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Also of interest to the following committees Intéresse également les comités suivants 37A, 64, 77	Supersedes document Remplace le document 81/238/CDV - 81/243A/RVC

Functions concerned
Fonctions concernées

☐ Safety Sécurité	☐ EMC CEM	☐ Environment Environnement	☐ Quality assurance Assurance de la qualité

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Title
IEC 62305-4 Ed. 1.0: Protection against lightning – Part 4: Electrical and electronic systems within structures

Titre
CEI 62305-4 Ed. 1.0: Protection contre la foudre – Partie 4: Réseaux de puissance et de communication dans les structures

ATTENTION
VOTE PARALLÈLE
CEI – CENELEC

L'attention des Comités nationaux de la CEI, membres du CENELEC, est attirée sur le fait que ce projet final de Norme internationale est soumis au vote parallèle. Un bulletin de vote séparé pour le vote CENELEC leur sera envoyé par le Secrétariat Central du CENELEC.

ATTENTION
IEC – CENELEC
PARALLEL VOTING

The attention of IEC National Committees, members of CENELEC, is drawn to the fact that this final Draft International Standard (DIS) is submitted for parallel voting. A separate form for CENELEC voting will be sent to them by the CENELEC Central Secretariat.

1906-2006 The electric century

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PROTECTION AGAINST LIGHTNING –

Part 4: Electrical and electronic systems within structures

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 62305-4 has been prepared by IEC technical committee 81: Lightning protection.

The IEC 62305 series (Parts 1 to 5), is produced in accordance with the New Publications Plan, approved by National Committees (81/171/RQ (2001-06-29)), which restructures and updates in a more simple and rational form and updates the publications of the IEC 61312 series and the IEC 61663 series.

The text of this first edition of IEC 62305-4 is compiled from and replaces

- IEC 61312-1, first edition (1995);
- IEC 61312-2, first edition (1998);
- IEC 61312-3, first edition (2000);
- IEC 61312-4, first edition (1998).

The text of this standard is based on the following documents:

FDIS	Report on voting
81/XX/FDIS	81/XX/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted, as close as possible, in accordance with the ISO/IEC Directives, Part 2.

IEC 62305 consists of the following parts, under the general title *Protection against lightning:*

Part 1: General principles

Part 2: Risk management

Part 3: Physical damage to structures and life hazard

Part 4: Electrical and electronic systems within structures

Part 5: Services

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date[1] indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

1 The National Committees are requested to note that for this publication the maintenance result date is 2010.

INTRODUCTION

Lightning as a source of harm is a very high-energy phenomenon. Lightning flashes release many hundreds of mega-joules of energy. When compared with the milli-joules of energy that may be sufficient to cause damage to sensitive electronic equipment in electrical and electronic systems within a structure, it is clear that additional protection measures will be necessary to protect some of this equipment.

The need for this International Standard has arisen due to the increasing cost of failures of electrical and electronic systems, caused by electromagnetic effects of lightning. Of particular importance are electronic systems used in data processing and storage as well as process control and safety for plants of considerable capital cost, size and complexity (for which plant outages are very undesirable for cost and safety reasons).

Lightning can cause different types of damage in a structure, as defined in IEC 62305-2:

D1 injuries to living beings due to touch and step voltages;

D2 physical damage due to mechanical, thermal, chemical and explosive effects;

D3 failures of electrical and electronic systems due to electromagnetic effects.

IEC 62305-3 deals with the protection measures to reduce the risk of physical damage and life hazard, but does not cover the protection of electrical and electronic systems.

This Part 4 of IEC 62305 therefore provides information on protection measures to reduce the risk of permanent failures of electrical and electronic systems within structures.

Permanent failure of electrical and electronic systems can be caused by the lightning electromagnetic impulse (LEMP) via:

a) conducted and induced surges transmitted to apparatus via connecting wiring;
b) the effects of radiated electromagnetic fields directly into apparatus itself.

Surges to the structure can be generated externally or internally:

– surges external to the structure are created by lightning flashes striking incoming lines or the nearby ground, and are transmitted to electrical and electronic systems via these lines;
– surges internal to the structure are created by lightning flashes striking the structure or the nearby ground.

The coupling can arise from different mechanisms:

– resistive coupling (e.g. the earth impedance of the earth termination system or the cable shield resistance);
– magnetic field coupling (e.g. caused by wiring loops in the electrical and electronic system or by inductance of bonding conductors);
– electric field coupling (e.g. caused by rod antenna reception).

NOTE The effects of electric field coupling are generally very small when compared to the magnetic field coupling and can be disregarded.

Radiated electromagnetic fields can be generated via

- the direct lightning current flowing in the lightning channel,
- the partial lightning current flowing in conductors (e.g. in the down conductors of an external LPS according to IEC 62305-3 or in an external spatial shield according to this standard).

PROTECTION AGAINST LIGHTNING –

Part 4: Electrical and electronic systems within structures

1 Scope

This part of IEC 62305 provides information for the design, installation, inspection, maintenance and testing of a LEMP protection measures system (LPMS) for electrical and electronic systems within a structure, able to reduce the risk of permanent failures due to lightning electromagnetic impulse.

This standard does not cover protection against electromagnetic interference due to lightning, which may cause the malfunctioning of electronic systems. However, the information reported in Annex A can also be used to evaluate such disturbances. Protection measures against electromagnetic interference are covered in IEC 60364-4-44 and in the IEC 61000 series[1][2].

This standard provides guidelines for cooperation between the designer of the electrical and electronic system, and the designer of the protection measures, in an attempt to achieve optimum protection effectiveness.

This standard does not deal with detailed design of the electrical and electronic systems themselves.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60364-4-44:2001*, Electrical installations of buildings – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances*

IEC 60364-5-53:2001, *Electrical installations of building – Part 5-53: Selection and erection of electrical equipment– Isolation, switching and control*

IEC 60664-1:2002, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*

IEC 61000-4-5:1995, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC 61000-4-9:1993, *Electromagnetic compatibility (EMC) – Part 4-9: Testing and measurement techniques – Pulse magnetic field immunity test*

IEC 61000-4-10:1993, *Electromagnetic compatibility (EMC) – Part 4-10: Testing and measurement techniques – Damped oscillatory magnetic field immunity test*

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[2] Figures in square brackets refer to the biblography.

IEC 61000-5-2:1997, *Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 2: Earthing and cabling*

IEC 61643-1:1998, *Surge protective devices connected to low-voltage power distribution systems – Part 1: Performance requirements and testing methods*

IEC 61643-12:2002, *Low-voltage surge protective devices – Part 12: Surge protective devices connected to low-voltage power distribution systems – Selection and application principles*

IEC 61643-21:2000, *Low voltage surge protective devices – Part 21: Surge protective devices connected to telecommunications and signalling networks – Performance requirements and testing methods*

IEC 61643-22:2004, *Low voltage surge protective devices – Part 22: Surge protective devices connected to telecommunications and signalling networks – Part 22: Selection and application principles*

IEC 62305-1, *Protection against lightning. Part 1: General principles*

IEC 62305-2, *Protection against lightning. Part 2: Risk management*

IEC 62305-3, *Protection against lightning. Part 3: Physical damage to structures and life hazard*

ITU-T Recommendation K.20:2003, *Resistibility of telecommunication equipment installed in a telecommunications centre to overvoltages and overcurrents*

ITU-T Recommendation K.21:2003, *Resistibility of telecommunication equipment installed in customer premises to overvoltages and overcurrent*

3 Terms and definitions

For the purposes of this document, the following terms and definitions, as well as those given in other parts of IEC 62305, apply.

3.1
electrical system
system incorporating low voltage power supply components

3.2
electronic system
system incorporating sensitive electronic components such as communication equipment, computer, control and instrumentation systems, radio systems, power electronic installations

3.3
internal systems
electrical and electronic systems within a structure

3.4
lightning electromagnetic impulse
LEMP
electromagnetic effects of lightning current

NOTE It includes conducted surges as well as radiated impulse electromagnetic field effects.

3.5
surge
transient wave appearing as overvoltage and/or overcurrent caused by LEMP

NOTE Surges caused by LEMP can arise from (partial) lightning currents, from induction effects in installation loops and as a remaining threat downstream of SPD.

3.6
rated impulse withstand voltage level
U_W
impulse withstand voltage assigned by the manufacturer to the equipment or to a part of it, characterizing the specified withstand capability of its insulation against overvoltages

NOTE For the purposes of this standard, only withstand voltage between live conductors and earth is considered.

(IEC 60664-1:2002)

3.7
lightning protection level
LPL
number related to a set of lightning current parameters values relevant to the probability that the associated maximum and minimum design values will not be exceeded in naturally occurring lightning

NOTE Lightning protection level is used to design protection measures according to the relevant set of lightning current parameters.

3.8
lightning protection zone
LPZ
zone where the lightning electromagnetic environment is defined

NOTE The zone boundaries of an LPZ are not necessarily physical boundaries (e.g. walls, floor and ceiling).

3.9
LEMP protection measures system
LPMS
complete system of protection measures for internal systems against LEMP

3.10
grid-like spatial shield
magnetic shield characterized by openings

NOTE For a building or a room, it is preferably built by interconnected natural metal components of the structure (e.g. rods of reinforcement in concrete, metal frames and metal supports).

3.11
earth-termination system
part of an external LPS which is intended to conduct and disperse lightning current into the earth

3.12
bonding network
interconnecting network of all conductive parts of the structure and of internal systems (live conductors excluded) to the earth-termination system

3.13
earthing system
complete system combining the earth-termination system and the bonding network

3.14
surge protective device
SPD
device intended to limit transient overvoltages and divert surge currents. It contains at least one non linear component

(IEC 61643-1:1998)

3.15

SPD tested with I_{imp}

SPDs which withstand the partial lightning current with a typical waveform 10/350 µs require a corresponding impulse test current I_{imp}

NOTE For power lines, a suitable test current I_{imp} is defined in the Class I test procedure of IEC 61643-1.

3.16

SPD tested with I_n

SPDs which withstand induced surge currents with a typical waveform 8/20 µs require a corresponding impulse test current I_n

NOTE For power lines a suitable test current I_n is defined in the Class II test procedure of IEC 61643-1.

3.17

SPD tested with a combination wave

SPDs that withstand induced surge currents with a typical waveform 8/20 µs and require a corresponding impulse test current I_{sc}

NOTE For power lines a suitable combination wave test is defined in the Class III test procedure of IEC 61643-1 defining the open circuit voltage U_{oc} 1,2/50 µs and the short-circuit current I_{sc} 8/20 µs of an 2 Ω combination wave generator.

3.18

voltage switching type SPD

SPD that has a high impedance when no surge is present, but can have a sudden change in impedance to a low value in response to a voltage surge

NOTE 1 Common examples of components used as voltage switching devices include spark gaps, gas discharge tubes (GDT), thyristors (silicon controlled rectifiers) and triacs. These SPD are sometimes called "crowbar type“.

NOTE 2 A voltage switching device has a discontinuous voltage/current characteristic.

(IEC 61643-1:1998)

3.19

voltage-limiting type SPD

SPD that has a high impedance when no surge is present, but will reduce it continuously with increased surge current and voltage

NOTE 1 Common examples of components used as non-linear devices are varistors and suppressor diodes. These SPDs are sometimes called "clamping type“.

NOTE 2 A voltage-limiting device has a continuous voltage/current characteristic.

(IEC 61643-1:1998)

3.20

combination type SPD

SPD that incorporates both voltage-switching and voltage-limiting type components and which may exhibit voltage-switching, voltage-limiting or both voltage-switching and voltage-limiting behaviour, depending upon the characteristics of the applied voltage

(IEC 61643-1:1998)

3.21

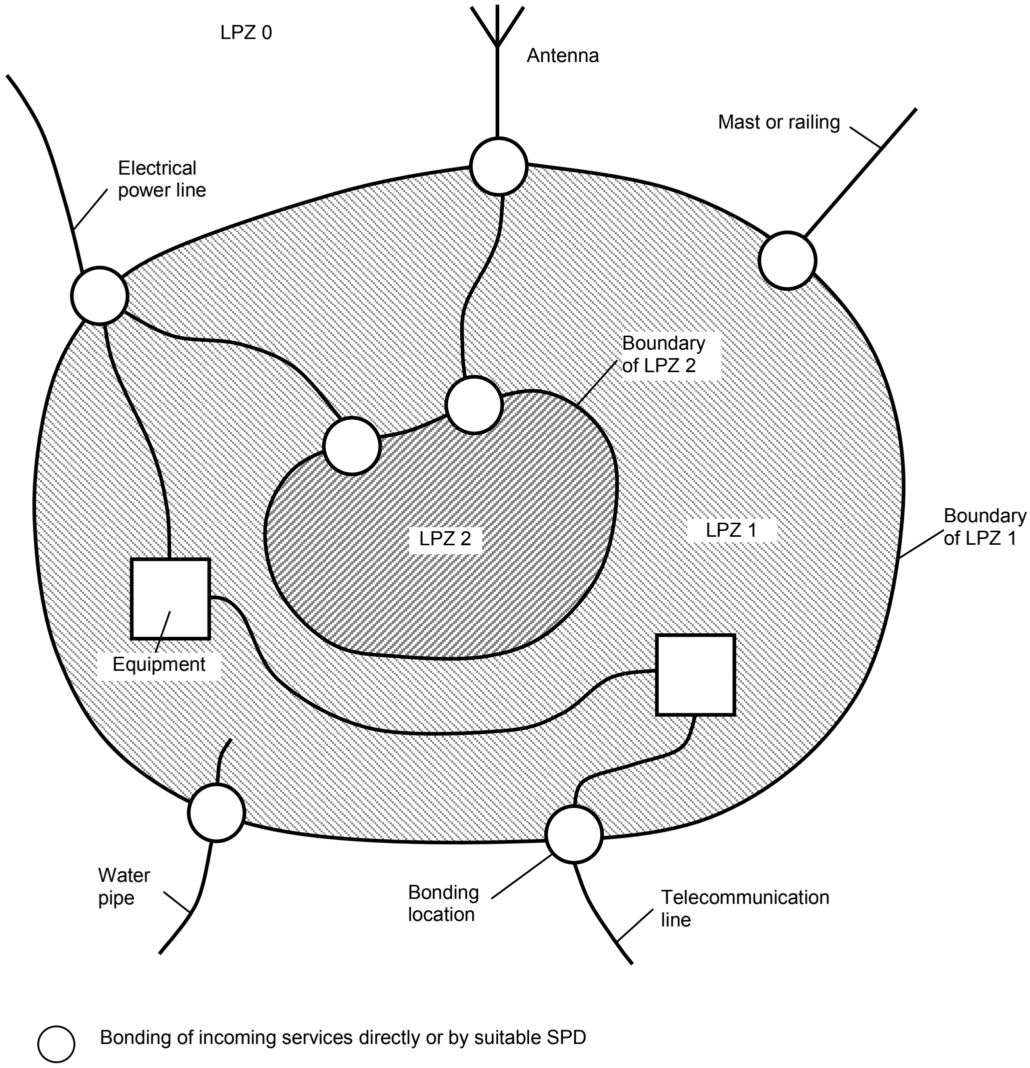
coordinated SPD protection

set of SPD properly selected, coordinated and installed to reduce failures of electrical and electronic systems

4 Design and installation of a LEMP protection measures system (LPMS)

Electrical and electronic systems are subject to damage from the lightning electromagnetic impulse (LEMP). Therefore LEMP protection measures need to be provided to avoid failure of internal systems.

Protection against LEMP is based on the lightning protection zone (LPZ) concept: the volume containing systems to be protected shall be divided into LPZ. These zones are theoretically assigned volumes of space where the LEMP severity is compatible with the withstand level of the internal systems enclosed (see Figure 1). Successive zones are characterized by significant changes in the LEMP severity. The boundary of an LPZ is defined by the protection measures employed (see Figure 2).



NOTE This figure shows an example for dividing a structure into inner LPZs. All metal services entering the structure are bonded via bonding bars at the boundary of LPZ 1. In addition, the conductive services entering LPZ 2 (e.g. computer room) are bonded via bonding bars at the boundary of LPZ 2.

Figure 1 – General principle for the division into different LPZ

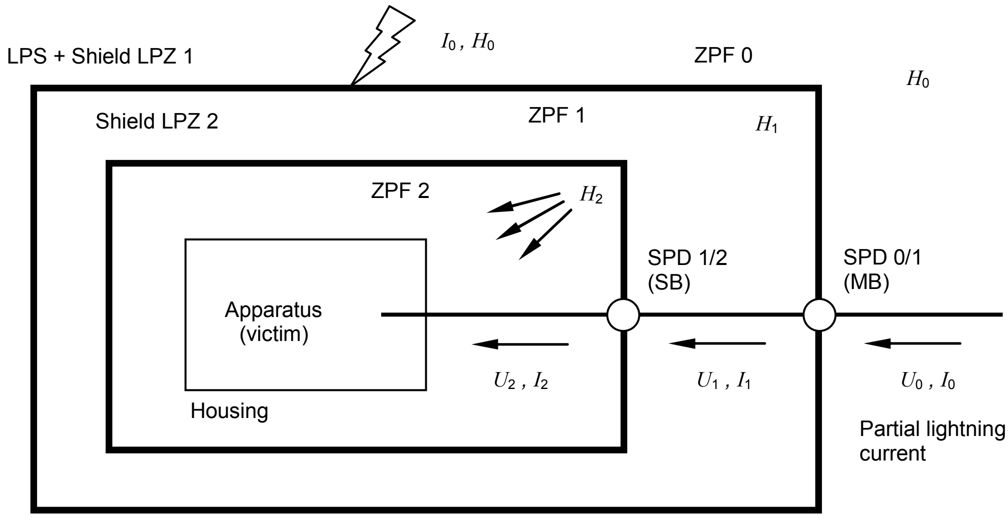


Figure 2a – LPMS using spatial shields and "coordinated SPD protection"– Apparatus well protected against conducted surges ($U_2 \ll U_0$ and $I_2 \ll I_0$) and against radiated magnetic fields ($H_2 \ll H_0$)

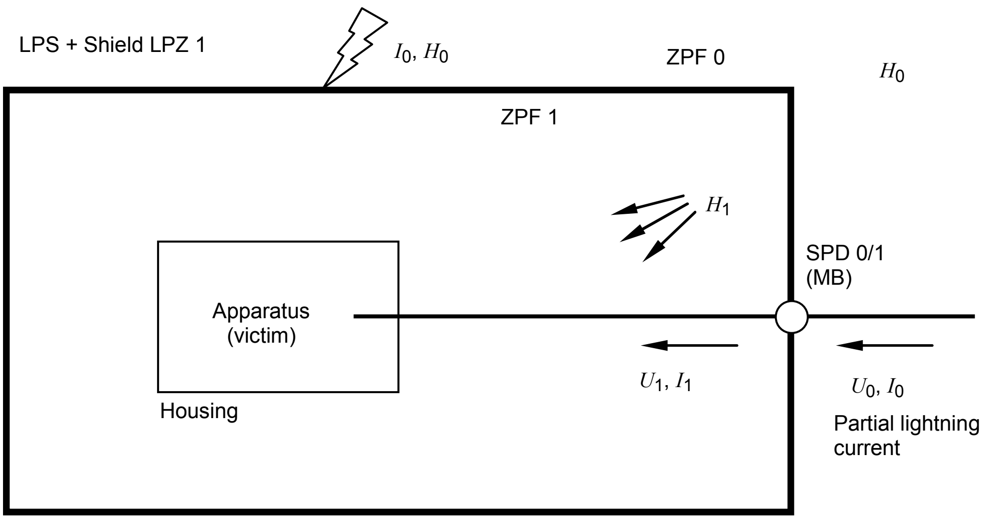


Figure 2b – LPMS using spatial shield of LPZ 1 and SPD protection at entry of LPZ 1 – Apparatus protected against conducted surges ($U_1 < U_0$ and $I_1 < I_0$) and against radiated magnetic fields ($H_1 < H_0$)

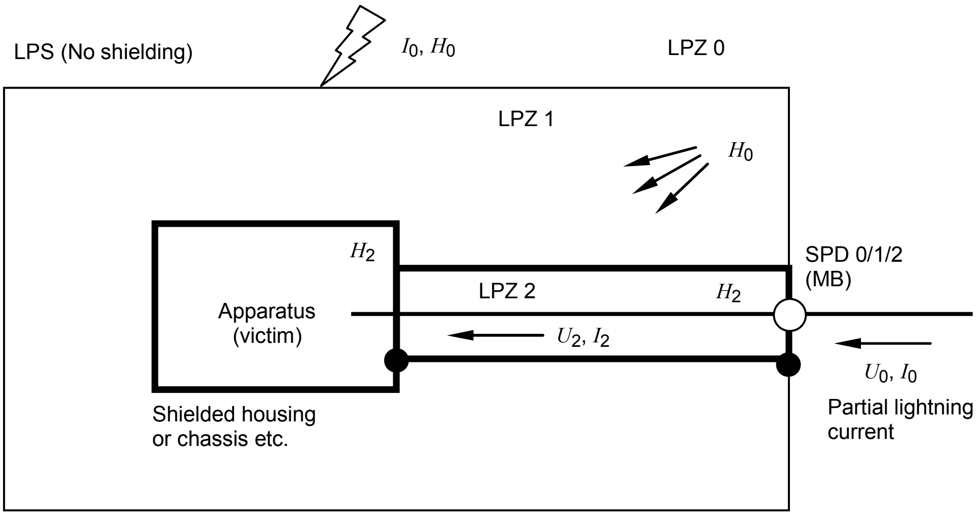


Figure 2c – LPMS using internal line shielding and SPD protection at entry of LPZ 1 – Apparatus protected against conducted surges (U_2<U_0 and I_2<I_0) and against radiated magnetic fields (H_2<H_0)

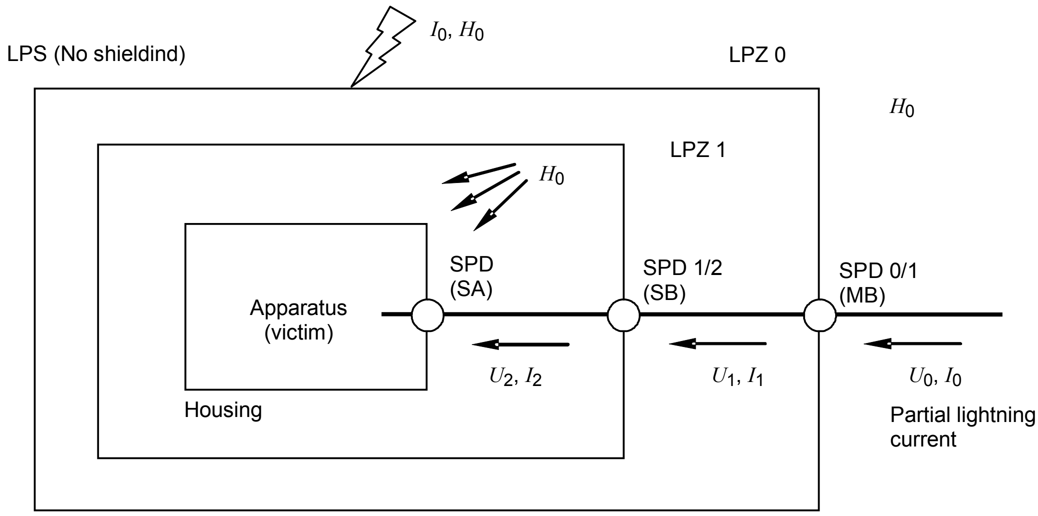


Figure 2d – LPMS using "coordinated SPD protection" only – Apparatus protected against conducted surges (U_2<<U_0 and I_2<<I_0), but not against radiated magnetic field (H_0)

NOTE 1 SPDs can be located at the following points (see also D.1.2):
- at boundary of LPZ 1 (e.g. at main distribution board MB);
- at boundary of LPZ 2 (e.g. at secondary distribution board SB);
- at or close to apparatus (e.g. at socket outlet SA).

NOTE 2 For detailed installation rules see also IEC 60364-5-53.

NOTE 3 Shielded ( ) and non shielded ( ) boundary.

Figure 2 – Protection against LEMP – Examples of possible LEMP protection measures systems (LPMS)

Permanent failure of electrical and electronic systems due to LEMP can be caused by:

– conducted and induced surges transmitted to apparatus via connecting wiring;
– effects of radiated electromagnetic fields impinging directly onto apparatus itself.

NOTE 1 Failures due to electromagnetic fields impinging directly onto the equipment are negligible provided that the equipment complies with radio frequency emission tests and immunity tests as defined in the relevant EMC product standards.

NOTE 2 For equipment not complying with relevant EMC product standards, Annex A provides information on how to achieve protection against electromagnetic fields directly impinging onto this equipment. The equipment's withstand level against radiated magnetic fields needs to be selected in accordance with IEC 61000-4-9 and IEC 61000-4-10.

4.1 Design of an LPMS

An LPMS can be designed for protection of equipment against surges and electromagnetic fields. Figure 2 provides examples:

- An LPMS employing spatial shields and "coordinated SPD protection" will protect against radiated magnetic fields and against conducted surges (see Figure 2a). Cascaded spatial shields and coordinated SPDs can reduce magnetic field and surges to a lower threat level.
- An LPMS employing a spatial shield of LPZ 1 and an SPD at the entry of LPZ 1 can protect apparatus against the radiated magnetic field and against conducted surges (see Figure 2b).

NOTE 1 The protection would not be sufficient, if the magnetic field remains too high (due to low shielding effectiveness of LPZ 1) or if the surge magnitude remains too high (due to a high voltage protection level of the SPD and due to the induction effects onto wiring downstream of the SPD).

- An LPMS created using shielded lines, combined with shielded equipment enclosures, will protect against radiated magnetic fields. The SPD at the entry of LPZ 1 will provide protection against conducted surges (see Figure 2c). To achieve a lower threat surge level, a special SPD may be required (e.g. additional coordinated stages inside) to reach a sufficient low voltage protection level.
- An LPMS created using a system of "coordinated SPD protection", is only suitable to protect equipment which is insensitive to radiated magnetic fields, since the SPDs will only provide protection against conducted surges (see Figure 2d). A lower threat surge level can be achieved using coordinated SPDs.

NOTE 2 Solutions according to Figures 2a to 2c are recommended especially for equipment, which does not comply with relevant EMC product standards.

NOTE 3 An LPS according to IEC 62305-3, which only employs equipotential bonding SPDs, provides no effective protection against failure of sensitive electrical and electronic systems. The LPS can be improved by reducing the mesh dimensions and selecting suitable SPDs, so as to make it an effective component of the LPMS.

4.2 Lightning protection zones (LPZ)

With respect to lightning threat, the following LPZ are defined (see IEC 62305-1):

Outer zones

LPZ *0* Zone where the threat is due to the unattenuated lightning electromagnetic field and where the internal systems may be subjected to full or partial lightning surge current. LPZ *0* is subdivided into:

LPZ 0_A zone where the threat is due to the direct lightning flash and the full lightning electromagnetic field. The internal systems may be subjected to full lightning surge current;

LPZ 0_B zone protected against direct lightning flashes but where the threat is the full lightning electromagnetic field. The internal systems may be subjected to partial lightning surge currents.

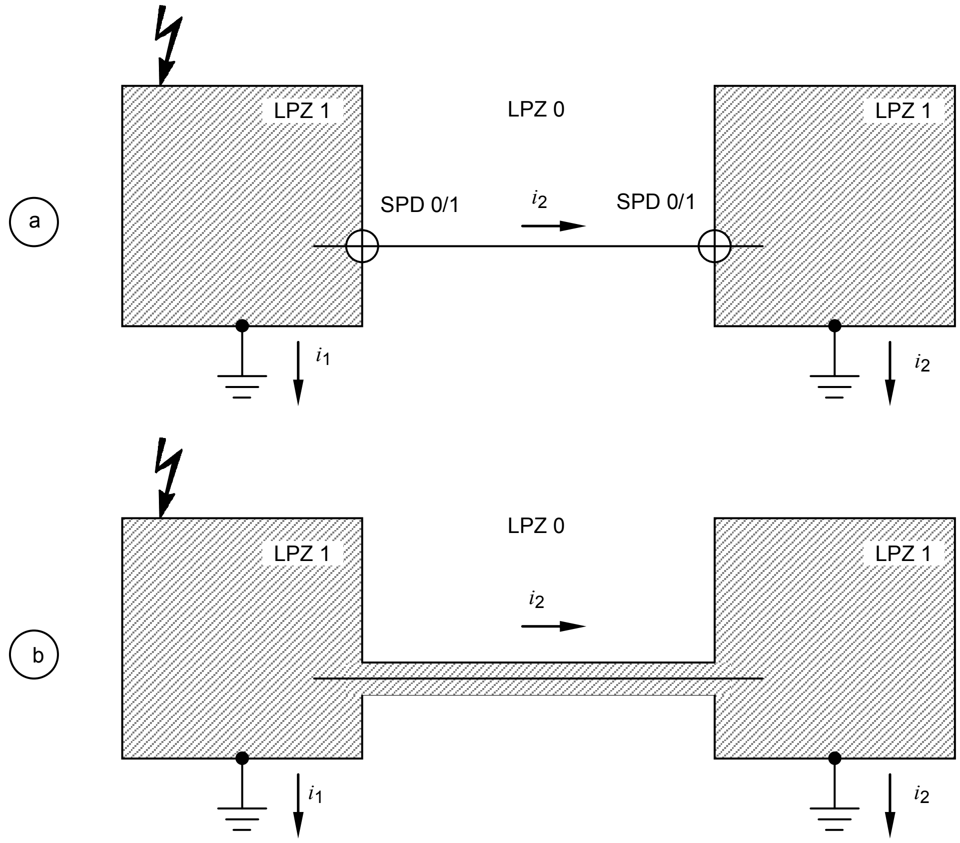
Inner zones: (protected against direct lightning flashes)

LPZ 1 Zone where the surge current is limited by current sharing and by SPDs at the boundary. Spatial shielding may attenuate the lightning electromagnetic field.

LPZ 2 ... n Zone where the surge current may be further limited by current sharing and by additional SPDs at the boundary. Additional spatial shielding may be used to further attenuate the lightning electromagnetic field.

The LPZs are implemented by the installation of the LPMS, e.g. installation of coordinated SPDs and/or magnetic shielding (see Figure 2). Depending on number, type and withstand level of the equipment to be protected, suitable LPZ can be defined. These may include small local zones (e.g. equipment enclosures) or large integral zones (e.g. the volume of the whole structure) (see Figure B.2).

Interconnection of LPZ of the same order may be necessary if either two separate structures are connected by electrical or signal lines, or the number of required SPDs is to be reduced (see Figure 3).



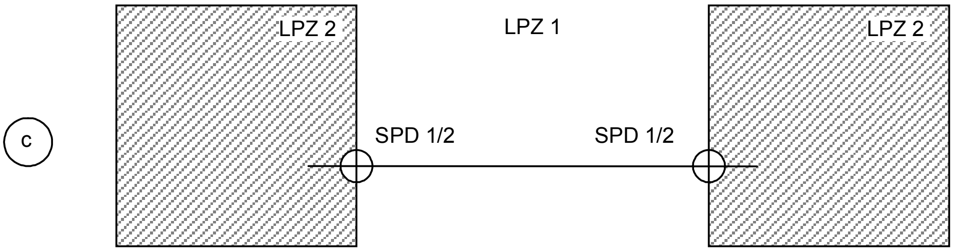
i_1, i_2 partial lightning currents

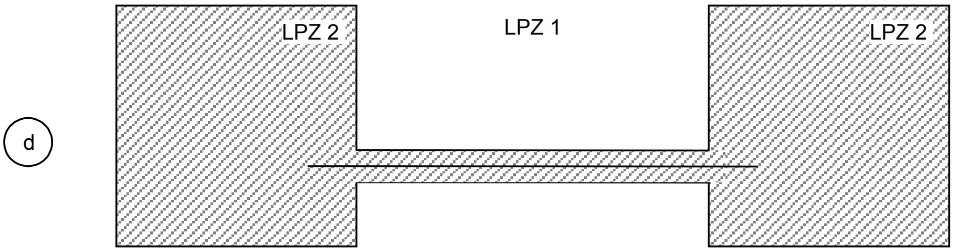
NOTE Figure 3a shows two LPZ 1 connected by electrical or signal lines. Special care should be taken if both LPZ 1 represent separate structures with separate earthing systems, spaced tens or hundreds of metres from each other. In this case, a large part of the lightning current can flow along the connecting lines, which are not protected.

Figure 3a – Interconnecting two LPZ 1 using SPD

NOTE Figure 3b shows, that this problem can be solved using shielded cables or shielded cable ducts to interconnect both LPZ 1, provided that the shields are able to carry the partial lightning current. The SPD can be omitted, if the voltage drop along the shield is not too high.

Figure 3b – Interconnecting two LPZ 1 using shielded cables or shielded cable ducts





NOTE Figure 3c shows two LPZ 2 connected by electrical or signal lines. Because the lines are exposed to the threat level of LPZ 1, SPD at the entry into each LPZ 2 are required.

Figure 3c – Interconnecting two LPZ 2 using SPD

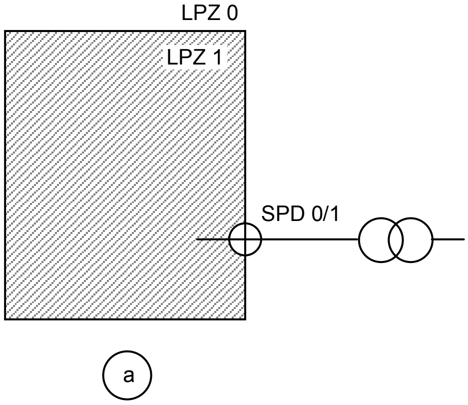
NOTE Figure 3d shows that such interference can be avoided and the SPD can be omitted, if shielded cables or shielded cable ducts are used to interconnect both LPZ 2.

