INTERNATIONAL STANDARD

Protection against lightning –
Part 4: Electrical and electronic systems within structures

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INTERNATIONAL STANDARD

Protection against lightning –
Part 4: Electrical and electronic systems within structures

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION
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PROTECTION AGAINST LIGHTNING –

Part 4: Electrical and electronic systems within structures

FOREWORD

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International Standard IEC 62305-4 has been prepared by IEC technical committee 81: Lightning protection.

This second edition cancels and replaces the first edition, published in 2006, and constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

1) Isolating interfaces capable of reducing conducted surges on lines entering the structure are introduced.

2) Minimum cross-sections for bonding components are slightly modified.

3) First negative impulse current is introduced for calculation purposes as electromagnetic source of harm to the internal systems.

4) Selection of SPD with regard to voltage protection level is improved to take into account oscillation and induction phenomena in the circuit downstream of SPD.

5) Annex C dealing with SPD coordination is withdrawn and referred back to SC 37A.

6) A new informative Annex D is introduced giving information on factors to be considered in the selection of SPDs.

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

FDIS	Report on voting
81/373/FDIS	81/383/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 closely as possible, in accordance with the ISO/IEC Directives, Part 2.

A list of all the parts in the IEC 62305 series, under the general title *Protection against lightning*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date 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- withdrawn,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.

A bilingual version of this standard may be issued at a later date.

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 62305-1:

D1   injury to living beings by electric shock;

D2   physical damage (fire, explosion, mechanical destruction, chemical release) due to lightning current effects, including sparking;

D3   failure of internal systems due to LEMP.

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 equipment via connecting wiring;

b)   the effects of radiated electromagnetic fields directly into equipment itself.

Surges to the structure can originate from sources external to the structure or from within the structure itself:

–   surges which originate externally from the structure are created by lightning flashes striking incoming lines or the nearby ground, and are transmitted to electrical and electronic systems within the structure via these lines;

–   surges which originate internally within the structure are created by lightning flashes striking the structure itself or the nearby ground.

NOTE 1 Surges can also originate internally within the structure, from switching effects, e.g. switching of inductive loads.

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 2 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 in accordance with IEC 62305-3 or in an external spatial shield in accordance with 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 electrical and electronic system protection (SPM) to reduce the risk of permanent failures due to lightning electromagnetic impulse (LEMP) within a structure.

This standard does not cover protection against electromagnetic interference due to lightning, which may cause malfunctioning of internal 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 [1] [^1] and in the IEC 61000 series [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 60364-5-53:2001, *Electrical installations of buildings – Part 5-53: Selection and erection of electrical equipment – Isolation, switching and control*

IEC 60664-1:2007, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*

IEC 61000-4-5:2005, *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 – Basic EMC Publication*

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

IEC 61643-1:2005, *Low-voltage surge protective devices – Part 1: Surge protective devices connected to low-voltage power distribution systems – Requirements and tests*

IEC 61643-12:2008, *Low-voltage surge protective devices – Part 12: Surge protective devices connected to low-voltage power distribution systems – Selection and application principles*

[^1]: Figures in square brackets refer to the bibliography.

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

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

IEC 62305-1:2010, *Protection against lightning – Part 1: General principles*

IEC 62305-2:2010, *Protection against lightning – Part 2: Risk management*

IEC 62305-3:2010, *Protection against lightning – Part 3: Physical damage to structures and life hazard*

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 telecommunication 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 protection
LP
complete system for the protection of structures and/or electrical and electronic systems in those structures from the effects of lightning, consisting of an LPS and SPM

3.5
lightning protection system
LPS
complete system used to reduce physical damage due to lightning flashes to a structure

NOTE   It consists of both external and internal lightning protection systems.

3.6
lightning electromagnetic impulse
LEMP
all electromagnetic effects of lightning current via resistive, inductive and capacitive coupling which create surges and electromagnetic fields

3.7
surge
transient created by LEMP that appears as an overvoltage and/or overcurrent

3.8
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 part of IEC 62305, only withstand voltage between live conductors and earth is considered.

3.9
lightning protection level
LPL
number related to a set of lightning current parameters 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.

3.10
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).

3.11
LEMP protection measures
SPM
measures taken to protect internal systems against the effects of LEMP

NOTE   This is part of overall lightning protection.

3.12
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).

3.13
earth-termination system
part of an external LPS which is intended to conduct and disperse lightning current into the earth

3.14
bonding network
interconnecting network of all conductive parts of the structure and of internal systems (live conductors excluded) to the earth-termination system

3.15
earthing system
complete system combining the earth-termination system and the bonding network

3.16
surge protective device
SPD
device intended to limit transient overvoltages and divert surge currents; contains at least one non-linear component

3.17

SPD tested with I_{imp}

SPDs which withstand the partial lightning current with a typical waveform 10/350 μs and 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 61643-1:2005.

3.18

SPD tested with I_n

SPDs which withstand induced surge currents with a typical waveform 8/20 μs and 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 61643-1:2005.

3.19

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 61643-1:2005 defining the open circuit voltage U_{OC} 1,2/50 μs and the short-circuit current I_{SC} 8/20 μs of a 2 Ω combination wave generator.

3.20

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 SPDs are sometimes called "crowbar type".

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

3.21

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.

3.22

combination type SPD

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

3.23

coordinated SPD system

SPDs properly selected, coordinated and installed to form a system intended to reduce failures of electrical and electronic systems

3.24

isolating interfaces

devices which are capable of reducing conducted surges on lines entering the LPZ

NOTE 1   These include isolation transformers with earthed screen between windings, metal-free fibre optic cables and opto-isolators.

NOTE 2   Insulation withstand characteristics of these devices are suitable for this application intrinsically or via SPD.

4 Design and installation of SPM

4.1 General

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

The design of SPM should be carried out by experts in lightning and surge protection who possess a broad knowledge of EMC and installation practices.

Protection against LEMP is based on the lightning protection zone (LPZ) concept: the zone containing systems to be protected shall be divided into LPZs. These zones are theoretically assigned part of space (or of an internal system) 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).

◯ Bonding of incoming services directly or by suitable SPD

IEC 2762/10
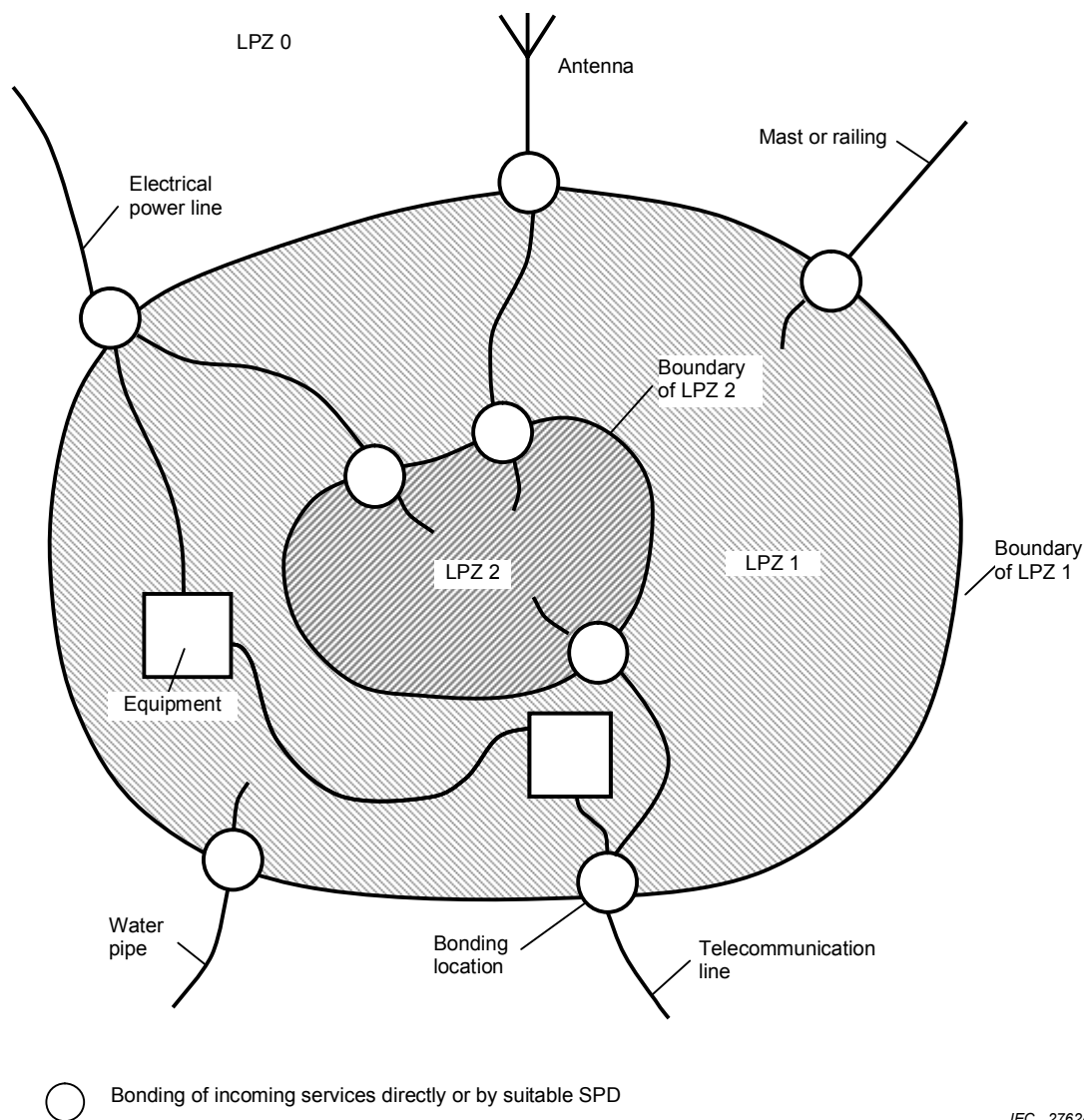
NOTE This figure shows an example of dividing a structure into inner LPZs. All metal services entering the structure are bonded via bonding bars at the boundary of LPZ 1. In addition, the conductive services entering LPZ 2 (e.g. computer room) are bonded via bonding bars at the boundary of LPZ 2.

Figure 1 – General principle for the division into different LPZ
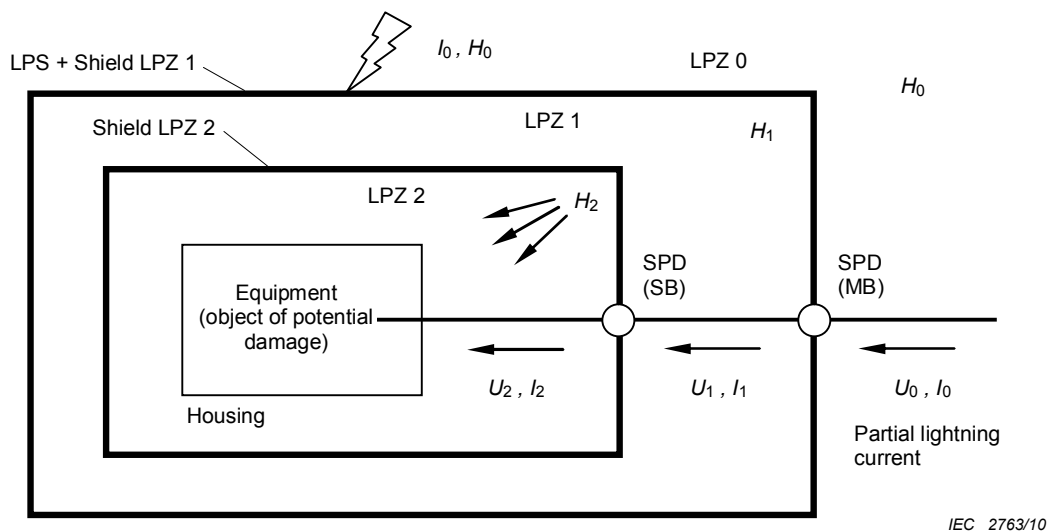
Figure 2a – SPM using spatial shields and a coordinated SPD system – Equipment well protected against conducted surges ($U_2 << U_0$ and $I_2 << I_0$) and against radiated magnetic fields ($H_2 << H_0$)
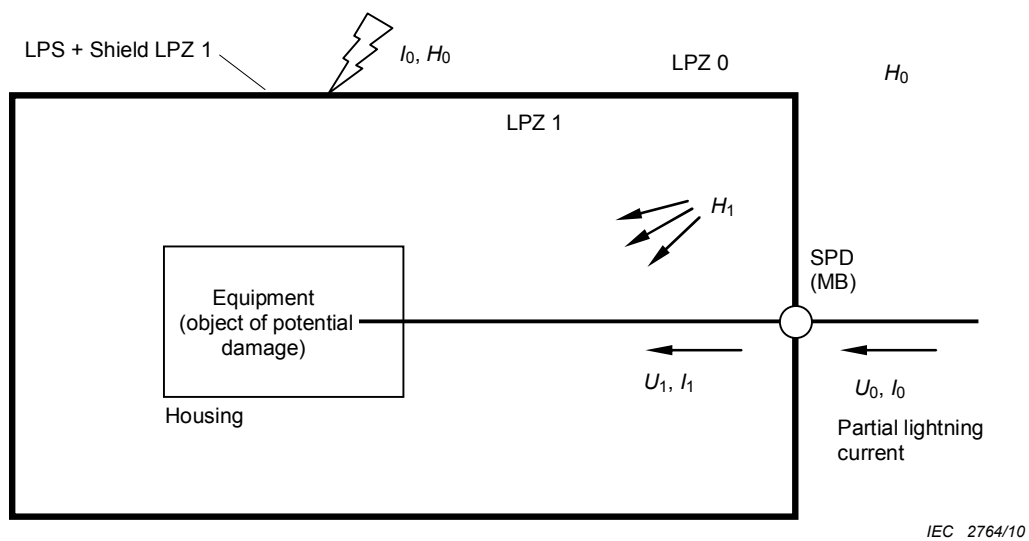
Figure 2b – SPM using spatial shield of LPZ 1 and SPD protection at entry of LPZ 1 – Equipment protected against conducted surges ($U_1 < U_0$ and $I_1 < I_0$) and against radiated magnetic fields ($H_1 < H_0$)

IEC 2765/10
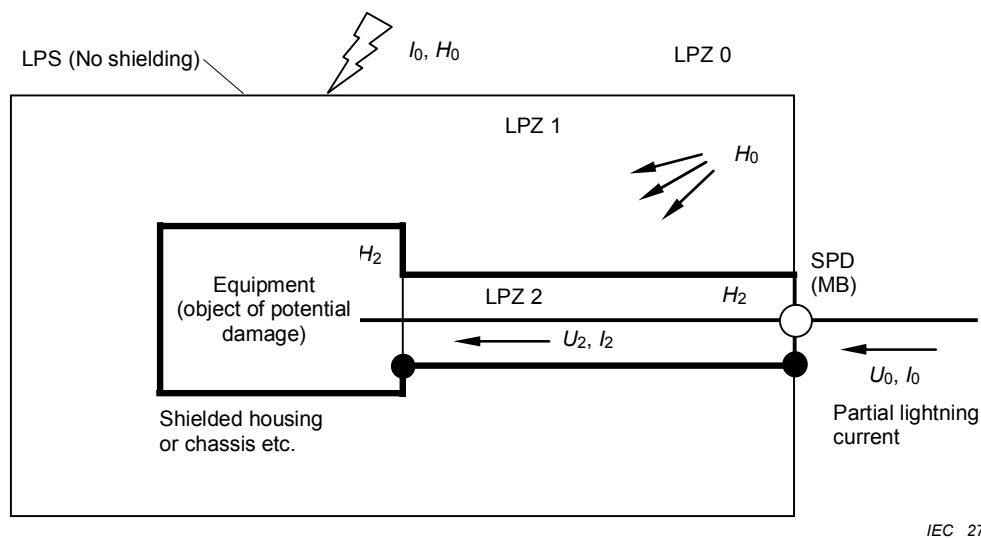
Figure 2c – SPM using internal line shielding and SPD protection at entry of LPZ 1 – Equipment protected against conducted surges ($U_2 < U_0$ and $I_2 < I_0$) and against radiated magnetic fields ($H_2 < H_0$)

IEC 2766/10
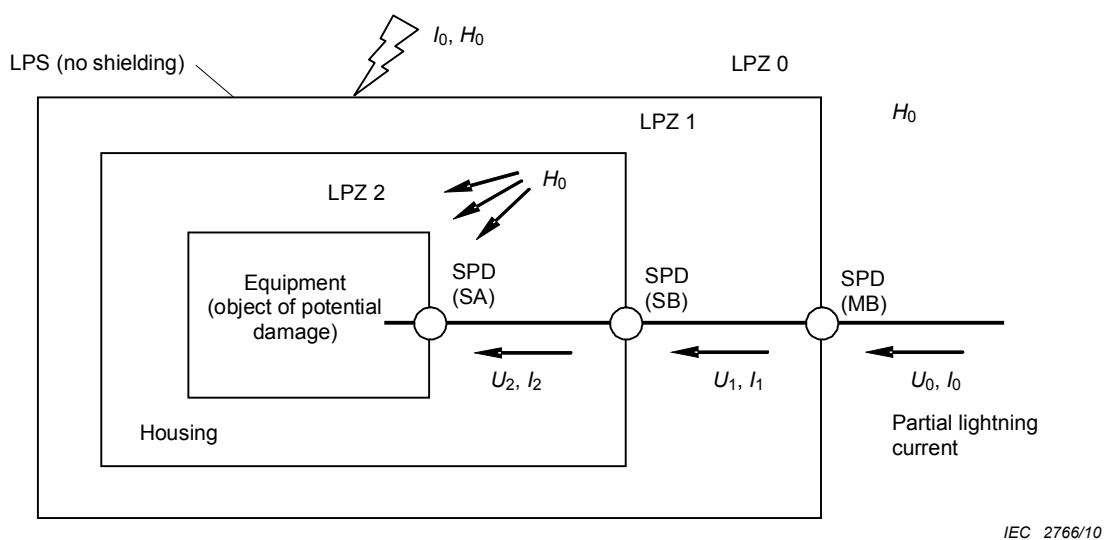
Figure 2d – SPM using a coordinated SPD system only –Equipment protected against conducted surges ($U_2 << U_0$ and $I_2 << I_0$), but not against radiated magnetic field (H_0)

Key

━━━ shielded boundary
───── non-shielded boundary

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

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

Figure 2 – Examples of possible SPM (LEMP protection measures)

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

- conducted and induced surges transmitted to equipment via connecting wiring,
- effects of radiated electromagnetic fields impinging directly onto equipment itself.

