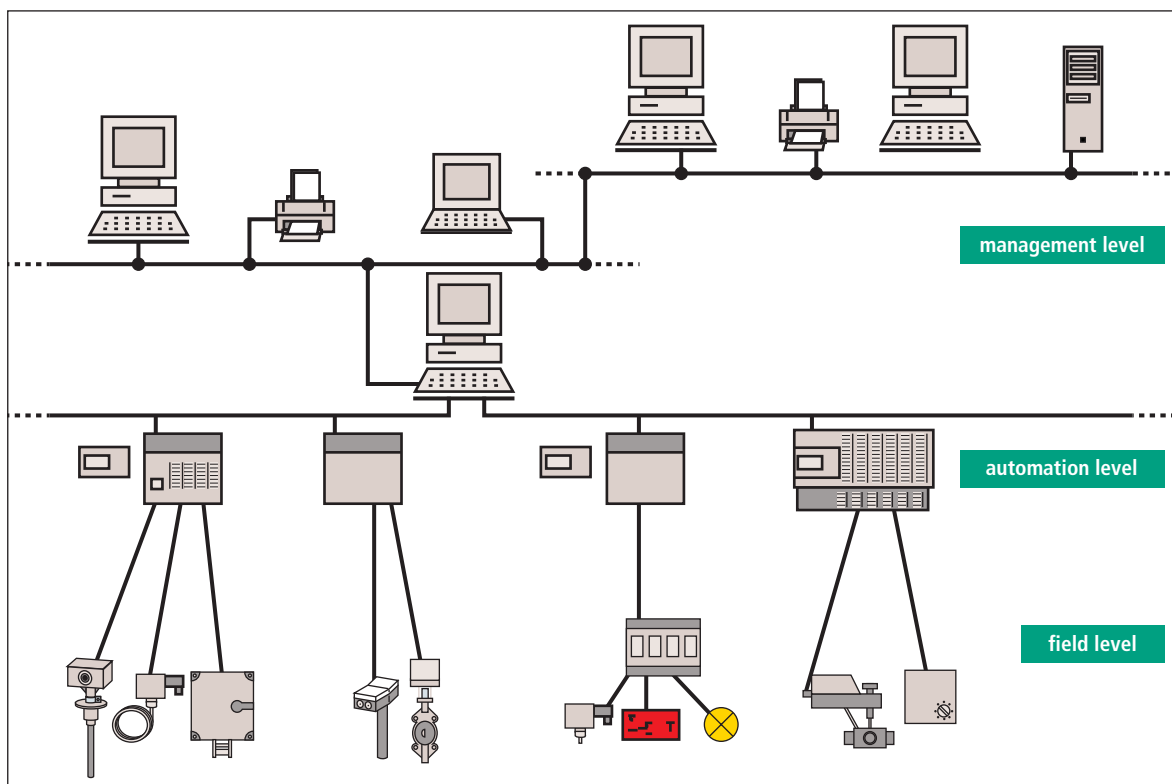
Fig. 8.2.2.1   Levels of building automation

into an electrical signal (temperature sensor, limit switch, etc.).

It is precisely the diffuse branched network of DDC stations and the consequential integration into building control systems which offer a large contact area for interferences caused by lightning currents and surges. If this causes a breakdown of the complete lighting, air-conditioning or heating control, this not only incurs primary costs for the equipment, it is also precisely the consequences of this system breakdown which make a difference. They can significantly increase the energy costs because peak loads can no longer be analysed and optimised due to the fault in the control electronics. If production processes are integrated into the BA, damage to the BA can lead to breakdowns in production and hence quite possibly to large economic losses. To ensure permanent availability, protective measures are required, whose exact nature depends on the risk to be controlled.

8.2.3 Generic cabling systems (EDP networks, TC installations)

The European standard EN 50173 "Information technology – Generic cabling systems" defines a universal cabling system which can be used in sites of one or more buildings. It deals with cable systems with balanced copper cables and optical fibre cables (OF cables). This universal cabling supports a wide range of services including voice, data, text and images.

It provides:

⇒ users with an application independent generic cabling system and an open market for (active as well as passive) cabling components;

⇒ users with a flexible cabling scheme that allows to carry out modifications in a both easy and economical way;

⇒ building professionals (for example, architects) with guidance allowing the accommodation
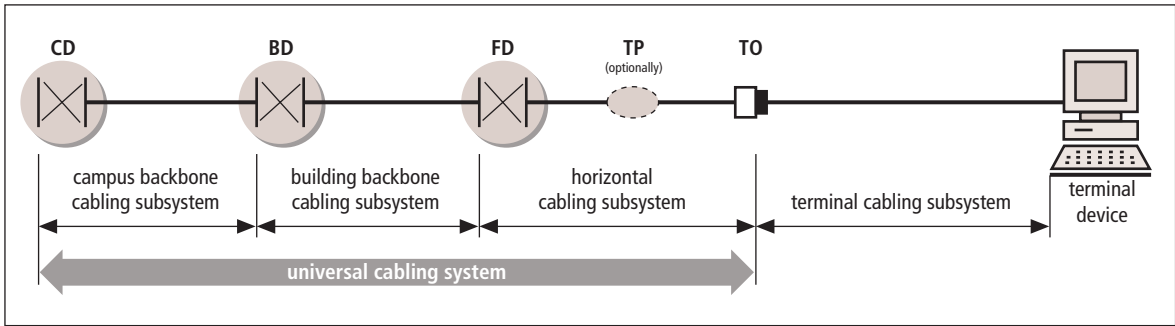
Fig. 8.2.3.1   Universal cabling structure

of cabling before specific requirements are known; i.e. in the initial design stage either for construction or refurbishment,

⇒ industry and standardisation bodies for applications with a cabling system which supports current products and provides a basis for future product development.

The universal cabling system comprises the following functional elements:

⇒ Campus distributors (CD),

⇒ Campus backbone cables,

⇒ Building distributors (BD),

⇒ Building backbone cables,

⇒ Floor distributors (FD),

⇒ Horizontal cables,

⇒ Transition points (optional),

⇒ Telecommunication outlet (TO).

Groups of these functional elements are connected together to form cabling subsystems.

Generic cabling schemes contain three cabling subsystems: campus backbone, building backbone and horizontal cabling. The cabling subsystems are connected together to create a generic cabling structure as shown in **Figure 8.2.3.1**. The distributors provide the means to configure the cabling to support different topologies like bus, star and ring.

The campus backbone cabling subsystem extends from the campus distributor to the building distributor(s) usually located in separate buildings. When present, it includes the campus backbone cables, the mechanical termination of the campus backbone cables (at both the campus and building

distributors) and the cross-connections at the campus distributor.

A building backbone cabling subsystem extends from building distributor(s) to the floor distributor(s). The subsystem includes the building backbone cables, the mechanical termination of the building backbone cables (at both the building and floor distributors) and the cross connections at the building distributor.

The horizontal cabling subsystem extends from the floor distributor to the telecommunications outlet(s) connected to it. The subsystem includes the horizontal cables, the mechanical termination of the horizontal cables at the floor distributor, the cross connections at the floor distributor and the telecommunications outlets.

Optical fibre cables are usually used as data connection between the CD and the BD. This means that no surge arrester (SPD) is required for the field side. If, however, the OF cables have a metal rodent protection, this must be integrated into the lightning protection system. The active OF components for the distribution of the optical fibre cables, however, are supplied with 230 V on the power side. In this case, SPDs can be used for the power supply system.

Nowadays, building backbone cables (BD to FD) are equipped almost exclusively with OF cables for the transmission of data. Balanced copper cables (so-called master cables), however, are still used to transmit voice (telephone).

With a few exceptions, balanced copper cables are used today for the horizontal cables (FD to TO).
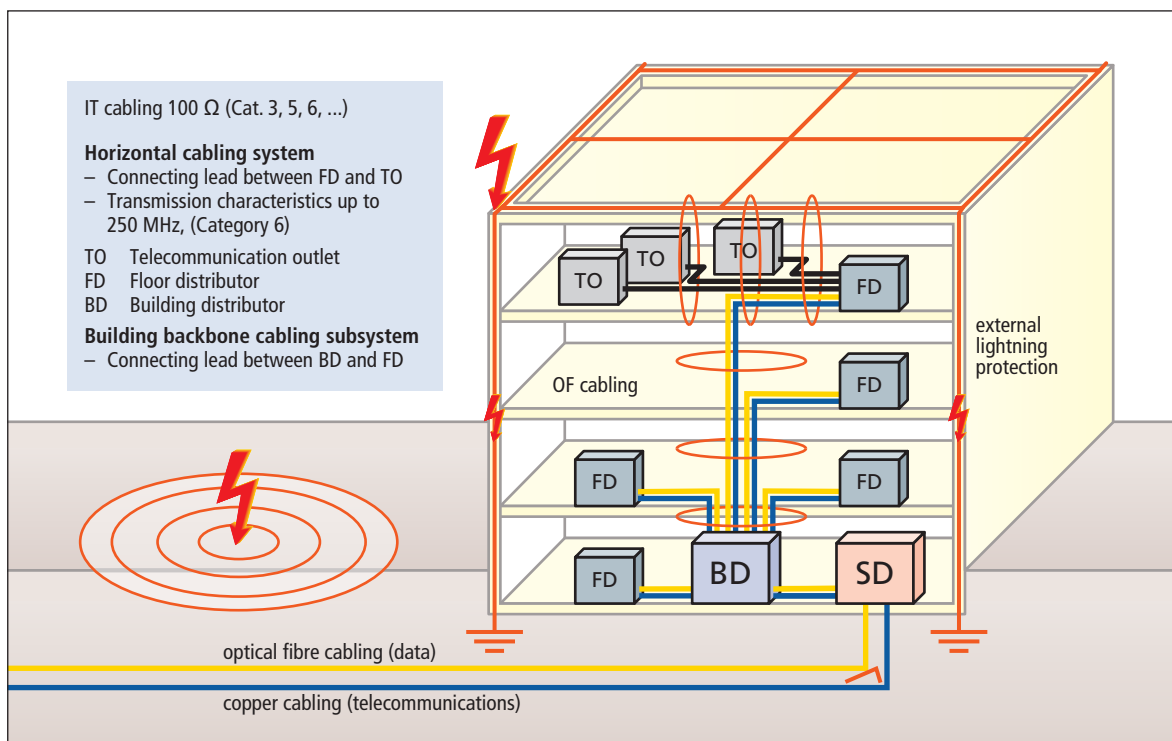
Fig. 8.2.3.2   Influence of lightning on IT cabling subsystems

For cable lengths of around 500 m (building backbone cables) or 100 m (horizontal cables) direct lightning strikes to the structure (**Figure 8.2.3.2**) can induce common-mode interferences which would overload the insulation capacity of a router or an ISDN card in the PC. Both the building/floor distributors (hub, switch, router) and the terminal equipment must be equipped with protective measures in this case.

The protective devices required here must be chosen according to the network application. Common network applications are:

⇒   Token Ring,

⇒   Ethernet 10 Base T,

⇒   Fast Ethernet 100 Base TX,

⇒   Gigabit Ethernet 1000 Base TX.

An appropriate protection concept for choosing the appropriate protective devices can be found in Chapter 9.11 "Surge protection for ETHERNET networks".

8.2.4 Intrinsically safe circuits

In all fields of industry where combustible materials are processed or transported gases, vapors, mist or dust will be produced. These, when mixed with air, can form a potentially explosive atmosphere of hazardous proportions. Therefore special measures must be taken to protect against explosions.

Depending on the possibility and the duration of the occurrence of a potentially explosive atmosphere, sections of the installation are divided into hazardous areas – so-called Ex-zones.

Hazardous areas:
Areas where hazardous potentially explosive atmospheres arise due to gases, vapors and mist, for example, are divided into zones 0 to 2. Those where hazardous potentially explosive atmospheres can arise due to dust are divided into zones 20, 21 or 22.
Explosion groups I, IIA, IIB and IIC provide a system of classification according to the explosiveness of the combustible materials used in the respective

field of application. Classification criteria are the "Maximum Experimental Safe Gap (MESG)" and the "Minimum Ignition Current (MIC)". The MESG and MIC are determined for the various gases and vapors according to a stipulated testing arrangement.

Explosion group IIC contains the most highly combustible materials such as hydrogen and acetylene. When heated, these materials have different ignition temperatures classified into temperature classes (T1 ... T6).

To avoid electrical equipment from being sources of ignition in explosive atmospheres, these are designed with different types of protection. One type of protection used all over the world, particularly in measuring and control systems, is the type of protection "Intrinsic safety" Ex(i).

Ignition protection type – intrinsic safety:

Intrinsic safety being a type of protection is based on the principle of current and voltage limitation in an electric circuit. With this system, the energy of the circuit or a part of the circuit, which is in a position to ignite potentially explosive atmospheres, is kept so low to ensure that neither sparks nor intolerable surface heating of the electrical components can cause an ignition of the surrounding potentially explosive atmosphere. Apart from voltages and currents of the electrical equipment, the inductances and capacitances in the complete circuit acting as energy storage devices must be limited to safe maximum values.

For the safe operation of a measuring and control system circuit, for example, this means that neither the sparks arising during the operational opening and closing of the circuit (e.g. at a make-or-break contact in an intrinsically safe circuit), nor those arising in the event of a fault (e.g. a short circuit or earth fault) must be capable of causing an ignition. Moreover, both for normal operation and also in the event of a fault, heat ignition as a result of overheating of the equipment and cables in the intrinsically safe circuit, must also be excluded.

This basically limits intrinsic safety as a type of protection to circuits requiring relatively little power. These are circuits of measuring and control systems and also data systems. Intrinsic safety which can be achieved by limiting the energies available in the circuit does not relate to individual devices – as is the case with other types of protection – but to the complete circuit. This produces a number of considerable advantages compared to other types of protection.

Firstly, no expensive special constructions are required for the electrical equipment used in the field, for example flame-proof encapsulation or embedding in cast resin, which results mainly in more cost-effective solutions. Another advantage is that the intrinsic safety is the only type of protection which allows the user to work freely at all live intrinsically safe installations in a hazardous area without having an adverse effect on the protection against explosion.

The economic advantage of using intrinsically safe circuits lies in the fact that, even in the hazardous areas, conventional non-certified passive equipment can be used. Thus this type of protection is also one of the simplest types of installation.

Intrinsic safety has therefore considerable significance, particularly in measuring and control systems, not least because of the increased use of electronic automation systems. However, intrinsic safety demands more from the designer or constructor of an installation than other types of protection. The intrinsic safety of a circuit not only depends on compliance with the design provisions for the individual pieces of equipment, but also on the correct connection of all equipment in the intrinsically safe circuit and the correct installation.

Transient surges in hazardous areas:

Intrinsic safety as type of protection considers all electrical energy storage devices present in the system but not energy from outside, such as coupled surges resulting from atmospheric discharges.

Coupled surges come up in expanded industrial installations mainly as a result of close and distant lightning strikes. In the event of a direct lightning strike, the voltage drop across the earth-termination system causes a potential rise between some 10 and 100 kV. This potential rise acts as a potential difference on all equipment connected via cables to distant equipment. These potential differences are considerably greater than the insulation resistance of the equipment and can easily be sparked over. For distant lightning strikes it is mainly the coupled surges in conductors that can destroy the inputs of electronic equipment by acting as differential-mode interferences (differential voltage between the lines).

Classification of electrical equipment into category ia or ib

An important aspect of intrinsic safety for explosion protection is the issue of the reliability with respect to maintaining of voltage and current limits, even assuming certain faults. There are two categories of reliability.

Category ib specifies that the intrinsic safety must be maintained if a fault occurs in the intrinsically safe circuit.

Category ia requires that the intrinsic safety must be maintained if two independent faults occur.

The classification of the BLITZDUCTOR CT or DEHNconnect DCO as category ia is the classification in the highest category. This means that the BLITZDUCTOR may also be used with other equipment located in zones 0 and 20. Extra attention must be paid to the special conditions of zones 0 and 20 and clarified in each individual case.

Figure 8.2.4.1 shows the principle use of SPDs in measuring and control circuits

Maximum values of current I_0, voltage U_0, inductance L_0 and capacitance C_0

At the interface between hazardous area and safe area, safety barriers or transmitters with Ex(i) output circuit are used to separate these two different zones.

The safety-related maximum values of a safety barrier or a measuring transformer with Ex(i) output circuit are defined by the test certificates of an authorised testing laboratory:

$\Rightarrow$ Maximum output voltage U_0

$\Rightarrow$ Maximum output current I_0

$\Rightarrow$ Maximum external inductance L_0

$\Rightarrow$ Maximum external capacitance C_0

The designer/constructor must test whether these safety-related permissible maximum values of the equipment connected and located in the intrinsically safe circuit (i.e. process field devices, conductors and SPD) are maintained for each individual case. The corresponding values have to be taken from the rating plate of the pertinent equipment or the type examination certificate.

Classification in explosion groups

Explosive gases, vapors and mist are classified according to the spark energy required to ignite the most explosive mixture with air.

Equipment is classified according to the gases which it can be used with.

Group II C applies to all fields of application, e.g. chemical industry, coal and grain processing, with exception of underground mining.

Group II has the highest risk of explosion, since this group considers a mixture with the lowest ignition energy.

The certification of BLITZDUCTOR for explosion group II C means that it fulfils the highest, i.e. most sensitive, requirements for a mixture of hydrogen in air.

Classification into temperature classes

When a potentially explosive atmosphere is ignited as a result of the hot surface of a piece of equip-
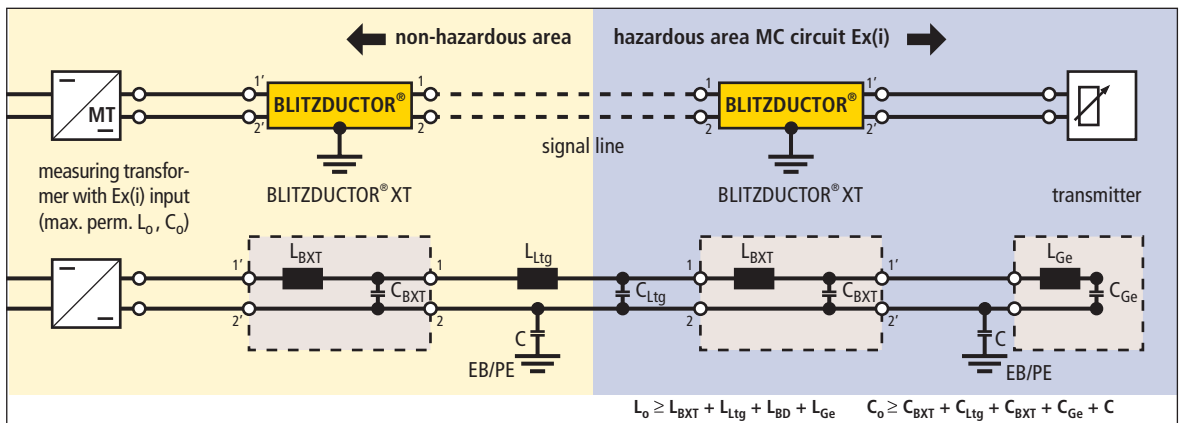
Fig. 8.2.4.1   Calculating of L_0 and C_0

ment, a minimum temperature specific to the material is required to cause the explosion. The ignition temperature is a characteristic of the material characterising the ignition behaviour of the gases, vapors or dust on a hot surface. For economic reasons, gases and vapors are therefore classified into certain temperature classes. Temperature class T6 specifies that the maximum surface temperature of the component must not exceed 85 °C either in operation or in the event of a fault, and that the ignition temperature of the gases and vapors must be higher than 85 °C.

With its T6 classification, BLITZDUCTOR CT also fulfils the highest stipulated requirements in this aspect.

In accordance with the certificate of conformity issued by KEMA, the following electrical parameters must also be taken into consideration.

Selection criteria for SPD – BLITZDUCTOR XT
Using the example of BLITZDUCTOR XT, BXT ML4 BD EX 24, the specific selection criteria for this component are explained below (**Figures 8.2.4.2a** and **8.2.4.2b**).

This component has already a certificate of conformity issued by KEMA.

The SPD has the following classification:

II 2(1) G EEx ia IIC T4 ,T5, T6

This classification states the:

II Group of devices – the SPD may be used in all fields apart from mining.

2(1) G Device category – the SPD may be installed in potentially explosive gas atmospheres in

zone 1 and also in conductors from zone 0 (to protect terminal devices in zone 0)

EEx Testing laboratory certifies that this electrical equipment conforms to the harmonised European standards.

EN 50014: General Principles

EN 50020: Intrinsic safety "i"

BLITZDUCTOR CT equipment has passed a type examination successfully.

ia Type of protection – the SPD controls even a combination of two arbitrary faults in an intrinsically safe circuit without causing ignition itself.

IIC Explosion group – the SPD fulfils the requirements of explosion group IIC and may also be used with ignitable gases such as hydrogen or acetylene.

T4 between -40 °C and +80 °C

T4 between -40 °C and +75 °C

T6 between -40 °C and +60 °C

Further important electrical data:

⇒ Maximum external inductance L_0 and maximum external capacitance (C_0):

The special choice of components in BLITZDUCTOR XT means that the values of the internal inductance and capacitance of the various individual components are negligibly small.

⇒ Maximum input current (I_i):

The maximum permissible current which may be supplied via the connections is 500 mA, without overriding the intrinsic safety.

KEMA 06 ATEX 0274 X
II 2(1) G EEx ia IIC
T4 / T5 / T6

Fig. 8.2.4.2a   Intrinsically safe SPD

protected intrinsically safe equipment

BLITZDUCTOR®XT

circuit   **application example**
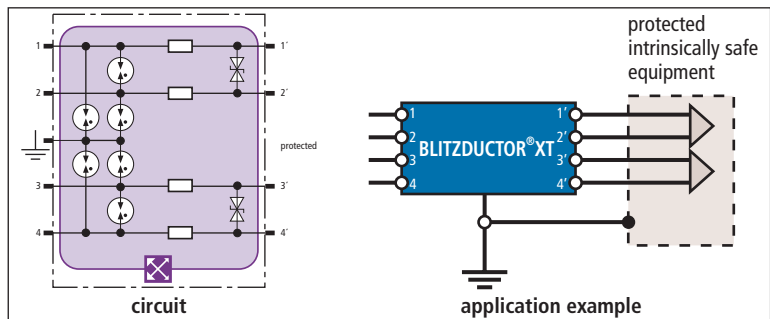
Fig. 8.2.4.2b   Schematic diagram of BXT ML4 BD EX 24
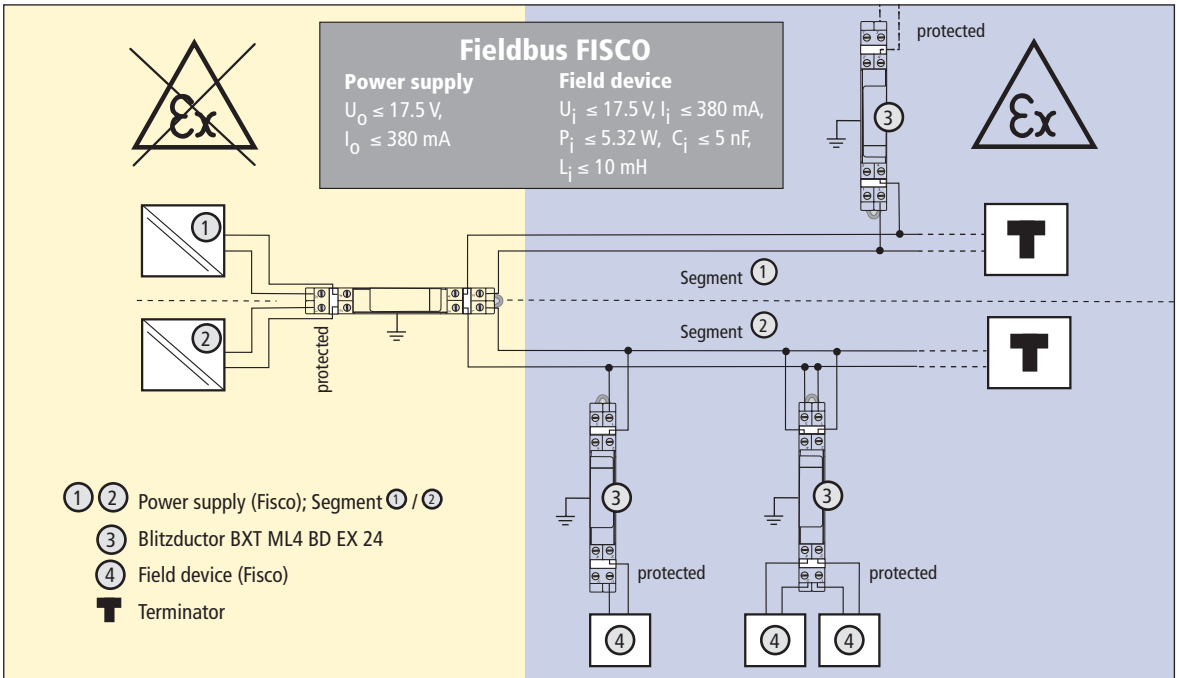
Fig. 8.2.4.3   SPD in hazardous location – Insulation resistance > 500 V a.c.

⇒ Maximum input voltage (U_i):

The maximum voltage which may be applied to BLITZDUCTOR XT is 30 V, without overriding the intrinsic safety.

Insulation resistance

The insulation between an intrinsically safe circuit and the frame of the electrical equipment or other components which can be earthed must usually be able to withstand the root mean square value of an a.c. test voltage which is twice as high as the voltage of the intrinsically safe circuit, or 500 V, whichever value is higher.

Equipment with an insulation resistance < 500 V a.c. is considered to be earthed. Intrinsically safe equipment (e.g. cables, sensors, transmitters) generally have an insulating strength > 500 V a.c. (**Figure 8.2.4.3**).

Intrinsically safe circuits must be earthed if this is required for safety reasons. They may be earthed if this is required for functional reasons. This earthing must be carried out at only one point by connection with the equipotential bonding. SPDs with a d.c. sparkover voltage to earth < 500 V d.c. represent an earthing of the intrinsically safe circuit.

If the d.c. sparkover voltage of the SPD is > 500 V d.c., the intrinsically safe circuit is considered to be non-earthed. This requirement corresponds to BLITZDUCTOR XT, BXT ML4 BD EX 24.

Fig. 8.2.4.4   Application – Insulation resistance < 500 V a.c.

In order to coordinate the dielectric strength of the devices to be protected (transmitter and sensor) with the voltage protection level of the SPDs, it must be ensured that the insulation resistance of the devices to be protected is considerably higher than the requirements for an a.c. test voltage 500 V a.c..

In order to avoid that the voltage drop of the interference current to be discharged in the earth connection does not degrade the voltage protection level, it must be ensured that the equipotential bonding between the device to be protected and the SPD is consistent.

Figure 8.2.4.4 illustrates a special type of application. This particular application arises if the terminal device to be protected has an insulation resistance < 500 V a.c.. In this case, the intrinsically safe measuring circuit is not floating.

A BLITZDUCTOR XT, BXT ML4 BE, which is not certified for use in hazardous areas, is used as the SPD in the hazardous area and realises a voltage protection level between lines to earth/equipotential bonding which is considerably less than 500 V. This is necessary in this particular application since the insulating strength of the transmitter corresponds to < 500 V a.c..

This example illustrates particularly the importance of a common consideration of the conditions of intrinsic safety and the EMC/surge protection to be brought into line with each other in systems engineering.

Earthing/Equipotential bonding
A consistent equipotential bonding and an intermeshing of the earth-termination system in the hazardous area of the installation must be ensured.
The cross section of the earth conductor from the SPD to the equipotential bonding must be at least 4 mm² Cu.

Installation of SPD BLITZDUCTOR CT in Ex(i)-circuits
The normative stipulations for Ex(i)-circuits from the point of view of the protection against explosion and of electromagnetic compatibility (EMC) correspond to different positions, a situation which occasionally causes consternation among designers and building constructors.

Chapter 9.15 "Installation of surge protective devices in intrinsically safe circuits", lists the most important selection criteria for both intrinsic safety and EMC/surge protection in installations in order to detect the interaction on the other requirement profile in each case.

8.2.5 Special features of the installation of SPDs

The protective effect of an SPD for a device to be protected is provided if a source of interference is reduced to a specified value below the interference or destruction limit and above the maximum operating voltage of a device to be protected. Generally, the protective effect of an arrester is indicated by the manufacturer in form of the voltage protection level U_p (see IEC 61643-21, EN 61643-21). The effectiveness of a surge protective device, however, depends on additional parameters, which are determined by the installation. During the discharge, the current flow through the installation (e.g. L and R of the equipotential bonding conductor) can cause a voltage drop $U_L + U_R$ which must be added to U_p and results in the residual voltage at the terminal device U_r.

$$U_r = U_p + U_L + U_R$$

Optimal surge protection is possible under the following conditions:

⇒ The maximum operating voltage U_c of the SPD is just above the open circuit voltage of the system

⇒ U_p of the SPD should be as low as possible, since additional voltage drops through the installation have less effect

⇒ The equipotential bonding should be designed to have the lowest impedance possible

⇒ Installing the SPD as close as possible to the terminal device has a favourable effect on the residual voltage

Installation examples:

Example 1: Correct installation **(Figure 8.2.5.1)**

The terminal device is only earthed directly via the earth connection point of the arrester. The consequence is that the U_p of the SPD is in fact available at the terminal device. This form of installation illustrates the most favourable application of the SPD for protection of the terminal device.

$$U_r = U_p$$

$U_L + U_R$ have no effect

Example 2: Most common installation **(Figure 8.2.5.2)**

The terminal device is earthed directly via the earth connection point of the arrester and is also connected via the protective conductor. The consequence is that a part of the discharge current, depending on the impedance ratio, flows away via the connection to the terminal device. To prevent a coupling of the interference from the connecting equipotential bonding conductor to the protected lines, and to keep the residual voltage low, this equipotential bonding conductor must be installed separately, if possible, and/or be designed to have extremely low impedance (e.g. metal mounting plate). This form of installation illustrates current installation practice for terminal devices protection class I.

$$U_r = U_p + U_v$$

Example 3: Wrong method of equipotential bonding **(Figure 8.2.5.3)**

The terminal device is only earthed directly via the protective conductor terminal, for example. There is no low impedance equipotential bonding to the surge protective device. The path of the equipotential bonding conductor from protective device to where it meets the protective conductor terminal of the terminal device (e.g. equipotential bonding bar) has considerable effect on the residual voltage. Depending on the length of the conductor, voltage drops up to a few kV can arise which add up to U_p and can lead to the destruction of the terminal device during the discharge of surges.

$$U_r = U_p + U_L + U_R$$

L and R of the line have no effect on U_r out of $U_r = U_p$

U_p = voltage protection level
U_r = residual voltage

Fig. 8.2.5.1   Correct installation

L and R of the line have a little effect on U_r, if the connection has a low impedance: $U_r = U_p + U_v$

U_v = voltage drop connection; BCT > terminal device
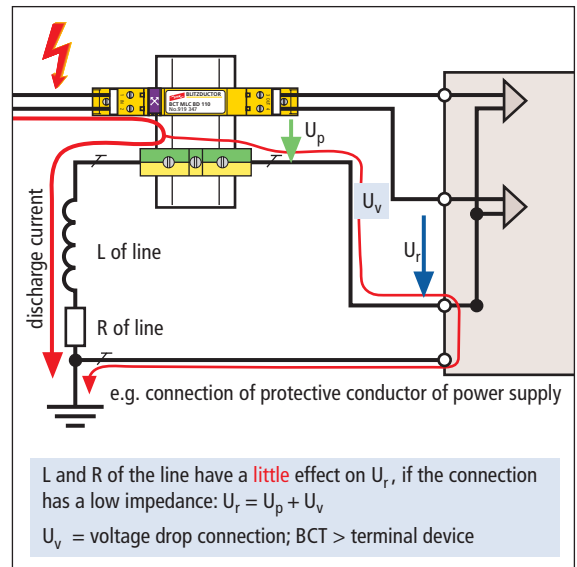
Fig. 8.2.5.2   Most frequent installation
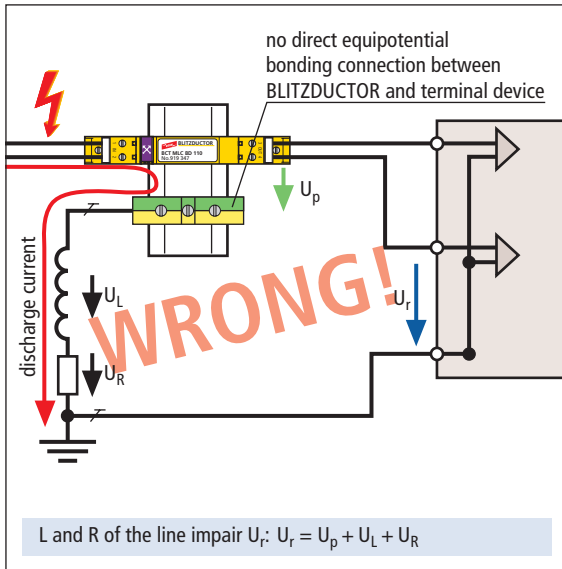
Fig. 8.2.5.3   Wrong method of equipotential bonding

L and R of the line impair U_r: $U_r = U_p + U_L + U_R$

Due to wrong conductor leading interferences are coupled from the unprotected to the protected line
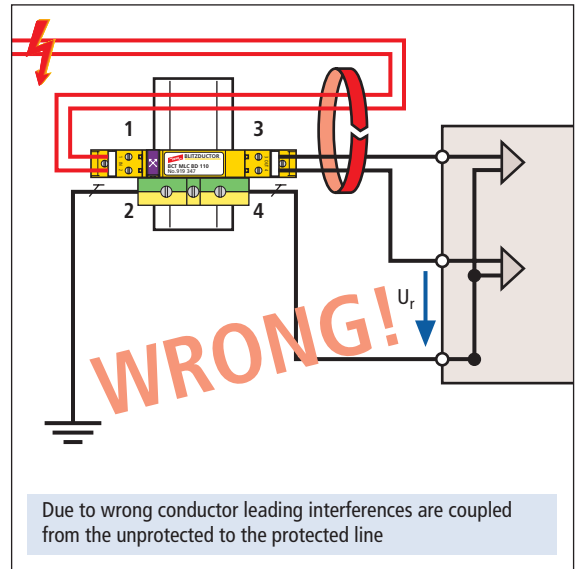
Fig. 8.2.5.4   Wrong conductor leading

Example 4: Wrong conductor leading
(Figure 8.2.5.4)

Even if the equipotential bonding is carried out correctly, a wrong conductor leading can interfere with the protective effect or even result in damage to the terminal device. If strict spatial separation or shielding of an unprotected conductor upstream of the SPD, and protected conductor downstream of the SPD, is not maintained, then the electromagnetic interference field can cause coupling of interference impulses on the protected conductor.

Shielding

The shielding of cables is described under 7.3.1.

Recommendations for installation:
The use of metal shields or cable ducts reduces the interaction between line pair and surroundings. For shielded cables, please note the following:

⇒ Shield earthing at one end reduces the irradiation of electric fields

⇒ Shield earthing at both ends reduces the irradiation of electromagnetic fields

Type of installation	Distance		
	Without divider or non-metallic divider	**Aluminium divider**	**Steel divider**
Unshielded l.v. supply lines and unshielded telecommunications lines	200 mm	100 mm	50 mm
Unshielded l.v. supply lines and shielded telecommunications lines	50 mm	20 mm	5 mm
Shielded l.v. supply lines and unshielded telecommunications lines	30 mm	10 mm	2 mm
Shielded l.v. supply lines and shielded telecommunications lines	0 mm	0 mm	0 mm

Table 8.2.5.1   Separation of telecommunications and low voltage supply lines (based on EN 50174-2)
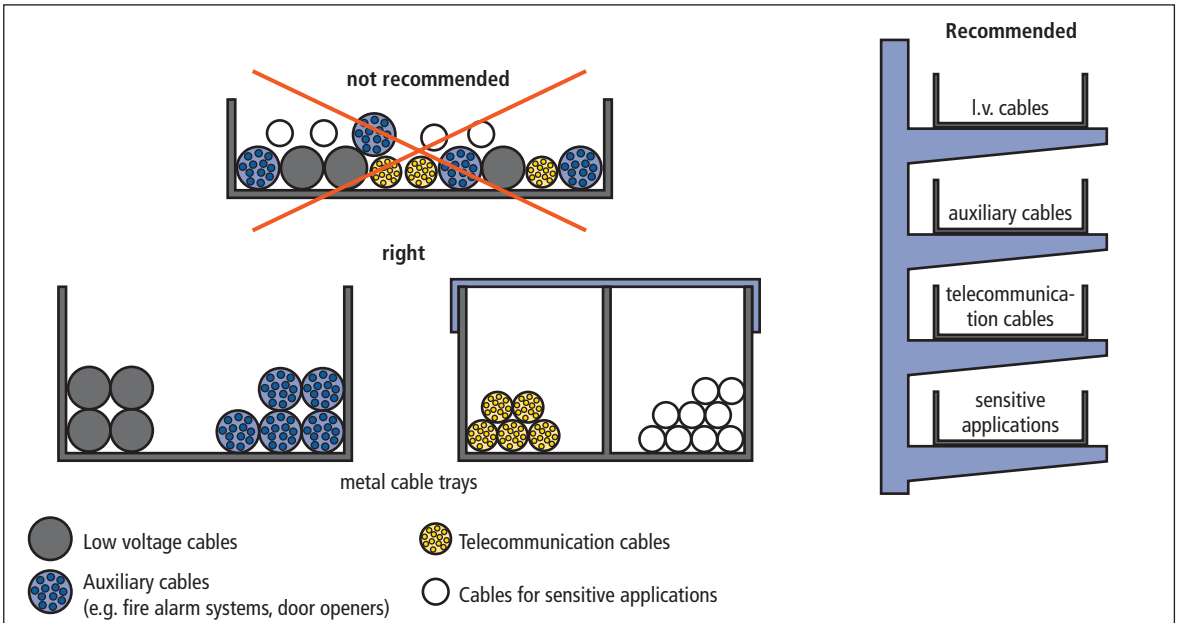
Fig. 8.2.5.5   Separation of cables in cable duct systems

⇒ Conventional shields offer no significant protection against low frequency magnetic fields.

Recommendations:
Shields should run continuously between IT installations, have a low coupling resistance and be conducted around the complete circumference, if possible. The shield must enclose the conductors completely, if possible. Interruptions in the shield and high impedance earth connections and "pig tails" of cables should be avoided.

The extent to which low voltage lines can affect telecommunication lines depends on a multitude of factors. The recommended guide values for the spatial distances to low voltage lines are described in EN 50174-2. For a cable length less than 35 m no distance is generally required. In all other cases, **Table 8.2.5.1** gives the distances applying.

It is recommended to install telecommunication lines in metal ducts which are electrically connected and completely enclosed. The metal cable duct systems should be connected with low impedance to earth as frequently as possible, at least at the beginning and the end (**Figure 8.2.5.5**).

9.   Application proposals
9.1 Surge protection for frequency converters

In principle a frequency converter consists of a rectifier, a d.c. link converter, an inverter and of the control electronics (**Fig. 9.1.1**).

At the input of the inverter the single phase or interlinked, three-phase a.c. voltage is changed into a pulsating d.c. voltage and is pushed into the d.c. link converter that also serves as energy store (buffer).

Capacitors in the d.c. link converter and the LC networks connected to earth in the a.c. line filter, can cause problems with the residual current devices (RCD) connected in series. The reason for this is often wrongly seen in the application of surge arresters.

The problems, however, result from the short-term induction of fault currents by the frequency converter. These are sufficient to activate sensitive earth leakage circuit breakers (RCDs). A surge-proof RCD circuit breaker available for a tripping current $I_{\Delta n} = 30$ mA and a min. discharge capability of 3 kA (8/20 μs) provides a remedy.