Figure 3d – Interconnecting two LPZ 2 using shielded cables or shielded cable ducts

Figure 3 – Examples for interconnected LPZ

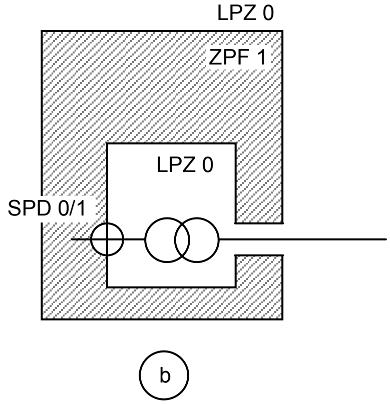
Extending an LPZ into another LPZ might be needed in special cases or can be used to reduce the number of required SPD (see Figure 4).

Detailed evaluation of the electromagnetic environment in an LPZ is described in Annex A.



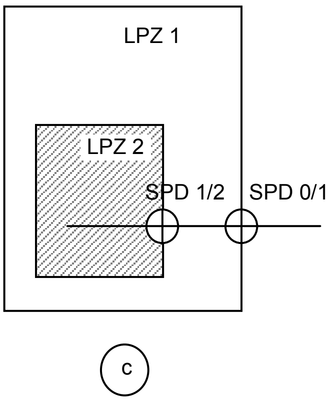
NOTE Figure 4a shows a structure powered by a transformer. If the transformer is placed outside the structure, only the low voltage lines entering the structure need protection by SPD. If the transformer should be placed inside the structure, the owner of the building often is not allowed to adopt protection measures on the high voltage side.

Figure 4a – Transformer outside the structure



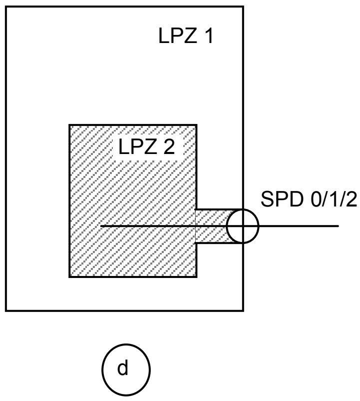
NOTE Figure 4b shows that the problem can be solved extending LPZ 0 into LPZ 1, which requires again SPDs at the low voltage side only.

Figure 4b – Transformer inside the structure (LPZ 0 extended into LPZ 1



NOTE Figure 4c shows an LPZ 2 supplied by an electrical or signal line. This line needs two coordinated SPDs: one at the boundary of LPZ 1, the other at the boundary of LPZ 2.

Figure 4c – Two coordinated SPD (0/1) and SPD (1/2) needed



NOTE Figure 4d shows that the line can enter immediately into LPZ 2 and only one SPD is required, if LPZ 2 is extended into LPZ 1 using shielded cables or shielded cable ducts. However this SPD will reduce the threat immediately to the level of LPZ 2.

Figure 4d – Only one SPD (0/1/2) needed (LPZ 2 extended into LPZ 1)

Figure 4 – Examples for extended lightning protection zones

4.3 Basic protection measures in an LPMS

Basic protection measures against LEMP include:

- **Earthing and bonding (see Clause 5)**

  The earthing system conducts and disperses the lightning current into the earth.

  The bonding network minimizes potential differences and may reduce magnetic field.

- **Magnetic shielding and line routing (see Clause 6)**

  Spatial shielding attenuates the magnetic field inside the LPZ, arising from lightning strikes direct to or nearby the structure, and reduces internal surges.

  Shielding of internal lines, using shielded cables or cable ducts, minimizes internal induced surges.

  Routing of internal lines can minimize induction loops and reduce internal surges.

  NOTE 1 Spatial shielding, shielding and routing of internal lines can be combined or used separately.

  Shielding of external lines entering the structure reduces surges from being conducted onto the internal systems.

- **Coordinated SPD protection (see Clause 7)**

  Coordinated SPD protection limits the effects of external and internal surges.

Earthing and bonding should always be ensured, in particular, bonding of every conductive service directly or via an equipotential bonding SPD, at the point of entry to the structure.

NOTE 2 Lightning equipotential bonding (EB) according to IEC 62305-3 will protect against dangerous sparking only. Protection of internal systems against surges requires coordinated SPD protection according to this standard.

Other LEMP protection measures can be used alone or in combination.

LEMP protection measures shall withstand the operational stresses expected in the installation place (e.g. stress of temperature, humidity, corrosive atmosphere, vibration, voltage and current).

Selection of the most suitable LEMP protection measures shall be made using a risk assessment in accordance with IEC 62305-2 taking into account technical and economic factors.

Practical information on the implementation of LEMP protection measures for electronic systems in existing structures are given in Annex B.

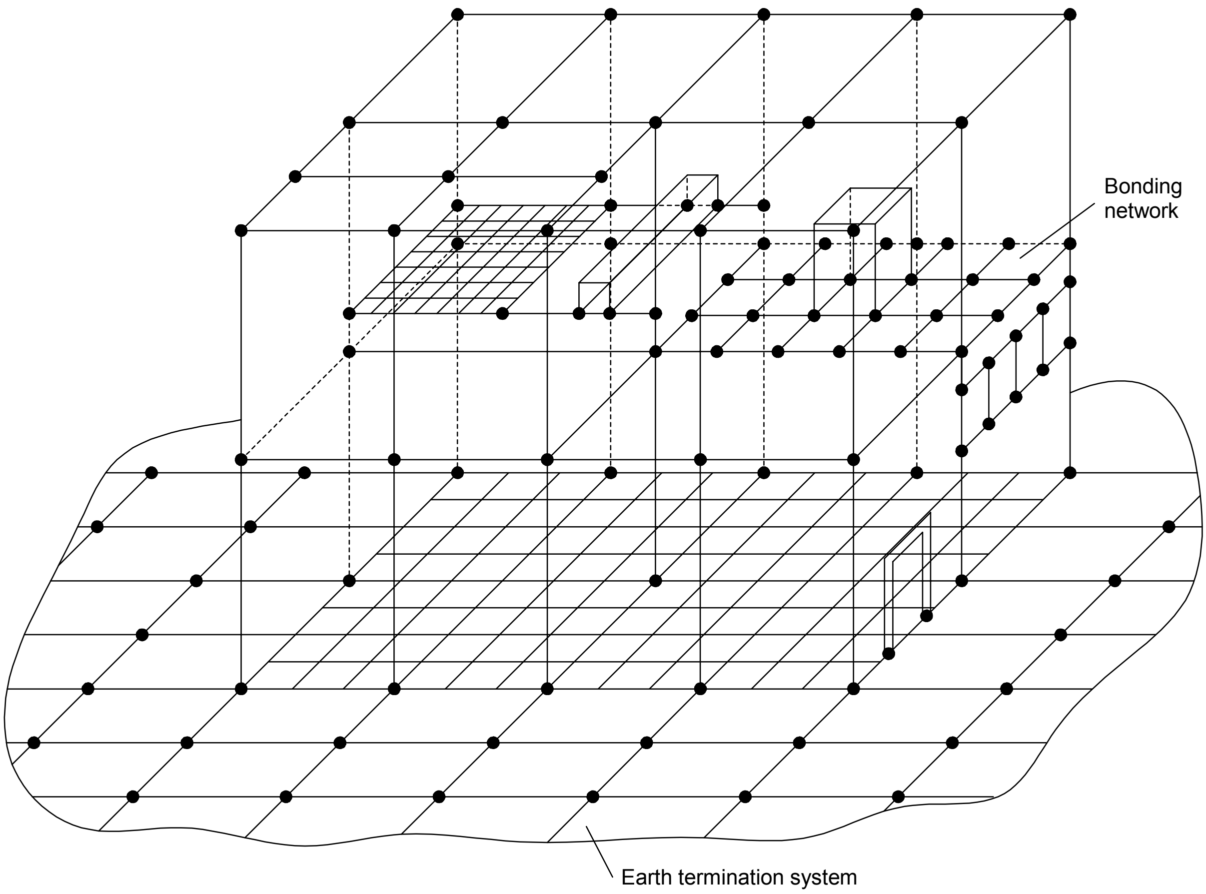
NOTE 3 Further information on the implementation of LEMP protection measures can be found in IEC 60364-4-44.

5 Earthing and bonding

Suitable earthing and bonding is based on a complete earthing system (see Figure 5) combining:

– the earth-termination system (dispersing the lightning current into the soil); and

– the bonding network (minimizing potential differences and reducing the magnetic field).



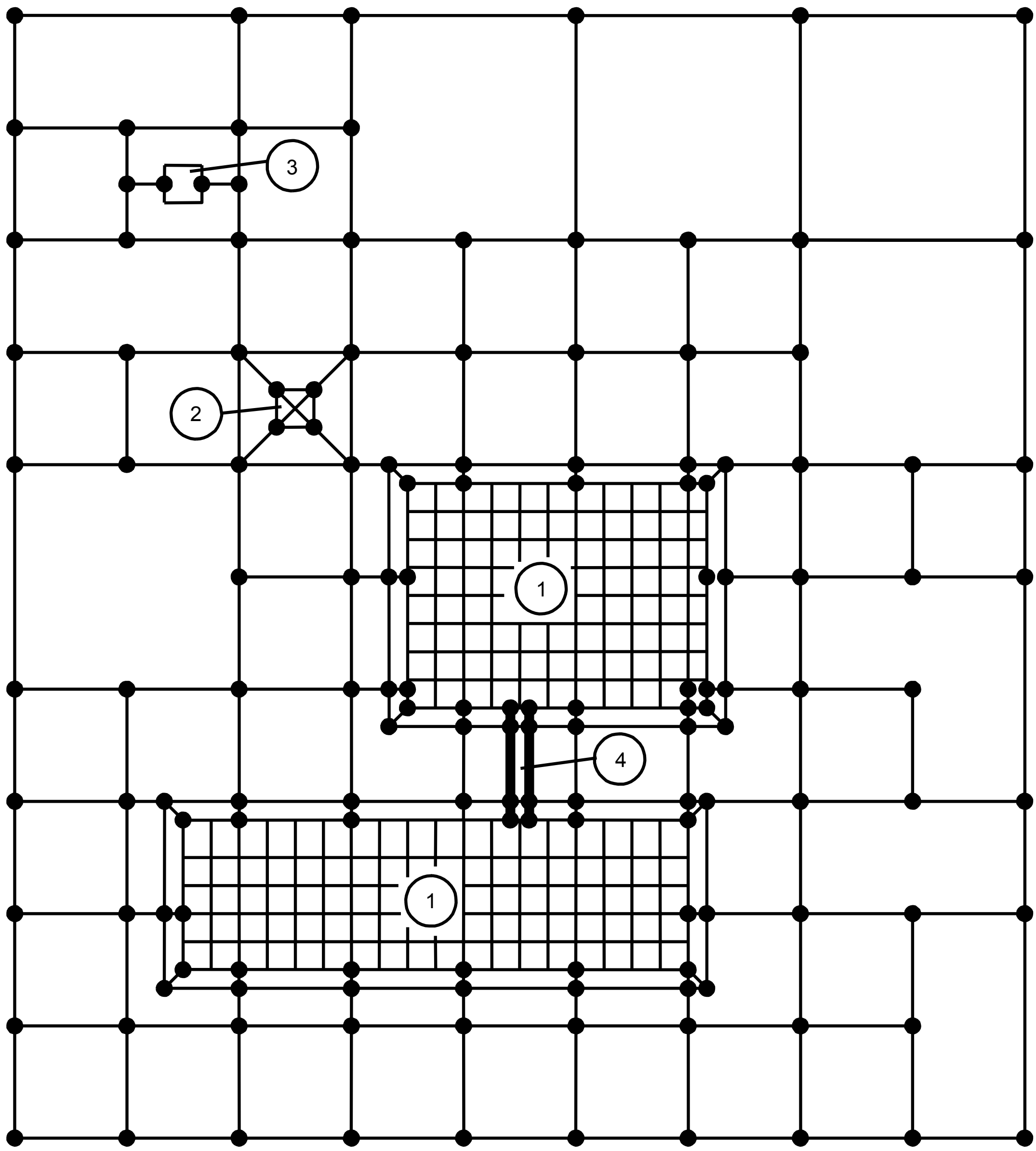
NOTE All drawn connections are either bonded structure metal elements or bonding connections. Some of them may also serve to intercept, conduct and disperse the lightning current into the earth.

Figure 5 – Example of a three-dimensional earthing system consisting of the bonding network interconnected with the earth termination system

5.1 Earth termination system

The earth termination system of the structure shall comply with IEC 62305-3. In structures where only electrical systems are provided, a Type A earthing arrangement may be used, but a Type B earthing arrangement is preferable. In structures with electronic systems a Type B earthing arrangement is recommended.

The ring earth electrode around the structure, or the ring earth electrode in the concrete at the perimeter of the foundation, should be integrated with a meshed network under and around the structure, having a mesh width of typically 5 m. This greatly improves the performance of the earth termination system. If the basement's reinforced concrete floor forms a well defined interconnected mesh and is connected to the earth termination system, typically every 5 m, it is also suitable. An example of a meshed earth termination system of a plant is shown in Figure 6.



Key

1 building with meshed network of the reinforcement

2 tower inside the plant

3 stand-alone equipment

4 cable tray

Figure 6 – Meshed earth termination system of a plant

To reduce potential differences between two internal systems, which have been referenced to separate earthing systems, the following methods may be applied:

– several parallel bonding conductors running in the same paths as the electrical cables, or the cables enclosed in grid-like reinforced concrete ducts (or continuously bonded metal conduit), which have been integrated into both of the earth-termination systems;

– shielded cables with shields of adequate cross-section, and bonded to the separate earthing systems at either end.

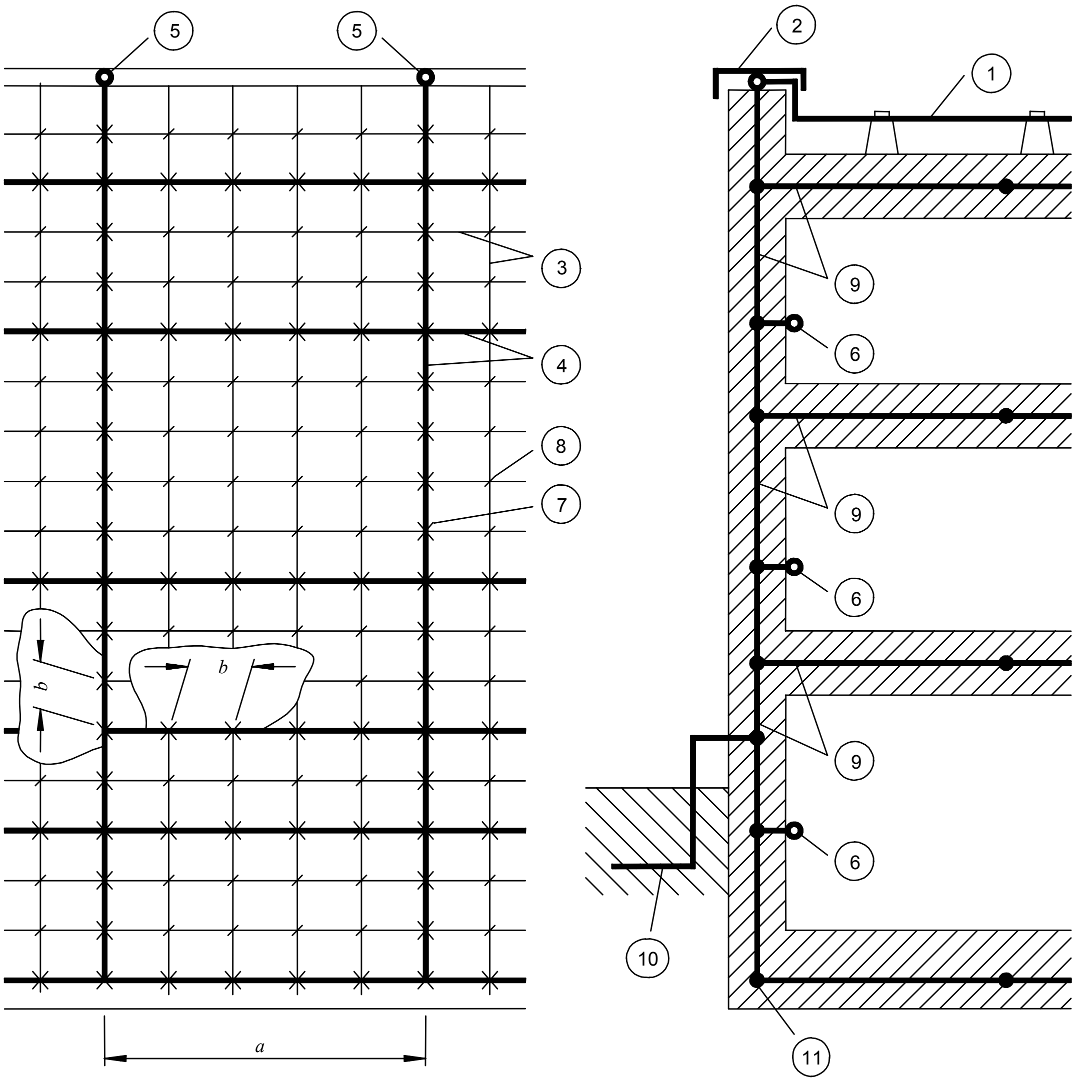
5.2 Bonding network

A low impedance bonding network is needed to avoid dangerous potential differences between all equipment inside the inner LPZ. Moreover, such a bonding network also reduces the magnetic field (see Annex A).

This can be realised by a meshed bonding network integrating conductive parts of the structure, or parts of the internal system, and by bonding metal parts or conductive services at the boundary of each LPZ directly or by using suitable SPDs.

The bonding network can be arranged as a three-dimensional meshed structure with a typical mesh width of 5 m (see Figure 5). This requires multiple interconnections of metal components in and on the structure (such as concrete reinforcement, elevator rails, cranes, metal roofs, metal facades, metal frames of windows and doors, metal floor frames, service pipes and cable trays). Bonding bars (e.g. ring bonding bars, several bonding bars at different levels of the structure) and magnetic shields of the LPZ shall be integrated in the same way.

Examples of bonding networks are shown in Figures 7 and 8.

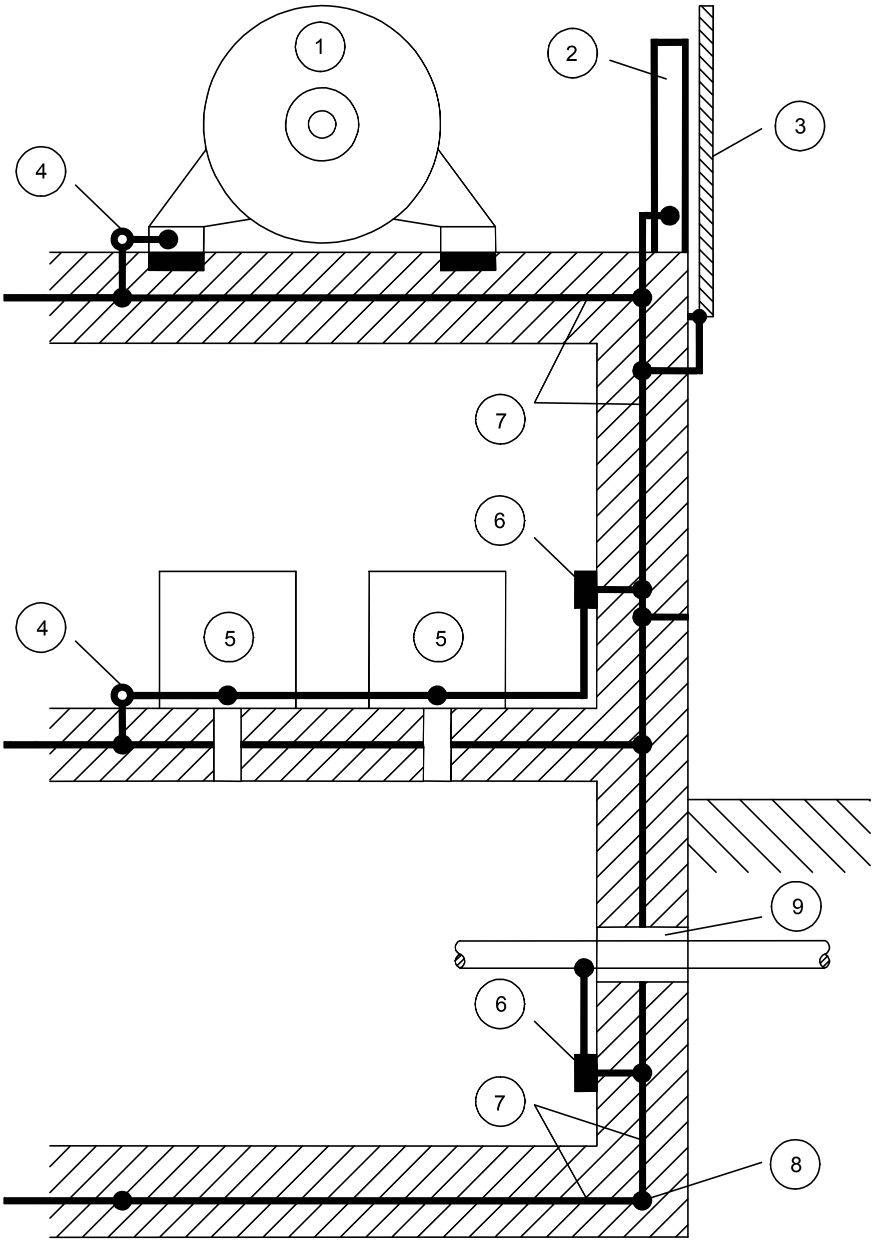


Key

1 air termination conductor
2 metal covering of the roof parapet
3 steel reinforcing rods
4 mesh conductors superimposed on the reinforcement
5 joint of the mesh conductor
6 joint for an internal bonding bar
7 connection by welding or clamping
8 arbitrary connection
9 steel reinforcement in concrete (with superimposed mesh conductors)
10 ring earthing electrode (if any)
11 foundation earthing electrode

a typical distance of 5 m for superimposed mesh conductors
b typical distance of 1 m for connecting this mesh with the reinforcement

Figure 7 – Utilization of reinforcing rods of a structure for equipotential bonding



Key

1 electrical power equipment

2 steel girder

3 metal covering of the facade

4 bonding joint

5 electrical or electronic equipment

6 bonding bar

7 steel reinforcement in concrete (with superimposed mesh conductors)

8 foundation earthing electrode

9 common inlet for different services

Figure 8 – Equipotential bonding in a structure with steel reinforcement

Conductive parts (e.g. cabinets, enclosures, racks) and the protective earth conductor (PE) of the internal systems shall be connected to the bonding network according to the following configurations (see Figure 9):

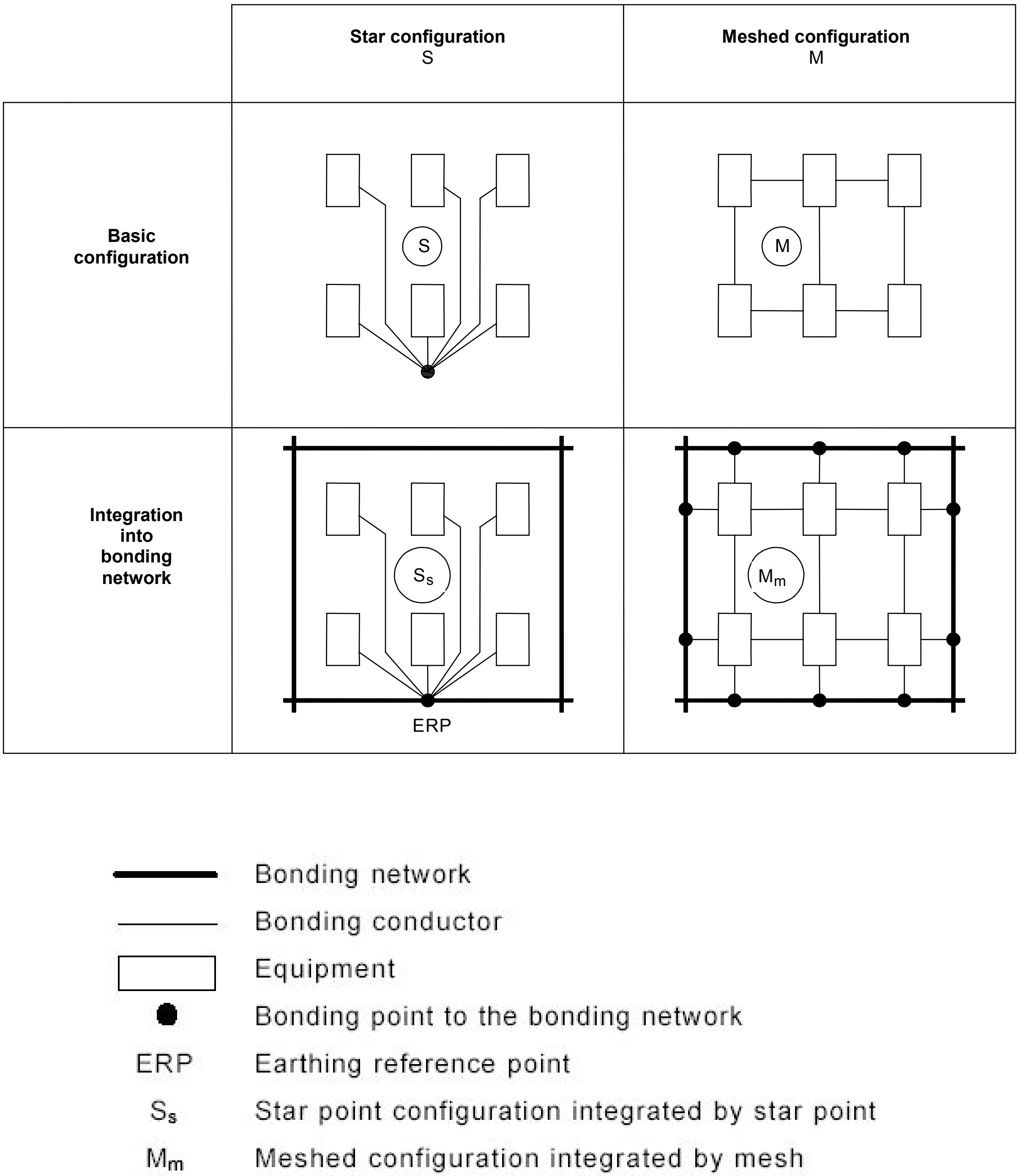


Figure 9 – Integration of electronic systems into the bonding network

If the configuration S is used, all metal components (e.g. cabinets, enclosures, racks) of the internal systems shall be isolated from the earthing system. The configuration S shall be integrated into the earthing system only by a single bonding bar acting as the earth reference point (ERP) resulting in type S_s. When configuration S is used, all lines between the individual equipment shall run in parallel with the bonding conductors following the star configuration in order to avoid induction loops. Configuration S can be used where internal systems are located in relatively small zones and all lines enter the zone at one point only.

If configuration M is used, the metal components (e.g. cabinets, enclosures, racks) of the internal systems are not to be isolated from the earthing system, but shall be integrated into it by multiple bonding points, resulting in type M_m. Configuration M is preferred for internal systems extended over relatively wide zones or over a whole structure, where many lines run between the individual pieces of equipment, and where the lines enter the structure at several points.

In complex systems, the advantages of both configurations (configuration M and S) can be combined as illustrated in Figure 10, resulting in combination 1 (S_s combined with M_m) or in combination 2 (M_s combined with M_m).

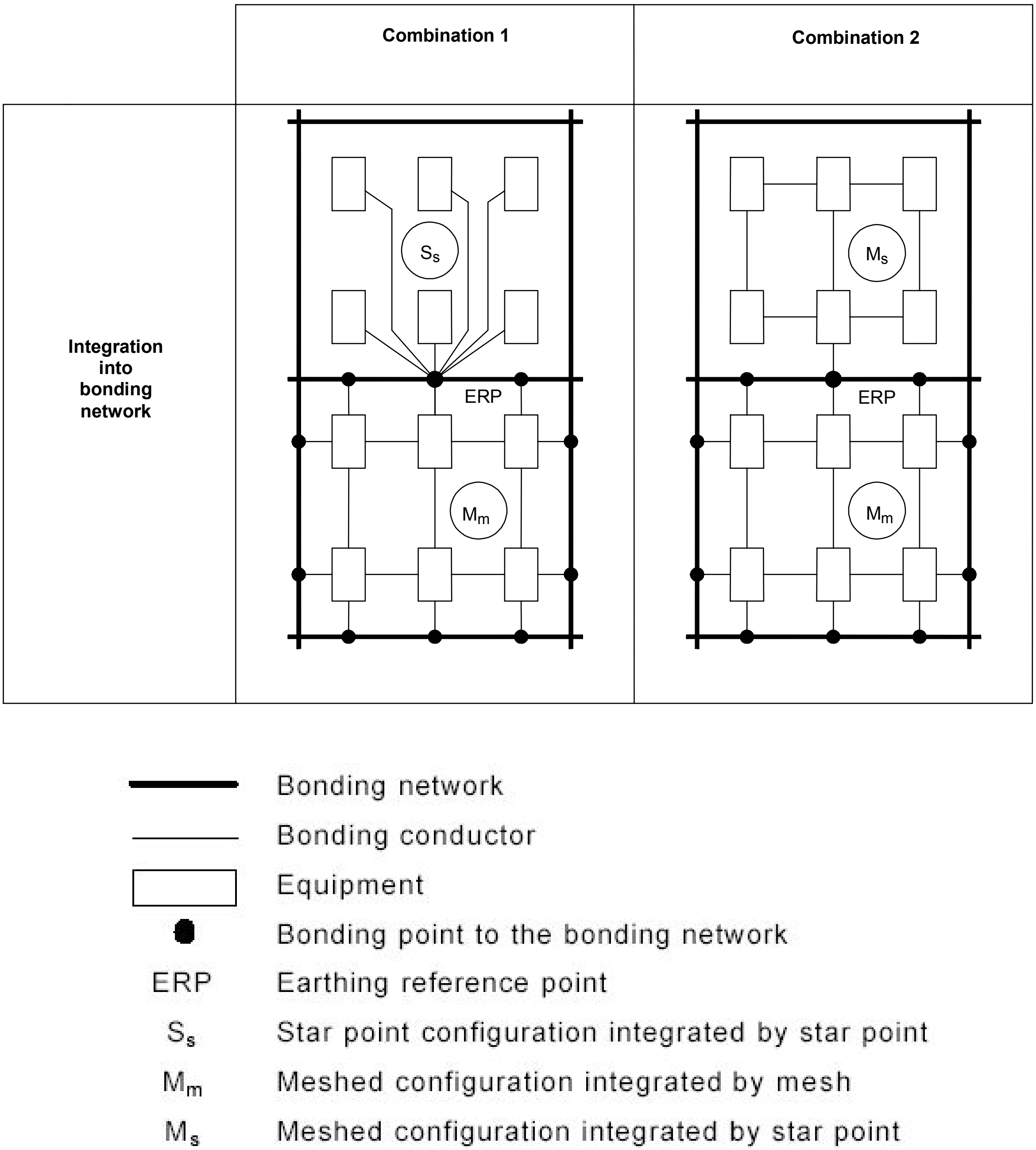


Figure 10 – Combinations of integration methods of electronic systems into the bonding network

5.3 Bonding bars

Bonding bars shall be installed for bonding of

– all conductive services entering a LPZ (directly or by using suitable SPDs),
– the protective earth conductor PE,
– metal components of the internal systems (e.g. cabinets, enclosures, racks),
– the magnetic shields of the LPZ at the periphery and inside the structure.

For efficient bonding the following installation rules are important:

– the basis for all bonding measures is a low impedance bonding network;
– bonding bars should be connected to the earthing system by shortest possible route (using bonding conductors not longer than 0,5 m);
– material and dimensions of bonding bars and bonding conductors shall comply with 5.5;

– SPD should use the shortest possible connections to the bonding bar as well as to the live conductors thus minimizing inductive voltage drops;

– on the protected side of the circuit (after an SPD), mutual induction effects should be minimized, either by minimizing the loop area or using shielded cables or cable ducts.

5.4 Bonding at the boundary of an LPZ

Where an LPZ is defined, bonding shall be provided for all metal parts and services (e.g. metal pipes, power lines or signal lines) penetrating the boundary of the LPZ.

NOTE Bonding of services entering LPZ 1 should be discussed with the service network providers involved (e.g. electrical power or telecommunication authorities), because there could be conflicting requirements.

Bonding shall be performed via bonding bars, which are installed as close as possible to the entrance point at the boundary.

Where possible, incoming services should enter the LPZ at the same location and be connected to the same bonding bar. If services enter the LPZ at different locations, each service shall be connected to a bonding bar and these bonding bars shall be connected together. To this end, bonding to a ring bonding bar (ring conductor) is recommended.

Equipotential bonding SPD(s) are always required at the entrance of the LPZ to bond incoming lines, which are connected to the internal systems within the LPZ, to the bonding bar. Using an interconnected or extended LPZ can reduce the number of required SPDs.

Shielded cables or interconnected metal cable ducts, bonded at each LPZ boundary, can be used either to interconnect several LPZ of the same order to one joint LPZ, or to extend an LPZ to the next boundary.

5.5 Material and dimensions of bonding components

Material, dimensions and conditions of use shall comply with IEC 62305-3. The minimum cross-section for bonding components shall comply with Table 1.

Clamps shall be dimensioned in accordance with the lightning current values of the LPL (see IEC 62305-1) and the current sharing analysis (see Annex B, IEC 62305-3).