For protection against the effects of radiated electromagnetic fields impinging directly onto the equipment, SPM consisting of spatial shields and/or shielded lines, combined with shielded equipment enclosures, should be used.

For protection against the effects of conducted and induced surges being transmitted to the equipment via connection wiring, SPM consisting of a coordinated SPD system should be used.

Failures due to electromagnetic fields impinging directly onto the equipment can be considered negligible provided the equipment complies with the relevant radio frequency emission and immunity EMC product standards.

In general, equipment is required to comply with the relevant EMC product standards therefore SPM consisting of a coordinated SPD system is usually considered sufficient to protect such equipment against the effects of LEMP.

For equipment not complying with relevant EMC product standards, SPM consisting of a coordinated SPD system alone is considered inadequate to protect such equipment against the effects of LEMP. In this case, Annex A provides further information as to how to achieve best protection against directly impinging electromagnetic fields. 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.

If required for specific applications, a simulated system-level test which includes the SPD(s), installation wiring and the actual equipment may be performed in the laboratory to verify protection withstand coordination.

4.2   Design of SPM

SPM can be designed for protection of equipment against surges and electromagnetic fields. Figure 2 provides some examples of SPM using protection measures, such as LPS, magnetic shields and coordinated SPD systems:

- SPM employing spatial shields and a coordinated SPD system will protect against radiated magnetic fields and against conducted surges (see Figure 2a). Cascaded spatial shields and coordinated SPDs can reduce the magnetic field and surges to a lower threat level.

- SPM employing a spatial shield of LPZ 1 and an SPD at the entry of LPZ 1 can protect equipment 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).

- SPM 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 level (in one step from LPZ 0 to LPZ 2), a special SPD may be required (e.g. additional coordinated stages inside) to reach a sufficient low voltage protection level.

- SPM using a coordinated SPD system 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 in accordance with Figures 2a to 2c are recommended especially for equipment which does not comply with relevant EMC product standards.

NOTE 3   An LPS in accordance with IEC 62305-3 that employs only 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 SPM.

4.3   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 isolating interfaces and/or 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 isolating interfaces and/or 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 SPM, e.g. installation of a coordinated SPD system and/or magnetic shielding (see Figure 2). Depending on the 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 whole structure) (see Figure B.2).

Interconnection of LPZs 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).

IEC 2767/10

IEC 2768/10
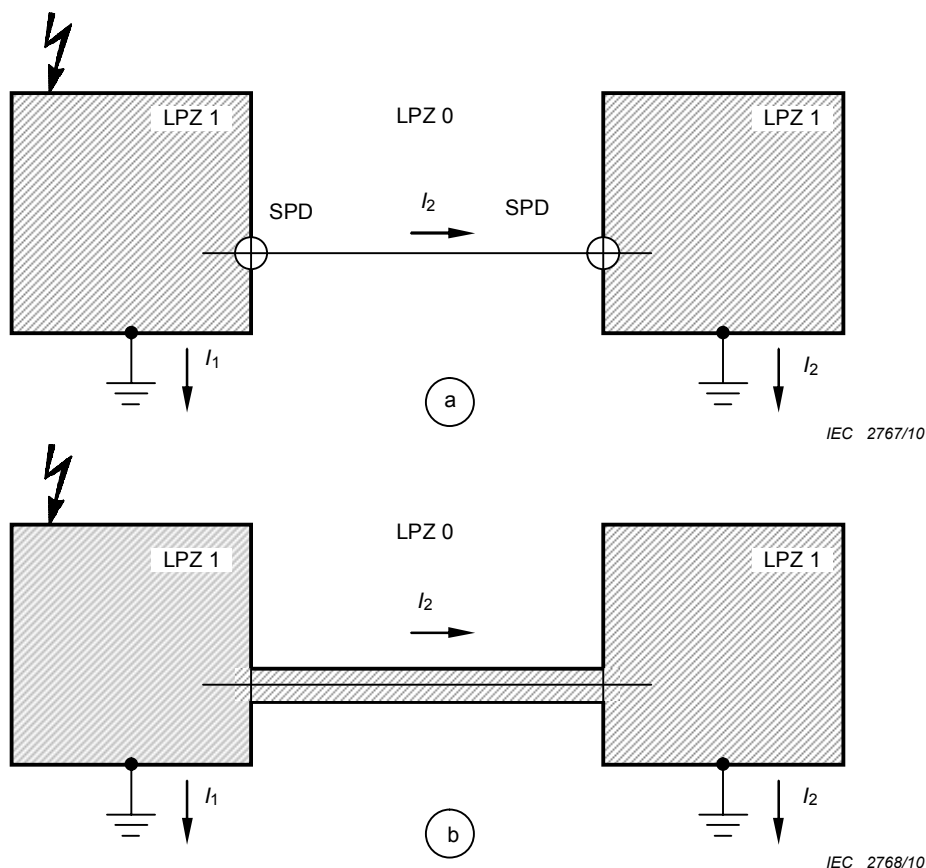
NOTE Figure 3a shows two LPZ 1 connected by electrical or signal lines. Special care should be taken if both LPZ 1 represent separate structures with separate earthing systems, spaced tens or hundreds of metres from each other. In this case, a large part of the lightning current can flow along the connecting lines, which are not protected.

Key

I_1, I_2 partial lightning currents

Figure 3a – Interconnecting two LPZ 1 using SPDs

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.

Key

I_1, I_2 partial lightning currents

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

IEC   2768/10

c

IEC   2769/10

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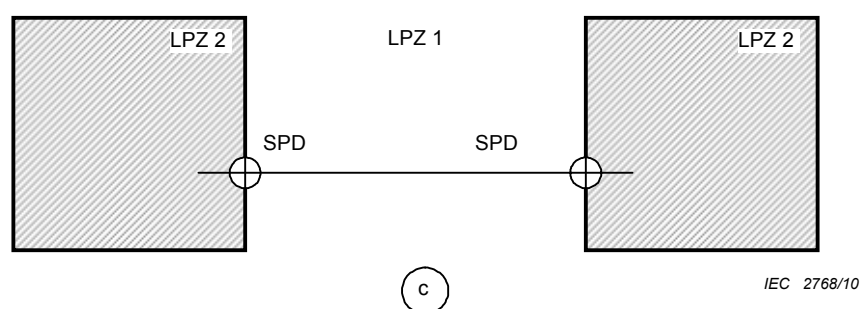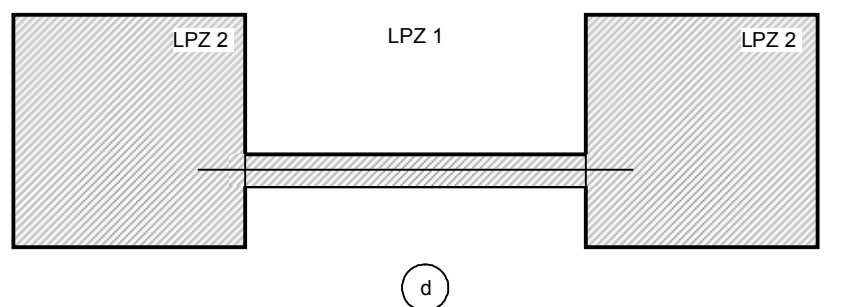
NOTE   Figure 3c shows two LPZ 2 connected by electrical or signal lines. Because the lines are exposed to the threat level of LPZ 1, SPDs at the entry into each LPZ 2 are required.

Figure 3c – Interconnecting two LPZ 2 using SPDs

NOTE   Figure 3d shows that such interference can be avoided and the SPDs 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 SPDs (see Figure 4).

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

IEC   2770/10

a

IEC   2771/10

b
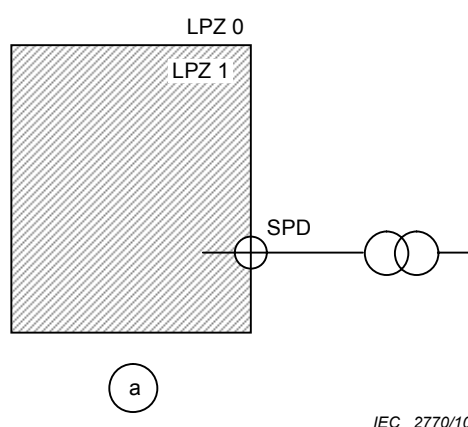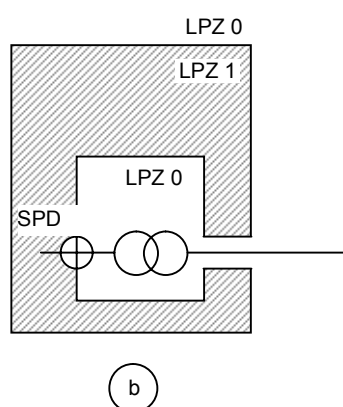
NOTE   Figure 4a shows a structure powered by a transformer. If the transformer is placed outside the structure, only the low voltage lines entering the structure require protection using an SPD.

NOTE   If the transformer is placed inside the structure and does not have an SPD installed on the HV side (since the owner of the building is often not permitted to adopt protection measures on the high voltage side) then Figure 4b applies. Figure 4b shows that the problem can be solved by extending LPZ 0 into LPZ 1, which again requires SPDs to be installed on the low voltage side only.

Figure 4a – Transformer outside the structure

Figure 4b – Transformer inside the structure

(within LPZ 0)   **(LPZ 0 extended into LPZ 1)**

IEC 2772/10

IEC 2773/10
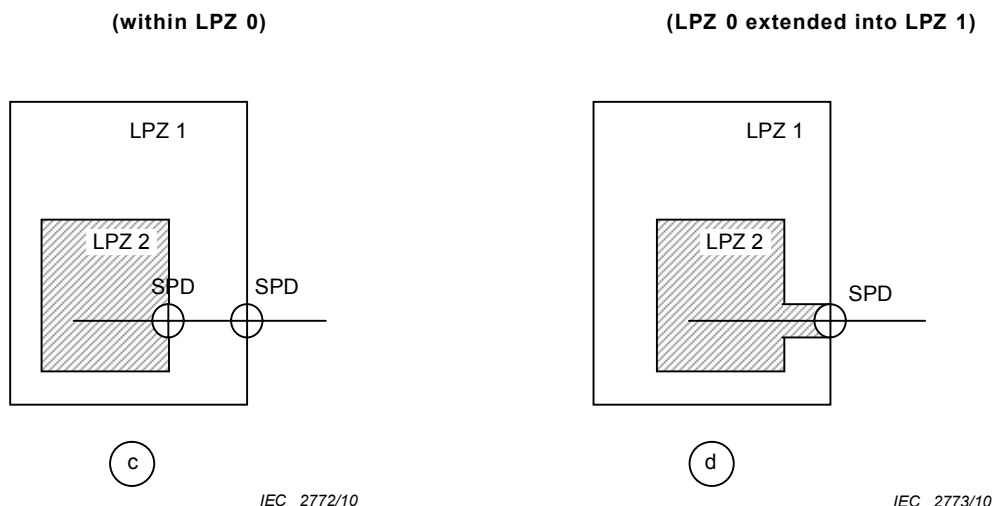
NOTE Figure 4c shows an LPZ 2 supplied by an electrical or signal line. This line needs two coordinated SPDs: one at the boundary of LPZs 0/1, the other at the boundary of LPZs 1/2.

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 4c – Two coordinated SPDs needed – SPD (between zones 0/1) and SPD (between zones 1/2)

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

Figure 4 – Examples for extended lightning protection zones

4.4   Basic SPM

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 the magnetic field.

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

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

   Shielding of internal lines, using shielded cables or cable ducts, minimizes internally-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 system (see Clause 7)**

   A coordinated SPD system limits the effects of externally originated and internally created surges.

- **Isolating interfaces (see Clause 8)**

   Isolating interfaces limits the effects of conducted surges on lines entering the LPZ.

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.

Other SPM can be used alone or in combination.

SPM 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 SPM 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 SPM for internal systems in existing structures is given in Annex B.

NOTE 2 Lightning equipotential bonding (EB) in accordance with IEC 62305-3 will protect against dangerous sparking only. Protection of internal systems against surges requires a coordinated SPD system in accordance with this standard.

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

5 Earthing and bonding

5.1 General

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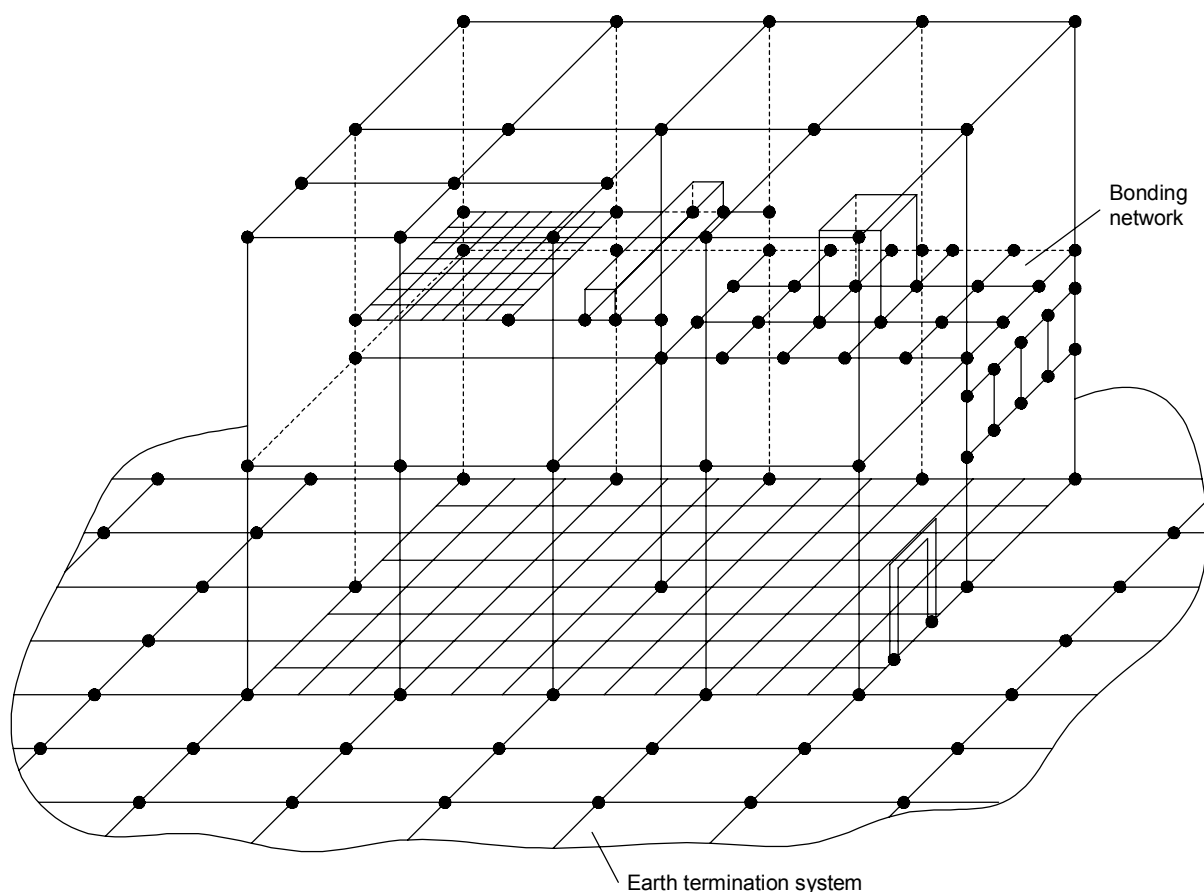
NOTE   All drawn conductors are either bonded structural metal elements or bonding conductors. Some of them may also serve to intercept, conduct and disperse the lightning current into the earth.

