Safety Standards

of the
Nuclear Safety Standards Commission (KTA)

KTA 2206 (2009-11)

Design of Nuclear Power Plants Against Damaging Effects from Lightning

(Auslegung von Kernkraftwerken gegen Blitzeinwirkungen)

The previous version of this safety standard was issued in 2000-06

If there is any doubt regarding the information contained in this translation, the German wording shall apply.

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KTA SAFETY STANDARD

November 2009	**Design of Nuclear Power Plants Against Damaging Effects from Lightning**	KTA 2206

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2000-06 (BAnz No. 159a of August 24, 2000)

Contents

PLEASE NOTE: Only the original German version of this safety standard represents the joint resolution of the 50-member Nuclear Safety Standards Commission (Kerntechnischer Ausschuss, KTA). The German version was made public in Bundesanzeiger BAnz No. 3a of January 07, 2010. Copies may be ordered through the Carl Heymanns Verlag KG, Luxemburger Str. 449, 50939 Koeln, Germany (Telefax +49-221-94373603).

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Comments by the Editor:

Taking into account the meaning and usage of auxiliary verbs in the German language, in this translation the following agreements are effective:

shall	indicates a mandatory requirement,
shall basically	is used in the case of mandatory requirements to which specific exceptions (and only those!) are permitted. It is a requirement of the KTA that these exceptions - other than those in the case of **shall normally** - are specified in the text of the safety standard,
shall normally	indicates a requirement to which exceptions are allowed. However, exceptions used shall be substantiated during the licensing procedure,
should	indicates a recommendation or an example of good practice,
may	indicates an acceptable or permissible method within the scope of this safety standard.

Fundamentals

(1) The safety standards of the Nuclear Safety Standards Commission (KTA) have the task of specifying those safety-related requirements which shall be met with regard to precautions to be taken in accordance with the state of science and technology against damage arising from the construction and operation of the plant (Sec. 7 para. 2 subpara. 3 Atomic Energy Act – AtG –) in order to attain the protective goals specified in the Atomic Energy Act and the Radiological Protection Ordinance (StrlSchV) and further detailed in the "Safety Criteria for Nuclear Power Plants" and in the "Guidelines for the Assessment of the Design of Nuclear Power Plants with Pressurized Water Reactors Against Design Basis Accidents as Defined in Sec. 28, para. 3 StrlSchV – Design Basis Accident Guidelines –" (the version released Oct. 18, 1983).

(2) In accordance with Criterion 2.6 “External Events” of the Safety Criteria for Nuclear Power Plants, protection measures are required with respect to natural external events. The Design Basis Accident Guidelines specify the required lightning protection measures in so far as stating that equipment-related protection measures shall be taken against this event. This is achieved by properly designing the lightning protection of the plant and by installing suitable lightning protection systems.

(3) In establishing this safety standard it is presumed that the requirements from conventional standards and regulations are fulfilled, e.g., building regulations of the individual German states, the German Accident Prevention Regulations, DIN standards and VDE regulations, EN standards as well as IEC standards.

(4) This safety standard specifies additional requirements for the lightning protection of nuclear power plants. The objective of this safety standard is to specify these additional requirements regarding the Exterior and the Interior Lightning Protection system such that the influence of lightning strikes on electrical facilities will not lead to impermissible adverse effects on pant safety.

(5) The basis for this safety standard is formed by

a) deriving and specifying lightning strike characteristics from the measurement results of actual lightning strikes,

b) evaluating specific experiments with pulse generators that simulate lightning strikes by inducing voltage pulses into cables and conductors of existing nuclear power plants which are already protected by defined and relevant lightning protection measures,

c) specifying analytical procedures for the determination of that portion of the lightning current that must be considered for the induced voltage pulses,

d) evaluating results from analytical and numeric procedures regarding the lightning-based voltage pulses induced into cables of cable ducts and into ground-routed cables [1], [2].

(5) The general requirements regarding quality assurance are specified in KTA 1401.

(6) This safety standard specifies the protection measures against lightning required in accordance with Sec. 4.3 of safety standard KTA 3501 “Reactor Protection System and Surveillance Equipment of the Safety System”.

(7) This safety standard does not specify analytical procedures regarding the induction of lightning-based voltages into the instrumentation and control circuitry within the nuclear reactor building. Various analytical procedures have been published in technical literature relating to the calculation of induced voltages in buildings of nuclear power plants. However, due to the differences between power plants with respect to geometric arrangement of the electrical equipment and the instrumentation and control equipment and due to the various induction possibilities, no single easily applicable analytical procedure is available that would suit all individual cases.

Note:

Additional information regarding voltages induced into buildings is available from building-shield measurements regarding electromagnetic damping and from measurements on building models (cf. Appendix E).

1 Scope

This safety standard applies to the protection of the electrical facilities in stationary nuclear power plants against impermissible adverse effects from a lightning strike.

2 Definitions

Note:

Some of the terms used in this safety standard, e.g. “lightning protection system”, are differently defined from the terms in DIN EN 6205, and, therefore, identical terms may be associated with differing contents.

(1) Lightning protection

Lightning protection is the entirety of all measures and equipment for the prevention of damaging effects from a lightning strike.

(2) Lightning protection system

The lightning protection system comprises the Exterior Lightning Protection system and the Interior Lightning Protection system.

(3) Exterior Lightning Protection system

Exterior Lightning Protection system is the entirety of all measures and equipment provided for catching and grounding the lightning current.

(4) Interior Lightning Protection system

Interior Lightning Protection system is the entirety of all measures and equipment provided against the effects of the lightning strike on conductive installations and electrical facilities inside structures and structural components. This includes all measures for the reduction and limitation of surge-voltages.

(5) Grounding, decentralized

Decentralized grounding is the multiple, low-impedance connection of the reference potential lead of the instrumentation and control systems to the voltage equalization system.

(6) Grounding, centralized

Centralized grounding is the stellate connection of the reference potential lead to the central ground point.

3 Design Parameters

3.1 General Requirements

(1) The lightning protection and the electrical facilities shall be designed and coordinated with each other such that no electrical facilities will suffer impermissible adverse effects from a lightning strike.

Note:

Impermissible adverse effects are, e.g., the blocking or erroneous initiation of protective actions by the safety systems as well as the loss of function of safety-related plant components.

(2) Type and extent of the electrical facilities that must be protected by lightning protection measures shall be specified before beginning with the erection of the structural components.

N o t e :

Requirements regarding technical modifications are specified in Section 7.

3.2 Assignment of Protection Categories

(1) The requirements with respect to dimensioning the lightning protection of structural components of the nuclear power plant shall be specified with regard to the electrical facilities contained in these structural components. The following
protection categories shall therefore be assigned to the individual buildings (structural components):

a) Level 1 protection category
Level 1 protection category applies to buildings that contain electrical facilities relevant to safety.

N o t e :

Level 1 protection category also applies to buildings that contain facilities of the plant-operation related instrumentation and controls if their malfunction might lead to impermissible adverse effects in safety-related plant components.

b) Level 2 protection category
Level 2 protection category applies to all buildings not assigned to item a.

N o t e :

No requirements are specified in this safety standard regarding Level 2 protection category buildings.

(2) It shall be prevented that electrical facilities in Level 2 protection category buildings have any impermissible feedbacks to electrical facilities inside Level 1 protection category buildings.

N o t e :

Impermissible feedbacks can be prevented by, e.g., spatial separation, galvanic decoupling, use of shielded cables whose shield is able to conduct currents, or by protective circuitry. A combination of multiple measures may be necessary.

3.3 Lightning Current Parameters

The lightning current parameters specified in **Tables 3-1** and **3-2** shall be used as basis for demonstrating the protection against lightning-based power surges (cf. Section 5).

Lightning	*Parameter*	*Symbol*	*Unit*	*Value*
Positive initial lightning strike	crest value of current	I_B	kA	200
	average current gradient	I_B/τ_1	kA/µs	20
	front time	τ_1	µs	10
	time of half-value	τ_2	µs	350
	impulse charge	Q_i	C	100
	specific energy	W/R	MJ/Ω	10
Negative initial lightning strike	crest value of current	I_B	kA	100
	average current gradient	I_B/τ_1	kA/µs	100
	front time	τ_1	µs	1
	time of half-value	τ_2	µs	200
Negative subsequent lightning strike	crest value of current	I_B	kA	50
	average current gradient	I_B/τ_1	kA/µs	200
	front time	τ_1	µs	0.25
	time of half value	τ_2	µs	100

Table 3-1: Parameters for the lightning current pulse

Height of Structure (Type of Lightning)	*Parameter*	*Symbol*	*Unit*	*Value*
h ≥ 60 m	charge of the longtime current	Q_l	C	400
	duration of the longtime current	t	s	0.5
h < 60 m	charge of the longtime current	Q_l	C	200
	duration of the longtime current	t	s	0.5

Table 3-2: Parameters for longer duration lightning currents

3.4 Lightning-strike Protected Areas of Level 1 Protection Category Buildings

(1) The lightning-strike locations and the lightning-strike protected areas shall normally be determined by the rolling sphere method using a radius of 20 m.

N o t e :

Electrical equipment located outside of the thus determined lightning-strike protected area may be subject to direct lightning strikes with a reduced crest current value.

(2) The design of protective measures with respect to their maximum current conductivity may be based on the crest current value of an initial lightning strike at the radius of the lightning sphere in accordance with **Table 3-3** touching at this location.

Radius of Lightning Sphere	*Corresponding Crest Current Value of the Initial Lightning Strike*
20 m	3 kA
30 m	6 kA
45 m	10 kA
60 m	16 kA

Table 3-3: Correlation of the crest current values to the lightning sphere radii

4 Design and Construction

4.1 Design and Construction Documents

(1) Prior to erection of the grounding devices and of the lightning protection system it shall be shown on the basis of the design specifications how the requirements of this safety standard are being met.

(2) The structural components to be protected may be subdivided into various lightning protection zones.

N o t e :

This may be necessary in order to be able to realize a graded protection concept. The basics and details for a concept of these lightning protection zones are contained in DIN EN 62305-4.

4.2 Exterior Lightning Protection System

4.2.1 General Requirements

The spacing specified in Sections 4.2.2 through 4.2.6 as well as in **Figures 4-1** through **4-4** are only general approximations. It is permissible to use deviating values for the spacing in order to adjust for the geometry of the structural components. However, the specified spacing shall normally not be exceeded by more than 20 %. A reduction of the spacing is permissible.

N o t e :

Requirements regarding materials and corresponding cross-sections for the capture devices, down conductors and grounding systems are specified in DIN EN 62305-3.

4.2.2 Capture devices

(1) All roof surfaces and wall parts that can be struck by lightning shall be provided with capture devices.

(2) The position of the capture devices shall normally be determined by the rolling sphere method using a radius of 20 m.

(3) In case the capture mesh lies directly on top of the building roof, the mesh width shall normally not exceed 5 meters (cf. **Figure 4-1**).

(4) Metallic structures on top of the roof may be used as capture devices. They shall be connected to the other capture devices.

4.2.3 Down conductors

4.2.3.1 Buildings without metal fronts

(1) A meshing of vertical down conductors and horizontal cross connectors shall be placed into or onto the walls in order to distribute the conducted lightning current over as large a surface as possible. The spacing of the down conductors and of the transvers connectors shall not exceed 5 meters.

(2) If the meshing is placed inside or onto the reinforcement steel rods, it shall itself be manufactured from round or flat bar steel with a minimum cross-section of 50 mm². The intersecting points of the meshing shall be welded or securely clamped or bolted together such that the connecting cross-section is at least equal to the cross-section of the meshing. The rods of the meshing shall be tie-wire connected at intervals of 1 meter to the reinforcement steel rods (cf. **Figure 4-1).**

(3) If a conductive interconnection of reinforcement steel rods, e.g. by welding, is permissible they may be used as down conductors and cross connectors, provided a continuous interconnection is ensured. These reinforcement steel rods shall have a diameter of at least 10 mm.

N o t e :

Requirements regarding the welding of reinforcement steel rods are contained in DIN EN ISO 17660.

(4) The terminal lugs for connecting the capture devices and the grounding system shall be corrosion protected wherever these lugs are led through the ground or through concrete. The meshing within or outside on the wall shall be welded or securely clamped or bolted to the mesh in the foundation such that the connecting cross-section is at least equal to the cross-section of the meshing. In the case of buildings with external structural sealing, cf. **Figure 4-2**, in case of buildings without external structural sealing, cf. **Figure 4-1.**

(5) For the purpose of testing, the connection to the external grounding system shall be achieved by accessible disconnect terminals. These disconnect terminals shall be unambiguously and durably marked. Their markings shall be identical to the corresponding markings used in the surveillance plans of the buildings.