SPD shall be dimensioned in accordance with Clause 7.

Table 1 – Minimum cross-sections for bonding components

Bonding component		Material	Cross-section mm²
Bonding bars (copper or galvanized steel)		Cu, Fe	50
Connecting conductors from bonding bars to the earthing system or to other bonding bars		Cu Al Fe	14 22 50
Connecting conductors from internal metal installations to bonding bars		Cu Al Fe	5 8 16
Connecting conductors for SPD	Class I Class II Class III	Cu	5 3 1
NOTE Other material used instead of copper should have equivalent cross-section.			

6 Magnetic shielding and line routing

Magnetic shielding can reduce the electromagnetic field as well as the magnitude of induced internal surges. Suitable routing of internal lines can also minimize the magnitude of induced internal surges. Both measures are effective in reducing permanent failure of internal systems.

6.1 Spatial shielding

Spatial shields define protected zones, which may cover the whole structure, a part of it, a single room or the equipment enclosure only. These may be grid-like, or continuous metal shields, or comprise the "natural components" of the structure itself (see IEC 62305-3).

Spatial shields are advisable where it is more practical and useful to protect a defined zone of the structure instead of several individual pieces of equipment. Spatial shields should be provided in the early planning stage of a new structure or a new internal system. Retrofitting to existing installations may result in higher costs and greater technical difficulties.

6.2 Shielding of internal lines

Shielding may be restricted to cabling and equipment of the system to be protected: metallic shield of cables, closed metallic cable ducts and metallic enclosure of equipment are used for this purpose.

6.3 Routing of internal lines

Suitable routing of internal lines minimizes induction loops and reduces the creation of surge voltages internal to the structure. The loop area can be minimized by routing the cables close to natural components of the structure which have been earthed and/or by routing electrical and signal lines together.

NOTE Some distance between power lines and unshielded signal lines may still be needed to avoid interference.

6.4 Shielding of external lines

Shielding of external lines entering the structure includes cable shields, closed metallic cable ducts and concrete cable ducts with interconnected reinforcement steel. Shielding of external lines is helpful, but often not within the responsibility of the LPMS planner (since the owner of external lines is normally the network provider).

6.5 Material and dimensions of magnetic shields

At the boundary of LPZ 0_A and LPZ 1, materials and dimensions of magnetic shields (e.g. grid-like spatial shields, cable shields and equipment enclosures) shall comply with the requirements of IEC 62305-3 for air termination conductors and/or down conductors. In particular:

– minimum thickness of sheet metal parts, metal ducts, piping and cable shields shall comply with Table 3 of IEC 62305-3;

– layouts of grid-like spatial shields and the minimum cross-section of their conductors, shall comply with Table 6 of IEC 62305-3.

Since magnetic shields are not intended to carry lightning currents, the dimensioning of these shields in accordance with Tables 3 and 6 of IEC 62305-3 is not required:

– at the boundary of zones LPZ 1/2 or higher, provided that the separation distance s between magnetic shields and the LPS is fulfilled (see 6.3 of IEC 62305-3),

– at the boundary of any LPZ, if the risk component R_d due to lightning flashes to the structure is negligible (see IEC 62305-2).

7 Coordinated SPD protection

The protection of internal systems against surges may require a systematic approach consisting of coordinated SPDs for both power and signal lines. The basic approach to the coordination of SPDs (see Annex C) is the same in both cases, but because of the extensive diversity of electronic system and their characteristics (analog or digital, d.c. or a.c., low or high frequency), the rules for the selection and installation of a “coordinated SPD protection” system are different to those which apply to the choice of SPDs for electrical systems only.

In an LPMS using the lightning protection zones concept with more than one LPZ (LPZ 1, LPZ 2 and higher), SPD(s) shall be located at the line entrance into each LPZ (see Figure 2).

In an LPMS using LPZ 1 only, SPD shall be located at the line entrance into LPZ 1 at least.

In both cases, additional SPDs may be required if the distance between the location of the SPD and the equipment being protected is long (see Annex D).

The SPD’s test requirements shall comply with

– IEC 61643-1 for power systems,

– IEC 61643-21 for telecommunication and signalling systems.

Selection and installation of a coordinated SPD protection shall comply with

– IEC 61643-12 and IEC 60364-5-53 for protection of power systems,
– IEC 61643-22 for protection of telecommunications and signalling systems.

Some basic information about the selection and installation of a coordinated SPD protection is given in Annex D.

Information on the magnitude of surges created by lightning for the purpose of dimensioning SPDs, at different installation points in the structure, is given in Annex E of IEC 62305-1.

8 Management of an LPMS

To achieve a cost effective and efficient protection system, the design of the protection system for the internal systems should be carried out during the building design stage and before construction. This allows one to optimize the use of the natural components of the structure and to choose the best compromise for the cabling layout and equipment location.

For retrofit to existing structures, the cost of LEMP protection measures is generally higher than that the cost for new structures. However, it is possible to minimize the investment cost by a proper choice of LPZ and by using existing installations or by upgrading them.

Proper protection can only be achieved if

– provisions are defined by a lightning protection expert,
– good coordination exists between the different experts involved in the building construction and in the LEMP protection measures (e.g. civil and electrical engineers),
– the management plan of 8.1 is followed.

The LPMS shall be maintained by inspection and maintenance. After relevant changes to the structure or to the protection measures, a new risk assessment should be carried out.

8.1 LPMS management plan

Planning and coordination of an LPMS requires a management plan (see Table 2), which begins with an initial risk assessment (IEC 62305-2) to determine the required protection measures needed to reduce the risk to a tolerable level. To accomplish this, the lightning protection zones shall be determined.

Table 2 – LPMS management plan for new buildings and for extensive changes in construction or use of buildings

Step	Aim	Action to be taken by
Initial risk analysis[1]	To check the need for LEMP protection If needed, select suitable LMPS using the risk assessment method	Lightning protection expert [2] Owner
Final risk analysis[1]	The cost/benefit ratio for the selected protection measures should be optimized using the risk assessment method again As a result the following are defined: - LPL and the lightning parameters - LPZ and their boundaries	Lightning protection expert [2] Owner
LPMS planning	Definition of the LPMS: - spatial shielding measures - bonding networks - earth termination systems - line shielding and routing - shielding of incoming services - coordinated SPD protection	Lightning protection expert Owner Architect Planners of internal systems Planners of relevant installations
LPMS design	General drawings and descriptions Preparation of lists for tenders Detailed drawings and timetables for the installation	Engineering office or equivalent
Installation of the LPMS including supervision	Quality of installation Documentation Possibly revision of the detailed drawings	Lightning protection expert Installer of the LPMS Engineering office Supervisor
Approval of the LPMS	Checking and document the state of the system	Independent lightning protection expert Supervisor
Recurrent inspections	Ensuring the adequacy of the LPMS	Lightning protection expert Supervisor

1) See IEC 62305-2.

2) With a broad knowledge of EMC and knowledge of installation practices.

According to the LPL defined in IEC 62305-1, and the protection measures to be adopted, the following steps shall be carried out:

– an earthing system, comprising a bonding network and an earth termination system, shall be provided;
– external metal parts and incoming services shall be bonded directly or via suitable SPDs;
– the internal system shall be integrated into the bonding network;
– spatial shielding in combination with line routing and line shielding may be implemented;
– requirements for a coordinated SPD protection shall be determined;
– for existing structures, special measures may be needed (see Annex B).

After this, the cost/benefit ratio of the selected protection measures should be re-evaluated and optimised using the risk assessment method again.

8.2 Inspection of an LPMS

The inspection comprises checking the technical documentation, visual inspections and test measurements. The object of the inspection is to verify that

– the LPMS complies with the design,
– the LPMS is capable of performing its design function,
– any newly added protection measure is integrated correctly into the LPMS.

Inspections shall be made

– during the installation of the LPMS,
– after the installation of the LPMS,
– periodically,
– after any alteration of components relevant to the LPMS,
– possibly after a lightning flash to the structure (e.g. where indicated by a lightning strike counter, or where an eyewitness account of a strike to the structure is provided, or where there is visual evidence of lightning-related damage to the structure).

The frequency of the periodical inspections shall be determined with consideration to

– the local environment, such as corrosive soils and corrosive atmospheric conditions,
– the type of protection measures employed.

8.2.1 Inspection procedure

8.2.1.1 Checking of technical documentation

After the installation of a new LPMS, the technical documentation shall be checked for compliance with the relevant standards, and for completeness. Consequently, the technical documentation shall be continuously updated, e.g. after any alteration or extension of the LPMS.

8.2.1.2 Visual inspection

Visual inspection shall be carried out to verify that

– there are no loose connections nor any accidental breaks in conductors and joints,
– no part of the system has been weakened due to corrosion, especially at ground level,
– bonding conductors and cable shields are intact,
– there are no additions or alterations which require further protection measures,
– there is no indication of damage to the SPDs and their fuses or disconnectors,
– appropriate line routings are maintained,
– safety distances to the spatial shields are maintained.

8.2.1.3 Measurements

For those parts of an earthing system and bonding network which are not visible for inspection, measurements of electrical continuity should be performed.

8.2.2 Inspection documentation

An inspection guide should be prepared to facilitate the process. The guide should contain sufficient information to assist the inspector with his task, so that all aspects of the installation and its components, tests methods and test data which is recorded, can be documented.

The inspector shall prepare a report, which shall be attached to the technical documentation and the previous inspection reports. The inspection report shall contain information covering

– the general status of the LPMS,
– any deviation(s) from the technical documentation,
– the result of any measurements performed.

8.3 Maintenance

After inspection, all defects noted shall be corrected without delay. If necessary, the technical documentation shall be updated.

Annex A
(informative)

Basics for evaluation of electromagnetic environment in a LPZ

This annex provides information for the evaluation of the electromagnetic environment inside an LPZ, which can be used for protection against LEMP. It is also suitable for protection against electromagnetic interference.

A.1 Harmful effects on electrical and electronic systems due to lightning

A.1.1 Source of harm

The primary source of harm is the lightning current and its associated magnetic field, which has the same waveshape as the lightning current.

NOTE In terms of protection, the influence of the lightning electric field is usually of minor interest.

A.1.2 Victims of harm

Internal systems installed in or on a structure, having only a limited withstand level to surges and to magnetic fields, may be damaged or operate incorrectly when subjected to the effects of lightning and its subsequent magnetic fields.

Systems mounted outside a structure can be at risk due to the unattenuated magnetic field and, if positioned in an exposed location, due to surges up to a full lightning current of a direct lightning strike.

Systems installed inside a structure can be at risk due to the remaining attenuated magnetic field and due to the conducted or induced internal surges and by external surges conducted by incoming lines.

For details concerning equipment withstand levels, the following standards are of relevance:

- The withstand level of the power installation is defined in IEC 60664-1: the withstand level is defined by the rated impulse withstand voltage 1,5 – 2,5 – 4 and 6 kV.
- The withstand level of telecommunication equipment is defined in ITU-T K.20 and K.21.
- The withstand level of general equipment is defined in their product specifications or can be tested
  - against conducted surges, using IEC 61000-4-5 with test levels for voltage: 0,5 – 1 – 2 – 4 kV at 1,2/50 μs waveshape and with test levels for current: 0,25 – 0,5 – 1 – 2 kA at 8/20 μs waveshape;

  NOTE In order for certain equipment to meet the requirements of the above standard, they may incorporate internal SPDs. The characteristics of these internal SPDs may affect the coordination requirements.

  - against magnetic fields, using IEC 61000-4-9 with test levels: 100 – 300 – 1 000 A/m at 8/20 μs waveshape and IEC 61000-4-10 with test levels: 10-30-100 A/m at 1 MHz.

Equipment not complying with radio frequency (RF), radiated emission and immunity tests, as defined by the relevant EMC product standards, can be at risk due to directly radiated magnetic fields into it. On the other hand, the failure of equipment complying with these standards can be neglected.

A.1.3 Coupling mechanisms between the victim and the source of harm

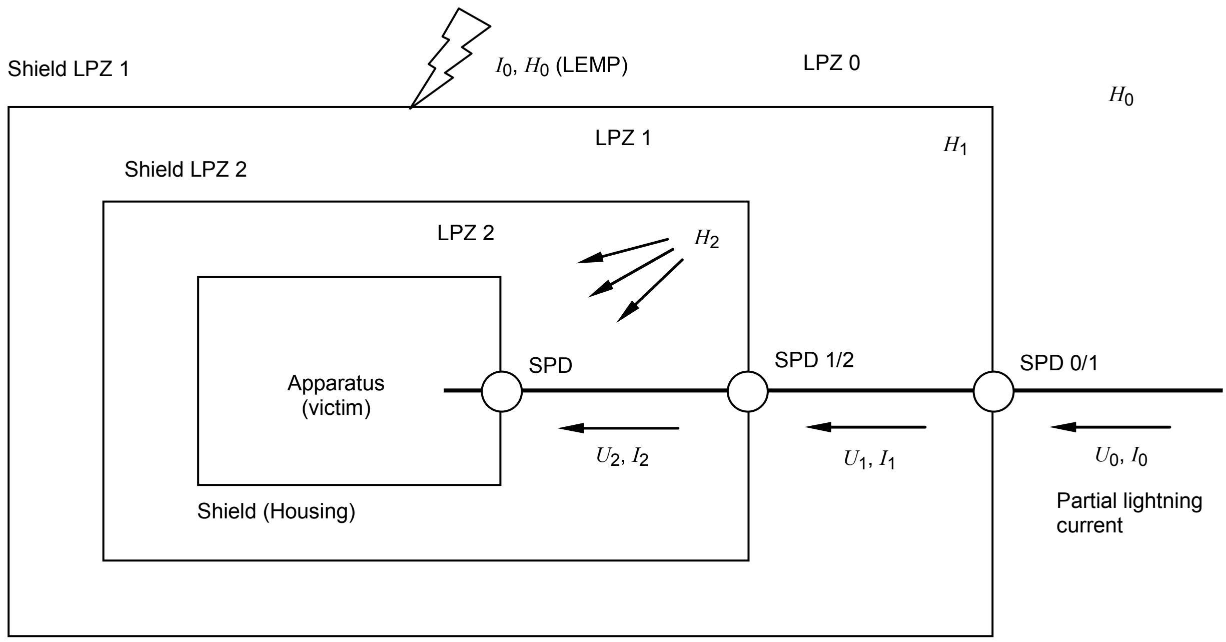
The equipment's withstand level needs to be compatible with the source of harm. To achieve this, the coupling mechanisms need to be adequately controlled by the appropriate creation of lightning protection zones (LPZ).

A.2 Spatial shielding, line routing and line shielding

A.2.1 General

The magnetic field caused inside an LPZ by lightning flashes to the structure or the nearby ground, may be reduced by spatial shielding of the LPZ only. Surges induced into the electronic system can be minimized either by spatial shielding, or by line routing and shielding, or by a combination of both methods.

Figure A.1 provides an example of the LEMP in the case of lightning strike to the structure showing the lightning protection zones LPZ 0, LPZ 1 and LPZ 2. The electronic system to be protected is installed inside LPZ 2.



1. **Primary source of harm – LEMP**
   As defined from parameters according to LPL I to IV:

IEC 62305-1	I_0	impulse 10/350 µs (and 0,25/100 µs)	200-150-100-100 kA
	H_0	impulse 10/350 µs (and 0,25/100 µs)	derived from I_0

2. **Withstand level of power installation**
   As defined for installation category I to IV for nominal voltages 230/400 V and 277/480 V:

IEC 60664-1	U	installation category I to IV	6 – 4 – 2,5 – 1,5 kV

3. **Withstand level of telecommunication installation**
   ITU Recommendation K.20 or K.21

4. **Tests for equipment without suitable product standards**
   Withstand level of apparatus (victim)
   As defined for conducted (U, I) lightning effects:

IEC 61000-4-5	U_{OC}	impulse 1,2/50 µs	4 – 2 – 1 – 0,5 kV
	I_{SC}	impulse 8/20 µs	2 – 1 – 0,5 – 0,25 kA

5. **Tests for equipment not complying with relevant EMC product standards**
   Withstand level of apparatus (victim)
   As defined for radiated (H) lightning effects:

IEC 61000-4-9	H	impulse 8/20 µs, (damped oscillation 25 kHz), T_p = 10 µs	1 000 – 300 – 100 A/m
IEC 61000-4-10	H	impulse 0,2/0,5 µs, (damped oscillation 1 MHz), T_p = 0,25 µs	100 – 30 – 10 A/m

Figure A.1 – LEMP situation due to lightning strike

The primary electromagnetic source of harm to the electronic system is the lightning current I_0 and the magnetic field H_0. Partial lightning currents flow on the incoming services. These currents as well as the magnetic fields have the same waveshape. The lightning current to be considered here consists of a first stroke I_f (typically with a long tail 10/350 µs waveshape) and subsequent strokes I_s (0,25/100 µs waveshape). The current of the first stroke I_f generates the magnetic field H_f and the currents of the subsequent strokes I_s generate the magnetic fields H_s.

The magnetic induction effects are mainly caused by the rising front of the magnetic field. As shown in Figure A.2, the rising front of H_f can be characterized by a damped oscillating field of 25 kHz with maximum value $H_{f/max}$ and time to maximum value $T_{p/f}$ of 10 µs. In the same way, the rising front of H_s can be characterized by a damped oscillating field of 1 MHz with maximum value $H_{s/max}$ and time to maximum value $T_{p/s}$ of 0,25 µs.

It follows that the magnetic field of the first stroke can be characterized by a typical frequency of 25 kHz and the magnetic field of the subsequent strokes can be characterized by a typical frequency of 1 MHz. Damped oscillating magnetic fields of these frequencies are defined for test purposes in IEC 61000-4-9 and IEC 61000-4-10.

By installing magnetic shields and SPDs at the interfaces of the LPZs, the effect of the unattenuated lightning defined by I_0 and H_0, is reduced to the withstand level of the victim. As shown in Figure A.1, the victim shall withstand the surrounding magnetic field H_2 and the conducted lightning currents I_2 and voltages U_2.

The reduction of I_1 to I_2 and of U_1 to U_2 is the subject of Annex C, whereas the reduction of H_0 to a sufficiently low value of H_2 is considered here as follows:

In the case of a grid-like spatial shield, it may be assumed that the waveshape of the magnetic field inside the LPZs (H_1, H_2) is the same as the waveshape of the magnetic field outside (H_0).

The damped oscillating waveforms shown in Figure A.2 comply with the tests defined in IEC 61000-4-9 and IEC 61000-4-10 and can be used to determine the equipment's withstand level to magnetic fields created by the rise of the magnetic field of the first stroke H_f and of the subsequent strokes H_s.

The induced surges caused by the magnetic field coupled onto the induction loop (see Clause A.4), should be lower than, or equal to, the equipment's withstand level.

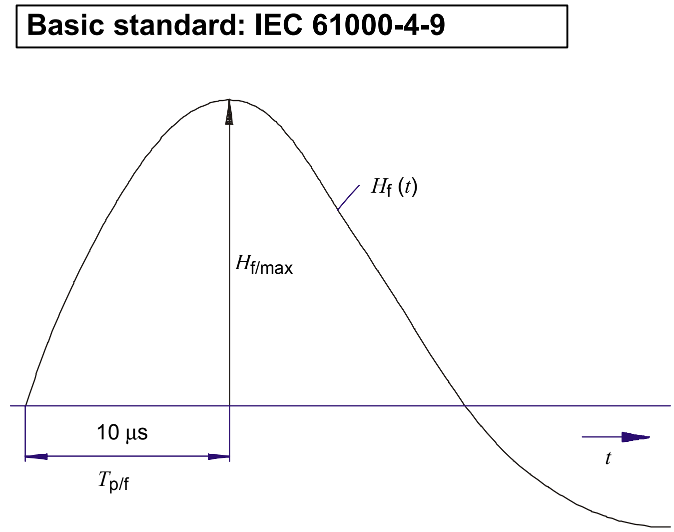


Figure A.2a – Simulation of the rise of the field of the first stroke (10/350 µs) by a single impulse 8/20µs (damped 25 kHz oscillation)

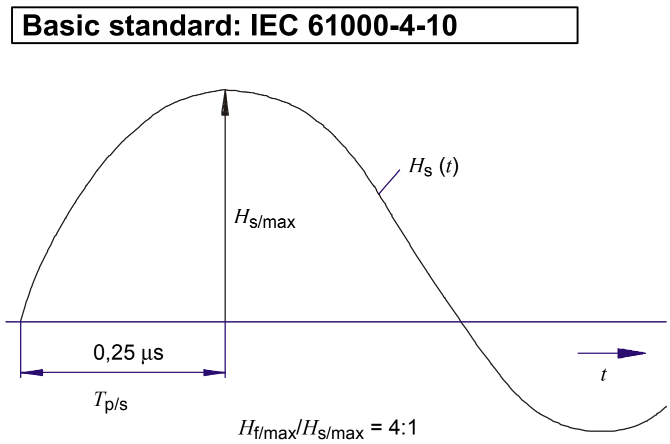


Figure A.2b – Simulation of the rise of the field of the subsequent stroke (0,25/100 µs) by damped 1 MHz oscillations (multiple impulses 0,2/0,5µs)

NOTE 1 Although the definitions of the time to the maximum value T_P and the front time T_1 are different, for a suitable approach their numerical values are taken as equal here.

NOTE 2 The ratio of the maximum values $H_{f/max}$ / $H_{s/max}$ = 4: 1.

Figure A.2 – Simulation of the rise of magnetic field by damped oscillations

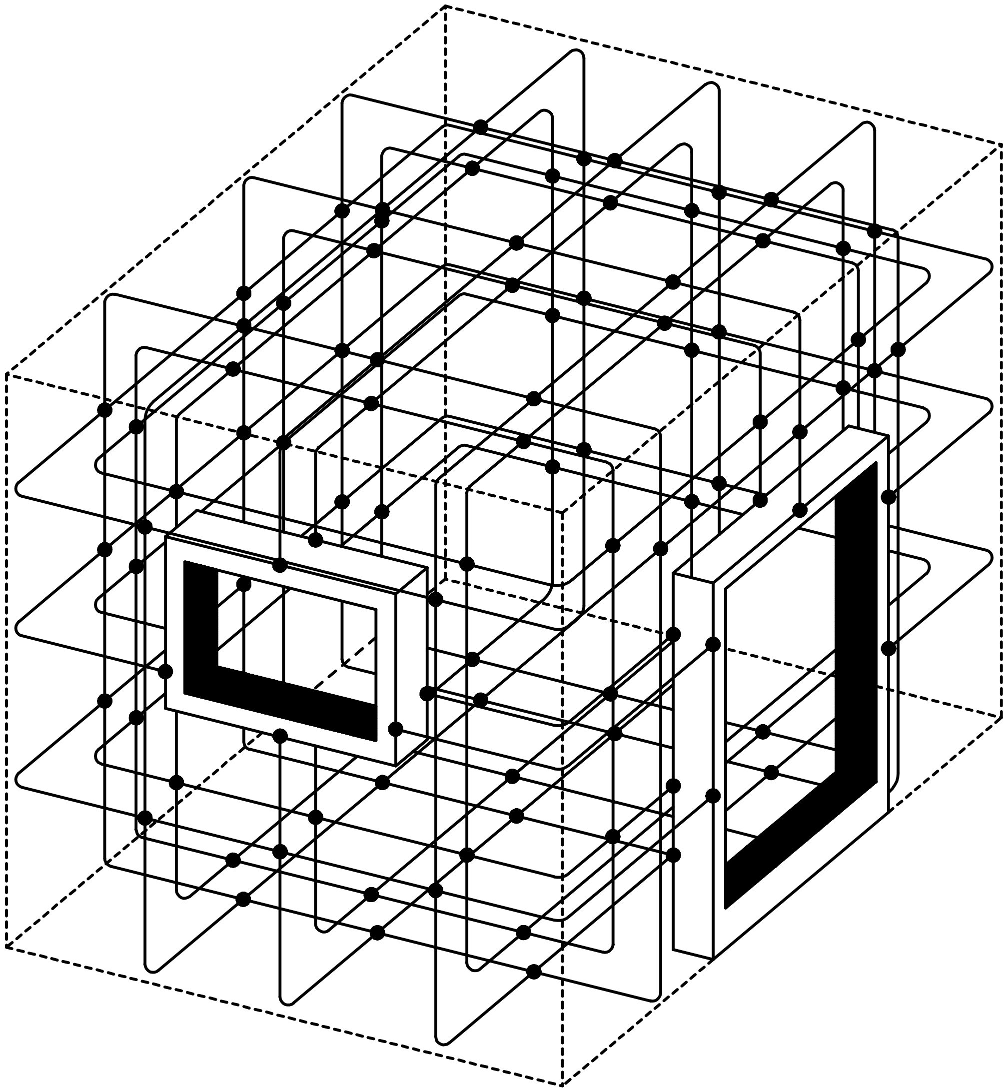
A.2.2 Grid-like spatial shields

In practice, the large volume shields of LPZs are usually created by natural components of the structure such as the metal reinforcement in the ceilings, walls and floors, the metal framework, the metal roofs and metal facades. These components together create a grid-like spatial shield. Effective shielding requires that the mesh width be typically less than 5 m.

NOTE 1 The shielding effect may be neglected if an LPZ 1 is created by a normal external LPS according to IEC 62305-3 with mesh widths and typical distances greater than 5 m. Otherwise a large steel frame building with many structural steel stanchions provides a significant shielding effect.

NOTE 2 Shielding in subsequent inner LPZs can be accomplished either by adopting spatial shielding measures, by using closed metal racks or cabinets, or by using the metal enclosure of the equipment.

Figure A.3 shows how in practice the metal reinforcement in concrete and metal frames (for metal doors and possibly shielded windows) can be used to create a large volume shield for a room or building.

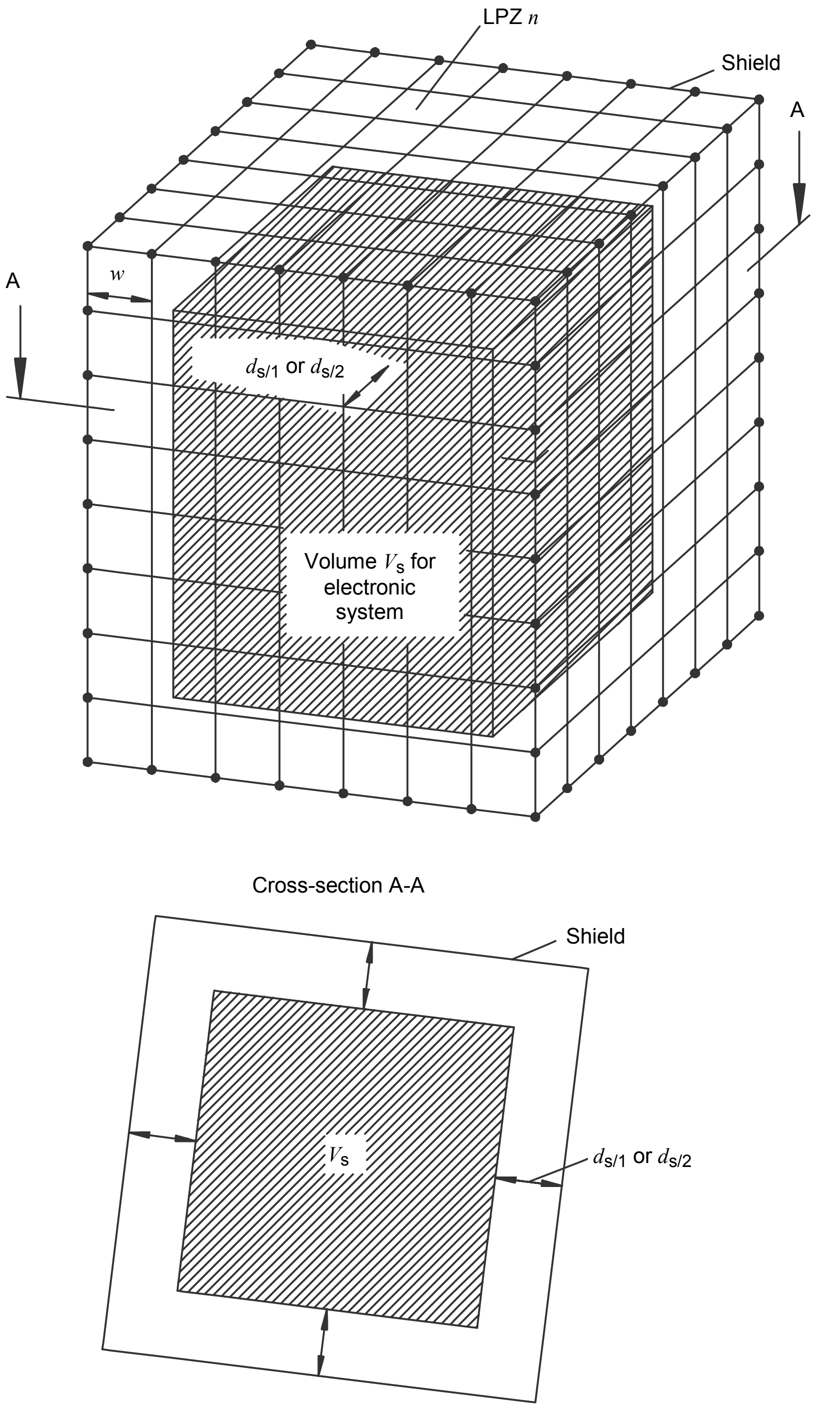


- **W**elded or clamped at every rod and at the crossings.

NOTE In practice, it is not possible for extended structures to be welded or clamped at every point. However, most of the points are naturally connected by direct contacts or by additional wiring. A practical approach therefore could be a connection at about every 1 m.

Figure A.3 – Large volume shield built by metal reinforcement and metal frames

Electronic systems shall be located inside a “safety volume” which respects a safety distance from the shield of the LPZ (see Figure A.4). This is because of the relatively high magnetic fields close to the shield, due to partial lightning currents flowing in the shield (particularly for LPZ 1).



NOTE The volume V_s keeps a safety distance $d_{s/1}$ or $d_{s/2}$ from the shield of LPZ n.

Figure A.4 – Volume for electrical and electronic systems inside an inner LPZ n

A.2.3 Line routing and line shielding

Surges induced into the electronic systems can be reduced by suitable line routing (minimizing the induction loop area) or by using shielded cables or metallic cable ducts (minimizing the induction effects inside), or a combination of both (see Figure 5).

The conductive cables connected to electronic systems should be routed as close to the metal components of the bonding network as possible. It is beneficial to run these cables in metal enclosures of the bonding network, for example U-shaped conduits or metal trunking (see also IEC 61000-5-2).

Particular attention should be paid when installing cables close to the shield of an LPZ (especially LPZ 1) due to the substantial value of the magnetic fields at that location.

When cables, which run between separate structures, need to be protected, they should be run in metal cable ducts. These ducts should be bonded at both ends to the bonding bars of the separate structures. If the cable shields (bonded at both ends) are able to carry the anticipated partial lightning current, additional metal cable ducts are not required.

Voltages and currents induced into loops, formed by installations, result in common mode surges at the electronic systems. Calculations of these induced voltages and currents are described in Clause A.4**.**

Figure A.6 provides an example of a large office building:

– Shielding is achieved by steel reinforcement and metal facades for LPZ 1, and by shielded enclosures for the sensitive electronic systems in LPZ 2. To be able to install a narrow meshed bonding system, several bonding terminals are provided in each room.
– LPZ 0 is extended into LPZ 1 to house a power supply of 20 kV, because the installation of SPDs on the high voltage power side immediately at the entrance was not possible in this special case.