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

5.2   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.
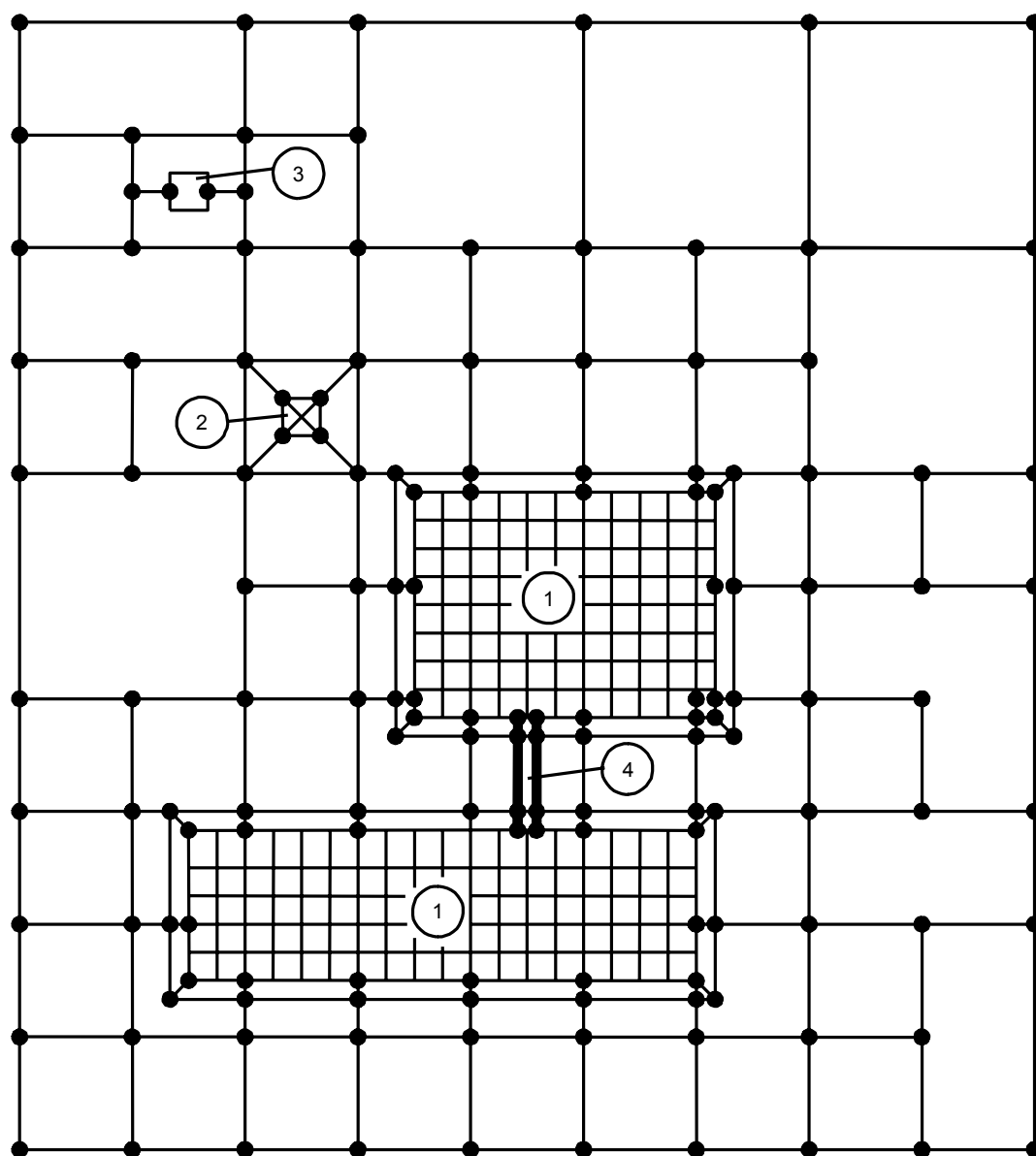
Key

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 may be referenced in some special cases 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.

5.3   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 systems, 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.
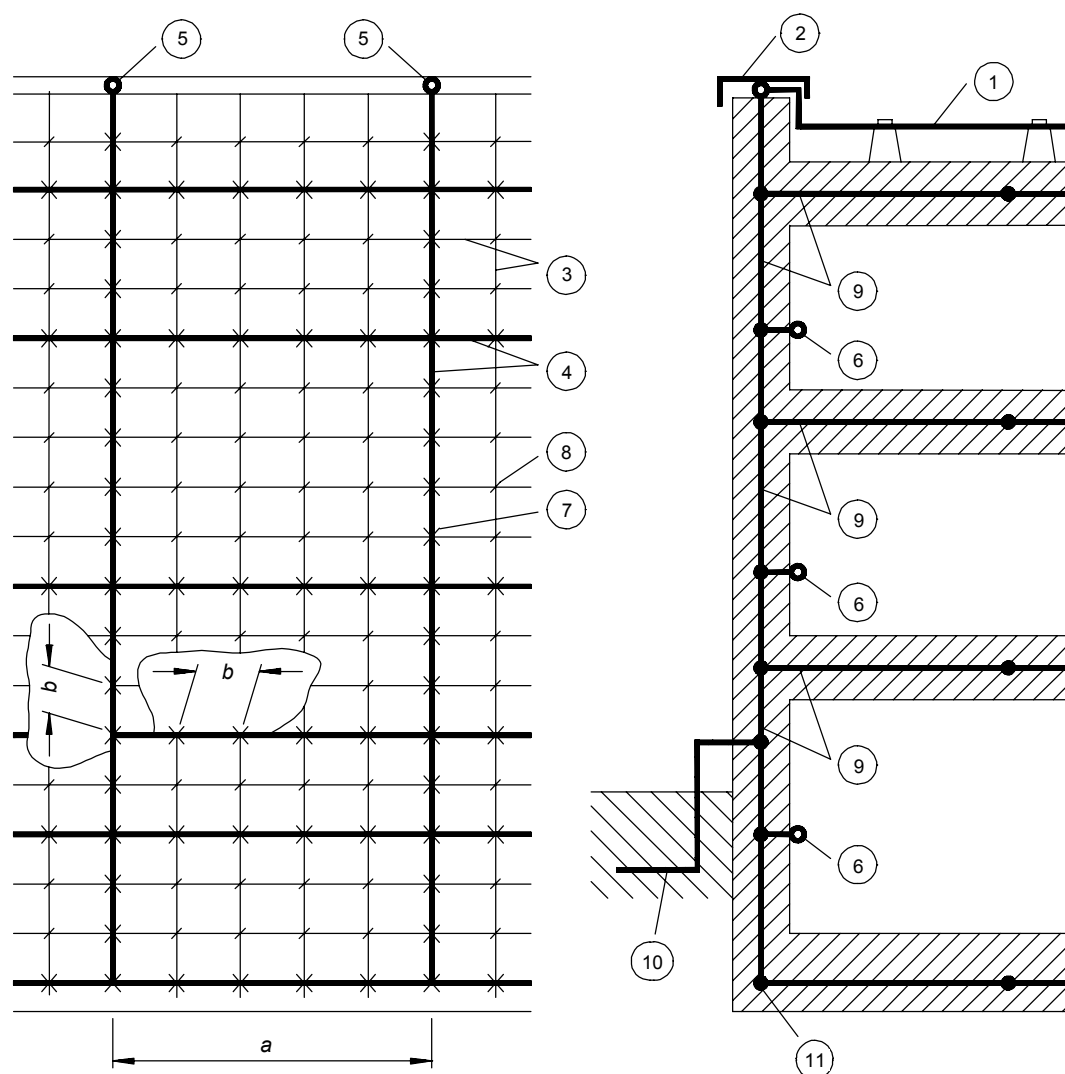
IEC 2776/10

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 made 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
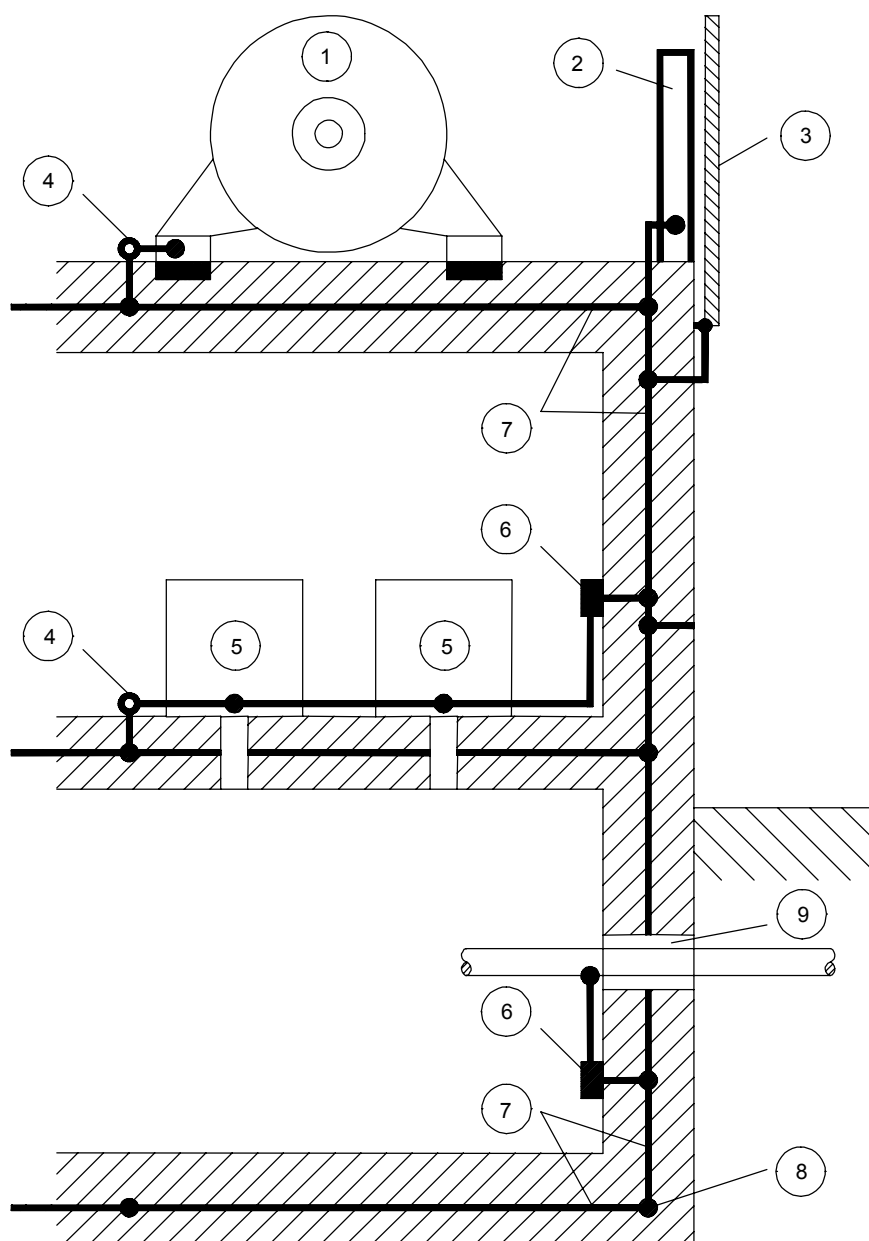
IEC 2777/10

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 entry point 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 in accordance with the following configurations (see Figure 9):
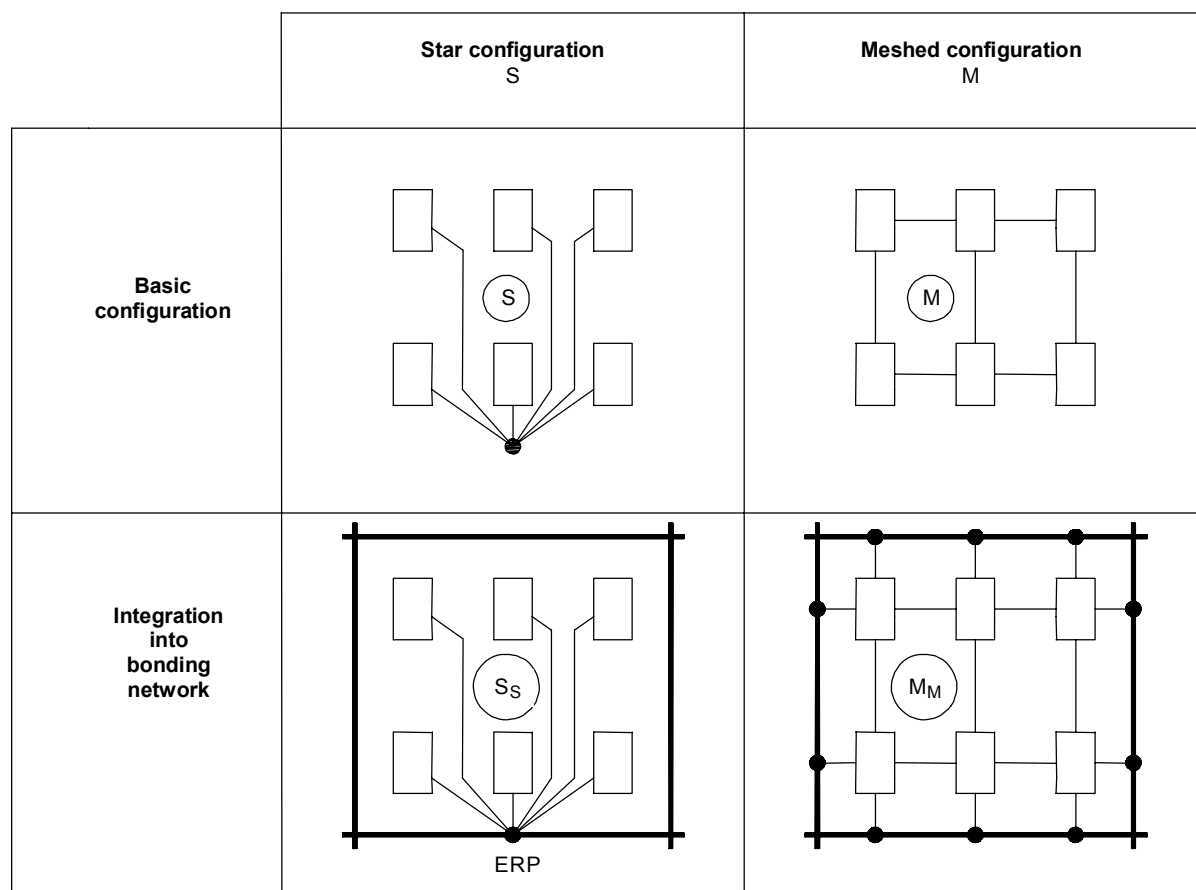
IEC   2778/10