By the control electronics, the inverter delivers a clocked output voltage. The higher the clock frequency of the control electronics for the pulse-width-modulation, the more sinusoidal is the output voltage. With each cycle, a peak voltage is created that is superimposed on the curve of the fun-
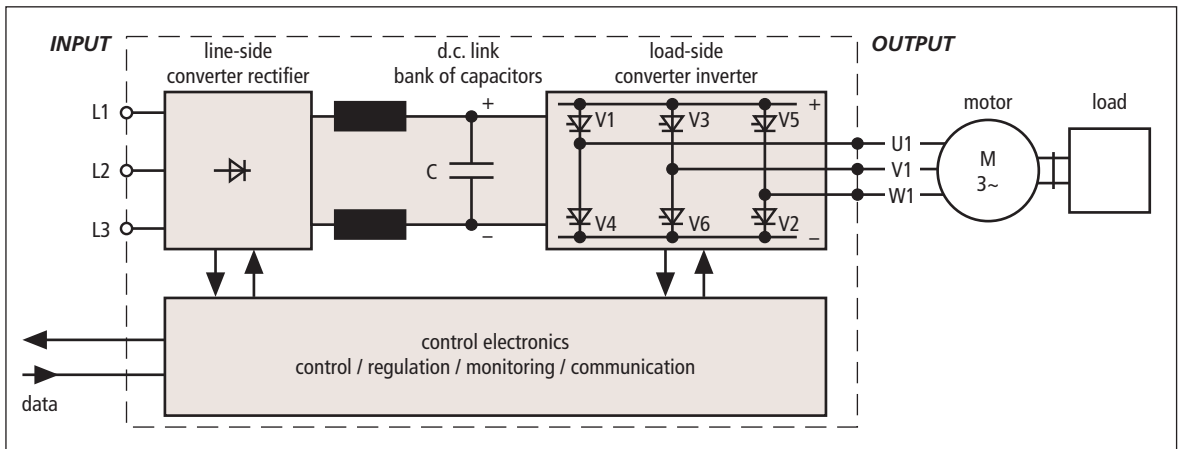
Fig. 9.1.1   Schematic diagram of a frequency converter

No.		Type	Part No.
①		**Constant force spring** SA KRF ...	919 031 - 919 038
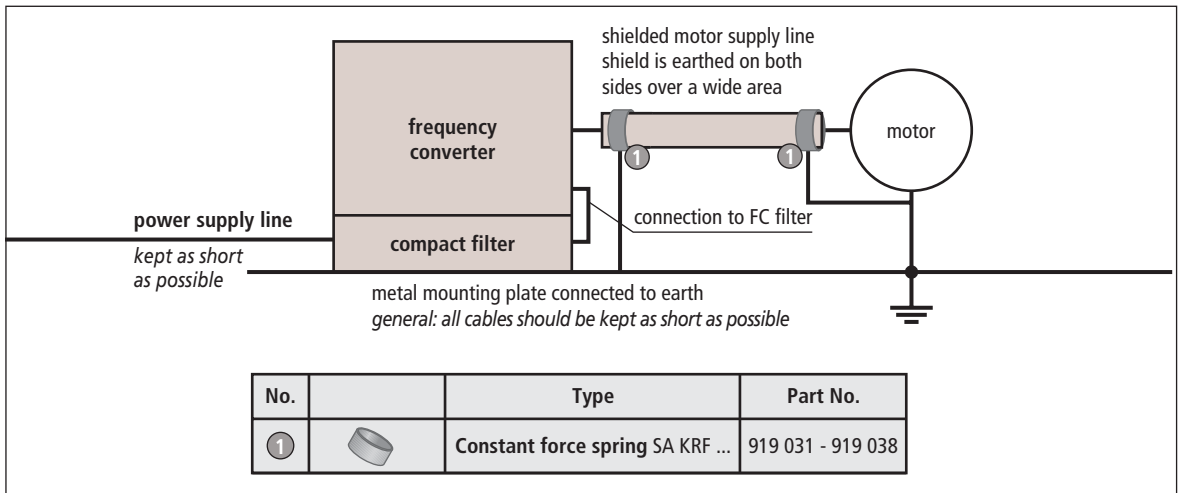
Fig. 9.1.2   EMC conforming shield connection of the motor supply line

damental frequency. This peak voltage reaches values of 1200 V and higher (according to the frequency converter). The better the simulation of the sine curve at the output, the better is the performance and control response of the motor. This means, however, that the voltage peaks appear at the output of the frequency converter more frequently.

For choosing of surge arresters, the maximum continuous operating voltage U_c has to be taken into account. It specifies the maximum permissible

No.		Type	Part No.
①		**DEHNguard S** DG S 275	952 070
②		**DEHNguard S** DG S 600	952 076
③		**BLITZDUCTOR XT** BXT ML4 BE 24 + BXT BAS	920 324 + 920 320
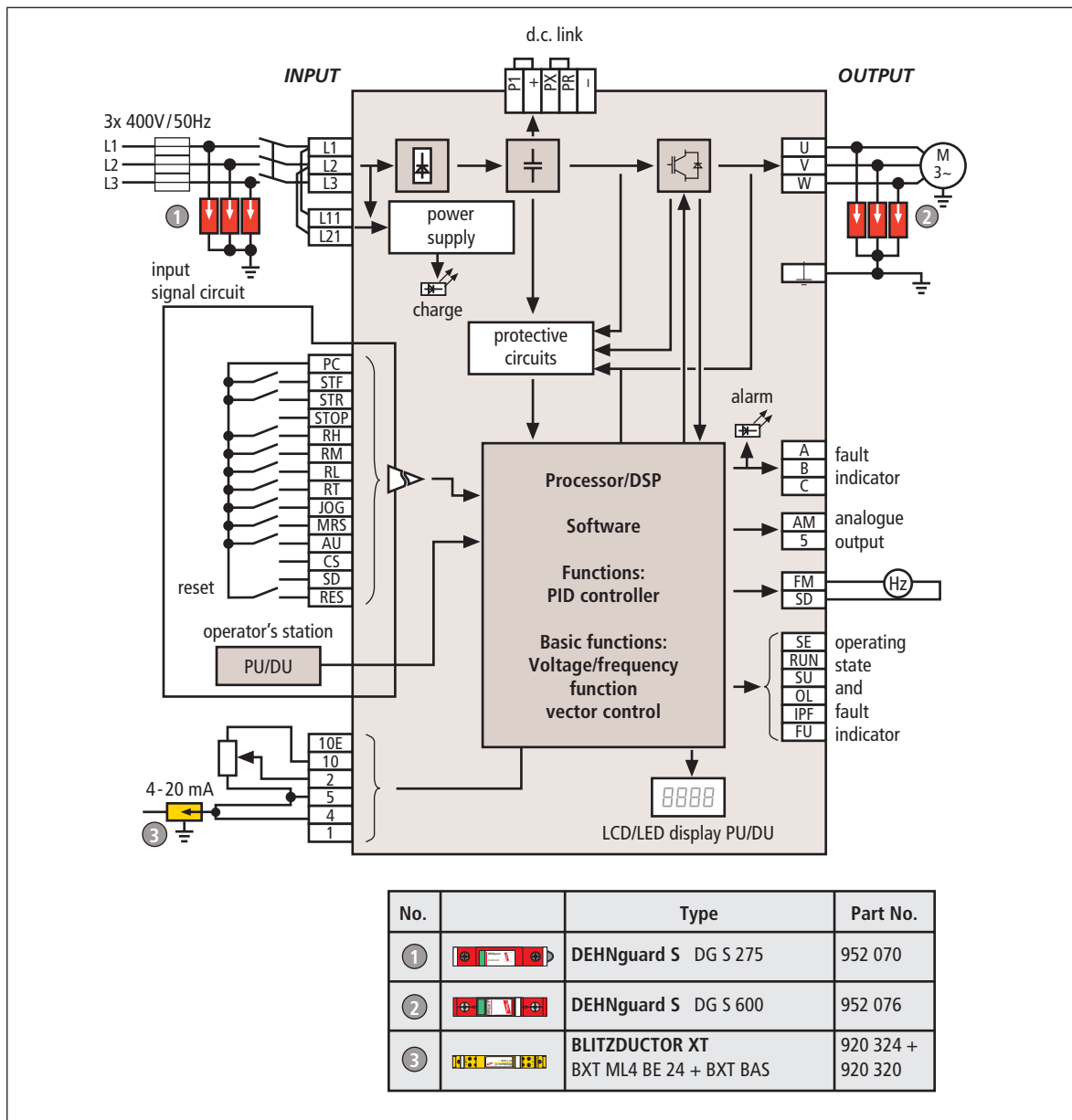
Fig. 9.1.3 Structure of a frequency converter with SPD

operating voltage a surge protective device may be connected to. This means that surge protective devices with a correspondingly higher U_c are used at the output side of the frequency converter. This avoids faster ageing due to gradually heating of the surge protective device under normal operating conditions and the consequential voltage peaks. This heating of the arrester leads to a shorter service life and consequently to a disconnection of the surge protective device from the system to be protected.

The voltage at the output of the frequency converter is variable and adjusted a little bit higher than the nominal voltage at the input. Often it is approx. + 5 % during continuous operation, in order to compensate the voltage drop at the connected line, for example. Otherwise, one can simply say that the maximum voltage at the input of the frequency converter is equal to the maximum voltage at the output of the frequency converter.

The high clock frequency at the output of the frequency converter generates fieldborne interferences and therefore, requires necessarily a shielded cabling so that adjacent systems are not disturbed.

For shielding the motor power supply line, a bilateral shield earthing at the frequency converter and the drive motor has to be ensured. The large-surface contacting of the shield results from the EMC requirements. Advantageous is here the use of constant force springs (**Fig. 9.1.2**). By means of intermeshed earth-termination systems, i.e. the earth-termination system the frequency converters and the drive motor are connected to, potential differences are reduced between the parts of the installation and thus equalising currents via the shield are avoided.

Figure 9.1.3 shows the use of surge protective devices Type DEHNguard on the power supply side and Type BLITZDUCTOR for 0 – 20 mA signals. The protective devices have to be individually adapted according to the interface.

For the integration of the frequency converter into the building automation it is absolutely essential that all evaluation and communication interfaces are connected with surge protective devices in order to avoid system failures.

9.2 Lightning and surge protection for outdoor lighting systems

Outdoor lighting can be installed at the outer walls of buildings as well as on open site. In any case it has to be considered whether the outdoor lighting is located in lightning protection zone LPZ 0_A or in lightning protection zone LPZ 0_B. Outdoor lighting in LPZ 0_A is at risk of direct lightning strikes, impulse currents up to the whole lightning current and of the whole field of the lightning flash. In LPZ 0_B they are protected against direct lightning strikes, however, at risk of impulse currents up to partial lightning currents and the whole field of lightning.

Lamp poles in lightning protection zone LPZ 0_A have to be interconnected underground and they have to be connected with the earth electrodes of the buildings or structures via permissible earthing conductors. The recommended materials, dimensions and cross sections are indicated in Table 7 of IEC 62305-3 (EN 62305-3). **Table 9.2.1** shows an excerpt of it for practical use. The material to be used always has to be selected with regard to probable corrosion.

Measures to reduce the risk of electric shock hazard due to touch and/or step voltage are subject to individual examination.
Analogously to IEC 62305-3 (EN 62305-3) the required measure to reduce the touch voltages is, for example, an asphalt layer of at least 5 cm thickness or 15 cm gravel, 3 m around the lamp pole (**Figure 9.2.1**).

In IEC 62305-3 (EN 62305-3) also the potential control, for example, is mentioned as measure to reduce step voltages. In this case four rings are installed in the distances 1.0 m, 4.0 m, 7.0 m, and 10.0 m, and in the corresponding depths of 0.5 m, 1.0 m, 1.5 m, and 2.0 m around the lamp pole. These rings are interconnected by four connecting leads which are staggered by 90 ° and also with the lamp pole (**Figure 9.2.2**).

Material	Form	Earthing conductor	Notes
Copper	cable round strip	50 mm² 50 mm² 50 mm²	min. wire thickness 1.7 mm Ø 8 mm min. thickness 2 mm
Steel	round galvanised 50 μm strip galvanised 70 μm	Ø 10 mm 90 mm²	- min. thickness 3 mm
Stainless Steel	round strip	Ø 10 mm 100 mm²	- min. thickness 2 mm

Table 9.2.1   Min. dimensions of earthing conductors for interconnecting lamp poles in LPZ 0_A and for connecting to the earth-termination system of the building or structure

asphalt layer ≥ 5 cm

3 m   3 m
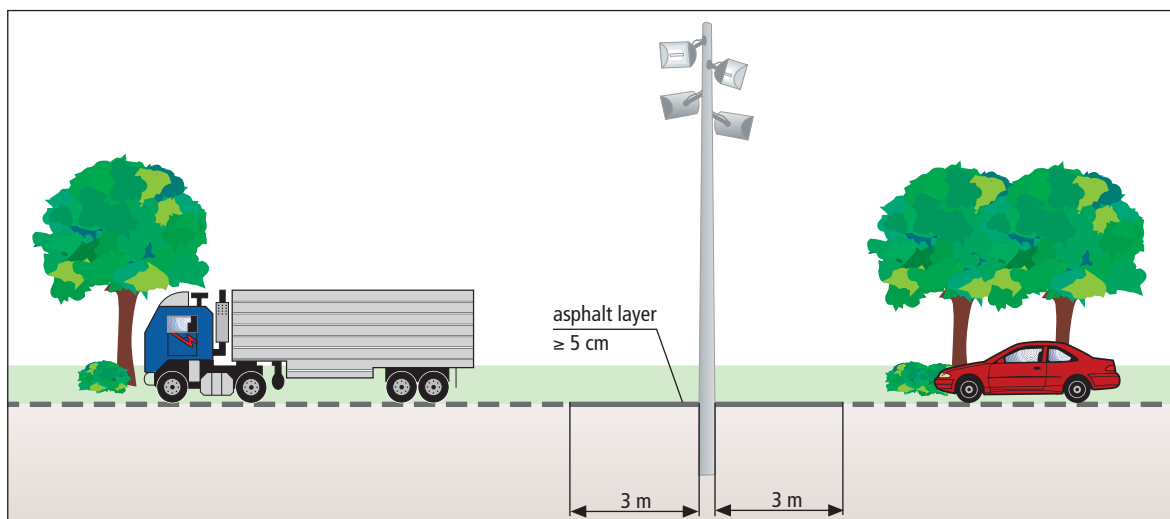
Fig. 9.2.1   Insulation of the place around the lamp pole to reduce the risk of touch voltage in case of lightning strike

The following types of lightning current and surge protective devices are installed at the boundary of the lightning protection zone LPZ 0_A – LPZ 1 or LPZ 0_B – LPZ 1.

All outdoor lightings in lightning protection zone LPZ 0_A shall be protected by lightning current arresters Type 1 to be installed at the entrance to the building or structure. This lightning protection zone to be determined, requires "to approach" the corresponding rolling sphere from all possible directions to the outdoor lighting. If it is touched by the rolling sphere, the outdoor lighting is in lightning protection zone LPZ 0_A (**Figure 9.2.3** and **Figure 9.2.4**).

Before installing lightning current arresters Type 1, it has to be checked, whether the circuits of the outdoor lighting are already protected by an energy coordinated SPD Type 2 in the current distribution board, if not, combined lightning current and surge arresters are recommended to be installed at the lightning protection zone boundary.
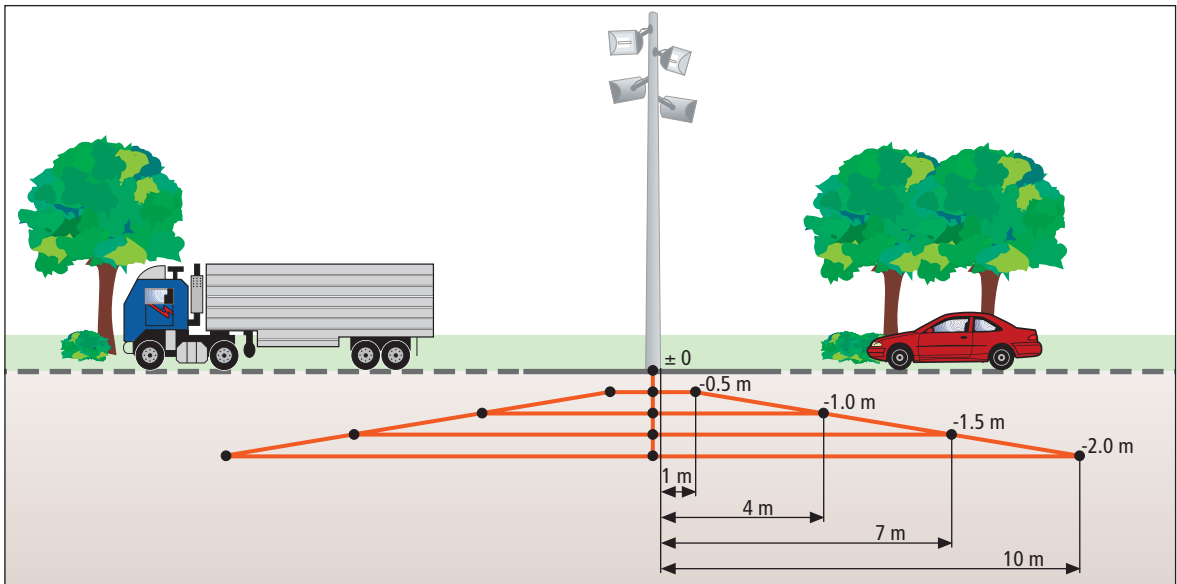
Fig. 9.2.2   Potential control to reduce the arising step voltage at lightning strikes into a lamp pole

Lightning current arresters

TN system
DB 1 255 H (2x),   Part No. 900 222

TT system
DB 1 255 H,   Part No. 900 222
DGP BN 255,   Part No. 900 132

Combined lightning current and surge arresters

TN system
DV M TN 255,   Part No. 951 200
TT system
DV M TT 2P 255,   Part No. 951 110
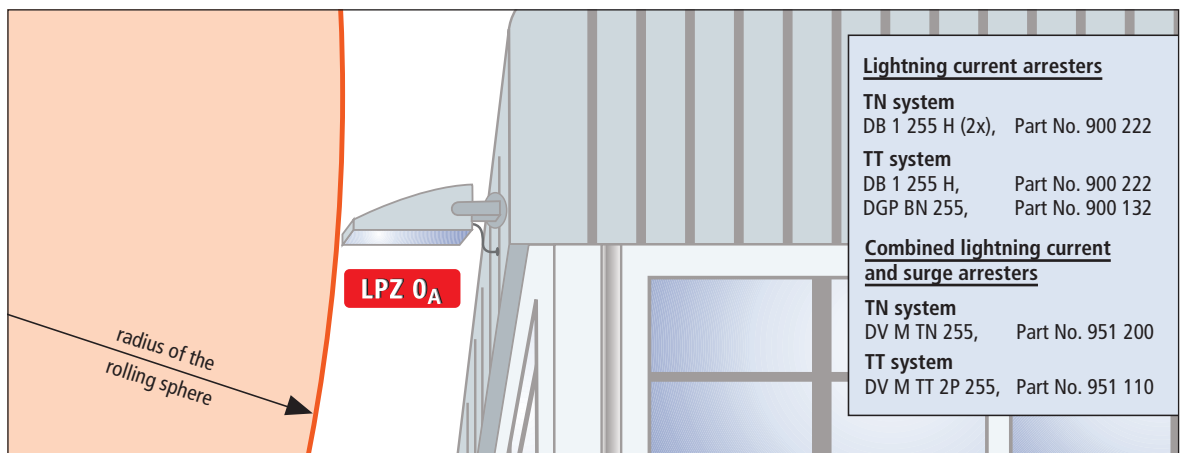
Fig. 9.2.3   230 V wall lamp as outdoor lighting in lightning protection zone LPZ 0_A

Lightning current arresters	
TNC system	
DB 3 255 H,	Part No. 900 120
TNS system	
DB 3 255 H,	Part No. 900 120
DB 1 255 H,	Part No. 900 222
TT system	
DB 3 255 H,	Part No. 900 120
DK 35,	Part No. 900 699
DGP BN 255,	Part No. 900 132
Combined lightning current and surge arresters	
TNC system	
DV M TNC 255,	Part No. 951 300
TNS system	
DV M TNS 255,	Part No. 951 400
TT system	
DV M TT 255,	Part No. 951 310
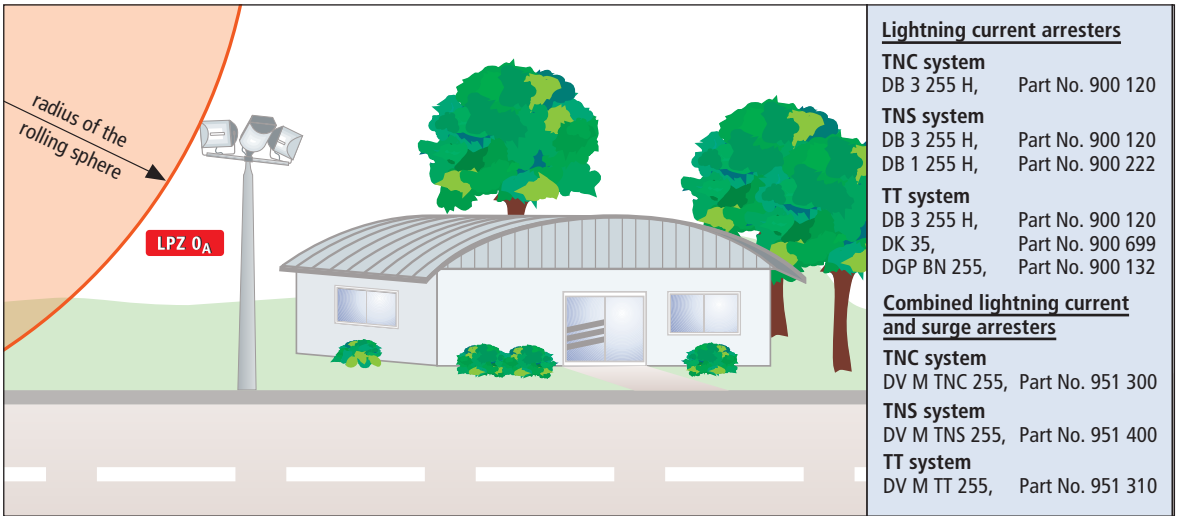
Fig. 9.2.4   Lamp pole with 3 x 230/400 V outdoor lighting in lightning protection zone LPZ 0_A

TN system	
DG M TN 275,	Part No. 952 200
TT system	
DG M TT 2P 275,	Part No. 952 110
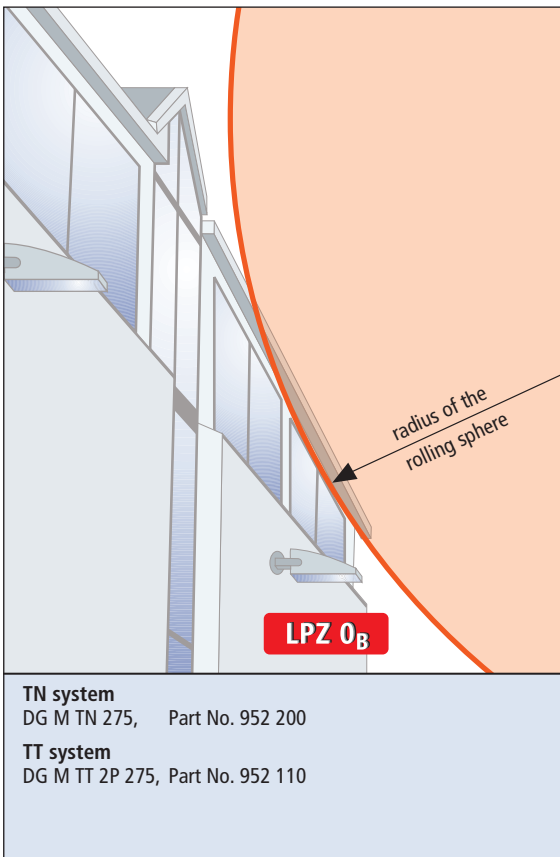
Fig. 9.2.5   230 V wall lamp as outdoor lighting in lightning protection zone LPZ 0_B

TNC system	
DG M TNC 275,	Part No. 952 300
TNS system	
DG M TNS 275,	Part No. 952 400
TT system	
DG M TT 275,	Part No. 952 310
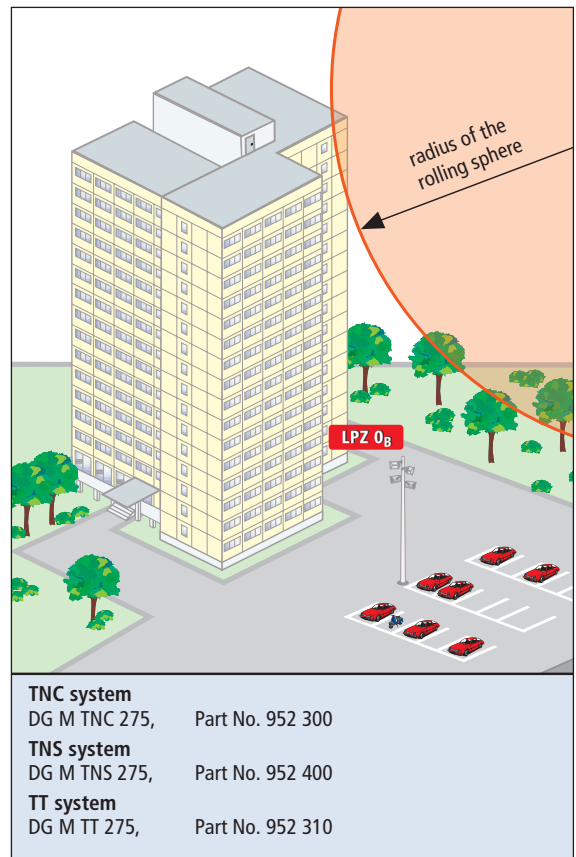
Fig. 9.2.6   Lamp pole with 3 x 230/400 V outdoor lighting in lightning protection zone LPZ 0_B

All outdoor lightings in lightning protection zone LPZ 0_B shall be protected by surge protective devices Type 2, to be installed at the entrance to the building or structure. This lightning protection zone to be determined, requires "to approach" the corresponding rolling sphere from all possible directions to the outdoor lighting, which in this case, may not be touched by the rolling sphere (**Figures 9.2.5** and **9.2.6**).

9.3 Lightning and surge protection for biogas plants

In modern biogas plants biodegradable organic substrates such as liquid manure, dung, grass, straw, biowaste, residues of sugar, wine, beer production, leftovers, and fats, are fermented in an air-tight container (fermenter/fermentation tank). In this atmosphere without oxygen, bacteria produce biogas of the fermentable, organic biomass components. This biogas is used to generate heat and current.

Figure 9.3.1 shows the system layout of a typical biogas plant usually consisting of a slurry store (collecting basin), a sanitation system, one or more heatable fermenters, a repository tank, probably a refermenter, a gasholder and a gas conditioner. Grain, for example, is preserved in the ligavator (liquids tank) shown in **Figure 9.3.1**. The gas motor with heat exchanger and connected generator is a combined heat and power unit (CHP). Depending on the energy content of biogas, the CHP generates electrical current with an efficiency degree of approx. 30 % and heat with an efficiency degree of approx. 60 %. Partly the heat is used for the fermenter while the surplus of it, for example, is used

for the heating of residential and agricultural buildings.

Necessity of a lightning protection system
Until January 2003, the ElexV "Verordnung über elektrische Anlagen in explosionsgefährdeten Bereichen" (Directive for electrical installations in explosion hazard areas) had to be applied and is now replaced by the German Health and Safety at Work Regulations (BetrSichV). These regulations are applicable for the provision of work equipment by employers as well as for the use of work equipment by employees (compare § 1 Subclause 1 BetrSichV). It is also applied for systems which require monitoring in the sense of § 2 Subclause 2a of the Device Safety Act (German: Gerätesicherheitsgesetz). According to the Device Safety Act, systems with hazard of explosion are rated to be monitored. As, for example, the vicinity of gasholders and gas tanks of a biogas plant is at risk of an explosive gas/air mixture, biogas plants are categorised as explosion endangered systems. According to the German Health and Safety at Work Regulations (BetrSichV § 12) biogas plants
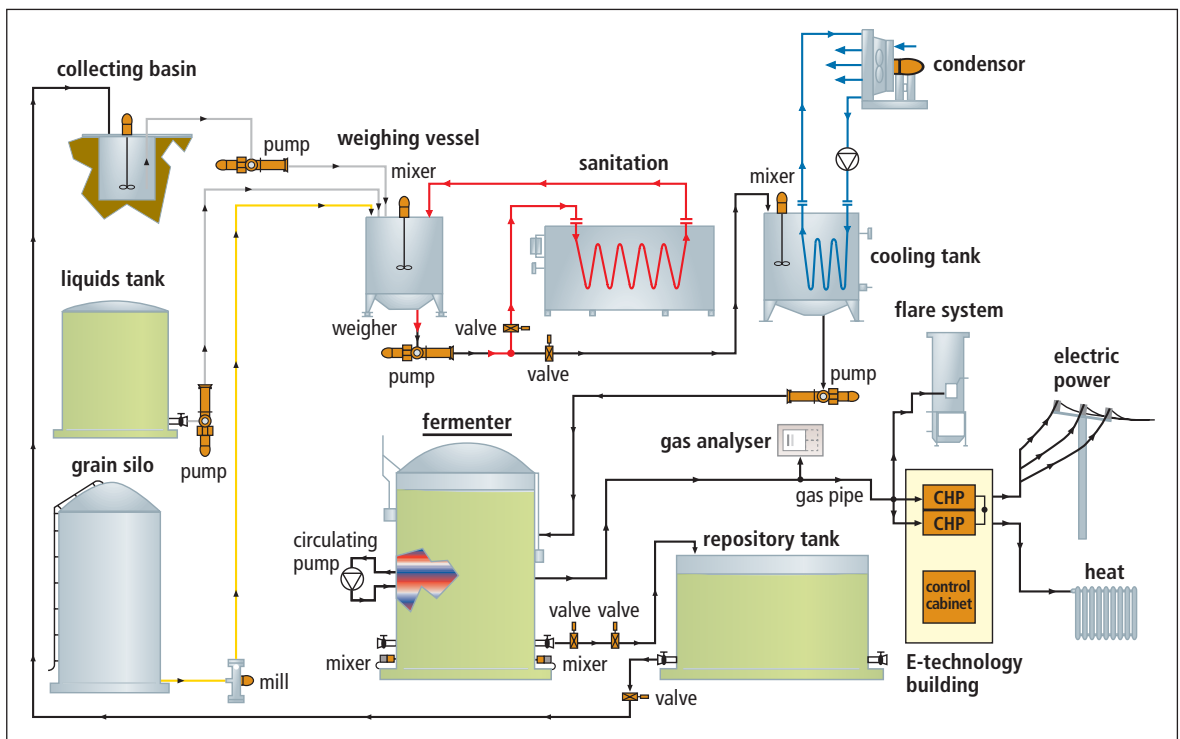
Fig. 9.3.1   System layout of a biogas plant

have to be mounted, installed, and operated according to the state of the art. Hence also the lightning protection systems have to meet the requirements of the BetrSichV.

In the German safety regulations for agricultural biogas plants BGR 104 Section E 2 it is pointed out that in areas with hazard of explosion "measures to avoid the ignition of hazardous explosive atmosphere" have to be carried out.

According to EN 1127-1 Subclause 5.3.1 there are thirteen different sources of ignition. In subclause 5.3.8 of EN 1127-1 and in the German safety regulations BGR 104 lightning is defined as source of ignition: "Lightning striking potentially explosive atmosphere will always cause ignition. Moreover, there is also a possibility of ignition due to the high temperature reached by lightning conductors. Large currents flow from where the lightning strikes and these currents can produce sparks in the vicinity of the point of impact. Even in the absence of lightning strikes, thunderstorms can cause high induced voltages in equipment, protective systems and components."
The rules of explosion protection require to take appropriate protection measures against lightning hazard.
The BetrSichV clearly obligates the employer to make a comprehensive determination and assessment of the risk factors for operation facilities with hazard of explosion. According to § 5 of the BetrSichV the employer have to subdivide explosion endangered areas into zones taking into regard the results of the risk assessment. The zones of protection against explosion have to be defined in a document of protection against explosion.
"Further information for lightning protection systems for buildings and installations with explosive areas" is given in the lightning protection standard IEC 62305-3 Annex D which requires a lightning protection system class II for such systems.
In special cases the requirement of additional measures, however, has to be checked according to IEC 62305-2. A risk analysis can be made by means of the calculation method specified in IEC 62305-2. For this risk analysis (acc. to IEC 62305-2) the software DEHNsupport can be used. So it is possible to determine the risk of damage for a building or structure and the persons and equipment therein from direct and indirect lightning strikes. The risk of damage being higher than an tolerable risk, it is

necessary to minimize the damage risk due to lightning strike by lightning protection measures so that the tolerable risk is no longer exceeded.

The German national Supplement 2 of DIN EN 62305-3 gives additional information for special buildings or structures and a closer specification of the requirements for the lightning protection of biogas plants. Thus biogas plants shall be protected by isolated air-termination and down conductors systems if the risk of ignition by sparks at joinings and connecting points can not be excluded.

External lightning protection
The fermenter is the core of every biogas plant. There is a wide spectrum of fermenters and fermenting systems on the market with different designs. The required lightning protection system must always be adapted to the structural conditions of the plant. Different solutions can be found for one protective aim. As already mentioned, a lightning protection system class II meets the general requirements for systems with explosive areas and hence those for biogas plants.
The lightning protection system comprises an external and an internal lightning protection.
The functions of the external lightning protection are to intercept all lightning strikes, including side strikes into the building or structure, to conduct the lightning current from the striking point to the earth and to distribute it in the earth without having any damage at the building or structure to be protected due to the thermal, mechanical, or electric effects.

Fermenter with film dome
In biogas plants often fermenters with film dome are used which can be damaged by lightning strike. The melting and spraying effect at the striking point causes the risk of fire and explosion. The lightning protection measures have to be designed in a way that there will be no direct lightning strike into the film dome of the fermenter (**Figure 9.3.2**).
In the safety regulations for agricultural biogas plants, the Ex zone 2 is determined to be in the area of 3 m around the film dome of the fermenter. In Ex zone 2 explosive atmosphere is unusual and only temporary. This means, in zone 2 explosive atmosphere has to be taken into consideration only at seldom, unforeseen operational conditions (in case of failure and service/mainte-
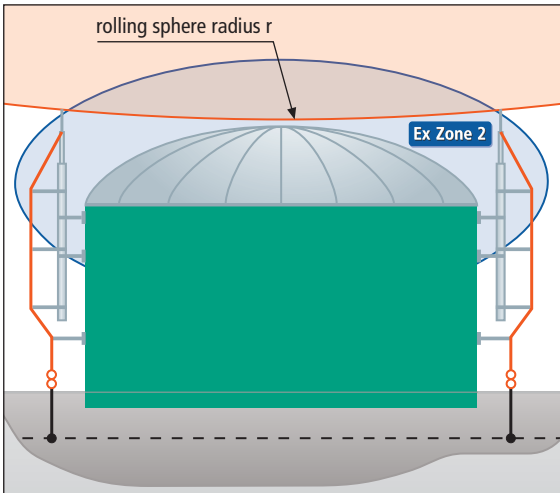
Fig. 9.3.2   Use of the DEHNiso-Combi system to protect a fermenter with film dome

DEHNiso-Combi Set (Part No. 105 455)
1-part unit, total length 5700 mm consisting of:
1x air-termination tip Al, L = 1000 mm (Part No. 105 071)
1x insulating pipe, L = 4700 mm (Part No. 105 301)
3x wall mounting bracket StSt (V2A) (Part No. 105 340)
2x distance holder GRP/Al, L = 1030 mm (Part No. 106 331)

Table 9.3.1   DEHNiso-Combi Set

nance work). According to IEC 62305-3 therefore the positioning of air-termination systems in Ex zone 2 is permitted.

The rolling sphere method is used to determine height and number of air-termination installations. The sag of the rolling sphere is decisive for the dimensioning of the air-termination system, which can be determined according to IEC 62305-3. The corresponding class II for systems with explosive areas requires a rolling sphere radius of 30 m (**Figure 9.3.2**).

Depending on the gas volume, the inner membrane in the gasholder of the fermenter is pressed more or less tightly against the metal inner wall of the fermenter. An isolated down conductor system

Fig. 9.3.3   Protection of a fermenter with film dome by steel telescopic lightning protection masts

has to be installed to avoid uncontrolled flashover from the down conductor to the metal wall of the fermenter. The isolated leading of the down conductors on distance holders out of GRP (glass-fibre reinforced plastic) ensures an electric isolation of the lightning protection system from conductive parts of the fermenter. The length of the distance holders being a function of the separation distance determined according to IEC 62305-3.
The DEHNiso-Combi Set according to **Table 9.3.1** is used in a case as illustrated in **Figure 9.3.2**.

Another possibility to avoid the film dome of the fermenter being at hazard of direct lightning strike is the use of steel telescopic lightning protection masts (**Figure 9.3.3**). These masts are installed in natural soil or in a concrete foundation. Free heights of 21 m above ground level can be achieved, even higher, if custom-made ones are used. The standard lengths of the steel telescopic lightning protection masts are supplied in sections of 3.5 m, offering enormous advantages for transportation. Further information about the use of steel telescopic lightning protection masts can be found in installation instructions No. 1574.

A third possibility to protect the fermenter with film dome against direct lightning strike is to use
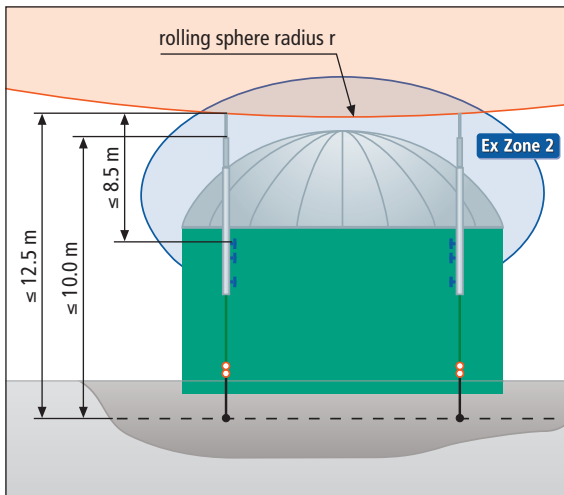
Fig. 9.3.4 Fermenter protected with air-termination masts isolated by 1 HVI conductor
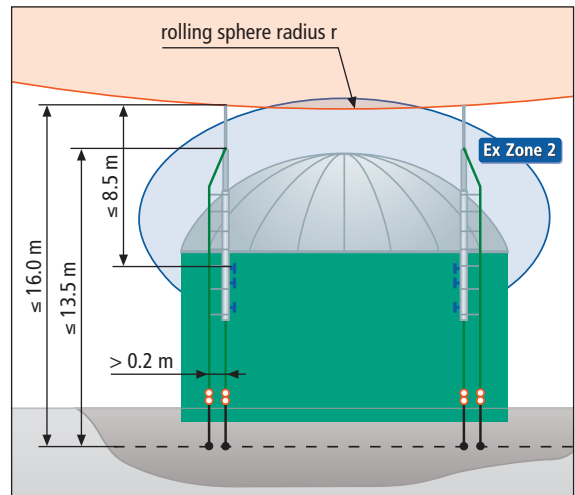
Fig. 9.3.5 Fermenter protected with air-termination masts isolated by 2 HVI conductors

the DEHNconductor system. The DEHNconductor system is a programme comprising the HVI conductor and the specially adapted connecting and fixing elements. The HVI conductor is a high voltage-resistant, insulating down conductor with a special outer coating. It is typically used as isolated down conductor in lightning protection to handle the separation distance according to IEC 62305-3. The separation distance has to be calculated according to IEC 62305-3. Subsequently it has to be examined if this calculated separation distance can be realised with the equivalent separation distance of the HVI conductor. The DEHNconductor system offers two variants of solution:

Variant 1: Air-termination masts with one HVI conductor (**Figure 9.3.4**). The maximum total length of the air-termination system from the equipotential bonding level (earth-termination system) to the air-termination tip here is 12.5 m, the maximum free length above the top edge of the fermenter must not exceed 8.5 m (for mechanical reasons).

Variant 2: Air-termination masts with two HVI conductors (**Figure 9.3.5**). The maximum total length of the air-termination system from the equipotential bonding level (earth-termination system) to the air-termination tip here is 16 m, the maximum free length above the top edge of the fermenter also 8.5 m.

Note: The distance between the two HVI conductors, to be installed in parallel, has to be more than 20 cm.

Further information about the DEHNconductor system can be found in the following installation instructions under www.dehn.de:

⇒ Installation instructions 1565: Air-termination mast with inner HVI conductor for biogas plants

⇒ Installation instructions 1501: HVI conductor in the Ex area

Designing service
Isolated air-termination systems being rather complex and extensive systems. DEHN + SÖHNE would be pleased to assist you in designing of isolated air-termination systems on the basis of the DEHNconductor system, DEHNiso-Combi system or steel telescopic lightning protection masts. This designing service offered against payment comprises

⇒ the compiling of drawings of the lightning protection (general layout drawings),

⇒ detail drawings for an isolated air-termination system (partly as explosion drawings),

⇒ comprehensive parts list of the necessary components for the isolated air-termination system,

⇒ a quotation based on this parts list.

If you are interested please contact your local consultant or the head office in Neumarkt (www.dehn.de).