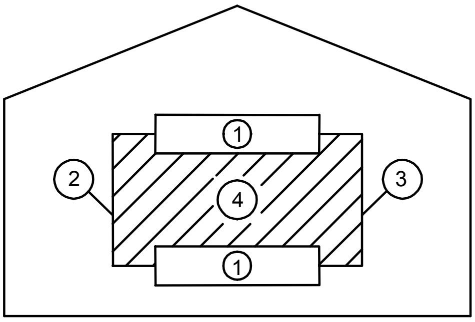


Figure A.5a – Unprotected system

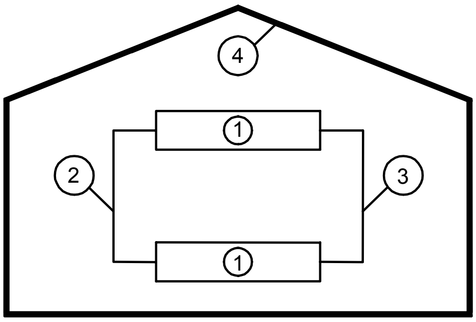


Figure A.5b – Reducing the magnetic field inside an inner LPZ by its spatial shield

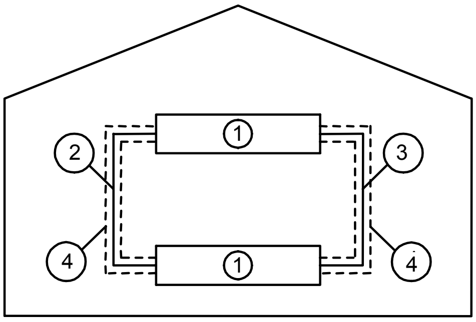


Figure A.5c – Reducing the influence of the field on lines by line shielding

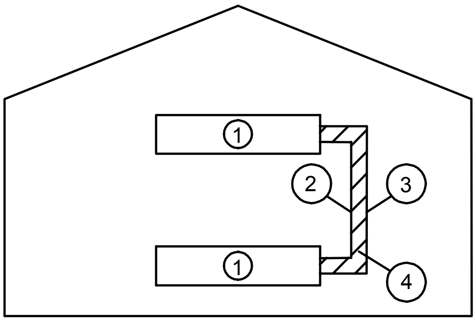


Figure A.5d – Reducing the induction loop area by suitable line routing

Key

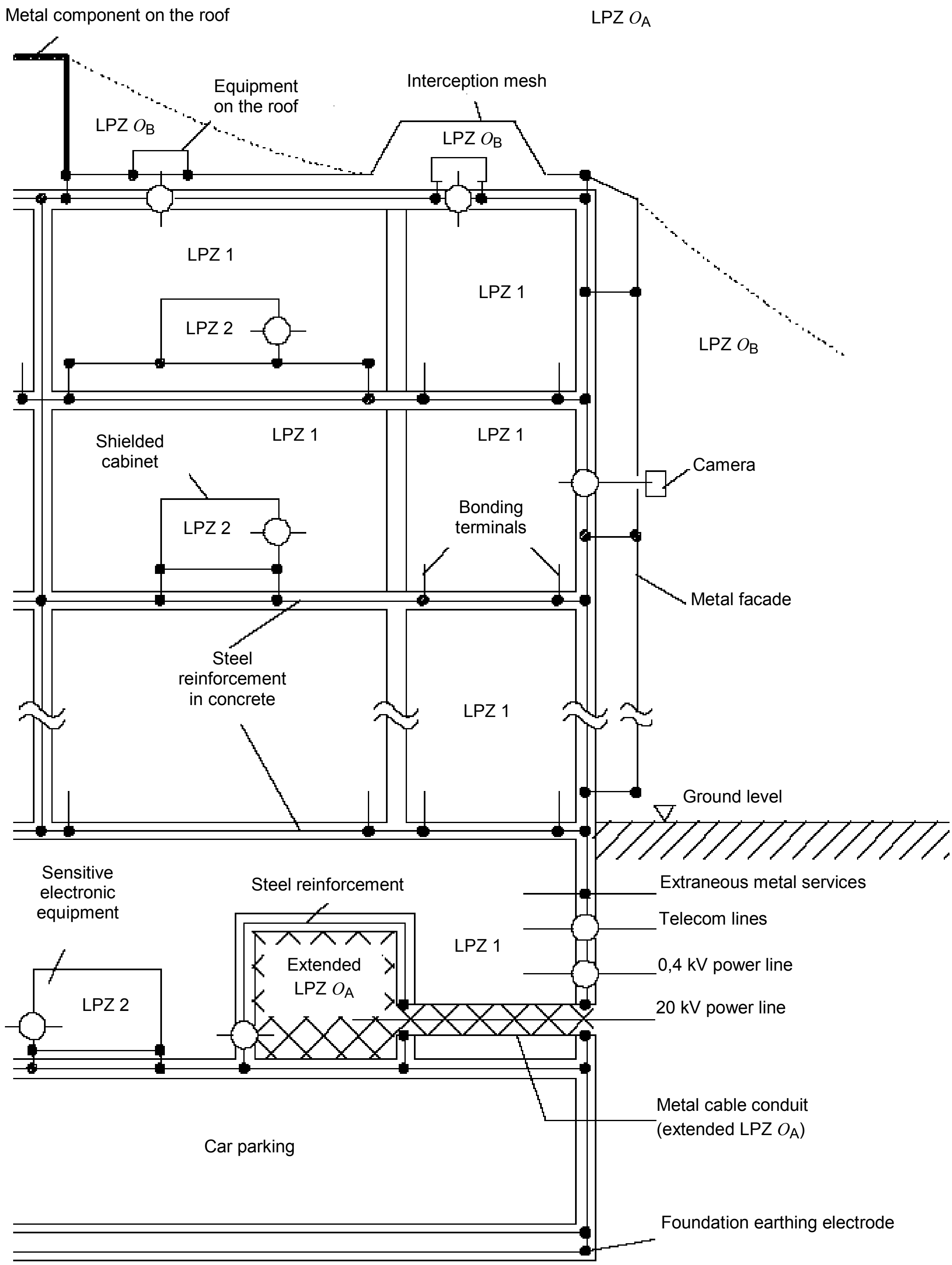
Equipment

Line a (for example electric)

Line b (for example electronic)

Induction loop

Figure A.5 – Reducing induction effects by line routing and shielding measures



• Equipotential bonding

O Surge protective device (SPD)

Figure A.6 – Example of an LPMS for an office building

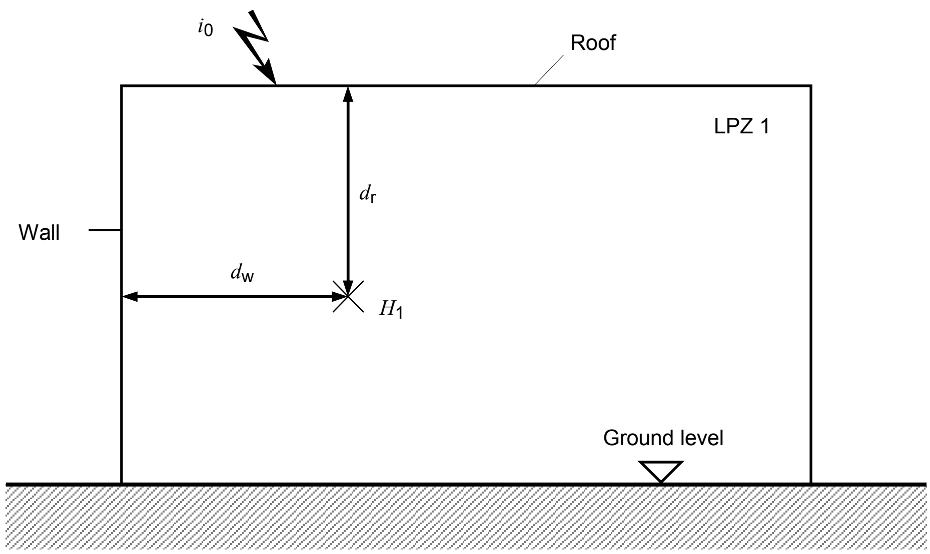
A.3 Magnetic field inside LPZs

A.3.1 Approximation for the magnetic field inside LPZs

If a theoretical (see A.3.2), or experimental (see A.3.3), investigation of the shielding effectiveness is not performed, the attenuation shall be evaluated as follows.

A.3.1.1 Grid-like spatial shield of LPZ 1 in the case of a direct lightning strike

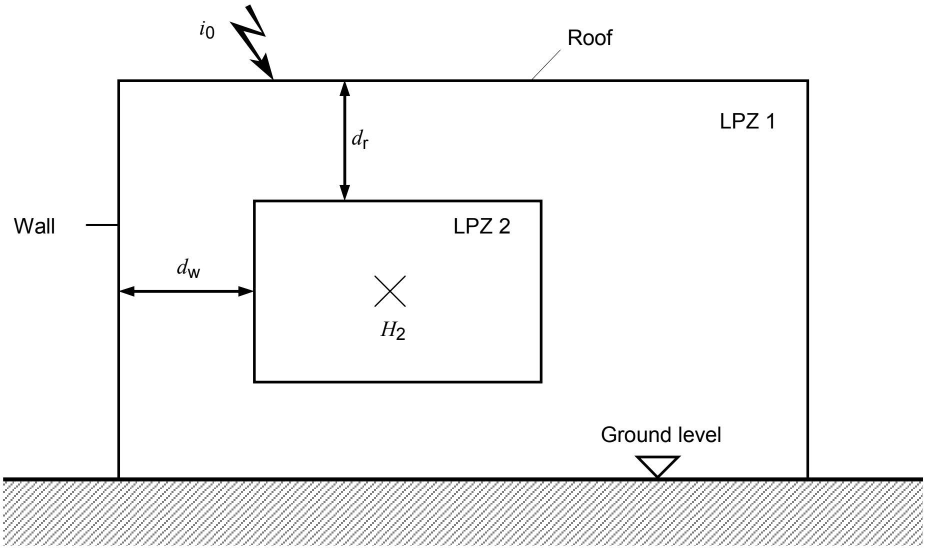
The shield of a building (shield surrounding LPZ 1) can be part of the external LPS and currents due to direct lightning strikes will flow along it. This situation is depicted by Figure A.7a assuming that the lightning hits the structure at an arbitrary point of the roof.



Inside LPZ 1 $H = k_H \cdot i_0 \cdot w_1 / (d_w \cdot \sqrt{d_r})$

NOTE Distances d_w and d_r are determined for the point considered.

Figure A.7a – Magnetic field inside LPZ 1



Inside LPZ 2 $H_2 = H_1 \ / \ 10^{\,SF_2/20}$

NOTE Distances d_w and d_r are determined for the boundary of LPZ 2.

Figure A.7b – Magnetic field inside LPZ 2

Figure A.7 – Evaluation of the magnetic field values in case of a direct lightning strike

For the magnetic field strength H_1 at an arbitrary point inside LPZ 1, the following formula applies:

$$H_1 = k_H \cdot i_0 \cdot w \Big/ \left(d_w \cdot \sqrt{d_r}\right) \quad \text{(A/m)} \tag{A.1}$$

where

d_r is the shortest distance, in metres, between the point considered and the roof of shielded LPZ 1;

d_w is the shortest distance, in metres, between the point considered to the wall of shielded LPZ 1;

I_0 is the lightning current in LPZ 0_A in A;

k_H is the configuration factor, (1/√m), typically k_H = 0,01 (1/√m);

w is the mesh width of the grid-like shield of LPZ 1, in m.

The result of this formula is the maximum value of the magnetic field in LPZ 1 (taking the Note below into account):

– caused by the first stroke: $H_{1/f/max} = k_H \cdot i_{f/max} \cdot w \Big/ \left(d_w \cdot \sqrt{d_r}\right)$ (A/m) (A.2)

– caused by the subsequent strokes: $H_{1/s/max} = k_H \cdot i_{s/max} \cdot w \Big/ \left(d_w \cdot \sqrt{d_r}\right)$ (A/m) (A.3)

where

$i_{f/max}$ is the maximum value, in amperes, of the first stroke current according to the protection level;

$i_{s/max}$ is the maximum value, in amperes, of the subsequent stroke currents according to the protection level.

NOTE The field is reduced by a factor of 2, if a meshed bonding network according to 5.2 is installed.

These values of magnetic field are valid only for a safety volume V_s inside the grid-like shield with a safety distance $d_{s/1}$ from the shield (see Figure A.4):

$$d_{s/1} = w \quad \text{(m)} \tag{A.4}$$

EXAMPLES

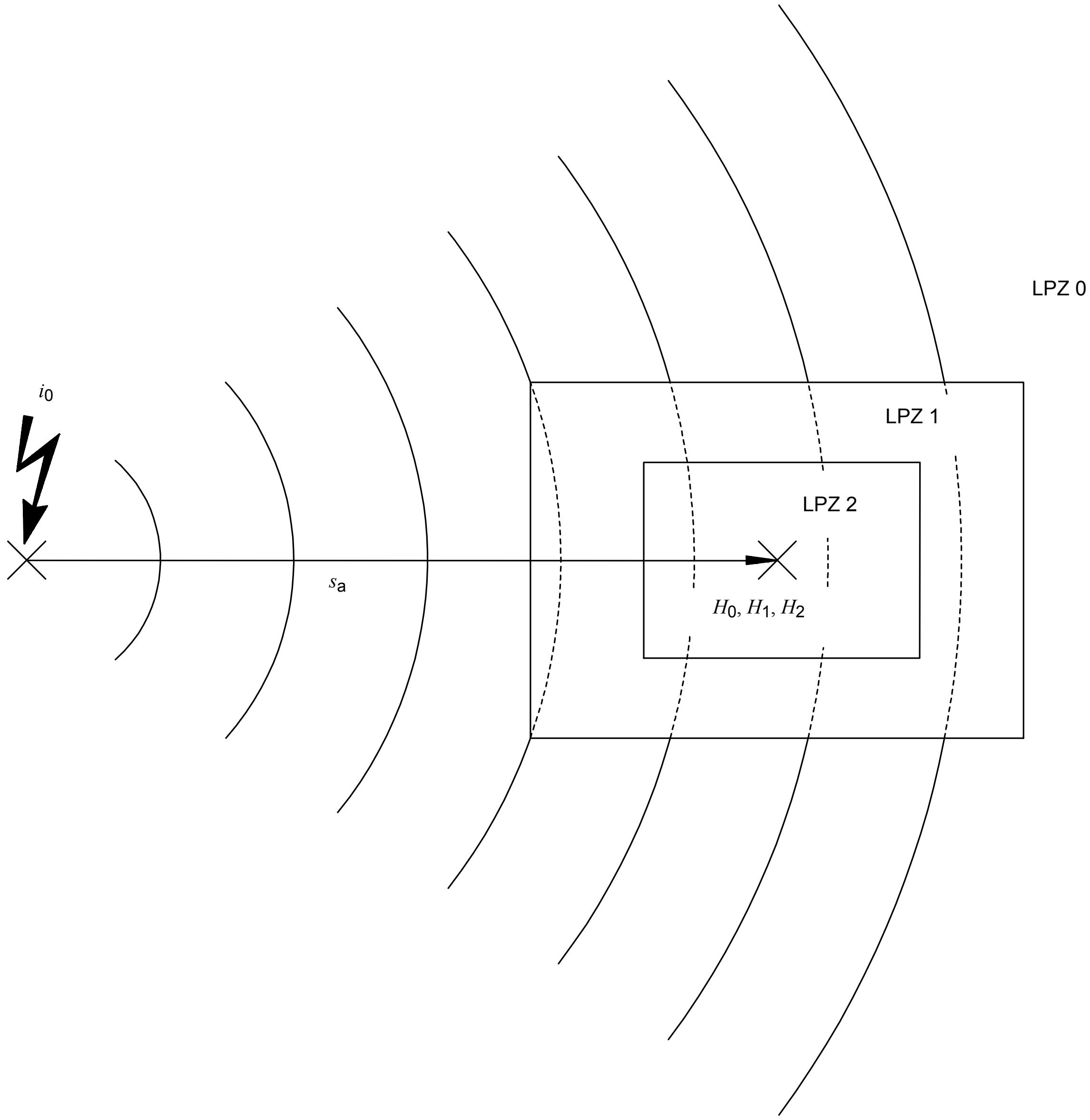
As an example, three copper grid-like shields with dimensions given in Table A.1, and having an average mesh width of w = 2 m, are considered (see Figure 10). This results in a safety distance $d_{s/1}$ = 2,0 m defining the safety volume V_s. The values for $H_{1/max}$ valid inside V_s are calculated for $i_{0/max}$ = 100 kA and shown in Table A.1. The distance to the roof is half the height: $d_r = H/2$. The distance to the wall is half the length: $d_w = L/2$ (centre) or equal to: $d_w = d_{s/1}$ (worst case near the wall).

Table A.1 – Examples for $i_{0/max}$ = 100 kA and w = 2 m

Type of shield (see Figure A.10)	$L \times W \times H$ m	$H_{1/max}$ (centre) A/m	$H_{1/max}$ ($d_w = d_{s/1}$) A/m
1	10 x 10 x 10	179	447
2	50 x 50 x 10	36	447
3	10 x 10 x 50	80	200

A.3.1.2 Grid-like spatial shield of LPZ 1 in the case of a nearby lightning strike

The situation for a nearby lightning strike is shown in Figure A.8. The incident magnetic field around the shielded volume of LPZ 1 can be approximated as a plane wave.



No shield $H_0 = i_0 / (2\pi s_a)$

Inside LPZ 1 $H_1 = H_0 / 10^{SF_1/20}$

Inside LPZ 2 $H_2 = H_1 / 10^{SF_2/20}$

Figure A.8 – Evaluation of the magnetic field values in case of a nearby lightning strike

The shielding factor SF of the grid-like spatial shields for a plane wave is given in Table A.2 below.

Table A.2 – Magnetic attenuation of grid-like spatial shields for a plane wave

Material	SF (dB) (see Notes 1 and 2)	
	25 kHz (valid for the first stroke)	1 MHz (valid for subsequent strokes)
Copper or aluminium	$20 \cdot \log(8{,}5/w)$	$20 \cdot \log(8{,}5/w)$
Steel (see Note 3)	$20 \cdot \log \left\{ \left[8{,}5/w \right] / \sqrt{1 + 18 \cdot 10^{-6}/r^2} \right\}$	$20 \cdot \log(8{,}5/w)$
w mesh width of the grid-like shield (m). r radius of a rod of the grid-like shield (m).		
NOTE 1 SF = 0 in case of negative results of the formulae. NOTE 2 SF increases by 6 dB, if a meshed bonding network according to 5.2 is installed. NOTE 3 Permeability $\mu_r \approx 200$.		

The incident magnetic field H_0 is calculated using:

$$H_0 = i_0 / (2\pi \cdot s_a) \qquad \text{(A/m)} \qquad \text{(A.5)}$$

where

i_0 is the lightning current in LPZ 0_A in amps;

s_a is the distance between the point of strike and the centre of the shielded volume, in metres.

From this follows for the maximum value of the magnetic field in LPZ 0:

- caused by the first stroke: $H_{0/f/max} = i_{f/max} / (2 \cdot \pi \cdot s_a)$ (A/m) (A.6)
- caused by the subsequent strokes: $H_{0/s/max} = i_{s/max} / (2 \cdot \pi \cdot s_a)$ (A/m) (A.7)

where

$i_{f/max}$ is the maximum value of the lightning current of the first stroke according to the chosen protection level, in amps;

$i_{s/max}$ is the maximum value of the lightning current of the subsequent strokes according to the chosen protection level, in amps.

The reduction of H_0 to H_1 inside LPZ 1 can be derived using the SF values given in Table A.2:

$$H_{1/max} = H_{0/max} \ / \ 10^{SF/20} \qquad \text{(A/m)} \qquad \text{(A.8)}$$

where

SF (dB) is the shielding factor evaluated from the formulae of Table A.2;

$H_{0/max}$ is the magnetic field in LPZ 0, in A/m.

From this follows for the maximum value of the magnetic field in LPZ 1:

caused by the first stroke: $H_{1/f/max} = H_{0/f/max} / 10^{SF/20}$ (A/m) (A.9)

caused by the subsequent strokes: $H_{1/s/max} = H_{0/s/max} / 10^{SF/20}$ (A/m) (A.10)

These magnetic field values are valid only for a safety volume V_s inside the grid-like shield with a safety distance $d_{s/2}$ from the shield (see Figure A.4):

$$d_{s/2} = w \cdot SF / 10 \quad \text{(m) for } SF \geq 10 \tag{A.11}$$

$$d_{s/2} = w \quad \text{(m) for } SF < 10 \tag{A.12}$$

where

SF is the shielding factor evaluated from the formulae of Table A.2, in decibels;

w is the mesh width of the grid-like shield, in metres.

For additional information concerning the calculation of the magnetic field strength inside grid-like shields in case of nearby lightning strikes, see A.3.3.

EXAMPLES

The magnetic field strength $H_{1/max}$ inside LPZ 1 in the case of a nearby lightning strike depends on: the lightning current $i_{0/max}$, the shielding factor SF of the shield of LPZ 1 and the distance s_a between the lightning channel and the centre of LPZ 1 (see Figure A.8).

The lightning current $i_{0/max}$ depends on the LPL chosen (see IEC 62305-1). The shielding factor SF (see Table A.2) is mainly a function of the mesh width of the grid-like shield. The distance s_a is either:

- a given distance between the centre of LPZ 1 and an object nearby (e.g. a mast) in case of a lightning strike to this object, or
- the minimum distance between the centre of LPZ 1 and the lightning channel in case of a lightning strike to ground near LPZ 1.

The worst-case condition then is the highest current $i_{0/max}$ combined with the closest distance s_a possible. As shown in Figure A.9, this minimum distance s_a is a function of height H and length L (respectively width W) of the structure (LPZ 1), and of the rolling sphere radius r corresponding to $i_{0/max}$ (see Table A.3), defined from the electro-geometric model (see IEC 62305-1, Clause A.4).

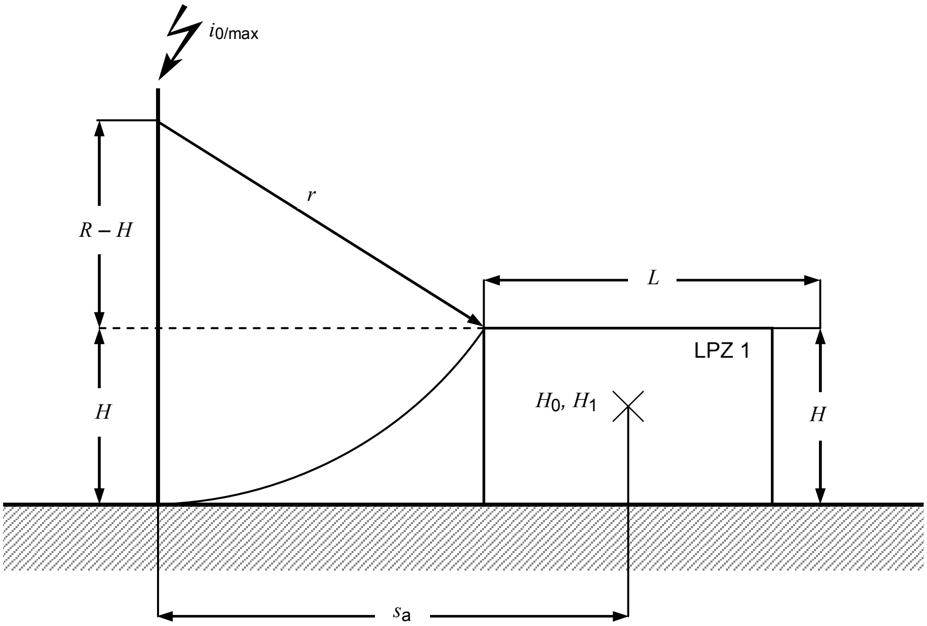


Figure A.9 – Distance s_a depending on rolling sphere radius and structure dimensions

The distance can be calculated as:

$$s_a = \sqrt{2 \cdot R \cdot H - H^2} + L/2 \quad \text{for } H < R \tag{A.13}$$

$$s_a = R + L/2 \quad \text{for } H \geq R \tag{A.14}$$

NOTE For distances smaller than this minimum value the lightning strikes the structure directly.

Three typical shields may be defined, having the dimensions given in Table A.4. A grid-like shield of copper with an average mesh width of w = 2 m is assumed. This results in a shielding factor SF = 12,6 dB and in a safety distance $d_{s/2}$ = 2,5 m defining the safety volume V_s. The values for $H_{0/max}$ and $H_{1/max}$ which are assumed to be valid everywhere inside V_s, are calculated for $i_{0/max}$ = 100 kA and shown in Table A.4.

Table A.3 – Rolling sphere radius corresponding to maximum lightning current

Protection level	Maximum lightning current $i_{0/max}$ kA	Rolling sphere radius r m
I	200	313
II	150	260
III – IV	100	200

Table A.4 – Examples for $i_{0/max}$ = 100 kA and w = 2 m corresponding to SF = 12,6 dB

Type of shield (see Figure A.10)	$L \times W \times H$ m	S_a m	$H_{0/max}$ A/m	$H_{1/max}$ A/m
1	10 x 10 x 10	67	236	56
2	50 x 50 x 10	87	182	43
3	10 x 10 x 50	137	116	27

A.3.1.3 Grid-like spatial shields for LPZ 2 and higher

In the grid-like shields of LPZ 2 and higher, no significant partial lightning currents will flow. Therefore, as a first approach, the reduction of H_n to H_{n+1} inside LPZ n+1 can be evaluated as given by A.3.1.2 for nearby lightning strikes:

$$H_{n+1} = H_n \ / \ 10^{SF/20} \quad \text{(A/m)} \qquad \text{(A.15)}$$

where

SF is the shielding factor from Table A.2, in decibels;

H_n is the magnetic field inside LPZ n, in amperes per metre.

If $H_n = H_1$ this field strength can be evaluated as follows:

– In the case of lightning strikes direct to the grid-like shield of LPZ 1, see A.3.1.1 and Figure A.7b, while d_w and d_r are the distances between the shield of LPZ 2 and the wall respectively the roof.

– In the case of lightning strikes nearby LPZ 1, see A.3.1.2 and Figure A.8.

These magnetic field values are valid only for a safety volume V_s inside the grid-like shield with a safety distance $d_{s/2}$ from the shield as defined in A.3.1.2 (see Figure A.4).

A.3.2 Theoretical evaluation of the magnetic field due to direct lightning strikes

In A.3.1.1, the formulas for the assessment of the magnetic field strength $H_{1/max}$ are based on numerical magnetic field calculations for three typical grid-like shields as shown in Figure A.10. For these calculations, a lightning strike to one of the edges of the roof is assumed. The lightning channel is simulated by a vertical conducting rod with a length of 100 m on top of the roof. An idealized conducting plate simulates the ground plane.

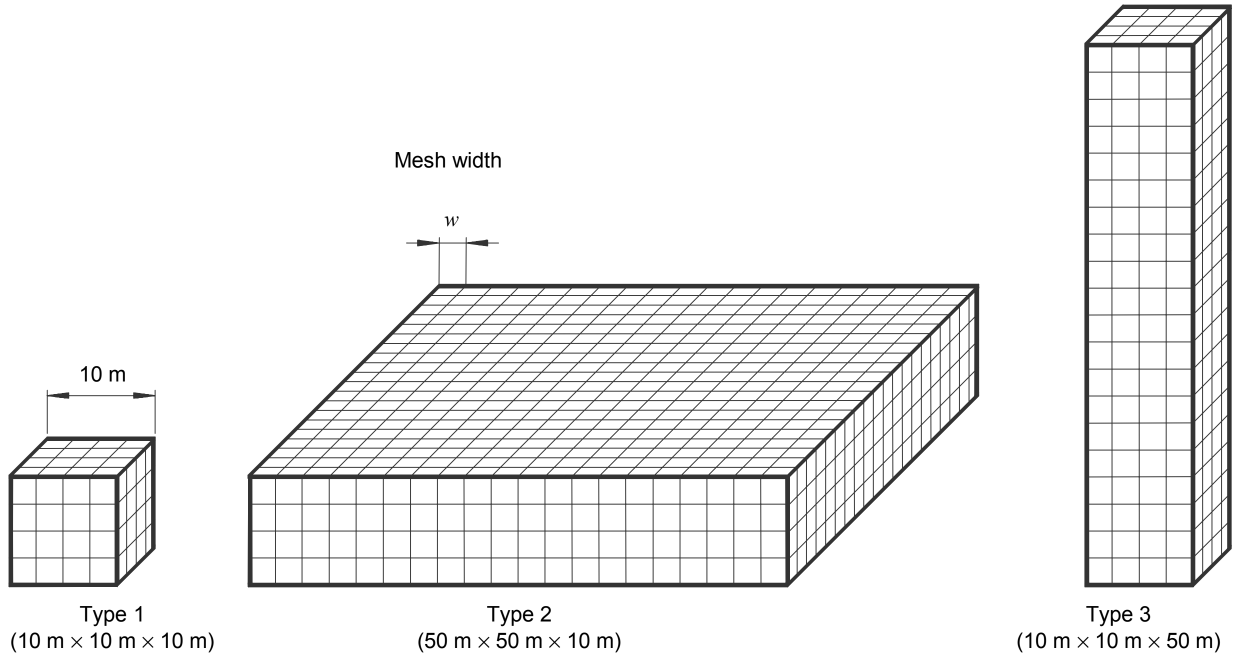


Figure A.10 – Types of grid-like large volume shields

In the calculation, the magnetic field coupling of every rod within the grid-like shield including all other rods and the simulated lightning channel, is considered and results in a set of equations to calculate the lightning current distribution in the grid. From this current distribution, the magnetic field strength inside the shield is derived. It is assumed that the resistance of the rods can be neglected. Therefore, the current distribution in the grid-like shield and the magnetic field strength are independent of the frequency. Also, capacitive coupling is neglected to avoid transient effects.

For the case of a Type 1 shield (see Figure A.10), some results are presented in Figures A.11 and A.12.

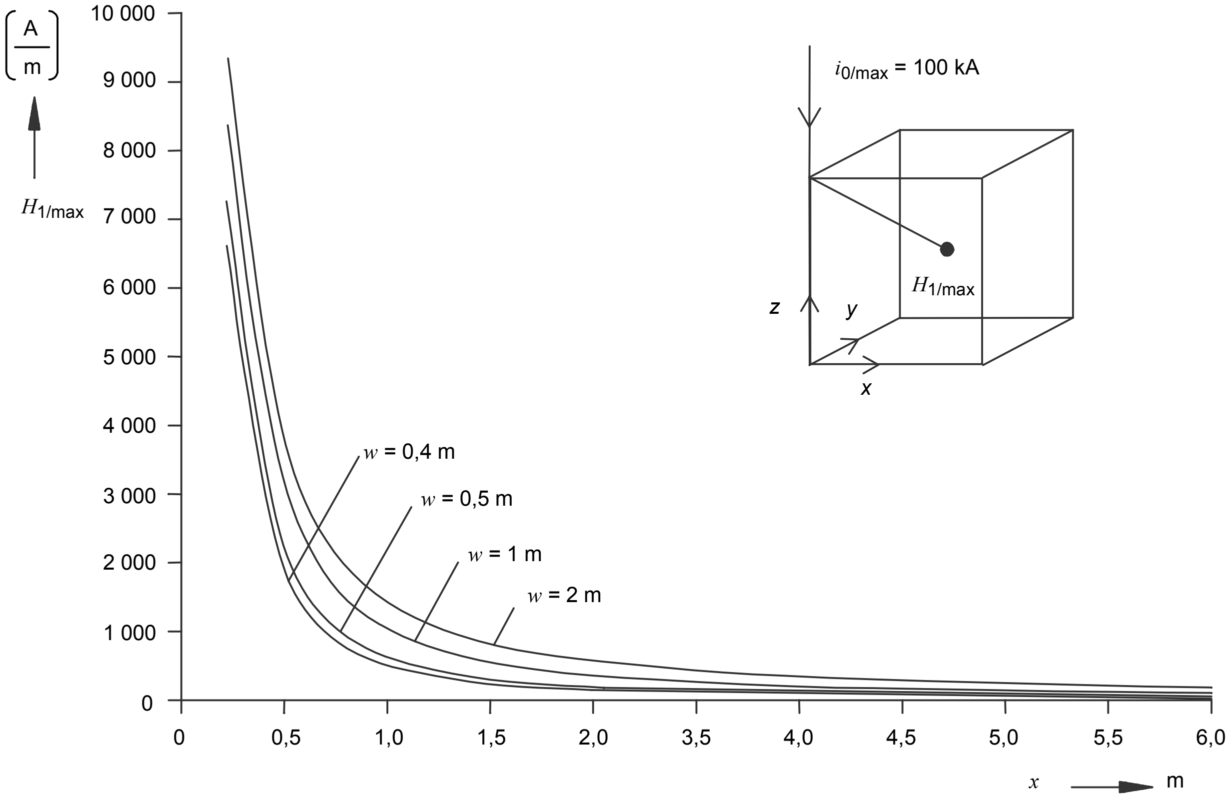


Figure A.11 – Magnetic field strength $H_{1/max}$ inside a grid-like shield Type 1

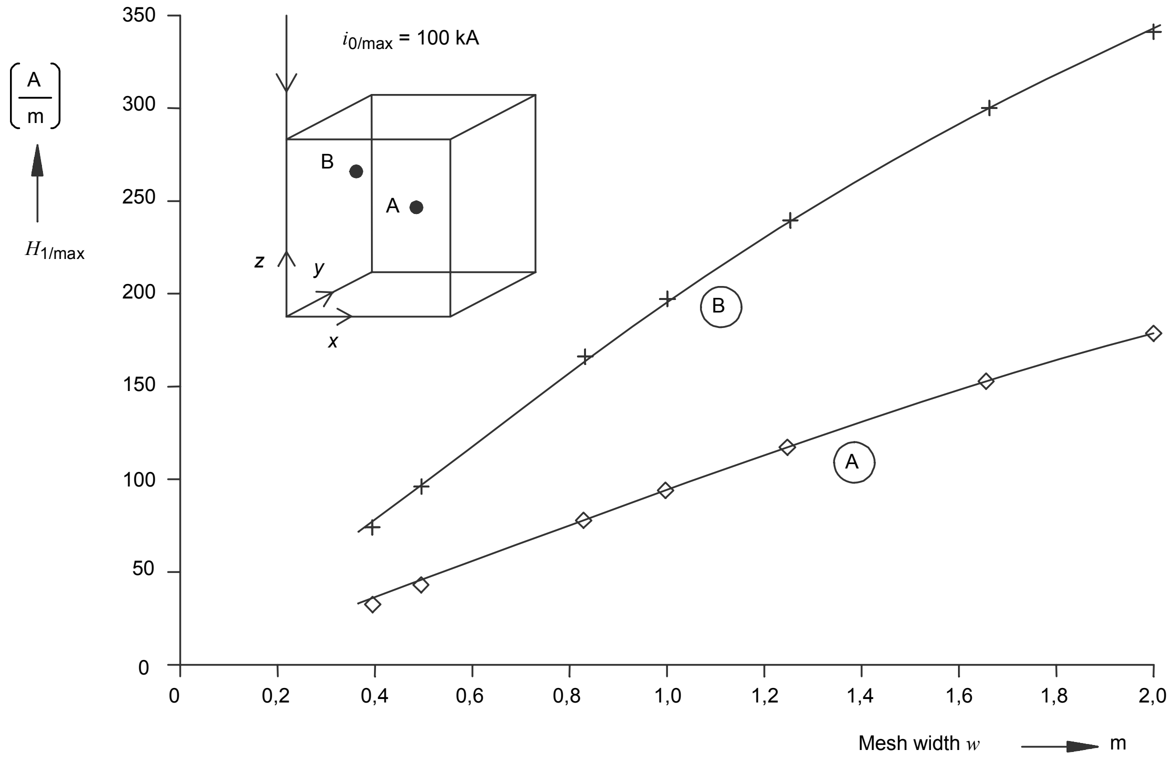


Figure A.12 – Magnetic field strength $H_{1/max}$ inside a grid-like shield Type 1

In all cases a maximum lightning current $i_{o/max}$ = 100 kA is assumed. In both figures $H_{1/max}$ is the maximum magnetic field strength at a point, derived from its components H_x, H_y and H_z:

$$H_{1/max} = \sqrt{H_x^2 + H_y^2 + H_z^2} \qquad \text{(A.16)}$$

In Figure A.11 $H_{1/max}$ is calculated along a straight line starting from the point of strike ($x = y = 0$, z = 10 m) and ending at the centre of the volume ($x = y$ = 5 m, z = 5 m).). $H_{1/max}$ is plotted as a function of the x-coordinate for each point on this line, where the parameter is the mesh width w of the grid-like shield.