Key

————— bonding network

——— bonding conductor

▢ equipment

● bonding point to the bonding network

ERP earthing reference point

S_S star point configuration integrated by star point

M_M meshed configuration integrated by mesh

Figure 9 – Integration of conductive parts of internal 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, and close to, 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).
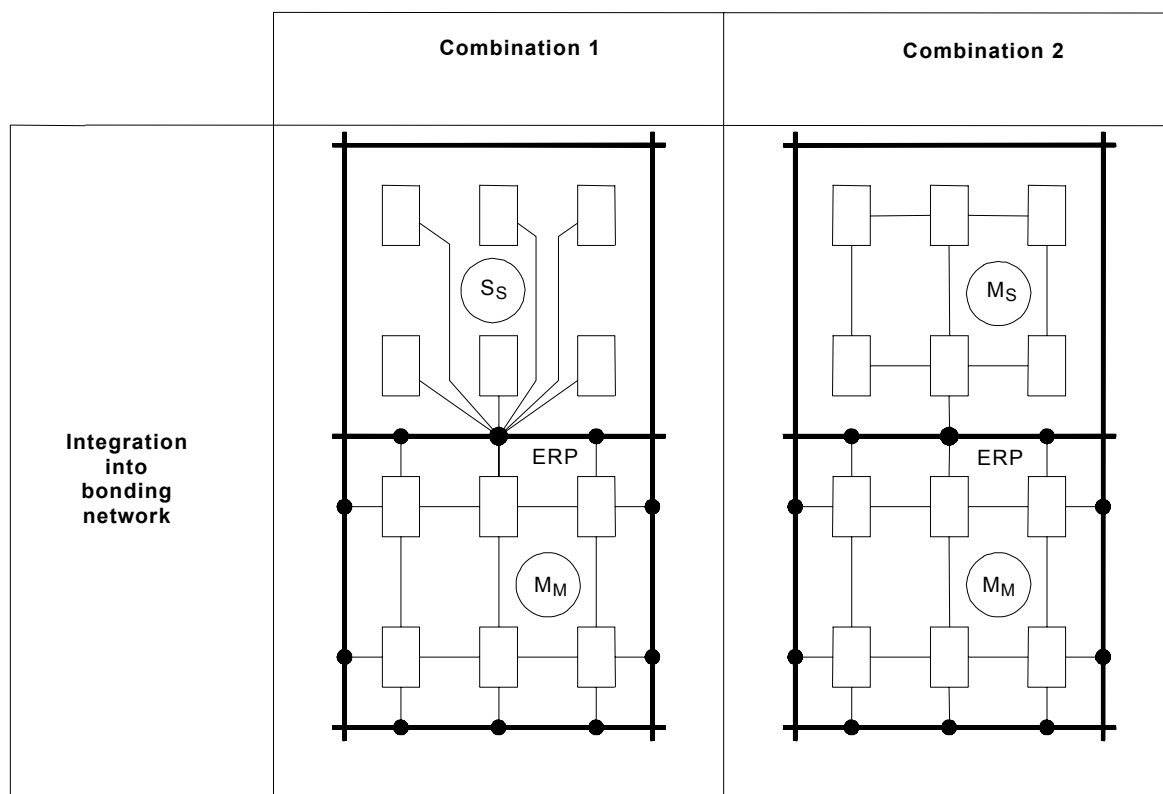
IEC   2779/10

Key

────────   bonding network

──────   bonding conductor

☐   equipment

●   bonding point to the bonding network

ERP   earthing reference point

S_S star point configuration integrated by star point

M_M meshed configuration integrated by mesh

M_S meshed configuration integrated by star point

Figure 10 – Combinations of integration methods of conductive parts of internal systems into the bonding network

5.4   Bonding bars

Bonding bars shall be installed for bonding of

- all conductive services entering an 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 the shortest possible route;
- material and dimensions of bonding bars and bonding conductors shall comply with 5.6;
- SPDs should be installed in such a way as to use the shortest possible connections to the bonding bar as well as to live conductors, thus minimizing inductive voltage drops;
- on the protected side of the circuit (downstream of an SPD), mutual induction effects should be minimized, either by minimizing the loop area or using shielded cables or cable ducts.

5.5   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 closely 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 realise this, bonding to a ring bonding bar (ring conductor) is recommended.

Equipotential bonding SPDs 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 SPDs required.

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.

5.6   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 below.

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

SPDs shall be dimensioned in accordance with Clause 7.

Table 1 – Minimum cross-sections for bonding components

Bonding component		Material [a]	Cross-section [b] mm²
Bonding bars (copper, copper coated steel or galvanized steel)		Cu, Fe	50
Connecting conductors from bonding bars to the earthing system or to other bonding bars (carrying the full or a significant part of lightning current)		Cu	16
		Al	25
		Fe	50
Connecting conductors from internal metal installations to bonding bars (carrying a partial lightning current)		Cu	6
		Al	10
		Fe	16
Earthing conductors to the SPD (carrying the full or a significant part of lightning current) [c]	Class I	Cu	16
	Class II		6
	Class III		1
	Other SPDs [d]		1

[a]   Other material used should have cross-sections ensuring equivalent resistance.

[b]   In some countries, smaller conductor sizes may be used, provided that they fulfil the thermal and mechanical requirements – see Annex D of IEC 62305-1:2010.

[c]   For SPDs used in power applications, additional information for connecting conductors is given in IEC 60364-5-53 and IEC 61643-12.

[d]   Other SPDs include SPDs used in telecommunication and signalling systems.

6   Magnetic shielding and line routing

6.1   General

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.

6.2   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.

6.3   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 enclosures of equipment are used for this purpose.

6.4   Routing of internal lines

Suitable routing of internal lines minimizes induction loops and reduces the creation of surge voltages internally in 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.

6.5   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 the responsibility of the SPM planner (since the owner of external lines is normally the network provider).

6.6   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 62305-3:2010;

– layouts of grid-like spatial shields and the minimum cross-section of their conductors, shall comply with Table 6 of IEC 62305-3:2010.

The dimensions of magnetic shields not intended to carry lightning currents are not required to conform to Tables 3 and 6 of IEC 62305-3:2010:

– at the boundary of LPZs 1/2 or higher, provided that the separation distance *s* between magnetic shields and the LPS is fulfilled (see 6.3 of IEC 62305-3:2010),

– at the boundary of any LPZ, if the number of dangerous events N_D due to lightning flashes to the structure is negligible, i.e. N_D < 0,01 per year.

7   Coordinated SPD system

The protection of internal systems against surges requires a systematic approach consisting of coordinated SPDs for both power and signal lines. The rules for the selection and installation of a coordinated SPD system are similar in both cases (see Annex C).

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

In SPM using LPZ 1 only, an 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 C).

The SPD's test requirements shall comply with

– IEC 61643-1 for power systems,

– IEC 61643-21 for telecommunication and signalling systems.

Information on selection and installation of a coordinated SPD system are reported in Annex C. Selection and installation of a coordinated SPD system shall comply also with

– IEC 61643-12 and IEC 60364-5-53 for protection of power systems,

– IEC 61643-22 for protection of telecommunications and signalling systems.

Information and guidelines as to the magnitude of surges created by lightning, for the purpose of dimensioning SPDs at different installation points in the structure, is provided in Annex D of this standard and Annex E of IEC 62305-1:2010.

8   Isolating interfaces

Isolating interfaces may be used to reduce the effects of LEMP. Protection of such interfaces against overvoltages, where needed, may be achieved using SPDs. The withstand level of the isolating interface, and the voltage protection level of the SPD U_P shall be coordinated with the overvoltage categories of IEC 60664-1.

NOTE   The scope of this part of IEC 62305 deals with protection of equipment within structures, and not protection of interconnected structures to which the isolation transformer may provide some benefit.

9   SPM management

9.1   General

To achieve a cost-effective and efficient protection system, the design should be carried out during the building conception 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 a retrofit to existing structures, the cost of SPM is generally higher than that of the cost for new structures. However, it is possible to minimize the cost by a proper choice of LPZ and by using existing installations or by upgrading them.

Proper protection can be achieved only if

–   provisions are defined by a lightning protection expert,
–   good coordination exists between the different experts involved in the building construction and in the SPM (e.g. civil and electrical engineers),
–   the management plan of 9.2 is followed.

The SPM 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.

9.2   SPM management plan

Planning and coordination of the SPM 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.

In accordance with 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 system shall be determined;
–   suitability of isolating interfaces 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.

**Table 2 – SPM 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 [a]	To check the need for LEMP protection If needed, select suitable SPM using the risk assessment method To check the risk reduction after each successive protection measure taken	Lightning protection expert [b] Owner
Final risk analysis [a]	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 - LPZs and their boundaries	Lightning protection expert [b] Owner
SPM planning	Definition of the SPM: - spatial shielding measures - bonding networks - earth-termination systems - line shielding and routing - shielding of incoming services - a coordinated SPD system - isolating interface	Lightning protection expert Owner Architect Planners of internal systems Planners of relevant installations
SPM design	General drawings and descriptions Preparation of lists for tenders Detailed drawings and timetables for the installation	Engineering office or equivalent
Installation of the SPM including supervision	Quality of installation Documentation Possibly revision of the detailed drawings	Lightning protection expert Installer of the SPM Engineering office Supervisor
Approval of the SPM	Checking and documenting the state of the system	Independent lightning protection expert Supervisor
Recurrent inspections	Ensuring the adequacy of the SPM	Lightning protection expert Supervisor
[a] See IEC 62305-2.		
[b] With a broad knowledge of EMC and knowledge of installation practices.		

9.3   Inspection of SPM

9.3.1   General

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

– the SPM complies with the design,
– the SPM is capable of performing its design function,
– any new additional protection measure is integrated correctly into the SPM.

Inspections shall be made

- during the installation of the SPM,

- after the installation of the SPM,

- periodically,

- after any alteration of components relevant to the SPM,

- possibly after a lightning flash to the structure (e.g. where indicated by a lightning flash counter, or where an eyewitness account of a flash 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.

NOTE   Where no specific requirements are identified by the authority having jurisdiction, the values of Table E.2 of IEC 62305-3:2010 are recommended.

9.3.2   Inspection procedure

9.3.2.1   Checking of technical documentation

After the installation of new SPM measures, 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 SPM.

9.3.2.2   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 and interconnected,

- 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.

9.3.2.3   Measurements

A measurement of electrical continuity should be performed on those parts of an earthing and bonding system that are not visible for inspection.

NOTE   If an SPD does not have a visual indicator (flag), measurements shall be performed in accordance with the manufacturer's instructions to confirm its operating status, when so required.

9.3.3   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 SPM,

- any deviation(s) from the technical documentation,

- the result of any measurements performed.

9.4   Maintenance

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

Annex A
(informative)

Basis of electromagnetic environment evaluation in an LPZ

A.1   General

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

A.2   Damaging effects on electrical and electronic systems due to lightning

A.2.1   The source of damage

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

NOTE   For protection considerations the influence of the lightning electric field is usually of minor interest.

A.2.2   Object of damage

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 the full lightning current of a direct lightning strike.

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

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

- the rated impulse voltage level of the power installation is defined in Table F.1 of IEC 60664-1:2007. The withstand level is defined by the rated impulse withstand voltage 1,5 kV – 2,5 kV – 4 kV and 6 kV for 230/400V and 277/480V systems;

- The withstand level of telecommunication equipment is defined in ITU-T K.20 [3], K.21 [4] and K.45 [5].

The withstand level of equipment is generally defined in the accompanying product specification sheet, or can be tested

- against conducted surges using IEC 61000-4-5 with test levels for voltage: 0,5 kV – 1 kV – 2 kV and 4 kV at 1,2/50 μs waveshape and with test levels for current: 0,25 kV – 0,5 kV – 1 kV and 2 kA at 8/20 μs waveshape,

  NOTE   In order for certain equipment to meet the requirements of the above standard, it 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 A/m – 300 A/m – 1 000 A/m at 8/20 μs waveshape and IEC 61000-4-10 with test levels: 10 A/m – 30 A/m – 100 A/m at 1MHz.

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.2.3 Coupling mechanisms between the object of damage and the source of damage

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

A.3 Spatial shielding, line routing and line shielding

A.3.1 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 minimised 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.
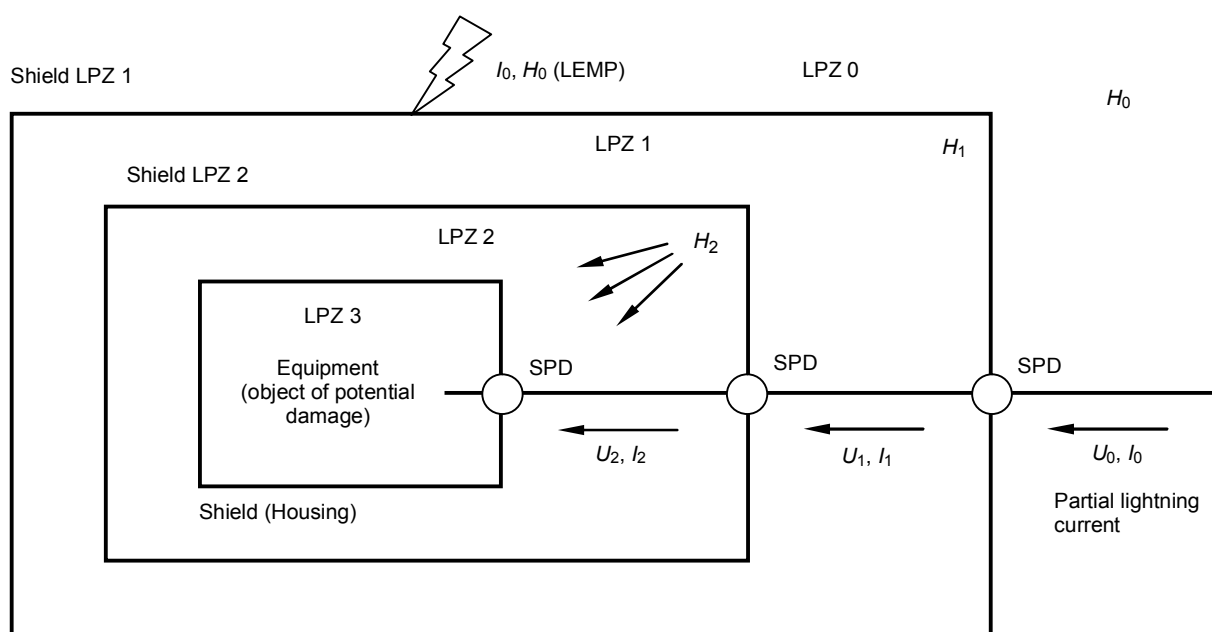
IEC 2780/10

Figure A.1 – LEMP situation due to lightning strike

In Table A.1 points 1, 2 and 3 define the parameters I_0, H_0, and U_W of Figure A.1; suitable test parameters, to assure that equipment is able to withstand the expected stress in its installation location, are given in points 4 and 5.

Table A.1 – Parameters relevant to source of harm and equipment

1.	**Primary source of harm LEMP** As defined from parameters in accordance with LPLs I to IV:				
	IEC 62305-1	I_0	**Impulse** μs	**Amplitude for LPL** I – II – III - IV kA	**Steepness for** LPL I – II – III - IV kA/μs	**Relevant effects:**
			10/350	200 – 150 – 100 – 100	20 – 15 – 10 – 10	Partial lightning current
			1/200	100 – 75 – 50 – 50	100 – 75 – 50 – 50	Induction
			0,25/100	50 – 37,5 – 25 – 25	200 – 150 – 100 – 100	Induction
		H_o	Derived from the corresponding I_0			
2.	**Rated impulse voltage level of power installation** As defined for overvoltage category I to IV for nominal voltages 230/400 V and 277/480 V:				
	IEC 60664-1	U_W	Overvoltage category I to IV		6 kV – 4 kV – 2,5 kV – 1,5 kV	
3.	**Withstand level of telecommunication equipment** ITU Recommendation K.20 [3], K.21 [4] and K.45 [5]				
4.	**Tests for equipment without suitable product standards** Withstand level of equipment as defined for conducted (U,I) lightning effects:				
	IEC 61000-4-5	U_{OC}	impulse 1,2/50 μs		4 kV – 2 kV – 1 kV – 0,5 kV	
		I_{SC}	impulse 8/20 μs		2 kVA – 1 kVA – 0,5 kVA – 0,25 kA	
5.	**Tests for equipment not complying with relevant EMC product standards** Withstand level of equipment 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 A/m – 300 A/m – 100 A/m	
	IEC 61000-4-10	H	Damped oscillation 1 MHz, (impulse 0,2/0,5 μs, T_P = 0,25 μs)		100 A/m – 30 A/m – 10 A/m	

The primary electromagnetic sources of harm to the electronic system are the lightning current I_0 and the magnetic field H_o. Partial lightning currents flow through the incoming services. These currents as well as the magnetic fields have approximately the same waveshape. The lightning current to be considered here consists of a first positive stroke I_F (typically with a long tail 10/350 μs waveshape) and first negative stroke I_{FN} (1/200 μs waveshape) and subsequent strokes I_S (0,25/100 μs waveshape). The current of the first positive stroke I_F generates the magnetic field H_F, the current of the first negative stroke I_{FN} generate the magnetic field H_{FN}, 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. Similarly the rising front of H_{FN} can be characterised by a damped oscillating field of 250 kHz with maximum value $H_{FN/MAX}$ and time to maximum value $T_{P/FN}$ of 1 μs.

It follows that the magnetic field of the first positive stroke can be characterized by a typical frequency of 25 kHz, the magnetic field of the first negative stroke by a typical frequency of 250 kHz, and the magnetic field of the subsequent strokes 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 LPZ, the effect of the unattenuated lightning defined by I_0 and H_0, should be reduced to or under the withstand level of the equipment. As shown in Figure A.1, the equipment should 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 positive stroke H_F and of the subsequent strokes H_S.

The induced surges caused by the magnetic field coupled into the induction loop (see Clause A.5), should be lower than, or equal to, the equipment's withstand level.