4.2.3.2 Buildings with metal fronts

(1) Metal fronts may be used as down conductors and shielding, thus, replacing the measures specified under Sections 4.2.3.1 and 4.2.4. If used as down conductor, the metal fronts shall be conductively interconnected in the vertical direction and such that they are capable of carrying the current of a lightning strike. If used as shielding, additional electrically conductive connections are required.

(2) The metal fronts shall be connected to the capture devices. If the metal fronts are used as down conductor, vertical interconnections capable of conducting the current of a lightning strike are required and shall be spaced no more than 5 meters apart from each other. If the metal fronts are also used as shielding, additional vertical and horizontal electrically conductive interconnections of the individual metal sheets are required and shall be spaced no more than 1 meter apart from each other.

(3) In case the lower part of the building has steel reinforced walls, then the metal fronts shall normally be interconnected with the reinforcement steel rods and these interconnections shall be spaced no more than 10 meters apart from each other. If there are no steel reinforced walls, the metal fronts shall be connected to the grounding system and these connections shall be spaced 10 meters apart from each other if the lower lip of the metal front is lower than 1 meter above ground. If the lower lip of the metal front is higher than 1 meter above ground, either the connections to the grounding system shall be spaced no more than 5 meters apart from each other or the fronts shall be interconnected to a meshing as specified under Section 4.2.3.1.

(4) The metal fronts used as down conductors shall be interconnected to the meshing in the roof, and these connections shall be spaced as specified in Section 4.2.4.1 (cf. **Figure 4-3**).

(5) In case of an external structural seal of the buildings, the connections of the foundation grounding devices shall be designed as shown in **Figure 4-2** and, in case of buildings without an external seal, as shown in **Figure 4-3**. For the purpose of testing, the connection to the external grounding system shall be achieved by accessible disconnect terminals. These disconnect terminals shall be unambiguously and durably marked. Their markings shall be identical to the corresponding markings used in the surveillance plans of the buildings.

4.2.4 Building Shield

4.2.4.1 Outer walls and roofs of buildings

(1) For the protection of the electrical facilities a shield shall be formed inside the buildings by interconnecting all electrically conductive parts of the building structure.

(2) In the case of structural components out of reinforced concrete, the reinforcement steel steel rods shall be used for the shielding. Thus, a meshing shall be created, either, by interconnecting the existing reinforcement steel rods or by interconnecting additional steel rods with the reinforcement steel rods. The mesh spacing shall not exceed 5 meters. To ensure a true contact, all parts of the meshing shall be welded or securely clamped or bolted together such that the connecting cross-section is at least equal to the cross-section of the meshing. The added rods shall be tie-wire connected at intervals of 1 meter to the reinforcement steel rods.

(3) Expansion joints within a building shall normally be bridged in intervals of 2 ± 1 meters.

(4) If the actual building construction does not deliver sufficient shielding, it is permissible to create a shielding effect for the electrical facilities located within this building by a suitable individual component shielding (e.g., shielding of the cable ways). In case of an insufficient shielding, e.g., due to the use of prefabricated steel-reinforced components, additional measures shall be taken (cf. Section 4.3).

4.2.4.2 Building penetrations

All conducting non-electrical components leading into the buildings shall normally be connected to the building shield.

N o t e :

Pipe lines, for example, are interconnected by low-impedance connections to the reinforcement steel rods at the point of entry into the building. In this context, corrosion protection shall be provided.

4.2.5 Grounding

4.2.5.1 Grounding of the buildings

(1) In the case of buildings without an external structural seal (non-insulated foundation), the grounding shall be achieved using the reinforcement steel rods of the foundations. Beneath the grounding connection within the foundation and the walls, an additional meshing shall be embedded with a mesh spacing of 10 meters; the rods of the meshing shall be tie-wire connected at intervals of one meter to the reinforcement steel rods (of the foundation?). The intersecting points of the meshing shall be welded or securely clamped or bolted such that the electrically conducting connecting cross-section is at least equal to the cross-section of the meshing. Inside the walls this meshing and the down conductors shall be welded or securely clamped or bolted together as specified in Section 4.2.3.1 (cf. **Figure 4-1**).

N o t e :

Additional requirements with regard to grounding systems outside of the buildings are specified in, e.g., DIN VDE 0100-410, DIN VDE 0100-540, DIN VDE 0101 and DIN VDE 0141.

(2) For the connection to the external grounding system, terminal lugs shall be led to the outside of the wall from the meshing connected to the reinforcement steel rods (of the foundation?). In this context, corrosion protection shall be provided. The terminal lugs shall be permanently connected to the steels reinforcement steel rods (of the foundation?) or to the metal building fronts; the connection to the grounding system shall be achieved through accessible disconnect terminals (**Figure 4-2**).

(3) In the case of buildings with an external structural seal (insulated foundation), a grounding mesh with a mesh spacing of 10 meters shall be embedded in the ground outside of the structural seal. If this grounding mesh is fabricated from reinforcement steel, the diameter of the rods shall normally be no smaller than 10 mm and shall be embedded in a concrete layer of a thickness no smaller than 10 cm and consisting of at least a grade B 15 concrete. The interconnection between the concrete reinforcement steel rods and the copper cable shall be protected against corrosion. This interconnection does not have to be detachable (cf. **Figure 4-2**). The interconnections of the grounding mesh shall be as specified in Section 4.2.5.3.

4.2.5.2 External grounding between the buildings

(1) A closely meshed grounding net of surface ground devices (ground rings and grounding meshes) shall be installed in the direct vicinity of Level 1 protection category buildings (cf. **Figure 4-4**).

(2) Each building complex that belongs together with regard to lightning protection shall be surrounded by a ground ring which shall be connected every 10 meters to the down conductors or, in the case of metal building fronts whose lower lip is higher than 1 meter above ground, shall be connected above the disconnect terminals at intervals of 5 meters (cf. Section 4.2.3). Starting out from the ground ring, surface ground devices shall be provided at intervals of 10 meters (mesh width) and such that a maximum mesh length of 30 meters is formed. The meshing of neighboring buildings shall be correlated to each other. The mesh of the surface ground devices connecting to these meshes shall not exceed 30 meters in width and 90 meters in length; further meshes interconnected to theses surface ground device meshes may be increased up to double this dimension. The overall expanse of the grounding mesh shall be specified in each individual case.

(3) The ground rings of Level 2 protection category buildings shall be connected to the grounding mesh.

(4) In the case of multi-unit power plants, the grounding meshes of the individual plant units as well as that of the mutually used buildings shall be interconnected to each other.

4.2.5.3 Corrosion resistance of the grounding mesh

All parts of the grounding mesh embedded in soil shall be constructed of corrosion resistant materials. Undetachable connections (e.g., welds, crimp connections) shall be used exclusively.

N o t e :

The required minimum cover of reinforcement steel is specified in DIN 1045.

4.2.6 Connections between the buildings

4.2.6.1 Cable ducts and cable bridges

(1) Cable ducts and cable bridges running between Level 1 protection category buildings shall be shielded throughout. The reinforcement steel rods of the ducts may be used as shielding.

(2) The duct ends and the expansion joints shall be provided with electrically conductive ring connections of steel rods or steel bars with a minimum cross-section of 100 mm², and these ring connections shall be tie-wire connected to the reinforcement steel rods and shall be welded or securely clamped or bolted to the meshing in the walls.

(3) Provisions shall be taken at the expansion joints and the anchor points to the building walls to ensure that the reinforcement steel rods are interconnected with each other such that it becomes possible to bridge the expansion joints by a low-impedance connection (cf. Figure 4-5).

(4) At the connecting points to the building walls, reinforcement steel rods shall be embedded in the wall with the same spacing as that of the bridging of the expansion joints; these reinforcement steel rods shall extend as far as the nearest down conductor or grounding mesh (cf. Figure 4-5).

(5) In the case of subterranean channels that have to be connected to buildings with an external structural seal, 2 meter long reinforcement steel rods shall be embedded in the walls starting from the bridging of the expansion joints, and these rods shall be tie-wire connected to the reinforcement steel rods and shall be welded or securely clamped or bolted to the meshing in the walls (cf. **Figure 4-6**).

(6) Cable bridges shall either be constructed in the same way as the cable ducts or shall be provided with a closed metal cladding that is interconnected by a low-impedance connection to the metal building front or to the reinforcement steel rods via the shortest route. The connections between the cable bridges and the buildings shall be spaced in intervals of no more that 1 meter (cf. **Figure 4-5**).

(7) In the case that metal building fronts are used as down conductors, structural measures shall be taken to connect the meshing in the cable bridges to the metal fronts with the same number of connections as for bridging the expansion joints (equally distributed over the circumference).

4.2.6.2 Ground-routed and open-air cables

(1) Ground cables shall be positioned over any ground-routed cables as protection against a direct lightning strike.

(2) If instrumentation and control cables are not laid through steel-reinforced cable ducts, these cables shall be provided with suitable protection measures, e.g., shielding. This shielding shall be interconnected by a low-impedance connection to the building shield.

N o t e :

Examples for such a shielding are:

a) Cables inside a current conductive shield, where this shield is interconnected by a low-impedance connection to the reinforcement steel rods of the building either at, or directly after, the point of entry of the cable into the building.

b) Cables led in continuous metal pipes, where the pipes are interconnected by low-impedance connections to the steel reinforcement of the building.

(3) In the case of electrical facilities located outside of buildings, the same measures shall be applied as specified under para. 1, and the shielding shall be interconnected by a low-impedance connection to the grounded housing.

(4) In the case of electrical facilities located outside of buildings where the possibility for a direct lightning strike must be taken into consideration, the cables leading from these facilities into buildings shall be equipped with surge-voltage protection devices at the point of entry into the building that would be capable of carrying the current of a lightning-strike.

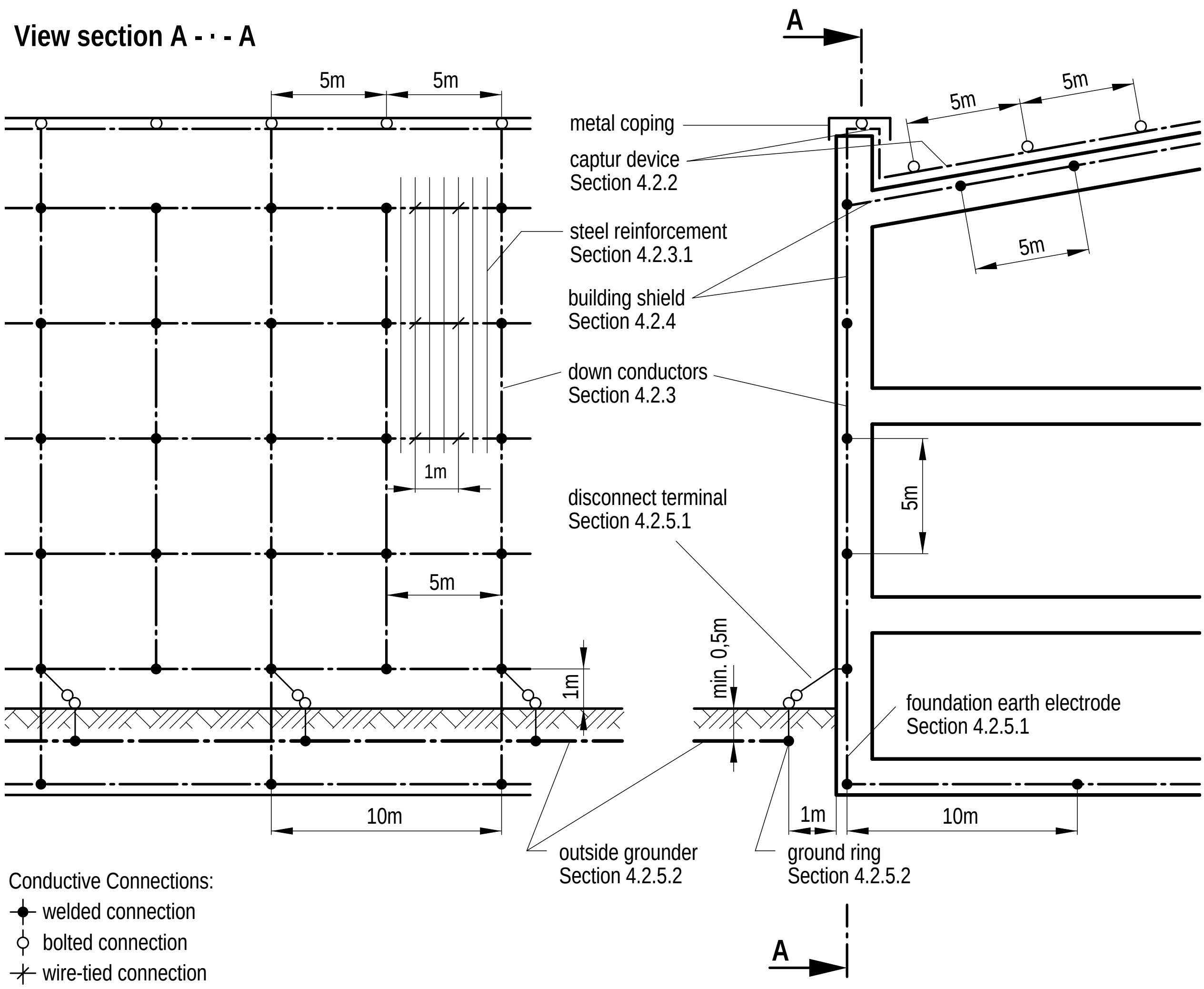


Figure 4-1: Reinforcement steel rods for the building shield in the case of buildings without a metal building front, and interconnection of the foundation earth electrode in the case of buildings without an external structural seal