In Figure A.12 $H_{1/max}$ is calculated for two points inside the shield (point A: $x = y$ = 5 m, z = 5 m; point B: $x = y$ = 7 m, z = 7 m). The result is plotted as a function of the mesh width w.

Both figures show the effects of the main parameters governing the magnetic field distribution inside a grid-like shield: the distance from the wall or roof, and the mesh width.

In Figure A.11 it should be observed that along other lines through the volume of the shield, there may be zero-axis crossings and sign changes of the components of the magnetic field strength $H_{1/max}$. The formulas in A.3.1.1 are therefore first-order approximations of the real, and more complicated, magnetic field distribution inside a grid-like shield.

A.3.3 Experimental evaluation of the magnetic field due to a direct lightning strike

The magnetic fields inside shielded structures can also be determined by taking experimental measurements. Figure A.13 shows a proposal for the simulation of a direct lightning strike to an arbitrary point of a shielded structure, using a lightning current generator. Normally, such tests can be carried out as low current level tests but where the waveshape of the simulated lightning current is identical to the actual lightning discharge.

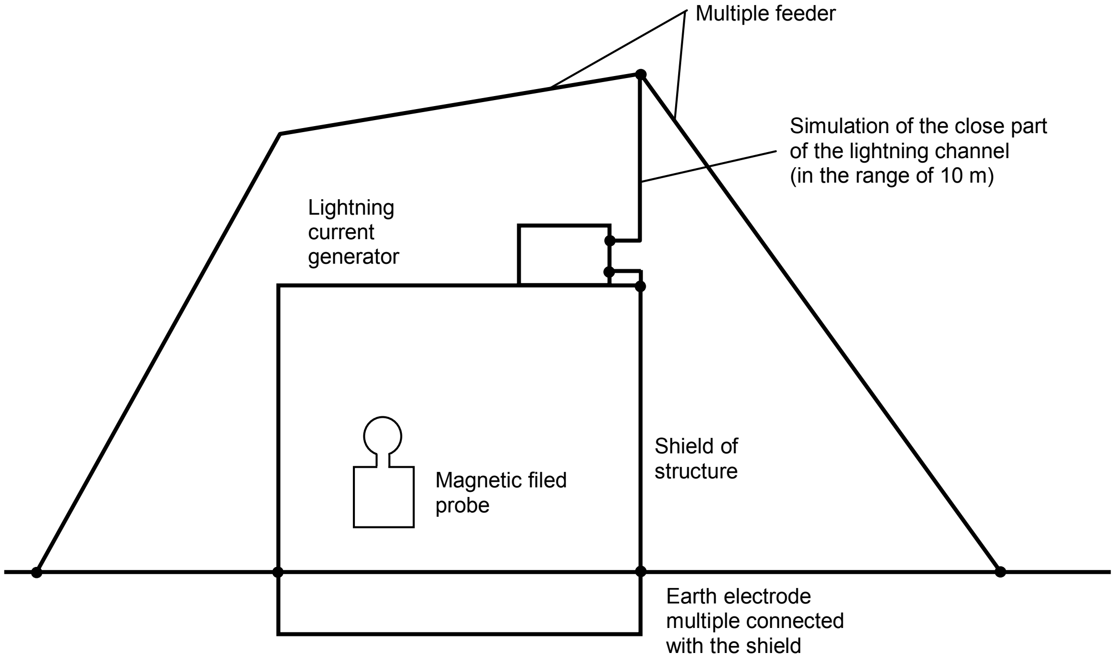
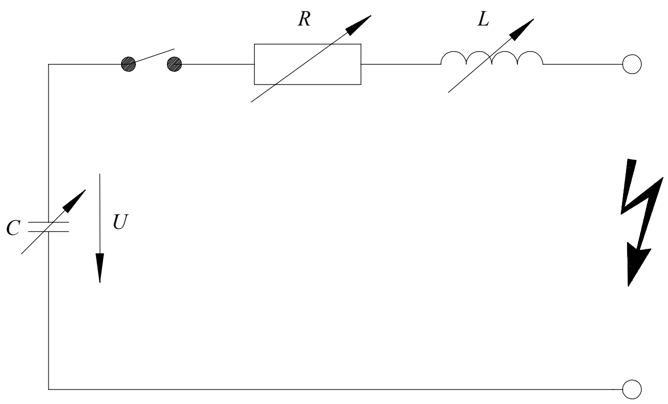


Figure A.13a – Test arrangement



Key

U typical some 10 kV

C typical some 10 nF

Figure A.13b – Lightning current generator

Figure A.13 – Low-level test to evaluate the magnetic field inside a shielded structure

A.4 Calculation of induced voltages and currents

Only rectangular loops according to Figure A.14 are considered. Loops with other shapes should be transformed into rectangular configurations having the same loop area.

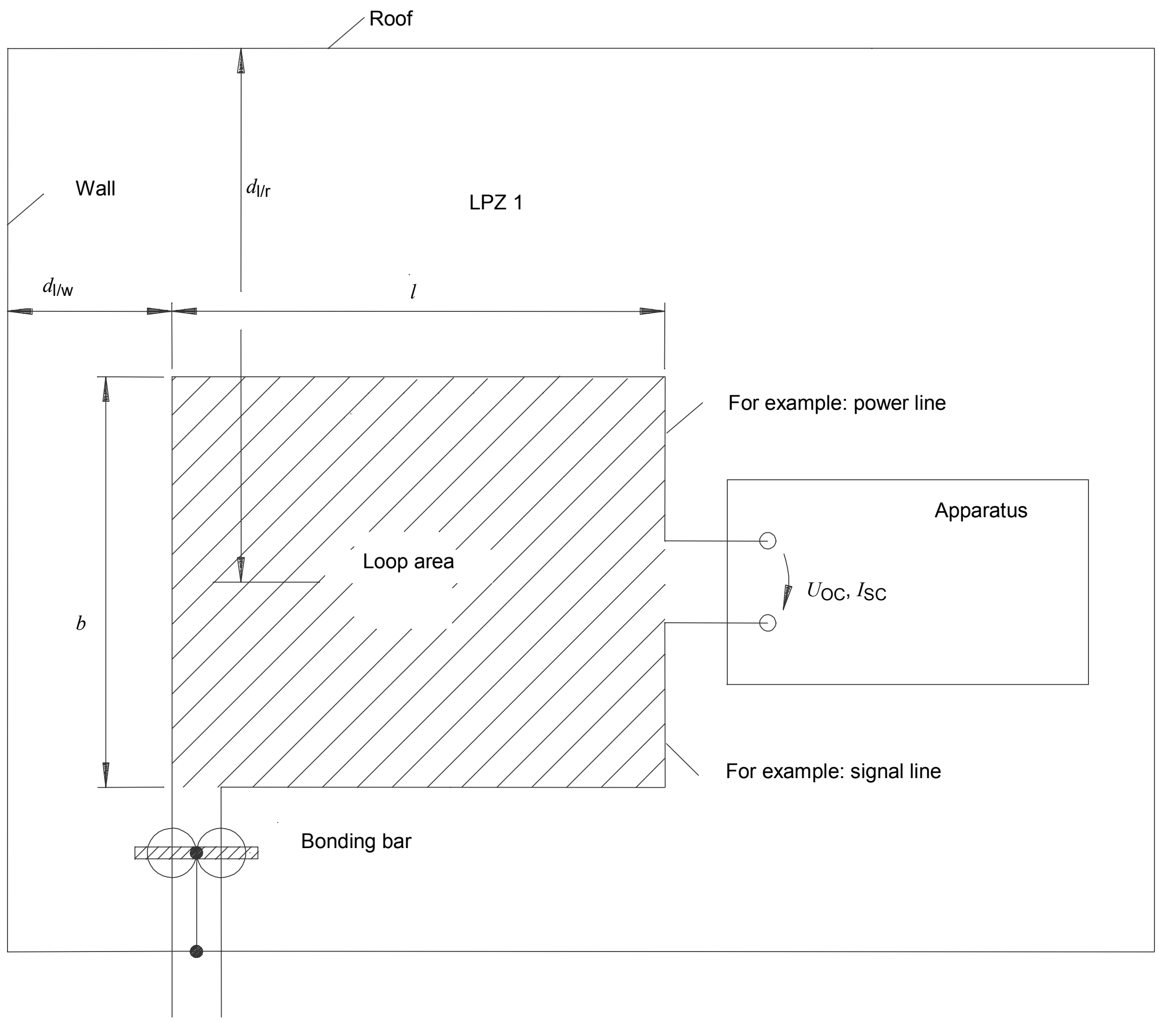


Figure A.14 – Voltages and currents induced into a loop built by lines

A.4.1 Situation inside LPZ 1 in the case of a direct lightning strike

For the magnetic field H_1 inside the volume V_s of an LPZ 1, the following applies (see A.3.1.1):

$$H_1 = k_H \cdot I_0 \cdot w / (d_w \cdot \sqrt{d_r}) \text{ (A/m)} \tag{A.17}$$

The open circuit voltage u_{oc} is given by:

$$u_{oc} = \mu_o \cdot b \cdot l_n(1 + l/d_{l/w}) \cdot k_H \cdot (w / \sqrt{d_{l/r}}) \cdot di_0 / dt \text{ (V)} \tag{A.18}$$

The peak value $u_{oc/max}$ occurs during the front time T_1

$$u_{oc/max} = \mu_o \cdot b\ l_n(1 + l/d_{l/w}) \cdot k_H \cdot (w/\sqrt{d_{l/r}}) \cdot i_{o/max} / T_1 \quad \text{(V)} \qquad \text{(A.19)}$$

where

μ_o is equal to $4\pi\ 10^{-7}$ (Vs)/(Am);

b is the width of the loop in (m);

$d_{l/w}$ is the distance of the loop from the wall of the shield, where $d_{l/w} \geq d_{s/1}$, in (m);

$d_{l/r}$ is the average distance of the loop from the roof of the shield, in (m);

i_0 is the lightning current in LPZ 0_A in (A);

$i_{o/max}$ is the maximum value of the lightning current stroke in LPZ 0_A, in (A);

k_H $(1/\sqrt{m})$ is the configuration factor $k_H = 0{,}01 \cdot (1/\sqrt{m})$;

l is the length of the loop, in (m);

T_1 is the front time of the lightning current stroke in LPZ 0_A in (s);

w is the mesh width of the grid-like shield, (m).

The short circuit current i_{sc} is given by:

$$i_{sc} = \mu_o \cdot b \cdot l_n(1 + l/d_{l/w}) \cdot k_H \cdot (w/\sqrt{d_{l/r}}) \cdot i_0 / L \quad \text{(A)} \qquad \text{(A.20)}$$

where the ohmic resistance of the wire is neglected (worst case).

The maximum value $i_{sc/max}$ is given by:

$$i_{sc/max} = \mu_o \cdot b\ l_n(1 + l/d_{l/w}) \cdot k_H \cdot (w/\sqrt{d_{l/r}}) \cdot i_{o/max} / L \quad \text{(A)} \qquad \text{(A.21)}$$

where L is the self-inductance of the loop, in (H).

For rectangular loops, the self-inductance L can be calculated from:

$$L = \Big\{0{,}8 \cdot \sqrt{l^2 + b^2} - 0{,}8 \cdot (l + b) + 0{,}4 \cdot l \cdot ln\left((2b/r) \Big/ \left(1 + \sqrt{1 + (b/l)^2}\right)\right)$$

$$+ 0{,}4 \cdot b \cdot l_n\left((2l/r) \Big/ \left(1 + \sqrt{1 + (l/b)^2}\right)\right)\Big\} \cdot 10^{-6} \quad \text{(H)} \qquad \text{(A.22)}$$

where r is the radius of the wire, in (m).

The voltage and current induced by the magnetic field of the first stroke (T_1 = 10 µs) is given by:

$$u_{oc/f/max} = 1{,}26 \cdot b \cdot l_n(1 + l/d_{l/w}) \cdot (w/\sqrt{d_{l/r}}) \cdot i_{f/max} \quad \text{(V)} \qquad \text{(A.23)}$$

$$i_{SC/f/max} = 12{,}6 \cdot 10^{-6} \cdot b \cdot l_n(1 + l/d_{l/w}) \cdot (w/\sqrt{d_{l/r}}) \cdot i_{f/max} / L \quad \text{(A)} \qquad \text{(A.24)}$$

The voltage and current induced by the magnetic field of the subsequent strokes (T_1 = 0,25 µs) is given by:

$$u_{oc/s/max} = 50{,}4 \cdot b \cdot l_n (1 + l/d_{l/w}) \cdot (w / \sqrt{d_{l/r}}) \cdot i_{f/max} \quad \text{(V)} \qquad \text{(A.25)}$$

$$i_{sc/s/max} = 12{,}6 \; 10^{-6} \cdot b \cdot l_n (1 + l/d_{l/w}) \cdot (w / \sqrt{d_{l/r}}) \cdot i_{s/max} / L \quad \text{(A)} \qquad \text{(A.26)}$$

where

$i_{f/max}$ is the maximum value of the current of the first stroke in (kA);

$i_{s/max}$ is the maximum value of the current of the subsequent strokes in (kA).

A.4.2 Situation inside LPZ 1 in the case of a nearby lightning strike

The magnetic field H_1 inside volume V_s of LPZ 1 is assumed to be homogeneous (see A.3.1.2).

The open circuit voltage u_{oc} is given by:

$$u_{oc} = \mu_o \cdot b \cdot l \cdot dH_1 / dt \quad \text{(V)} \qquad \text{(A.27)}$$

The peak value $u_{oc/max}$ occurs during the front time T_1:

$$u_{oc/max} = \mu_o \cdot b \cdot l \cdot H_{1/max} / T_1 \quad \text{(V)} \qquad \text{(A.28)}$$

where

μ_o	is equal to 4π 10^{-7} (Vs)/(Am);
b	width of the loop, in (m);
H_1	time dependent magnetic field inside LPZ 1, in (A/m);
$H_{1/max}$	maximum value of the magnetic field inside LPZ 1 in (A/m);
l	length of the loop, in (m);
T_1	front time of the magnetic field, identical with the front time of the lightning current stroke, in (s).

The short circuit current i_{sc} is given by:

$$i_{sc} = \mu_o \cdot b \cdot l \cdot H_1 / L \quad \text{(A)} \qquad \text{(A.29)}$$

where the ohmic resistance of the wire is neglected (worst case).

The maximum value $i_{sc/max}$, is given by:

$$i_{sc/max} = \mu_o \cdot b \cdot l \cdot H_{1/max} / L \quad \text{(A)} \qquad \text{(A.30)}$$

where L is the self-inductance of the loop in (H) (for the calculation of L, see A.4.1).

The voltage and current induced by the magnetic field $H_{1/f}$ of the first stroke (T_1 = 10 µs) is given by:

$$u_{oc/f/max} = 0{,}126 \cdot b \cdot l \cdot H_{1/f/max} \quad \text{(V)} \qquad \text{(A.31)}$$

$$i_{sc/f/max} = 1{,}26 \; 10^{-6} \cdot b \cdot l \cdot H_{1/f/max} / L \quad \text{(A)} \qquad \text{(A.32)}$$

The voltage and current induced by the magnetic field $H_{1/s}$ of the subsequent strokes (T_1 = 0,25 µs) is given by:

$$u_{oc/s/max} = 5{,}04 \cdot b \cdot l \cdot H_{1/s/max} \quad \text{(V)} \qquad \text{(A.33)}$$

$$i_{sc/s/max} = 1{,}26 \cdot 10^{-6} \cdot b \cdot l \cdot H_{1/s/max} / L \quad \text{(A)} \qquad \text{(A.34)}$$

where

$H_{1/f/max}$ is the maximum of the magnetic field inside LPZ 1 due to the first stroke in (A/m) ;

$H_{1/s/max}$ maximum of the magnetic field inside LPZ 1 due to the subsequent strokes in (A/m).

A.4.3 Situation inside LPZ 2 and higher

The magnetic field H_n inside LPZ n for n ≥ 2 is assumed to be homogeneous (see A.3.1.3).

Therefore the same formulae for the calculation of induced voltages and currents apply (A.3.1.2), where H_1 is substituted by H_n.

Annex B
(informative)

Implementation of LEMP protection measures for electronic systems in existing structures

B.1 Checklist

In existing structures suitable protection measures against lightning effects need to take into account the given construction and conditions of the structure and the existing electrical and electronic systems.

A checklist facilitates risk analysis and selection of the most suitable protection measures.

For existing structures in particular, a systematic layout should be established for the zoning concept and for earthing, bonding, line routing and shielding.

The checklist given in Tables B.1 to B.4 should be used to collect the required data of the existing structure and its installations. Based on this data, a risk assessment according to IEC 62305-2 shall be performed to determine the need for protection and, if so, to identify the most cost-effective protection measures to be used.

NOTE 1 For further information on protection against electromagnetic interferences (EMI) in building installations, see IEC 60364-4-44.

Table B.1 – Structural characteristics and surroundings

Item	Question
1	Masonry, bricks, wood, reinforced concrete, steel frame structures, metal facade?
2	One single structure or interconnected blocks with expansion joints?
3	Flat and low or high-rise structures? (dimensions of the structure)
4	Reinforcing rods electrically connected throughout the structure?
5	Kind, type and quality of metallic roof material?
6	Metal facades bonded?
7	Metal frames of the windows bonded?
8	Size of the windows?
9	Structure equipped with an external LPS?
10	Type and quality of this LPS?
11	Material of ground (rock, soil)?
12	Height, distance and earthing of adjacent structures?
NOTE For detailed information see IEC 62305-2.	

Table B.2 – Installation characteristics

Item	Question
1	Type of incoming services (underground or overhead)?
2	Type of aerials (antennas or other external devices)?
3	Type of power supply (high voltage, low voltage, overhead or underground)?
4	Line routing (number and location of risers, cable ducts)?
5	Use of metal cable ducts?
6	Are the electronics self-contained within the structure?
7	Metal conductors to other structures?
NOTE For detailed information see IEC 62305-2.	

Table B.3 – Equipment characteristics

Item	Question
1	Type of electronic system interconnections (shielded or unshielded multicore cables, coaxial cable, analog and/or digital, balanced or unbalanced, fibre optic cables)? (see Note 1)
2	Withstand level of the electronic system specified? (see Notes 1 and 2)
NOTE 1 For detailed information see IEC 62305-2. NOTE 2 For detailed information see ITU-T K.21, IEC 61000-4-5, IEC 61000-4-9 and IEC 61000-4-10.	

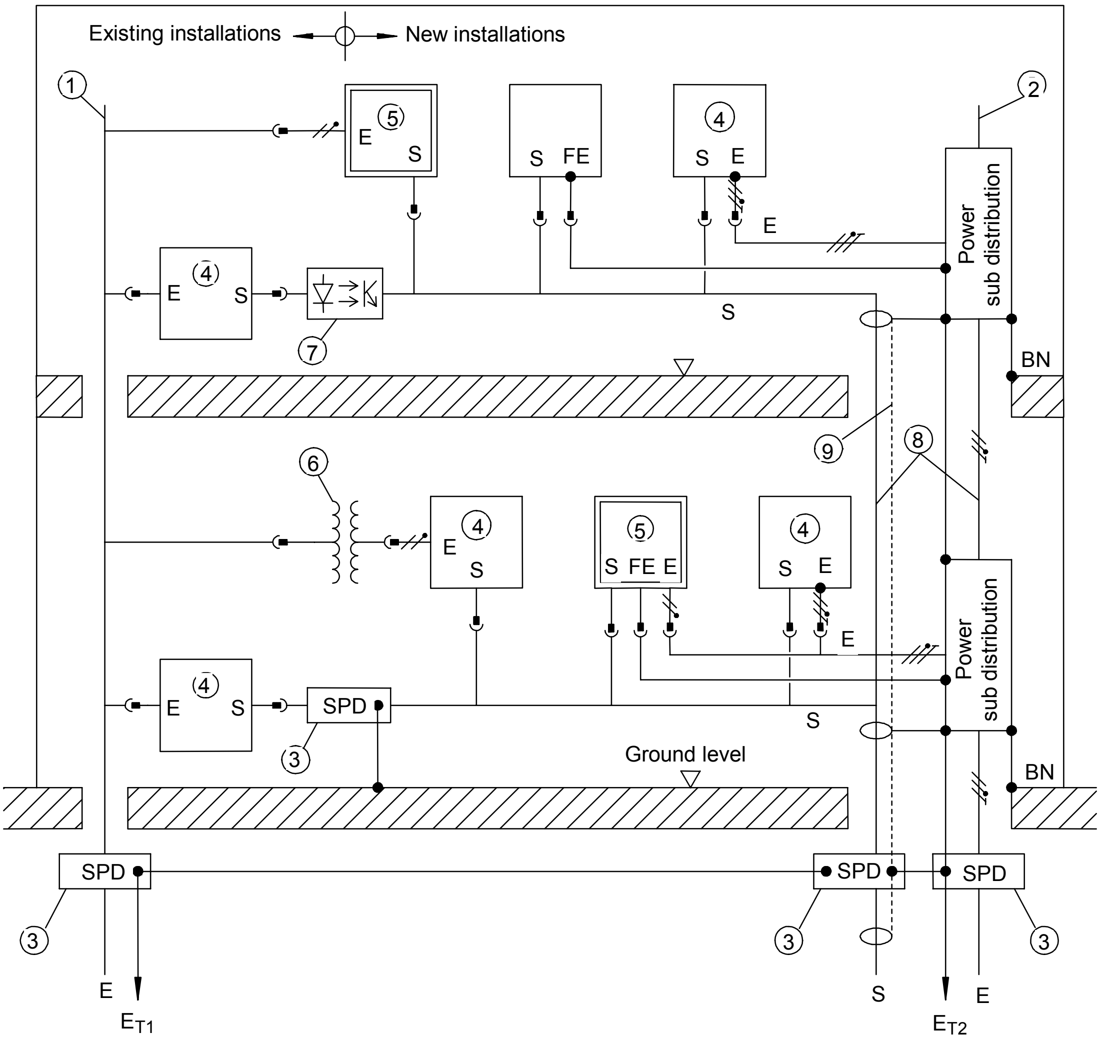
Table B.4 – Other questions to be considered for the protection concept

Item	Question
1	Configuration TN (TN-S or TN-C), TT or IT?
2	Location of the electronic equipment? (see Note)
3	Interconnections of functional earthing conductors of the electronic system with the bonding network?
NOTE For detailed information see Annex A.	

B.2 Integration of new electronic systems into existing structures

When adding new electronic systems to an existing structure, the existing installation might restrict the protection measures that can be employed.

Figure B.1 shows an example where an existing installation, shown on the left, is interconnected to a new installation, shown on the right. The existing installation has restrictions on the protection measures that can be employed. However design and planning of the new installation can allow for all necessary protection measures to be adopted.



Key

1	existing mains (TN-C,TT,IT)	E	electrical lines
2	new mains (TN-S,TN-CS,TT,IT)	S	signal lines (shielded or unshielded)
3	surge protective device (SPD)	ET	earth termination system
4	Class I standard isolation	BN	bonding network
5	Class II double isolation without PE	PE	protective earthing conductor
6	isolation transformer	FE	functional earthing conductor (if any)
7	opto-coupler or fibre optic cable	///T	3-wire electrical line: L, N, PE
8	adjacent routing of electrical and signal lines	//	2-wire electrical line: L, N
9	shielded cable ducts	•	bonding points (PE, FE, BN)

Figure B.1 – Upgrading of LEMP protection measures and electromagnetic compatibility in existing structures

B.2.1 Overview of possible protection measures

B.2.1.1 Power supply

Existing mains supply (see Figure B.1, no.1) in the structure is very often of the type TN-C, which can cause power frequency interference. Such interference can be avoided by isolating interfaces (see below).

If a new mains supply (see Figure B.1, no.2) is installed, type TN-S is strongly recommended.

B.2.1.2 Surge protective devices

To control conducted surges on lines, SPDs shall be installed at the entry into any LPZ and possibly at the equipment to be protected (see Figure B.1, no.3 and Figure B.2).

B.2.1.3 Isolating interfaces

To avoid interferences, isolating interfaces between existing and new equipment can be used: Class II isolated equipment (see Figure B.1, no.5), isolation transformers (see Figure B.1, no.6), fibre optic cables or optical couplers (see Figure B.1, no.7).

B.2.1.4 Line routing and shielding

Large loops in line routing might lead to very high induced voltages or currents. These can be avoided by routing electrical and signal lines adjacent to each other (see Figure B.1, no.8), thereby minimizing the loop area. It is recommended to use shielded signal lines. For extended structures, additional shielding, for example by bonded metal cable ducts (see Figure B.1. no.9), is also recommended. All these shields shall be bonded at both ends.

Line routing and shielding measures become more important the smaller the shielding effectiveness of the spatial shield of LPZ 1, and the larger the loop area.

B.2.1.5 Spatial shielding

Spatial shielding of LPZ against lightning magnetic fields requires mesh widths typical less than 5 m.

An LPZ 1 created by a normal external LPS according to IEC 62305-3 (air-termination, down-conductor and earth-termination system) has mesh widths and typical distances greater than 5 m, resulting in negligible shielding effects. If higher shielding effectiveness is required, the external LPS shall be upgraded (see Clause B.7).

LPZ 1 and higher may require spatial shielding to protect electronic systems not complying with radiated radio frequency emission and immunity requirements.

B.2.1.6 Bonding

Equipotential bonding for lightning currents with frequencies up to several MHz requires a meshed low impedance bonding network having a typical mesh width of 5 m. All services entering a LPZ shall be bonded directly, or via suitable SPD, as close as possible to the boundary of the LPZ.

If, in existing structures, these conditions cannot be fulfilled, other suitable protective measures shall be provided.

B.2.2 Establishment of LPZ for electrical and electronic systems

Depending on the number, type and sensitivity of the electrical and electronic systems, suitable inner LPZ are defined, from small local zones (the enclosure of a single electronic equipment), up to large integral zones (the whole building volume).

Figure B.2 shows typical LPZ layout for the protection of electronic systems providing different solutions suitable, in particular for existing structures:

Figure B.2a shows the installation of a single LPZ 1, creating a protected volume inside the whole structure, e.g. for enhanced withstand voltage levels of the electronic systems:

- This LPZ 1 could be created using an LPS, according to IEC 62305-3, which consists of an external LPS (air-termination, down-conductor and earth-termination system) and an internal LPS (lightning equipotential bonding and compliance of the separation distances).
- The external LPS protects LPZ 1 against lightning flashes to the structure, but the magnetic field inside LPZ 1 remains nearly unattenuated. This is because air terminations and down-conductors have mesh widths and typical distances greater than 5 m, therefore the spatial shielding effect is negligible as explained above. If the risk R_D of lightning flashes to the structure is very low, the external LPS may be omitted.
- The internal LPS requires bonding of all services entering the structure at the boundary of LPZ 1, which includes the installation of tested with I_{imp} SPDs for all electrical and signal lines. This ensures that the conducted surges on the incoming services are limited at the entrance by SPDs.

NOTE Isolating interfaces could be useful inside LPZ 1 in order to avoid low-frequency interference.

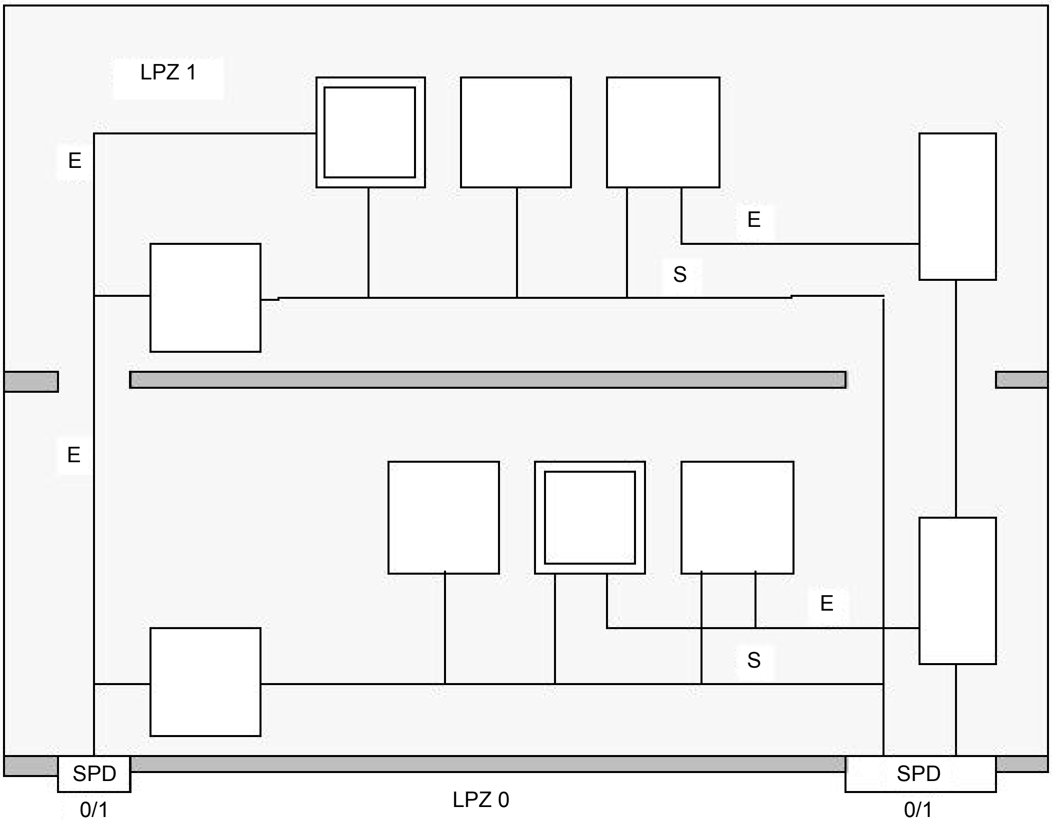


Figure B.2a – Unshielded LPZ 1 using LPS and SPDs at the entrance of the lines into the structure (e.g. for enhanced withstand voltage level of the systems or for small loops inside the structure)

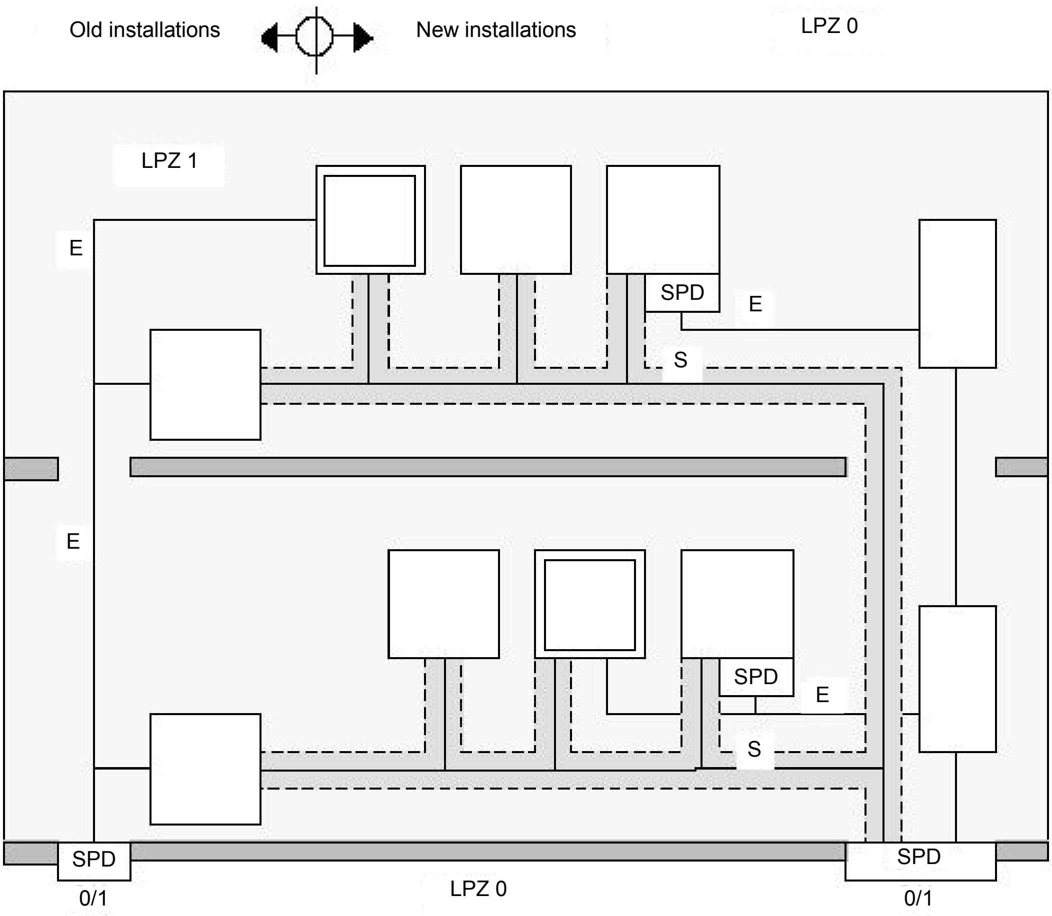


Figure B.2b – Unshielded LPZ 1 with protection for new electronic systems using shielded signal lines and coordinated SPDs in power lines