Fermenters out of sheet metal
Fermenters out of sheet metal usually have a wall thickness between 0.7 and 1.2 mm. The individual plates being screwed together (**Figure 9.3.6**)

If sheet metal shall be used as natural air-termination system Table 3 of IEC 62305-3 is applicable for the thickness. In case the required values of plate thickness are not complied with, a lightning strike might cause through-melting or intolerable heating-up at the point of strike with risk of fire and explosion. These fermenters then must be protected by supplementary air-termination systems to avoid melting-out at the point of strike. In this case an isolated lightning protection system will be installed. Its location be to determined by the rolling sphere method. The down-conductor system has to be installed on distance holders according to the determined separation distance at the metal plates (**Figure 9.3.7**).

Steel tank
Figure 9.3.8 shows completely welded biogas tank with a sheet steel enclosure of at least 4 mm thickness. The requirements of Table 3 of IEC 62305-3 with regard to the material are met. For the lightning protection system hence the requirement according to IEC 62305-3 Annex D "Additional information for LPS in case of structures with risk of explosion" is applicable. The Ex zones of ex-

hausting vents being in the protected area of metal enclosure parts capable of carrying lightning currents, supplementary air-termination systems are not necessary. Otherwise supplementary air-termination systems have to be installed to protect the exhausting vents from direct strike.

Fig. 9.3.6 Fermenter out of screwed sheet metal

Fig. 9.3.7 Isolated air-termination system to protect a fermenter out of sheet metal (Ref.: Büro für Technik, Hösbach)
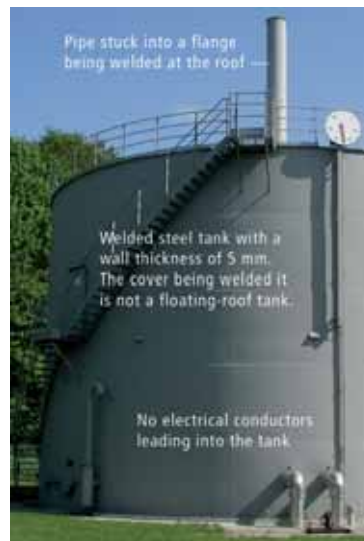
Fig. 9.3.8 Welded steel tank (Ref.: Eisenbau Heilbronn GmbH)
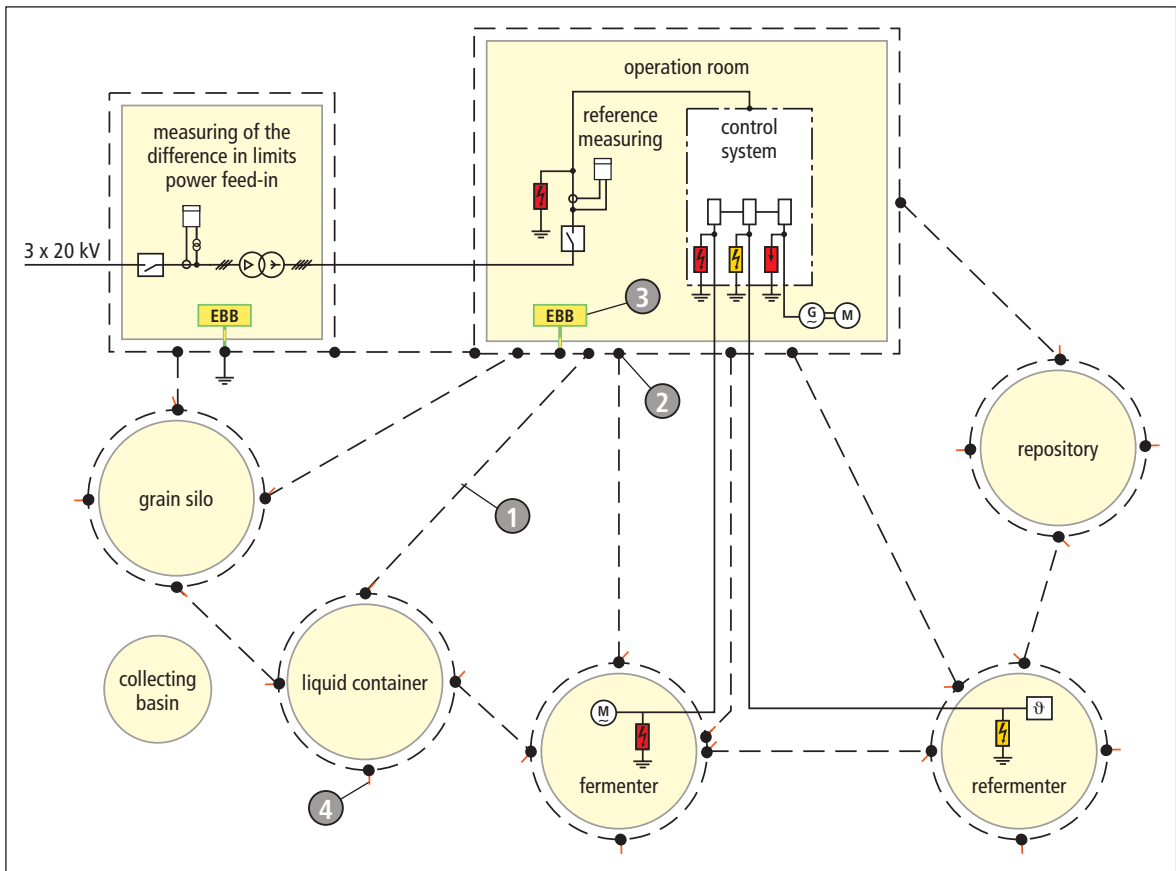
Fig. 9.3.9   Intermeshed earth-termination system for a biogas plant

Earthing concept

Connecting the individual earth-termination systems with an overall earth-termination system prevents the arising of high potential differences (**Figure 9.3.9** and **Table 9.3.2**). Intermeshing the individual building and system earth-termination systems, the mesh sizes varying between 20 m x 20 m up to 40 m x 40 m, is an economically and technically reasonable method. Potential differences between the various parts of the installation are clearly reduced, by intermeshing all earth-termination systems. Also the voltage loading of the cables going outside of the building will be lower in case of lightning effects.

Power feed-in

By the biogas produced, usually pilot injection gas engines generate current and heat. In this context such engines are called combined heat and power units (CHP). These CHPs are installed in a separate operation building, with the switching and control cabinets in the same or a separate room. The electric power generated

No.		Part No.
1	Strip steel StSt (V4A) 30 mm x 3.5 mm	860 335
	Alternative: Round-bar StSt (V4A), Ø 10 mm	860 010
2	Cross unit StSt (V4A)	319 209
	Alternative: SV Terminal StSt (V4A)	308 229
	Note: Anticorrosive band	556 125
3	Equipotential bonding bar StSt	472 209
	Alternative: Earthing busbar	472 139
4	Terminal lugs directional strip steel StSt (V4A)	860 215
	Alternative: Terminal lugs directional round-bar StSt (V4A)	860 115

Table 9.3.2   Material recommendation for earthing and equipotential bonding

Fig. 9.3.10   Sectional view of an overall circuit diagram of a biogas plant

tems shall be incorporated into the equipotential bonding so as to cause as little impedance as possible and that all live systems shall be connected indirectly via surge protective devices Type 1. The lightning equipotential bonding should be performed preferably near the entrance of the structure in order to prevent a penetration of partial lightning currents into the building. The 230/400 a.c. power input of the low-voltage main distribution of the consumer system (**Figure 9.3.10**) shall be protected by surge protective devices SPDs Type 1. Such a surge protective device SPD Type 1 on RADAX Flow spark gap basis for power supply systems is DEHNbloc. This lightning current arrester has a discharge capability up to 50 kA (10/350 µs) each pole. By the patented RADAX Flow principle the amplitude of system short-circuit currents up to 50 kA_{rms} is reduced to approx. 500 A and extinguished after approx. 5 ms. Hence a disconnection selectivity of the surge protective device is possible also in case of too weak system fuses. An interruption of supply by tripping of the main fuse thus is avoided. Surge protective devices Type 2, for example DG TNS H230 400 LI, will be installed in downstream subdistributions (**Table 9.3.3**). This surge protective device has a three-stage visual service life indication with remote signalling link informing any time about the function standby of surge protection.

The DEHNventil, a multipole modular combined lightning current and surge arrester with high follow current limitation is installed in the CHP distribution (**Figure 9.3.10**). This combined lightning current and surge arrester is wired ready for connection, comprising a base part and plug-in protective modules. The DEHNventil ensures utmost system availability and a disconnection selectivity to 20 A gl/gG fuses up to 50 kA_{rms} short-circuit current.

by the CHP is feed into the public power supply system (**see Figure 9.3.10**).

An essential part of a lightning protection system is the lightning equipotential bonding to be carried out for all conductive systems entering the building or structure from outside. Lightning equipotential bonding requires that all metal sys-

No.	Protection for:	SPDs	Part No.	Note
Lightning current arrester Type 1				
1	TN-C system	3 x DB 1 255 H	900 222	1-pole lightning current arrester with high follow current limiting
	TN-S system	4 x DB 1 255 H	900 222	
	TT system	3 x DB 1 255 H + 1 x DGP BN 255	900 222 + 900 132	
Alternative				
1	TN-C system	3 x DBM 1 255 S	900 220	Coordinated lightning current arrester with integrated backup fuse for industrial busbar systems
	TN-S system	4 x DBM 1 255 S	900 220	
	TT system	3 x DBM 1 255 S + 1 x DGPM 1 255 S	900 220 + 900 050	
Surge arrester Type 2				
2	TN-C system	DG TNC H230 400 LI	950 160	Multi-pole surge arrester with SPD control „Pro-Active-Thermo-Control" and 3-stage visual service life indicator
	TN-S system	DG TNS H230 400 LI	950 170	
	TT system	DG TT H230 400 LI	950 150	
Combined lightning current and surge arrester				
3	TN-C system	1 x DV M TNC 255	951 300	Modular combined lightning current and surge arrester with high follow current limiting and a protection level ≤ 1.5 kV
	TN-S system	1 x DV M TNS 255	951 400	
	TT system	1 x DV M TT 255	951 310	

Table 9.3.3   Surge protection for the power supply

At little distances between the DEHNventil and the consumers (≤ 5 m) also the terminal equipment is protected.

Remote monitoring

By the remote monitoring system the performance data of the biogas plant are always available. The system specific measured data can be directly read at the acquisition unit. The data acquisition unit has RS 232 or RS 485 interfaces to connect a PC and/or modems for remote enquiry and maintenance. The remote monitoring, for example per modem, allows the service staff to log on an existing system and to provide direct assistance to the operator in case of failure. The modem is connected to the network termination unit (NTBA) of an ISDN basic access. The forwarding of the measured data via the telecommunication network per ISDN modem must be provided as well, in order to provide a continuous control and optimisation of the performance of the installation. For this purpose

the U_{k0} interface upstream of the NTBA which the ISDN modem is connected to, is protected by a surge protective adapter NT PRO (**Figure 9.3.11**). This adapter ensures additional protection of the 230 V power supply of the NTBA. The recommended protection of telecommunication terminal devices and telecommunication system with RJ socket outlet and plug is the surge arrester Type BLITZDUCTOR VT ISDN (**Table 9.3.4**).

Figure 9.3.11 shows the protection of a surveillance camera. The shielded surge arrester UKGF BNC protects the coaxial cable of the video transmission system (**Table 9.3.4**). More about the protection of video surveillance systems is provided in the protection proposal "Surge protection for video surveillance systems" in Chapter 9.

Process control

One of the most important components of operating a biogas plant is the process control. All pumps
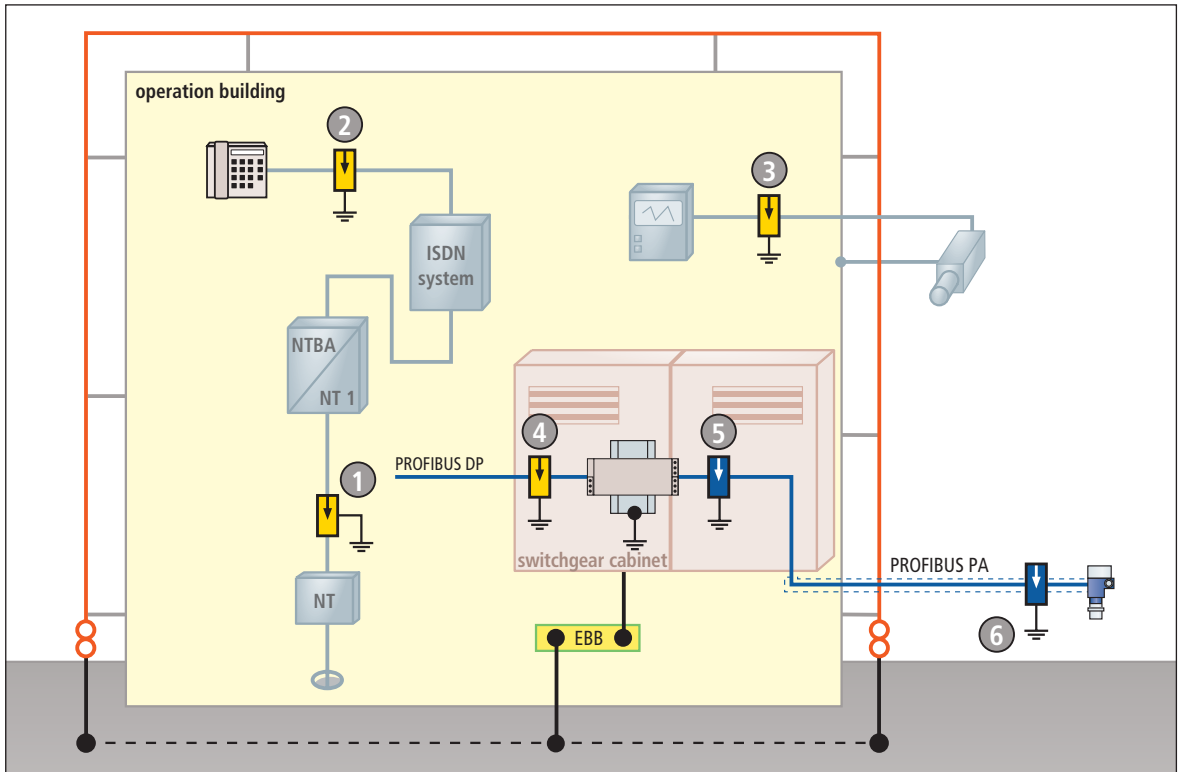
Fig. 9.3.11   Surge protection for information technology systems

No.	Protection for...	SPDs	Part No.
1	Power and data input of an NTBA	NT PRO	909 958
2	Telcommunications terminal devices and telephone system with RJ-plug-in connector	BLITZDUCTOR BVT ISDN	918 410
3	Coaxial line (frame transfer)	UGKF BNC	929 010

Table 9.3.4   Surge protection for information technology systems

No.	Protection for...	BLITZDUCTOR XT Type	Part No.
	4 – 20 mA	BXT ML4 BE 24 + BXT BAS	920 324 + 920 300
	0 – 10 V	BXT ML4 BE 12 + BXT BAS	920 322 + 920 300
4	Profibus DP/FMS	BXT ML4 BD HF 5 + BXT BAS	920 371 + 920 300
	Temperature measuring PT 100, PT 1000, Ni 1000	BXT ML4 BE 5 + BXT BAS	920 320 + 920 300
5	Profibus PA; Ex (i)	BXT ML4 BD EX 24 + BXT BAS EX	920 381 + 920 301

Table 9.3.5   Surge arresters for the measuring and control technology

No.	DEHNpipe Type	Application/Approval	Thread	Part No.
6	DPI MD EX 24 M 2	4 – 20 mA, Profibus PA, Fieldbus Foundadtion; Ex (i)	M20 x 1,5; Internal / External thread	929 960

Table 9.3.6   Surge arresters for field devices

Fig. 9.3.12   Combined lightning current and surge arrester modules with LifeCheck

Fig. 9.3.13   Surge arrester DEHNpipe for outdoor areas for screwing into 2-wire process field devices

and agitators shall be operated centrally, process data such as gas volume and gas quality shall be recorded, temperature and all input materials shall be acquired, all data shall be visualised and documented.

A failure of the process control due to surges results in procedural disturbances and interruptions of the biogas generation. These processes being very complex anyway, unscheduled placing out of operation can lead to additional difficulties, and the period of standstill might be extended to several weeks.

The control unit is installed in a control cabinet. In addition to digital inputs and outputs, T 1000 signals, 20 mA signals are evaluated. To ensure an undisturbed and continuous transmission of the measured data to the control unit in the control cabinet, the control and signal lines entering the building, for example from frequency inverters and actuators have to be protected as close as possible to the point where they enter the building by lightning current arresters, Type BLITZDUCTOR XT (**Figure 9.3.12**).

A non-contact and quick arrester check, called LifeCheck, is integrated in this surge protective device. An extreme thermal or electrical loading is safely detected and can be read out in a second by the DEHNrecord DRC LC, a hand-held reader with non-contact RFID technology. The protective devices for IT systems are selected according to the maximum operating voltage, the nominal current, the type of signal (d.c., LF, HF) and the signal supply (balanced, unbalanced).

Table 9.3.5 exemplifies protective devices for signal and control lines.

In order to protect 2-wire process field devices such as pressure or fill level sensors, valves, pressure transmitters, flow meters, the installation of the surge arrester DEHNpipe (**Figure 9.3.13, Table 9.3.6**) is recommended. This arrester offers an energy coordinated surge protection for process field devices in the outside area at a minimum need of space. The German safety regulations for agricultural biogas plants BGR 104 and European Standard EN 1127 are applicable for biogas plants, being a system with risk of explosion.

In BGR 104 and EN 1127 lightning is described as source of ignition. If the risk of lightning strike is stipulated, the BGR 104 requires all zones to be protected by suitable lightning protection measures.

The lightning protection standard IEC 62305-3 requires to implement at least a lightning protection system Class II for systems with hazard of explosion. The external lightning protection to be designed in such a way that no partial lightning currents can flow into the explosive area. This target of protection can be achieved by an isolated air-termination system. In order to increase the availability of sensitive electronic equipment supplementary measures as the use of surge protective devices shall be taken.

9.4 Lightning and surge protection retrofitting for sewage plants

Resources of drinking water running short require a more efficient treatment. Therefore, sewage plants play a central role in the circle of drinking water. The necessary high efficiency of sewage plants (**Figure 9.4.1**) requires the optimisation of the operating procedure at a simultaneous reduction of the running operating costs. For this purpose, considerable financial efforts were made for electronic measuring equipment and decentralised electronic control and automation systems in recent years. Compared to conventional technology, however, the new electronic systems provide only a low resistance against transient surges. The structural conditions of the spacious open-air plants with wastewater treatment technology and the spread measuring devices and controls increase additionally the risk of interferences due to lightning discharges or surges. Thus, a failure of the complete process control system or parts of it, is highly probable to expect, if no protective measures are taken. The consequences of such a failure can be far-reaching. They can reach from the costs for the recovery of the system function to the undefinable costs for the removal of ground water contamination. In order to come up to this threat effectively and increase the availability of the systems, external and internal lightning protection must be provided.

Lightning protection zones concept

In order to obtain the best technical and economical protection, the sewage plant control is divided into lightning protection zones (LPZ). Subsequently, a risk analysis is carried out for each LPZ and for the relevant types of damage. For the risk analysis acc. to IEC 62305-2 the software tool DEHNsupport can be used. Lastly, the mutual dependences of the LPZs are examined and the finally required protection measures are defined in order to reach the necessary protection aim in all lightning protection zones. The following areas were assigned lightning protection zone LPZ 1 and lightning protection zone LPZ 2:

⇒ Electronic evaluation system in the control room (LPZ 2)
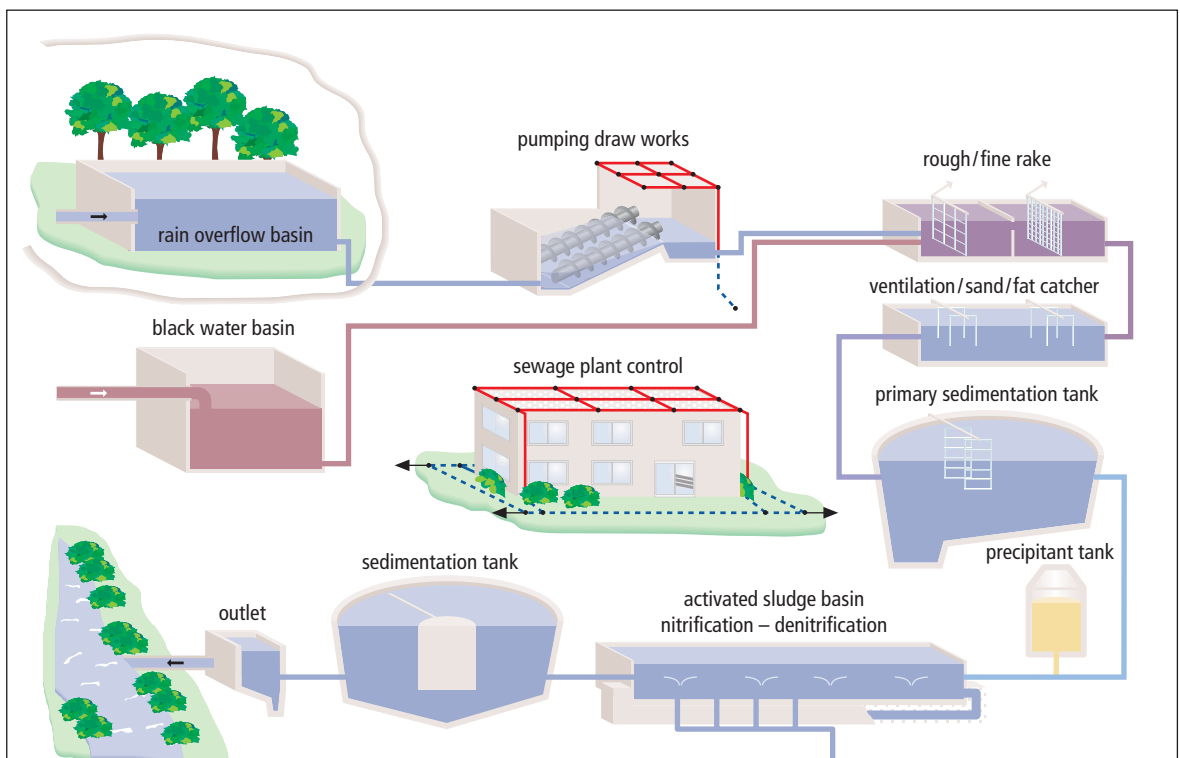
Fig. 9.4.1 Schematic structure of a sewage plant

www.dehn.de
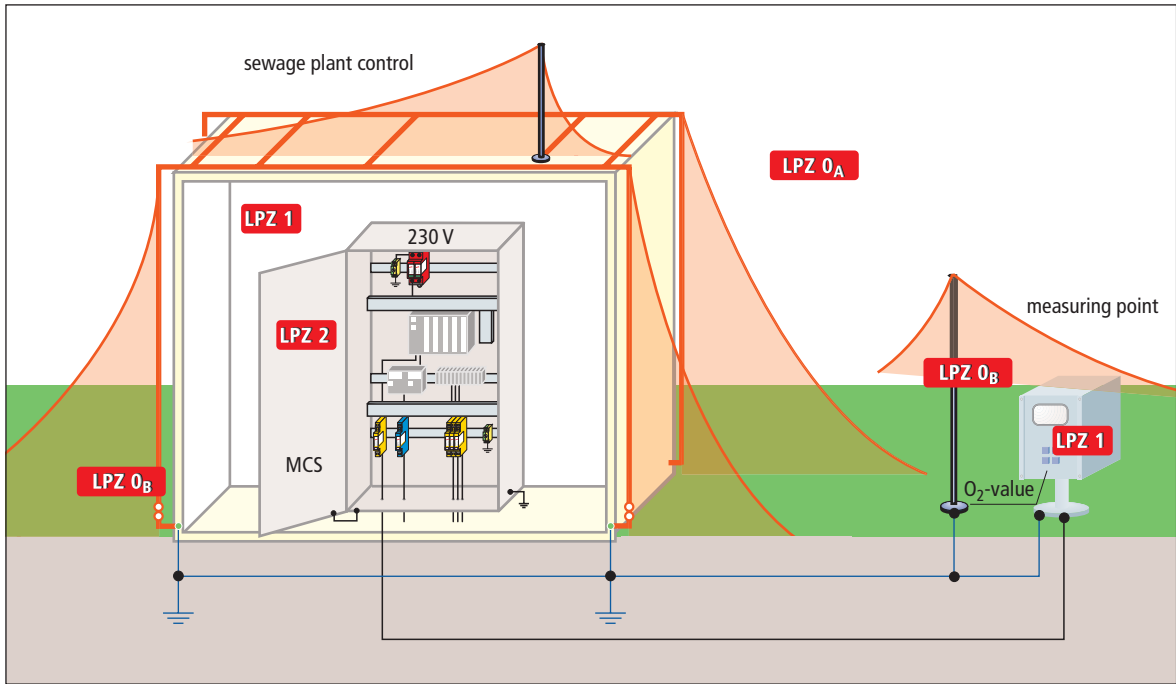
Fig. 9.4.2   Division of a sewage plant control into lightning protection zones

⇒ Oxygen measurement in the aeration tank (LPZ 1)

⇒ Interior of the control room (LPZ 1)

According to the lightning protection zones concept of IEC 62305-4 (EN 62305-4), all conductors at the LPZ boundaries must be provided with appropriate protective measures against surges, (**Figure 9.4.2**).

Risk assessment for the sewage plant control

The following example was calculated by using IEC 62305-2 (EN 62305-2). It should be pointed out that the procedure is only described as an example. The solution presented is in no way binding and can be replaced by any other equivalent solutions. The following states only the essential characteristics of the example.

First, a questionnaire with relevant questions on the structure and its utilisation was discussed with the operator and fixed in writing. This proceeding ensures the elaboration of a lightning protection concept that is comprehensible for all parties involved. This concept represents then the minimum requirements, which, however, can still be technically improved anytime.

Site description

The complete process control of the sewage plant is situated centrally in the sewage plant control. Characterised by the extended cable connections to the measuring stations as well as substations, considerable partial lightning currents and surges are imported by these lines into the control rooms at a lightning strike. In the past, this resulted again and again in destruction of the installation and system failures.

The same applies to the power supply line and the telephone line (**Figure 9.4.3**).

The sewage plant control itself shall be protected against damage by fire (direct lightning strike), and the electric and electronic systems (control and automation system, telecontrol) against the effects of lightning electromagnetic pulses (LEMP).

Additional conditions

⇒ Protective measures against effects of lightning actually are already existing (external lightning protection, surge protective devices (SPD), (previously class B), type VGA 280/4 at the service entrance of the 230/400 V power supply line, SPD, (previously class C) type
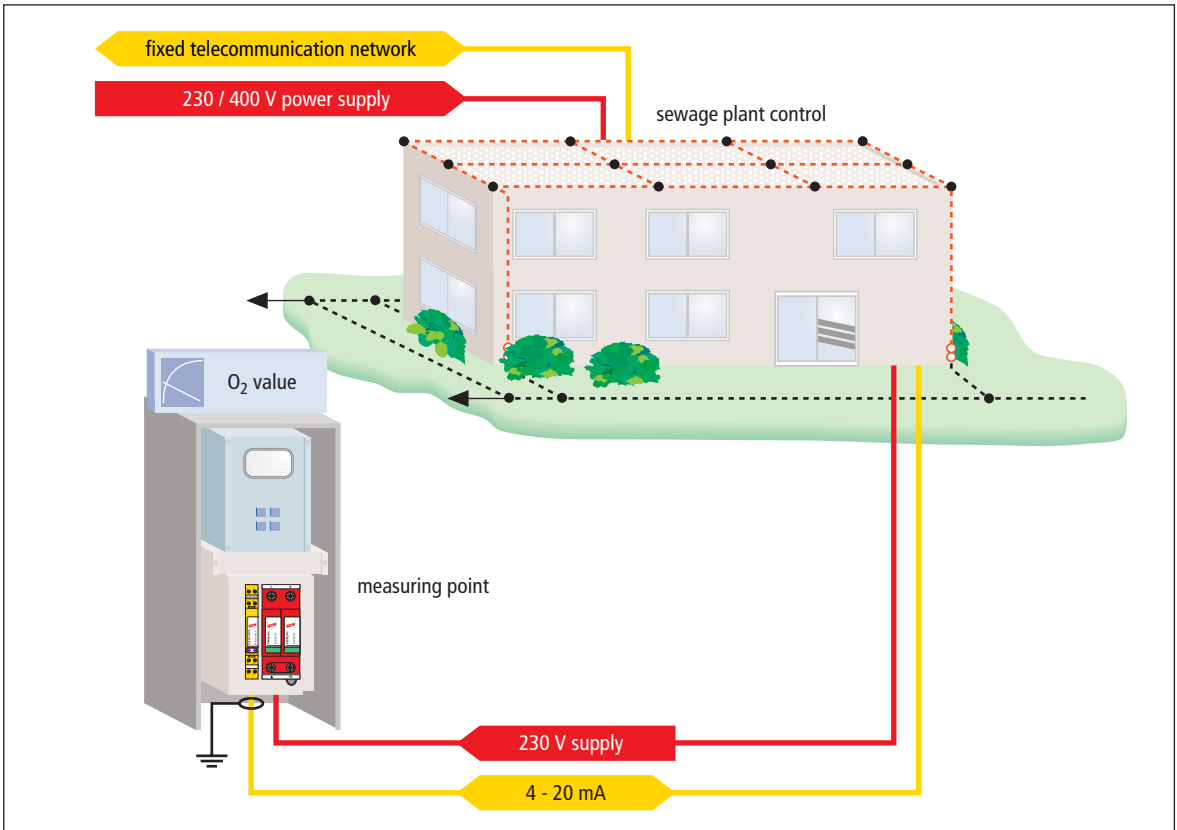
Fig. 9.4.3   Electrical lines going into the sewage plant control

VM 280 in the switchgear cabinets of the measuring and control system).

⇒ The following types of damage are relevant: L2 for loss of services (water supply and water disposal) and L4 for economic losses (buildings or structures and their contents). Type of damage L1 (loss of human life) was excluded, since the installation should run fully automatically in future operation.

The result after calculating the actual state is that the calculated risk R for L2 for loss of service is still well above the tolerable risk R_T.

Now, possible protective measures are initiated in order to obtain $R < R_T$ whereas with respect to L4 loss of economic values the most cost effective solution has to be selected:

⇒ Installation of a lightning protection system Class III according to IEC 62305-3 (EN 62305-3)

(this is the same result as stated in VdS publication 2010)

⇒ Installation of SPDs Type 1 according to EN 61643-11 (power supply) and SPDs, category D1 according to IEC 61643-21 for the data processing lines (data lines of the measuring and control system and telecommunication lines)

⇒ SPD Type 2 according to EN 61643-11 (power supply) and surge protective devices, category C2 according to IEC 61643-21 for the data processing lines (data lines of the measuring and control system and telecommunication lines)

Lightning protection system
The existing lightning protection system of the sewage plant control was upgraded in accordance with the requirements of lightning protection systems Class III (**Figure 9.4.4**). The existing, indirect connection of the structures mounted on the roof (air conditioning systems) via isolating spark gaps
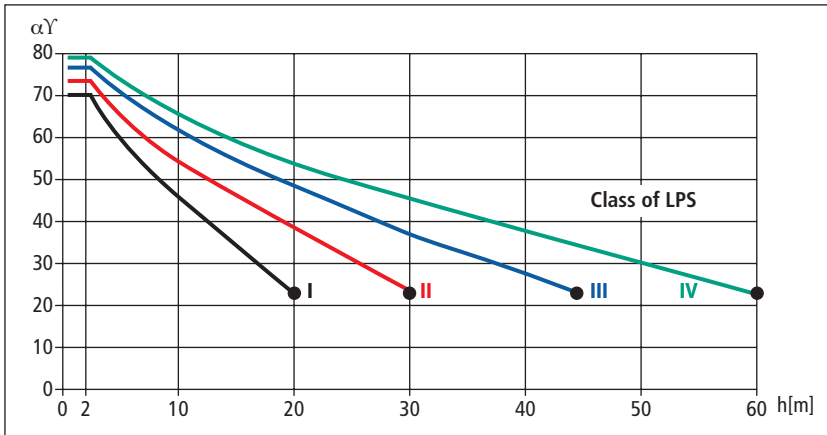
Fig. 9.4.4   Protective angle method according to IEC 62305-3 (EN 62305-3)

room, no more partial lightning current can flow into the structure and cause damage. Due to the size of the control room (15 m x 12 m), the number of down conductors (4) did not have to be changed. The local earthing system of the sewage plant control was checked at all measuring points and the values were recorded. Also, no upgrades had to be made here.

Lightning equipotential bonding for all cables entering from the outside

was removed. The protection against direct lightning strikes was realised by means of air-termination rods in compliance with requested separation distances and protective angles. Consequently, in the case of a direct lightning strike into the control

In principle, all conductive systems entering the sewage plant from the outside must be integrated into the lightning equipotential bonding (**Figure 9.4.5**) The requirements of lightning equipotential bonding are fulfilled by direct connection of all
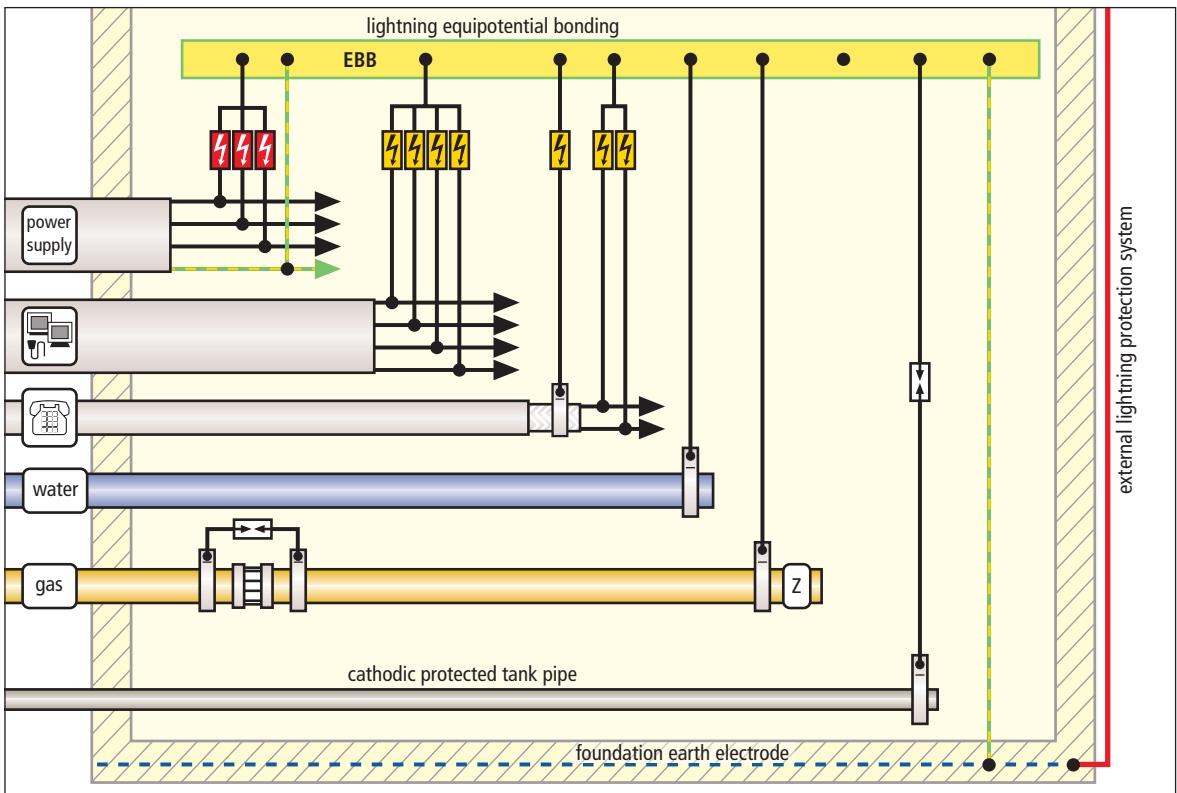
Fig. 9.4.5   Lightning equipotential bonding according to IEC 62305-3 (EN 62305-3)

Fig. 9.4.6 DEHNventil installed into a switchgear cabinet for protection of the power supply system

metal systems and indirect connection of live systems via surge protective devices. The SPD Type 1 (power supply system) and the SPD Type D1 (information technology) must have a lightning current discharge capability of test waveform 10/350 µs. The lightning equipotential bonding shall preferably be installed near the entrance into the building or structure in order to prevent a penetration of lightning currents into the inside of the building.

Equipotential bonding
In the entire sewage plant control, a consistent equipotential bonding is carried out according to IEC 60364-4-41 and IEC 60364-5-54. The already existing equipotential bonding is tested to avoid potential differences between different as well as extraneous conductive parts. Also, supporting parts of the building and parts of the construction, pipelines, containers, etc., are included in the equipotential bonding, so that voltage differences

do not have to be expected, even at a failure. For the application of surge protective devices, the cross section of the earth conductor for equipotential bonding must be minimum 6 mm² Cu for SPDs for power supply systems, and minimum 4 mm² Cu for SPDs for information technology. Moreover, in areas with potentially explosive atmospheres the connections of the equipotential bonding conductors must be secured at e.g. equipotential bonding bars against self-loosening (e.g. by means of spring washers).

Surge protection for the low-voltage power supply
In the described application, the SPD type VGA 280/4 installed at the service entrance of the building is replaced by an SPD Type 1 DEHNventil M TNS 255 (**Figure 9.4.6**), since the "old" SPD does no more comply with the requirements for lightning protection systems according to IEC 62305-3 (EN 62305-3). The SPDs Type 2, (previously class C), Type VM 280, were tested with an arrester test unit, type PM 10. Since the test values were still within the tolerances, there was no reason to remove the SPDs. If further SPDs are installed for protection of the terminal equipment as in the present case, they must be coordinated among each other and with the terminal equipment to be protected. The corresponding instructions given in the enclosed installation instructions must be observed.

Otherwise, the use of surge protective devices in low voltage consumer's installations shows no peculiarities compared to other applications and has already been described many times (for more information, please also see publication DS649 E "Surge Protection – Easy Choice").

Surge protection in data processing systems
From the protection point of view, the transfer interface of all data processing lines to the sewage plant is the service entrance. At this point SPDs (category D1) type DRL 10B 180 FSD are used, which are capable of carrying lightning currents. From the transfer interface, the cables are led directly to the switchgear cabinets and are connected there. In accordance with the performed risk analysis, the incoming cables must be led via SPDs, types DCO RK ME 24 (20 mA signal) or DCO RK MD 110 (telecontrol). These are suitable for use in the lightning protection zones concept (catego-

Fig. 9.4.7   DCO ME 24 surge protective device installed into a
switchgear cabinet for protection of the complete
measuring and control system

Fig. 9.4.8   DCO ME 24 surge protection device installed into a
switchgear cabinet, incoming lines from double bottom

ry C2), and are system compatible (**Figures 9.4.7 and 9.4.8)**.

This ensures a complete surge protection concept for the data processing cabling.

Additional applications for protection of sewage plants can be found in publication DS107 E.

This can be downloaded from our website: www.dehn.de.

9.5 Lightning and surge protection for cable networks and antennas for TV, sound signals and interactive services

IEC 60728-11: 2005 complies with the state of the art and offers easy, standardised and effective protective mechanisms against the effects of lightning strikes into antennas.

Antennas installed according to this standard do not increase the probability of lightnings to strike the object under consideration. Nor is an antenna system installed according to this standard a substitute for a lightning protection system of a building or structure. This standard deals with the safety requirements for stationary systems and devices and is, if applicable, also valid for mobile and temporary systems (e.g. campers, recreational vehicles). The range of validity comprises cable TV networks (CATV networks) and satellite community antenna television systems as well as individual receiving networks.