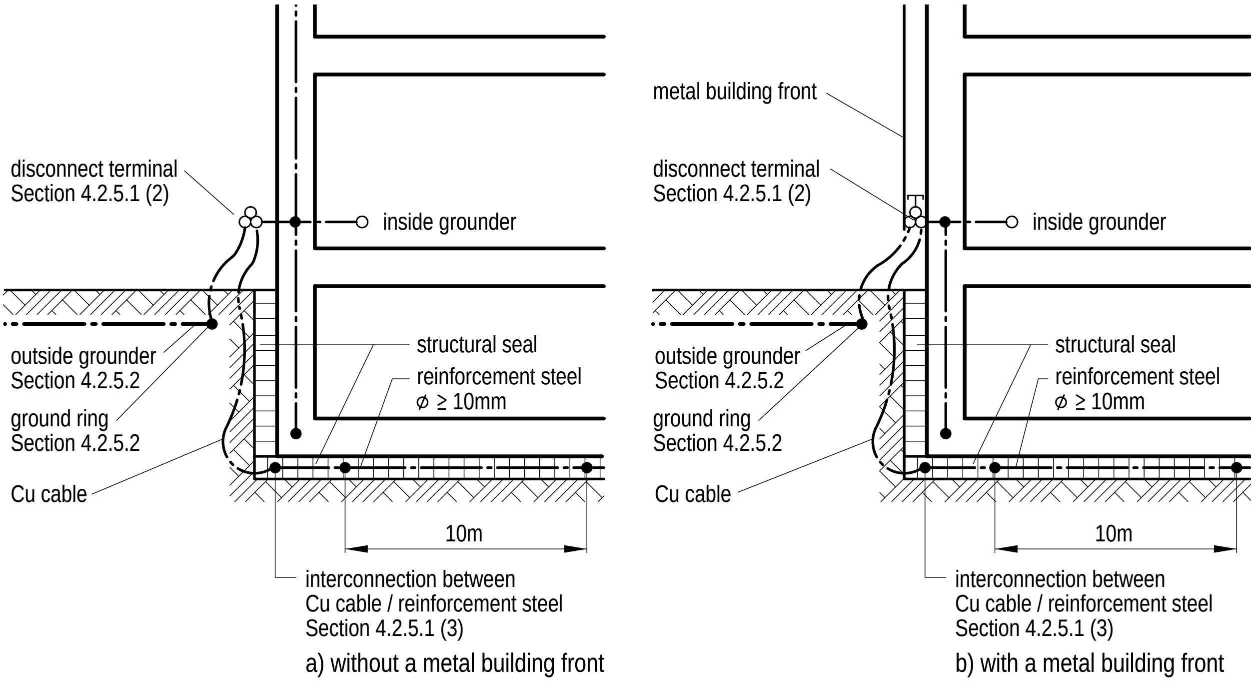


Figure 4-2: Interconnection of the foundation earth electrode in the case of buildings with an external structural seal

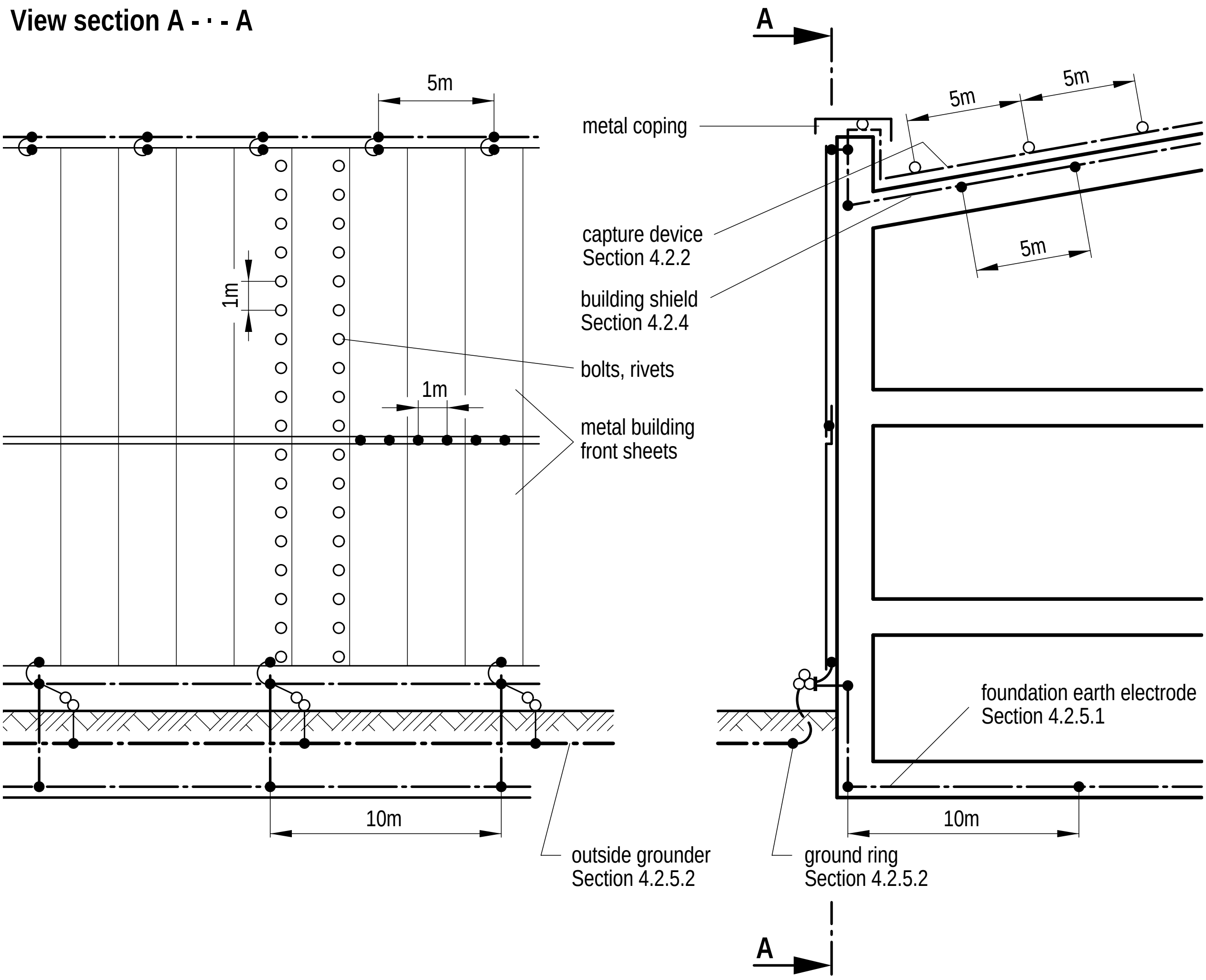


Figure 4-3: External lightning protection in the case of buildings with metal building fronts (height of lower lip less than 1 meter above ground) and without an external structural seal