IEC   2781/10
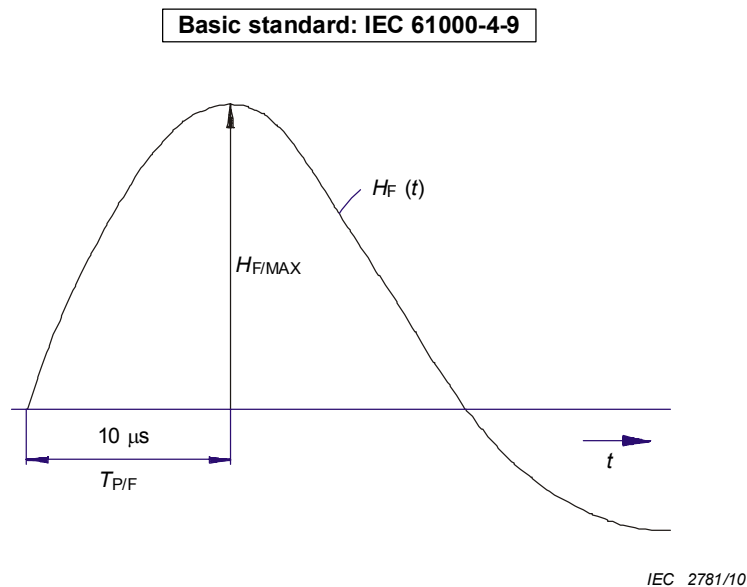
Figure A.2a – Simulation of the rise of the field of the first positive stroke (10/350 μs) by a single impulse 8/20 μs (damped 25 kHz oscillation)

Basic standard: IEC 61000-4-10

$H_S(t)$

$H_{S/MAX}$

0,25 μs

$T_{P/S}$

t

$H_{F/MAX}/H_{F/MAX} = 4:1$

IEC 2782/10
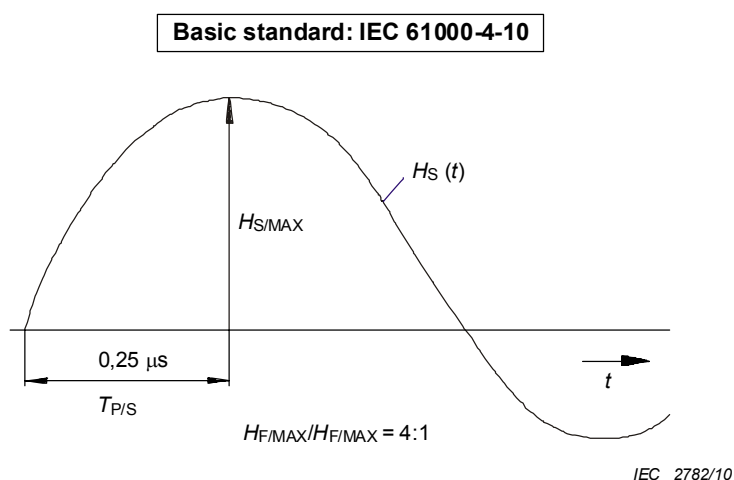
**Figure A.2b – Simulation of the rise of the field of the subsequent stroke
(0,25/100 μs) by damped 1MHz oscillations (multiple impulses 0,2/0,5 μs)**

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

NOTE 2   The ratio of the maximum values $H_{F/MAX}$ / $H_{FN/MAX}$ / $H_{S/MAX}$ = 4: 2: 1

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

A.3.2   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 in accordance with 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 LPZ 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.
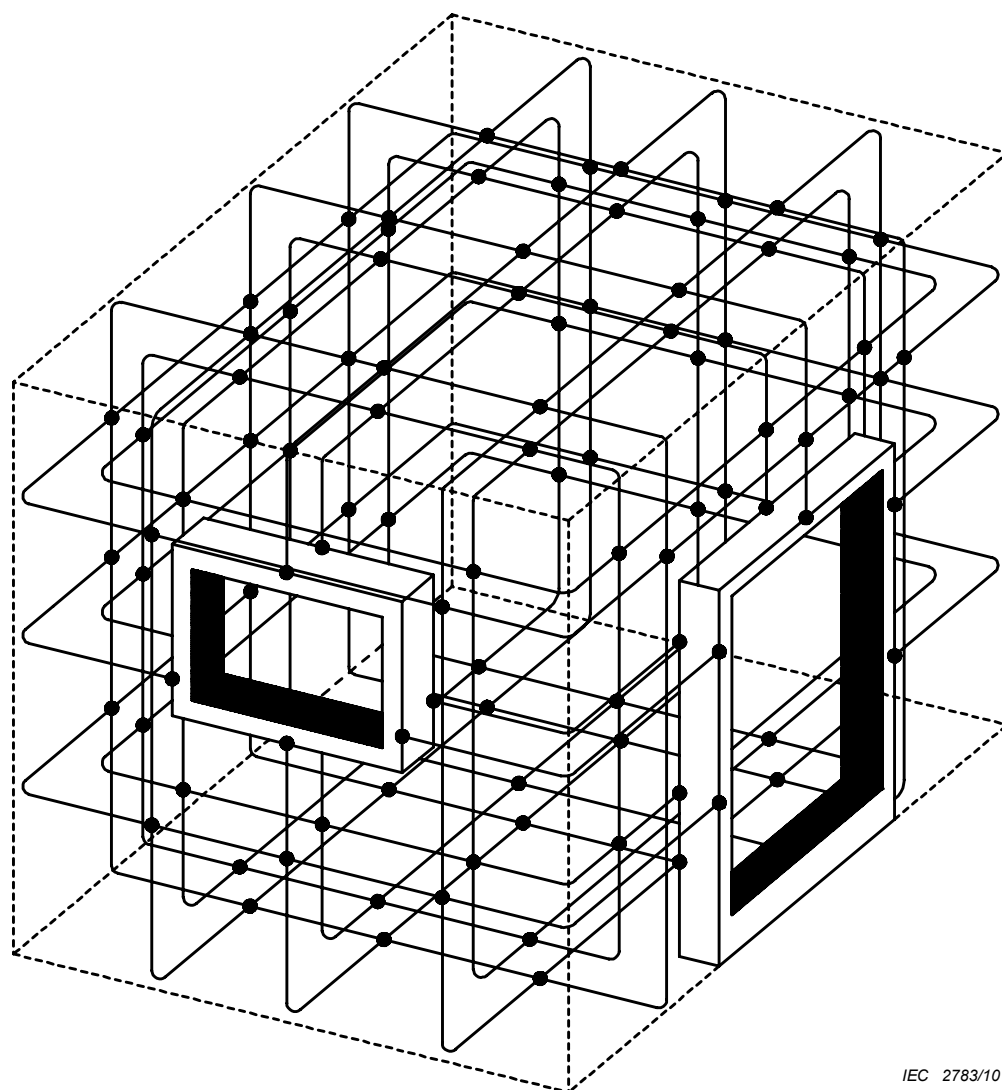
IEC 2783/10

Key

●   welded 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

Internal systems should 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).
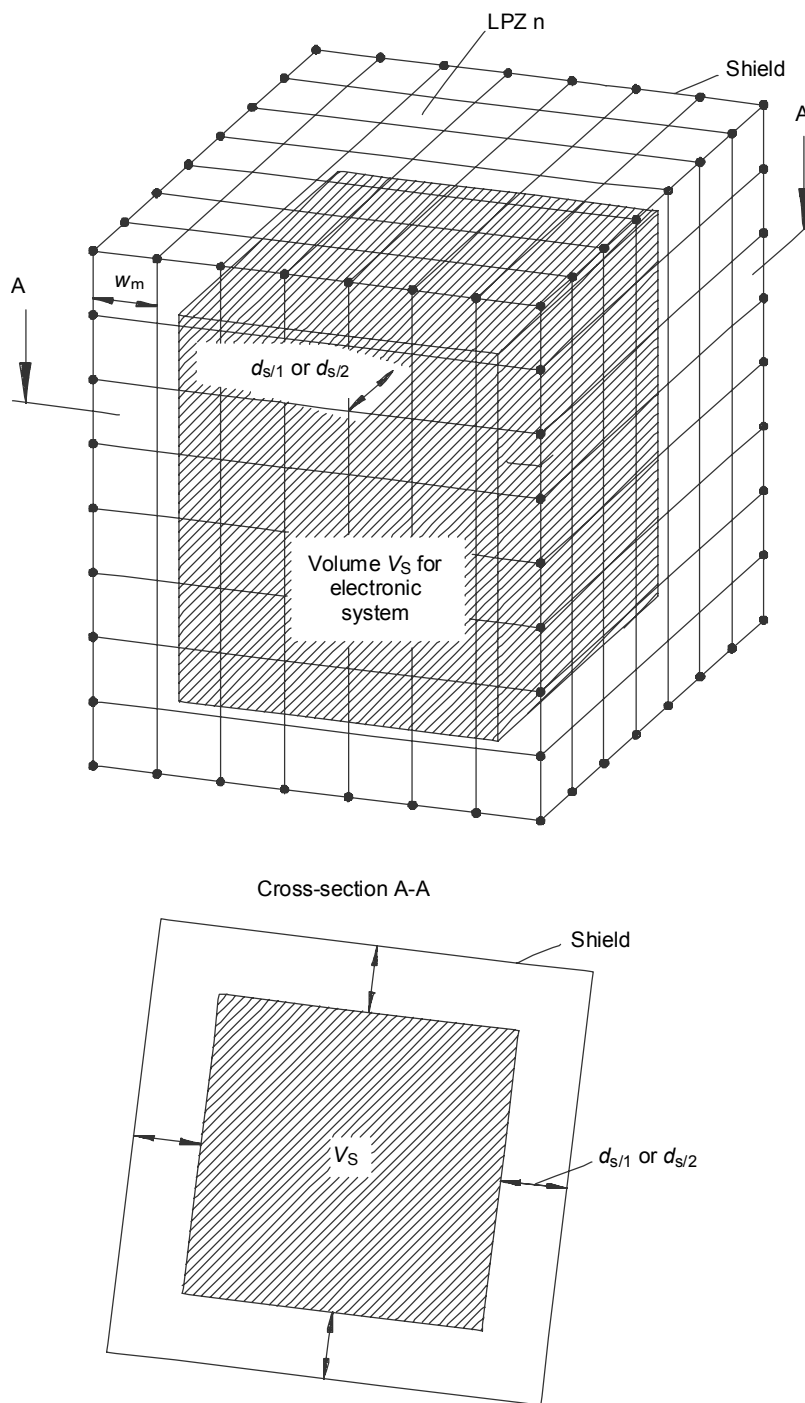
NOTE   The volume V_S should keep a safety distance $d_{s/1}$ or $d_{s/2}$ from the shield of LPZ n – see Clause A.4.

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

A.3.3   Line routing and line shielding

Surges induced into the internal 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 Figures A.5).

Key
1 equipment
2 signal wiring
3 power wiring
4 induction loop
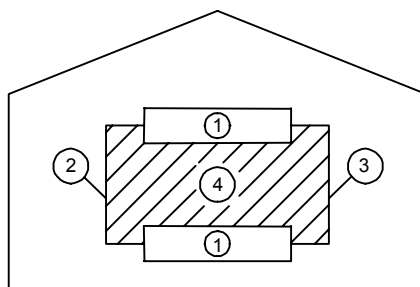
IEC 2785/10

Figure A.5a – Unprotected system

Key
1 equipment
2 signal wiring
3 power wiring
5 spatial shielding
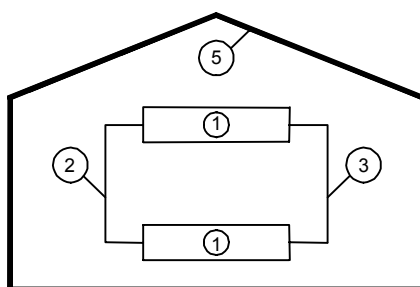
IEC 2786/10

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

Key
1 equipment
2 signal wiring
3 power wiring
6 line shielding
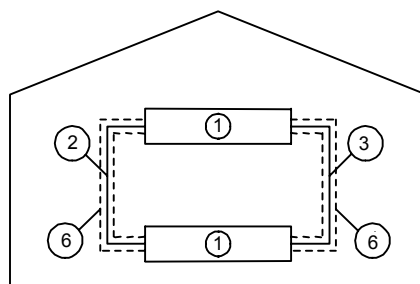
IEC 2787/10

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

Key
1 equipment
2 signal wiring
3 power wiring
7 reduced loop area
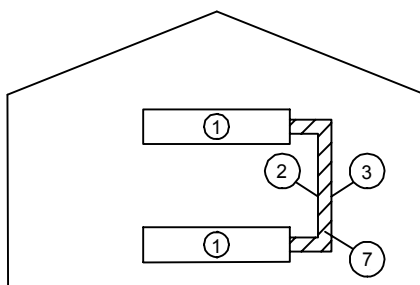
IEC 2788/10

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

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

The conductive cables connected to internal systems should be routed as closely 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 [6]).

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 internal systems. Calculations of these induced voltages and currents are described in Clause A.5.

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 internal 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.

Metal component on the roof

LPZ 0_A

Equipment on the roof

Interception mesh

LPZ 0_B

LPZ 0_B

LPZ 1

LPZ 1

LPZ 0_B

LPZ 2

Shielded cabinet

LPZ 1

LPZ 1

Camera

LPZ 2

Bonding terminals

Metal facade

Steel reinforcement in concrete

LPZ 1

Ground level

Sensitive electronic equipment

Steel reinforcement

Extraneous metal services

Telecom lines

LPZ 1

0,4 kV power line

Extended LPZ 0_B

20 kV power line

LPZ 2

Metal cable conduit (extended LPZ 0_B)

Car parking

Foundation earthing electrode

IEC 2789/10

Key

· equipotential bonding

O surge protective device (SPD)

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

A.4   Magnetic field inside LPZ

A.4.1   Approximation for the magnetic field inside LPZ

If a theoretical (A.4.2), or experimental (A.4.3), investigation of the shielding effectiveness is not performed, the attenuation should be evaluated as follows.

A.4.1.1   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; 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.
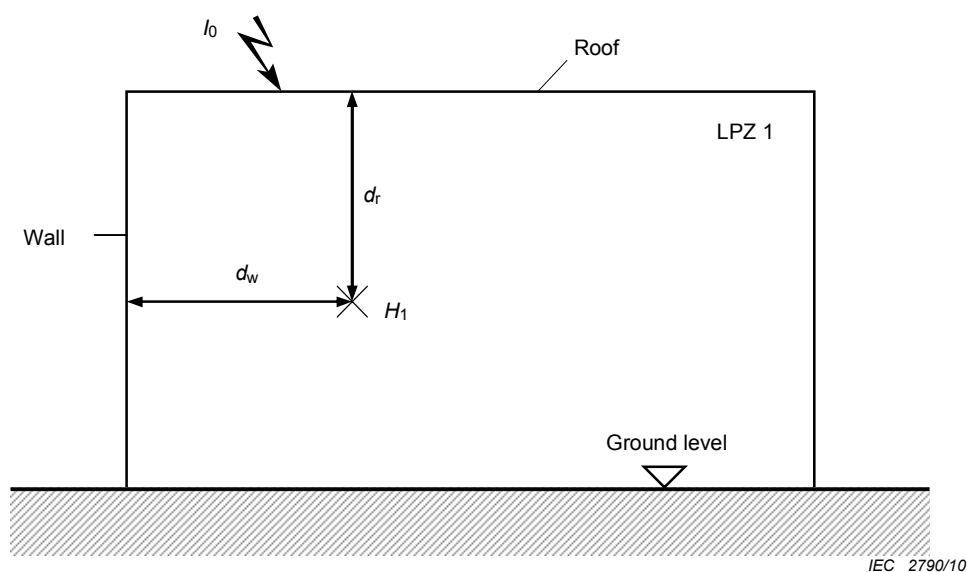
NOTE   Distances d_w and d_r are determined for the point considered.