Outside antennas which are installed at a level of more than 2 m below the roofing or the roof-edge and at distance of less than 1.5 m from the building (**Figure 9.5.1**) as well as antenna systems inside a building are excepted from the following measures. However, at least the connection of the coaxial cable shields to an equipotential bonding conductor is urgently recommended. All interconnect-ed, conductive and touchable components of the installation should be integrated into the equipotential bonding as well.
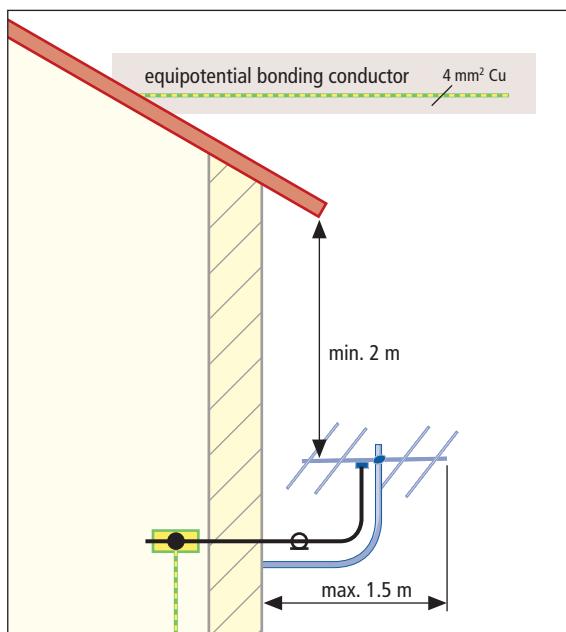
Antennas must not be installed on buildings with easily inflammable roofing (e.g. thatch or similar materials). Antenna cables and earthing conductors must not lead through those sections of rooms where easily inflammable materials like hay, straw or alike are stored, or in which there is a potential risk of explosive atmosphere to arise.

An equipotential bonding conductor has to be mechanically solid with a copper cross section of minimum 4 mm^2. The shields of the coaxial cables going in or out of the building have to be connected with an equipotential bonding conductor and by the shortest route with a common equipotential bonding bar.
An earthing conductor being capable of carrying lightning current can be a single solid wire having a minimum cross section of 16 mm^2 of insulated or bare copper, or of insulated 25 mm^2 aluminium or of 50 mm^2 aluminium wrought alloy (not to be directly installed on or in plaster nor on or in concrete), or of steel 50 mm^2, preferably for external installation.

Natural components which can be used, are for example,

⇒ the metal frame of the building or structure,

⇒ the interconnected reinforcement steel of the building or structure,

⇒ facades, railings and substructures of metal facades,

provided that

⇒ their dimensions meet the requirements of down-conductor systems and their thickness is not less than 0.5 mm,

⇒ their electrical conductivity in vertical direction is ensured (these permanent connections have to be carried out by brazing, welding, pressing, screwing or riveting), or that the distance between metal structures does not exceed 1 mm and the overlapping of two structural elements is at least 100 cm^2.

IEC 62305-3 does no longer stipulate this possibility of overlapping sheet metal, except the substructure is continuously conductive in vertical direction. If not, the overlapping sheet

equipotential bonding conductor   4 mm^2 Cu

min. 2 m

max. 1.5 m

Fig. 9.5.1   Horizontal and vertical distances of antenna arrangements requiring no earthing connection

foundation earth electrode

flat shaped earth electrode

$\alpha > 60°$

2.5 m 2.5 m

1 m

0.5 m

earth rod

2.5 m

1 m

1 m

1.5 m

3 m

1.5 m

earth rod

earthing connection

building foundation

steel skeleton, reinforced concrete buildings
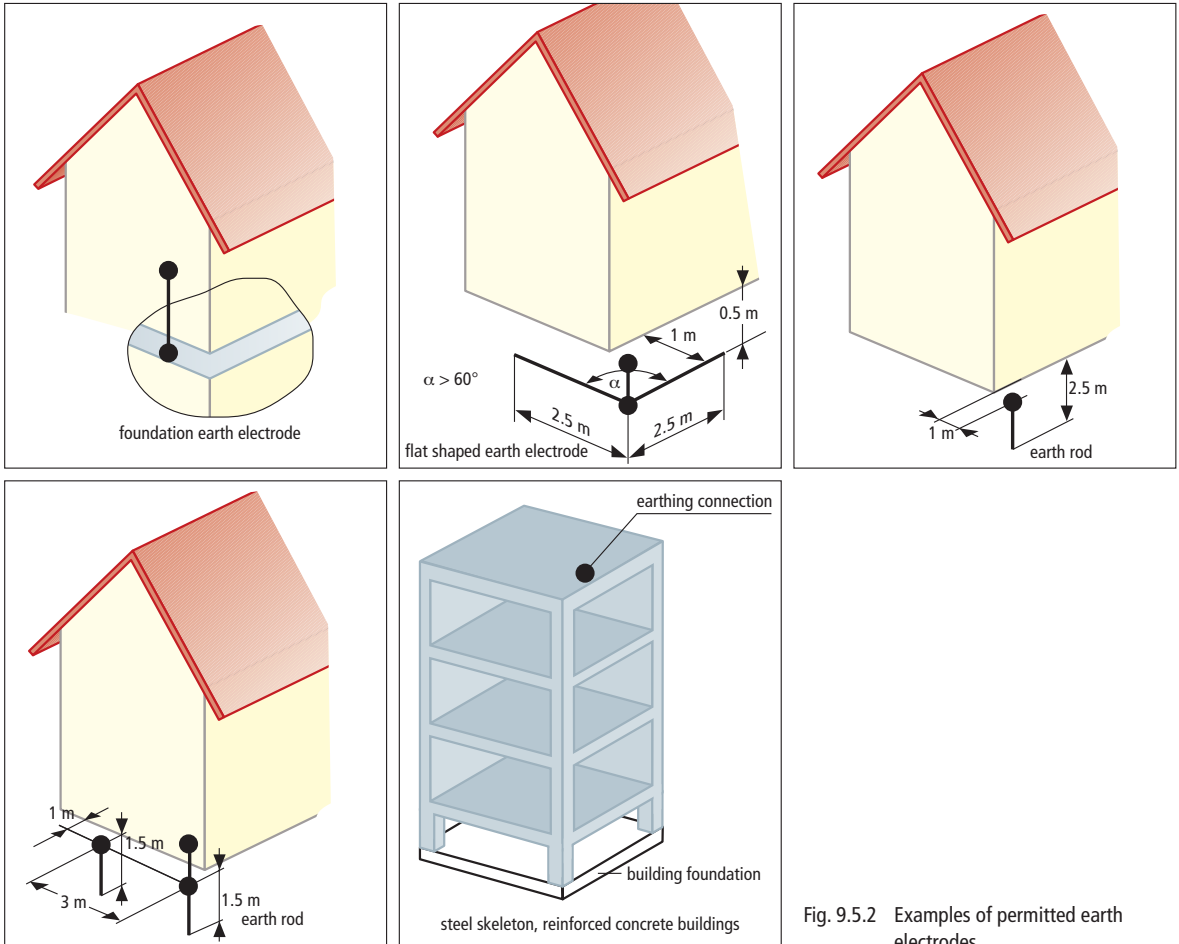
Fig. 9.5.2 Examples of permitted earth electrodes

metals have to be safely interconnected according to the requirements of IEC 62305-3.

Attention: Forming of loops has to be avoided.

The earth-termination system has to be designed according to one of the following manners (**Figure 9.5.2**):

⇒ Connection with the external lightning protection system of the building or structure.

⇒ Connection with the earth-termination system of the building or structure.

⇒ Connection with at least two horizontal earth electrodes having a minimum length of 2.5 m, being installed in an angle > 60 °, at least 0.5 m deep and not closer than 1 m to the foundation, or connected with one vertical or slanted

earth electrode not shorter than 2.5 m or two vertical earth electrodes not shorter than 1.5 m, installed at a distance of 3 m from each other and not closer than 1 m to the foundation.

Minimum cross section of each earth electrode to be 50 mm^2 copper or 80 mm^2 steel.

Natural components such as interconnected reinforcement of concrete or other suitable underground metal constructions embedded into the foundation of the building the dimensions of which complying with the above limit values, can be used as well.

Other earth-termination system according to IEC 62305-3 are also permitted. If a supplementary earth electrode is installed adjacent to the earth-
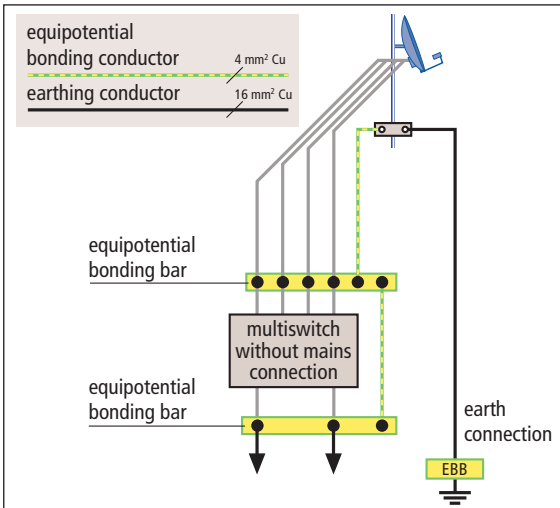
Fig. 9.5.3   Earthing and equipotential bonding of antennas on buildings without external lightning protection system
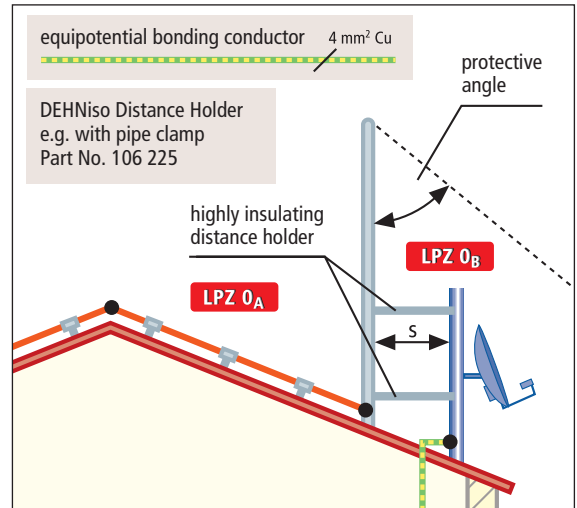
Fig. 9.5.5   Antenna with air-termination rod and highly insulating distance holder on pitched roofs with external lightning protection system
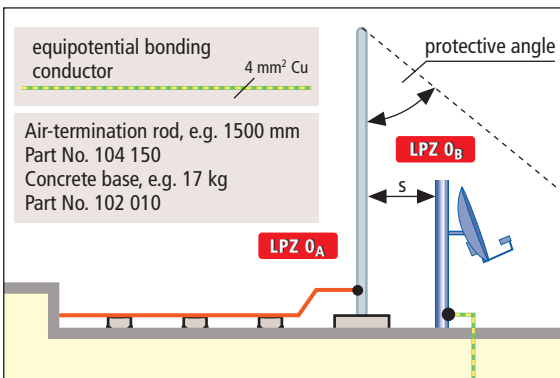
Fig. 9.5.4   Antenna with air-termination rod on a flat roof of buildings with external lightning protection system

Fig. 9.5.6   Surge protective devices downstream the equipotential bonding bar for the coaxial cable shields in case of antenna systems with external lightning protection system and isolated air-termination system

termination system of the building, the earth electrodes have to be interconnected.

In case of buildings without lightning protection system (LPS), the mast with an earthing conductor has to be connected by the shortest route with the earth electrode. The earthing conductor has to be installed straightly and vertically. The coaxial cable shields have to be connected with the mast by equipotential bonding conductors (**Figure 9.5.3**).

In case of buildings with lightning protection system (LPS), the antennas preferably shall be installed within the protective range of an air-termination system, which means in the range of

existing protective zones or by isolated air-termination systems. Only if this is not possible, a direct connection with the external lightning protection system shall be implemented. In this case the aris-
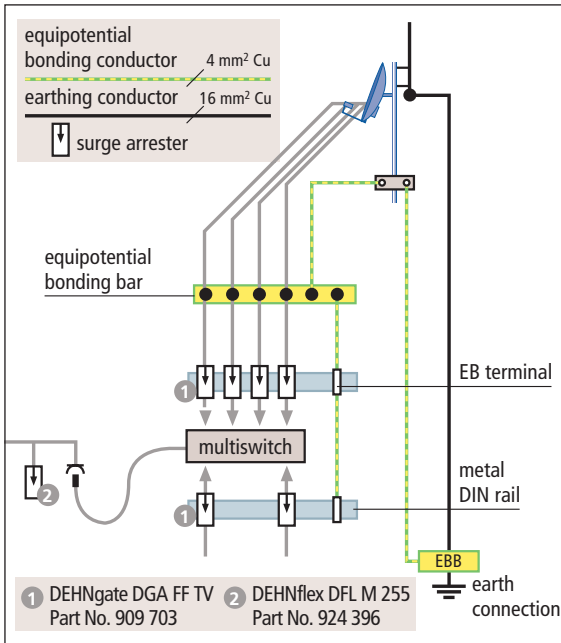
Fig. 9.5.7   Surge protective devices downstream the equipotential bonding bar for the coaxial cable shields in case of antenna systems without external lightning protection system and with isolated air-termination system
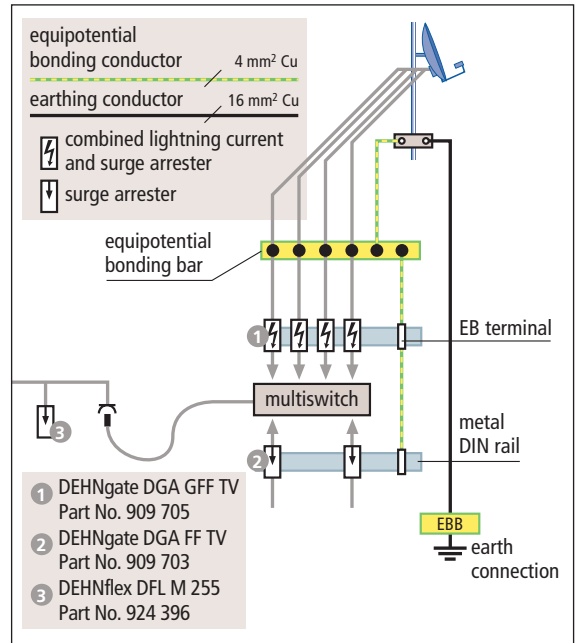
Fig. 9.5.8   Combined lightning current and surge arresters downstream the equipotential bonding bar for the coaxial cable shields in case of antenna systems without external lightning protection system

ing partial lightning currents via the coaxial conductors have to be taken into account individually. Lightning equipotential bonding has to be performed for the conductors going into the building.

If an antenna is protected by isolated air-termination systems it means

⇒ that in the area of flat roofs an air-termination rod will be installed with the required separation distance s, putting the whole antenna arrangement (mast and antennas) in the protective zone of the protective angle (**Figure 9.5.4**). Now the antenna arrangement is no longer in lightning protection zone LPZ 0_A (risk of direct lightning currents) but lightning protection zone LPZ 0_B (risk of indirect impulse currents and of the unattenuated electromagnetic field of lightning.

⇒ that in the area of pitched roofs an air-termination rod will be installed with the required separation distance s using highly insulating distance holders (DEHNiso distance holders) to fix it at the antenna mast, putting the whole antenna arrangement (mast and antenna) into

the protective zone of the protective angle (according to the applicable class of LPS) (**Figure 9.5.5**). Also here the antenna arrangement is no longer in lightning protection zone LPZ 0_A (risk of direct lightning currents), but in lightning protection zone LPZ 0_B (risk of indirect impulse currents and of the unattenuated electromagnetic field of lightning).

Protection against surges, irrespective of an installed isolated air-termination system, has to be provided for the coaxial cable shields by surge protective devices, to be installed downstream the equipotential bonding bar (**Figure 9.5.6**). These surge protective devices to be used both as single devices and for rail mounting protect the downstream devices against inductive and/or capacitive inputs of waveform 8/20 µs, arising from cloud/cloud flashes, distant strikes or direct strikes into the isolated air-termination system.

Surge protective devices Type 3 have to be provided for any electrical equipment with 230/50 Hz downstream the equipotential bonding bar, which
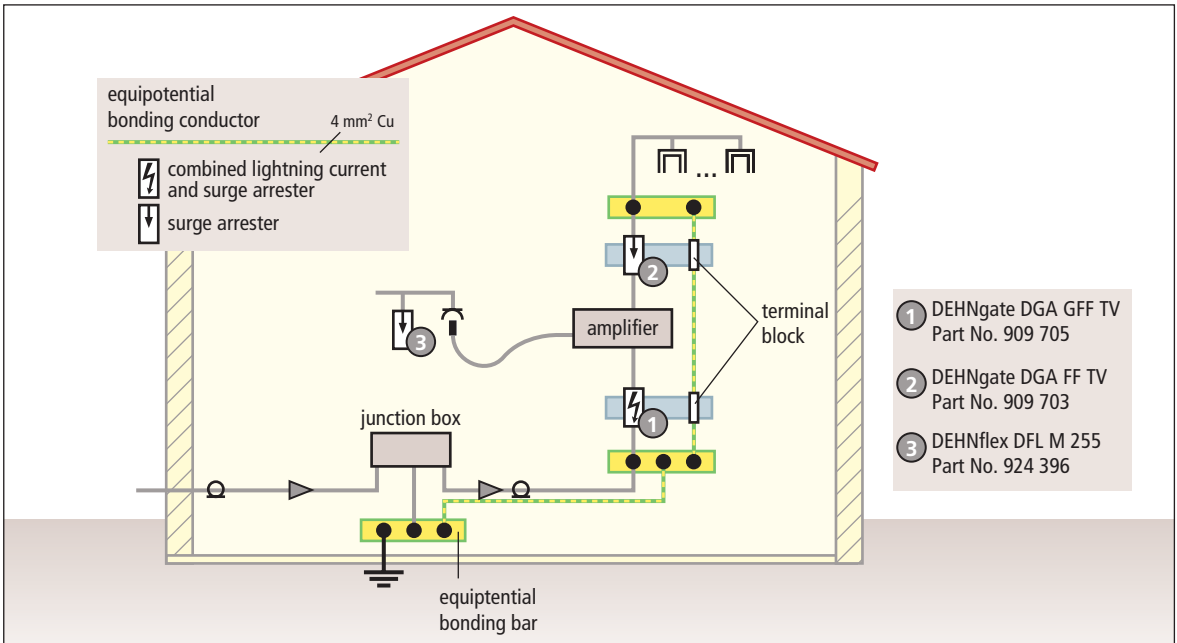
Fig. 9.5.9   Combined lightning current and surge arresters downstream the equipotential bonding bar for the coaxial cable shields in case of underground cable networks

is installed for the coaxial cable shields. Care has to be taken that the lightning equipotential bonding is carried out for all systems leading into the building.

A lightning protection system not being installed, the following is recommended:

⇒ An air-termination rod mounted with insulated distance holders prevents from a direct strike to the antenna. For this the air-termination rod has to be connected with the earth electrode by a separately installed earthing conductor (**Figure 9.5.7**) to be guided preferably on the outside of the building and to be connected with the earth electrode at ground level. Antenna mast and equipotential bond-

ing bar have to be connected with the earth electrode via an equipotential bonding conductor.

⇒ If the antenna mast is earthed directly, combined lightning current and surge arresters have to be provided (**Figure 9.5.8**), because partial lightning currents, which the surge arresters are not able to control, will be conducted in this case through the coaxial cables. The antenna mast has to be connected with the earth electrode by an earthing conductor.

Underground utility lines of systems require combined lightning current and surge arresters being able to carry lightning currents. They also have to be mounted near the point of entrance into the building (**Figure 9.5.9**).

9.6 Lightning and surge protection in modern agriculture

Fig. 9.6.1   Modern automatic milking system

BLITZDUCTOR CT
BCT BAS
Part No. 919 506 +

BCT MLC BE 24
Part No. 919 323

DEHNguard S
DG S 275
Part No. 952 070
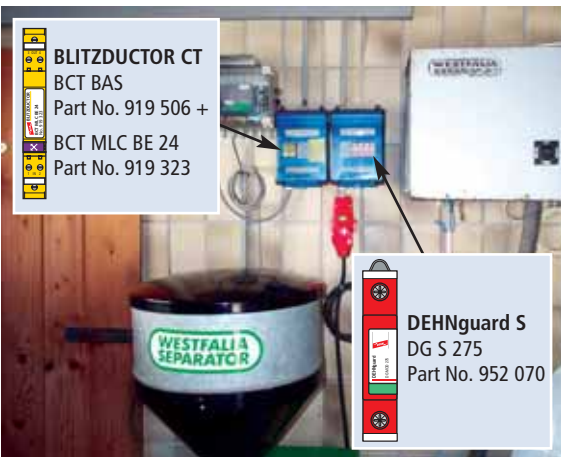
Fig. 9.6.2   Automatic feeding system

DEHNflex
DFL M 255
Part No. 924 396

Fig. 9.6.3   Ventilation and flushing system

DEHNrail
DR M 2P 255 FM
Part No. 953 205

Fig. 9.6.4   Heating system with heat recovery and service water supply

Complex electrical and data processing systems characterise the picture of modern agriculture. Many processes are automated, and controlled and monitored by computers. Today, an intact data network is an important survival factor on the market not only for industry but also for agriculture.

For protecting the installations and systems against the destruction by powerful transient surges, the use of surge protective devices is required. An external lightning protection alone is by far no longer sufficient there.

Structure

An example for the high degree of automation in agriculture is the keeping of cattle. Ultramodern electrical and electronic installations like automatic milking systems (**Figure 9.6.1**), automatic feeders (**Figure 9.6.2**), ventilation systems, flushing plants (**Figure 9.6.3**), and heating systems with heat recovery and industrial water supply (**Figure 9.6.4**) ensure a trouble-free operation.

The milking system (**Figure 9.6.5**), for example, runs almost fully automatically in a modern farm.

Fig. 9.6.5   Electrical milking system with control box

Fig. 9.6.6   Cow with collar and registration chip

Following to a natural rhythm, the dairy cows enter the milking carousel once in the early morning and once in the evening – always at the same time – to deliver their milk. The quantity delivered is immediately acquired by the electronic operating control system of this installation, saved and transmitted online to an existing computer network for administration.

Each animal has a collar with a registration chip (**Figure 9.6.6**) for identification. Beside the milk quantity, inter alia the name, date of birth, descent, diseases, feed quantity, pregnancy duration, etc. of the animal is acquired and stored. The farmer can immediately intervene, when e.g. the milk quantity changes, by modifying the feed quantity accordingly, and compensate for losses as quickly as possible.

The failure of even only one plant component due to surges leads to non-foreseeable consequences for operators and animals. For example to

⇒ an impairment of the animals' health,

⇒ downtimes of the systems,

⇒ production losses,

⇒ additional costs of medical care for the animals,

⇒ high expenditure on data reconstruction and

⇒ expenses for the replacing of the faulty devices and the time required for it.

Reports on such damage in the following:

[Donaukurier Online] 29.06.2001
Lightning killed cow in the barn
Power failed: Pigs suffocated
Munich. During the thunderstorms in the night towards Thursday, a flash of lightning set a barn on fire in the rural district of Roth. In a barn in Höttingen (rural district of Weißenburg-Gunzenhausen), a cow was killed by lightning. The strongest cloudburst happened in Kempten, where more than 21 litres of rain per square metre fell in one hour. In Weißenburg, it was 20 litres.

Around 450 pigs suffocated in a fattening shed in Kitzingen and died of panic attacks. A power failure, apparently caused by a thunderstorm, has put the ventilation of the stable out of operation in the night towards Thursday, said the police. The farmer could still open a window of the barn but could not prevent the perishing of the animals.

[Oberpfalznet] 16.06.2003
60 cows burn in the stable
Lightning discharge sets farm on fire in Kainsricht – 500,000 Euro damage
Kainsricht. A flash of lightning struck a farm on early Saturday evening and set a stable with two outbuildings on fire. 60 cows died in the flames. The owner of the farm, a 70 year old farmer, suffered a shock. The caused damage amounts to at least 500,000 Euro.
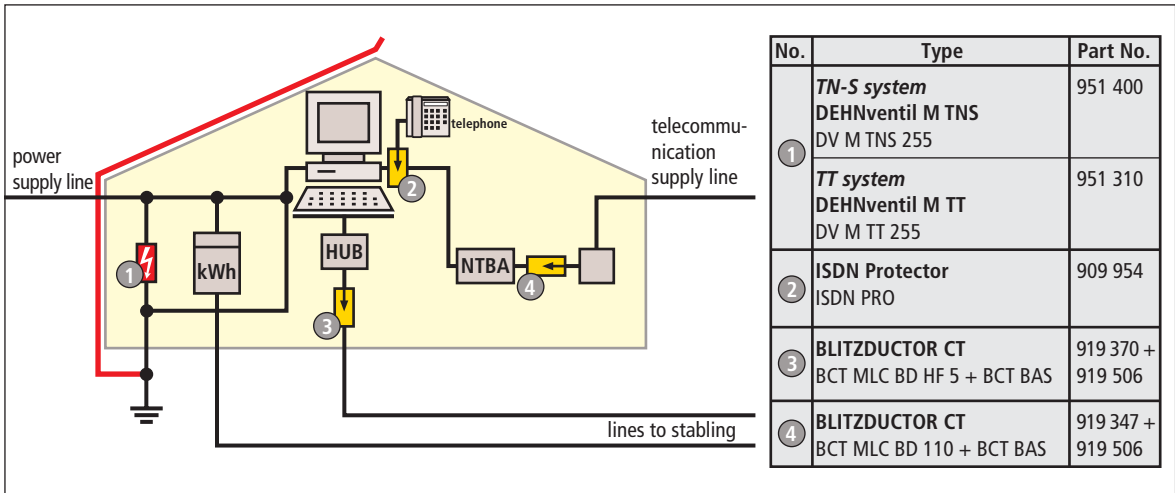
Fig. 9.6.7   Lightning and surge protection for agricultural installations, residential building and office

No.	Type	Part No.
1	**TN-S system** **DEHNventil M TNS** DV M TNS 255	951 400
1	**TT system** **DEHNventil M TT** DV M TT 255	951 310
2	**ISDN Protector** ISDN PRO	909 954
3	**BLITZDUCTOR CT** BCT MLC BD HF 5 + BCT BAS	919 370 + 919 506
4	**BLITZDUCTOR CT** BCT MLC BD 110 + BCT BAS	919 347 + 919 506
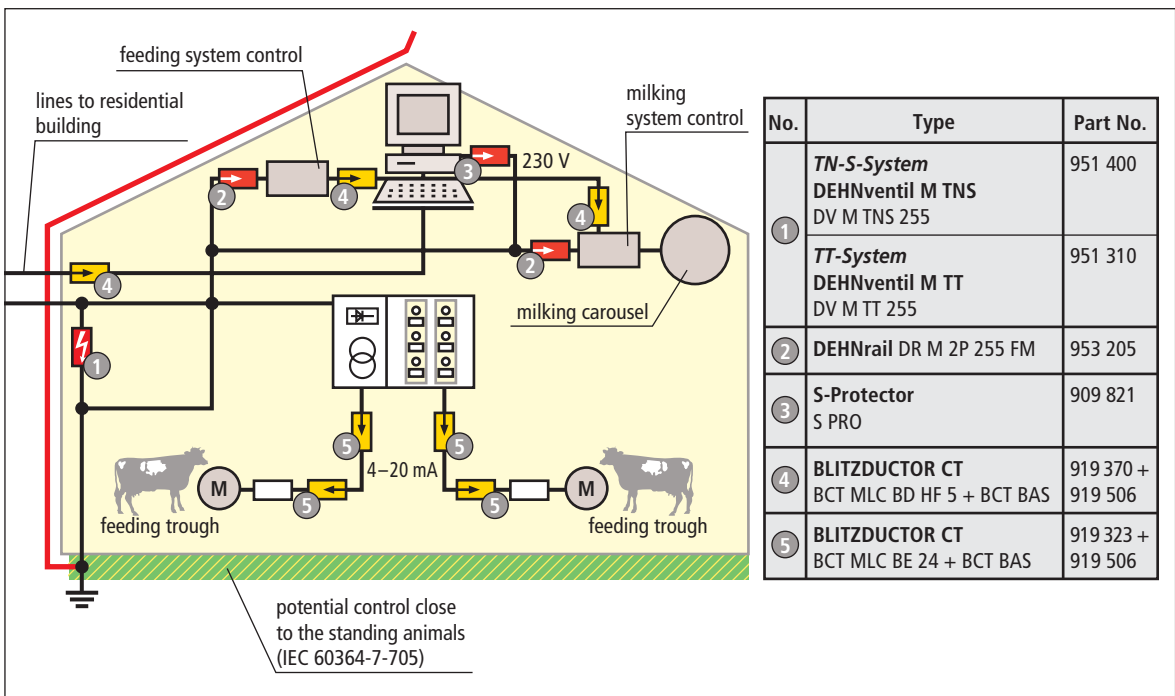
Fig. 9.6.8   Lightning and surge protection for agricultural installations, stabling

No.	Type	Part No.
1	**TN-S-System** **DEHNventil M TNS** DV M TNS 255	951 400
1	**TT-System** **DEHNventil M TT** DV M TT 255	951 310
2	**DEHNrail** DR M 2P 255 FM	953 205
3	**S-Protector** S PRO	909 821
4	**BLITZDUCTOR CT** BCT MLC BD HF 5 + BCT BAS	919 370 + 919 506
5	**BLITZDUCTOR CT** BCT MLC BE 24 + BCT BAS	919 323 + 919 506

[Stuttgarter Nachrichten Online] 09.05.2003
Many fires and full cellars
The fire brigade of Fribourg moved out for more than 60 deployments. Within two hours, the police received 150 emergency calls in the city. In Ober- *wolfach (district of Ortenau), a flash of lightning set a farm on fire and caused a damage of approximately 150,000 Euro. The almost 100 year old building burned down to the foundation walls. Nobody was injured.*

These examples obviously show the importance of lightning and surge protection in agricultural systems. An extensive protection requires the use of components for electrical engineering as well as for information technology (telecommunications network, computer network, measuring and control line). Companies located at network spurs of distribution networks are especially at risk.

The **Figures 9.6.7** and **9.6.8** show the implementation of lightning and surge protection in agricultural buildings or structures. Here, the design of the lightning and surge protection on the power supply side using protective devices arranged in a decentralised manner by means of combined lightning current and surge arresters.

9.7 Lightning and surge protection for video surveillance systems

In the industry as well as in the private sector, video surveillance systems are used more and more frequently for entrance monitoring and property supervision.

The following describes protective measures against surges that meet the availability requirements on video surveillance systems.

A video surveillance system consists at least of one camera, one monitor and one suitable video transmission line. Remotely controllable camera stations are normally equipped with an inclination and swivel support so that position and viewing angle of the station can be individually adapted by an operator.

As shown in **Figure 9.7.1**, video transmission and power supply of the camera are implemented via an interface cable between terminal box and camera.

The communication line between terminal box and monitor can be a coaxial cable or a balanced two-wire cable. The transfer of the video signals through coaxial cables is certainly the most common type in video technology. In this case, an unbalanced transfer is used, i.e. the video signal is transferred through the core of the coaxial cable (inner conductor). The shielding (earth) is the reference point for the signal transmission. The two-wire transmission is, beside the coaxial cable transmission, a common possibility. If there is already a global telecommunication infrastructure for the object to be monitored, a free twin wire (two-wire cable) in the telecommunication cables is used to transfer the video signal

Video surveillance systems are partially powered directly from the distribution panels, but also via inserted UPS.

Choice of surge protective devices

Building with external lightning protection system
In **Figure 9.7.1**, the camera is installed on a pole. A direct lightning strike into the camera can be prevented by an air-termination rod mounted at the top end of the pole. With reference to the camera as well as to its connection cable, a sufficient separation distance (IEC 62305-3 (EN 62305-3)) must be maintained from parts of the external lightning protection system.

| ① | Surge arrester DEHNguard modular | ② | BLITZDUCTOR XT ML4 BE HF5 for two-wire cables or UGKF BNC for coax cable | ③ | BLITZDUCTOR XT ML4 BE... (e.g. 24 V) | ④ | Combined lightning current and surge arrester DEHNventil modular |
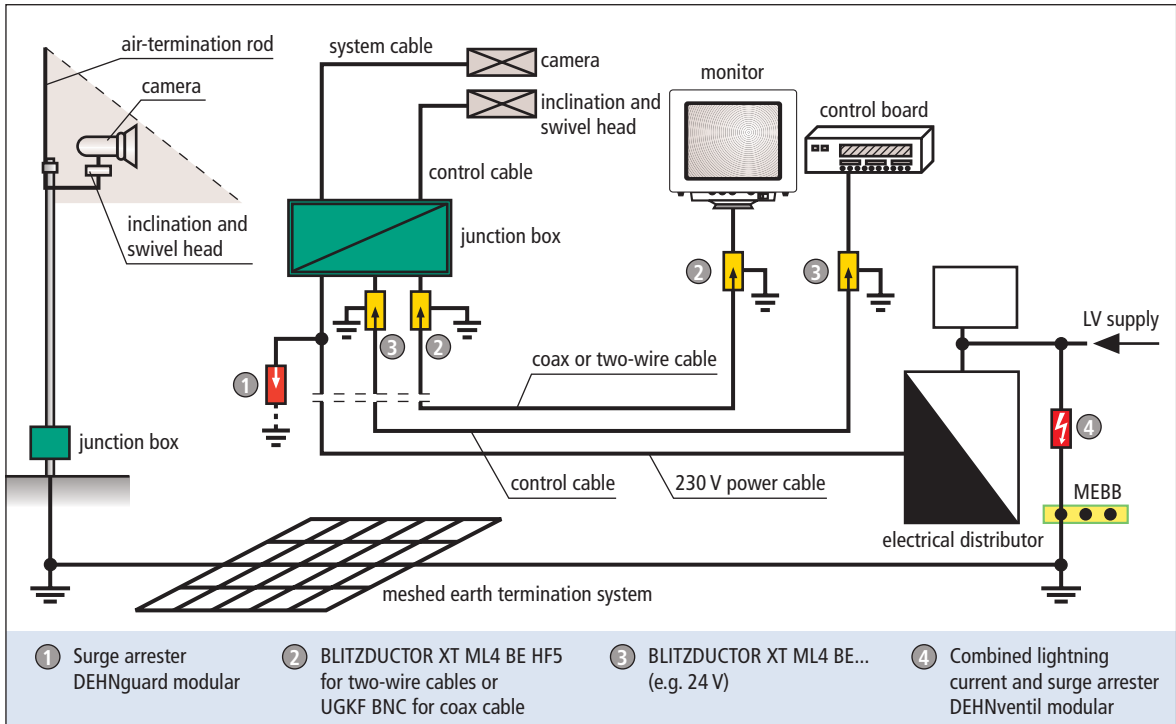
Fig. 9.7.1   Video surveillance system – Lightning and surge protection

Usually, the connecting cable between terminal box and camera is laid inside the metal pole.

If this is not possible, the camera cable has to be laid in a metal pipe, which must be electrically connected with the pole. For cable lengths of a few meters, a protective circuit in the terminal box is not necessary in these cases.

For the coaxial cable or the two-wire cable as well as for the control cable leading from the terminal box at the pole into a building with an external lightning protection system, lightning equipotential bonding must be implemented (**Table 9.7.1**). This includes connecting the lightning protection system with pipings, metal installations within the building and the earth-termination system. Additionally, all earthed parts of the power supply and data processing systems must be integrated into the lightning equipotential bonding. All live wires of power supply and data processing cables and

air-termination rod

Fig. 9.7.2 Camera for video surveillance in the protective area of the air-termination rod

No. in Figure 9.7.1 and 9.7.3	Protection for ...	SPDs	Part No.
②	2-wire cable (video transmission)	BLITZDUCTOR XT, BXT ML4 BE HF 5 + BXT BAS	920 370 920 300
②	Coax cable (video transmission)	UGKF BNC	929 010
③	Control cable (e.g. 24 V DC)	BLITZDUCTOR XT, BXT ML4 BD 24 + BXT BAS	920 324 920 300

Table 9.7.1   Lightning and surge protection for signal lines

No. in Figure 9.7.1	Combined SPDs (lightning current and surge arresters)		
	Protection for ...	SPDs	Part No.
④	3-phase TN-C system	DEHNventil DV M TNC 255	951 300
	3-phase TN-S system	DEHNventil DV M TNS 255	951 400
	3-phase TT system	DEHNventil DV M TT 255	951 310
	Single-phase TN system	DEHNventil DV M TN 255	951 200
	Single-phase TT system	DEHNventil DV M TT 2P 255	951 110
No. in Figure 9.7.1 and 9.7.3	Surge arresters		
	Protection for ...	SPDs	Part No.
①	3-phase TN-C system	DEHNguard DG M TNC 275	952 300
	3-phase TN-S system	DEHNguard DG M TNS 275	952 400
	3-phase TT system	DEHNguard DG M TT 275	952 310
	Single-phase TN system	DEHNguard DG M TN 275	952 200
	Single-phase TT system	DEHNguard DG M TT 2P 275	952 110

Table 9.7.2   Lightning and surge protection for power supply lines
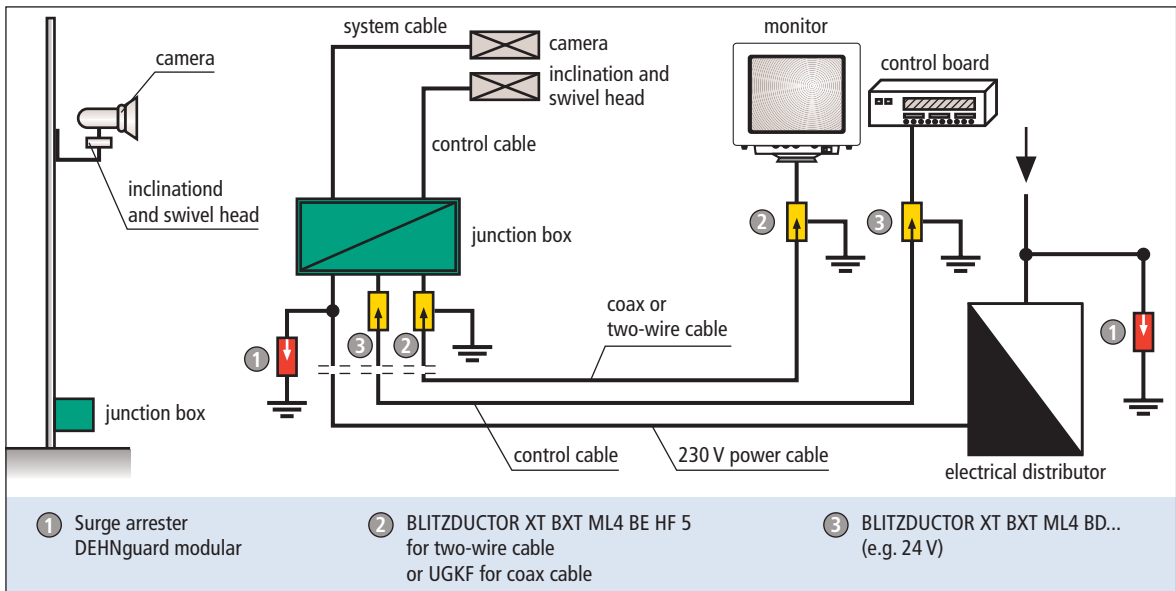
Fig. 9.7.3   Video surveillance system – Surge protection

In the figure labels:

camera

inclinationd and swivel head

junction box

system cable

camera

inclination and swivel head

control cable

junction box

coax or two-wire cable

control cable

230 V power cable

monitor

control board

electrical distributor

① Surge arrester
DEHNguard modular

② BLITZDUCTOR XT BXT ML4 BE HF 5
for two-wire cable
or UGKF for coax cable

③ BLITZDUCTOR XT BXT ML4 BD...
(e.g. 24 V)

lines leading in and coming out of the structure are connected indirectly with the lightning equipotential bonding via lightning current arresters (SPD Type 1). If no lightning current arresters (SPD Type 1) are installed in the low voltage main distribution board, the operator must be informed that these need to be upgraded.

Tables 9.7.1 and **9.7.2** show the surge protective devices to be used for signal and power supply lines according to consecutive numbers in **Figure 9.7.1**.

Figure 9.7.1 (No. 4) shows the application of a combined lightning current and surge arrester DEHNventil modular (**Table 9.7.2**). This combined SPD unites lightning current arrester and surge arrester (SPD Type 1 + 2) in one device, requires no decoupling coil and is available as complete prewired unit for each type of low voltage system (TN-C, TN-S, TT).

Up to cable lengths of ≤ 5 m between DEHNventil and terminal equipment, there is sufficient protection without additional protective devices. In case of greater cable lengths, additional surge protective devices are required for the terminal equipment, e.g. DEHNrail modular.

When mounting the camera at an external building facade it should be ensured that the camera is fixed below the outer edge of the roof, in the protection zone. If this is not possible, an area must be created that is protected against lightning strikes by means of additional external lightning protection measures. This can be done with an air-termination system, as shown in **Figure 9.7.2**, to safeguard the camera against direct lightning strikes.

Buildings without external lightning protection system

For buildings without external lightning protection system, it is assumed that the risk of damage caused by a direct or close lightning strike into the building, is low and therefore accepted.