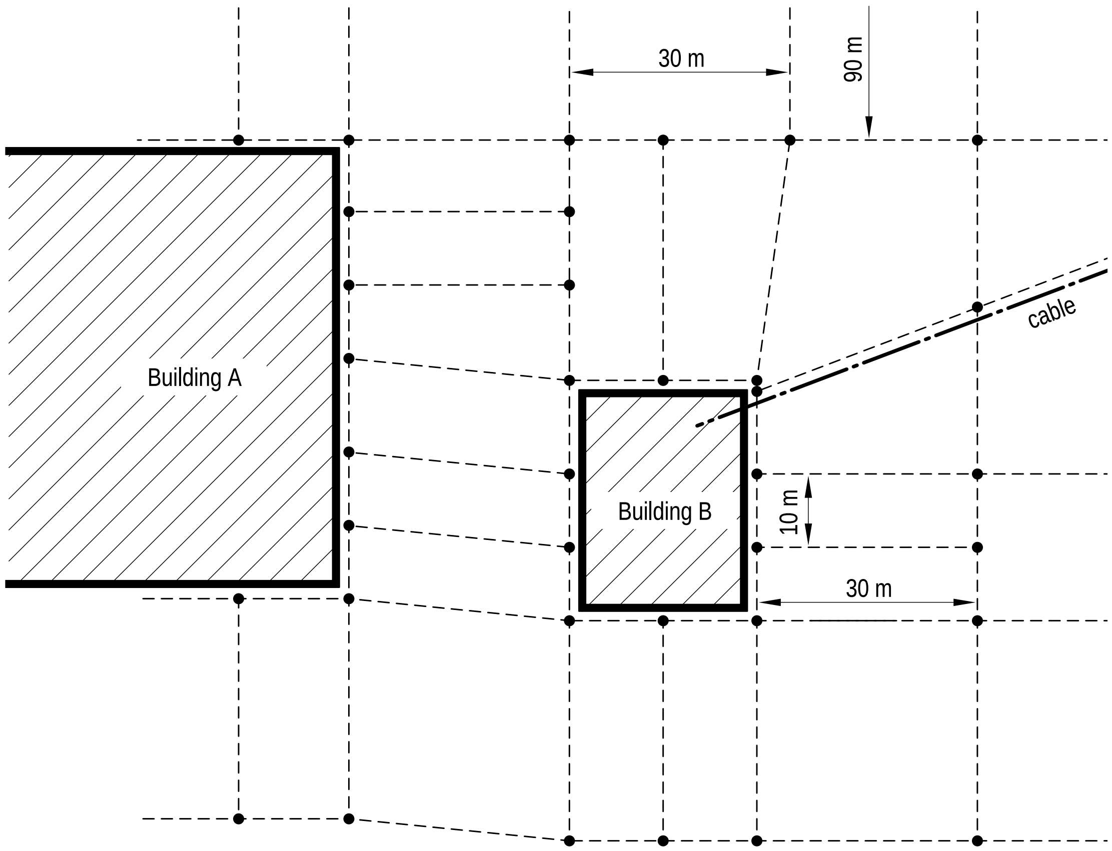


Figure 4-4: External grounding between buildings

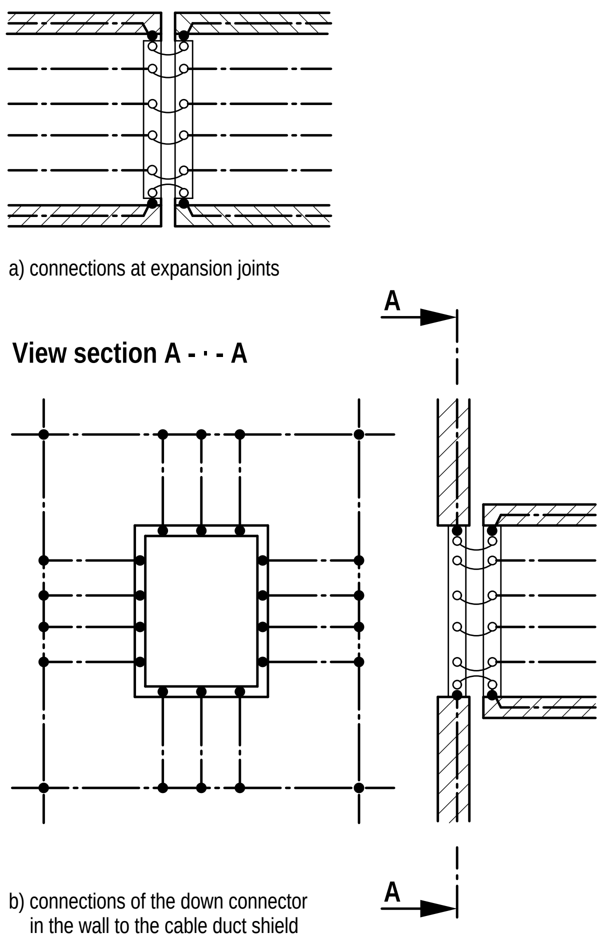


Figure 4-5: Cable ducts and cable bridges

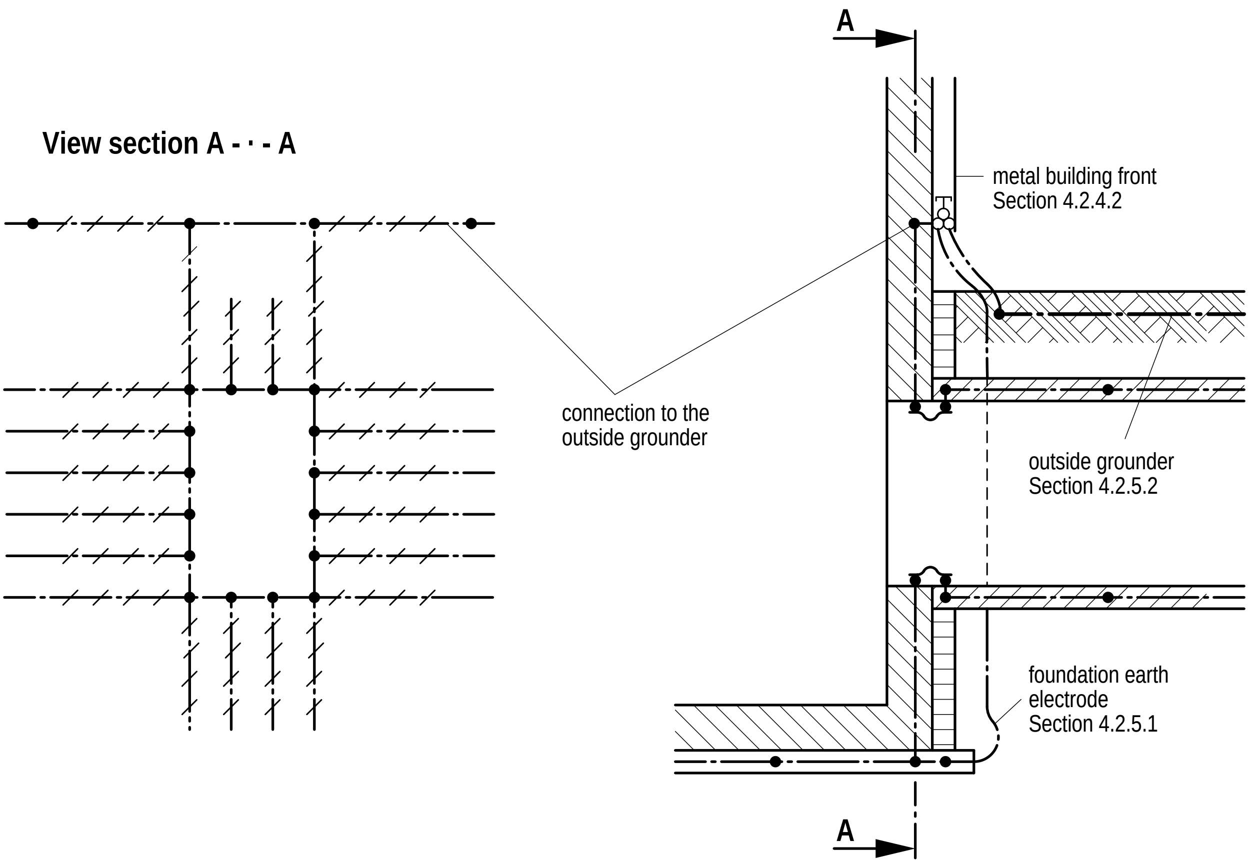


Figure 4-6: Cable duct, interconnection of the cable duct shield to the metal building fronts and to the foundation earth electrode in the case of an insulated foundation

4.3 Interior Lightning Protection

4.3.1 General requirements

In addition to the measures specified under Section 4.2 for the Exterior Lightning Protection system, the measures specified under Sections 4.3.2 through 4.3.5 are required for electrical facilities specified under Section 3.2 that are located within Level 1 protection category buildings. In addition, the measures specified under Section 4.3.6 shall be applied to all those electrical facilities

a) in which the maximum permissible voltage would be exceeded in case of a lightning strike, or

b) which are interconnected to electrical facilities outside of the buildings or to grounding facilities and which are not able to be protected by other measures.

4.3.2 Voltage equalization (internal grounding)

4.3.2.1 Collective ground conductor

(1) All rooms inside Level 1 protection category buildings shall be provided with collective ground conductors in the form of ground cable rings or with a collective ground tracks (voltage equalization track). The collective ground conductors shall be interconnected with low-impedance connections to the meshing which provides the connection to the reinforcement steel rods. The meshing embedded in the reinforcement steel rods may be used as collective ground conductor.

(2) All cabinets or related groups of cabinets shall be connected to these collective ground conductors, provided, their function so allows. However, it is permissible to use other connections to the meshing connected to the reinforcement steel rods than the connection to the collective ground conductor.

4.3.2.2 Cable racks and cable troughs

(1) Inside the buildings, the cable racks and cable troughs shall normally be conductively interconnected in order to enhance voltage equalization. They shall be connected at least at both ends to the meshing or to the reinforcement steel rods in the walls or to the collective ground conductor.

Note:
In the sense of this safety standard, a conductive interconnection may be a bolt connection secured against self-loosening to construction elements, or a copper cable connection between joints of those cable trays or troughs not interconnected through construction elements.

(2) Cable ways inside buildings that run directly along the outside walls shall normally be additionally shielded from the outside wall if an induction of voltages is not reduced to permissible values by other means, e.g., by metal building fronts.

(3) All cable racks and cable troughs for instrumentation and controls cables in those connecting channels and cable bridges to which design requirements of the Level 1 protection category buildings apply shall be conductively interconnected over their entire length between the buildings and shall be connected to the collective ground conductors inside the buildings. This also applies to the connections of cable trays and cable troughs traversing partitions or expansion joints.

4.3.3 Grounding of the reference potential lead of the power supply

(1) The reference potential lead of the power supply of functionally related instrumentation and control systems shall be connected to the voltage equalization system. Whether this is achieved by a decentralized (planar, intermeshed) or centralized connection (stellate connection to a central ground point) shall be decided primarily on the basis of the requirements of the instrumentation and control system. In the case of instrumentation and control systems with a large-area reference potential system, decentralized grounding shall be given preference from the standpoint of lightning protection.

Note:

Instrumentation and control systems are considered functionally related if they are galvanically connected to each other.

In the case of a centralized grounding of the reference potential system one must consider that high transient voltage differences, caused by the coupling of lightning currents or by switching as well as equalization procedures, may occur in the reference potential lead system. Furthermore, electromagnetic compatibility (EMC) tests (tests performed in accordance with DIN EN 61000-4-4) have shown that several instrumentation and control systems with centralized grounding of the reference potential lead system were not sufficiently immune to fast electric transients (bursts).

(2) If the power supplies of the individual systems are operated isolated from each other and no galvanic couplings exist between the systems, then each system may be connected at the most convenient location to the voltage equalization system.

(3) It shall be ensured that low frequency effects from the electrical power supply have no impermissible adverse effects on the instrumentation and control systems.

Note:

Low frequency effects may be caused by, e.g., ground shorts or short-circuits.

(4) With regard to the search for ground shorts, the connection of the reference potential lead to the central ground point shall be unambiguously and permanently marked and shall be constructed to be easily accessible and detachable.

(5) In case of a decentralized voltage equalization of functionally related instrumentation and control systems, the reference potential lead of the power supply in each of the concerned cabinets, control desks and control panels shall be interconnected with low-impedance connections to the housings and frames. The housings and frames, in turn, shall be interconnected with low-impedance connections to the reinforcement steel rods.

(6) To avoid any cross-interference of a lightning strike in the case of multi-unit power plants, the signaling lines between the units or between the units and mutually used facilities shall be galvanically separated with regard to their operation.

Note:

A galvanic separation excludes the use of high-resistance connections.

4.3.4 Cable shields

(1) The instrumentation and control cables shall be provided with a shielding that shall be grounded in order to reduce undue capacitive or inductive interferences. With regard to lightning protection, it is advantageous to ground, at least, the two ends of the cable shield.

Note:

In the case of short cable connections and branch cable connections between sub-distributors and transducers, a single grounding of the cable shield within the sub-distributor is usually sufficient, provided the requirements under Section 3.1 para. 1 are met.

(2) The cable shield shall be grounded in the cabinets, at the central ground point or at other points especially designed for shield grounding.

(3) In order to reduce the axial lightning-based voltage components, if the shield of an instrumentation and control cable is grounded at more than one location, it shall be ensured that any other coupled interference voltages will also not lead to impermissible signal distortions and that the cable shield is not subjected to undue thermal effects from possible equalization currents.

Note:

In the case of multiple grounding of the cable shield, care shall be taken that the coupling impedance of the cable is sufficiently low.

(4) Cable wires of the same circuits, e.g. power supply wires and signal wires, shall be contained within the same shield.

(5) Within a building, the signal cables and corresponding supply cables (power supply cables of the electronics cabinets) shall be led in cable trays or troughs that are interconnected by low-impedance connections.

(6) If additional shielding measures are required, e.g., piping or metal sheet channels around the stretch of cables, then the signal cables and supply cables along the respective stretch of cables shall be equivalently shielded.

(7) To reduce the axial voltage components, unused cable wires may be grounded at both ends. It shall be ensured that the radial voltage components in the other wires do not exceed permissible limit values.

4.3.5 Routing of cables

(1) Cables leading from Level 2 protection category buildings or from the external area of the power plant into Level 1 protection category buildings shall be routed apart from the local cables or shall be shielded unless it is ensured that no coupling of impermissible voltages can occur.

(2) The minimum separation distance in the case of a separate routing of cables of Level 1 and Level 2 protection category buildings shall be specified on the basis of the relevant influencing parameters.

Note:

Relevant influencing parameters may be, e.g., length of the parallel routing, wire arrangement within the cables as well as the interference parameters from cables in Level 2 protection category buildings (steepness of voltage and current transients, frequency spectrum).

4.3.6 Surge-voltage protection devices

(1) The instrumentation and control equipment shall be protected against lightning-based voltage surges. If this requires surge-voltage protection devices, they shall be provided with low-impedance connections to ground.

Note:

The surge-voltage protection devices used may be, e.g., spark gaps, Zener diodes or varistors or a combination of these components.

It may be necessary to install a system of graduated and coordinated surge-voltage protection devices. The graduation will be in accordance with the discharge capacities and response characteristics.

To increase the input resistance, opto-electrical signal connections, buffer transmitters, buffer amplifiers and coupling relays or coupling switches may be used.

The surge-voltage protection devices employed depend on the type of instrumentation or control equipment to be protected, i.e., on the type of transmission and effective signal processing of the effective signal involved.

(2) It shall be possible to test the surge-voltage protection devices required for limiting the lightning-based voltage surges. Testing shall normally be possible without any changes to circuitry. The surge-voltage protection devices shall, preferably, be designed as plug-in units. The surge-voltage protection plug-in devices shall be constructed such that a mix-up is not possible. In the case of hardwired surge-voltage protection devices, built-in testing aids (e.g. disconnect terminals, testing jacks) shall be provided.

5 Proof of the Protection Against Lightning-Based Voltage Surges

5.1 General Requirements

(1) It shall be demonstrated that the permissible voltages of the instrumentation and control equipment and systems employed are not exceeded in case of a lightning strike (cf. Section 5.3).