Figure A.7a – Magnetic field inside LPZ 1
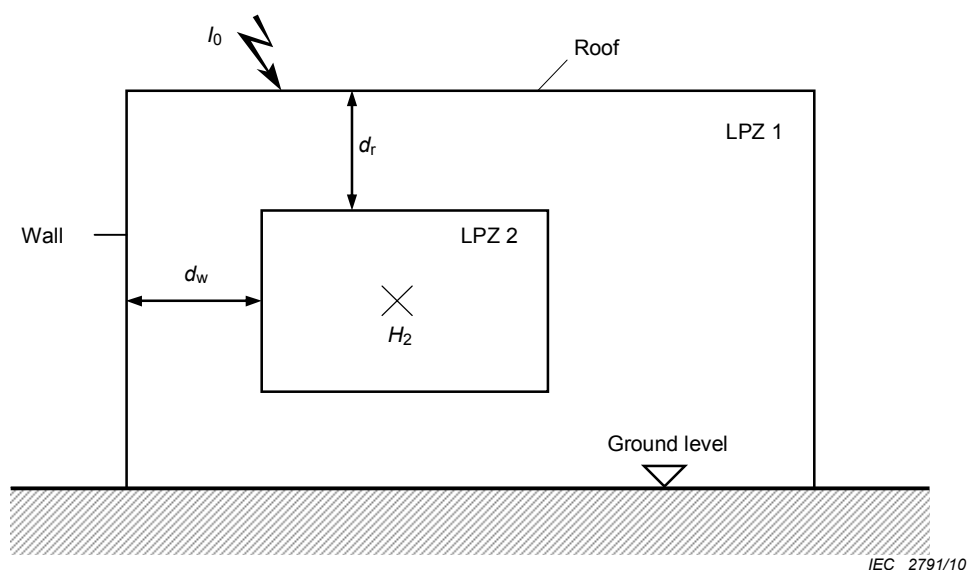
NOTE   Distances d_w and d_r are determined for the boundary of LPZ 2.

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:

$$H_1 = k_h \times I_0 \times w_m / (d_w \times \sqrt{d_r}) \quad \text{(A/m)} \tag{A.1}$$

where

d_r (m)   is the shortest distance between the point considered and the roof of shielded LPZ 1;

d_w (m)   is the shortest distance between the point considered to the wall of shielded LPZ 1;

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

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

w_m (m)   is the mesh width of the grid-like shield of LPZ 1.

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

– $H_{1/F/MAX}$ = $k_h \times I_{F/MAX} \times w_m / (d_w \times \sqrt{d_r})$ (A/m) caused by the first positive stroke   (A.2)

– $H_{1/FN/MAX}$ = $k_h \times I_{FN/MAX} \times w_m / (d_w \times \sqrt{d_r})$ (A/m) caused by the first negative stroke   (A.3)

– $H_{1/S/MAX}$ = $k_h \times I_{S/MAX} \times w_m / (d_w \times \sqrt{d_r})$ (A/m) caused by the subsequent strokes   (A.4)

where

$I_{F/MAX}$ (A)   is the maximum value of the first positive stroke current in accordance with the protection level;

$I_{FN/MAX}$ (A)   is the maximum value of the first negative stroke current in accordance with the protection level;

$I_{S/MAX}$ (A)   is the maximum value of the subsequent stroke currents in accordance with the protection level.

NOTE 1   The field is reduced by a factor of 2, if a meshed bonding network in accordance with 5.2 is installed.

These values of the 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):

$$d_s/1 = w_m \times SF / 10 \quad \text{(m) for } SF \geq 10 \tag{A.5}$$

$$d_s/1 = w_m \quad \text{(m)   for } SF < 10 \tag{A.6}$$

where

SF (dB) is the shielding factor evaluated from the formulae of Table A.3;

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

NOTE 2   Experimental results of the magnetic field inside an LPZ 1 with a grid-like shield indicate that the increase of the magnetic field close to the shield is less than that resulting from the equations above.

EXAMPLE

As an example, three copper grid-like shields with dimensions given in Table A.2, and having an average mesh width of w_m = 2 m, are considered (see Figure A.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.2. The distance to the roof is half of the height: d_r = $H/2$. The distance to the wall is half of the length: d_w = $L/2$ (centre) or equal to: d_w = $d_{s/1}$ (worst case near the wall).

Table A.2 – Examples for I_{0MAX} = 100 kA and w_m = 2 m

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

A.4.1.2   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.

IEC 2792/10
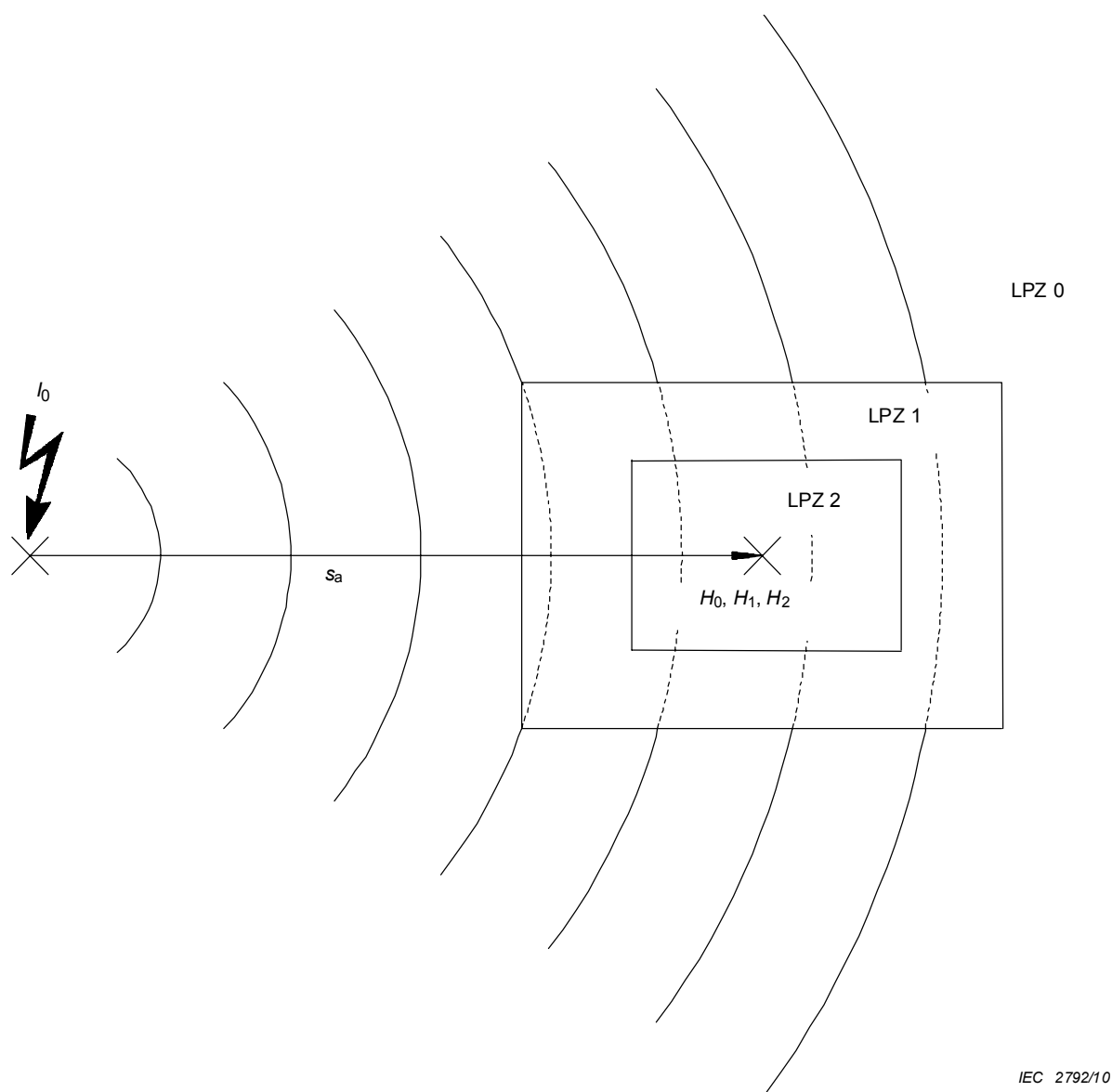
Figure A.8 – Evaluation of the magnetic field values in case of a nearby lightning strike

The shielding factor *SF* of the grid-like spatial shields for a plane wave is given in Table A.3 below.

Table A.3 – Magnetic attenuation of grid-like spatial shields for a plane wave

Material	*SF* (dB) [a, b]	
	25 kHz (valid for the first positive stroke)	1 MHz (valid for subsequent strokes) or 250 kHz (valid for the first negative stroke
Copper or aluminium	$20 \times \log (8{,}5/ w_m)$	$20 \times \log (8{,}5/ w_m)$
Steel [c]	$20 \times \log \left[(8{,}5 / w_m)/\sqrt{1 + 18 \times 10^{-6} / r_c^2} \right]$	$20 \times \log (8{,}5/ w_m)$
w_m mesh width of the grid-like shield (m).		
r_c radius of a rod of the grid-like shield (m).		
[a] *SF* = 0 in the case of negative results of the formulae.		
[b] *SF* increases by 6 dB, if a meshed bonding network in accordance with 5.2 is installed.		
[c] Permeability $\mu_r \approx 200$.		

The incident magnetic field H_0 is calculated using:

$$H_0 = I_0 / (2 \times \pi \times s_a) \quad \text{(A/m)} \tag{A.7}$$

where

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

s_a (m)   is the distance between the point of strike and the centre of the shielded volume.

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

– $H_{0/F/MAX} = I_{F/MAX} / (2 \times \pi \times s_a)$ (A/m) caused by the first positive stroke   (A.8)
– $H_{0/FN/MAX} = I_{FN/MAX} / (2 \times \pi \times s_a)$ (A/m) caused by the first negative stroke   (A.9)
– $H_{0/S/MAX} = I_{S/MAX} / (2 \times \pi \times s_a)$ (A/m) caused by the subsequent strokes   (A.10)

where

$I_{F/MAX}$ (A)   is the maximum value of the lightning current of the first positive stroke in accordance with the chosen protection level;

$I_{FN/MAX}$ (A)   is the maximum value of the lightning current of the first negative stroke in accordance with the chosen protection level;

$I_{S/MAX}$ (A)   is the maximum value of the lightning current of the subsequent strokes in accordance with the chosen protection level.

The reduction of H_0 to H_1 inside LPZ 1 can be derived using the *SF* values given in Table A.3:

$$H_{1/MAX} = H_{0/MAX} / 10^{SF/20} \quad \text{(A/m)} \tag{A.11}$$

where

SF (dB)   is the shielding factor evaluated from the formulae of Table A.3;

$H_{0/MAX}$ (A/m)   is the magnetic field in LPZ 0.

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

– $H_{1/F/MAX} = H_{0/F/MAX} / 10^{SF/20}$ (A/m) caused by the first positive stroke   (A.12)
– $H_{1/FN/MAX} = H_{0/FN/MAX} / 10^{SF/20}$ (A/m) caused by the first negative stroke   (A.13)

- $H_{1/S/MAX} = H_{0/S/MAX} / 10^{SF/20}$ (A/m) caused by the subsequent strokes   (A.14)

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).

- $d_{s/2} = w_m^{SF/10}$ (m)   for $SF \geq 10$ (A.15)
- $d_{s/2} = w_m$ (m)   for $SF < 10$ (A.16)

where

SF (dB)   is the shielding factor evaluated from the formulae of Table A.3;

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

For additional information concerning the calculation of the magnetic field strength inside grid-like shields in case of nearby lightning strikes, see A.4.3.

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.3) 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 (or width W) of the structure (LPZ 1), and of the rolling sphere radius, r, corresponding to $I_{0/MAX}$ (see Table A.4), defined from the electro-geometric model (see Clause A.4 of IEC 62305-1:2010).
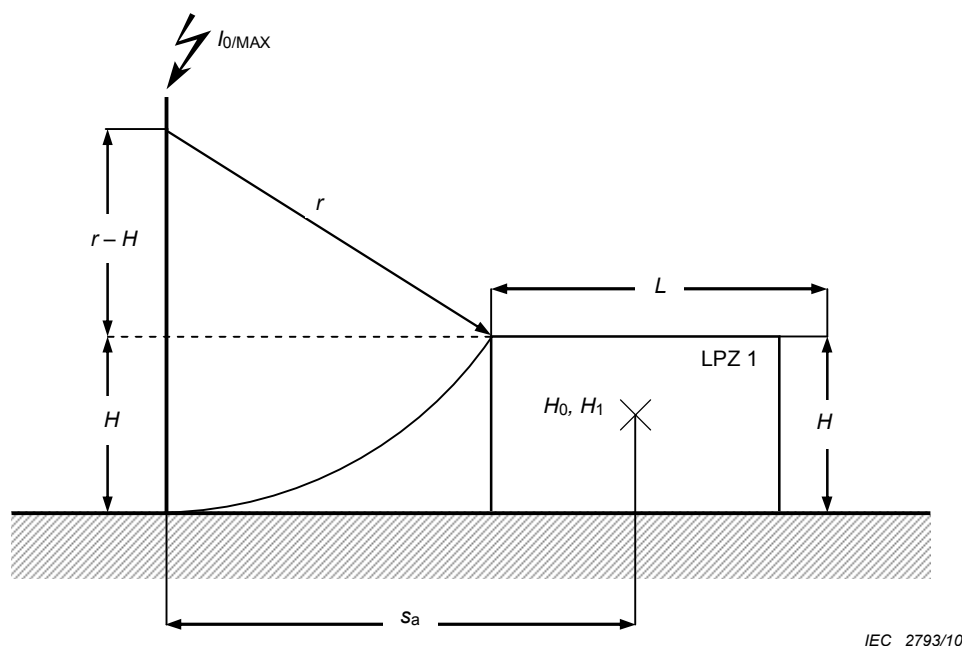
IEC 2793/10

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

The distance can be calculated as:

$$s_a = \sqrt{2 \times r \times H - H^2} + L/2 \qquad \text{for } H < r \qquad (A.17)$$

$$s_a = r + L/2 \qquad \text{for } H \geq r \qquad (A.18)$$

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.5. A grid-like shield of copper with an average mesh width of w_m = 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.5.

Table A.4 – 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.5 – Examples for $I_{0/MAX}$ = 100 kA and w_m = 2 m corresponding to SF = 12,6 dB

Type of shield see Figure A.10	L x W x H m	s_a m	$H_{0/MAX}$ A/m	$H_{1/MAX}$ A/m
1	10 × 10 × 10	67	236	56
2	50 × 50 × 10	87	182	43
3	10 × 10 × 50	137	116	27

A.4.1.3   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.4.1.2 for nearby lightning strikes:

$$H_{n+1} = H_n / 10^{SF/20} \text{ (A/m)} \qquad (A.19)$$

where

SF (dB)   is the shielding factor from Table A.3;

H_n (A/m)   is the magnetic field inside LPZ n (A/m).

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.4.1.1 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.4.1.2 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.4.1.2 and shown in Figure A.4).

A.4.2   Theoretical evaluation of the magnetic field due to direct lightning strikes

In A.4.1.1, the formulae 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.