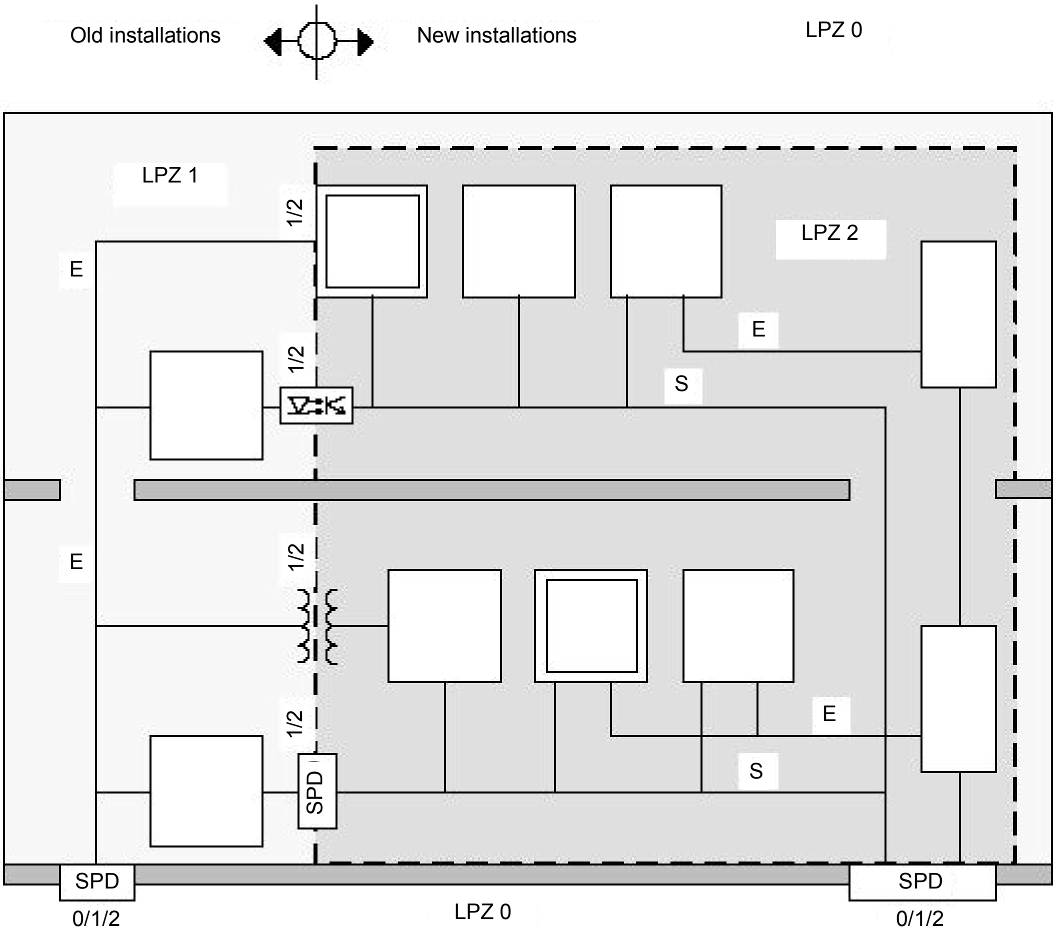


Figure B.2c – Unshielded LPZ 1 and large shielded LPZ 2 for new electronic systems

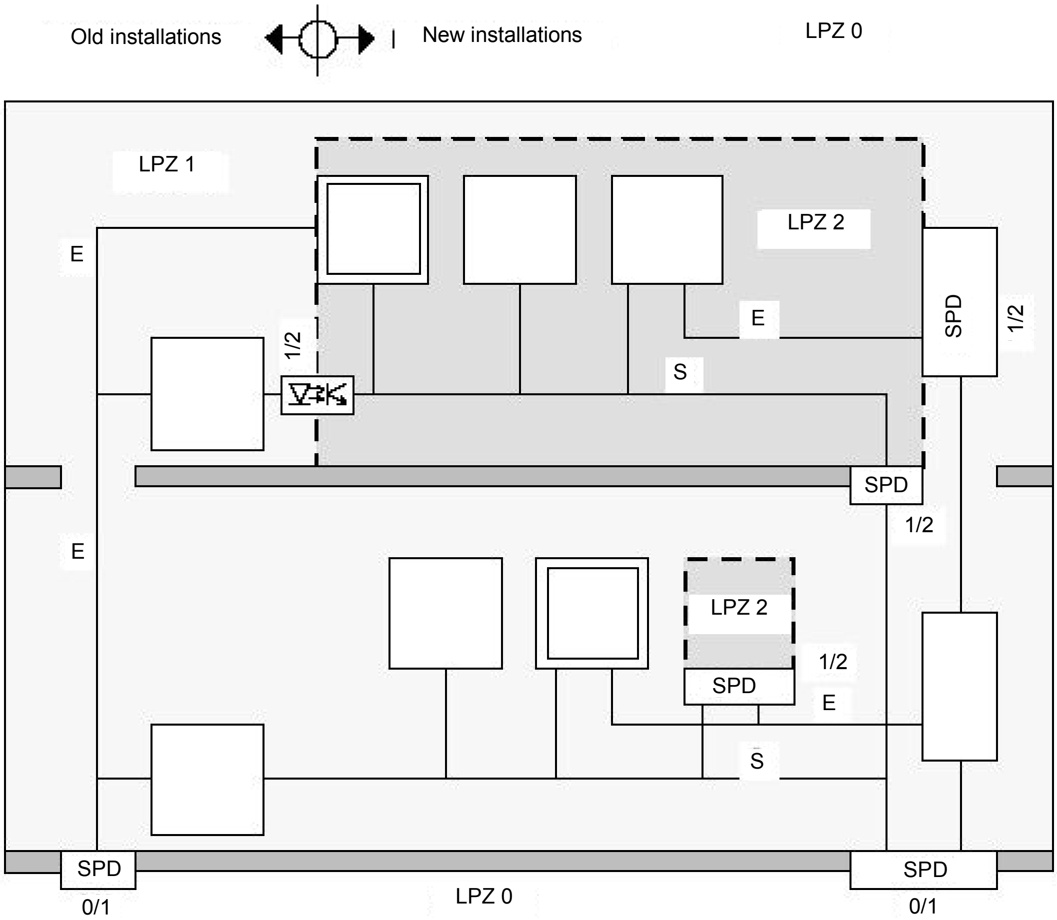


Figure B.2d – Unshielded LPZ 1 and two local LPZ 2 for new electronic systems

Figure B.2 – Possibilities to establish LPZs in existing structures

Figure B.2b shows that in an unshielded LPZ 1, new apparatus also needs to be protected against conducted surges. As an example, the signal lines can be protected using shielded cables and the power lines using a coordinated SPD protection. This may require additional SPDs tested with I_n and SPDs tested with a combination wave, installed close to the equipment, and coordinated with the SPDs at service entrance. It may also require additional Class II double isolation of the equipment.

Figure B.2c shows the installation of a large integral LPZ 2 inside of LPZ 1, to accommodate the new electronic systems. The grid-like spatial shield of LPZ 2 provides a significant attenuation of the lightning magnetic field. On the left hand side, the SPDs installed at the boundary of LPZ 1 (transition LPZ 0/1) and subsequently at the boundary of LPZ 2 (transition LPZ 1/2), shall be coordinated according to Annex C. On the right hand side, the SPDs installed at the boundary of LPZ 1 shall be selected for a direct transition LPZ 0/1/2 (see C.3.4).

Figure B.2d shows the installation of two smaller LPZ 2 inside of LPZ 1. Additional SPDs for power as well as for signal lines at the boundary of each LPZ 2 shall be installed. These SPDs shall be coordinated with the SPDs at the boundary of LPZ 1 according to Annex C.

B.3 Upgrading a power supply and cable installation inside the structure

The power distribution system in older structures (see Figure B.1, no.1) is very often TN-C. Interference at 50/60 Hz arising from the connection of earthed signal lines with the PEN conductors, can be avoided by:

– isolating interfaces using Class II electrical equipment or double insulated transformers. This can be a solution if there are only few electronic equipment (see Clause B.5);
– changing the power distribution system to a TN-S (see Figure B.1 no 2). This is the recommended solution, especially for extensive systems of electronic equipment.

The requirements of earthing, bonding and line routing shall be fulfilled.

B.4 Protection by surge protective devices

To limit conducted surges on electrical lines due to lightning, SPDs shall be installed at the entry of any inner LPZ (see Figure B.1, no.3 and Figure B.2). Such SPDs shall be coordinated as detailed in Annex C.

In buildings with uncoordinated SPDs, damage to the electronic system may result if a downstream SPD, or an SPD within the equipment, prevents the proper operation of the SPD at the service entrance.

In order to maintain the effectiveness of the protection measures adopted, it is necessary to document the location of all installed SPDs.

B.5 Protection by isolating interfaces

Power frequency interference currents through the equipment and its connected signal lines can be caused by large loops or the lack of a sufficiently low impedance bonding network. To prevent such interference (mainly in TN-C installations), a suitable separation between existing and new installations can be achieved using isolating interfaces, such as:

– Class II isolated equipment (i.e. double isolation without a PE-conductor),
– isolation transformers,
– metal-free fibre optic cables,
– optical couplers.

For isolating interfaces used to avoid lightning induced overvoltages, an enhanced withstand voltage is required. A typical withstand voltage of 5 kV for a 1,2/50 waveshape is required. Protection of such interfaces against higher overvoltages, where needed, may be achieved using SPDs. The voltage protection levels U_p of these SPDs needs to be selected to be only slightly below the withstand voltage of the isolating interface. A lower U_p may violate safety requirements.

NOTE Care should be taken that metal equipment enclosures do not have an unintended galvanic connection to the bonding network or to other metal parts, but must be isolated. This is the situation in most cases, since electronic equipment installed in domestic rooms or offices is linked to the earth reference through connection cables only.

B.6 Protection measures by line routing and shielding

Suitable line routing and shielding are effective measures to reduce induced overvoltages. These measures are especially important, if the spatial shielding effectiveness of LPZ 1 is negligible. In this case, the following principles provide improved protection:

– minimizing the induction loop area;

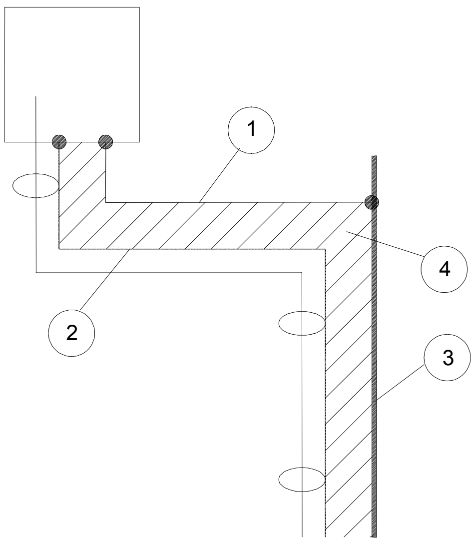
– powering new equipment from the existing mains should be avoided, because it creates a large enclosed induction loop area, which will significantly increase the risk of isolation damage. Furthermore, routing electrical and signal lines adjacent to one another can avoid large loops (see Figure B.1, no.8);

– using shielded cables – the shields of these signal lines should at least be bonded at either end.

– using metal cable ducts or bonded metal plates – the separate metal sections should be electrically well interconnected. The connections should be performed by bolting the overlapping parts or by using bonding conductors. In order to keep the impedance of the cable duct low, multiple screws or strips should be distributed over the perimeter of the cable duct (see IEC 61000-5-2).

Examples of good line routing and shielding techniques are given in Figures B.3 and B.4.

NOTE Where the distance between signal lines and electronic equipment within general areas (which are not specifically designated for electronic systems) is greater than 10 m, it is recommended to use balanced signal lines with suitable galvanic isolation ports, e.g. optical couplers, signal isolation transformers or isolation amplifiers. In addition, the use of triaxial cables can be advantageous.



Key

1 PE, only when Class I equipment is used

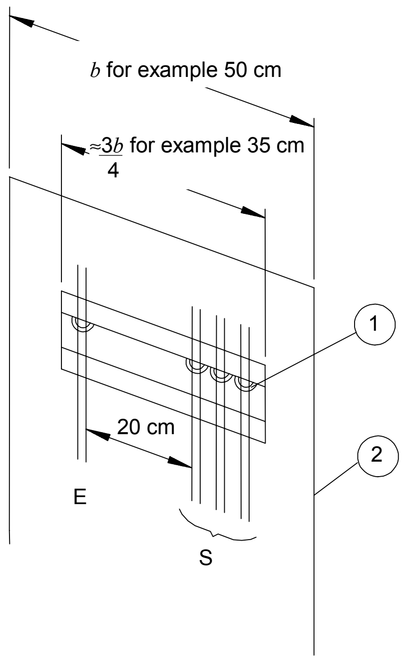
2 optional cable shield needs to be bonded at both ends

3 metal plate as additional shield (see Figure B.4)

4 small loop area

NOTE Owing to the small loop area, the induced voltage between the cable shield and the metal plate is small.

Figure B.3 – Reduction of loop area using shielded cables close to a metal plate



Key

1 cable fixing with or without bonding of cable shields to the plate

2 at edges, the magnetic field is higher than in the middle of the plate

E electrical lines

S signal lines

Figure B.4 – Example of a metal plate for additional shielding

B.7 Improvement of an existing LPS using spatial shielding of LPZ 1

An existing LPS (according to IEC 62305-3) around LPZ 1 can be improved by

– integrating existing metal facades and metal roofs into the external LPS,
– using the reinforcing bars (which are electrically continuous from the upper roof to the earth termination system) of the structure,
– reducing the spacing of the down conductors and reducing the mesh size of the air termination system to typically below 5 m,
– installation of flexible bonding conductors across the expansion joints between adjacent, but structurally separated, reinforced blocks.

B.8 Protection using a bonding network

Existing power frequency earthing systems might not provide a satisfactory equipotential plane for lightning currents with frequencies up to several MHz, because their impedance may be too high at these frequencies.

Even an LPS designed in accordance with IEC 62305-3, which allows mesh widths typically greater than 5 m, and which includes lightning equipotential bonding as a mandatory part of the internal LPS, might not be sufficient for sensitive electronic systems. This is because the impedance of this bonding system may still be too high for this application.

A low impedance bonding network with typical mesh width of 5 m and below is strongly recommended.

In general the bonding network should not be used either as a power, or signal, return path. Therefore the PE conductor shall be integrated into the bonding network, but the PEN conductor shall not.

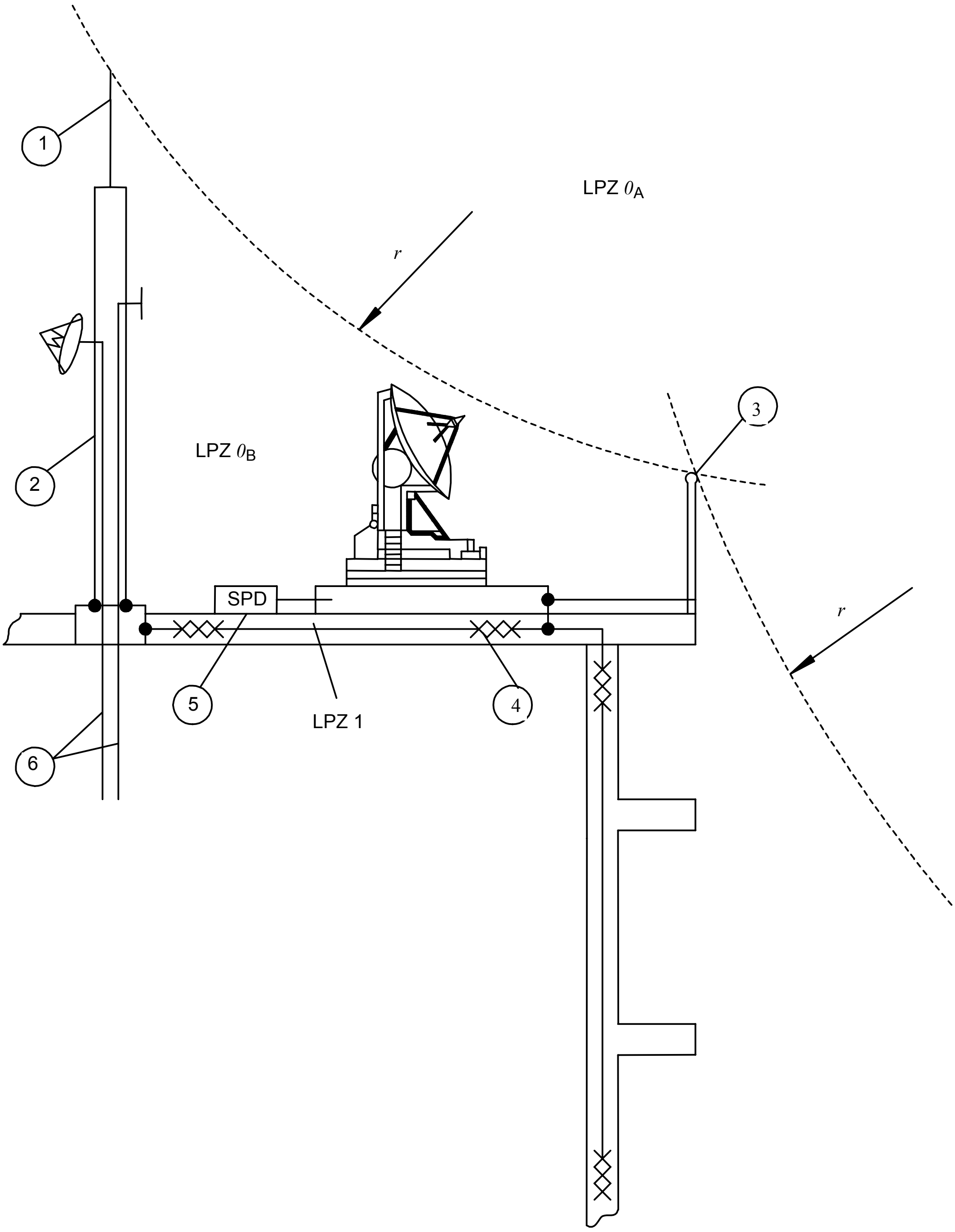
Direct bonding of a functional earthing conductor (e.g. a clean earth specific to an electronic system) to the low impedance bonding network is allowed, because in this case the interference coupling into electrical or signal lines will be very low. No direct bonding is allowed to the PEN conductor, or to other metal parts connected to it, so as to avoid power frequency interference in the electronic system.

B.9 Protection measures for externally installed equipment

Examples of externally installed equipment are: sensors of any kind including aerials, meteorological sensors, surveillance TV cameras, exposed sensors on process plants (pressure, temperature, flow rate, valve position, etc.) and any other electrical, electronic or radio equipment on external positions on structures, masts and process vessels.

B.9.1 Protection of the external equipment

Wherever possible, the equipment should be brought under the protective zone LPZ 0_B using for example a local air terminal to protect it against direct lightning strikes (see Figure B.5).



Key

1 lightning rod

2 steel mast with antennas

3 hand rails

4 interconnected reinforcement

5 line coming from LPZ 0_B needs SPD at entry

6 lines coming from LPZ 1 (inside the mast) may not need SPDs at entry

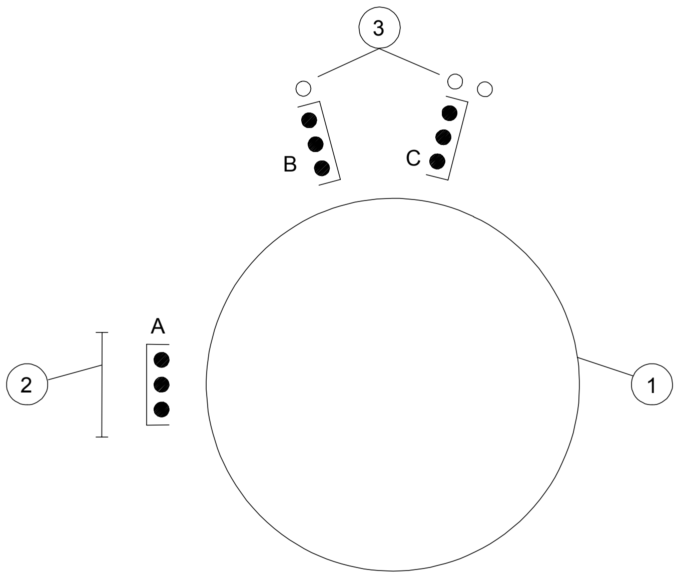
r radius of the rolling sphere

Figure B.5 – Protection of aerials and other external equipment

On tall structures, the rolling sphere method (see IEC 62305-3) should be applied to determine if the equipment installed on the top or sides of the building are possibly subject to a direct strike. If this is the case, additional air terminations should be used. In many cases handrails, ladders, pipes etc. can adequately perform the function of an air termination. All equipment, except some types of aerials, can be protected in this manner. Aerials sometimes have to be placed in exposed positions to avoid their performance being adversely affected by nearby lightning conductors. Some aerial designs are inherently self-protecting because only well earthed conductive elements are exposed to lightning strike. Other might require SPDs to be installed on their feeder cables to prevent excessive transients from flowing down the cable to the receiver or the transmitter. When an external LPS is available the aerial supports should be bonded to it.

B.9.2 Reduction of overvoltages in cables

High induced voltages and currents can be prevented by running cables in bonded ducting, trunking or metal tubes. All cables leading to the specific equipment should leave the cable duct at a single point. Where possible, the inherent shielding properties of the structure itself should be used to maximum advantage by running all cables together within the tubular components of the structure. Where this is not possible, as in the case of process vessels, cables should run on the outside but close to the structure and make as much use as possible of the natural shielding provided by metal pipes, steel rung ladders and any other well bonded conducting materials (see Figure B.6). On masts which use L-shaped corner members, cables should be placed in the inside corner of the L for maximum protection (see Figure B.7).



Key

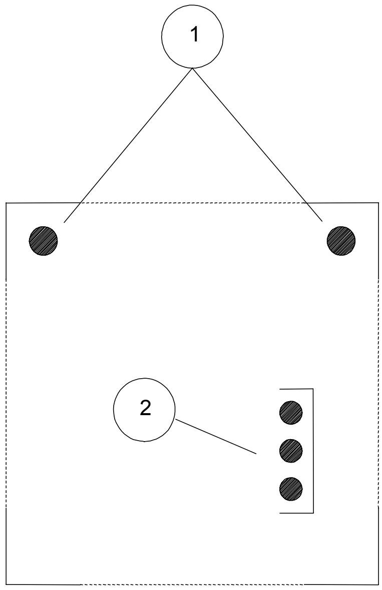
1 process vessel

2 rung ladder

3 pipes

NOTE A, B, C are good alternatives for cable tray positioning.

Figure B.6 – Inherent shielding provided by bonded ladders and pipes



Key

1 ideal positions for cables in corners of L-girders

2 alternative position for bonded cable tray within the mast

Figure B.7 – Ideal positions for lines on a mast (cross-section of steel lattice mast)

B.10 Improving interconnections between structures

Lines interconnecting separate structures are either:

– isolating (metal-free fibre optic cables), or
– metallic (e.g. wire pairs, multicores, wave guides, coaxial cables or fibre optic cables with continuous metal components).

Protection requirements depend on the type of the line, the number of lines and whether the earth termination systems of the structures are interconnected.

B.10.1 Isolating lines

If metal-free fibre optic cables (i.e. without metal armouring, moisture barrier foil or steel internal draw wire) are used to interconnect separate structures, no protection measures for these cables are needed.

B.10.2 Metallic lines

Without proper interconnection between the earth termination systems of separate structures, the interconnecting lines form a low impedance route for the lightning current. This may result in a substantial portion of the lightning current flowing along these interconnecting lines.

– The required bonding, directly or via SPD, at the entries to both LPZs 1 will protect only the equipment inside, whereas the lines outside remain unprotected.
– The lines might be protected by installing an additional bonding conductor in parallel. The lightning current will then be shared between the lines and this bonding conductor.
– It is recommended that the lines be run in closed and interconnected metal cable ducts. In this case the lines as well as the equipment are protected.

Where proper interconnection between the earth termination systems of separate structures is implemented, the protection of lines by interconnected metal ducts is still recommended. Where many cables are run between interconnected structures, the shields or the armouring of these cables, bonded at either end, can be used instead of cable ducts.

Annex C
(informative)

SPD coordination

C.1 General

Where two or more SPDs are installed one after another in the same circuit, they shall be coordinated in such a way as to share the energy between them according to their energy absorbing capability.

For effective coordination, the characteristics of the individual SPDs (as published by the manufacturer), the threat at the point of installation and the characteristics of the equipment to be protected, need to be considered.

The primary lightning threat is given by the three lightning current components:

– the first short stroke,
– the subsequent short strokes,
– the long stroke.

All three components are impressed currents. In the coordination of downstream SPDs, the first short stroke is the predominating factor when considering the sharing of energy (charge and amplitude). Subsequent short strokes have lower values of specific energy, but a higher current steepness. The long stroke is an additional stress factor which need not be considered for coordination purposes.

NOTE 1 If SPDs are specified for the first short stroke threat, the subsequent short strokes cause no additional problems. If inductances are used as decoupling elements, the higher current steepness facilitates coordination between SPDs.

Parameters of the total lightning current for the different LPL are listed in Table 3 of IEC 62305-1, Table 3. However, a single SPD will only be stressed by a portion of this total lightning current. This requires the determination of the current distribution, either by computer simulation using network analysing software, or by approximation as given in Annex E of IEC 62305-1.

NOTE 2 Analytical functions of the short strokes for analysis purposes are given in Annex B of IEC 62305-1.

The first short stroke current of a direct lightning strike can be simulated using a waveshape 10/350 μs. Partial lightning or induced currents within the system can have different waveshapes due to interactions between the lightning current and the low-voltage installation. For coordination purposes, therefore, the following impulse test currents (surges) are considered:

$I_{10/350}$ A test current with a 10/350 μs waveshape – is especially used to test the energy coordination of SPDs. For SPDs intended for use on power lines, this waveshape is used in the Class I test (see IEC 61643-1), which is defined by its peak value I_{peak} and its charge transfer Q.

$I_{8/20}$ A test current with an 8/20 μs waveshape. For SPDs intended for use on power lines, this waveshape is used in the Class II test (IEC 61643-1).

I_{CWG} Output current of a combination wave generator (IEC 61000-4-5). The waveshape depends on the load (open circuit voltage 1,2/50 μs and short circuit current 8/20 μs). This output current is used in the Class III test (IEC 61643-1).

I_{RAMP} A test current with a current steepness of 0,1 kA/µs. It is defined to simulate partial lightning currents within the system having minimum steepness due to interaction between the lightning current and the low-voltage installation. This current is used especially to test the decoupling of subsequent SPDs.

Figure C.1 shows an example of the application of SPDs in power distribution systems according to the lightning protection zones concept. The SPDs are installed in sequence. They are chosen according to the requirements at their particular installation point.

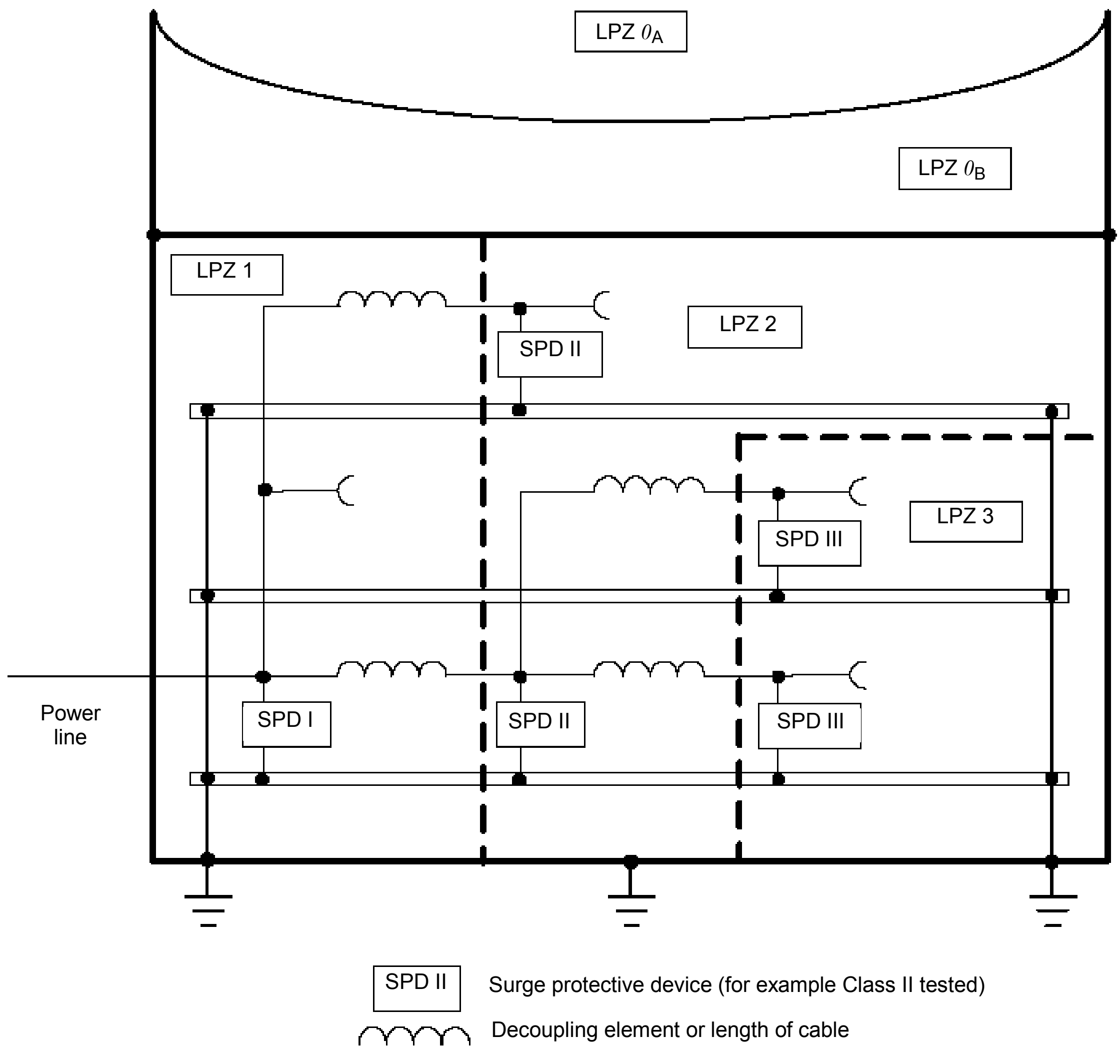


Figure C.1 – Example for the application of SPD in power distribution systems

The SPDs selected and their integration into the overall electrical system inside the structure shall ensure that the partial lightning current will mainly be diverted into the earthing system at the interface LPZ 0_A/LPZ 1.

Once the majority of the energy of the partial lightning current has been diverted via the first SPD, the subsequent SPDs need to be designed only to cope with the remaining threat from the interface LPZ 0_A to LPZ 1 plus the induction effects from the electromagnetic field within LPZ 1 (especially if LPZ 1 has no electromagnetic shield).

NOTE 3 It must be considered when choosing subsequent SPDs, that voltage switching type SPDs may not reach their operating threshold.

Lines entering from LPZ 0_A (where direct strikes are possible) carry partial lightning currents. At the interface LPZ 0_A to LPZ 1 therefore, SPDs tested with I_{imp} (Class I tested SPD) are needed to divert these currents.

Lines entering from LPZ 0_B (where direct strikes are excluded but the full electromagnetic field exists), carry only induced surges. At the interface LPZ 0_B to LPZ 1 the induced effects should be simulated by means of either a surge current with a waveshape 8/20 µs (Class II tested SPD) or an adequate combination wave test (Class III tested SPD) according to IEC 61643-1.

The remaining threat at the zone transition LPZ 0 to LPZ 1 and the induced effects of the electromagnetic field within LPZ 1 define the requirements for the SPDs at the interface LPZ 1 to LPZ 2. If no detailed analysis of the threat is possible, the dominant stress should be simulated by means of either a surge current with a waveshape 8/20 µs (Class II tested SPD) or combination wave test (Class III tested SPD) according to IEC 61643-1. If the SPD at the interface LPZ 0 to LPZ 1 is of the voltage switching type, there is a chance that the level of the incoming lightning current may not be sufficient to trigger it. In such a case the downstream SPDs may be subjected to a 10/350 µs waveshape.

C.2 General objectives of SPD coordination

The energy coordination is needed to avoid SPDs within a system from being overstressed. The individual stresses of SPDs, depending on their location and characteristics, must therefore be determined.

As soon as two or more SPDs are installed in cascade, a study of the coordination of the SPDs and the equipment being protected is needed.

Energy coordination is achieved if the portion of energy which each SPD is subjected to is lower than, or equal, to its withstand energy. This coordination of energy needs to be considered for the four waveforms considered in C.1.

The withstand energy should be obtained from:

– electrical testing according to IEC 61643-1;
– technical information provided by the SPD manufacturer.

Figure C.2 illustrates the basic model of the energy coordination for SPDs. This model is only valid when the impedance of the bonding network and the mutual inductance between the bonding network and the installation formed by the connection of SPD 1 and SPD 2, is negligible.

NOTE The decoupling element is not required if the energy coordination can be assured using other suitable measures (e.g. coordination of the voltage/current characteristics of the SPDs, or use of voltage switching type SPDs specifically designed to trigger at lower voltages “triggered SPDs”).