N o t e :

In order to be able to determine the induced voltages it is necessary to know the lightning current that would flow through the individual cable duct or cable way in case of a lightning strike. This current can be calculated from the characteristics of the lightning current specified under Section 3.3 by taking the impedances of the ducts, ground cables and ground itself and correspondingly distributing the entire lightning current over these paths.

(2) This safety standard does not specify any analytical procedures that deal with the induction of lightning-based voltages into instrumentation and control cables inside the power plant buildings. After shielding of the buildings as well as the routing and shielding of the cables in accordance with this safety standard, no impermissibly high lightning-based voltage induction into the cable ways inside buildings needs to be considered.

(3) In designing the lightning protection system it is permissible to use the results of previous measurements or calculations for nuclear power plants, provided, the dimensions and arrangements of the buildings and cable ducts are comparable.

(4) In the calculations it is permissible that those currents induced into cables routed in channels or in the ground that would be caused by close-vicinity lightning strikes are neglected.

5.2 Calculation of the Expected Voltages

N o t e :

The following calculations apply to the measures specified under Sections 4.2 through 4.3.5.

5.2.1 General requirements

(1) For the calculation of the occurring voltages, the critical lightning strike locations shall be specified.

N o t e :

Possible lightning strike locations are considered as critical that would lead to a large voltage induction into the cables. These are, above all, lightning strike locations in buildings at the end of a longer cable duct and there, essentially, into the smaller building. For cables in cable ducts the critical lightning strike locations would be the ones in the emergency feed building and the emergency diesel building. The critical lightning strike locations with regard to voltage induction in ground-routed cables are the smaller buildings at the edge or outside of the nuclear power plant site.

(2) The calculations shall be based on the lightning current parameters specified under Section 3.3.

(4) The pulse currents shall be modeled in accordance with the analytical lightning current function given by Equation 5-1:

$$i_B = \frac{I_B}{\eta} \cdot \frac{\left(\frac{t}{\tau_1}\right)^{10}}{1+\left(\frac{t}{\tau_1}\right)^{10}} \cdot \exp\left(-\frac{t}{\tau_2}\right) \qquad (5\text{-}1)$$

Nomenclature:

i_B	in kA	lightning current
I_B	in kA	crest current value of lightning
t	in µs	time
η	(dimensionless)	correction factor for crest value
τ_1	in µs	front end response time
τ_2	in µs	back end response time

In this context, the parameters listed in Table 5-1 shall be used.

N o t e :

Using the parameters listed in Table 5-1, the Equation 5-1 results in a lightning current function that corresponds to the lightning current parameters specified under Section 3.3.

(5) In twisted-wire pairs, the transverse voltage may be neglected.

N o t e :

The transverse voltages are influenced by the input impedances of the connected component groups, transducers, etc., and by the type of cable routing. The transverse voltages are equal to, at the most, from about 1/5 to 1/3 of the axial voltages.

5.2.2 Cables routed in cable ducts

5.2.2.1 Determination of the current distribution

(1) When determining the distribution of the lightning current, it shall be assumed for all lightning types that 1/3 of the lightning current flows to ground through the grounding system of the lightning struck building via the foundation earth electrode. The remaining 2/3 of the lightning current shall be proportionately distributed among all cable ducts and soil-contacting conductors (pipes, ground cables) leading away from the lightning struck building.

$$I_{ab} = \frac{2}{3} I_B \qquad (5\text{-}2)$$

Nomenclature:

I_{ab}	(in kA)	partial lightning current conducted into the ground via the cable ducts and soil-contacting conductors of the building struck by lightning
I_B	(in kA)	crest current value from Equation 5-1

(2) The relative portions, p_K (weighting factor), for the various partial lightning currents conducted by the cable ducts and soil-contacting conductors of the building struck by lightning shall be chosen as listed in **Table 5-2**.

(3) The partial lightning current, I_K, via the individual cable duct shall be calculated using Equation 5-3.

$$I_K = \frac{p_{KK}}{\sum_{\nu=1}^{n} p_{K\nu}} I_{ab} \qquad (5\text{-}3)$$

Nomenclature:

I_{ab}	(in kA)	cf. Equation 5-2
I_K	(in kA)	crest value of partial lightning current via the individual cable duct
p_{KK}	(dimensionless)	relative portion of the lightning current through the individual cable duct
$\Sigma p_{K\nu}$	(dimensionless)	sum of the relative portions of the partial lightning currents through all cable ducts and soil-contacting cables
n	(dimensionless)	number of considered parallel conducting plant components
ν	(dimensionless)	running index of considered parallel conducting plant components

5.2.2.2 Fictive length of the cable duct

(1) When calculating the induced voltage it may be assumed that the partial lightning current along the cable duct remains constant for a fictive length, l_f , and then falls off to zero.

(2) The fictive length, l_f , of the cable duct shall be calculated from Equation 5-4:

$$l_f = K\sqrt{\rho_e} \qquad (5\text{-}4)$$

Nomenclature:

l_f	(in meters)	fictive length of the cable duct to be applied when determining the induced voltage
K	(in $(\Omega/m)^{1/2}$)	lightning type factor
ρ_e	(in Ωm)	specific resistance of ground soil

(3) The lightning type factor, K, shall be chosen as specified in **Table 5-3**.

(4) If the actual cable duct length l_K is smaller than the length calculated from Equation 5-4, then the fictive length shall be set equal to the actual length:

$$l_f = l_K \qquad (5\text{-}5)$$

Parameter	*Symbol*	*Unit*	*Value of*		
			positive initial lightning strike	***negative initial lightning strike***	***negative subsequent lightning strike***
Crest current value	I_B	kA	200	100	50
Correction factor	η	-	0.930	0.986	0.993
Front end response time	τ_1	µs	19.0	1.82	0.454
Back end response time	τ_2	µs	485	285	143

Table 5-1: Parameters for calculating the lightning current function

Type of Cable Duct, Type of Soil-Contacting Cable	*Weighting Factor, p_K, for the partial lightning current*
Cable duct (approx. 2 m × 2 m)	3
Threefold or fourfold cable duct (each approx. 2 m × 2 m)	6
Soil-contacting cable: Ø < 0.1 m (e.g., ground cable)	1
Soil-contacting cable: 0.1 m ≤ Ø ≤ 1 m (e.g., pipe line)	2
Soil-contacting cable: Ø > 1 m (e.g., pipe line)	3

Table 5-2: Weighting factors, p_K

Type of Lightning	*Lightning Type Factor K (in $(\Omega/m)^{1/2}$)*
Positive initial lightning strike	3
Negative initial lightning strike	1
Negative subsequent lightning strike	0.5

Table 5-3: Lightning type factor, K

5.2.2.3 Calculation of the induced axial voltage component

(1) The induced axial voltage component, U_L, shall be calculated from Equation 5-6:

$$U_L = Z'_M \cdot I_K \cdot l \qquad (5\text{-}6)$$

Nomenclature:

U_L	(in V)	induced axial voltage component
Z'_M	(in V/kAm)	coupling impedance overlay
l	(in meters)	actual length

(2) The influence of the expansion joints along the course of a cable duct and to the buildings shall be accounted for by assuming a fictive extension, l_{DF}, of the cable duct. The values for l_{DF} shall be chosen from **Table 5-6**. Only those expansion joints shall be considered that are located within reach of the fictive length l_f of the cable duct.

$$l = l_f + \sum_{\nu=1}^{N} l_{DF_\nu} \qquad (5\text{-}7)$$

Nomenclature:

l_{DF}	(in meters)	influence of an expansion joint
N	(dimensionless)	number of expansion joints to be considered
ν	(dimensionless)	running index

(3) The value for the coupling impedance overlay, Z'_M, needed in calculating the axial voltage component shall normally be chosen from **Table 5-5**; deviations from these values shall be substantiated.

5.2.3 Ground-routed cables

5.2.3.1 Determination of the current distribution

(1) The current distribution in ground-routed cables shall be determined for the case of a positive initial lightning strike.

Note:

In ground-routed cables the highest induced voltages are caused by currents from a positive initial lightning strike.

(2) In the case of buildings with a steel reinforced foundation it shall be assumed, with regard to determining the lightning current distribution, that 1/3 of the lightning current of the lightning struck building flows to ground through the grounding system. The remaining 2/3 of the lightning current shall be proportionately distributed to the cables leading away from the lightning struck building.

$$I_{ab} = \frac{2}{3} I_B \qquad (5\text{-}8)$$

Nomenclature:

I_{ab}	(in kA)	crest value of partial lightning current led through all conductors (soil-contacting and non-soil-contacting conductors) of the lightning struck building
I_B	(in kA)	crest current value from Equation 5-1

(3) If the building struck by lightning has only a single ground ring or one or more ground rods then the entire lightning

current shall be proportionately distributed to all conductors leading away from the building as specified in **Table 5-4** (pipe lines, ground cables, cable ducts):

$$I_{ab} = I_B \tag{5-9}$$

(4) If ground-routed cables are laid together in a single duct (ground-routed cable duct), the partial lightning current shall be determined for the entire duct.

(5) The relative portions, p_E (weighting factor), of the various partial lightning currents conducted by the ground-routed cables leading away from the building struck by lightning as well as for the soil-contacting or insulated conductors shall be chosen as specified in **Table 5-4**.

Type of Ground Cable, Type of Soil-Contacting or Insolated Conductor	***Weighting Factor, p_E, for the partial lightning current***
Single cable (instrumentation and control equipment)	1
Ground-routed cable duct with from 2 up to 10 instrumentation and control cables	2
Ground-routed cable duct with more than 10 instrumentation and control cables	3
Cable duct (approx. 2 m x 2 m)	3
Threefold or fourfold cable duct (each approx. 2 m x 2 m)	6
Soil-contacting or insulated conductor: Ø < 0.1 m (e.g., ground cable)	1
Soil-contacting or insulated conductor: 0.1 m ≤ Ø ≤ 1 m (e.g., pipe line)	2
Soil-contacting or insulated conductor: Ø > 1 m (e.g., pipe line)	3

Table 5-4: Weighting factor, p_E

(6) The crest value of the partial lightning current, I_E, flowing through the individual ground-routed cable duct shall be calculated from Equation 5-10.

$$I_E = \frac{p_{EE}}{\sum_{\nu=1}^{n} p_{E\nu}} I_{ab} \tag{5-10}$$

Nomenclature:

I_{ab}	(in kA)	cf. Equation 5-8 or 5-9
I_E	(in kA)	crest value of partial lightning current flowing through the individual ground-routed cable duct
p_{EE}	(dimensionless)	relative portion of the lightning current flowing through the individual ground-routed cable duct
$\Sigma p_{E\nu}$	(dimensionless)	sum of the relative portions of the partial lightning currents flowing through all ground-routed cables and soil-contacting conductors
n	(dimensionless)	number of all parallel conducting plant components considered
ν	(dimensionless)	running index of the parallel conducting plant components considered

(7) The crest value of the partial lightning current, I_E, flowing through the individual ground-routed cable duct shall be evenly distributed over the crest values of the partial lightining currents, I_{KS}, flowing through the current conductive shields of all parallel cables in the individual ground-routed cable duct.

Equation 5-11 shall be applied to single cables:

$$I_{KS} = I_E \tag{5-11}$$

Nomenclature:

I_E	(in kA)	cf. Equation 5-10
I_{KS}	(in kA)	crest value of partial lightning current flowing through the ground-covered cable

Equation 5-12 shall be applied to a ground-routed cable duct:

$$I_{KS} = \frac{1}{q} \cdot I_E \tag{5-12}$$

Nomenclature:

I_E	(in kA)	cf. Equation 5-10
I_{KS}	(in kA)	cf. Equation 5-11
q	(dimensionless)	number of instrumentation and control cables in the ground-routed cable duct. (This count may include all soil-contacting accompanying cables of the duct and the voltage equalization cable in the cable-drawing tubes.)

5.2.3.2 Calculation of the induced axial voltage component

(1) The induced axial voltage component, U_L, shall be calculated from Equation 5-13:

$$U_L = Z'_M \cdot I_{KS} \cdot l_E \tag{5-13}$$

Nomenclature:

U_L	(in V)	induced axial voltage component
l_E	(in meters)	actual length of the ground-routed cable
I_{KS}	(in kA)	cf. Equation 5-11 or 5-13
Z'_M	(in V/kAm)	coupling impedance overlay

(2) The direct-current resistance, R'_{DC}, specified by the cable manufacturer, shall be used as coupling impedance overlay, Z'_M.