If this risk is also accepted for a subsequently mounted video transmission equipment, this can be sufficiently protected by installing SPDs.

The surge protective devices to be used for the power supply line in **Figure 9.7.3** can be taken from **Table 9.7.2**.

The surge arresters for protection of the signal lines in **Figure 9.7.3** are listed in **Table 9.7.1**.

9.8 Surge protection for public address systems (PA systems)

Public address systems are applied as compact devices with standardised performance characteristics as well as in 19 " modular design. They are used for voice, music and signal transmission. For this the wanted signal is modulated to a carrier voltage (50, 70, 100 V) and transmitted to the loudspeakers.

This transmitter transforms the low impedance of the loudspeaker to a higher value, thus reducing the signal current. This allows also telecommunication cables (0.6 or 0.8 mm diameter) to be used.

Most different kinds of loudspeakers are used. The nominal power in the range of fitting or surface-mounted loudspeakers being at approx. 6 – 30 W,

of loudspeaker columns at approx. 20 – 100 W and of horns at approx. 10 – 60 W. The lowest nominal power of amplifiers in modular design is about 100 W going up to 600 W and more.

In a line or group, loudspeakers of different power can be used in common. The minimum power of the amplifier is equal to the sum of power of the individual loudspeakers. Not the sum of the loudspeakers' nominal power is decisive for the addition, but rather the sum of power levels actually chosen at the tappings of the transmitters.

Designing of the conductor system of a public address system is subject to EN 50174-2.

① DGA FF TV, Part No. 909 703	③ DGA G BNC, Part No. 929 042	⑥ DR M 2 P 255, Part No. 953 200
② DR M 2P 150, Part No. 953 204 (currents > 1 A – 25 A) or BCT MLC BE 110, Part No. 919 327 BCT BAS, Part No. 919 506 (currents < 1A)	④ FS 9E HS 12, Part No. 924 019	⑦ DCO RK ME 110, Part No. 919 923 AD DCO RK GE, Part No. 919 979 (currents < 0.5 A)
	⑤ BXT ML4 BD HF 5, Part No. 920 371 BXT BAS, Part No. 920 300	⑧ S PRO, Part No. 909 821
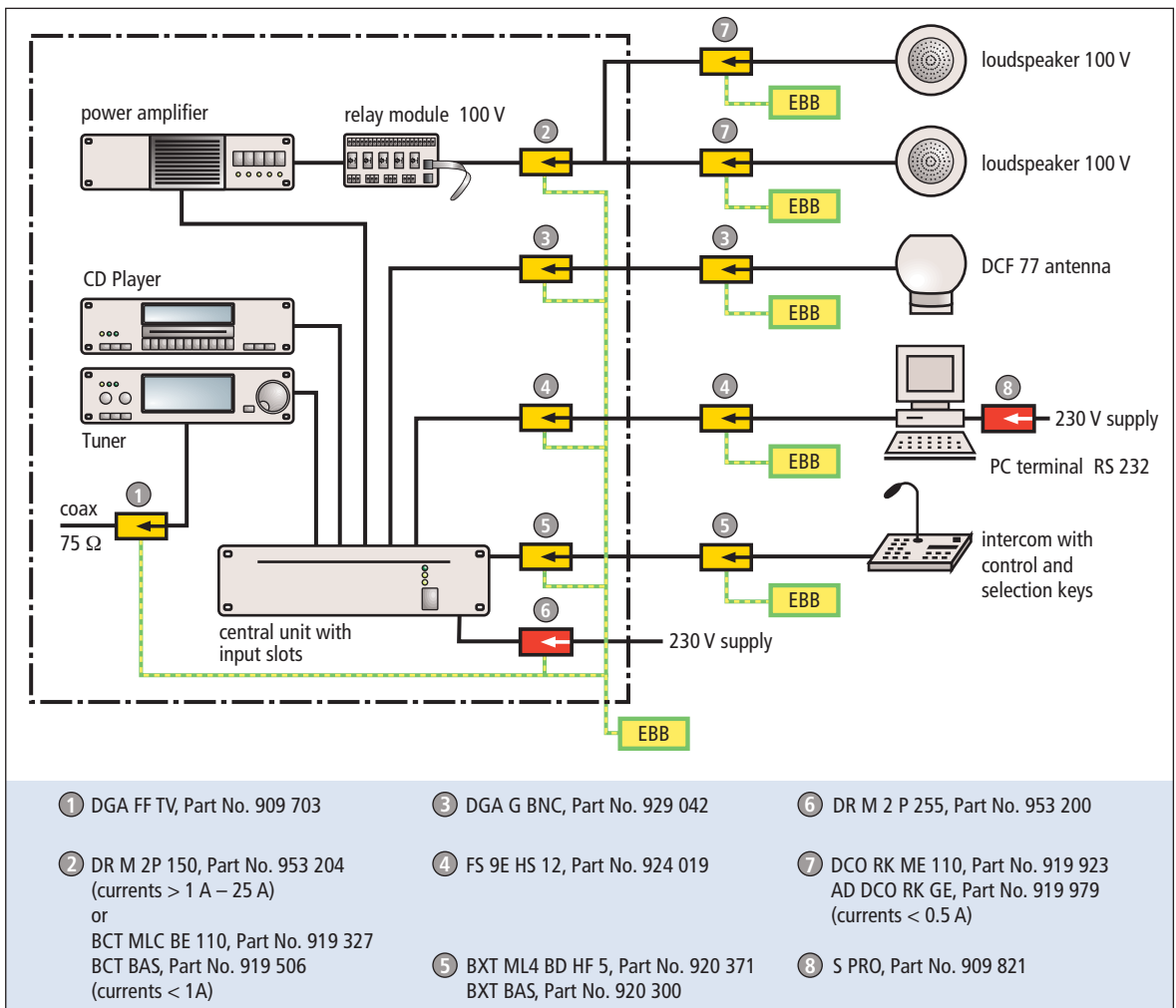
Fig. 9.8.1 Public address system in modular design with surge protective devices
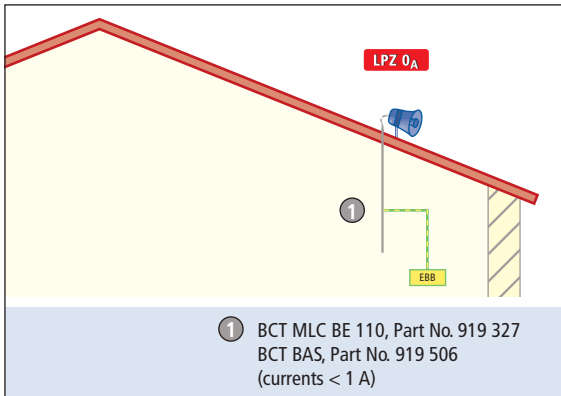
Fig. 9.8.2 Building without external lightning protection and horn in LPZ 0_A protected by combined lightning current and surge arresters
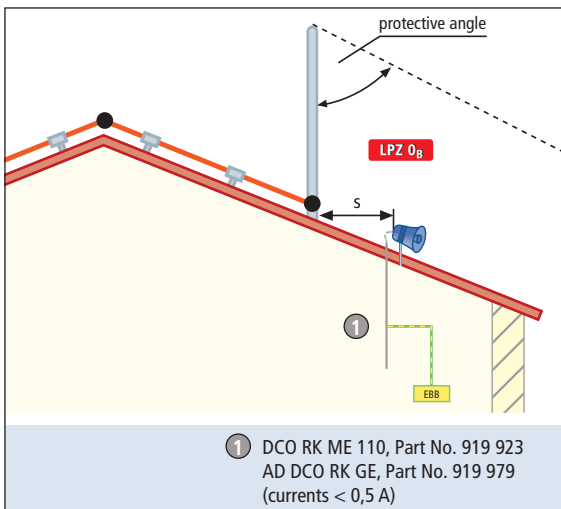
Fig. 9.8.3 Building with external lightning protection and horn in LPZ 0_B protected by surge arresters

In the quoted EN standard, surge protection is described in the installation guidelines under 6.11.3. Beside the mentioned protection of the conductors, the main focus, namely the protection of the devices installed in the conductor system, is pointed out.

In the following presentation we do not refer to any further regulations which might be applicable (e.g. building regulation, public address emergency systems, danger alarm in case of fire and raid, etc.).

Major PA systems have a 19 " modular design (**Figure 9.8.1**) and are in the vicinity of a permanently occupied working place.

Therefore the existing interconnecting line to the PC or the site of the intercom is determining for the use of the surge arresters given under ④ and ⑤. A protection of the line usually is required if the distance is > 5 m.

Dimensioning of the surge arresters listed under ② and ⑦ requires to determine the maximum current in the corresponding conductor branch. This is done by the relation I = P/U, with U being the carrier voltage and P the power of the amplifier to dimension the surge arrester ② and the power of the loudspeaker to dimension the surge arrester ⑦. In case of several loudspeakers in close spatial vicinity, P is the sum of the individual loudspeaker's power.

It is recommended to connect all earthing terminals of the surge arresters ① to ⑥ with an adjacent equipotential bonding point (mini EB bar).

If loudspeakers are positioned in lightning protection zone LPZ 0_A (area with hazard of direct lightning strike) of buildings without external lightning protection system, combined lightning current and surge arresters have to be installed (**Figure 9.8.2**). If here only a lightning current arrester is installed, the loudspeakers in the building installed in this track can be damaged.

If loudspeakers are positioned in lightning protection zone LPZ 0_B (area without hazard of lightning strike) of buildings with external lightning protection system, surge arresters have to be installed at the entrance of the building (**Figure 9.8.3**).

9.9   Surge protection for hazard alert systems

In a dangerous situation, hazard alert systems (fire alarm systems or burglar alarm systems) shall signal actively, and remain passive in safe situations. Malfunctions of these systems (no response in case of danger, or alarm signal in case of no danger) are undesirable and expensive. False alarms sent by hazard alert systems result in expenses, which, in the industrial countries, amount to several hundred million Euro per year. Another aspect of malfunctions is the possible direct or indirect danger to human lives. In this context, we may remember the malfunction of the fire alarm system in the tower of the Frankfurt Rhein-Main airport in 1992, where a false activation of the fire extinguishing system occurred because of a lightning strike. Within a few minutes, the air traffic controllers had to leave the control room. In this critical situation, approaching airplanes had to be redirected to other airports. Considerable delays occurred in the air traffic.

False alarms of hazard alert systems are also disturbing in another respect:

⇒   When false alarms accumulate, the operator can no longer rely on the system and questions the significance of the system (investment) as such.

⇒   The guard starts ignoring alarm messages.

⇒   Neighbours will be disturbed by acoustic alarms.

⇒   Action forces (e.g. fire brigade) will be bound unnecessarily.

⇒   The activation of the fire extinguishing system causes interruptions of operations.

⇒   Damage is caused by not signalling existing hazard.

All these factors cause unnecessary expenses. They can be avoided, when possible causes for false alarms are already recognised in the design stage and are eliminated by suitable preventive measures. For this purpose, the German Insurance Association (Gesamtverband der Deutschen Versicherungswirtschaft e.V. - GDV) published VdS guidelines (VdS 2095; VdS 2311; VdS 2833). One of the measures also requested in the VdS guidelines is lightning and surge protection.

A coordinated lightning and surge protection prevents a false alarm caused by atmospheric discharges and improves the availability of the early detection of dangers and alarms.

When installing comparable alarm transmission systems, for which, out of financial reasons, a VdS approval is not used (e.g. residential building), the guidelines may also be used for project design and for the construction as well as for agreeing individual measures between constructors and operators.

Indeed, most of the nowadays installed fire alarm systems have an increased surge immunity in accordance with IEC 61000-4-5 for primary and secondary wires as well as for the mains inputs. However, a comprehensive protection against damage by lightning discharge and surges can only be achieved by external and internal lightning protection measures (**Figure 9.9.1** to **Figure 9.9.4**).

Monitoring principles

Different monitoring principles are applied for hazard alert systems:

⇒   **Impulse line technology**

The information from the triggering alarm device is transferred in digital form. This allows to recognise the alarm device and the exact localisation of the trouble spot (**Figure 9.9.1**).

⇒   **d.c. line technology**

Each alarm line is permanently monitored according to the closed-circuit principle. If an alarm device is activated in the line, this line is interrupted and an alarm is triggered in the control and indication equipment. Hereby, however, only the alarm line can be identified but not the individual detector (**Figures 9.9.3** and **9.9.4**).

Regardless of the used monitoring principle, the lines of the hazard alert system must be integrated into the lightning and surge protection of the complete system.

Protection recommendations

For protection of alarm lines with d.c. line technology, BLITZDUCTOR XT, Type BXT ML4 BE ... is recommended. It is chosen according to the voltage of the alarm lines, which is normally 12 or 24 V.

BLITZDUCTOR XT, Type BXT
ML4 BE is recommended in
order not to change the loop
resistance of the alarm lines
too much.

Regardless of the line topolo-
gy, the outputs of the control
and indication equipment, as
e.g. for acoustic and visual
signalisation, should be pro-
tected by BLITZDUCTOR XT.
Care should be taken that the
nominal current of the pro-
tective devices is not exceed-
ed. In case of nominal cur-
rents > 0.5 A, DEHNrail, Type
DR M 2P 30 protective device
has to be used alternatively.

The control and indication
unit is normally connected
to an exchange line of a
fixed-network operator (e.g.
Deutsche Telekom) by means
of a telephone dial unit. For
this application, the SPD type
BLITZDUCTOR XT, BXT ML4
BD 180 is suitable (see also
Chapter 9.14 "Surge protec-
tion for telecommunications
accesses").

The surge protection of the
power supply is important,
too. It is recommended to use
DEHNguard modular surge
protective devices here (see
Table 9.9.2).

For alarm systems, which are
certified by the German
Insurance Association, (sys-
tems recognised by VdS), the
manufacturer of the alarm
system should be contacted.
The installations as well as
the lightning and surge pro-
tection equipment have to be
set up in accordance with VdS
2095, VdS 2311 or VdS 2833.
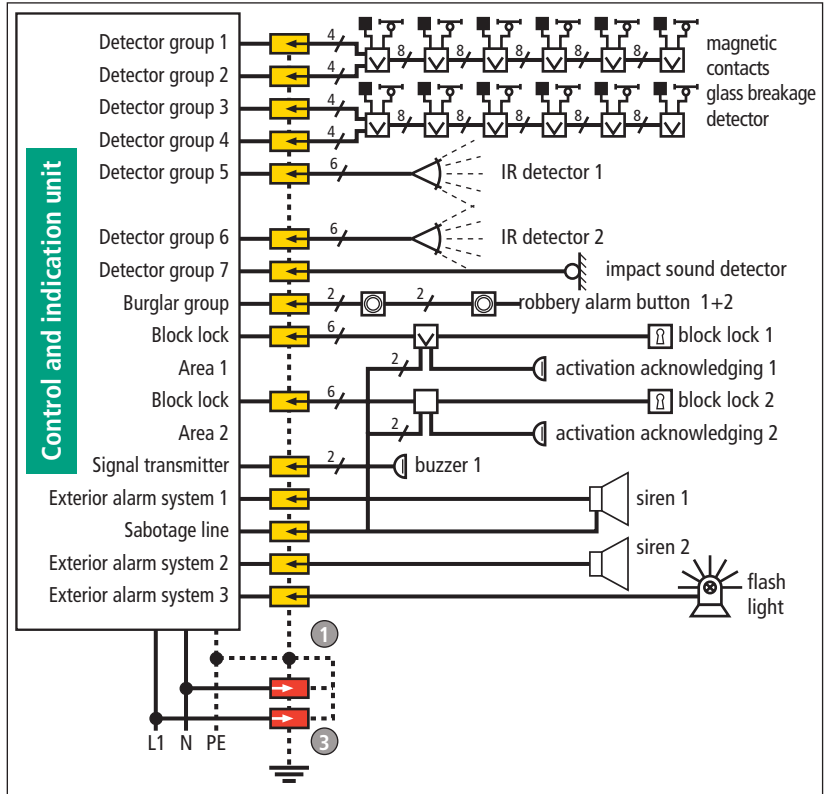
Fig. 9.9.1   Lightning and surge protection for the control unit of a burglar alarm system with
impulse line technology
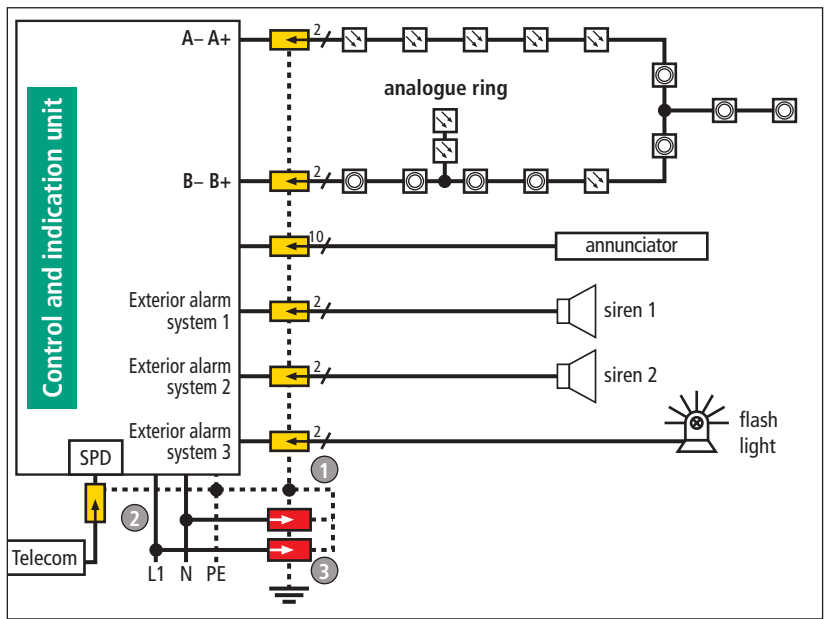
Fig. 9.9.2   Lightning and surge protection for the control unit of a fire alarm system – Analogue ring

No.	Protective device BLITZDUCTOR XT ...	Short definition Four pole, universal device as terminal block for protection of IT systems and devices consisting of a base part and a protection module with integrated LifeCheck	Part No.
1	BXT ML4 BE 12 or BXT ML4 BE 24 + BXT BAS	Combined lightning current and surge arrester for use in the EMC-orientated lightning protection zones concept at the boundaries **LPZ 0_A to LPZ 1 or LPZ 0_A to LPZ 2**	920 322 or 920 324 + 920 300
2	BXT ML4 BD 180 + BXT BAS	Combined lightning current and surge arrester for use in the EMC-orientated lightning protection zones concept at the boundaries **LPZ 0_A to LPZ 1 or LPZ 0_A to LPZ 2**	920 347 + 920 300

Table 9.9.1   Short definition of the SPDs
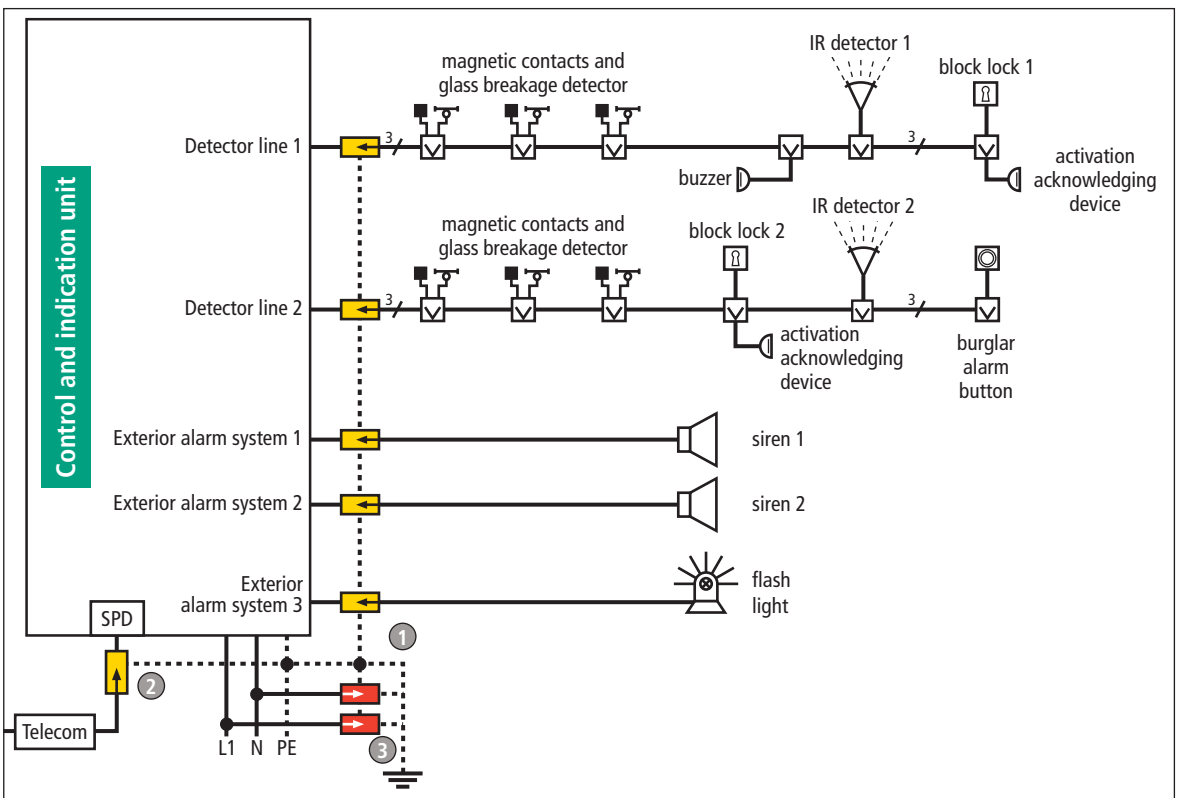
Fig. 9.9.3   Lightning and surge protection for the control unit of a burglar alarm system with d.c. line technology

As an example, the enclosed diagrams contain a proposal for surge protection of fire alarm and burglar alarm control and indication units, which are operated on the principle of d.c. line technology or pulse engineering.

If the fire and burglar alarm post and the control unit shall be integrated into a lightning protection system, then all lines entering the building shall be connected with lightning current arresters or combined lightning current and surge arresters. See **Tables 9.9.1** and **9.9.2**.

A distinct increase of the operational reliability of these systems can be reached with specific light-

No.	Multi pole, modular combined lightning current and surge arrester, Type 1 (LPZ 0_A – LPZ 2)		
	Protection for ...	**SPDs**	**Part No.**
	TN system	DEHNventil DV M TN 255	951 200
	TT system	DEHNventil DV M TT 2P 255	951 110
	Multi pole, modular surge arrester, Type 2 (LPZ 0_B – LPZ 1 and higher)		
	Protection for ...	**SPDs**	**Part No.**
③	3-phase TN-C system	DEHNguard DG M TNC 275	952 300
	3-phase TN-S system	DEHNguard DG M TNS 275	952 400
	3-phase TT system	DEHNguard DG M TT 275	952 310
	Single-phase TN-S system	DEHNguard DG M TN 275	952 200
	Single-phase TN-C system	DEHNguard DG S 275	952 070
	Single-phase TT system	DEHNguard DG M TT 2P 275	952 110

Table 9.9.2   Selection of SPDs
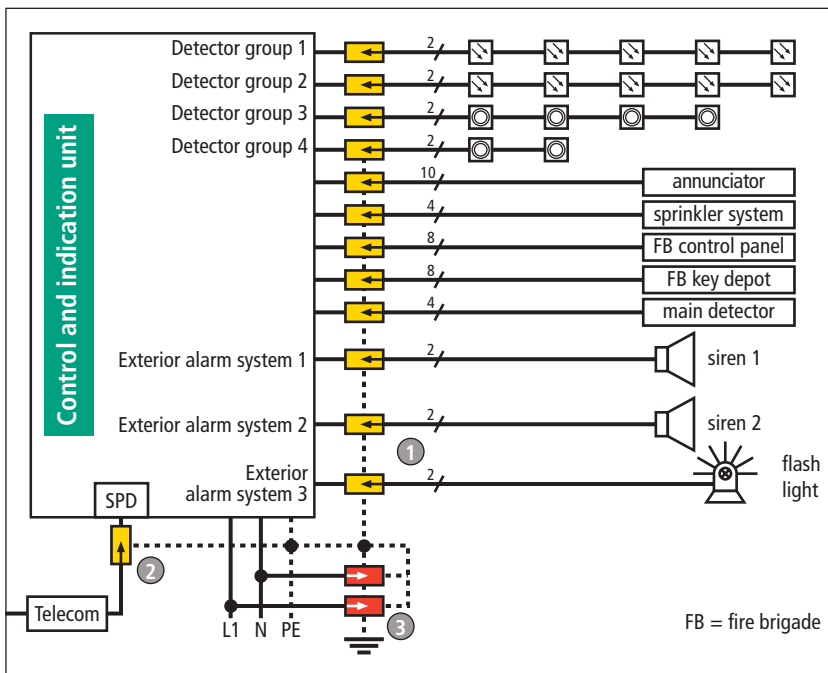
Fig. 9.9.4   Lightning and surge protection for the control unit of a fire alarm system with d.c. line technology

ning and surge protection of hazard alert systems. On the one hand, this refers to the prevention of false alarms when no danger exists, and on the other, costs eventually arising from this, can be prevented. This again, allows an effective damage limitation by informing the auxiliary personnel reliably. This counteracts a possible formation of catastrophic conditions (e.g. danger to human lives, pollution of the environment, etc.). Notice that in case of injuries to persons or environmental damage, the operator of a plant is liable first. This comprehensive responsibility for security can normally be expected from managers or executives of a company. However, in the legal sense, an operator of a plant is a technical layman, who is not able to estimate, if threats can arise from a technical solution. Therefore, skilled persons as suppliers of technical solutions must ensure in each individual case, that the solutions offered also correspond to the actual requirements. Retreating to the accepted rules of technology is not sufficient, if the state of the art already describes a higher quality solution. This may entitle a technical layman (plant operator) to claim recourses.

Regardless of the fact, whether fire alarm systems are VdS-approved systems or not, they should be furnished with a surge protection.

9.10 Lightning and surge protection for KNX systems

Fig. 9.10.1   Application of the BUStector (Part No. 925 001)

In modern office buildings and public utilities, like schools, KNX bus systems are used for the automation of sequences of operations of the building control system. KNX offers the possibility to realise complex processes with a single, upwards compatible system. However, this future-proof investment can be quickly destroyed by lightning discharges. Then, the building automation is not available and further costs are caused by replacement and reconfiguration of the system. Therefore, measures shall be taken against the direct and indirect effects of a lightning discharge when designing and installing such complex systems (**Figure 9.10.1**).

Lightning protection or surge protection?

Basic conditions must be considered when choosing the surge arresters correctly. This does not only include the system-specific electric data, like nominal voltage, nominal current, frequency, but also the threat parameters, which must be controlled. It makes a difference, if the risk of direct lightning strikes into buildings, where the KNX is installed, must be considered when designing the protective measures, or if safety against surges is desired only. If direct lightning strikes and the high destruction potential involved should be handled properly, the infrastructure of the KNX system must be designed according to the lightning protection zones concept. The lightning protection zones concept is standardised in IEC 62305-4 (EN 62305-4) and describes the protective measures against lightning electromagnetic impulses. An important part is the classification of the infrastructure to be protected in lightning protection zones. The higher the ordinal number of the lightning protection zones, the smaller must be the electromagnetic threat parameters. Electrical and electronic systems like the KNX system have to be classified in accordance with their electromagnetic immunity into lightning protection zones, which also offer an electromagnetic environment in case of a direct lightning strike to ensure that the equipment continues to function without getting disturbed or even destroyed.

If an external lightning protection system is installed in accordance with IEC 62305-3 (EN 62305-3), an effective lightning and surge protection is necessary and is to be implemented for the KNX according to the lightning protection zones concept. Within the context of KNX systems, the measures taken are often called primary and secondary protective measures.

If the aim of the protective measures is only the protection against surges (secondary protection), the hazard potential of a direct lightning strike is not taken into account. In the case of a direct or very near lightning strike into buildings with built-in KNX, damage must be expected there. Only interferences resulting from inductive or capacitive coupling, as they occur during lightning discharges some kilometres away or during switching operations, can be controlled. Lightning discharges create electromagnetic interference fields, which can cause dangerously high voltages and currents in installation loops.

Cabling between buildings

In an extended building complex, which is equipped with a lightning protection system, a KNX installation shall be integrated and protected against transient surges. A gatehouse is approximately 50 m away from a main building. Both buildings are equipped with a lightning protection system. Since the gatehouse is connected to the KNX installation of the main building via a bus line, measures for internal lightning protection must be taken both for the 230/400 V line as well as for the bus line.

General conditions 1:
Connecting the two buildings with a buried cable (copper cable).
Solution 1: Figure 9.10.2, Table 9.10.1

General conditions 2:
Connection of the two buildings with cable and lines in a supply duct, the reinforcement of which is integrated into the equipotential bonding at both ends. This condition is also fulfilled by an earthing strip steel 50 mm² laid upon the buried cables and connected to the equipotential bonding bar at both ends.
Solution 2: Figure 9.10.3, Table 9.10.1

General conditions 3:
The KNX connection between both buildings is achieved via an optical fibre connection (OFC). If the fibre-optic cable has a metal braid inside the cable (protection against rodents), this braid has to be connected to the equipotential bonding at the point where it enters the building.
Solution 3: Figure 9.10.4, Table 9.10.1

For the design and implementation of an KNX system, it is absolutely necessary that designers and contractors take appropriate measures for the correct operation of such a system. Of particular con-

No.	Protection for ...	SPDs	Part No.
1	3-phase TN-C system 3-phase TN-S system 3-phase TT system	DEHNventil DV M TNC 255 DEHNventil DV M TNS 255 DEHNventil DV M TT 255	951 300 951 400 951 310
2		BLITZDUCTOR XT, Typ BXT ML4 BD 180 + BXT BAS	920 347 920 300
3	3-phase TN-C system 3-phase TN-S system 3-phase TT system	DEHNguard DG M TNC 275 DEHNguard DG M TNS 275 DEHNguard DG M TT 275	952 300 952 400 952 310
4		BUStector BT 24	925 001

Table 9.10.1   Short description of the SPDs
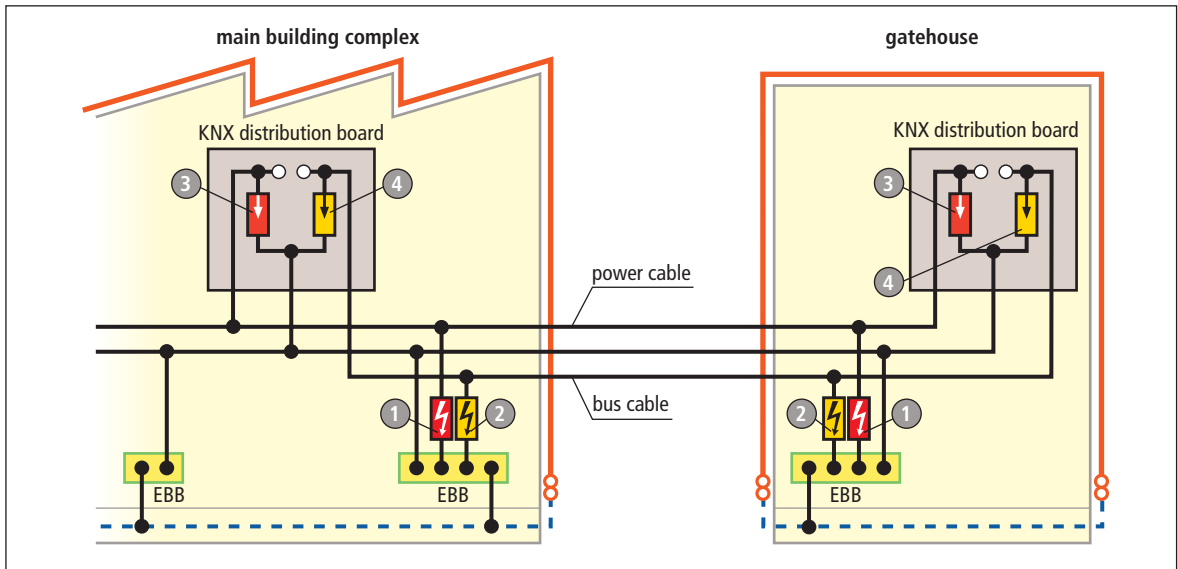
Fig. 9.10.2   Lightning and surge protection for cabling systems installed between buildings without interconnection of the foundation earth electrodes
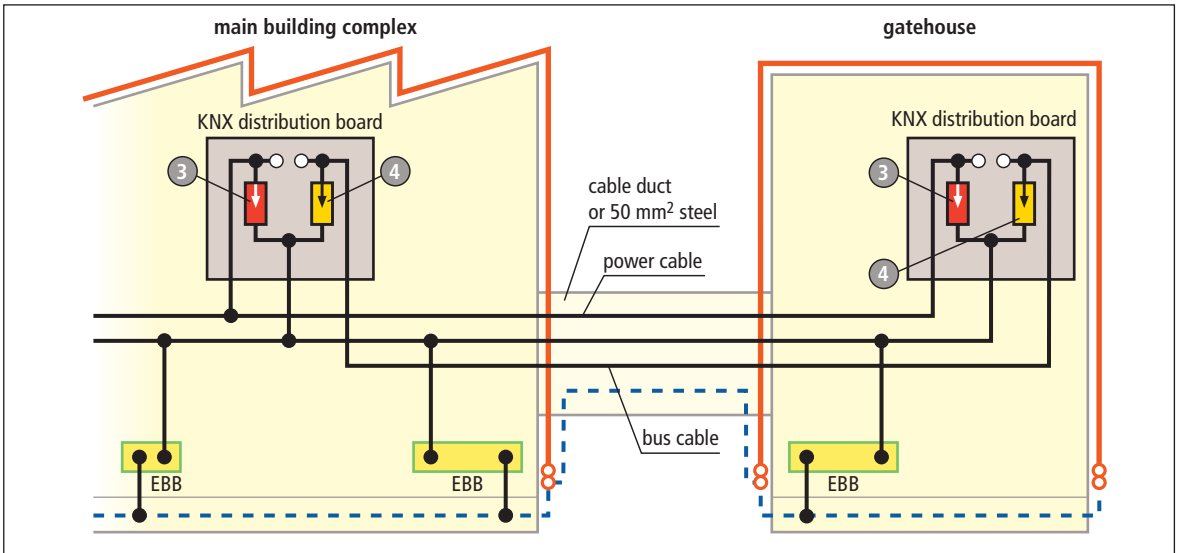
Fig. 9.10.3   Lightning and surge protection for cabling systems installed between buildings with interconnection of the foundation earth electrodes
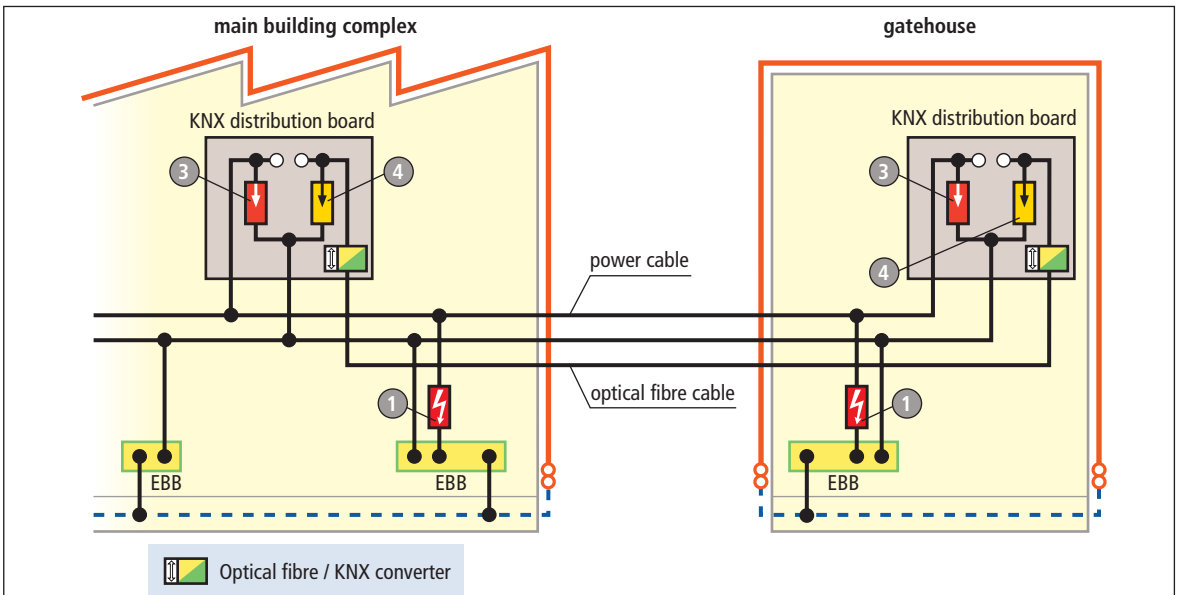
Fig. 9.10.4   Lightning and surge protection for cabling systems installed between buildings without interconnection of the foundation earth electrodes, with KNX optical fibre cabling

cern should be into which surroundings the KNX system is integrated and installed. Interfaces to other infrastructures, like low-voltage systems, telecommunications and data systems have to be protected against interferences or even destruction as the KNX itself.

Proper lightning protection systems and surge protection systems and the corresponding surge protective devices are available for protection against the effects of interferences. These can protect the future-proof KNX building installation cost-effectively due to technical and economic considerations during the design and by expert installation.

9.11 Surge protection for Ethernet and Fast Ethernet networks

Surges not only cause malfunctions but also destructions and thus, failures of computer systems, by which the operation can be persistently impaired because of longer down times. Besides a protected power supply and data backup, the reliable utilisation of computer systems also requires protection concepts against surges.

Causes of damage

Failures of computer systems are typically caused by

⇒ distant lightning strikes generating conducted transient overvoltages in power supply lines, data lines, or communication lines

⇒ close lightning strikes generating electromagnetic fields, by which transient surges are induced in power supply lines, data lines, or communication lines

⇒ direct lightning strikes creating impermissible potential differences and partial lightning currents in the building installations.

Choice of surge protective devices

For an effective surge protection it is necessary that the measures for the different systems are coordinated by the involved experts like electrical engineering technicians, computer specialists and telecommunications technicians as well as the manufacturer. In case of bigger projects, it is necessary to consult an expert (e.g. from an engineering company).

Protection of the power equipment

Figure 9.11.1 shows an administration building as an example. For the power supply, lightning current arresters Type 1 (e.g. DEHNbloc Maxi) and SPDs Type 2 (e.g. DEHNguard modular) can be

No.	SPD	Type	Part No.
1	DEHNbloc Maxi	DBM 1 255	900 025
2	DEHNrapid LSA	DRL 10 B 180 FSD	907 401
	Disconnection block	TL2 10 DA LSA	907 996
	Mounting frame for term. blocks 10 x 10 TC	MB2 10 LSA	907 995
3	Equipotential bonding bar	K12	563 200
4	DEHNguard modular	DG M TNS 275	952 400
5	DEHNrail modular	DR M 2P 255	953 200
6	DEHNpatch	DPA M CAT6 RJ45H 48	929 110
7	DEHNlink (upstream splitter)	DLI TC 1 I	929 027
8	SFL-Protector	SFL PRO	912 260
9	NET-Protector for 8 x 2 DA	NET PRO TC 2 LSA	929 072
	19" bay	EG NET PRO 19"	929 034
10	DEHNflex M	DFL M 255	924 396
11	Telephone protection module DSM	DSM TC 1 SK	924 271
12	DATA-Protector	DATA PRO 4TP	909 955

Fig. 9.11.1   Administration building with highly available installation parts

installed. DEHNrail, SFL-Protector, or DEHNflex M, for example, can be used for protection of the terminal equipment.

Protection of the data and telephone lines
Whether data or voice transmission is concerned, both require appropriate protective components for safe operation. Even if fibre optic cables between building distributors and floor distributors are the standard practice, copper wires are still used between the floor distributor and the terminal equipment. Therefore, it is necessary to protect active components with DEHNpatch for example. Terminal equipment should also be protected for example by DEHNpatch.

9.12 Surge protection for M-Bus

M-Bus is used for the transmission of readings from consumption meters. All devices connected to an M-Bus system can be read off centrally, either directly on the spot or per data transmission from an external head office. This increases the housing quality of the tenants, and the energy budget of an entire building can be controlled anytime.

The following describes surge protective measures that meet the availability claim of this system.

The M-Bus

The M-Bus (meter bus) is a cost-optimised field bus for the transmission of energy consumption data. As shown in **Figure 9.12.1**, a central master (in the simplest case a PC with a level converter downstream of the PC) communicates via a two-wire bus with the units sharing the bus. Using M-Bus repeaters, the installation can be divided in M-Bus segments. Each segment can include up to 250 slaves like heat counters, water meters, power meters, gas meters, and also sensors and actuators of any type. More and more manufacturers implement the electric M-Bus interface including protocol layer into their consumption meters.