Mesh width

w_m

10 m

Type 1
(10 m × 10 m × 10 m)
(with mesh width 2 m)

Type 2
(50 m × 50 m × 10 m)

Type 3
(10 m × 10 m × 50 m)

IEC   2794/10
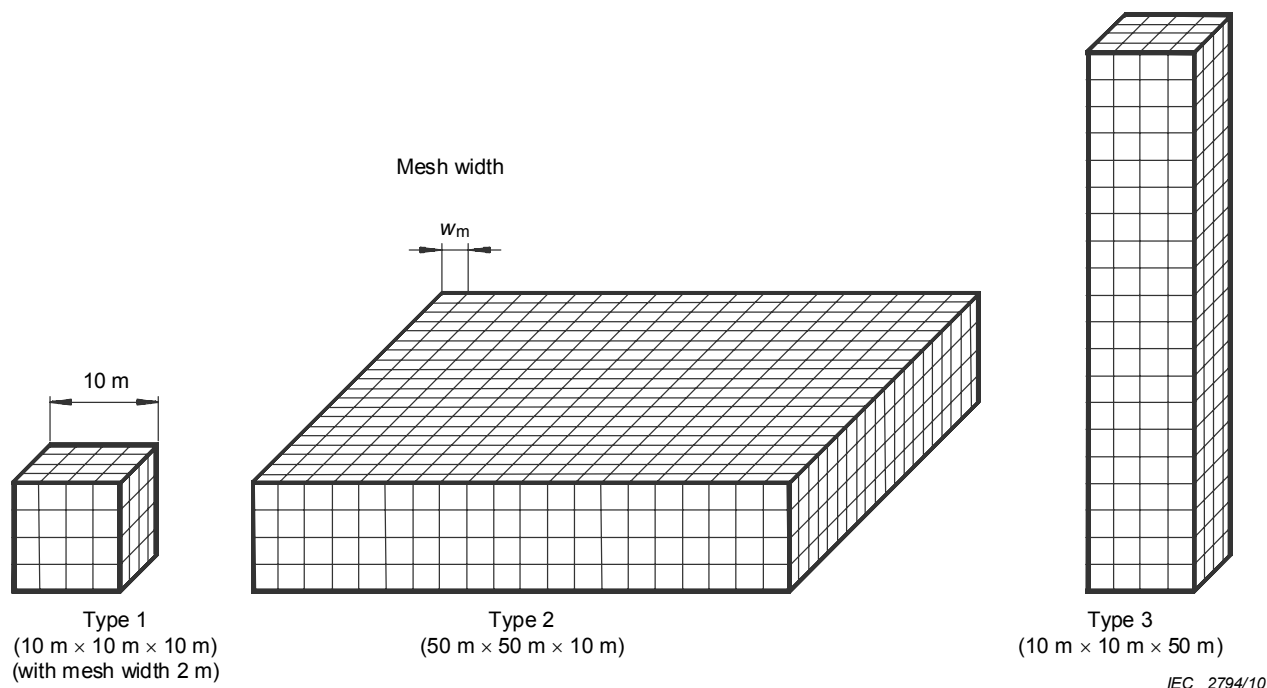
Figure A.10 – Types of grid-like large volume shields

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 according to mesh width

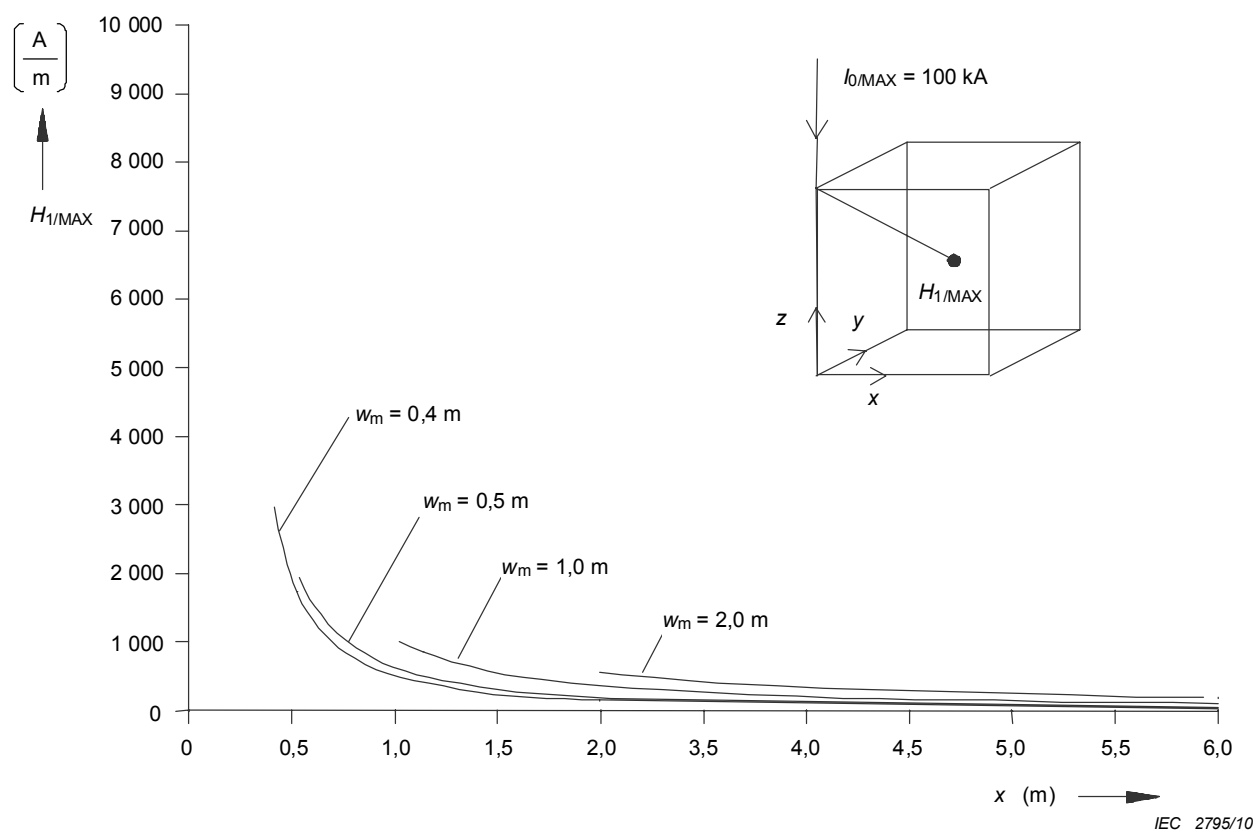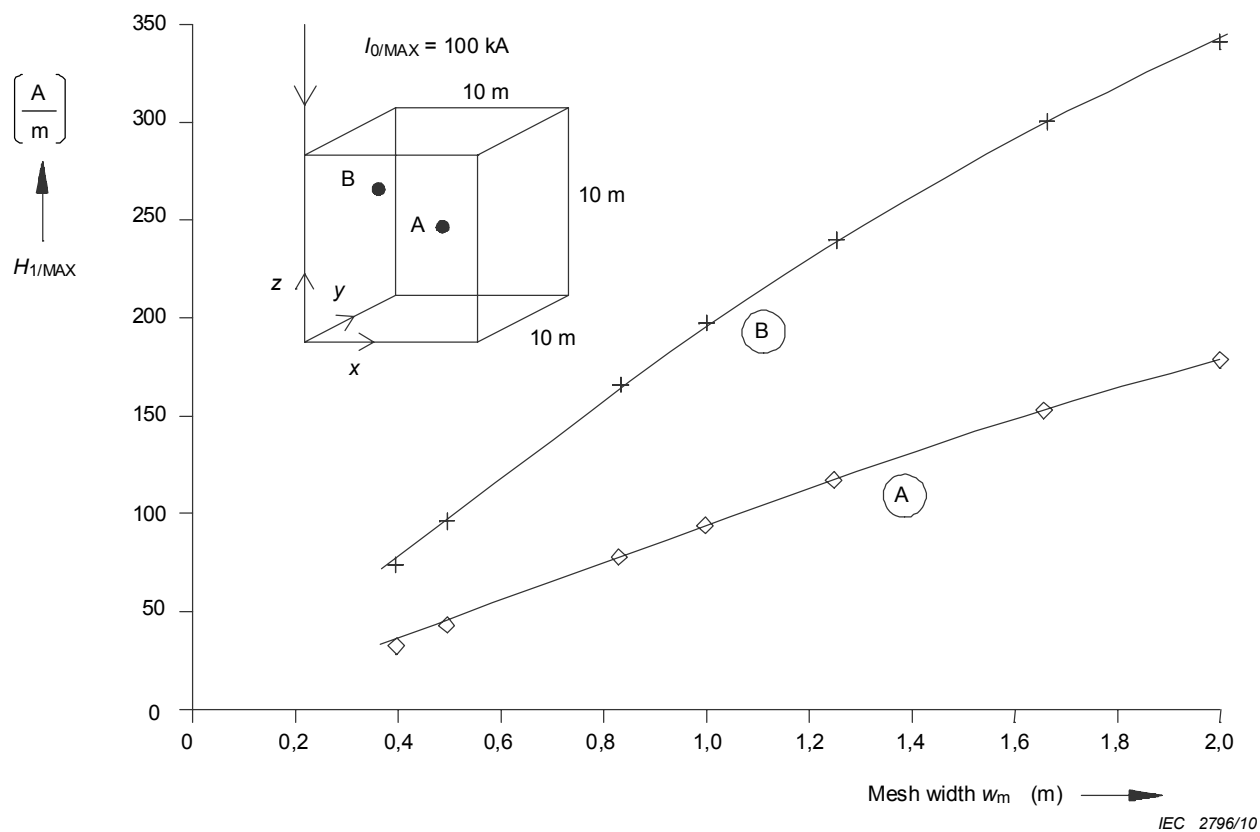NOTE 1 Experimental results of the magnetic field inside an LPZ 1 with a grid-like shield indicate that the increase of the magnetic field close to the shield is less than that resulting from the equations above.

NOTE 2 The calculated results are valid only for distances $d_{s/1} > w_m$ to the grid-like shield.

In all cases, a maximum lightning current $I_{O/MAX} = 100$ kA is assumed. In both Figure A.11 and Figure A.12, $H_{1/MAX}$ is the maximum magnetic field strength at a point, derived from its components H_x, H_y and Hz:

$$H_{1/MAX} = \sqrt{H_x^2 + H_y^2 + H_z^2} \qquad (A.20)$$

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_m 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: $x = y = 3$ m, $z = 7$ m). The result is plotted as a function of the mesh width w_m.

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 formulae in A.4.1.1 are therefore first-order approximations of the real, and more complicated, magnetic field distribution inside a grid-like shield.

A.4.3 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. Such tests can be performed using a simulated lightning current source of lower current level but with the same representative waveshape as the actual lightning discharge.
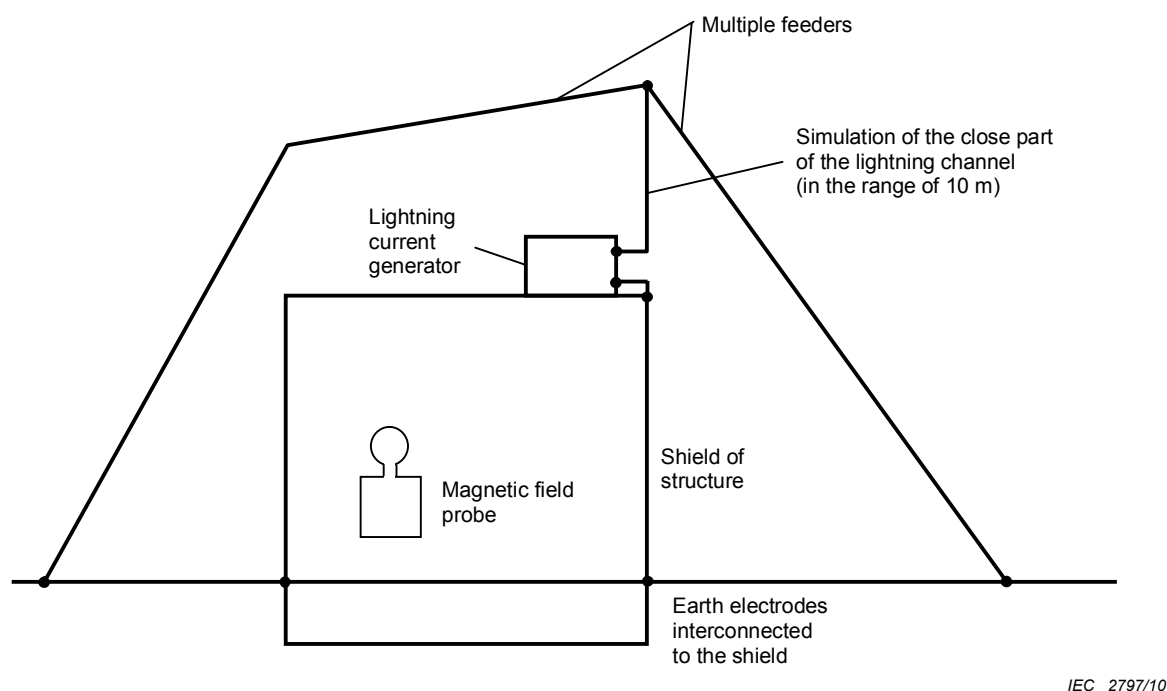
Figure A.13a – Test arrangement
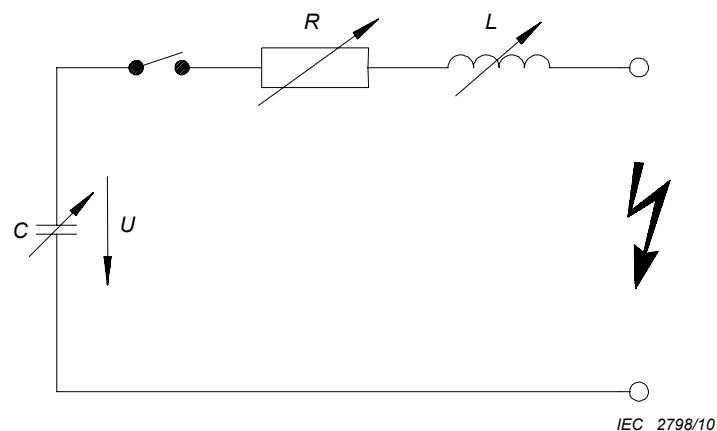
Key

U typically some 10 kV
C typically 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.5 Calculation of induced voltages and currents

A.5.1 General

Only rectangular loops in accordance with Figure A.14 are considered. Loops with other shapes should be transformed into rectangular configurations having the same loop area.
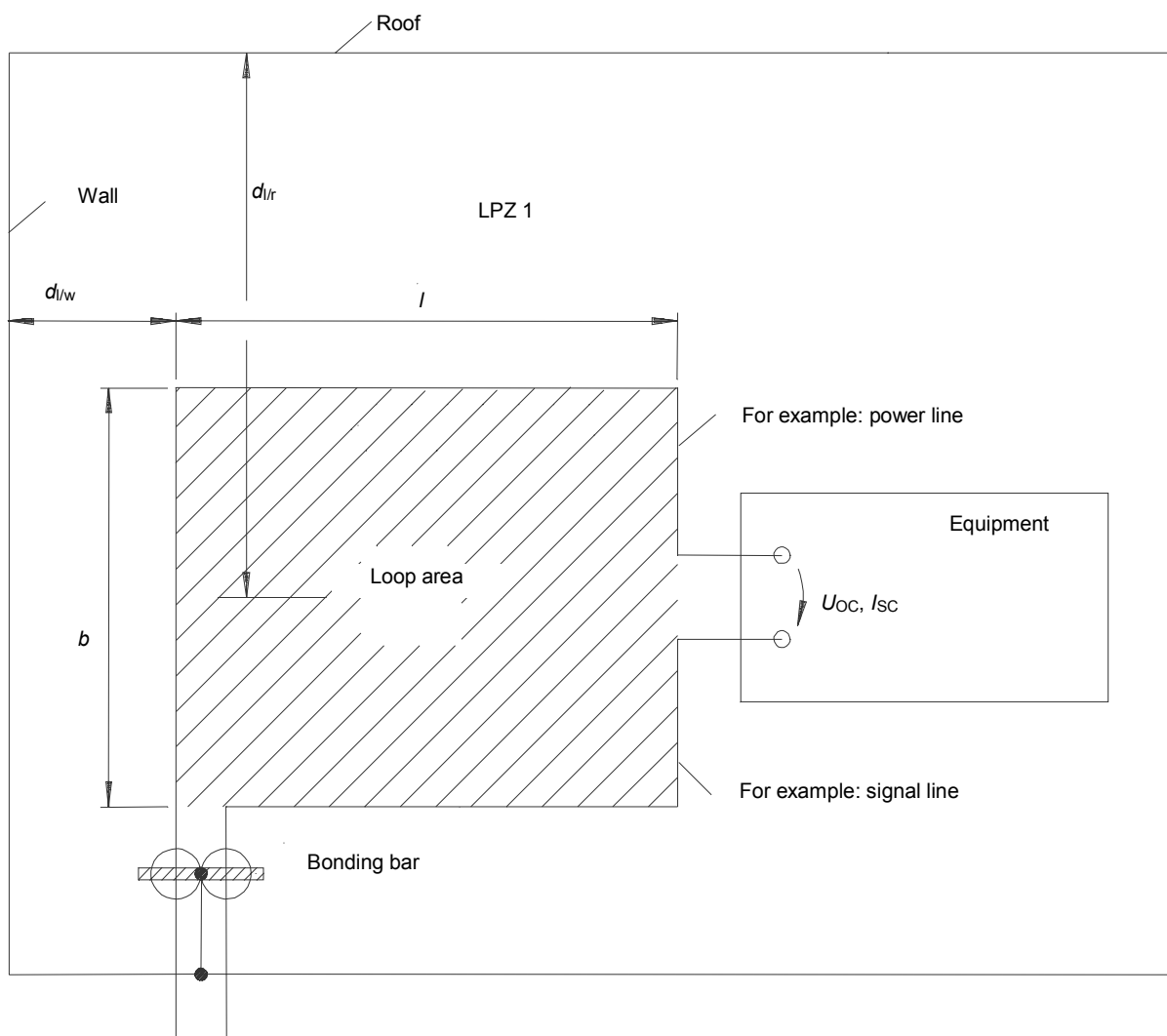
IEC 2799/10

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

A.5.2 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.4.1.1):

$$H_1 = k_h \times I_0 \times w_m / (d_w \times \sqrt{d_r}) \text{ (A/m)} \tag{A.21}$$

The open circuit voltage U_{OC} is given by:

$$U_{OC} = \mu_0 \times b \times \ln(1 + l/d_{l/w}) \times k_h \times (w_m / \sqrt{d_{l/r}}) \times dI_0 /dt \text{ (V)} \tag{A.22}$$

The peak value $U_{OC/MAX}$ occurs during the front time T_1

$$U_{OC/MAX} = \mu_0 \times b \ln(1 + l/d_{l/w}) \times k_h \times (w_m / \sqrt{d_{l/r}}) \times I_{0/MAX} /T_1 \text{ (V)} \tag{A.23}$$

where

μ_0 is equal to $4 \times \pi \times 10^{-7}$ (Vs)/(Am);

b (m)   is the width of the loop;

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

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

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

$I_{0/MAX}$ (A)   is the maximum value of the lightning current stroke in LPZ 0_A;

k_h (1/√m)   is the configuration factor $k_h = 0,01$;

l (m)   is the length of the loop;

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

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

The short-circuit current I_{SC} is given by:

$$I_{SC} = \mu_o \times b \ln(1 + l/d_{l/w}) \times k_h \times (w_m / \sqrt{d_{l/r}}) \times I_0 / L_S \text{ (A)} \qquad (A.24)$$

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

The maximum value $I_{SC/MAX}$ is given by:

$$I_{SC/MAX} = \mu_o \times b \ln(1 + l/d_{l/w}) \times k_h \times (w_m / \sqrt{d_{l/r}}) \times I_{0/MAX} / L_S \text{ (A)} \qquad (A.25)$$

where L_S (H) is the self-inductance of the loop.