5.3 Testing for Permissible Voltages

(1) The test for the permissible voltages of the devices and systems interconnected to the cables specified under Sections 5.2.2 and 5.2.3 shall be based on the maximum dielectric strength against voltage pulses.

Note:

DIN EN 61000-4-5 describes a hybrid voltage generator for testing the immunity against disturbance and destruction of devices and systems in the case of lightning-based voltage pulses. This hybrid voltage generator creates an idling voltage with a pulse shape of 1.2/50 µs and a short circuit current with a pulse shape of 8/20 µs. The test setup takes the standard surge-voltage protection devices employed into consideration.

(2) In the case of devices with a decoupling function, e.g. measuring transducers or high-resistance separation modules, the resistance against axial voltage components shall also be determined.

Note:

Axial voltages are the voltage levels that builds up between decoupled interconnections and between the connections and the housing.

(3) If the voltages determined as specified under Section 5.2 exceed the permissible voltage, then these cables shall be provided with surge-voltage protection devices as specified under Section 4.3.6.

5.4 Certification in Case of Design Deviations

In case the demonstrations under Section 5.2 cannot or should not be performed due to a deviating plant concept or due to other reasons, then the induced axial voltage, U_L, shall be determined either

a) by other suitable analytical procedures,
b) by modeling tests,
c) by lightning simulation,

or by a combination of these methods.

Arrangement	Type of Lightning	***Front Time, τ_1 (in μs)***	***Coupling Impedance Overlay, Z'_M (in V/kAm)***
Cable duct (approx.. 2 m × 2 m)	Negative subsequent lightning strike	0.25	0.50
	Negative initial lightning strike	1.0	0.30
	Positive lightning strike	10	0.08

Note:
1. The values specified apply to cable ducts designed in accordance with this safety standard..
2. The same value apply to multi-channel cable ducts. For the calculation in this case, the entire current through the multi-channel cable duct is split up into partial currents and distributed over the individual cable ducts.

Table 5-5: Guide values for the coupling impedance overlay, Z'_M, for calculating the axial voltage component as a function of the front time, τ_1, of the current pulse

Type of Lightning	***Front Time, τ_1 (in μs)***	***Fictive Extension, l_{DF}, per Expansion Joint (in meters)***			
		for 16 expansion joint bridgings	for 8 expansion joint bridgings	for 4 expansion joint bridgings	for 2 expansion joint bridgings
Negative subsequent lightning strike	0.25	15	30	50	70
Negative initial lightning strike	1.0	10	20	35	55
Positive lightning strike	10	5	10	20	30

Note:
The values specified apply to a single-channel cable ducts designed in accordance with this safety standard.

Table 5-6: Fictive extension, l_{DF}, of a cable duct per expansion joints as a function of the front time, τ_1, of the current pulse

6 Tests and Inspections

6.1 Design Review

(1) Prior to the erection of the lightning protection system it shall be verified on the basis of documents (e.g., design specifications, building survey plans) that the requirements of this safety standard are met.

(2) The design of the lightning protection system shall be reviewed to verify that the components and operating media meet the requirements of this safety standard with regard to the materials used, their dimensions and corrosion behavior.

(3) The measures provided by the Interior Lightning Protection system shall be reviewed to verify that they meet the requirements of this safety standard. Descriptions, arrangement drawings, circuit diagrams and data sheets shall be used to check, e.g., the correct design and arrangement of the intended surge-voltage protection devices.

6.2 Tests and Inspections During Construction

Those parts of the lightning protection system that will not be accessible at a later time (e.g. connections of the meshing, the terminal points, the anchor plates and the foundation earth electrodes as well as the connections to the reinforcement steel rods) shall be inspected before concreting or refilling to verify that they conform with the design reviewed construction documents.

6.3 Acceptance Tests

(1) After assembly of the lightning protection system and before beginning with nuclear commissioning, the following acceptance tests of the Exterior Lightning Protection system shall be performed:

a) The accessible parts of the Exterior Lightning Protection system shall be visually inspected with respect to fabrication quality and to the required dimensions, spacing and materials.
b) The conductive resistances via the ground ring, the down conductors and the connections to the ground rings of neighboring buildings shall be determined. This requires that the disconnect terminals are individually opened. The two resistance values to the two corresponding neighboring disconnect terminals shall be measured and the measurement results documented. These measurements shall be used in each case to verify the required low-impedance connection to the grounding system.

(2) Prior to nuclear commissioning, the following acceptance tests of the Interior Lightning Protection system shall be performed:

a) A visual inspection shall be performed with regard to the fabrication quality of the collective ground conductor (voltage equalization tracks), to the grounding of the instrumentation and control system, to the connection between the collective ground conductor and the grounding system, and to the electrical connections of the cable racks and cable troughs.

b) In case of a centralized grounding, the insulation resistance of the reference potential lead to ground shall be measured and the measurement results documented. A random check of the insulation of the reference potential lead at the transducer shall be performed

N o t e :

An exemplary measurement procedure is presented in Appendix B.

c) The devices of the surge-voltage protection system shall be tested.

(3) Prior to nuclear commissioning, a testing schedule shall be set up for the acceptance tests and must be agreed upon by the authorized expert (under Sec. 20 Atomic Energy Act). This testing schedule shall list the systems or system components to be tested, the tests to be performed, the test instructions and the participation of the authorized expert (under Sec. 20 Atomic Energy Act).

(4) The acceptance tests shall be performed by qualified personnel determined by the licensee. In as far as the testing schedule so provides, authorized experts (under Sec. 20 Atomic Energy Act) shall be consulted in these tests.

6.4 Inservice Inspections

(1) The Interior Lightning Protection system shall be subjected to inservice inspections in approximately annual intervals (e.g., during refueling), and the Exterior Lightning Protection system in three year intervals (e.g., annually one third of the overall test volume). The following tests shall be performed:

a) The accessible parts of the Exterior Lightning Protection system shall be visually inspected with respect to their physical condition.

b) The conductive resistances via ground ring, down conductors and connections to the ground rings of neighboring buildings shall be determined. This requires that in each case the individual disconnect terminal is opened. The two resistance values to the two corresponding neighboring disconnect terminals shall be measured and the measurement results documented and compared to previous measurement values.

c) The surge-voltage protection devices shall normally be tested in intervals of one year. An extension of these testing intervals is permissible on the basis of reliability data of the individual surge-voltage protection devices under consideration of the location of installation.

N o t e :

The evaluation of operating experience indicates that, for certain components, an extension of the testing interval to four years could be permissible.

(2) In the case of instrumentation and control systems with a central ground point, the insulation resistance of the reference potential lead shall be tested at the central ground point in approximately one year intervals (e.g. during refueling); the results shall be documented and compared to the respective previous measurement values. The measurement procedures used for these measurements shall be equivalent to those used in the course of the acceptance tests.

(3) The inservice inspections shall be performed by qualified personnel determined by the licensee. If the testing schedule in accordance with safety standard KTA 1202 so provides, authorized experts (under Sec. 20 Atomic Energy Act) shall be consulted in these tests.

6.5 Test Certification

The acceptance tests and the inservice inspections performed shall be recorded in test certificates. These test certificates shall, in accordance with safety standard KTA 1202, contain all data required for the assessment and evaluation of the individual tests.

7 Requirements Regarding Technical Modifications

(1) It shall be ensured that the requirements of this safety standard are fulfilled in case of any technical modifications of instrumentation and control equipment, of mechanical and structural components. The modifications shall not have any impermissible adverse effects on the existing lightning protection system.

(2) In the case of technical modifications, it is required that the tests specified under Section 6 are performed. The extent of these tests shall be specified in each individual case.

(3) After completion of any modifications of the instrumentation and control equipment with a central ground point, the insulation of the reference potential lead as well as the static shields of the instrumentation and control cables shall be checked on the modified device.

8 Documentation

The extent of the documentation shall be specified in accordance with safety standard KTA 1404.

Appendix A

Examples for Calculating the Occurring Voltages

A 1 Determination of the Induced Voltages for One Cable in a Cable Duct

(1) The calculation shall be based on the following assumptions:

a) The lightning strikes a building with a foundation earth electrode.

b) The specific resistance of the soil is ρ_e = 500 Ωm.

c) The following conductors lead away from the building struck by lightning:

ca) two soil-contacting pipe lines, 0.1 m < Ø < 1 m;

cb) two soil-contacting pipe lines, Ø > 1 m;

cc) ten ground cables (soil-contacting conductor, Ø < 0.1 m);

cd) one single channel cable duct (approx. 2 m x 2 m).

d) The respective cable duct has a length of l_K = 50 meters and has a total of four expansion joints (two between the connecting buildings and two additional joints after every 16.7 meters). Each expansion joint is bridged eight times.

(2) Calculation of the Negative Subsequent Lightning (I_B = 50 kA)

a) Based on Equation 5-2, the crest value of the partial lightning current leaving the building is calculated to be

$$I_{ab} = \frac{2}{3} \cdot I_B = 33.3\ \text{kA}$$

b) Based on Equation 5-3 and Table 5-2, the crest value of the partial lightning current through the respective cable duct is calculated, with p_{KK} = 3 und $\sum p_{K\nu}$ = 23, to be

$$I_K = \frac{p_{KK}}{\sum\limits_{\nu=1}^{n} p_{K\nu}} \cdot I_{ab} = 4.34\ \text{kA}$$

c) Based on Equation 5-4 and Table 5-3, the fictive length of the cable duct is calculated to be

$$l_f = K \cdot \sqrt{\rho_e} = 11.2\ \text{m}$$

d) Table 5-5 lists the coupling impedance overlay for a negative subsequent lightning strike as Z'_M= 0.50 V/kAm, and Table 5-6 lists the fictive extension of this cable duct for one expansion joint as l_{DF} = 30 meters. Only one expansion joint needs to be considered (l_f = 11.2 m). Based on Equations 5-6 and 5-7, the induced axial voltage component is calculated to be

$$\begin{aligned} U_L &= Z'_M \cdot I_K \cdot \left(l_f + \sum l_{DF} \right) \\ &= 0.50 \frac{\text{V}}{\text{kAm}} \cdot 4.34\ \text{kA} \cdot (11.2\ \text{m} + 30\ \text{m}) = 89.4\ \text{V} \end{aligned}$$

(3) Calculation of the Negative Initial Lightning Strike (I_B = 100 kA)

a) Based on Equation 5-2, the crest value of the partial lightning current leaving the building is calculated to be

$$I_{ab} = \frac{2}{3} \cdot I_B = 66.7\ \text{kA}$$

b) Based on Equation 5-3 and Table 5-2, the crest value of the partial lightning current through the respective cable duct is calculated, with p_{KK} = 3 und $\sum p_{K\nu}$ = 23, to be

$$I_K = \frac{p_{KK}}{\sum\limits_{\nu=1}^{n} p_{K\nu}} \cdot I_{ab} = 8.70\ \text{kA}$$

c) Based on Equation 5-4 and Table 5-3, the fictive length of the cable duct is calculated to be

$$l_f = K \cdot \sqrt{\rho_e} = 22.4\ \text{m}$$

d) Table 5-5 lists the coupling impedance overlay for a negative subsequent lightning strike as Z'_M= 0.30 V/kAm, and Table 5-6 lists the fictive extension of this cable duct for one expansion joint as l_{DF} = 20 meters. In this case, two expansion joints must be considered (l_f = 22.4 m). Based on Equations 5-6 and 5-7, the induced axial voltage component is calculated to be

$$\begin{aligned} U_L &= Z'_M \cdot I_K \cdot \left(l_f + \sum l_{DF} \right) \\ &= 0.30 \frac{\text{V}}{\text{kAm}} \cdot 8.70\ \text{kA} \cdot (22.4\ \text{m} + 2 \cdot 20\ \text{m}) = 162.8\ \text{V.} \end{aligned}$$

(4) Calculation of the Positive Lightning Strike (I_B = 200 kA)

a) Based on Equation 5-2, the crest value of the partial lightning current leaving the building is calculated to be

$$I_{ab} = \frac{2}{3} \cdot I_B = 133\ \text{kA}$$

b) Based on Equation 5-3 and Table 5-2, the crest value of the partial lightning current through the respective cable duct is calculated, with p_{KK} = 3 und $\sum p_{K\nu}$ = 23, to be

$$I_K = \frac{p_{KK}}{\sum\limits_{\nu=1}^{n} p_{K\nu}} \cdot I_{ab} = 17.3\ \text{kA}$$

c) Based on Equation 5-4 and Table 5-3, the fictive length of the cable duct is calculated to be

$$l_f = K \cdot \sqrt{\rho_e} = 67.1\ \text{m}$$

d) Table 5-5 lists the coupling impedance overlay for a negative subsequent lightning strike as Z'_M= 0.08 V/kAm, and Table 5-6 lists the fictive extension of this cable duct for one expansion joint as l_{DF} = 10 meters. In this case, all four expansion joint must be considered ($l_f > l_K$). Based on Equations 5-6 and 5-7, the induced axial voltage component is calculated to be

$$\begin{aligned} U_L &= Z'_M \cdot I_K \cdot \left(l_f + \sum l_{DF} \right) \\ &= 0.08 \frac{\text{V}}{\text{kAm}} \cdot 17.3\ \text{kA} \cdot (50\ \text{m} + 4 \cdot 10\ \text{m}) = 124{,}6\ \text{V} \end{aligned}$$

A 2 Determination of the Induced Voltage for a Ground-Routed Cable with a Current Conductive Shield

(1) The calculations shall be based on the following assumptions:

a) The lightning strikes a building surrounded by a ground ring.

b) The following conductors lead away from the building struck by lightning:

ba) one ground-routed cable duct containing eight instrumentation and control cables;

bb) three ground cables (soil-contacting conductors, Ø < 0.1 meters).

c) The respective ground-routed cable duct considered has a length l_E = 160 meters.

d) The coupling impedance overlay is Z'_M= 1.2 mΩ/m.