The M-Bus corresponds to European standard and is described in standard EN 1434.

Previously, the energy data of individual buildings were transferred via on-wire connections from the network to the master station. Frequently, in case of widespread building complexes, the data is transmitted via a modem connection.

The M-Bus system is used for the consumption cost accounting and remote monitoring of
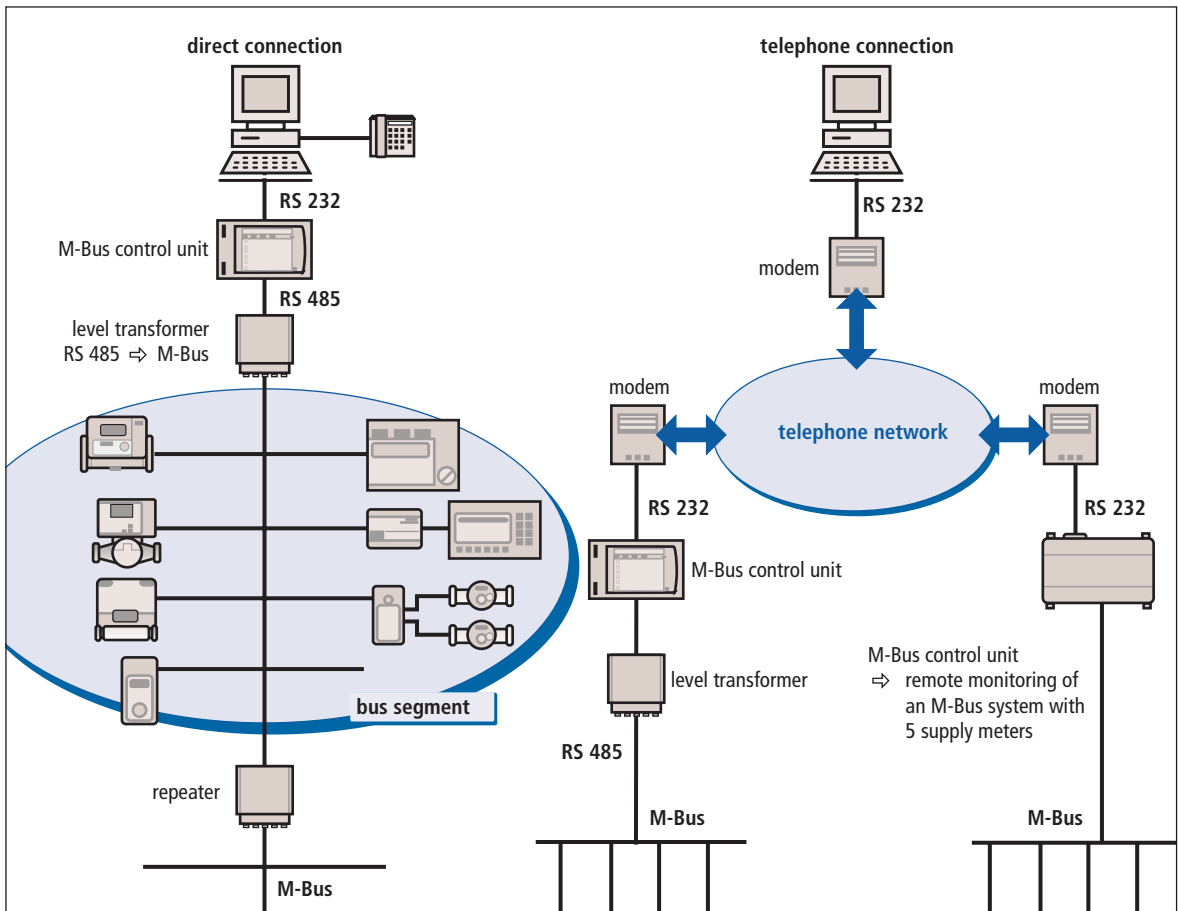
Fig. 9.12.1   Example of an M-Bus system

Total capacity M-Bus segment	Max. data transmision rate
up to 382 nF	9600 Baud
up to 1528 nF	2400 Baud
up to 12222 nF	300 Baud

Table 9.12.1   Max. data transmission rate

⇒ local and district heating systems

⇒ multifamily residences

The readout of the supply meters can be performed by central and decentralised systems. If the supply meters are situated immediately close, the simple and economical central system network architecture is chosen. This includes a star-shaped connection of each individual meter to the control centre. In case of a decentralised system, the data of the meters installed on the spot is first collected in substations and is then sent via a bus line to the control centre.

The M-Bus is a two-wire bus system, which is powered by an isolated supply source from the bus master. For all other units sharing the M-Bus, no reference to the ground may be created during operation. The maximum bus voltage amounts to 42 V.

The expansion of the network as well as the maximum bit rate is limited by the number of M-Bus devices, the protective wiring, the cable routing, and the cable types used.
The total sum of all cables as well as of the connected M-Bus devices and of protective wirings creates a capacitance in the M-Bus segment. This capacitance restricts the baud rate.

The maximum baud rate per M-Bus segment can be determined by means of the following table (**Table 9.12.1**).

If surge protective devices are used, the capacitances and series impedances of the surge protective devices must be considered and taken into account when defining the network clients. The following tables show the capacitances and the series impedances of the surge protective devices (**Table 9.12.2**).

Choice of surge protective devices for M-Bus systems
For establishing an M-Bus system, the bus lines are also installed outside the buildings. Therefore, the devices are exposed to the danger of destruction by transient surges of lightning discharges and must be protected accordingly. In the following, the surge protective circuit for M-Bus systems is described in detail considering two applications.

Example of application: Building with external lightning protection system
If a building has an external lightning protection system, the lightning equipotential bonding must be implemented. This comprises connecting of the lightning protection system to pipelines, metal installations within the building and the earth-termination system. In addition, all earthed parts of the power supply and data processing systems must be integrated into the lightning equipotential bonding. All live lines of power supply and data processing cables and lines entering and coming out of the building or structure are indirectly connected to the lightning equipotential bonding via lightning current arresters. If no lightning current arresters are installed at the service entrance of the building (for example in the low-voltage

SPDs		Part No.	Capacity: line/line	Series impedance per line
BLITZDUCTOR CT	BCT MLC BD 48	919 345	≤ 0.6 nF	2.2 Ω
BLITZDUCTOR CT	BCT MLC BE 24	919 323	≤ 0.7 nF	2.2 Ω
BLITZDUCTOR CT	BCT MLC BE 5	919 320	≤ 3 nF	1.4 Ω
DEHNconnect	DCO RK MD 48	919 942	≤ 0.6 nF	0.4 Ω
DEHNconnect	DCO RK ME 24	919 921	≤ 0.5 nF	1.8 Ω
DEHNconnect	DCO RK MD HF 5	919 970	≤ 19 pF	1 Ω

Table 9.12.2   Capacitances and series impedances of surge protective devices

consumer's installation of the low-voltage main distribution), the operator must be informed that these must be added.

Further measures for protection of electrical installations and systems include installing of surge protective measures. These measures also allow the protection of the electrical installations and systems in the event of a direct lightning strike as additional measure to the lightning equipotential bonding.

If lightning equipotential bonding and the installation of surge protective measures are implemented as carefully as the external lightning protection system, this contributes to a reliable performance of electrical systems. Failures, even in the event of direct lightning strikes, are reduced.

Cascaded use of lightning current and surge arresters

Energy coordination is the principle of a cascaded application of lightning current and surge arresters. Energy coordination is usually achieved by the impedance of the connecting cable of at least 15 m length between the SPDs. If this is not possible, the surge protection concept can be individually adjusted to the requirements of the system by the installation of coordinated lightning current arresters DEHNbloc Maxi and of DEHNguard surge arresters.

Another possibility is using DEHNventil. This combined SPD unites lightning current and surge arrester in one device, requires no decoupling coil, and is available as complete prewired unit for every low-voltage (TN-C, TN-S, TT) system (**Table 9.12.3**).
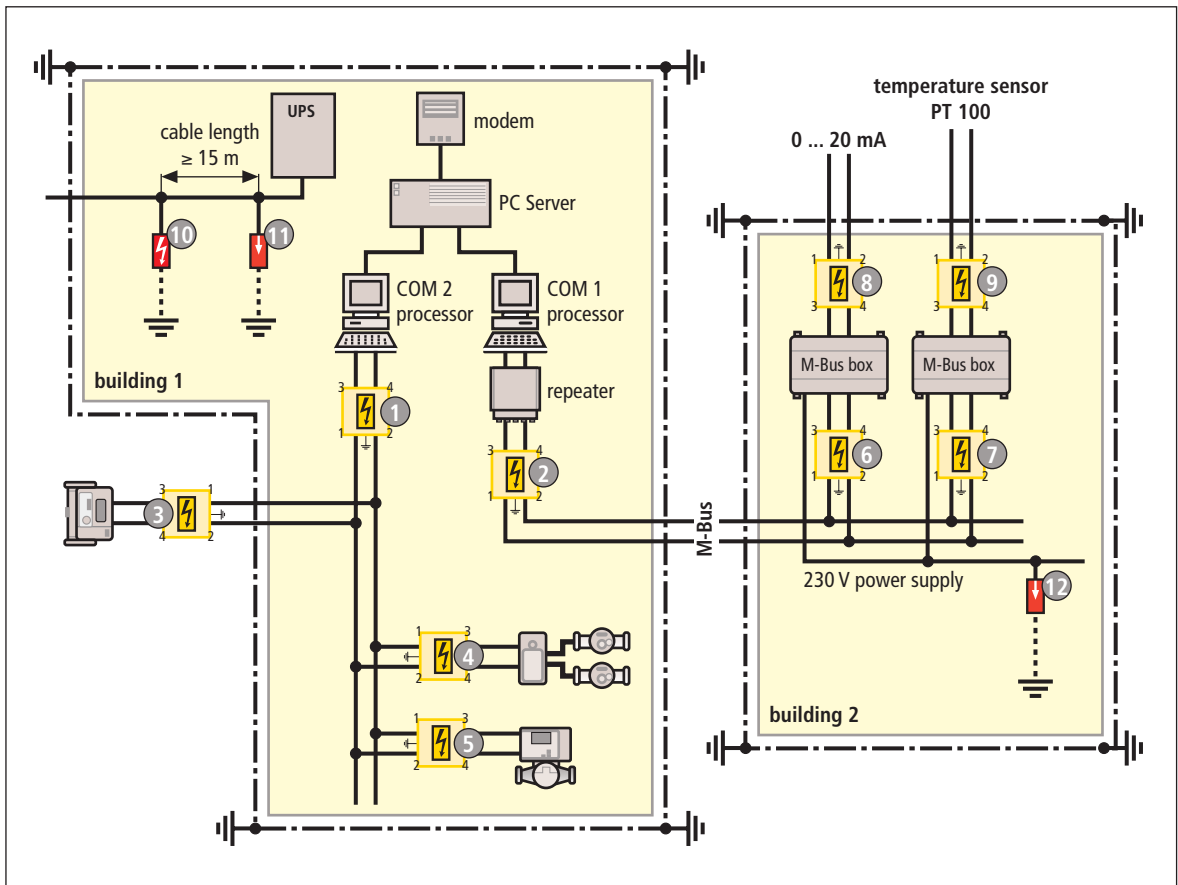
Fig. 9.12.2   Protection concept for M-Bus systems in buildings with external lightning protection system

No. in Fig. 9.12.2	Protection for ...	SPDs	Part No.
⑩	3-phase TN-C system	DEHNventil DV M TNC 255	951 300
	3-phase TN-S system	DEHNventil DV M TNS 255	**951 400**
	3-phase TT system	DEHNventil DV M TT 255	951 310
	Single-phase TN system	DEHNventil DV M TN 255	951 200
	Single-phase TT system	DEHNventil DV M TT 2P 255	**951 110**

Table 9.12.3   Selection of combined SPD with regard to the power supply system

No. in Fig. 9.12.2	Protection for ...	SPDs BLITZDUCTOR CT Type	Part No.
① to ⑦	M-Bus	BCT MLC BD 48 + base part BCT BAS	919 345 + 919 506
⑧	0 – 20 mA, 4 – 20 mA	BCT MLC BE 24 + base part BCT BAS	919 323 + 919 506
⑨	temperature measure-ment PT 100, PT 1000	BCT MLC BE 5 + base part BCT BAS	919 320 + 919 560

Table 9.12.4   Surge protection for signal interfaces

No. in Fig. 9.12.2	Protection for ...	SPDs	Part No.
⑩	3-phase TN-C system	DEHNbloc DB 3 255 H – phase L1/L2/L3 to PEN	900 120
	3-phase TN-S system	DEHNbloc DB 3 255 H – phase L1/L2/L3 to PE + DEHNbloc DB 1 255 H – N to PE	900 120 900 222
	3-phase TT system	DEHNbloc DB 3 255 H – phase L1/L2/L3 to N + DEHNgap DGP BN 255 – N to PE	900 120 900 132
	Single-phase TN system	2 x DEHNbloc DB 1 255 H – phase L + N to PE	900 222
	Single-phase TT system	DEHNbloc DB 1 255 H – phase L to N + DEHNgap DGP BN 255 – N to PE	900 222 900 132
⑪ ⑫	3-phase TN-C system	DEHNguard DG M TNC 275	952 300
	3-phase TN-S system	DEHNguard DG M TNS 275	952 400
	3-phase TT system	DEHNguard DG M TT 275	952 310
	Single-phase TN system	DEHNguard DG M TN 275	952 200
	Single-phase TT system	DEHNguard DG M TT 2P 275	952 110

Table 9.12.5   Surge protection for the 230 V power supply

Up to cable lengths of ≤ 5 m between DEHNventil and terminal equipment, sufficient protection exists without additional surge protective devices. For greater cable lengths, additional surge protective devices have to be installed at terminal equipment, e.g. DEHNrail.

Tables 9.12.3, 9.12.4 and **9.12.5** list surge protective devices to be applied in accordance with the consecutive numbers in **Figure 9.12.2**.

Application example:

Building without external lightning protection system

Figure 9.12.3 shows an example how a networked M-Bus system must be wired in order to get an efficient protection against surges.

Tables 9.12.6 and **9.12.7** list the surge protective devices to be used.
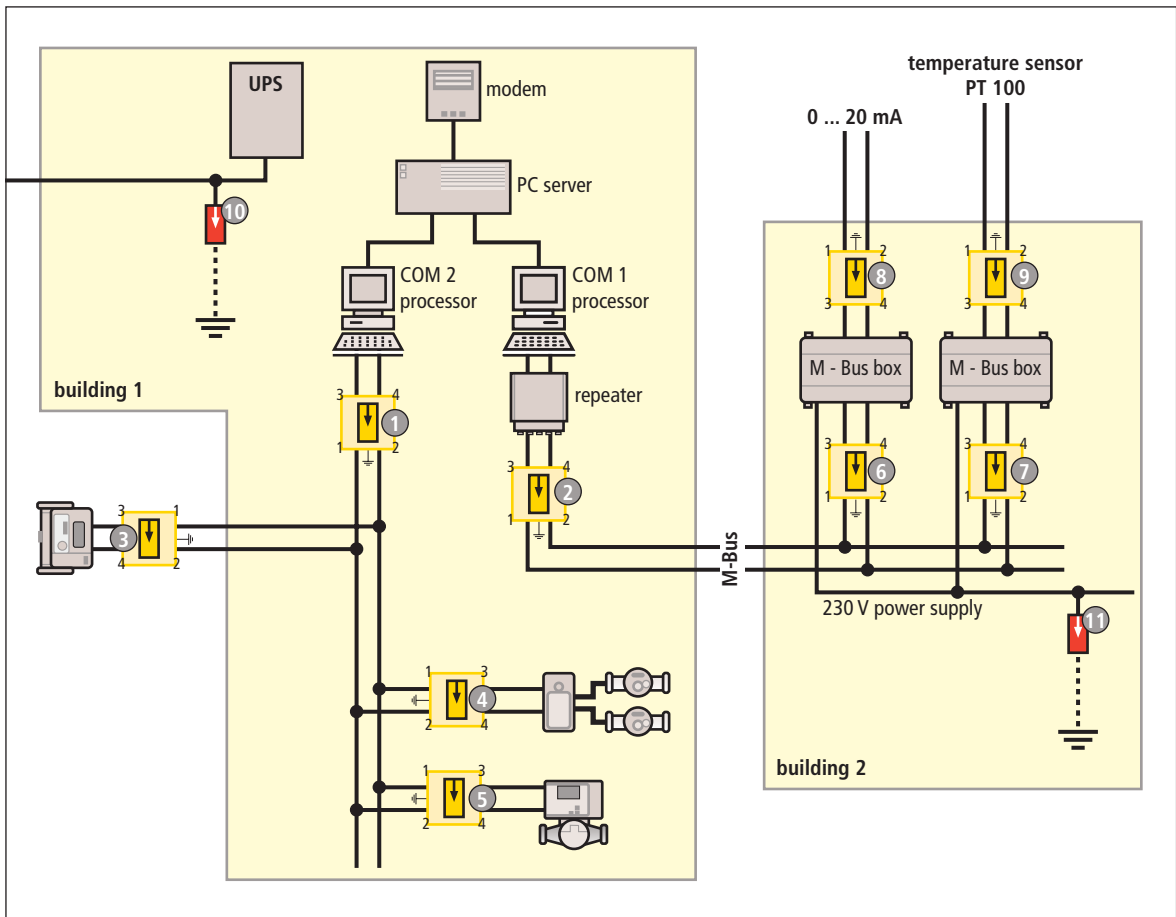
Fig. 9.12.3   Protection concept for M-Bus systems in buildings without external lightning protection system

No. in Fig. 9.12.3	Protection for ...	SPDs	Part No.
① to ⑦	M-Bus	DEHNconnect DCO RK MD 48	919 942
⑧	0 – 20 mA, 4 – 20 mA	DEHNconnect DCO RK ME 24	919 921
⑨	Temperature measurement PT 100, PT 1000	DEHNconnect DCO RK MD HF 5	919 970

Table 9.12.6   Surge protection for signal interfaces

No. in Fig. 9.12.3	Protection for ...	SPDs	Part No.
⑩ ⑪	3-phase TN-C-System	DEHNguard DG M TNC 275	952 300
	3-phase TN-S-System	DEHNguard DG M TNS 275	952 400
	3-phase TT-System	DEHNguard DG M TT 275	952 310
	Single-phase TN-System	DEHNguard DG M TN 275	952 200
	Single-phase TT-System	DEHNguard DG M TT 2P 275	952 110

Table 9.12.7   Surge protection for the power supply

9.13 Surge protection for PROFIBUS FMS, PROFIBUS DP, and PROFIBUS PA

The application of PROFIBUS as communications system in process-related and production-related fields as well as its use as multi-data cell and multi-object control medium results in high availability requirements on this bus system. These availability requirements face a high degree of surge risks due to the application sites.

PROFIBUS

Is the SIEMENS name for communication products (hardware/software) of the PROFIBUS standard (Process Field Bus) standardised in the German standard DIN 19245 and EN 50170. Alternative Siemens names for PROFIBUS FMS and PROFIBUS DP are SINEC L2 and SINEC L2-DP. While PROFIBUS FMS is designed for baud rates up to 500 kBit/s only, PROFIBUS DP is able to transfer data with a rate of up to 12 MBit/s. First of all, the main application of PROFIBUS FMS (SINEC L2) is the handling of big quantities of data at the process management and group control level. The fast PROFIBUS DP is designed for applications in the field of the decentralised periphery of programmable control systems.

The most recent development in the PROFIBUS segment is the intrinsically safe PROFIBUS PA, which, in process engineering, can also be used in areas where explosion hazards may occur.

A two-wire bus cable serves normally as transmission medium. The physical characteristics of the bus system essentially correspond to the RS 485 standard.

The bus sharing units can be connected in various ways:

⇒ Connection via 9-pin D subminiature plug (usual pin assignment 3/8)

⇒ Connection via screw terminals

⇒ Connection via bus terminals.

Selection of surge protective devices

Building with external lightning protection system

If a building has an external lightning protection system, lightning equipotential bonding must be implemented. This includes connecting the lightning protection system to pipelines, metal installations within the building, and the earthing system. Additionally, all earthed parts of the power supply and data processing systems must be integrated into the lightning equipotential bonding. All live wires of power supply and data processing cables and lines leading into and coming out of the structure are indirectly connected to the lightning equipotential bonding via lightning current arresters. If no lightning current arresters are installed in the low-voltage consumer's system, the operator must be informed that these have to be refitted.

Further measures for protection of electrical installations and systems include the installation of surge protection systems. As an additional measure to lightning equipotential bonding, these devices also allow the protection of electrical

No. in Fig. 9.13.1	SPD	DEHN-Type	Part No.
①	at service entrance	BLITZDUCTOR XT BXT ML4 B 180 + Base part BXT BAS	920 310 920 300
②	at bus station	BLITZDUCTOR XT BXT ML4 BE HF 5 + Base part BXT BAS	920 370 920 300

Table 9.13.1   Surge protection for bus lines of PROFIBUS DP/PROFIBUS FMS

No. in Fig. 9.13.2	SPD	DEHN-Type	Part No.
⑤	at bus station	BLITZDUCTOR XT BXT ML4 BD EX 24 + Base part BXT BAS EX	920 381 920 301
		or DEHNpipe DPI MD EX 24 M 2	929 960

Table 9.13.2   Surge protection for bus lines of PROFIBUS PA
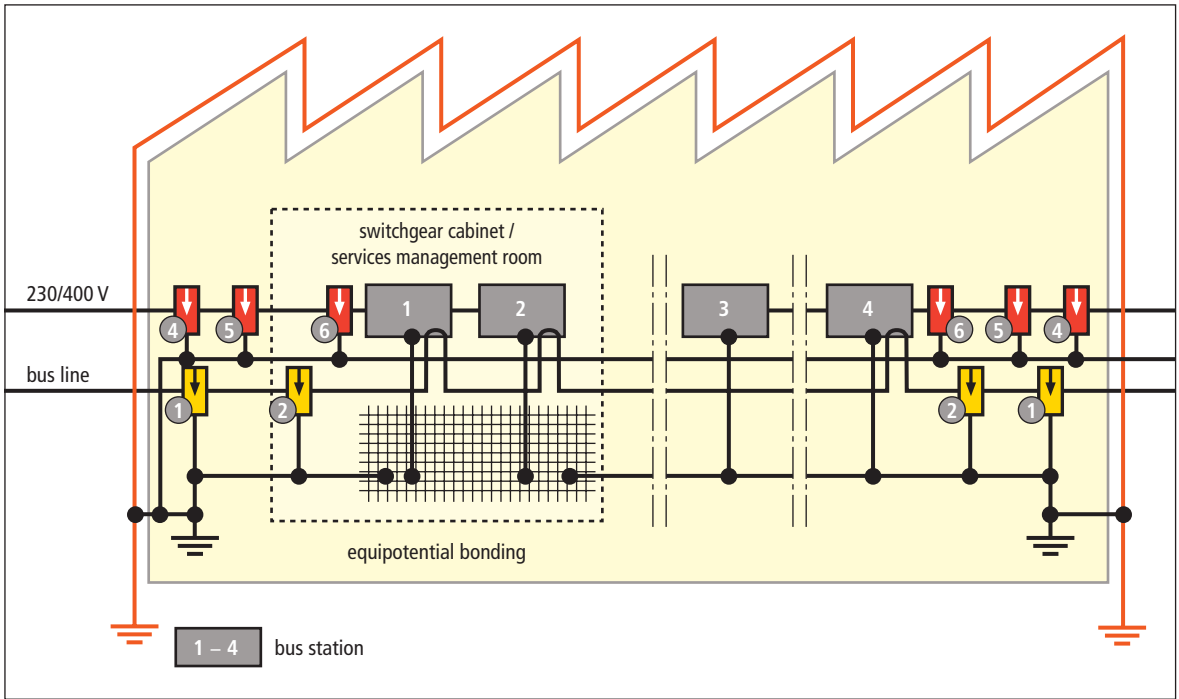
Fig. 9.13.1   Lightning and surge protection for SIMATIC Net PROFIBUS FMS and DP
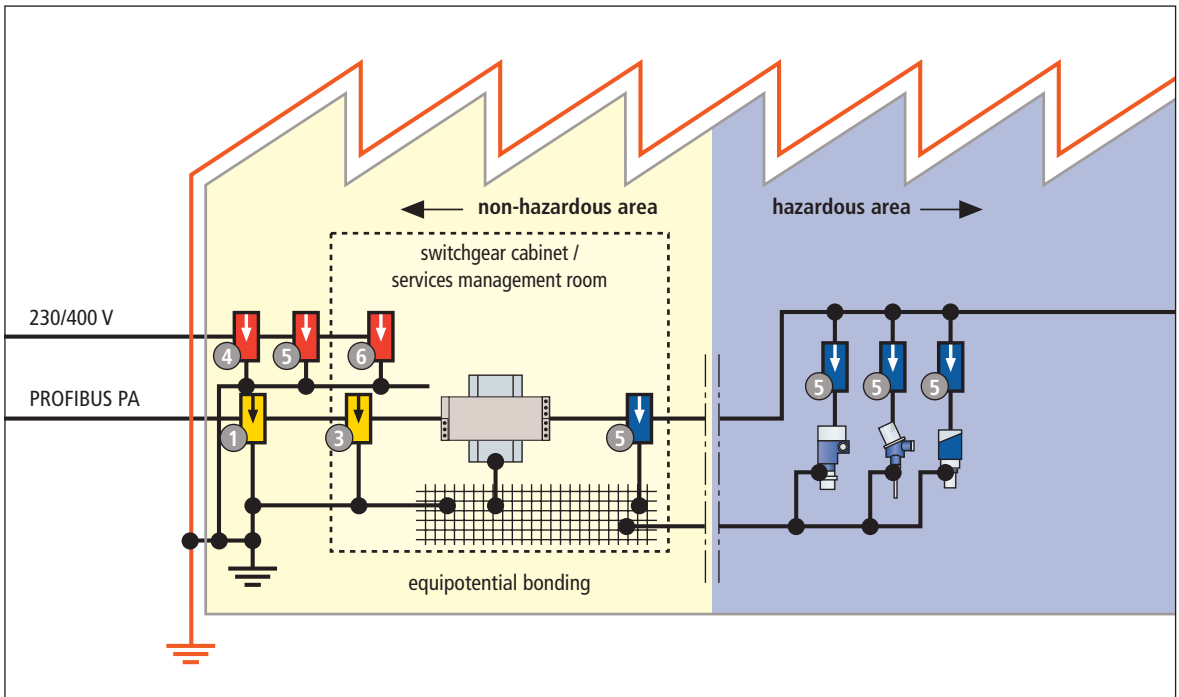
Fig. 9.13.2   Use of surge protective devices in an intrinsically safe PROFIBUS PA

No. in Fig. 9.13.1 und 9.13.2	Protection for ...	SPDs	Part No.
Combined arresters – Type 1			
④	3-phase TN-C system	DEHNventil DV M TNC 255	951 300
		DEHNventil DV M TNC 255 FM	951 305
	3-phase TN-S system	DEHNventil DV M TNS 255	951 400
		DEHNventil DV M TNS 255 FM	951 405
	3-phase TT system	DEHNventil DV M TT 255	951 310
		DEHNventil DV M TT 255 FM	951 315
	Single-phase TN system	DEHNventil DV M TN 255	951 200
		DEHNventil DV M TN 255 FM	951 205
	Single-phase TT system	DEHNventil DV M TT 2P 255	951 110
		DEHNventil DV M TT 2P 255 FM	951 115
Surge arresters – Type 2			
⑤	3-phase TN-C system	DEHNguard DG M TNC 275	952 300
		DEHNguard DG M TNC 275 FM	952 305
	3-phase TN-S system	DEHNguard DG M TNS 275	952 400
		DEHNguard DG M TNS 275 FM	952 405
	3-phase TT system	DEHNguard DG M TT 275	952 310
		DEHNguard DG M TT 275 FM	952 315
	Single-phase TN system	DEHNguard DG M TN 275	952 200
		DEHNguard DG M TN 275 FM	952 205
	Single-phase TT system	DEHNguard DG M TT 2P 275	952 110
		DEHNguard DG M TT 2P 275 FM	952 115
Surge arresters – Type 3			
⑥	for 230 V supply	DEHNrail DR M 2P 255	953 200
		DEHNrail DR M 2P 255 FM	953 205
	for 24 V d.c. supply	DEHNrail DR M 2P 30	953 201
		DEHNrail DR M 2P 30 FM	953 206

Table 9.13.3   Surge protection for power supply

installations and systems, even in case of a direct lightning strike.

If lightning equipotential bonding and the installation of surge protection systems are performed as carefully as the external lightning protection system, failures are reduced even at direct lightning strikes.

The 230/400 V a.c. supply lines going from outside to the low-voltage main distribution board will be protected by a DEHNventil modular, an SPD Type 1. This complete prewired unit is available for every low voltage system (TN-C, ,TN-S, TT) (**Table 9.13.3**). In addition to the operating state/fault indication which is not supplied by operating currents, this SPD Type 1 has a 3-pole terminal for remote signalling.

Up to conductor lengths of ≤ 5 m between DEHNventil and terminal equipment, there is sufficient protection without additional protective devices.

Longer conductors require additional surge protective devices at terminal equipment, e.g. DEHN-rail.

Tables 9.13.1 and **9.13.2** show surge protective devices for bus lines and **Table 9.13.3** lists the surge protective devices to be installed for the power supply.

Building without external lightning protection system
If there is no external lightning protection system, the bus sharing units must be connected to surge protective devices. Here, the use of lightning current arresters on the power supply and data cables is not required. In Figure **9.13.1** and **9.13.2** the combined arrester Type 1 with No. (4) on the power line nor the lightning current arrester with No. (1) on the bus line are not required.

9.14 Surge protection for telecommunication accesses

Beside the power supply line, telecommunication lines are the most important line connection to the outside. For the high-technological process in industrial plants and offices, an always functioning interface to the "outside world" is essential for survival today. The user faces difficult problems when this service is unavailable. The damage to one's image due to surge-related equipment trouble of the network termination NT (NTBA, NTPM, or data network terminating unit) is only one aspect of these incidents. High downtime costs arise for the user for a short time, since customer's orders can not be handled, for example, or company records can only be updated locally, and can no longer be provided nationwide. Regarding the question of protection-worthiness, the focus is not on the protection of the hardware but on the permanent availability of an important service by the fixed-network operator.

According to the statistics of the damage insurers of electronic devices, the most frequent cause of damage are surges.

The most relevant type of the formation is the surge caused by direct or distant lightning effects. Surges due to direct lightning strikes into a building or structure is the severest load but the rarer case.

Telecommunication lines often cover a surface of a few km² as network.

With a frequency of lightning strikes of approximately 1 to 5 lightning strikes per km² and year e.g. in Germany, frequent surge inductions have to be expected for large area networks.

A complete lightning protection system including external and internal lightning protection measures is the safest way to protect a building or structure against the effects of lightning discharges.

This total measure, however, is the duty of the owner of the structure and also comprises the complete lightning equipotential bonding within the internal lightning protection system and therefore also the protection of the telecommunication cables. This is described in the lightning protection standards IEC 62305-3 (EN 62305-3) and IEC 62305-4 (EN 62305-4).

The threat

The connecting cables to the local exchange as well as the internal house wiring is implemented by copper cables whose shielding effect is very low. By laying cables between several buildings, high potential differences can arise between the build-ing installation and the incoming cables. A potential increase on the wires by galvanic and inductive coupling has to be expected. When arranging power supply and communication lines in parallel, switching surges in the power mains can also cause interferences to the telecommunication lines. Proceeding from cases of damage in installations, surge protective devices were sought for the NT, which could also be installed subsequently.

A common customer preference, but also a question of reliability of the offered service, is the use of a surge protective circuit already at the input side in order to prevent the penetration of dangerous surges into the NT and via the NT. Surge protection for the a/b wires and the 230 V power supply of the modem is recommended. The same applies to telephone systems, where outputs to extensions must be additionally protected.

Surge protection for ADSL with analogue port or ISDN access

Requirements for an ADSL connection

Additionally to the conventional telephone extension, an ADSL connection requires, according to access version, a network interface card or ATM card in the PC and a particular ADSL modem plus a splitter for the separation of telephone and data communication traffic. The telephone extension can alternatively be installed with analogue or ISDN access.

The splitter separates the analogous voice signal or the digital ISDN signal of the ADSL data under consideration of all important system parameters like impedances, attenuation, levels, etc. Consequently it fulfils the function of a crossover network. The splitter is connected at its input side to the telephone outlet. At its output side, it provides the higher frequency signals of the ADSL frequency band for the ADSL modem on the one hand, and on the other hand, it controls the communication in the low frequency range with the NTBA or the analogous terminal equipment. Since the splitter should be compact and cost-effective, it is usually designed in passive form, i.e. without own power supply.

ADSL modems are manufactured in different types. External devices very often use a separate splitter. The ADSL modem is connected to the PC via an Ethernet (10 MBit/s), ATM25, or a USB interface. Additionally, the modem requires a 230 V supply voltage (**Figures 9.14.1** and **9.14.2**).

Surge protection for data transmission ISDN primary rate multiplex access

ISDN (Integrated Services Digital Network) is used to provide different services in a common public network. Both voice as well as data can be trans-ferred by digital transmission. A network termination unit (NT) is the transfer interface for the subscriber. The supply line of the digital local exchange is a 4-wire line. Additionally, the NT is powered with 230 V.

No.	Type	Part No.
1	**BLITZDUCTOR® XT** BXT ML4 BD 180 + BXT BAS	920 347 +920 300
	DRL DRL 10 B 180 FSD + DRL PD 180 + EF 10 DRL	907 401 +907 430 +907 498
2	**NT-Protector** NT PRO	909 958
3	**DATA-Protector** DATA PRO 4TP	909 955
4	**DEHNlink** DLI TC 1 I	929 027
	DSM DSM TC 1 SK	924 271
5	**DEHNguard® modular** DG M TNS 275	952 400

[1] **N**etwork **T**ermination
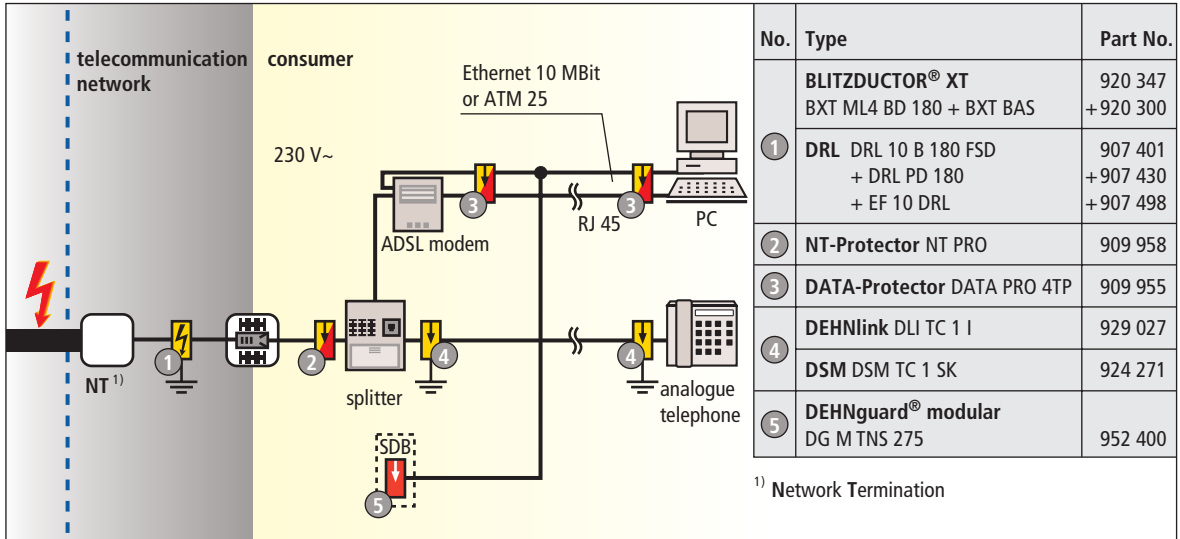
Fig. 9.14.1   Lightning and surge protection for ADSL with analogue connections

No.	Type	Part No.
1	**BLITZDUCTOR® XT** BXT ML4 BD 180 + BXT BAS	920 347 +920 300
	DRL DRL 10 B 180 FSD + DRL PD 180 + EF 10 DRL	907 401 +907 430 +907 498
2	**NT-Protector** NT PRO	909 958
3	**DATA-Protector** DATA PRO 4TP	909 955
4	**ISDN-Protector** ISDN PRO	909 954
5	**DEHNlink** DLI ISDN I **DSM** DSM IDSN SK	929 024 924 270
6	**DEHNguard® modular** DG M TNS 275	952 400

[1] **N**etwork **T**ermination
[2] **B**road **B**and **T**ermination **U**nit

*BLITZDUCTOR® CT and NT Protector have been officially approved by Deutsche Telekom for protection of NTBAs

Fig. 9.14.2   Lightning and surge protection for ISDN and ADSL connections

No.	Type	Part No.
1	**BLITZDUCTOR® XT** BXT ML4 BD HF 24 + BXT BAS	920 375 +920 300
1	**DRL** DRL 10 B 180 FSD + DRL HD 24 + EF 10 DRL	907 401 +907 470 +907 498
2	**DEHNlink** DLI TC 1 I	929 027
2	**DSM** DSM TC 1 SK	924 271
3	**DEHNguard® modular** DG M TNS 275	952 400
4	**SFL-Protector** SFL PRO	912 260

1) **N**etwork **T**ermination
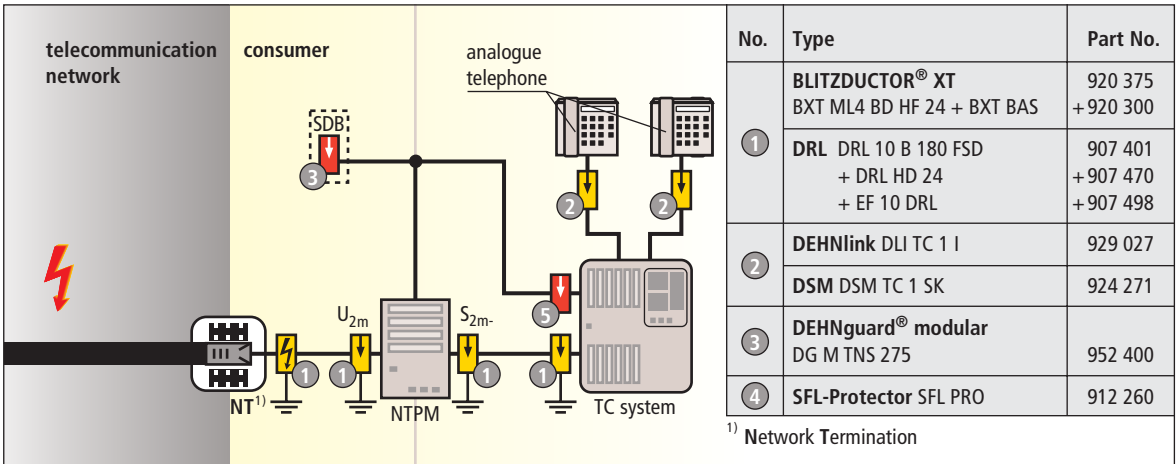
Fig. 9.14.3   Surge protection for telecommunications systems "ISDN Primary rate Multiplex access"

Figure 9.14.2 shows the protection of an ISDN connection with th corresponding surge protective devices.

The primary rate multiplex access
The **N**etwork **T**ermination for **P**rimary rate **M**ultiplex access (NTPM) has 30 B channels with 64 kBit/s and one D channel with 64 kBit/s. Via the primary rate access, data transmission can be handled up to 2 MBit/s. The NT is powered by the U_{2m} interface – the subscriber interface is called S_{2m}. PABX with a high number of extensions or data transmission lines with high data volumes are connected to this interface .

Figure 9.14.3 shows the protection of such a connection against surges.

9.15 Lightning and surge protection for intrinsically safe circuits

In chemical and petrochemical industrial plants, potentially explosive areas develop frequently during the manufacture, processing, storage, and transportation of flammable materials (e.g. gasoline, alcohol, liquid gas, explosive dust), where any source of ignition must be avoided to prevent explosions. Relevant protective provisions refer to the threat of atmospheric discharges (lightning) to such installations. Here it has to be considered that there is a fire risk and explosion hazard by direct or indirect lightning discharges due to the partially widespread extension of such installations.