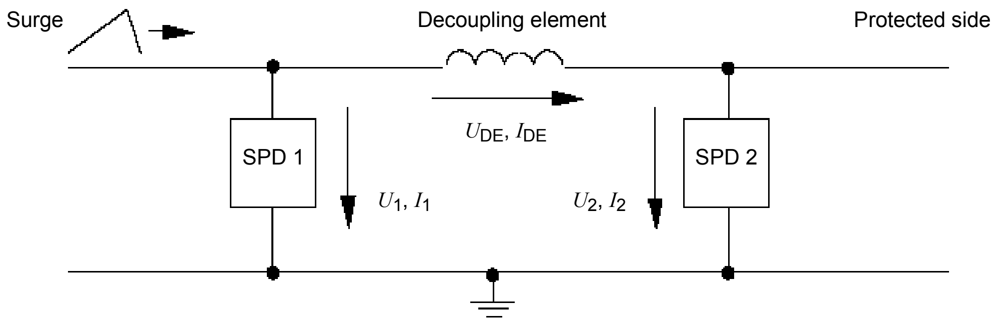


Figure C.2 – Basic model for energy coordination of SPD

C.2.1 Coordination principles

The coordination between SPDs can be achieved by using one of the following principles:

– Coordination of the voltage/current characteristics (without decoupling elements).

  This method is based on the voltage/current characteristic and is applicable to voltage limiting type SPDs (e.g. MOV or suppressor diodes). This method is not very sensitive to the current waveshape.

  NOTE 1 This method does not need decoupling, even if some inherent decoupling is given from the natural impedance of the lines.

– Coordination using dedicated decoupling elements

  For coordination purposes, additional impedances with sufficient surge withstand capability can be used as decoupling elements. Resistive decoupling elements are primarily used in information systems. Inductive decoupling elements are primarily used for power systems. For the coordination efficiency of inductances the current steepness di/dt is the decisive parameter.

  NOTE 2 Decoupling elements can be realised either by separate devices, or by using the natural impedance of cables between subsequent SPDs.

  NOTE 3 The inductance of a line is that of two parallel conductors: If both conductors (phase and ground wire) are within one cable, then the inductance is about 0,5 µH/m to 1 µH/m (depending on the cross-section of the wires). If both conductors are separated, higher values of inductance should be assumed (depending on the separation distance of both conductors).

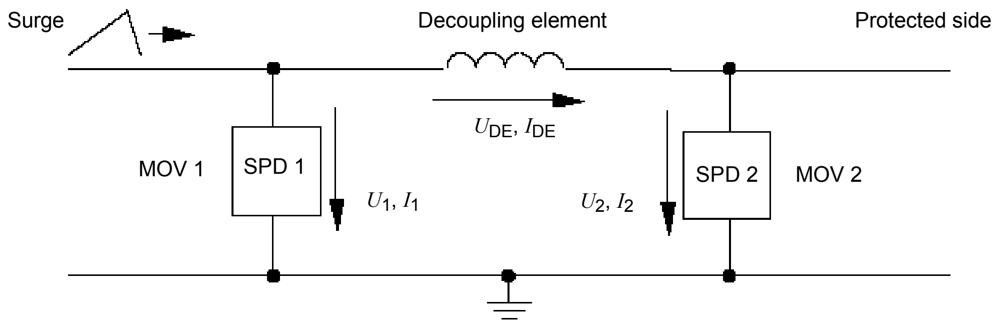
– Coordination using triggered SPDs (without decoupling elements).

  Coordination can also be achieved using triggered SPDs if the electronic trigger circuit can assure that the energy withstand capability of subsequent SPDs is not exceeded.

  NOTE 4 This method does not require additional decoupling elements, even if some inherent decoupling is provided by the natural impedance of the lines.

C.2.2 Coordination of two voltage-limiting type SPDs

Figure C.3a shows the basic circuit diagram for the coordination of two voltage-limiting type SPDs. Figure C.3b illustrates the energy dispersion within the circuit. The total energy feed into the system increases with the growing impulse current. As long as the energy dissipated in each of the two SPDs does not exceed their energy withstand capability, coordination is achieved.



Key
MOV metal oxide varistor

Figure C.3a – Circuit with two voltage-limiting type SPDs

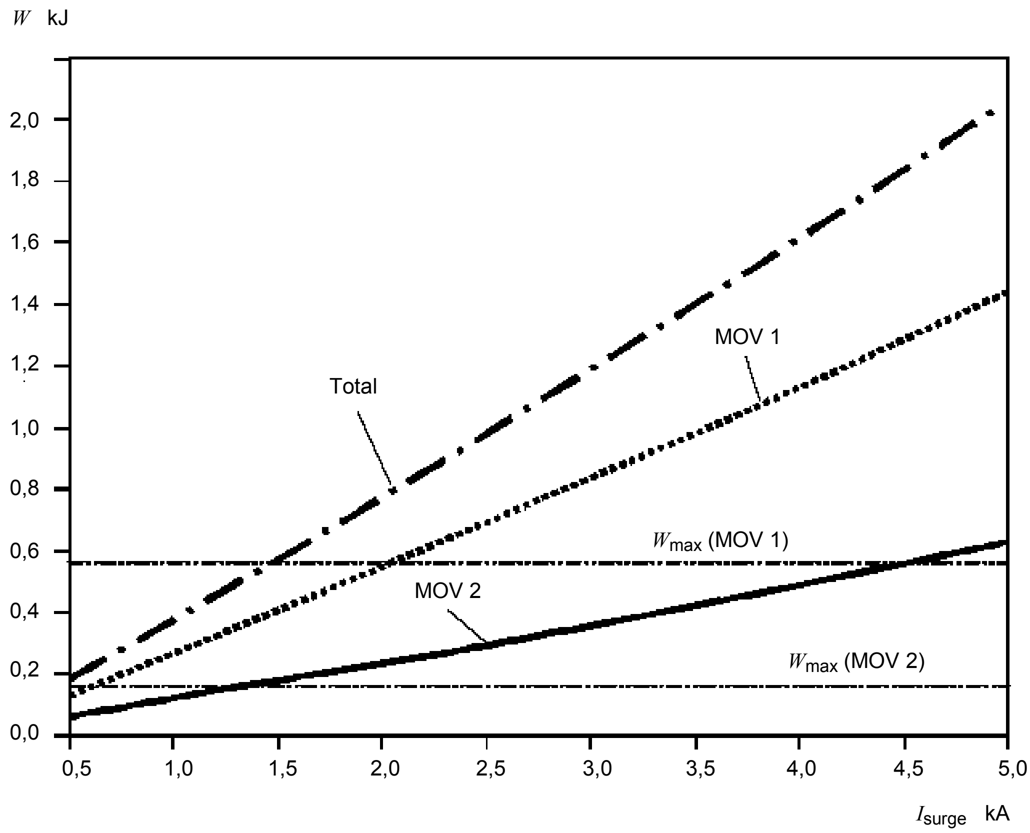


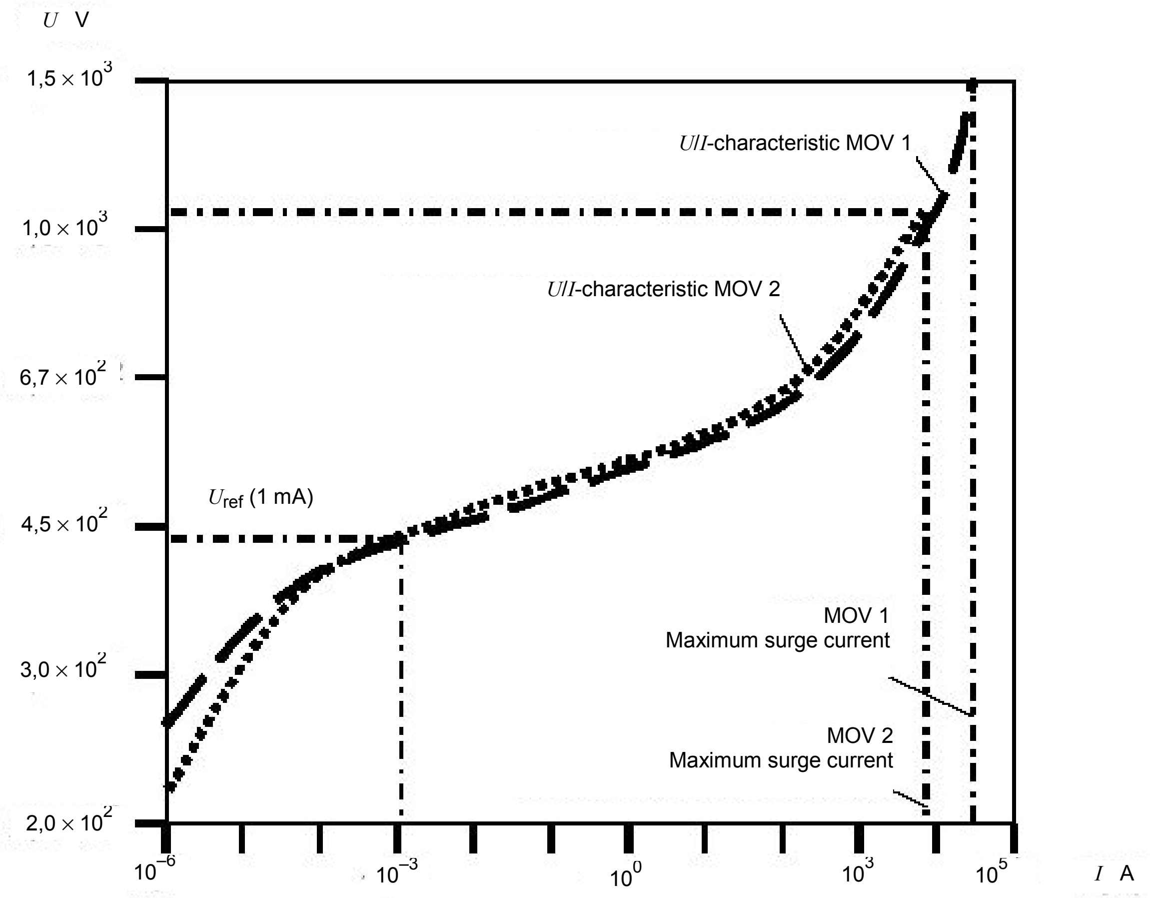
Figure C.3b – Principles of energy coordination between MOV 1 and MOV 2

Figure C.3 – Combination of two voltage-limiting type SPDs

Energy coordination of two voltage-limiting type SPDs without dedicated decoupling elements should be realised by coordination of their voltage/current characteristics over the relevant current range. This method is not very dependent on the current waveshape considered. If additional inductances are required as decoupling elements, the waveshape of the surge current shall be considered (e.g. 10/350 µs or 8/20 µs).

The use of inductances as the decoupling elements between different stages in an SPD, is not very effective when the waveshape is of a low current steepness (e.g. 0,1 kA/µs). In SPDs intended for use on signal lines, this coordination may better be achieved using resistances (or the natural resistances of wires) as the decoupling elements.

If two voltage-limiting type SPDs are coordinated, both shall be dimensioned for their respective surge current and energy. The duration of the current wave considered will be as long as that of the impinging current. Figures C.4a and C.4b provide an example of the energy coordination between two voltage-limiting type SPDs in the case of a 10/350 µs surge.



NOTE As can be seen in this example, the knowledge of the MOV's reference voltage U_{ref} only, in not sufficient for coordination purposes.

Figure C.4a – Current/voltage characteristics of MOV 1 and MOV 2

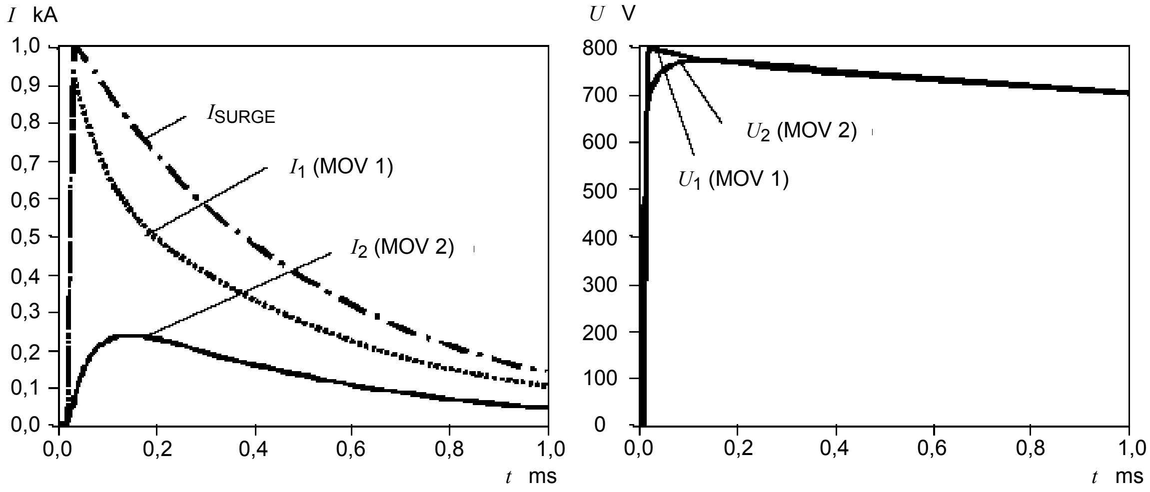


Figure C.4b – Current and voltage characteristics at MOV 1 and MOV 2 from 10/350 µs surge

Figure C.4 – Example with two voltage-limiting type MOV 1 and MOV 2

C.2.3 Coordination between voltage switching type and voltage limiting type SPDs

Figure C.5a shows the basic circuit diagram of this coordination variant using a spark gap (SPD 1) and a MOV (SPD 2) as example technologies. Figure C.5b illustrates the basic principle of energy coordination using the characteristics of the voltage-switching type SPD 1 and the voltage-limiting type SPD 2.

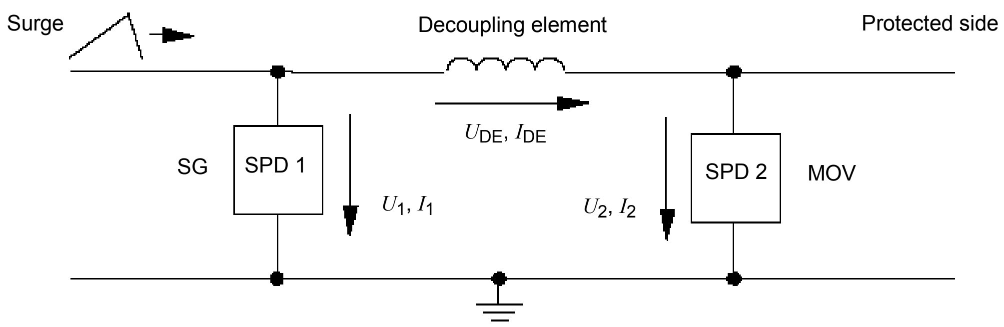


Figure C.5a – Circuit with spark gap and MOV

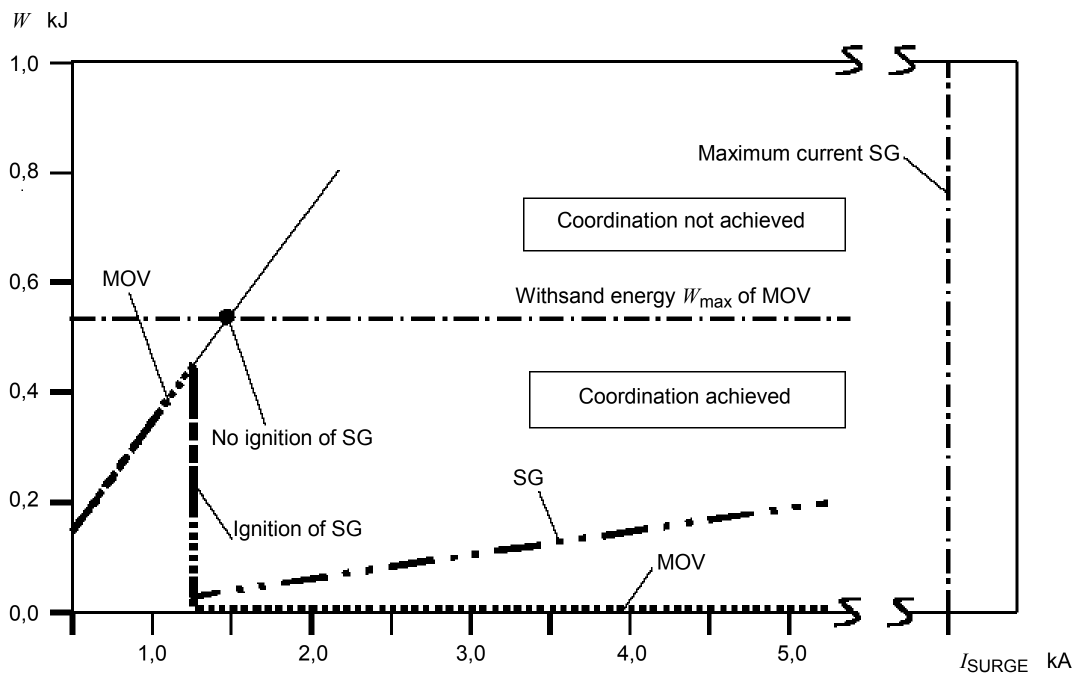


Figure C.5b – Principle for energy coordination of a spark gap and a MOV

Figure C.5 – Combination of voltage-switching type spark gap and voltage-limiting type MOV

The ignition of the spark gap (SPD 1) depends on the sum of the residual voltage U_{res} across the MOV (SPD 2) and of the dynamic voltage drop across the decoupling element U_{DE}. As soon as the voltage U_1 exceeds the dynamic spark over voltage U_{SPARK}, the spark gap will ignite and coordination is achieved. This depends only on the

– characteristics of the MOV,
– steepness and magnitude of the incoming surge current,
– decoupling element (inductance or resistance).

When an inductance is used as a decoupling element, the rise time and peak magnitude of the surge current shall be considered. The greater the steepness di/dt, the smaller the inductance required for decoupling. When coordinating SPDs tested with I_{imp} (Class I tested) and SPDs tested with I_n (Class II tested) a lightning current with a minimum current steepness of 0,1 kA/µs should be used (see Clause C.1 of IEC 62305-1). The coordination of these SPDs shall be ensured for both the 10/350 µs lightning current as well as for the minimum current steepness of 0,1 kA/µs.

Two basic situations should be considered:

– No ignition of the spark gap (Figure C.6a):

  If the spark gap does not ignite, the complete surge current flows through the MOV. As shown in Figure C.5b the coordination has not been achieved, if the energy dissipated by this surge is higher than the withstand energy of the MOV. If an additional inductance is required as the decoupling element, coordination should be evaluated using the worst-case minimum current steepness of 0,1 kA/µs.

– Ignition of the spark gap (Figure C.6b):

  If the SG does ignite, the duration of the current flowing through the MOV is considerably reduced. As shown in Figure C.5b the proper coordination is achieved when he spark gap ignites before the withstand energy of the MOV is exceeded.

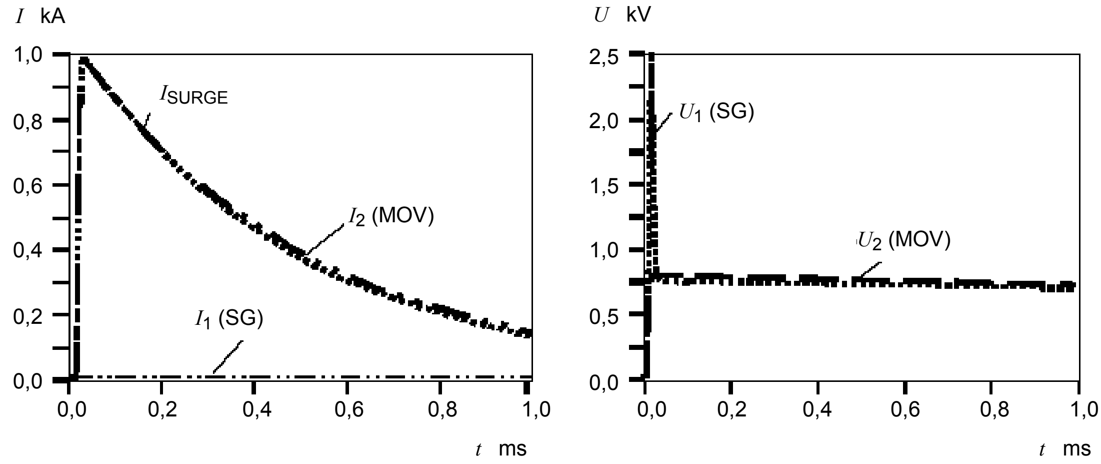


Figure C.6a – Current and voltage of spark gap and MOV from a 10/350 µs surge (SPD 1 not ignited)

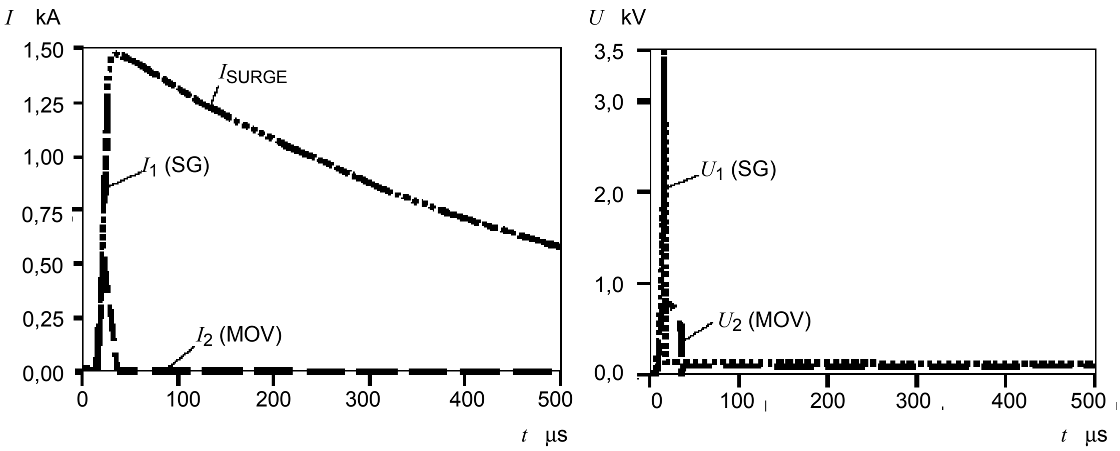
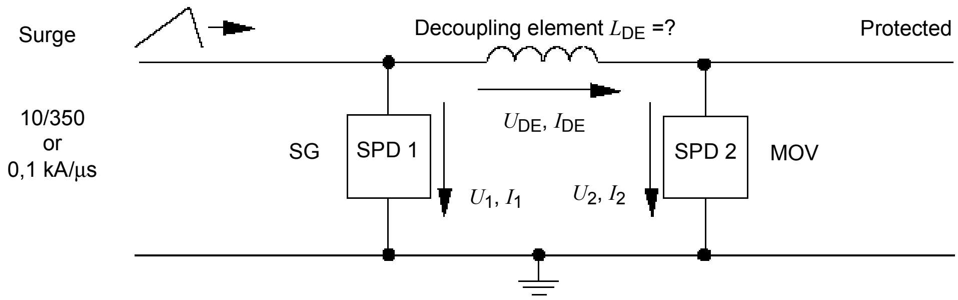


Figure C.6b – Current and voltage of spark gap and MOV from a 10/350 µs surge (SPD 1 ignited)

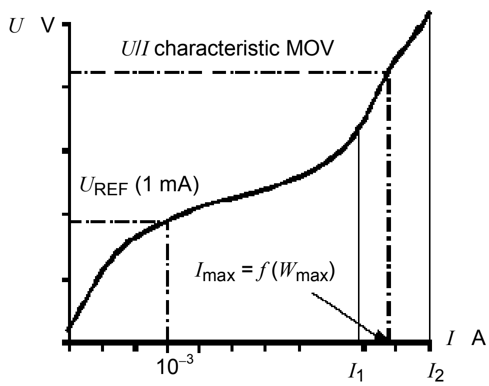
Figure C.6 – Example with voltage-switching type spark gap and voltage-limiting type MOV

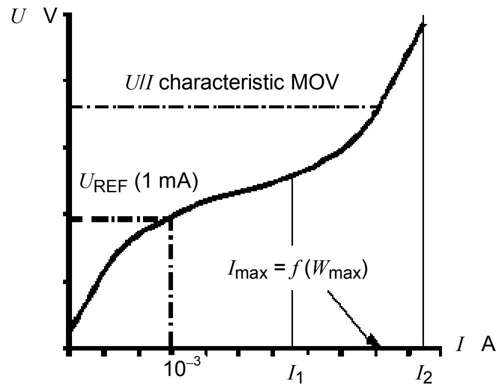
Figure C.7 shows the procedure for determination of the required decoupling inductance for both criteria: the 10/350 µs lightning current as well as the 0,1kA/µs minimum lightning current steepness. The dynamic voltage/current characteristics of both SPDs shall be considered to determine the decoupling element required. The condition for successful coordination requires the spark gap to ignite before the energy withstand of the MOV is exceeded.



Voltage condition	$U_1 = U_2 + U_{DE} = U_2 + L \cdot dI/dt$
Ignition of SG	$U_1 = U_{SPARK}$
Coordination achieved	Ignition of SG before withstand energy W_{max} of MOV is exceeded

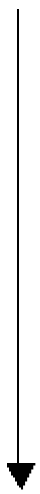
Energy coordination with 10/350 µs surge	Energy coordination with 0,1kA/µs surge

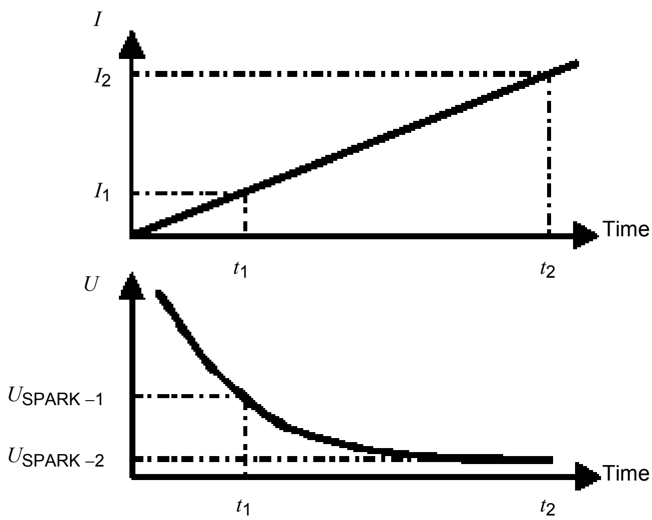




($I_1 < I_{max}$ for ($L_{DE-1} \geq L_{DE-10/350}$)
($I_2 > I_{max}$ for ($L_{DE-2} \leq L_{DE-10/350}$)

($I_1 < I_{max}$ for ($L_{DE-1} \geq L_{DE-0,1kA/µs}$)
($I_2 > I_{max}$ for ($L_{DE-2} \leq L_{DE-0,1kA/µs}$)





$L_{DE} = (U_{SPARK} - U_2) / (dI/dt)$ where $U_2 = f(I_{max})$	
$L_{DE-10/350\,µs} = (U_{SPARK} - U_2) / (I_{max}$ / 10 µs)	$L_{DE-0,1kA/µs} = (U_{SPARK} - U_2)$ / (0,1kA/µs)
The required L_{DE} is the higher value of both inductances $L_{DE-10/350\,µs}$ and $L_{DE-0,1kA/µs}$	

Figure C.7 – Determination of decoupling inductance for 10/350 µs and 0,1kA/µs surges

The ignition of the spark gap depends on its spark over voltage U_{SPARK} and on the sum of the voltage U_2 across the MOV (SPD 2) and of the voltage across the decoupling element U_{DE}. The voltage U_2 depends on the current i (see voltage/current characteristic of the MOV), whereas the voltage $U_{DE} = L_{DE}\, \mathrm{d}i/\mathrm{d}t$ depends on the current steepness.

For the 10/350 µs surge, the current steepness $\mathrm{d}i/\mathrm{d}t \approx I_{max}$ /10 µs depends on the permissible amplitude I_{max} of the MOV (determined from its energy withstand W_{max}). Because both voltages U_{DE} and U_2 are functions of I_{max}, the voltage U_1 across the spark gap depends also on I_{max}. The higher I_{max}, the higher the steepness of the voltage U_1 across the spark gap. For this criterion therefore, the spark-over voltage U_{SPARK} of the spark gap is usually described by the impulse sparkover voltage at 1 kV/µs.

For the 0,1 kA/µs ramp, the current steepness $\mathrm{d}i/\mathrm{d}t$ = 0,1 kA/µs is constant. Thus the voltage U_{DE} is constant too, whereas the voltage U_2 is a function of I_{max} as before. The steepness of the voltage U_1 across the spark gap therefore follows the voltage/current characteristic of the MOV and is much lower compared to the first case. Because of the dynamic operating voltage characteristic of the spark gap, its spark over voltage decreases with a longer duration of the voltage drop across the spark gap. (This duration depends on I_{max} derived from the withstand energy W_{max} of the MOV.) Hence, the sparkover voltage U_{SPARK} should be assumed to decrease almost to the DC-operating voltage at 500 V/s for increasing duration of current flowing through the MOV.

The higher value of both inductances $L_{DE\text{-}10/350\,\mu s}$ and $L_{DE\text{-}0,1kA/\mu s}$ finally shall be applied for the decoupling inductance L_{DE}. See Figures C.8 and C.9 for examples.

NOTE For the determination of a decoupling element in a low-voltage power system, the worst case would be a short-circuit at SPD 2 (U_2 = 0), hence maximizing the required voltage U_{DE}. Where SPD 2 is a voltage-limiting type it has a residual voltage U_2 > 0, which will considerably reduce the required voltage U_{DE}. This residual voltage is at least higher than the peak voltage of the power supply (e.g. AC nominal voltage 230 V: peak value $\sqrt{2}$ 230 V = 325 V). Taking into account the residual voltage of SPD 2 allows one to suitably dimension the decoupling elements. Otherwise they would be over-dimensioned.