(2) The calculations are performed only for the positive lightning strike (I_B = 200 kA)

a) Based on Equation 5-9, the partial lightning current leaving the building is calculated to be

$$I_{ab} = I_B = 200\,\mathrm{kA}$$

b) Based on Equation 5-10 and Table 5-4, the partial lightning current through the examined ground-routed cable duct is calculated, with p_{EE} = 2 and $\sum p_{E\nu}$ = 5, to be

$$I_E = \frac{p_{EE}}{\sum_{\nu=1}^{n} p_{E\nu}} \cdot I_{ab} = 80.0\ \mathrm{kA}$$

c) Based on Equation 5-12, the partial lightning current through a ground-routed cable (instrumentation and control cable) is calculated to be

$$I_{KS} = \frac{1}{8} \cdot I_E = 10.0\ \mathrm{kA}$$

d) Based on Equation 5-13, the induced axial voltage component is calculated to be

$$U_L = Z'_M \cdot I_{KS} \cdot l_E = 1.2\,\frac{m\Omega}{m} \cdot 10.0\ kA \cdot 160\ m = 1920\ V$$

Appendix B

Example for Measuring the Insulation Resistances to Ground of the Reference Potential Lead and of the Static Shield at the Central Ground point

B 1 General Requirements

The measurement of the insulation resistances at the central ground point (ZEP) refers to the ± 24 V facility of a typical nuclear power plant unit. Three tracks come together at the ZEP, as well as the static shield (S), the central or reference potential lead (M) and the local ground (E) and, possibly, two additional tracks, the plus pole conductor (P) and the minus pole conductor (N). Here at this location are also the terminal lugs that have to be opened for the measurements. **Figure B-1** shows the simplified schematic of a ± 24 V facility with the ZEP and the four corresponding insulation resistances to ground of the tracks S, P, M, and N as well as a possible mutual galvanic induction between tracks S and M (resistance R_3). Generally, these five resistances are caused by the parallel connection of many variously sized individual insulation resistances. The result is an active network consisting of five resistances and the two voltage sources U_1 and U_2. With respect to the terminals E-M and E-S, the individual equivalent schematics consist of one equivalent voltage source and one series-connected equivalent resistance. In order to determine these equivalent resistances, the two terminal lugs must both be opened and, as shown in **Figure B-2**, a separate adjustable voltage source must be sequentially connected to the terminals E-M and then E-S, while recording the resulting voltage/current-characteristics (U/I-characteristic).

B 2 Calculation of the U/I Characteristic

(1) A measurement circuit consisting of an adjustable direct current source, K, an ampere meter, I, and a volt meter, U, is sequentially connected (as shown in **Figure B-2**) to the terminal lugs E-M and then E-S. The relationship between U and I is described as follows:

a) Connection to terminal lug E-M (cf. **Figure B-3**):

$$I = \frac{1}{R_{EM_o}} \cdot \left(U - U_{EM_o}\right) \qquad \text{(B 2-1)}$$

b) Connection to terminal lug E-S (cf. **Figure B-4**):

$$I = \frac{1}{R_{ES_o}} \cdot \left(U - U_{ES_o}\right) \qquad \text{(B 2-2)}$$

(2) In accordance with the theory of equivalent voltage sources, the terms in Equations B 2-1 and B 2-2 signify the following:

U_{EM_o} and U_{ES_o} equivalent voltages of the circuit shown in **Figure B-2** relative to the terminal lugs E-M or E-S, respectively, in the idling condition, i.e., both terminal lugs are open.

R_{EM_o} and R_{ES_o} equivalent resistances of the circuit shown in **Figure B-2** with short-circuited voltage sources U_1 and U_2 as seen from the terminal lugs E-M or E-S, respectively.

(3) The quantities specified in para. 1 are calculated on the basis of **Figure B-2** as follows:

$$U_{EM_o} = \frac{\frac{U_1}{R_1} - \frac{U_2}{R_2}}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_M} + \frac{1}{R_S + R_3}} \qquad \text{(B 2-3)}$$

$$U_{ES_o} = U_{EM_o} \cdot \frac{R_S}{R_S + R_3} < U_{EM_o} \qquad \text{(B 2-4)}$$

$$\frac{1}{R_{EM_o}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_M} + \frac{1}{R_S + R_3} \qquad \text{(B 2-5)}$$

$$\frac{1}{R_{ES_o}} = \frac{1}{R_S} + \frac{1}{R_3 + \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_M}}} < \frac{1}{R_{EM_o}} \qquad \text{(B 2-6)}$$

(4) The equation B 2-6 is exactly true if

$$\frac{1}{R_S} < \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_M}$$

which is the case after completion of the search for shorts to ground (see Section B 4).

(5) Equations B 2-5 and B 2-6 show that the insulation resistances R_M and R_S cannot be measured individually and are always larger than the measurable equivalent resistances R_{EM_o} and R_{ES_o}.

B 3 Interpretation of the Results

(1) **Figure B-3** and **Figure B-4** show that the insulation resistance shall, generally, be determined based on the gradient of the U/I-characteristic and not based on individual point values on this characteristic. This gradient, however, corresponds to the parallel connection of many individual insulation resistances (cf. Equations B 2-5 and B 2-6) and not to the significant resistances during a lightning strike, R_M or R_S.

(2) Even without specific numeric values, the Equations B 2-3 and B 2-6 show that

$$U_{EM_o} > U_{ES_o} \text{ (superimposed voltage)} \qquad \text{(B 3-1)}$$

$$R_{EM_o} < R_{ES_o} \text{ (very important)} \qquad \text{(B 3-2)}$$

(3) Even in the case that R_3 is very large relative to the other resistances, the following applies:

$$U_{EM_o} \neq 0$$

$$R_{EM_o} < R_M \text{ or} \qquad \text{(B 3-3)}$$

$$R_{EM_o} = \frac{R_M}{3} \text{ (if } R_1 = R_2 = R_M\text{)}$$

and

$$U_{ES_o} = 0 \quad \text{(B 3-4)}$$
$$R_{ES_o} = R_S$$

(4) Apart from the design details of the nuclear power plant and from actual numeric values, it shall be noted that a measurement at the terminals E-M does not deliver R_M but, rather, a result that is approximately one third of this value, and that this measurement result is always smaller than when the measurement is carried out at the terminal lugs E-S. This fact shall be taken into account from the start by specifying a smaller target value for R_{EM_o} than the target value specified for R_{ES_o}.

B 4 Performing the Measurements and Evaluation of the Measurement Results

(1) Prior to the final measurement of the insulation resistances, any shorts-to-ground shall be searched for and eliminated. The shorts-to-ground can be detected with a 5 Hz locating equipment.

(2) After elimination of any detected shorts-to-ground, the equivalent resistances in accordance with **Figures B-3** and **B-4** shall be determined by the U/I-procedure using an adjustable direct current source. This requires that both terminal lugs are opened simultaneously and that the measurement circuit is sequentially connected to each of the terminal pairs. The voltage of the measurement circuit shall be varied between -U_2 and +U_1 ; the voltage steps shall normally be smaller than or equal to 5 V and the maximum current shall be limited to a safe value with regard to the electronics involved (approx. 0.5 A). Experience shows that the insulation resistances R_{EM_o} may reach values be larger than 100 Ohm and R_{ES_o} larger than 1000 Ohm.

(3) Experience shows, furthermore, that, in case of a measurement with both terminal lugs simultaneously open, the pulsation of the electronics can lead to fluctuating ambiguous measurement values, in particular, at the terminals E-S. In this case, the terminal lug E-M shall normally be kept closed when measuring at terminal lug E-S, and vice versa.

(4) Connecting peripheral equipment irrelevant to safety (e.g. clocks, transient recorders, computers) to the 24 V facility will result in a reduction of the equivalent insulation resistance even if the actual – not measurable – resistance, e.g., R_M, is considerably higher. Therefore, in case of lower values of the equivalent insulation resistance than specified in para. 2, the measurement of the equivalent insulation resistance shall normally be performed only after disconnection of the peripheral equipment or by evaluating each existing short-to-ground separately.

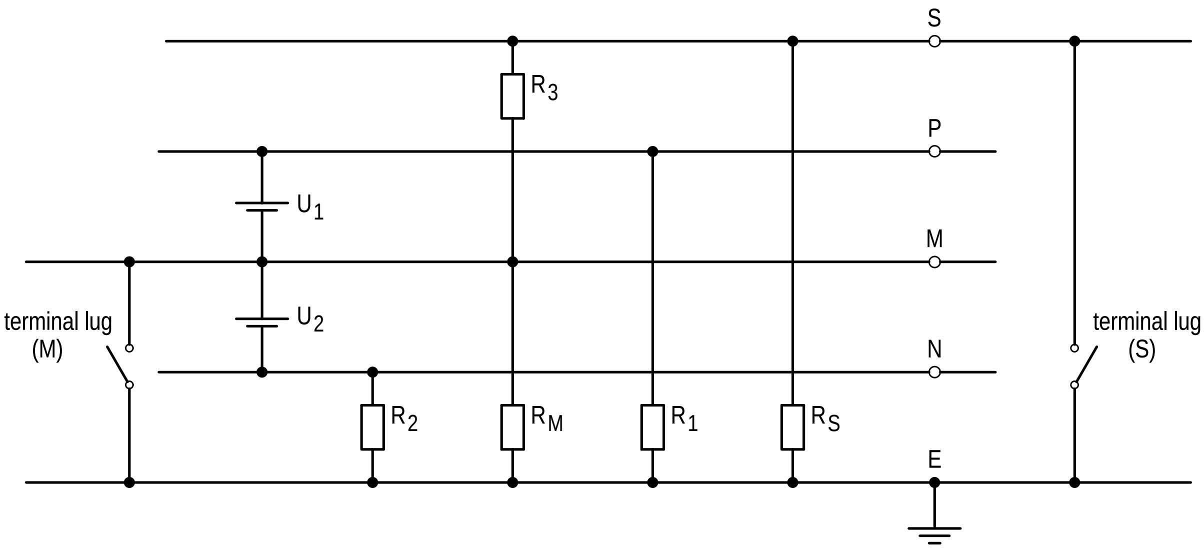


Figure B-1: Simplified circuitry of a 24-volt facility with a central grounding point