To achieve necessary plant availability and also the necessary safety of the system, a conceptual action is necessary for protection of process-specific electric and electronic parts of the plant against lightning currents and surges.

Lightning Protection Zones Concept

Intrinsically safe circuits are often used in areas where explosion hazard may occur. **Figure 9.15.1** shows the principal design of such a system and the assignment in lightning protection zones. Due to the necessary, very high availability of the systems and in order to meet the high requirements on safety in the hazardous area, the following

areas were divided into lightning protection zone LPZ 1 and lightning protection zone LPZ 2:

⇒ Electronic evaluation unit in the control room (LPZ 2)

⇒ Temperature transducer at the tank (LPZ 1)

⇒ Interior of the tank (LPZ 1)

In accordance with the lightning protection zones concept according to IEC 62305-4 (EN 62305-4), all lines at the LPZ boundaries must be equipped with corresponding surge protective devices as described below.

External lightning protection

The external lightning protection system is the entire equipment installed and existing outside at or in the installation to be protected for interception and conducting the lightning current into the earth-termination system.

A lightning protection system for explosive areas corresponds to lightning protection system Class II at normal conditions. In well-founded, individual cases and under special conditions (legal provisions), or by the result of a risk analysis in accordance with IEC 62305-2 (EN 62305-2) it can differ from the standards.
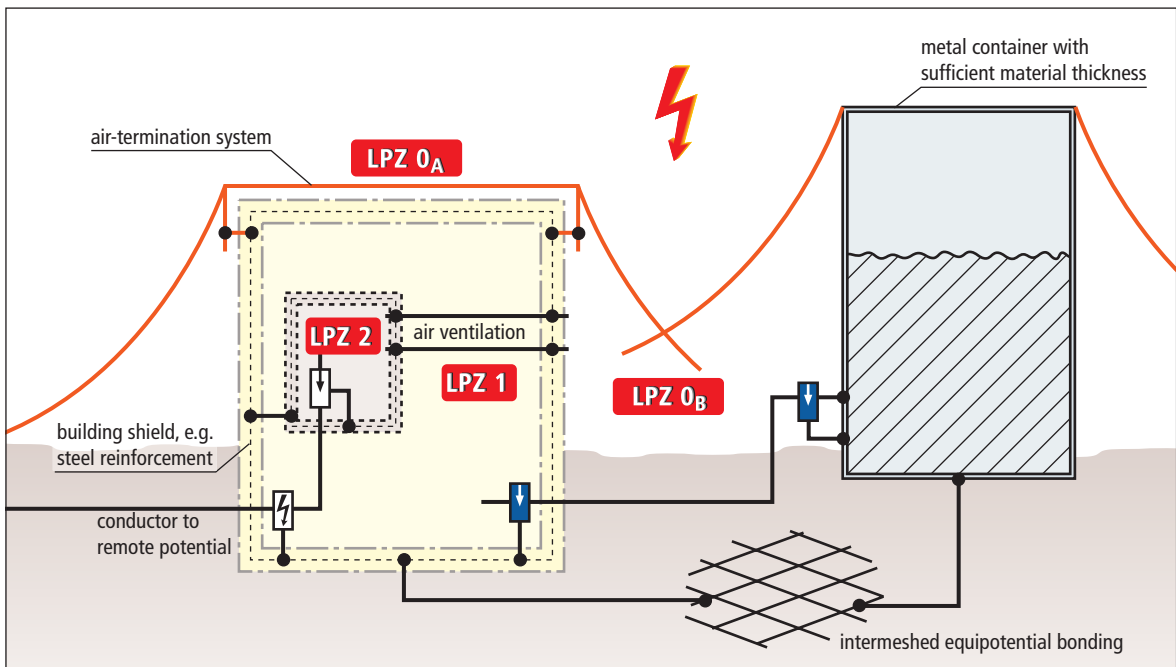
Fig. 9.15.1   Division of a hazardous location into lightning protection zones (LPZ)

In order to prevent direct lightning strikes to tank facilities they are very often protected by air-termination rods with additional air-termination cables in case of greater distances (**Figure 9.15.2**).

In any case, the following requirements are based on lightning protection system Class II. As with all lightning protection systems, the separation distance must also be maintained here.

Lightning equipotential bonding outside the hazardous area
The application of surge protective devices in the low voltage installation and for telecommunication lines outside the hazardous area (control room) shows no peculiarities with respect to other applications. In this context it should be noted that the surge protective devices for lines of LPZ 0_A to LPZ 1 (**Figures 9.15.3** and **9.15.4**) must have a lightning current discharge capacity, which is specified in test waveform 10/350 µs. The surge protective devices of the different requirement classes must be coordinated among each other.

Equipotential bonding
In all areas where explosion hazard may occur, a consistent equipotential bonding has to be implemented. Also building supports and parts of the construction, pipelines, containers, etc., must be included in the equipotential bonding so that a voltage difference must not be feared, even in the event of a failure. The connections of the equipotential bonding conductors must be secured against self-loosening. The equipotential bonding must be carefully realised, installed, and tested in compliance with IEC 60364-4-41, IEC 60364-5-54 and IEC 60364-6-61. Using surge protective devices of the BLITZDUCTOR product range, the cross section of the earth conductor for equipotential bonding must be at least 4 mm² Cu.

Surge protection in intrinsically safe circuits
Already during the design process, the lightning protection zones and hazardous areas shall be harmonised. The consequence is that the requirements both for use of surge protective devices in hazardous areas and at the LPZ boundaries must be met likewise. Thus, the installation site of the surge protective device was determined precisely. It is located at the boundary of LPZ 0_B and LPZ 1. This prevents the penetration of dangerous surges into Ex zone 0 or 20, since the surges are already
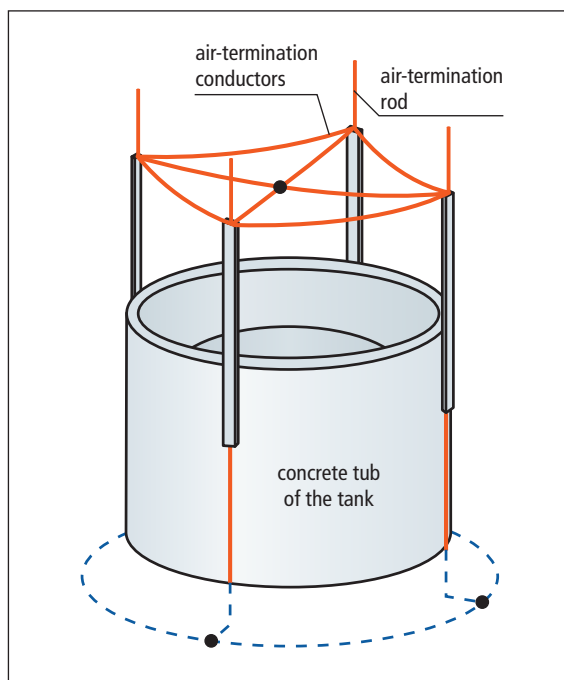
Fig. 9.15.2   Air-termination system for a tank with air-termination rods and conductors

discharged previously. Also, the availability of the temperature transmitter, which is important for the process, is considerably increased in this way. Furthermore, the requirements according to EN 60079-14 must be met (**Figure 9.15.5**):

⇒ Use of surge protective devices with a minimum discharge capacity of 10 impulses with 10 kA (8/20 µs), each without malfunction or impairment of the surge protective function (**Table 9.15.1**).

⇒ Mounting of the surge protective device into a metallic shielded enclosure and earthing with at least 4 mm² Cu.

⇒ Installation of the cables between the surge protective device and the equipment in a metal pipe earthed at both ends or the application of shielded cables with a maximum length of 1 m.

In accordance with the definition of the protection concept, the programmable controller in the control room is defined as LPZ 2. The intrinsically safe cable leaving the temperature transmitter is also led at the boundary from LPZ 0_B to LPZ 1 via a
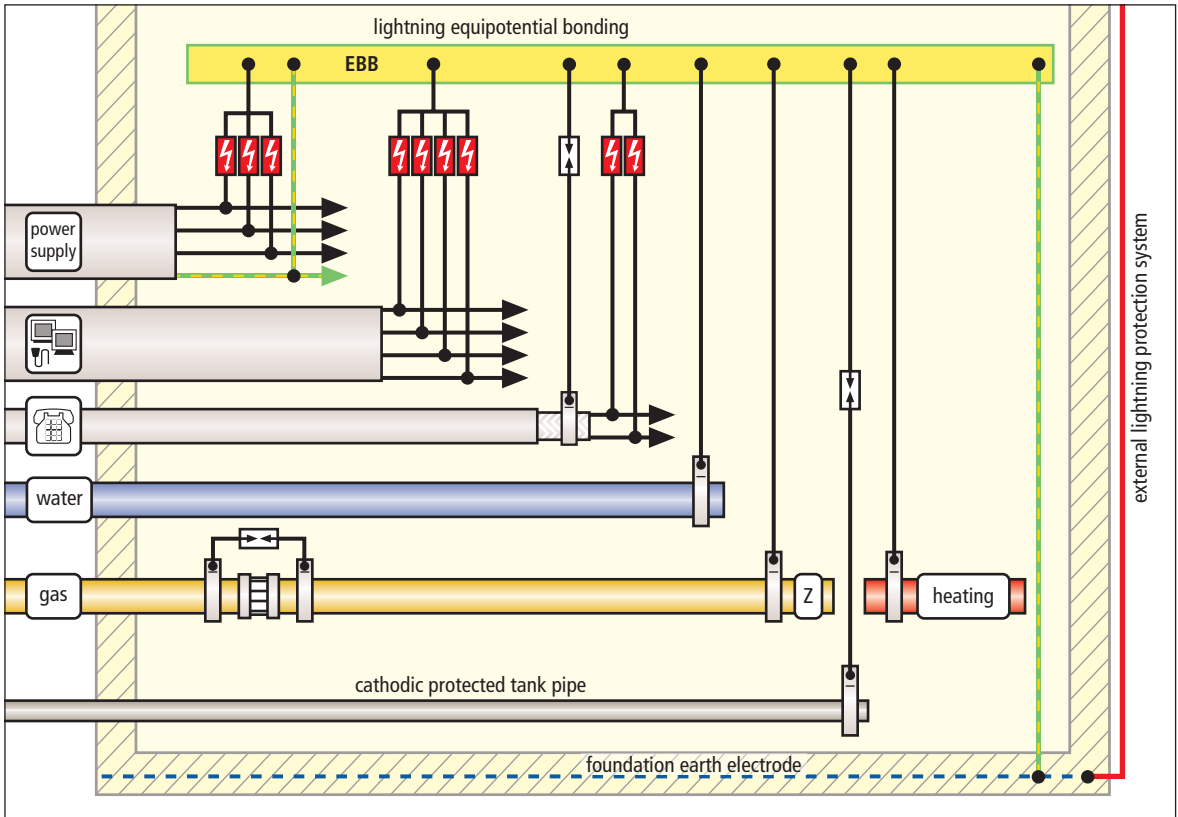
Fig. 9.15.3   Lightning equipotential bonding according to IEC 62305-3 (EN 62305-3) based on main equipotential bonding according to IEC 60364-4-41 and IEC 60364-5-54
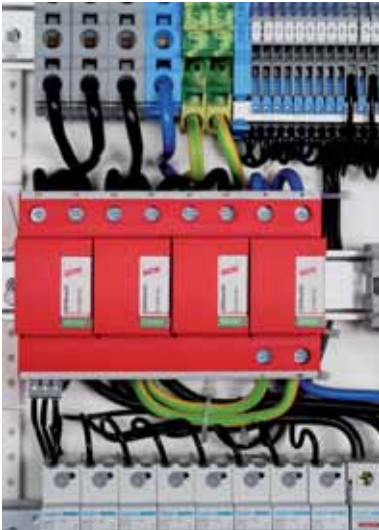
Fig. 9.15.4   DEHNventil DV TT 255 in a switchgear cabinet for protection of the power supply system
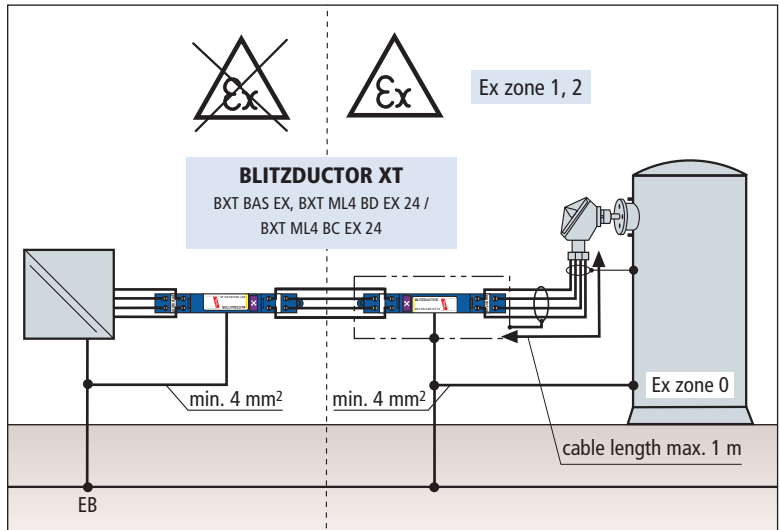
Fig. 9.15.5   Surge protective devices in intrinsically safe circuits

Technical data	Measuring transducer TH02	Surge protective device BCT MOD MD EX 30
Installation site	zone 1	zone 1
Type of protection	ib	ia
Voltage	U_i max. = 29.4 V d.c.	U_c = 34.8 V d.c.
Current	I_i max. = 130 mA	I_N = 500 mA
Frequency	f_{Hart} = 2200 Hz frequency-modulated	f_G = 6 MHz
Immunity	acc. to NE 21, e.g. 0.5 kV line/line	discharge capacity 10 kA (8/20 µs) Y/L SPD TYPE 2 P1
Test standards	ATEX, CE	ATEX, CE, IEC 61643-21
Isolated from earth 500V	Yes	Yes
Inner capacitance C_i	C_i = 15 nF	negligibly small
Inner inductance L_i	L_i = 220 µH	negligibly small

Table 9.15.1   Example of a temperature transducer

surge protective device BLITZDUCTOR CT, BCT MOD MD EX 24. This protective device at the other end of the field line between the buildings must have the same discharge capacity as the protective device installed at the tank. After the surge protective device, the intrinsically safe line is led via an isolation amplifier (**Figures 9.15.5** and **9.15.6**). From there, the shielded cable is laid to the programmable controller in LPZ 2. Because of the two-sided earth connection of the cable shield, no protective device is required at boundary LPZ 1 to LPZ 2, since the residual electromagnetic interference still to be expected is strongly attenuated by the cable shield earthed at both ends.

Criteria for the choice of surge protective devices in intrinsically safe circuits

The example treating a temperature transducer (**Table 9.15.1**) shows which aspects must be observed for choosing surge protective devices (SPD):

Insulation resistance of the equipment

In order to prevent measuring errors by compensating currents, the sensor signals from the tank are often isolated electrically. The transducer has an insulation resistance of < 500 V a.c. between the intrinsically safe 4 ... 20 mA current loop and the earthed temperature sensor. Consequently the equipment is considered as floating. The use of surge protective devices must not interfere with this isolation from earth.

If the transducer has an insulation resistance of < 500 V a.c., the intrinsically safe circuit is regarded as earthed. This requires protective devices, the voltage protection level of which is below the insulation resistance of the earthed transducer (e.g. U_p (wire/PG) ≤ 35 V) at a nominal discharge current of 10 kA (pulse shape 8/20 µs).

Type of protection (explosive atmoshperes): Intrinsic Safety – Category ia or ib ?

The transducer and the surge protective device are installed in protection zone LPZ 1 so that the category ib is sufficient for the 4 ... 20 mA current loop. The used surge protection fulfils the highest requirements in conformity with certification according to ia and consequently, is also suitable for ib applications.

Fig. 9.15.6   BCT MOD MD EX 24 for intrinsically safe circuits

Fig. 9.15.7   Surge arrester for field devices – DEHNpipe, DPI MD EX 24 M 2

Permissible maximum values for L_0 and C_0

Before an intrinsically safe circuit is put into operation, the proof of its intrinsic safety must be provided. For this purpose, the supply unit, the transducer, the used cables, as well as the surge protective devices must fulfil the interconnection conditions. If necessary, the inductances and capacitances of the protective devices must also be taken into consideration. In accordance with the EC type examination certificate (PTB 99 ATEX 2092), the internal capacitances and inductances are negligible in the surge protective device type BCT MOD MD EX 24 of DEHN + SÖHNE (**Figure 9.15.6**) and need not be taken into account when considering the interconnection conditions.

Maximum values for voltage U_i and current I_i

According to its technical specifications for intrinsically safe circuits, the transducer to be protected has a maximum supply voltage U_i and a maximum short-circuit current I_i (**Table 9.15.1**). The rated voltage U_c of the protective device must be at least as high as the open-circuit voltage of the supply unit. Also the nominal current of the protective device must be at least as high as the short-circuit current I_i of the transducer to be expected in the event of a failure. If these parameters differ from the basic conditions when choosing the surge arresters, the protective device can be overloaded and, consequently, can fail or the intrinsic safety of the circuit is eliminated by an impermissible increase in temperature at the protective device.

Coordination of the surge protective devices with terminal equipment

The NAMUR recommendation NE 21 determines the requirements on the immunity against interferences for process technology and process control equipment and its general application (e.g. transducers). The signal inputs of such equipment must withstand transient voltages of 0.5 kV between the wires (differential-mode interference) and of 1.0 kV between wire and earth (common-mode interference). The test arrangement and the waveform are described in the EN 61000-4-5 basic standard. According to the amplitude of the test pulse, a corresponding surge immunity is assigned to the terminal equipment. These immunities of the terminal equipment are documented by the surge immunity (1 – 4). 1 means the lowest and 4 the highest surge immunity. When there is a risk of lightning and surge effects, the conducted interference pulses (voltage, current and energy) must be limited to a value that lies within the immunity of the terminal equipment. The coordination characteristics [TYPE 2][P1] on the protective devices indicate a direct reference to the test level of the terminal equipment. P1 describing the requested test level of the terminal equipment and Type 2, the discharge capacity of the protective device of 10 kA (waveform 8/20 µs).

A threat to chemical and petrochemical installations by a lightning discharge and the electromagnetic influence resulting from it, is covered in the relevant

Intrinsically safe interface	SPD type appoved by FISCO[1]	Part No.
0 – 20 mA, 4 – 20 mA (also with HART)	BCT MOD MD EX 24 + BCT BAS EX	919 580 + 919 507
Digital I/O	BCT MOD MD EX 30 + BCT BAS EX	919 581 + 919 507
NAMUR signal	DCO RK MD EX 24	919 960
PROFIBUS-PA	DPI MD EX 24 M 2	929 960
Foundation Fieldbus		
PROFIBUS-DP	BCT MOD MD HFD EX 6 + BCT BAS EX	919 583 + 919 507
[1] FISCO = Fieldbus Intrinsically Safe Concept		

Table 9.15.2   Surge protective devices for use in intrinsically safe circuits and bus systems

guidelines. During the realisation of the lightning protection zones concept in design and implementation of such installations, the risks of a sparking by a direct strike or discharging of conducted interference energies can be minimised within a safety-related and also economically justifiable scope. The used surge arresters must fulfil the requirements of explosion protection, the coordination to the terminal equipment, as well as the requirements from the operational parameters of the measuring and control circuits (**Table 9.15.2**).

9.16 Lightning and surge protection of multi-megawatt wind turbines

There is an unabated trend for the utilisation of regenerative energy gained from wind turbines, solar, photovoltaic and biogas plants or geothermal heat. This is an enormous market potential not only for the energy industry but also for the suppliers and the electrical trade and that worldwide.

In Germany meanwhile about 19,000 wind turbines supply a total power of almost 21,000 megawatt which is more than three percent of the power needed.

The prognoses for the future turn out to be positive. According to the German wind power institute (Deutsches Windenergie-Institut, DEWI), approximately 4,000 wind turbines are supposed to be installed on the open seas until 2030.

Thus, a nominal power of approx. 20,000 megawatt could be produced by offshore windfarms. The importance of wind turbines is obvious. Looking at the growth rates of this power market, the reliable availability of energy is also an important aspect.

Danger resulting from lightning effects

An operator of these installations cannot afford downtimes. On the contrary, the high capital investments for a wind turbine shall amortize within a few years. Wind turbines are comprehensive electrical and electronic installations, concentrated on a very small area. Everything, what electrical engineering and electronics offer, can be found: switchgear cabinets, motors and drives, frequency converters, bus systems with actuators and sensors. It goes without saying that surges can cause considerable damage there. Due to the exposed position and the overall height, wind turbines are exposed to direct lightning effects. The risk of being hit by lightning increases quadratically versus the height of the structure. Multimegawatt wind turbines with blades reach a total height up to 150 m and are therefore particularly exposed to danger. A comprehensive lightning and surge protection is required.

Frequency of lightning strikes

The annual number of cloud-to-earth lightning flashes for a certain region results from the well-known isokeraunic level. In Europe, a mean number of one to three cloud-to-earth flashes per km^2 and year applies to coast areas and low mountain ranges.

For dimensioning lightning protection installations, it has to be considered that in case of objects with a height of > 60 m, and which are exposed to lightning, also earth-to-cloud flashes can come up, so-called upward flashes, beside cloud-to-earth flashes. This results in greater values as specified in the above formula.

Furthermore, earth-to-cloud flashes starting from high exposed objects carry high charges of a lightning current, which are of special importance for the protection measures at rotor blades and for the design of lightning current arresters.

Standardisation

The guidelines of Germanischer Lloyd are the basis for the design of the protection concept.

The German Insurance Association (GDV) recommends in its publication VdS 2010 "Risikoorientierter Blitz- und Überspannungsschutz" (Risk oriented lightning and surge protection) to implement at least lightning protection systems Class II for wind turbines in order to meet the minimum requirements for protection of these installations.

Protection measures

The main concern in this technical contribution is the realisation of lightning protection measures and measures of protection against surges for the electric and electronic devices/systems of a wind turbine.

The complex problems of the protection of rotor blades and swivelling parts and bearings require a detailed examination. They are also producer-specific and type-specific.

Fig. 9.16.1   Impulse current laboratory DEHN + SÖHNE – Max. lightning impulse current 200 kA, wave form 10/350 µs

DEHN + SÖHNE offers the following engineering and testing service in the company's impulse current laboratory to provide best solutions for the individual customer (**Figure 9.16.1**):

⇒ Testing of customer-specific, pre-wired connection units for protection of the electrical installation

⇒ Testing of the lightning current carrying capacity of bearings

⇒ Lightning current test at down conductors and receptors of rotor blades

These tests in the laboratory prove the effectiveness of the chosen protection measures and contribute to the optimisation of the "protection package".

Lightning Protection Zones Concept
The lightning protection zones concept is a structuring measure for creating a defined EMC environment within a structure (**Figure 9.16.2**). The defined EMC environment is specified by the electromagnetic immunity of the used electric equipment.
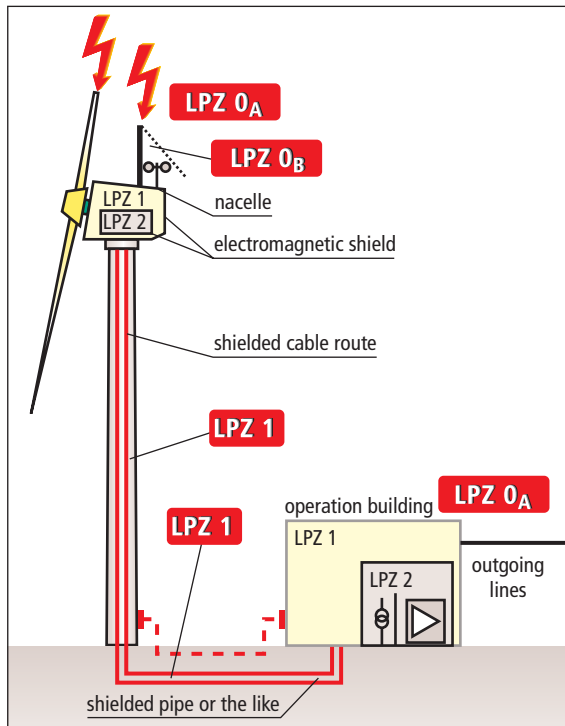
Fig. 9.16.2   Lightning protection zones concept for a wind turbine

Being a protection measure, the lightning protection zones concept includes therefore a reduction of the conducted and radiated interferences at boundaries down to agreed values. For this reason, the object to be protected is subdivided into protection zones. The protection zones result from the structure of the wind turbine and shall consider the architecture of the structure. It is decisive that direct lightning parameters affecting lightning protection zone LPZ 0_A from outside are reduced by shielding measures and installation of surge protective devices to ensure that the electric and electronic systems and devices situated inside the wind turbine can be operated without interferences.

Shielding measures
The nacelle should be designed as a metal shield that is closed in itself. Thus a volume can be obtained inside the nacelle with a considerably attenuated, electromagnetic field compared to the outside. The switchgear and control cabinets in the nacelle and, if existing, in the operation building should also be made out of metal. The connecting cables should be provided with an outer, conductive shield. With respect to interference suppression, shielded cables are effective against EMC coupling only if the shields are connected with the equipotential bonding on both sides. The shields must be contacted with encircling contact terminals to avoid long and for EMC improper "pigtails".

Earth-termination system
For earthing a wind turbine, the reinforcement of the tower should always be integrated. Installation of a foundation earth electrode in the tower base, and, if existing, in the foundation of an operation building, should also be preferred in view of the corrosion risk of earth conductors.

The earthing of the tower base and the operation building (**Figure 9.16.3**) should be connected by an intermeshed earthing in order to get an earthing system with the largest surface possible.

The extent to which additional potential controlling ring earth electrodes must be arranged around the tower base depends on the fact whether too high step and touch voltages must possibly be reduced to protect the operator in case of a lightning strike.
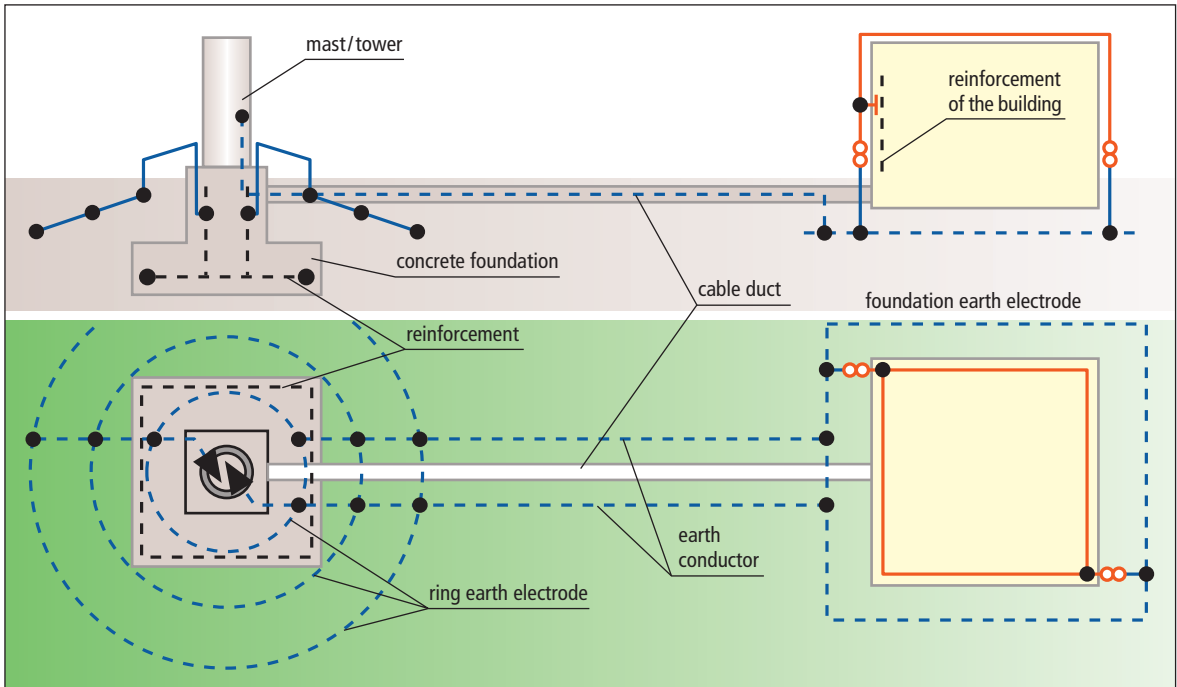
Fig. 9.16.3   Intermeshed network of earth electrodes of a wind turbine

Protective circuit for conductors at the boundary of lightning protection zone LPZ 0_A to LPZ 1 and higher

Besides shielding against radiated sources of interference, protection against conducted sources of interference at the boundaries of the lightning protection zones must also be provided for reliable operation of the electric and electronic devices.

At the boundary of lightning protection zone LPZ 0_A to LPZ 1 (conventionally also called lightning equipotential bonding) SPDs must be used, which are capable of discharging considerable partial lightning currents without damage to the equipment. These SPDs are called lightning current arresters (SPDs Type 1) and tested with impulse currents, wave form 10/350 μs.

At the boundary of LPZ 0_B to LPZ 1 and LPZ 1 and higher, only low energy impulse currents have to be controlled which result from voltages induced from the outside or from surges generated in the system itself. These protection devices are called surge protective devices (SPDs Type 2) and tested with impulse currents, wave form 8/20 μs.

Surge protective devices should be chosen according to the operating characteristics of the electric and electronic systems.

After the discharge, surge protective devices to be used in the power supply system must be capable of extinguishing safely the follow currents coming from mains afterwards. Beside the impulse current carrying capability, this is the second important aspect of design.

Figure 9.16.4 shows lightning current arrester DEHNbloc with encapsulated spark gap.

Fig. 9.16.4   Application of DEHNbloc Maxi coordinated lightning current arrester for 400/690 V TN-C systems

Fig. 9.16.5   DEHNguard surge arrester,
DG MOD 750 + DG M WE 600

Fig. 9.16.6   Application of BLITZDUCTOR XT lightning current and
surge arrester

This lightning current arrester can be mounted among bare live system parts in the installation to be protected without having to take minimum distances into account. The protective device DEHN-bloc is used, for example, for low voltage lines coming from the wind turbine.

Surge arresters (**Figure 9.16.5**) are dimensioned for loads as they occur in case of inductive couplings and switching operations. Within the scope of energy coordination, they have to be connected downstream of the lightning current arresters. They include a thermally monitored metal oxide varistor.

Contrary to surge protective devices for power supply systems, special attention has to be paid on system compatibility and the operating characteristics of the measuring and control or data line when installing SPDs in data processing systems. These protective devices are connected in series with the data processing lines and must be able to reduce the interference level below the immunity of the equipment to be protected.

Considering a single telephone line within the lightning protection zones concept, the partial lightning current on this conductor can be assumed to be blanket 5 %. For a lightning protection system Class III/IV, this would amount to a partial lightning current of 5 kA, wave form 10/350 µs.

Figure 9.16.6 shows the approved multipurpose device BLITZDUCTOR XT, BCT MOD BE as a lightning current and surge arrester. This protective device can be used for protection of equipment in EMC lightning protection zone I and higher. BLITZDUCTOR XT is designed as a four-terminal network and limits both common-mode interferences as well as differential-mode interferences. It can be fixed directly in the course of terminal blocks or, instead of these terminals, on supporting rails. Its special design allows a space-saving arrangement.

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9.17 Surge protection for radio transmitter / receiver stations (mobile radio)

According to the requirements of DIN VDE 0855-300 radio transmitting/receiving systems in Germany are designed in such a way that incoupled lightning currents will be safely discharged to the earth electrode via the earthing conductor. Hence also the transmitter/receiver station (radio base station RBS) has to be protected against surges due to lightning currents. The radio base station (RBS) comprises the power supply (power supply unit PSU), the radio transmitting technology and the transmitting technology for the fixed network (optional).

Fig. 9.17.1   Dual cell site

9.17.1 Power supply 230/400 V a.c.

The power supply of the RBS has to be independent from the power supply of the building. Supplying via the subdistribution/floor distribution shall be avoided. The energy meter shall be near the service entrance box. The distribution of circuits is effected upstream the RBS or directly inside (in Germany almost exclusively subdistributions are installed directly in and near the RBS).

The DEHNventil DV M TT 255, a combined lightning current and surge arrester on spark gap basis, protects the power supply unit (PSU) of a RBS. This surge protective device is an arrester Type 1 designed for the protection of power supply units in transmitting/receiving systems.
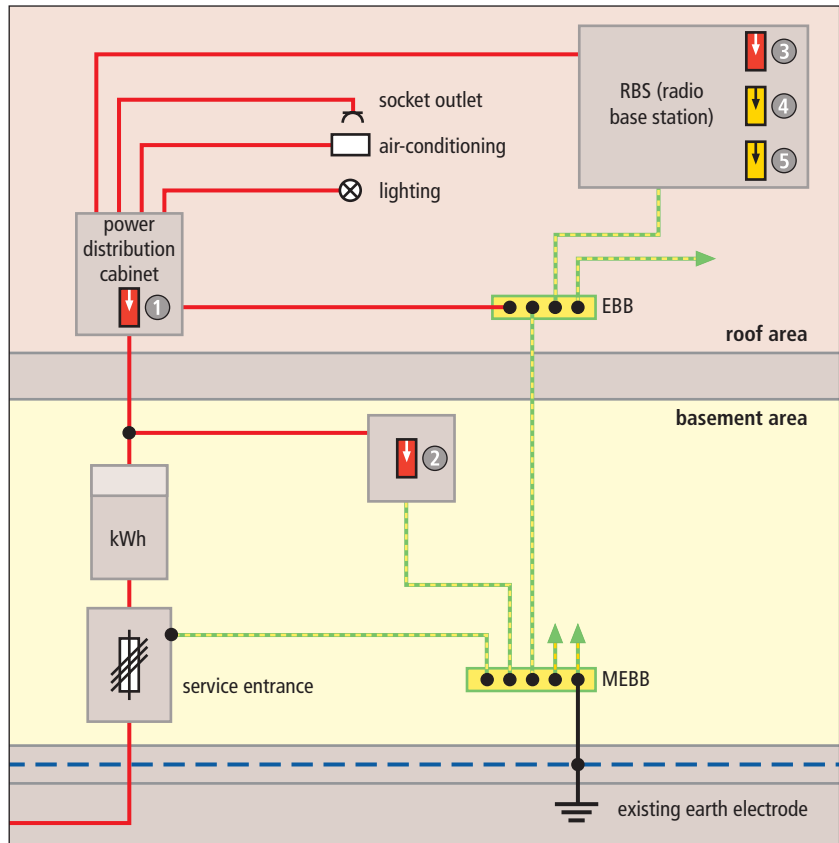
Fig. 9.17.2   Electrical circuit diagram

The DEHNventil DV M TT 255 either can be installed in the subdistribution directly upstream the RBS or in the area of the service entrance. The protective device being installed in the subdistribution, there is a selected input of lightning current and a selected output in the service entrance area. **Figure 9.17.2** shows the circuit diagram with the location of the surge protective equipment. In addition **Figure 9.17.3** shows the structural diagram of an RBS on a roof and the application of DEHNventil DV M TT 255. Producers of transmitting/receiving systems sometimes perform a standardised application of surge arresters Type 2 according to **Table 9.17.2**. **Figure 9.17.3** also shows where to install the DEHNguard modular DG M TT 275.

The application of lightning current and surge protective equipment depends on the type of low-voltage system (TT system, TN-C system or TN-S system). The international standard IEC 60364-5-53 describes the use of lightning current and surge arresters in accordance with the "Protection at indirect contact" in low-voltage consumer's systems. In addition to this requirement of protection against life hazards, care has to be taken when using surge protective equipment, that there is an energy coordination with the terminal devices to be protected. The coordination of the DEHNventil DV M TT 255 and hence the protection capability of this surge protective equipment even without using a surge arrester Type 2 in the RBS has been comprehensively tested at different PSUs.

In order to realise a coordinated surge protection at all sites of an operator and to be independent in designing with regard to the different network systems, the DEHNventil DV M TT 255 a protective device with "3 + 1" circuit provides a universal solution for TN-C, TN-S and TT systems.

A quality characteristic of special importance for using combined lightning current and surge arresters is a sufficient follow current extinguishing capability and follow current limiting/selectivity. Thus false tripping of the system fuses and the disconnection from power supply is avoided. This quality characteristic of the combined lightning current and surge protective equipment or combined SPDs called "selectivity" is necessary. If applied in the range of transmitting/receiving systems, a selectivity according to **Table 9.17.1** is required.
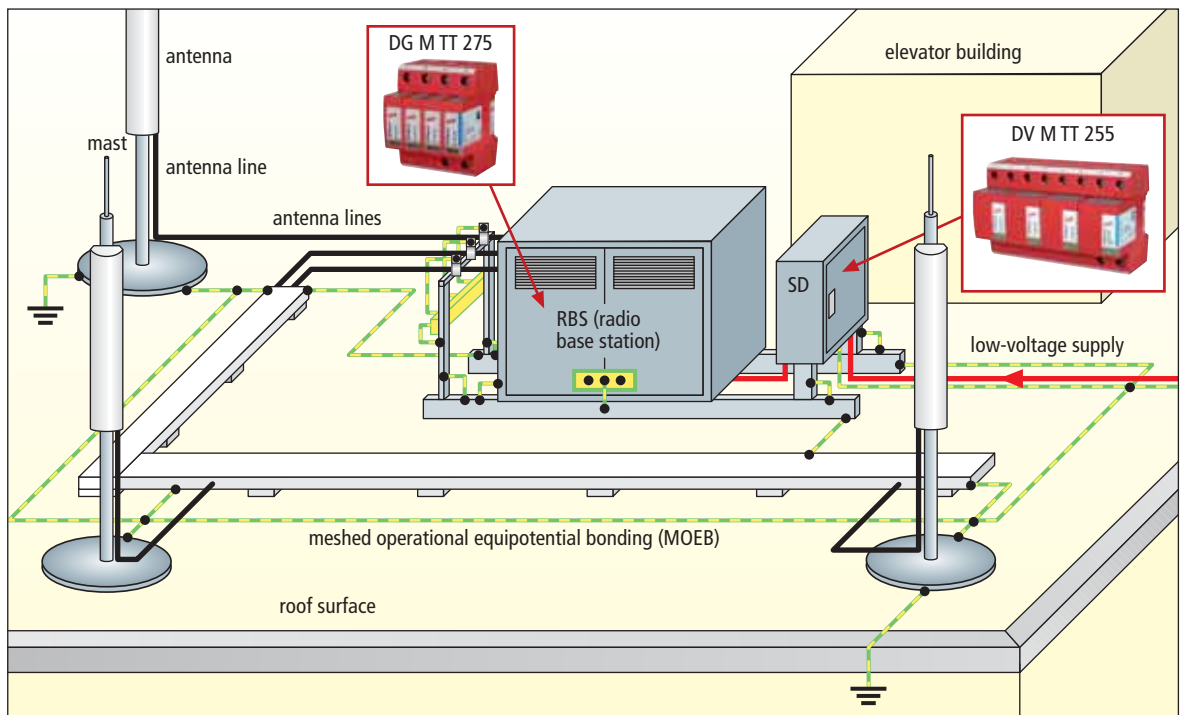
Fig. 9.17.3   Basic structure of a RBS with DV M TT 255 and DG M TT 275

9.17.2 Fixed network connection (if existing)

Depending on the network operator, either fixed network links (copper cable) or radio links are chosen to connect the RBS with the primary switching technology (base station controller (BSC), mobile switching centre (MSC). In case of a fixed network connection partial lightning currents also will flow through the telecommunication cable if a direct lightning strikes the antenna system. Here combined SPDs provide sufficient protection as well. Surge protective equipment according to **Table 9.17.3** is applied.

9.17.3 Radio transmission technology

The radio transmission band (frequency) and the connection mechanics (connector) are the decisive factors concerning the selection of suitable surge protective equipment for the protection of the radio transmission technology. Sufficient discharge capability, remote supply voltages of point-to-point (PTP) radio systems, and depending on the application, also low passive intermodulation (PIM) have to be taken into account. **Table 9.17.4** shows a choice of DEHN + SÖHNE protection products.

9.17.4 Lightning protection, earthing, equipotential bonding

With regard to earthing, equipotential bonding, lightning and surge protection mainly DIN VDE 0855-300 (national) as well as IEC 62305-3 (EN 62305-3) are applicable for design and installation of transmitting/receiving systems. A difference has to be made whether a transmitting/receiving system shall be installed on an building or structure with an already existing or planned lightning protection system or whether the object under consideration is without lightning protection system. The measures of earthing and equipotential bonding then have to be met the requirements of DIN VDE 0855-300 or IEC 62305-3 (EN 62305-3). Chapter 5.2.4.2 of the Lightning Protection Guide describes possible measures of protection against lightning applicable for cell sites.