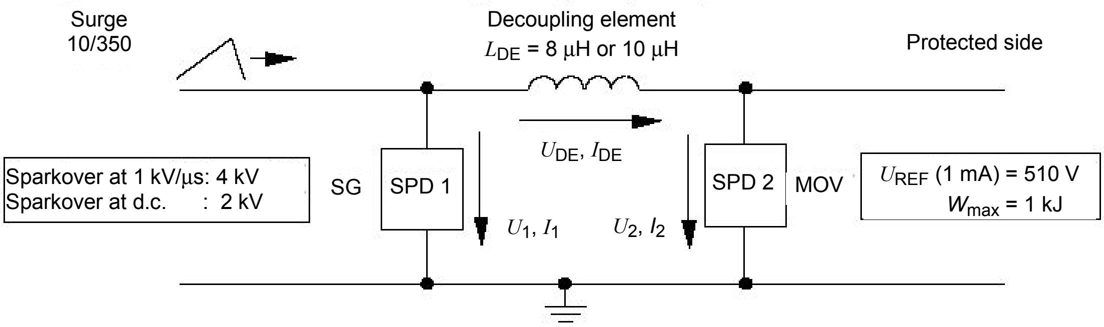


Figure C.8a – Circuit diagram of coordination for a 10/350 µs surge

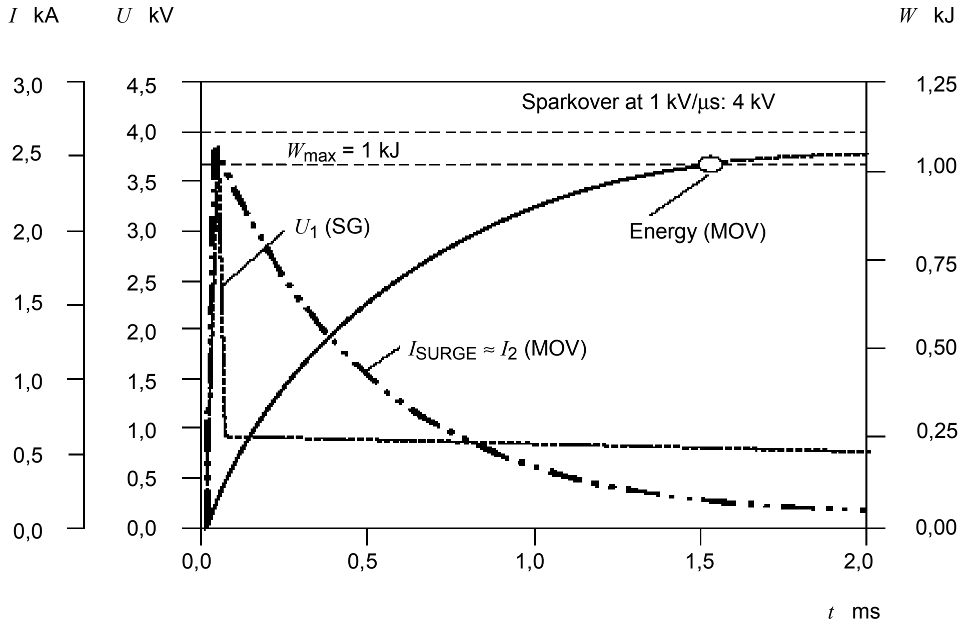


Figure C.8b – Current/voltage/energy characteristics for L_{DE}= 8μH – Energy coordination for a 10/350 surge not achieved (spark gap not ignited)

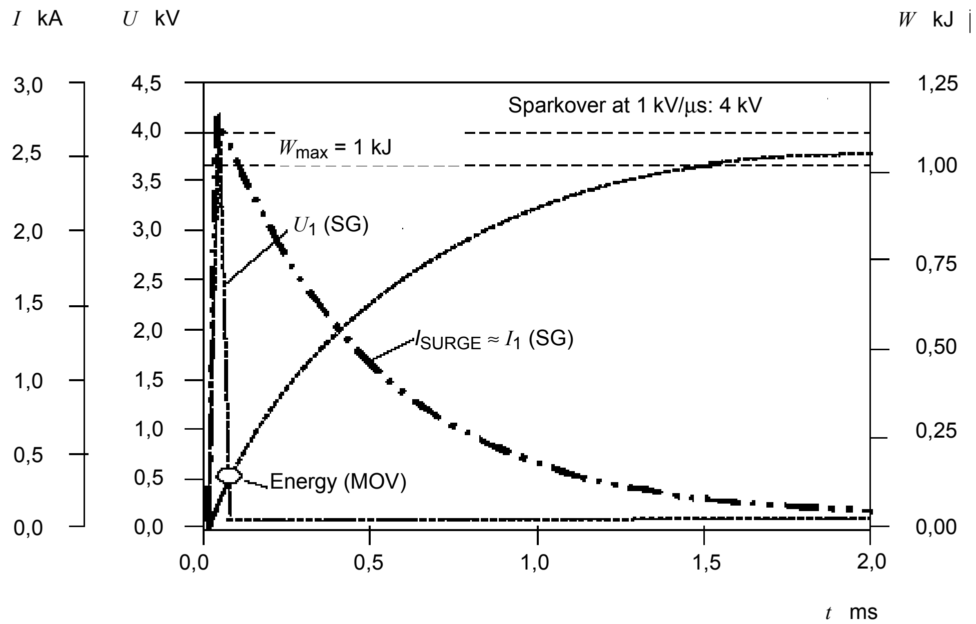


Figure C.8c – Current/voltage/energy characteristics for L_{DE}= 10 μH – Energy coordination for a 10/350 μs surge achieved (spark gap ignited)

Figure C.8 – Example with spark gap and MOV for a 10/350 μs surge

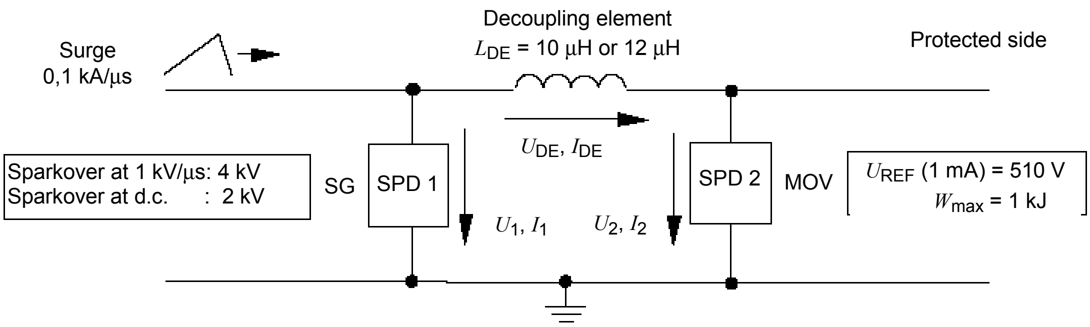


Figure C.9a – Circuit diagram of coordination for a 0,1kA/µs surge

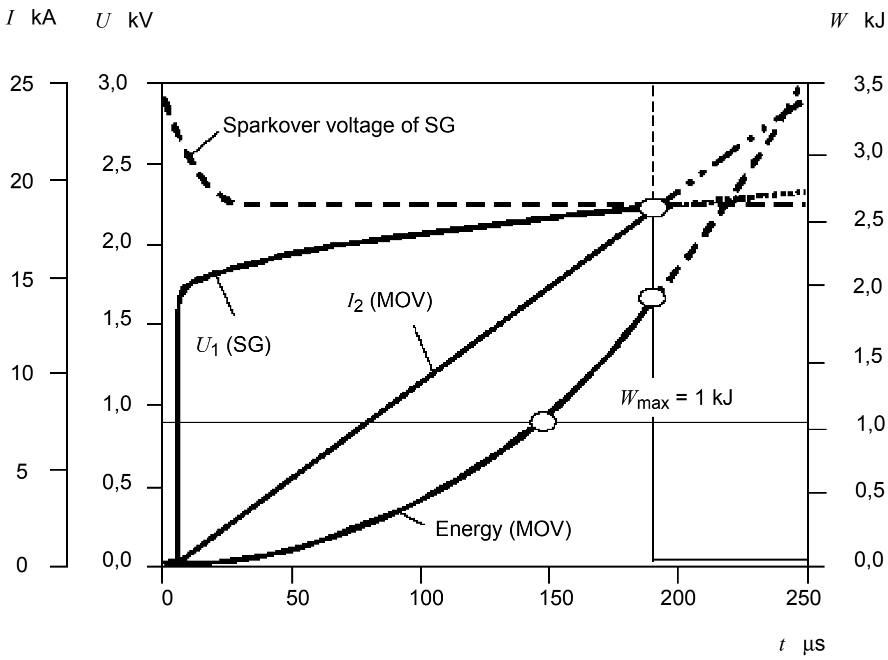


Figure C.9b – Current/voltage/energy characteristics for L_{DE}=10 µH – Energy coordination for a 0,1kA/µs surge not achieved

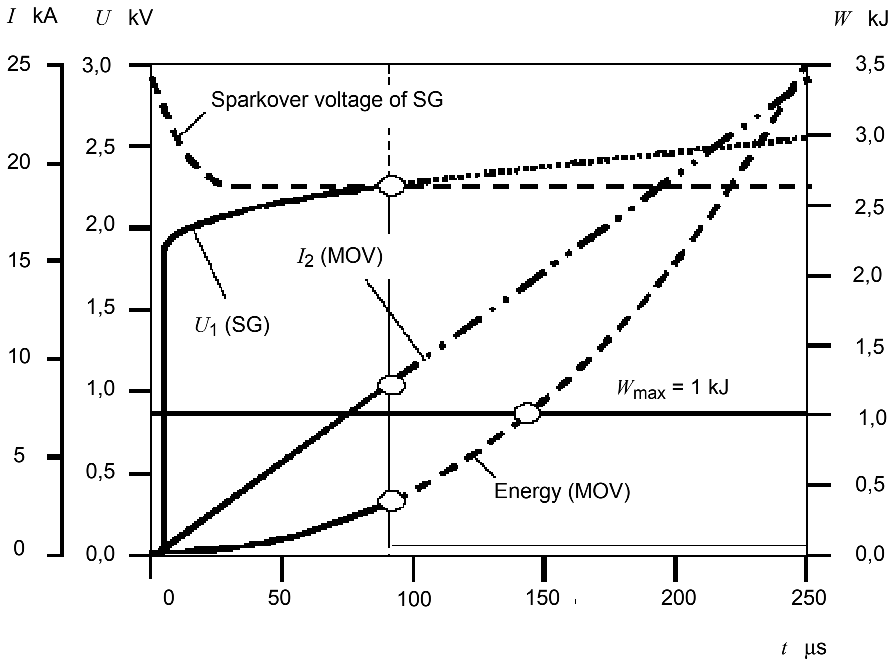


Figure C.9c – Current/voltage/energy characteristics for L_{DE}=12 µH – Energy coordination for a 0,1kA/µs surge achieved

Figure C.9 – Example with spark gap and MOV for 0,1kA/µs surge

C.2.4 Coordination of two voltage switching type SPDs

This coordination variant is described using spark gaps (SG) as example technologies. For the coordination between spark gaps, the dynamic operating characteristics shall be considered.

After ignition of SG 2, the coordination will be realised by means of a decoupling element. To determine the required value of the decoupling element, SG 2 can be replaced by a short-circuit. For the ignition of SG 1, the dynamic voltage drop across the decoupling element shall be higher than the operating voltage of SG 1.

Using inductances as decoupling elements, the required U_{DE} depends mainly on the steepness of the surge current. Therefore waveshape and steepness of the surge shall be considered.

Using resistances as decoupling elements, the required U_{DE} depends mainly on the peak value of the surge current. This value shall also be considered when selecting the pulse rating parameters of the decoupling element.

After the ignition of the SG 1, the total energy will be divided according to the voltage/current characteristics of the individual elements.

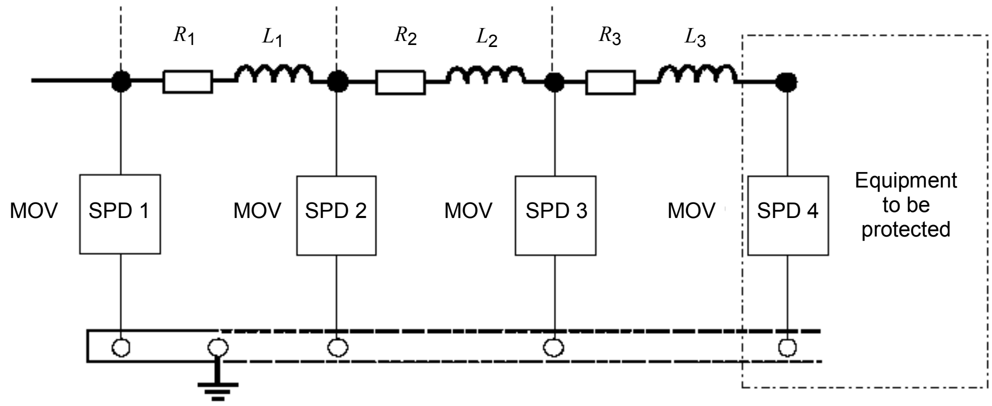
NOTE In the case of spark gaps or gas discharge tubes, the impulse steepness is of primary significance.

C.3 Basic coordination variants for protection systems

There are four coordination variants for protection systems: The first three use one-port SPDs, whereas the fourth uses two-port SPDs with integrated decoupling elements. These coordination variants should be considered (also taking into account SPDs integrated in the equipment to be protected).

C.3.1 Variant I

All SPDs have a continuous voltage/current characteristic (e.g. MOVs or suppressor diodes) and the same residual voltage U_{RES}. The coordination of the SPDs and of the equipment to be protected is normally achieved by the impedances of lines between them (see Figure C.10).



U_{RES} (SPD 1) = U_{RES} (SPD 2) = U_{RES} (SPD 3) = U_{RES} (SPD4)

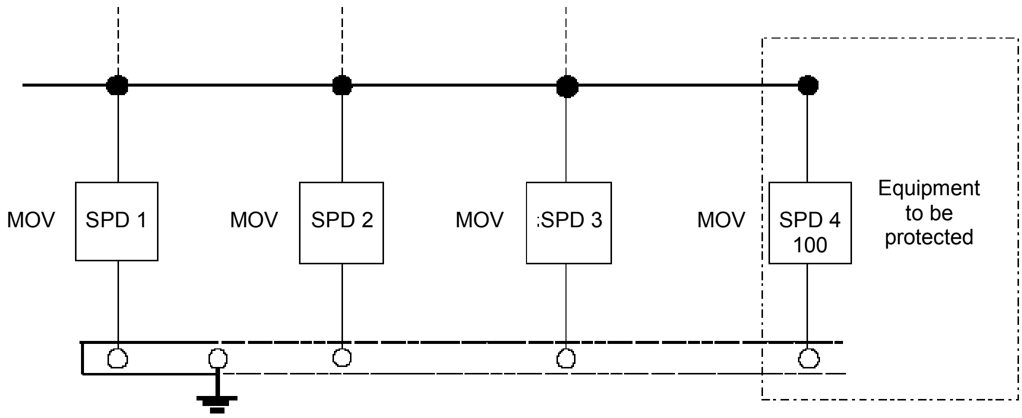
Figure C.10 – Coordination variant I – Voltage-limiting type SPD

C.3.2 Variant II

All SPDs have a continuous voltage/current characteristic (e.g. MOVs or suppressor diodes). The residual voltage U_{RES} rises stepwise from SPD 1 to SPD 3 (see Figure C.11).

This is a coordination variant for power supply systems.

NOTE This variant requires that the residual voltage of the protective component inside the equipment to be protected (SPD 4) is higher than the residual voltage of the SPD installed directly before (SPD3).



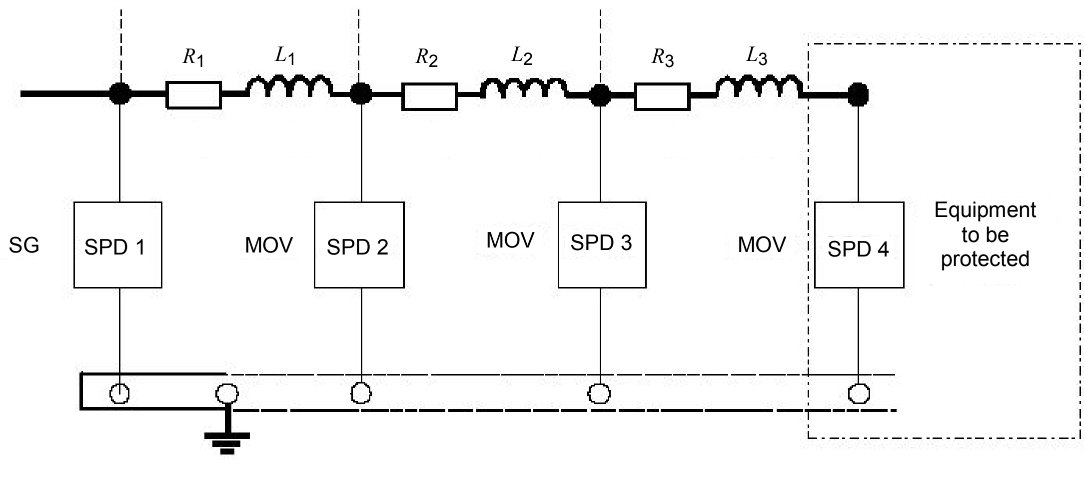
U_{RESv} (SPD 1) < U_{RES} (SPD 2) < U_{RES} (SPD 3) < U_{RES} (SPD 4)

Figure C.11 – Coordination variant II – Voltage-limiting type SPD

C.3.3 Variant III

SPD 1 has a discontinuous voltage/current characteristic (e.g. spark gaps). Subsequent SPDs have a continuous voltage/current characteristic (e.g. MOVs or suppressor diodes). All SPDs have the same residual voltage U_{RES} (see Figure C.12).

The characteristic of this variant is, that by the switching behaviour of SPD 1, a reduction of the time to half value of the original current impulse 10/350 µs will be achieved, which relieves the subsequent SPDs considerably.

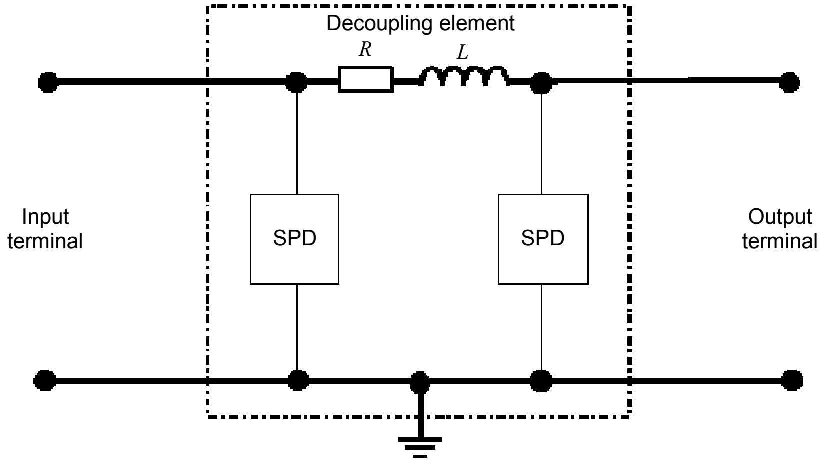


SPD 1 = U_{RES} (SPD 2) = U_{RES} (SPD 3) U_{RES} (SPD 4)

Figure C.12 – Coordination variant III –
Voltage-switching type SPD and voltage-limiting type SPD

C.3.4 Variant IV

Two-port SPDs are available which incorporate cascaded stages of SPDs internally coordinated with series impedances or filters (see Figure C.13). Successful internal coordination ensures minimum energy transfer to downstream SPDs or the equipment. These SPDs should be fully coordinated with other SPD in the system in accordance with variant I, II or III as appropriate.



U_{RES} (SPD 1) = U_{RES} (SPD 2) = U_{RES} (SPD 3)

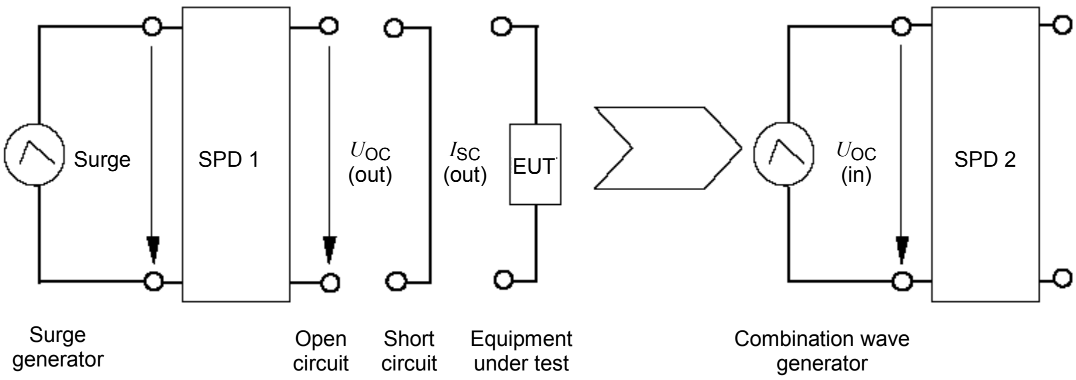
NOTE The series impedance or the filter can be omitted, if the energy coordination is assured by other suitable measures (e.g. coordination of the voltage/current characteristics or use of triggered SPDs).

Figure C.13 – Coordination variant IV – Several SPDs in one element

C.4 Coordination according to the “let-through energy” method

Impulses from a combination wave generator can be used to select and coordinate SPD. The main advantage of this method is the possibility to treat the SPD as a black box (see Figure C.14). For a given surge at the input of SPD 1, the output values of open-circuit voltages as well as of short-circuit currents, are determined ("let-through energy" method). These output characteristics are converted into an equivalent 2 Ω combination wave stres” (open circuit voltage 1,2/50 µs, short-circuit current 8/20 µs). The advantage is that there is no need for any special knowledge of the internal design of the SPD.

NOTE This method gives good results when SPD 2 has no feedback to SPD 1. This means that the surge conditions at the input of SPD 2 are quasi-impressed current conditions. This is given when the voltage/current characteristics of SPD 1 and SPD 2 are very different (e.g. the coordination of a spark gap with an MOV).



U_{OC} (out) of SPD 1 ≤ U_{OC} (in) of SPD 2

Conversion of U_{OC} (out) and I_{SC} (out) into an equivalent combination wave:
U_{OC} (1,2/50 µs waveshape), I_{SC} (8/20 µs waveshape), Z_i = 2 Ω

Figure C.14 – Coordination according to the “let through energy” method

The aim of this coordination method is to make the input values of SPD 2 (e. g. discharge current) comparable to the output values of SPD 1 (e.g. voltage protection level).

For proper coordination, the equivalent combination wave at the output of SPD 1 shall not exceed the combination wave which can be absorbed by SPD 2 without damage.

The equivalent combination wave at the output of SPD 1 shall be determined for the worst-case stress (I_{max}, U_{max}, let-through energy).

NOTE Additional information concerning this coordination method is given in IEC 61643-12 [4].

C.5 Proving coordination

The energy coordination should be proved by the following:

1) Coordination test

Coordination can be demonstrated on a case-by-case basis.

2) Calculation

Simple cases can be approximated while complex systems may require computer simulation.

3) Application of coordinated SPD families

The manufacturer of the SPDs shall prove that coordination is achieved.

Annex D
(informative)

Selection and installation of a coordinated SPD protection

In complex electrical and electronic systems both power and signal circuits must be taken into account for the selection and installation of a suitable coordinated SPD protection.

D.1 Selection of SPD

D.1.1 Selection with regard to voltage protection level

The impulse withstand voltage U_w of the equipment to be protected should be defined for:

– power lines and equipment terminals according to IEC 60664-1,
– telecom lines and equipment terminals according to ITU-T K.20 and K.21,
– other lines and equipment terminals according to information obtained from the manufacturer.

Internal systems are protected if

– their impulse withstand voltage U_w is greater than or equal to the voltage protection level U_P of the SPD plus a margin necessary to take into account the voltage drop of the connecting conductors;
– they are energy coordinated with the upstream SPD.

NOTE 1 The protection level U_P of an SPD is related to the residual voltage at a defined nominal current I_n. For higher or lower currents passing through the SPD, the value of voltage at the SPD terminals will change accordingly.

NOTE 2 When an SPD is connected to equipment to be protected, the inductive voltage drop ΔU of the connecting conductors will add to the protection level U_P of the SPD. The resulting effective protection level, $U_{P/f}$, defined as the voltage at the output of the SPD resulting from the protection level and the wiring voltage drop in the leads/connections (see Figure D.1), can be assumed as being:

$U_{P/f} = U_P + \Delta U$ for voltage-limiting type SPDs;

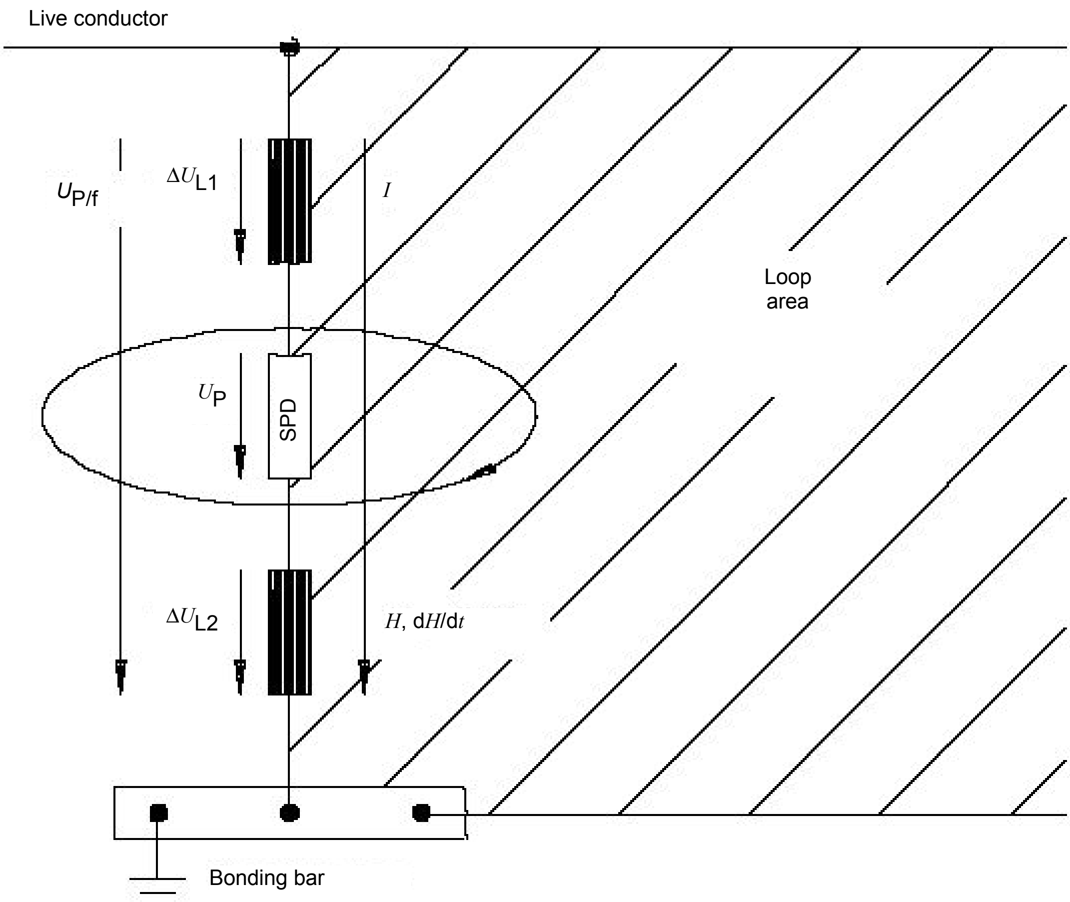
$U_{P/f} = \max (U_P, \Delta U)$ for voltage-switching type SPDs.

For some switching type SPDs it may be required to add the arc voltage to ΔU. This arc voltage may be as high as some hundreds of volts. For combination type SPDs, more complex formulas may be needed.

When the SPD is carrying the partial lightning current, ΔU = 1 kV per m length, or at least a safety margin of 20 %, should be assumed when the length of the connection conductors is ≤ 0,5 m. When the SPD is carrying induced surges only, ΔU can be neglected.

NOTE 3 The voltage protection level U_P should be compared with the impulse withstand voltage U_w of the equipment, tested under the same conditions as the SPD (overvoltage and overcurrent waveform and energy, energized equipment, etc). This matter is under consideration.

NOTE 4 Equipment may contain internal SPDs. The characteristics of these internal SPDs may affect the coordination.



Key

I	partial lightning current
$U_{P/f} = U_P + \Delta U$	surge voltage between live conductor and bonding bar
U_P	limiting voltage of SPD
$\Delta U = \Delta U_{L1} + \Delta U_{L2}$	inductive voltage drop on the bonding conductors
H, dH/dt	magnetic field and its time derivative

The surge voltage $U_{P/f}$ between the live conductor and the bonding bar is higher than the protection level U_p of the SPD, because of the inductive voltage drop ΔU at the bonding conductors (even if the maximum values of U_P and ΔU do not necessarily appear simultaneously). Moreover, the partial lightning current flowing through the SPD induces additional voltage into the loop on the protected side of the circuit following the SPD. Therefore the maximum voltage endangering the connected equipment can be considerably higher then the protection level U_P of the SPD.

Figure D.1 – Surge voltage between live conductor and bonding bar

D.1.2 Selection with regard to location and to discharge current

SPDs shall withstand the discharge current expected at their installation point in accordance with Annex E of IEC 62305-1. The use of SPDs depends on their withstand capability, classified in IEC 61643-1 for power, and in IEC 61643-21 for telecommunication systems.

SPDs shall be selected according to their intended installation location, as follows:

a) At the line entrance into the structure (at the boundary of LPZ 1, e.g. at the main distribution board MB):

- **SPD tested with I_{imp} (Class I test)**

  The required impulse current I_{imp} of the SPD shall provide for the (partial) lightning current to be expected at this installation point based on the chosen LPL according to Clause E.1 and/or Clause E.2 of IEC 62305-1.

- **SPD tested with I_n (Class II test)**

  This type of SPD can be used when the lines entering are entirely within LPZ 0_B or when the risk of failures of the SPDs due to sources of damage S1 and S3 can be disregarded. The required nominal discharge current I_n of the SPD shall provide for the surge level to be expected at the installation point based on the chosen LPL according to E.2.2 of IEC 62305-1.

b) Close to the apparatus to be protected (at boundary of LPZ 2 and higher, e.g. at secondary distribution board SB, or at socket outlet SA).

- **SPD tested with I_n (Class II test)**

  The required nominal discharge current I_n of the SPD shall provide for the surge level to be expected at the installation point based on the chosen LPL according to Clause E.3 of IEC 62305-1.

- **SPD tested with a combination wave (Class III test)**

  The required open circuit voltage U_{OC} of the combination wave generator shall be selected to ensure that the corresponding short circuit current I_{sc} will provide for the surge level to be expected at the installation point based on the chosen LPL according again to Clause E.3 of IEC 62305-1.

D.2 Installation of a coordinated SPD protection

The efficiency of a coordinated SPD protection depends not only on the proper selection of the SPDs, but also on their correct installation.. Aspects to be considered include:

– location of the SPDs;

– connecting conductors;

– the protection distance due to oscillation phenomena;

– the protection distance due to induction phenomena.

D.2.1 Location of SPD

The location of SPDs should comply with D.1.2 and is mainly affected by:

– the specific source of damage (e.g. lightning flashes direct to a structure (S1), direct to a line (S3), to ground nearby a structure (S2) or to ground nearby a line (S4)),

– the nearest opportunity to divert the surge current to ground (as close to the entrance point of a line into the structure as possible).

The first criterion to be considered is: the closer an SPD is to the entrance point of the incoming line, the greater the amount of equipment within the structure which is protected by this SPD (economical advantage). Then the second criterion should be checked: the closer an SPD is to the equipment being protected, the more effective its protection (technical advantage).

D.2.2 Connecting conductors

SPD connecting conductors shall have minimum cross-sections as given in Table 1.

D.2.3 Oscillation protection distance I_{po}

During the operating state of an SPD, the voltage between the SPD terminals is limited to U_p at the location of the SPD. If the length of the circuit between the SPD and the equipment is too long, propagation of surges can lead to an oscillation phenomenon. In the case of an open-circuit at the equipment's terminals, this can increase the overvoltage up to $2 \cdot U_p$ and failure of equipment may result even if $U_p \leq U_w$.

The oscillation protection distance I_{po} is the maximum length of the circuit between the SPD and the equipment, for which the SPD protection is still adequate (taking into account oscillation phenomena and capacitive load).

This depends on the SPD technology, the installation rules and the load capacity.

If the circuit length is less than 10 m or $U_{P/f} < U_w /2$, the protection distance I_{po} may be disregarded.

NOTE When the maximum length of the circuit between the SPD and the equipment is greater than 10 m and $U_{P/f} > U_w /2$, the oscillation protection distance can be estimated using the following equation:

$$I_{po} = [U_w - U_{P/f}] / k \quad \text{(m)}$$

where k = 25 V/m.

D.2.4 Induction protection distance I_{pi}

Lightning flashes to the structure or to ground nearby the structure, can induce an overvoltage in the circuit loop between the SPD and the equipment, which adds to U_p and thereby reduces the protection efficiency of the SPD. Induced overvoltages increase with dimensions of the loop (line routing, length of circuit, distance between PE and active conductors, loop area between power and signal lines) and decrease with attenuation of the magnetic field strength (spatial shielding and/or line shielding).

The induction protection distance I_{pi} is the maximum length of the circuit between the SPD and the equipment, for which the protection of the SPD is still adequate (taking into account the induction phenomena).

In general, one should seek to minimize the loop between the SPDs and the equipment when the magnetic field generated by lightning is considered too high. Otherwise, the magnetic field and the induction effects can be reduced by

- spatial shielding of the building (LPZ 1) or of the rooms (LPZ 2 and higher),
- line shielding (use of shielded cables or cable ducts).

When these precautions are followed, the induction protection distance I_{pi} can be disregarded.

NOTE In the very heavy conditions (large loop of unshielded lines and very high values of inducing lightning current) the induction protection distance I_{pi} can be estimated using the following equation:

$$I_{pi} = [U_w - U_{P/f}] / h \quad \text{(m)}$$

where

$h = 300 \times K_{S1} \times K_{S2} \times K_{S3}$ (V/m) for flashes near the structure, or

$h = 30\,000 \times K_{S0} \times K_{S2} \times K_{S3}$ (V/m) for flashes to the structure (worst case).

K_{S1}, K_{S2}, K_{S3} are the factors reported in Clause B.3 of IEC 62305-2, namely:

K_{S1} : spatial shielding due to LPS or other shields at boundary LPZ 0/1,

K_{S2} : spatial shielding due to shields at boundary LPZ 1/2 or higher,

K_{S3} : characteristics of internal wiring.

K_{S0} is a factor which takes into account the shielding effectiveness due to the LPS at boundary LPZ 0/1 and is given by:

$K_{S0} = 0{,}06 \times w^{0{,}5}$ for grid-like LPS with mesh width w (m), or

$K_{S0} = K_c$ for no grid-like LPS (see Annex C of IEC 62305-3).

D.2.5 Coordination of SPDs

In a coordinated SPD protection, cascaded SPDs shall be energy coordinated in accordance with IEC 61643-12 or IEC 61643-22. The SPD manufacturer shall provide sufficient information as to how to achieve energy coordination between their SPDs.

Information on SPD coordination is provided in Annex C.

D.2.6 Procedure for installation of a coordinated SPD protection

A coordinated SPD protection should be installed as follows:

1) At the line entrance into the structure (at the boundary of LPZ 1, e.g. at installation point MB) install SPD 1 (D.1.2).
2) Determine the impulse withstand voltage U_w of internal systems to be protected.
3) Select the voltage protection level U_{p1} of SPD 1 to ensure that the effective protection level $U_{p1} \leq U_w$.
4) Check the requirements for the protection distances $I_{po/1}$ and $I_{pi/1}$ (D.2.3 and D.2.4)

If conditions 3) and 4) are fulfilled the equipment is protected by SPD 1.

Otherwise, an additional SPD 2(s) is needed.

5) Closer to the equipment (at the boundary of LPZ 2, e.g. at the installation point SB or SA), install SPD2 (D.1.2), and energy coordinated with the upstream SPD1 (D.2.5).
6) Select protection level U_{p2} of SPD 2 so to ensure that the effective protective level $U_{p2} \leq U_w$.
7) Check the requirements for the protection distances $I_{po/2}$ and $I_{pi/2}$ (D.2.3 and D.2.4).

If conditions 6) and 7) are fulfilled, the equipment is protected by coordinated SPD 1 and SPD 2.

Otherwise an additional SPD 3(s) is needed close to the equipment (e.g. at installation point SA), and energy coordinated with the upstream SPD1 and SPD2 (D.2.5).

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[1] IEC 61000-1-1:1992, *Electromagnetic compatibility (EMC) – Part 1: General – Section 1: Application and interpretation of fundamental definitions and terms*

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