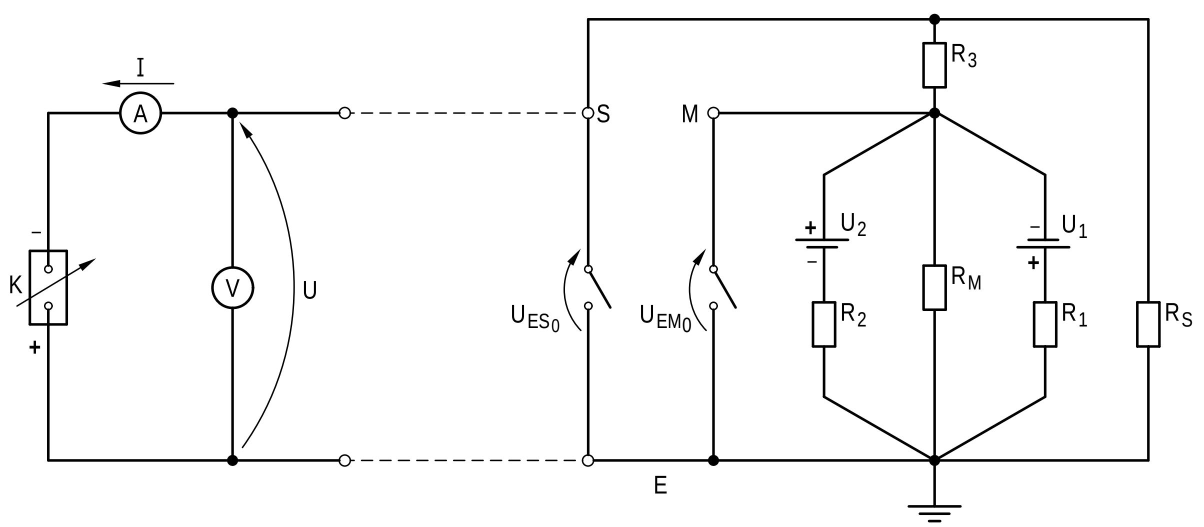
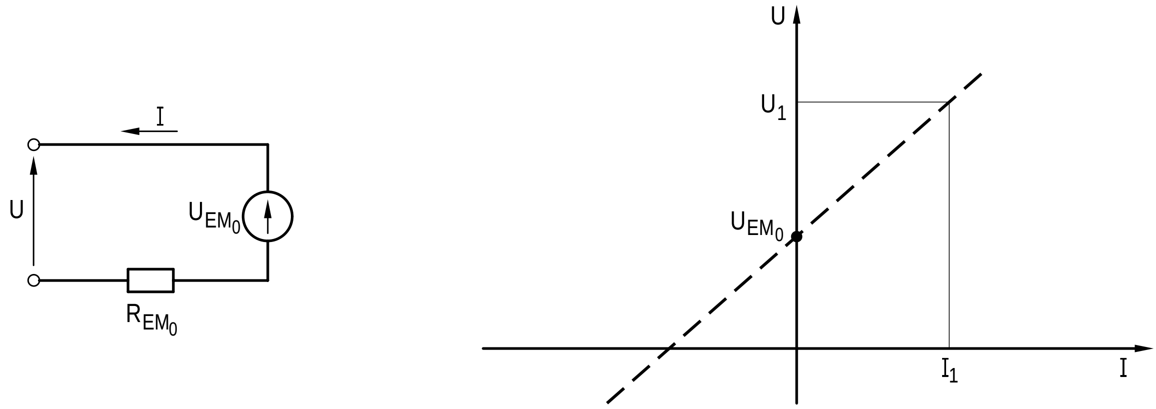


Figure B-2: Connection of a Measurement Circuit to the Circuitry shown in Figure B-1

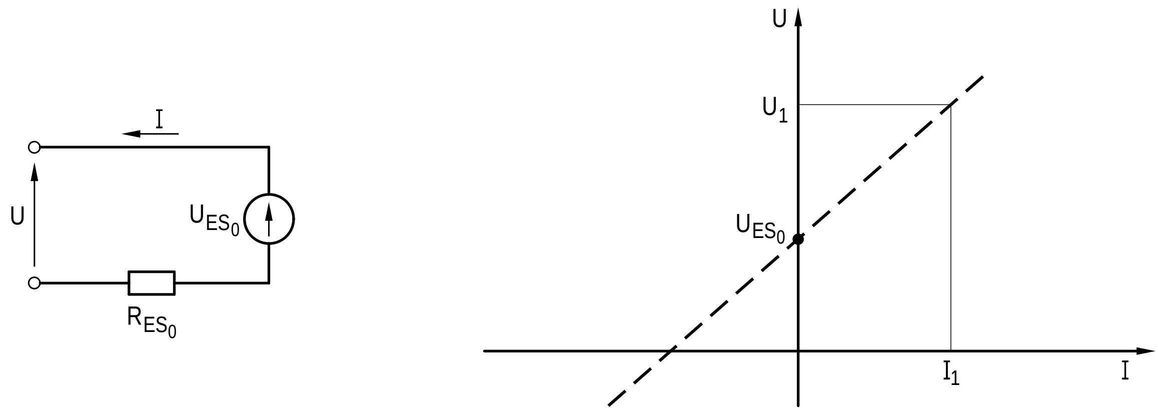


State 0: terminal lug E - S closed,
terminal lug E - M open,
induced current $I = 0$:
voltage E - M equals U_{EM_0}

State 1: terminal lug E - S closed,
terminal lug E - M open,
induced current $I = I_1$:
voltage E - M equals U_1

The resistance R_{EM_0} is calculated as $R_{EM_0} = \dfrac{U_1 - U_{EM_0}}{I_1}$

Figure B-3: Measurement Results in Case of the Connection of the Measurement Circuit at Terminals E-M



State 0: terminal lug E - M closed,
terminal lug E - S open,
induced current $I = 0$:
voltage E - M equals U_{ES_0}

State 1: terminal lug E - M closed,
terminal lug E - S open,
induced current $I = I_1$:
voltage E - M equals U_1

The resistance R_{ES_0} is calculated as $R_{ES_0} = \dfrac{U_1 - U_{ES_0}}{I_1}$

Figure B-4: Measurement Results in Case of the Connection of the Measurement Circuit at Terminals E-S

Appendix C

Regulations Referred to in this Safety Standard

Regulations referred to in this safety standard are valid only in the versions cited below. Regulations which are referred to within these regulations are valid only in the version that was valid when the latter regulations were established or issued.

Atomic Energy Act		Act on the peaceful utilization of atomic energy and the protection against its hazards (Atomic Energy Act) of December 23, 1959, in the version of July 15, 1985 (BGBl. I 1985, p. 1565), most recently changed by Article 1 of the Act of August 29, 2008 (BGBl. I 2008, No. 40)
StrlSchV		Ordinance on the protection against damages and injuries caused by ionizing radiation (Radiation Protection Ordinance) of July 20, 2001 (BGBl. I 2001, No. 38, page 1714), most recently changed by Article 2 of the Act of August 29, 2008 (BGBl. I 2008, No. 40)
KTA 1202	(1984-06)	Requirements for the testing manual
KTA 1401	(1996-06)	General requirements regarding quality assurance
KTA 1404	(2001-06)	Documentation during the construction and operation of nuclear power plants
KTA 3501	(1985-06)	Reactor protection system and monitoring equipment of the safety system

Appendix D (informative)

Additional Relevant Standards

DIN 1045-1	(2008-08)	Concrete, reinforced and prestressed concrete structures - Part 1: Design and construction
DIN EN ISO 17660-1	(2006-12)	Welding - Welding of reinforcing steel - Part 1: Load-bearing welded joints (ISO 17660-1:2006); German version EN ISO 17660-1:2006
DIN EN ISO 17660-2	(2006-12)	Welding - Welding of reinforcing steel - Part 2: Non load-bearing welded joints (ISO 17660-2:2006); German version EN ISO 17660-2:2006
DIN EN 61000-4-4 (VDE 0847-4-4)	(2005-07)	Electromagnetic compatibility (EMC) - Part 4-4: Testing and measurement techniques - Electrical fast transient/burst immunity test (IEC 61000-4-4:2004); German version EN 61000-4-4:2004
DIN EN 61000-4-5 (VDE 0847-4-5)	(2007-06)	Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test (IEC 61000-4-5:2005); German version EN 61000-4-5:2006
DIN EN 50164-1 (VDE 0185-201)	(2009-03)	Lightning protection components (LPC) - Part 1: Requirements for connection components; German version EN 50164-1:2008
DIN EN 50164-2 (VDE 0185-202)	(2009-03)	Lightning protection components (LPC) - Part 2: Requirements for conductors and earth electrodes; German version EN 50164-2:2008
DIN EN 50164-3 (VDE 0185-203)	(2009-09)	Lightning protection components (LPC) - Part 3: Requirements for isolating spark gaps; German version EN 50164-3:2006 + A1:2009
DIN EN 62305-1 (VDE 0185-305-1)	(2006-10)	Protection against lightning - Part 1: General Principles
DIN EN 62305-2 (VDE 0185-305-1)	(2006-10)	Protection against lightning - Part 2: Risk management: Assessment of damage risks for structural components (IEC 62305-2:2006); German version EN 62305-2:2006
DIN EN 62305-2 Suppl.1 (VDE 0185-305-2 Suppl. 1)	(2007-01)	Protection against lightning - Part 2: Risk management: Assessment of risk for structures - Supplement 1: Lightning threat in Germany
DIN EN 62305-2 Suppl. 2 (VDE 0185-305-2 Suppl. 2)	(2007-02)	Protection against lightning - Part 2: Risk management - Supplement 2: Calculation assistance for assessment of risk for structures
DIN EN 62305-3	(2006-10)	Protection against lightning - Part 3: Physical damage to structures and life

(VDE 0185-305-3)		hazard (IEC 62305-3:2006, modified); German version EN 62305-3:2006
DIN EN 62305-3 Suppl. 1 (VDE 0185-305-3 Suppl. 1)	(2009-10)	Protection against lightning - Part 3: Physical damage to structures and life hazard - Supplement 1: Additional information for the application of DIN EN 62305-3 (VDE 0185-305-3)
DIN EN 62305-3 Suppl. 2 (VDE 0185-305-3 Suppl. 2)	(2007-01)	retracted
DIN EN 62305-3 Suppl. 3 (VDE 0185-305-3 Suppl. 4)	(2007-01)	retracted
DIN EN 62305-4 (VDE 0185-305-4)	(2006-10)	Protection against lightning - Part 4: Electrical and electronic systems within structures (IEC 62305-4:2006); German version EN 62305-4:2006
DIN VDE 0100-410	(2007-06)	Low-voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock (IEC 60364-4-41:2005, modified); German implementation HD 60364-4-41:2007
DIN VDE 0100-540	(2007-06)	Low-voltage electrical installations - Part 5-54: Selection and erection of electrical equipment - Earthing arrangements, protective conductors and protective bonding conductors (IEC 60364-5-54:2002, modified); German implementation HD 60364-5-54:2007
DIN VDE 0101	(2000-01)	Power installations exceeding 1 kV; German version HD 637 S1:1999
DIN VDE 0141	(2000-01)	Earthing system for special power installations with nominal voltages above 1 kV

Appendix E (informative)

Literature

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[2] Zischank, W.; Wiesinger, J.
Induzierte Spannungen auf Leittechnik-Kabeln in bewehrten Kabelkanälen infolge von Blitz-Stoßströmen (Versuchsbericht), Universität der Bundeswehr München, Institut für Elektrische Energieversorgung, Neubiberg, 1996, *Induced voltages in instrumentation and control cables in steel reinforced cable ducts due to lightning strike currents*

[3] Frentzel, R.; Kern, A.; Seevers, M.
Schirmdämpfungsmessungen an Gebäuden im blitzfrequenten Bereich – Messergebnisse und Unterschiede zu Berechnungsergebnissen nach VDE V 0185 Teil 4-6 VDE/ABB-Blitzschutztagung, Neu-Ulm, 2005 *Measurements of shield damping effects on buildings frequently struck by lightning –Comparison of measurement results and analytic results following VDE V 0185 Part 4-6*

[4] Zischank W.; Heidler, F.; Wiesinger, J.; Kern, A.; Seevers, M.; Metwally, I.
Laboratory simulation of direct lightning strokes to a modelled building - measurement of magnetic fields and induced voltages, 26th International Conference on Lightning Protection (ICLP), Krakau (PL), 2002.

[5] Zischank, W.; Heidler, F.; Wiesinger, J.; Stimper, K.; Kern, A.; Seevers, M.
Magnetic fields and induced voltages inside LPZ 1 measured at a 1:6 scale model building, 27th International Conference on Lightning Protection (ICLP), Avignon (FR), 2004

[6] Kern, A.; Heidler, F.; Seevers, M.; Zischank, W.
Magnetic fields and induced voltages in case of a direct strike – Comparison of results obtained from measurements at a scaled building to those of IEC 62305-4, 27th International Conference on Lightning Protection (ICLP), Avignon (FR), 2004