No. in Fig. 9.17.2	No tripping of a fuse…	…at an earth fault/short-circuit current up to	Type Part No.
① ②	20 A gL/gG	50 kA$_{eff}$	DEHNventil DV M TT 255 951 310

Table 9.17.1   Selectivity surge arrester Type 1

No. in Fig. 9.17.2	Purpose of use	Type	Part No.
③	"Basic surge protection"	DEHNguard modular DG M TT 275	952 310

Table 9.17.2   Standardised surge arrester Type 2

No. in Fig. 9.17.2	Connection system	Type	Part No.
④	LSA-PLus, series 2	DEHNrapid DRL 10 B 180 FSD	907 401
	screw terminal (D+S recommendation)	BLITZDUCTOR XT BXT BD 180	920 347
		BLITZDUCTOR XT Base part BXT BAS	920 300

Table 9.17.3   Surge protection for the fixed network connection

No. in Fig. 9.17.2	Band/Frequency	Type	Part No.
⑤	GSM/876 … 960 + GSM/1710 … 1880 UMTS	DEHNgate DGA L4 7 16 B or DEHNgate DGA L4 N B	929 048 929 049
	Microwave link/2400	DEHNgate DGA G N	929 044
	WLAN/2400	DEHNgate DGA G BNC	929 042
	TETRA/380 … 512	DEHNgate DGA L4 7 16 S	929 047

Table 9.17.4   Surge protection for the transmission technology

9.18 Lightning and surge protection for PV systems and solar power plants

9.18.1 Lightning and surge protection for photovoltaic (PV) systems

The guaranteed service life of 20 years for photovoltaic generators and their exposed installation sites as well as the sensitive electronics of the inverter really require effective lightning and surge protection.

Not only house owners install a PV system on their rooftop but also private operating companies make more and more investments in shared systems, which are erected on large-surface roofs, on traffic structures, or unused open areas.

Because of the big space requirements of the photovoltaic generator, PV systems are especially threatened by lightning discharges during thunderstorms. Causes for surges in PV systems are inductive or capacitive voltages deriving from lightning discharges as well as lightning surges and switching operations in the upstream power supply system. Lightning surges in the PV system can damage PV modules and inverters. This can have serious consequences for the operation of the system. Firstly, high repair costs, for example, those of the inverter, have a negative effect, and, secondly, the system failure can result in considerable profit cuts for the operator of the plant.

Necessity of lightning protection

For the installation of PV systems it must be generally distinguished between an installation on a building with or without lightning protection. For public buildings, e.g., assembly places, schools, hospitals, in Germany building regulations request lightning protection systems for safety reasons. For this purpose, buildings or structures are differentiated, for which, according to their location, construction type, or utilisation, a lightning strike could easily have severe consequences. Such buildings or structures in need of protection have to be provided with a permanently effective lightning protection system.

In case of privately used buildings lightning protection is often refrained from. This happens partly out of financial reasons, but also because of lacking sensibility with respect to this topic.

If a building without external lightning protection was selected as location for a PV system, the question arises, if, with the additional installation of the PV generator on the roof, lightning protection should be provided for the entire structure. According to the current scientific state of the art, the installation of PV modules on buildings does not increase the risk of a lightning strike, so that the request for lightning protection can not be derived directly from the mere existence of a PV system. However, there may be an increased danger for the electric facilities of the building in the event of a lightning strike. This is based on the fact that, due to the wiring of the PV lines inside the building in existing risers and cable runs, strong conducted and radiated interferences may result from lightning currents. Therefore, it is necessary, to estimate the risk by lightning strikes, and to take the results from this into account for the design. IEC 62305-2 (EN 62305-2) states procedures and data for the calculation of the risk resulting from lightning strikes into structures and for the choice of lightning protection systems. For this purpose DEHN + SÖHNE offers the software DEHNsupport. The risk analysis presented here ensures that it is possible to draw up a lightning protection concept which is understood by all parties involved, and which meets optimum technical and economic requirements, i.e. the necessary protection can be guaranteed with as little expenditure as possible.

The German Insurance Association has picked up the risk estimate in their guideline VdS 2010 "Risikoorientierter Blitz- und Überspannungsschutz für Objekte" (Risk oriented lightning and surge protection for objects) (taken from IEC 62305-2 (EN 62305-2)) and present lightning protection measures for buildings or structures as they are seen by the insurance industry. In Table 3, this guideline assigns classes of lightning protection systems and measures against surges to objects in a simplified manner. Furthermore, the guideline also refers to buildings with alternative power supply installations, as for example, buildings with a PV system (> 10 kW). According to this, for such objects lightning protection level (LPL) III has to be taken into account. Hence a LPS Class III is required as well as additional surge protective measures.

A system of protection against lightning (LPS) designed for class III meets the usual requirements for PV and solar thermal systems: "Photovoltaic and solar thermal systems on buildings must not interfere the existing lightning protection measures. Photovoltaic and solar thermal systems shall be protected by isolated air-termination systems according to 5.2 and 6.3 of IEC 62305-3 (EN 62305-3) against direct lightning strikes. If a direct connec-

tion can not be avoided, the effects of partial lightning currents entering the building have to be taken into consideration."

Protection of photovoltaic inverters against surges also in case of direct lightning strikes
If a PV system shall be installed on a building with external lightning protection system, one of the basic requirements is that the PV modules are within the protective area of an isolated air-termination system. Additionally, the separation distance between the PV supporting frame and the external lightning protection system has to be kept in order to prevent uncontrolled sparkover. Otherwise considerable partial lightning currents can be carried into the building or structure.

Often the operator wants the whole roof to be covered with PV modules in order to gain a possibly high economic profit. In these cases the separation distance often can not be realised and the PV supporting frame has to be integrated into the external lightning protection. Here, the effects of the currents coupled into the building or structure have to be taken into consideration and a lightning equipotential bonding has to be provided. Meaning that lightning equipotential bonding now also is necessary for the d.c. conductors carrying lightning current. According to IEC 62305-3 the d.c. conductors have to be protected by surge protective devices (SPDs) Type 1. Surge protective devices Type 1 on spark gap basis, for use on the d.c. voltage side, were not available up to now. The problem was that the spark gap once being tripped, could not be quenched again and hence the arc persisted.

With the combined lightning current and surge arrester DEHNlimit PV 1000 (**Figure 9.18.1.1**) DEHN + SÖHNE succeeded in developing a direct current extinguishing spark gap arrester. Thus DEHNlimit PV 1000 is the ideal arrester for use in photovoltaic power plants. The encapsulated creeping spark gap technology provides a safe protection of the PV generator and the inverter also in case of direct

lightning currents. This combined arrester is applicable for PV systems up to 1000 V $U_{OC\ STC}$. DEHNlimit PV 1000 has a high lightning current discharge capability of 50 kA 10/350 μs.

Single pole photovoltaic arrester Type 2 with integrated short-circuiting device
The inner structure of DEHNguard PV 500 SCP a surge arrester Type 2 (**Figure 9.18.1.2**) sets new patterns for safety. In this arrester the proved double effect of the monitoring and disconnecting device Thermo Dynamic Control has been combined with an additional short-circuiting device. This completely new kind of arrester monitoring ensures operation safety without risk of fire hazard, even if the devices are overloaded for example at insulation faults in the PV generator circuit. The following example explains the effectiveness of the short-circuiting device in DEHNguard PV 500 SCP:

1. **Figure 9.18.1.3**: An insulation fault arises during the operation of the PV system.
2. **Figure 9.18.1.4**: With the consequence of the surge arrester being overloaded by the exceeding maximum continuous voltage U_c.
3. **Figure 9.18.1.5**: The combined disconnection and short-circuiting device of DEHNguard PV 500 SCP will be activated. It is able to carry a short-circuit current up to 50 A automatically until the PV system is repaired. This ensures a safe operation without risk of fire hazard for the system even at an insulation fault in the PV generator circuit.

Fig. 9.18.1.1   Combined arrester Type 1, DEHNlimit PV, to protect photovoltaic inverters from surges also in case of direct lightning strikes

Fig. 9.18.1.2 Single pole photovoltaic arrester Type 2, DEHNguard PV 500 SCP, with integrated short-circuiting device
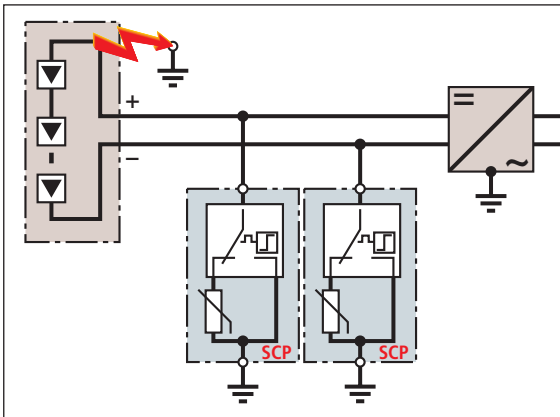
Fig. 9.18.1.3   Isolation fault at the PV generator
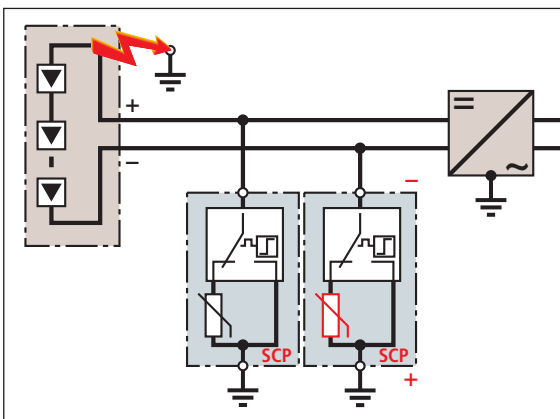
Fig. 9.18.1.4   Overloading of SPD due to an isolation fault
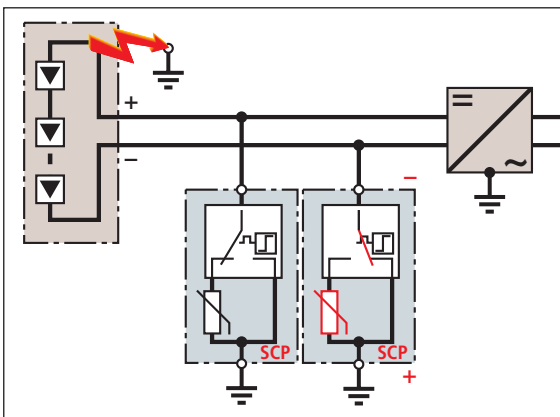
Fig. 9.18.1.5   Activation of the DEHNguard PV 500 SCP disconnect-
                ing and short-circuiting device ensures safe operating
                state also in case of an isolation fault in the PV gener-
                ator circuit

Examples of application

**Buildings without external lightning protection
system**
Figure 9.18.1.6 shows the surge protection concept
for a PV system on a building without external
lightning protection system. Possible installation
sites of the surge protective devices can be:

⇒ d.c. input of the inverter

⇒ a.c. output of the inverter

⇒ low-voltage (l.v.) supply

DEHNguard, an SPD Type 2 is installed in the l.v.
incoming feeder. This DEHNguard M Type of surge
arrester, a complete prewired unit is available for
each low-voltage system (TN-C, TN-S, TT) (**Table
9.18.1.1**). If the distance between the PV inverter
and the installation site of the DEHNguard is not
greater than 5 m (l.v. supply), the a.c. output of the
inverter is sufficiently protected. At greater con-
ductor lengths additional surge protective devices
SPDs Type 2 are necessary upstream the a.c. input
of the inverter (**Table 9.18.1.1**).
At the d.c. input of the inverter each of the incom-
ing string conductors has to be protected to earth
by a DEHNguard surge protective device Type PV
500 SCP installed between plus and minus. This
installation provides safe surge protection for PV
systems with a generator voltage up to 1000 V d.c..

The operating voltage of the chosen surge protec-
tive devices shall be approx. 10 % higher than the
expected open-circuit voltage of the solar genera-
tor during maximum solarisation on a cold winter
day.

**Buildings with external lightning protection sys-
tem and separation distance kept**
The correct operating condition of the lightning
protection system has to be proven by existing test
reports or by maintenance tests. If faults are found
during the examination of the external lightning
protection system (i.e. intense corrosion, loose and
free clamping elements), the constructor of the PV
system has the duty to inform the owner of the
building about these faults in writing.
The PV system on the roof surface should be
designed under consideration of the existing
external lightning protection system. For this pur-
pose, the PV system has to be installed within the
protection zone of the external lightning protec-
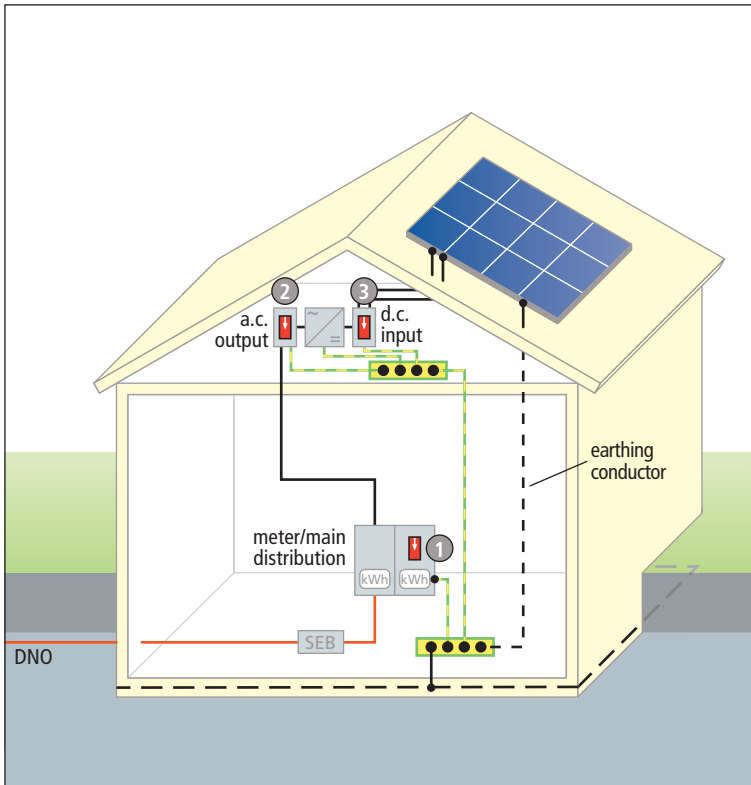
Fig. 9.18.1.6   Surge protection concept for a PV system on a building without external light-ning protection

tion system to ensure its protection against a direct lightning strike. By using suitable air-termination systems, like air-termination rods, for example, direct lightning strikes into the PV modules can be prevented. The necessary air-termination rods possibly to be installed additionally, must be arranged to prevent a direct strike into the PV module within their protection zone and, secondly, any casting of a shadow on the modules.

It has to be considered that a separation distance s must be kept between the PV components and metal parts like lightning protection systems, rain gutters, skylights, solar cells or antenna systems in compliance with IEC 62305-3 (EN 62305-3). The separation distance has to be calculated according to IEC 62305-3 (EN 62305-3)3. The PV system shown in **Figure 9.18.1.7** is located in the protective area of the external lightning protection system. **Figure 9.18.1.7** illustrates the concept of

Figure 9.18.1.6	Protection for...	SPDs	Part No.
L.v. supply			
①	TN-C system	DEHNguard M, DG M TNC 275 DEHNguard M, DG M TNC 275 FM	952 300 952 305
	TN-S system	DEHNguard M, DG M TNS 275 DEHNguard M, DG M TNS 275 FM	952 400 952 405
	TT system	DEHNguard M, DG M TT 275 DEHNguard M, DG M TT 275 FM	952 310 952 315
Ac output of the inverter/ac, inverter installed in the attic			
②	TN system	DEHNguard M, DG M TN 275 DEHNguard M, DG M TN 275 FM	952 200 952 205
	TT system	DEHNguard M, DG M TT 2P 275 DEHNguard M, DG M TT 2P 275 FM	952 110 952 115
Dc input of the inverter			
③	2 x (each between plus and minus to earth)	DEHNguard, DG PV 500 SCP DEHNguard, DG PV 500 SCP FM	950 500 950 505

Table 9.18.1.1   Selection of the surge protective devices for PV systems on buildings without external lightning protection system
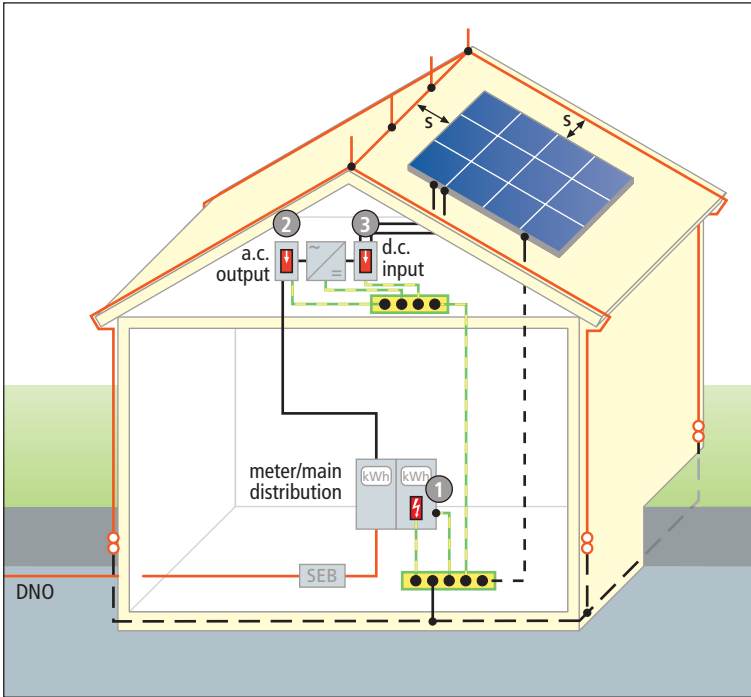
Fig. 9.18.1.7   Surge protection concept for a PV system on a building with external lightning protection system and the separation distance is being kept
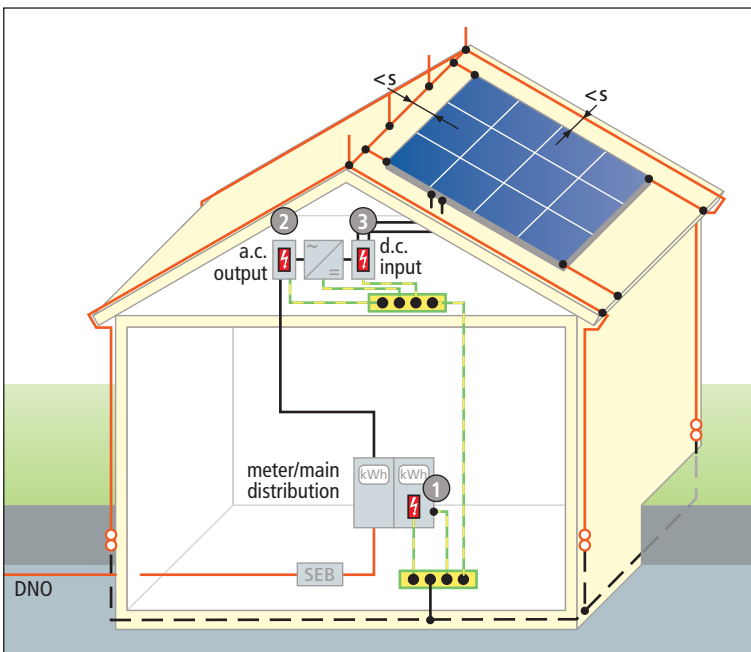
Fig. 9.18.1.8   Surge protection concept for a PV system on a building with external lightning protection system and the separation distance is not being kept

surge protection for a PV system on a building with external lightning protection system and a sufficient separation distance of the PV modules to the external lightning protection system.

An essential part of a lightning protection system is the lightning equipotential bonding for all conductive systems entering the building from the outside. The requirements of lightning equipotential bonding are met by direct connection of all metal systems and by indirect connection of all live systems via lightning current arresters. The lightning equipotential bonding should be performed preferably near the entrance of the structure in order to prevent a penetration of partial lightning currents into the building. The low-voltage power supply of the building is protected by a DEHNventil ZP, a multi-pole combined lightning current and surge arrester with spark gap technology. It is designed for installation on 40 mm DIN rails on the meter mounting board. The surge protective device has to be chosen according to the type of power supply system (**Table 9.18.1.2**).

This combined lightning current and surge arrester unites lightning current and surge arrester in one device has no interaction limiting reactor and is available as complete prewired unit for every low-voltage system (TN-C, TN-S, TT). There is sufficient protection without additional protective devices between DEHNventil and terminal equipment up to a cable length of < 5 m. For greater cable lengths SPDs Type 2 or 3 have to be used in addition. If the distance between the a.c. output of the inverter and the application site of DEHNventil is not greater than 5 m, no further protective devices are required for the a.c. side.

At the d.c. input of the inverter each of the incoming string conductors has to be protected to earth by a DEHNguard surge protective device Type PV 500 SCP installed between plus and minus.

Buildings with external lightning protection system and separation distance not kept
Often the whole roof is covered with PV modules in order to gain a possibly high economic profit. For the mounting technicians, however, then it is often not possible to keep the required separation distance. At these points a direct conductive connection must be provided between the external lightning protection system and the metal PV components. In this case, however, the effects of the currents carried into the structure or building via the d.c. conductors have to be taken into account and hence lightning equipotential bonding has to be ensured. Meaning that now also the lightning current carrying d.c. conductors have to be included into the lightning equipotential bonding (**Figure 9.18.1.8**). According to IEC 62305-3 (EN 62305-3), surge protective devices Type 1 have to be installed at the d.c. conductors. Here DEHNlimit PV 1000, the combined lightning current and surge arrester is used, which in this case will be connected in parallel with the string conductor. The combined arrester DEHNlimit PV 1000 has been especially developed for application in photovoltaic power plants. The encapsulated creeping spark

Figure 9.18.1.7	Protection for...	SPDs	Part No.
L.v. supply			
①	TN-C system	DEHNventil ZP, DV ZP TNC 255	900 390
	TN-S system and TT system	DEHNventil ZP, DV ZP TT 255	900 391
A.c. output of the inverter/a.c., inverter installed in the attic			
②	TN system	DEHNguard M, DG M TN 275 DEHNguard M, DG M TN 275 FM	952 200 952 205
	TT system	DEHNguard M, DG M TT 2P 275 DEHNguard M, DG M TT 2P 275 FM	952 110 952 115
D.c. input of the inverter			
③	2 x (each between plus and minus to earth)	DEHNguard, DG PV 500 SCP DEHNguard, DG PV 500 SCP FM	950 500 950 505

Table 9.18.1.2   Selection of the surge protective devices for PV systems on buildings with external lightning protection system and the separation distance is being kept

Figure 9.18.1.8	Protection for...	SPDs	Part No.
L.v. supply			
①	TN-C system	DEHNventil ZP, DV ZP TNC 255	900 390
	TN-S system and TT system	DEHNventil ZP, DV ZP TT 255	900 391
A.c. output of the inverter/a.c., inverter installed in the attic			
②	TN-C system	DEHNventil M, DV M TN 255 DEHNventil M, DV M TN 255 FM	951 200 951 205
	TT-S system and TT system	DEHNventil M, DV M TT 255 DEHNventil M, DV M TT 255 FM	951 110 951 115
D.c. input of the inverter			
③	Each string conductor	DEHNlimit, DLM PV 1000	900 330

Table 9.18.1.3   Selection of the surge protective devices for PV systems on buildings with external lightning protection and the separation distance is not being kept

gap technology provides safe protection of the PV generator, even at direct lightning currents.

Lightning equipotential bonding has to be performed also for the l.v. input. The DEHNventil ZP, a surge protective device with spark gap technology is used there (**Table 9.18.1.3**). If the distance between the PV inverter and the l.v. input is not greater than 5 m, the a.c. output of the inverter is also protected. Surge protection measures always are effective only locally, which applies also for the protection of the PV inverter. The PV inverter being installed in the attic, additional surge protective devices are necessary to protect the a.c. output of the inverter, to be performed in this case also by the DEHNventil surge protective devices Type 1. This protective device is used because the partial lightning currents flowing via the protective conductor and the a.c. supply conductor have to be controlled by the surge protective device.

Note

The surge protection of so-called thin-film module applications possibly requires separate consideration.

- ● Air-termination rod
- ■ Generator junction box
- ⬜ PV array
- - - Earth-termination system Mesh size 20 x 20 m
- —— d.c. line

Fig. 9.18.2.1 Layout of a large PV installation in an open area

9.18.2 Lightning and surge protection for solar power plants

For such a complex type of installation as a solar power plant, it is necessary to make an assessment of the damage risk due to lightning strikes according to IEC 62305-2 (EN 62305-2), the result to be taken into account on designing. In case of a solar power plant the aim is to protect both the operation building and the PV array against damage by fire (direct lightning strike), and the electrical and electronic systems (inverters, remote diagnostics system, generator main line) against the effects of lightning electromagnetic impulses (LEMP).

Air-termination system and down-conductor system

For protecting the PV array against direct lightning strikes, it is necessary to arrange the solar modules in the protection zone of an isolated air-termination system. Its design is based on lightning protection system Class III for PV systems greater 10 kW in compliance with VdS guideline 2010. According to the class of lightning protection system, the height and the quality of the air-termination rods required is determined by means of the rolling sphere. Furthermore, it has to be ensured that the separation distance s is kept between the PV supporting frames and the air-termination rods in compliance with IEC 62305-3 (EN 62305-3). Also, the operation building is equipped with an external lightning protection system Class III. The down conductors are connected with the earth-termination system by using terminal lugs. Due to the corrosion risk at the point where the terminal lugs come out of the soil or concrete, they have to be made out of corrosion-resistant material (stainless steel V4A, Material No. 1.4571) or, in case of using galvanised steel they have to be protected by corresponding measures (applying sealing tape or heat-shrinkable tubes, for example).

Earthing system

The earthing system of the PV system is designed as a ring earth electrode (surface earth electrode) with a mesh size of 20 m x 20 m (**Figure 9.18.2.1**). The metal supporting frames which the PV modules are fixed onto, are connected to the earth-termination system approx. every 10 m. The earthing system of the operation building is designed as a foundation earth electrode according to DIN 18014 (German standard). The earth-termination
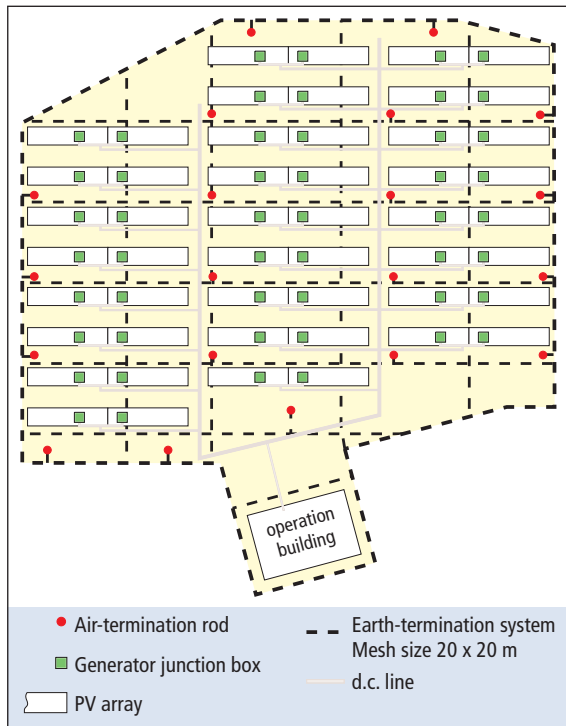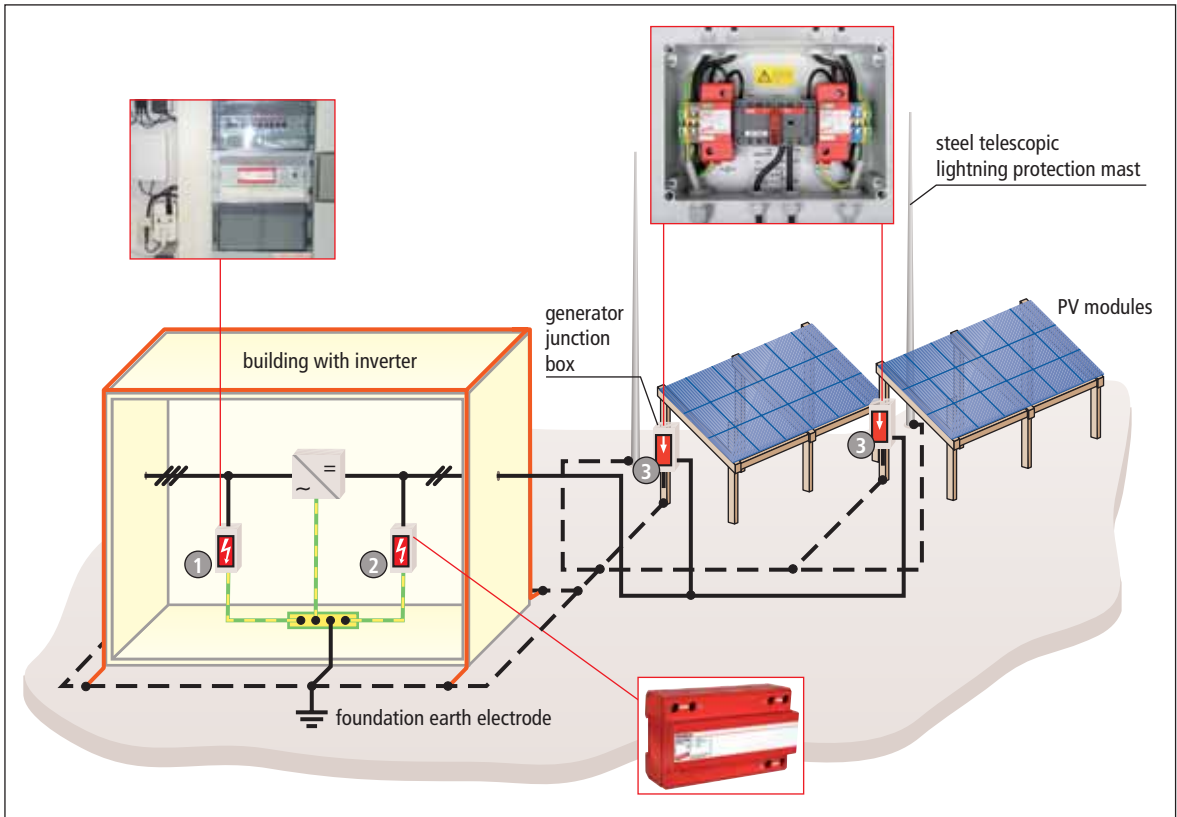
Fig. 9.18.2.2 Basic circuit diagram – Surge protection for a solar power plant

No. in Fig. 9.18.2.2	Protection for...	SPDs	Part No.
①	TN-C system TN-S system TT system	DEHNventil, DV M TNC 255 DEHNventil, DV M TNS 255 DEHNventil, DV M TT 255	951 300 951 400 951 310
②	D.c. input of the inverter	DEHNlimit, DLM PV 1000	900 330
③	Generator junction box	DEHNguard DG PV 500 SCP DEHNguard DG PV 500 SCP FM	950 500 950 505

Table 9.18.2.1 Selection of surge protective devices for solar power plants

system of the PV system and the one of the operation building have to be connected with each other via at least one conductor (30 mm x 3.5 mm steel strip V4A, Material No. 1.4571 or galvanised steel). The interconnection of the individual earthing systems reduces considerably the total earthing resistance. The intermeshing of the earthing systems creates an equipotential surface which reduces

considerably the voltage load of lightning effects on the electric connecting cables between PV array and operation building. The surface earth electrodes are laid at least 0.5 m deep in the soil. The meshes are interconnected with four-wire connectors. The joints in the soil have to be wrapped with an anticorrosive band. This also applies to V4A steel strips laid in the soil.
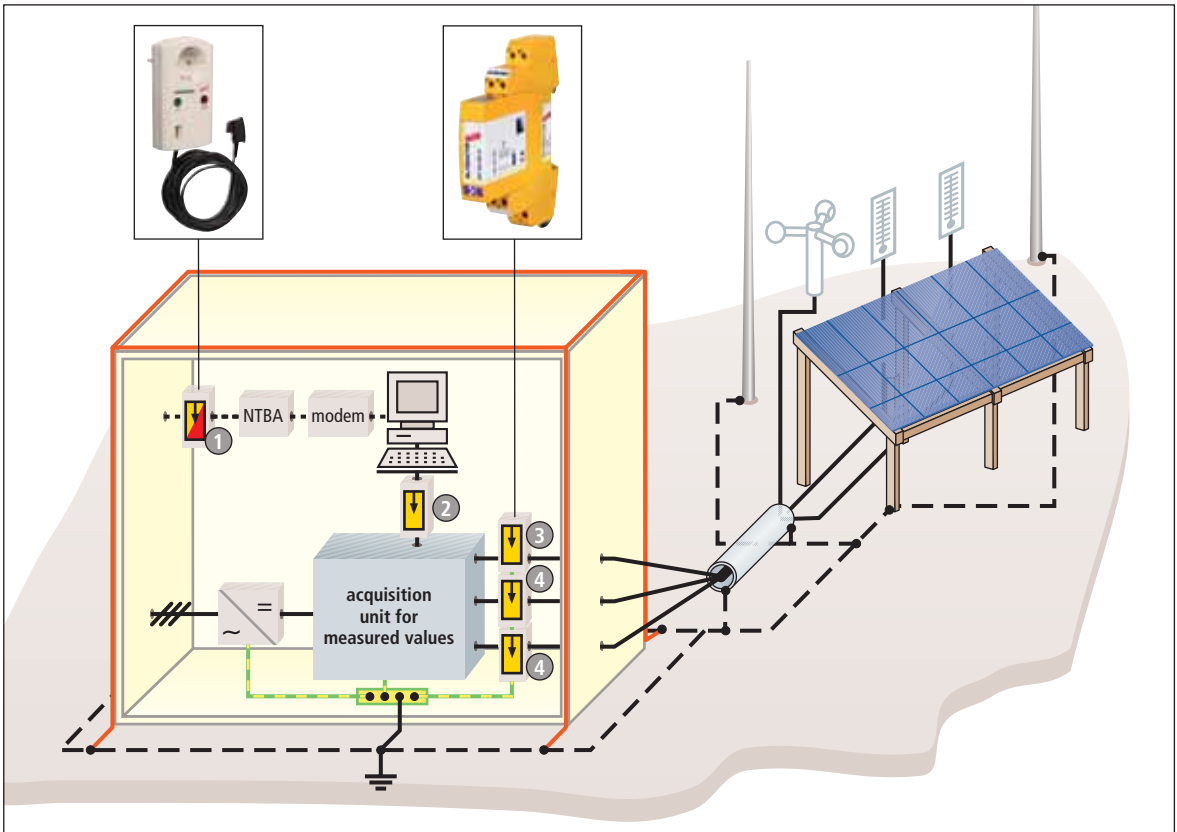
Fig. 9.18.2.3   Protection concept for data acquisition and evaluation

No. in Fig. 9.18.2.3	Protection for...	SPDs	Part No.
1	Network and data input of an NTBA	NT PRO	909 958
2	Measuring and control systems and devices with four-wire data transmission e.g. RS 485 bus systems	BLITZDUCTOR VT, BVT RS 485 5	918 401
3	Wind direction indicators, e.g. analogue transmission of measured values 4 to 20 mA	BLITZDUCTOR XT, BXT ML4 BE 24 + Base part BXT BAS	920 324 920 300
4	Sensor for environment and module temperature	BLITZDUCTOR XT, BXT ML4 BE 5 + Base part BXT BAS	920 320 920 300

Table 9.18.2.2   Surge protective devices for data acquisition and evaluation

Lightning equipotential bonding

In principle, all conductive systems, entering the operation building from outside, have to be generally included into the lightning equipotential bonding. The requirements of lightning equipotential bonding are fulfilled by the direct connection of all metal systems and by the indirect connection of all live systems via lightning current arresters. Lightning equipotential bonding should be performed preferably near the entrance of the structure in order to prevent partial lightning currents from penetrating the building. In this case (**Figure 9.18.2.2**), the low voltage power supply in the operation building is protected by a multi pole DEHNventil combined lightning current and surge arrester (**see Table 9.18.2.1**).

Furthermore, the d.c. lines entering the PV inverter in the operation building have to be protected by a suitable spark-gap-based lightning current arrester, such as DEHNlimit PV 1000, a combined lightning current and surge arrester.

Surge protective measures in the PV array

In order to reduce the load on the isolation inside the solar modules at a lightning strike into the isolated air-termination system, thermally controlled surge protective devices are installed in a generator junction box as close as possible to the PV generator. For generator voltages up to 1000 V d.c., a DEHNguard PV 500 SCP type of surge protective device is installed here between plus and minus to earth. In this case surge protective devices Type 2 are sufficient because the PV modules are within the protective area of the external lightning protection.

In practice, it is a proven method to use surge protective devices with floating contacts to indicate the operating state of the thermal disconnection device. Thus, the intervals between the regular on-site inspections of the protection devices are extended.

The surge protective devices in the generator junction boxes assume the protection for the PV modules locally and ensure that no sparkovers caused by conducted or field-related interferences come up at the PV modules.

Note

The surge protection of so-called thin-film module applications possibly requires separate consideration.

Surge protective measures for data processing systems

The operation building provides a remote diagnostics system, which is used for a simple and quick function check of the PV systems. This allows the operator to recognise and remedy malfunctions in good time. The remote supervisory control system provides the performance data of the PV generator constantly in order to optimise the output of the PV system.

As shown in **Figure 9.18.2.3**, measurements of wind velocity, module temperature and ambient temperature are performed via external sensors at the PV system. These measurements can be read directly from the acquisition unit. The data acquisition unit provides interfaces like RS 232 or RS 485, which a PC and/or modems are connected to for remote enquiry and maintenance. Thus, the service engineers can determine the cause of a malfunction by telediagnosis and then directly eliminate it. The modem in **Figure 9.18.2.3** is connected to the network termination unit (NTBA) of an ISDN basic access.

The measuring sensors for wind velocity and module temperature are also installed in the zone protected against lightning strikes like the PV modules. Thus, no lightning currents come up in the measuring leads, but probably conducted transient surges resulting from induction effects in the event of lightning strikes into the isolated air-termination system.

In order to provide a reliable trouble-free and continuous transmission of the measured data to the measuring unit, it is necessary, to lead the sensor cables entering the building via surge protective devices (**Table 9.18.2.2**). When choosing the protective devices, it has to be ensured that the measurements cannot be impaired. The forwarding of the measured data via the telecommunication network per ISDN modem must be provided as well, in order to provide a continuous control and optimisation of the performance of the installation. For this purpose, the U_{k0} interface upstream of the NTBA which the ISDN modem is connected to, is protected by a surge protective adapter. This adapter ensures additional protection for the 230 V power supply of the NTBA.

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DEHNsupport
Planning software for lightning protection systems

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Main catalogue UE	DS 570 E
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DEHN protects Cell Sites	DS 104
Safety for Sewage Plants	DS 107 E
DEHN protects Photovoltaic Systems	DS 109
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DEHN protects	DS 509
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DEHNtour	DS 707

Index

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☐ Surge Protection – Main catalogue ☐ Seminarplan

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☐ Professional training	☐ Data technology	☐ Petrochemistry
☐ Occupational safety	☐ Power supply systems	☐ Photovoltaics
☐ Construction of lightning protection systems	☐ Measuring and control technology	☐ Wind turbines
		☐ Biogas plants

Which kind of sector are you working in? (Name one sector only):

☐ 1.1 Electrical installation	☐ 5.1 Electrical industry
☐ 1.2 Construction of lightning protection	☐ 5.2 Industry, in general
☐ 1.3 Other kinds of handicraft business	☐ 5.3 Construction of switchgear cabinets
	☐ 5.4 Manufacture of PCs
☐ 2.1 Electrical wholesale	☐ 6.1 Telecommunications
☐ 2.2 Other type of wholesale	☐ 6.2 Railways
☐ 2.3 Export business	☐ 6.3 Military
☐ 2.4 Electronics accessory wholesale	☐ 6.4 Other public, communal, specialised authorities/ institutions
☐ 3.1 Civil engineering, industrialised and pipeline construction	☐ 7.1 Technical design, technical supervisory committees
☐ 3.2 Construction of chimneys and combustion plants	☐ 7.2 Service industry, in general
	☐ 7.3 Insurance sector
☐ 4.1 Supply industry	☐ 7.4 Architectural practice

Name:		First name:
Company:		
Department:		
Employees:	Total:	Specialised:
Address:		
Country:		
Phone:		Fax:
eMail:		