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

$$L_s = \{0,8 \times \sqrt{l^2 + b^2} - 0,8 \times (l + b) + 0,4 \times l \times \ln\left[(2b/r_c)/\left(1 + \sqrt{1 + (b/l)^2}\right)\right]$$

$$+ 0,4 \times b \times \ln\left[\left(2l/r_c\right)/\left(1 + \sqrt{1 + (l/b)^2}\right)\right]\} \times 10^{-6} \quad \text{(H)} \qquad (A.26)$$

where r_c (m) is the radius of the loop conductor.

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

$$U_{OC/F/MAX} = 1,26 \times b \times \ln(1 + l/d_{l/w}) \times (w_m / \sqrt{d_{l/r}}) \times I_{F/MAX} \text{ (V)} \qquad (A.27)$$

$$I_{SC/F/MAX} = 12,6 \times 10^{-6} \times b \times \ln(1 + l/d_{l/w}) \times (w_m / \sqrt{d_{l/r}}) \times I_{F/MAX}/ L_S \text{ (A)} \qquad (A.28)$$

The voltage and current induced by the magnetic field of the first negative stroke (T_1 = 1 μs) is given by:

$$U_{OC/FN/MAX} = 12,6 \times b \times \ln(1 + l/d_{l/w}) \times (w_m / \sqrt{d_{l/r}}) \times I_{FN/MAX} \text{ (V)} \qquad (A.29)$$

$$I_{SC/FN/MAX} = 12,6 \times 10^{-6} \times b \times \ln(1 + l/d_{l/w}) \times (w_m / \sqrt{d_{l/r}}) \times I_{FN/MAX}/ L_S \text{ (A)} \qquad (A.30)$$

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

$$U_{OC/S/MAX} = 50,4 \times b \times \ln(1 + l/d_{l/w}) \times (w_m / \sqrt{d_{l/r}}) \times I_{S/MAX} \text{ (V)} \qquad (A.31)$$

$$I_{SC/S/MAX} = 12,6 \times 10^{-6} \times b \times \ln(1 + l/d_{l/w}) \times (w_m / \sqrt{d_{l/r}}) \times I_{S/MAX}/L_S \text{ (A)} \qquad (A.32)$$

where

$I_{F/MAX}$ (kA)   is the maximum value of the current of the first positive stroke;

$I_{FN/MAX}$ (kA)   is the maximum value of the current of the first negative stroke;

$I_{S/MAX}$ (kA)   is the maximum value of the current of the subsequent strokes.

A.5.3   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.4.1.2).

The open circuit voltage U_{OC} is given by:

$$U_{OC} = \mu_o \times b \times l \times dH_1 / dt \ (V) \tag{A.33}$$

The peak value $U_{OC/MAX}$ occurs during the front time T_1:

$$U_{OC/MAX} = \mu_o \times b \times l \times H_{1/MAX} / T_1 \ (V) \tag{A.34}$$

where

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

b (m)   is the width of the loop;

H_1 (A/m)   is the time dependent magnetic field inside LPZ 1;

$H_{1/MAX}$ (A/m)   is the maximum value of the magnetic field inside LPZ 1;

l (m)   is the length of the loop;

T_1 (s)   is the front time of the magnetic field, identical with the front time of the lightning current stroke.

The short circuit current I_{SC} is given by:

$$I_{SC} = \mu_o \times b \times l \times H_1 / L_S \ (A) \tag{A.35}$$

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

The maximum value $I_{SC/MAX}$, is given by:

$$I_{SC/MAX} = \mu_o \times b \times l \times H_{1/MAX} / L_S \ (A) \tag{A.36}$$

where L_S (H) is the self-inductance of the loop (for the calculation of L_S see A.5.2).

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

$$U_{OC/F/MAX} = 0{,}126 \times b \times l \times H_{1/F/MAX} \ (V) \tag{A.37}$$

$$I_{SC/F/MAX} = 1{,}26 \times 10^{-6} \times b \times l \times H_{1/F/MAX} / L_S \ (A) \tag{A.38}$$

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

$$U_{OC/FN/MAX} = 1{,}26 \times b \times l \times H_{1/FN/MAX} \ (V) \tag{A.39}$$

$$I_{SC/FN/MAX} = 1{,}26 \ 10^{-6} \times b \times l \times H_{1/FN/MAX} / L_S \ (A) \tag{A.40}$$

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

$$U_{OC/S/MAX} = 5{,}04 \times b \times l \times H_{1/S/MAX}\ (V) \tag{A.41}$$

$$I_{SC/S/MAX} = 1{,}26 \times 10^{-6} \times b \times l \times H_{1/S/MAX}\ /\ L_S\ (A) \tag{A.42}$$

where

$H_{1/F/MAX}$ (A/m)   is the maximum of the magnetic field inside LPZ 1 due to the first positive stroke;

$H_{1/FN/MAX}$ (A/m)   is the maximum of the magnetic field inside LPZ 1 due to the first negative stroke;

$H_{1/S/MAX}$ (A/m)   is the maximum of the magnetic field inside LPZ 1 due to the subsequent strokes.

A.5.4   Situation inside LPZ 2 and higher

The magnetic field H_n inside LPZ n for n ≥ 2 is assumed to be homogeneous (see A.4.1.3).

Therefore, the same formulae for the calculation of induced voltages and currents apply (A.4.1.2), where H_1 is substituted by H_n.

Annex B
(informative)

Implementation of SPM for an existing structure

B.1   General

For equipment within existing structures it is not always possible to follow the SPM outlined in this standard. This annex attempts to describe the main points for consideration and provides information on protection measures which are not mandatory but may help to improve the overall protection provided.

B.2   Checklists

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

A set of checklists 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 checklists 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 these data, a risk assessment in accordance with IEC 62305-2 should 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 interference (EMI) in building installations, see IEC 60364-4-44 [1].

The data collected by means of the checklists are also useful in the design process.

Table B.1 – Structural characteristics and surroundings

Item	Question [a]
1	Masonry, bricks, wood, reinforced concrete, steel-framed 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?
[a] For detailed information see IEC 62305-2.	

Table B.2 – Installation characteristics

Item	Question [a]
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 equipments self-contained within the structure?
7	Metal conductors to other structures?
[a] For detailed information see IEC 62305-2.	

Table B.3 – Equipment characteristics

Item	Question [a,b]
1	Type of internal system interconnections (shielded or unshielded multicore cables, coaxial cable, analogue and/or digital, balanced or unbalanced, fibre optic cables)? [a]
2	Withstand level of the electronic system specified? [a, b]
[a] For detailed information see IEC 62305-2.	
[b] For detailed information see ITU-T K.21 [4], 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 [a]
1	Configuration of power supply earthing - TN (TN-S, TN-C or TN-C-S), TT or IT?
2	Location of the equipment? [a]
3	Interconnections of functional earthing conductors of the internal system with the bonding network?
[a] For detailed information see Annex A.	

B.3   Design of SPM for an existing structure

The first step in the design process is to work through the checklist in accordance with Clause B.2 and to conduct the risk assessment.

If this analysis shows that SPM is required, then this should be implemented following the steps outlined in Figure B.1.

Assign suitable LPZs to all locations where equipment to be protected is located (see 4.3).

The basis of the SPM shall be an internal screening and bonding network. This network should have mesh widths not exceeding 5 m in any direction. If the lay-out of the structure does not permit this screening and bonding network at least a ring conductor inside the outer wall of the structure on each floor should be installed. This ring conductor should be bonded to each down-conductor of the external LPS.

NOTE   Retrofitting screening measures to an existing building is often impractical and uneconomic. Where this is the case, the use of SPDs provides an effective alternative.

B.4   Design of basic protection measures for LPZ

B.4.1   Design of basic protection measures for LPZ 1

The protection measures should be based on the internal screening and bonding network or the ring conductor inside the outer wall, which is normally the boundary of LPZ 1. If the outer wall is not the boundary of LPZ 1 and an internal screening and bonding network is not possible, a ring conductor should be installed at the boundary of LPZ 1. The ring conductor has to be connected to the ring conductor of the outer wall at least at two locations as far apart as possible.

B.4.2   Design of basic protection measures for LPZ 2

The protection measures are based on the internal screening and bonding network or the ring conductor inside the outer wall. If an internal screening and bonding network is not possible, a ring conductor should be installed at the boundary of every LPZ 2. If an LPZ 2 is larger than 5 m × 5 m a subdivision has to be made creating meshes not exceeding 5 m × 5 m. The ring conductor has to be connected to the ring conductor of the surrounding LPZ 1 at two locations at least, and as far apart as possible.

B.4.3   Design of basic protection measures for LPZ 3

The protection measures are based on the internal screening and bonding network or the ring conductor inside the LPZ 2. If an internal screening and bonding network is not possible, a ring conductor should be installed at the boundary of every LPZ 3. If an LPZ 3 is larger than 5 m × 5 m a subdivision has to be made creating meshes not exceeding 5 m × 5 m. The ring conductor has to be connected to the ring conductor of the surrounding LPZ 2 at two locations at least, and as far apart as possible.

B.5   Installation of a coordinated SPD system

A coordinated SPD system should be designed to protect the cables crossing borders of the different LPZs.

Designing additional measures will greatly improve the protection by bonding and SPD systems.

The design of cable trays, cable ladders and the like has to be improved to make them proper screens for the cables running in and/or over them.

If possible, additional measures such as screening of walls, floors, ceilings etc should be considered to provide additional protection to that already applied (see Clause 6).

Design measures to improve interconnections between the structure under consideration and other structures (see Clause B.11).

In the case where new internal systems are installed in a structure already equipped with protection measures, the design process should be repeated for the location of those internal systems.

The complete design process is illustrated in the flow chart (see Figure B.1).

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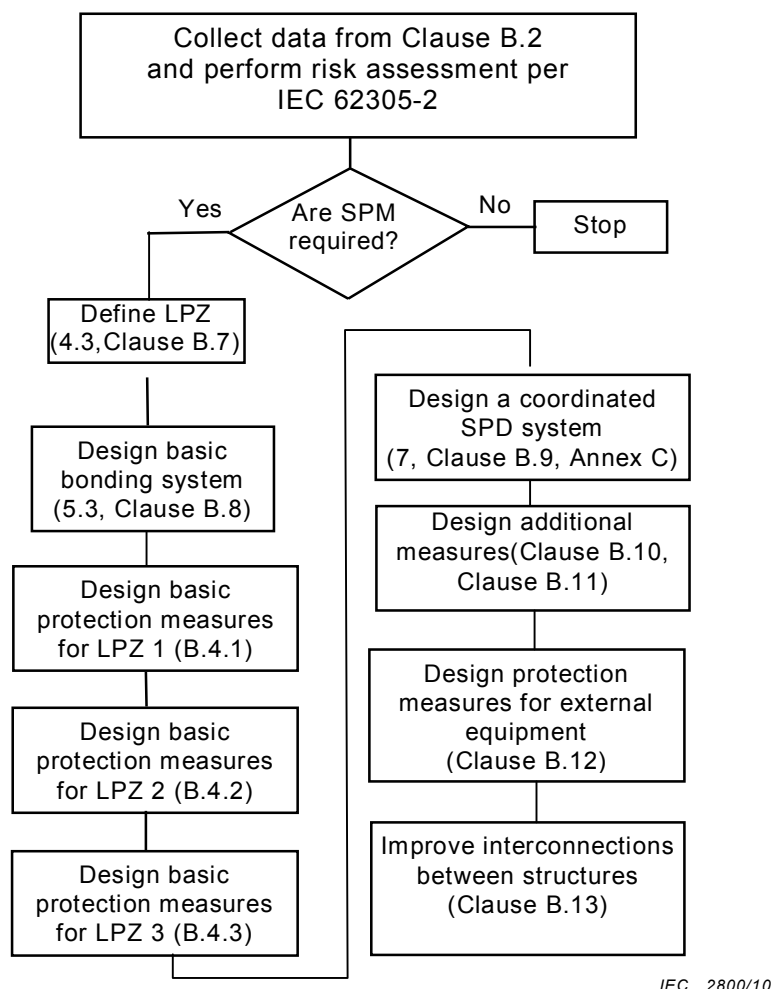
Figure B.1 – SPM design steps for an existing structure

B.6   Improvement of an existing LPS using spatial shielding of LPZ 1

An existing LPS (in accordance with IEC 62305-3) around LPZ 1 can be improved by

– integrating existing metal facades and metal roofs into the external LPS,

– using such structural reinforcing bars as are electrically continuous from the upper roof to the earth termination system,

– 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.7   Establishment of LPZs for electrical and electronic systems

Depending on the number, type and sensitivity of the electrical and electronic systems, suitable inner LPZs 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 layouts for the protection of internal systems providing different solutions suitable for existing structures in particular:

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 internal systems:

– This LPZ 1 could be created using an LPS, in accordance with IEC 62305-3, that consists of an external LPS (air-termination, down-conductor and earth-termination system) and an internal LPS (lightning equipotential bonding and compliance with 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.

– The internal LPS requires bonding of all services entering the structure at the boundary of LPZ 1, including the installation of 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 can be useful inside LPZ 1 in order to avoid low-frequency interference.

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Key
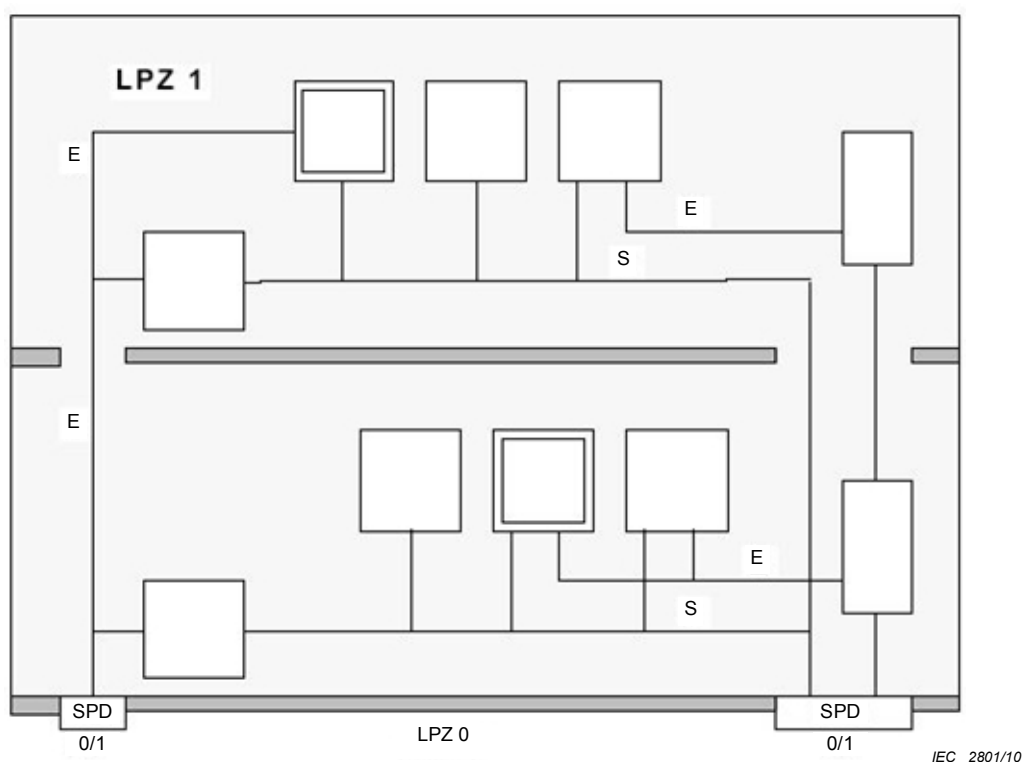
E   power lines
S   signal lines

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)

Key
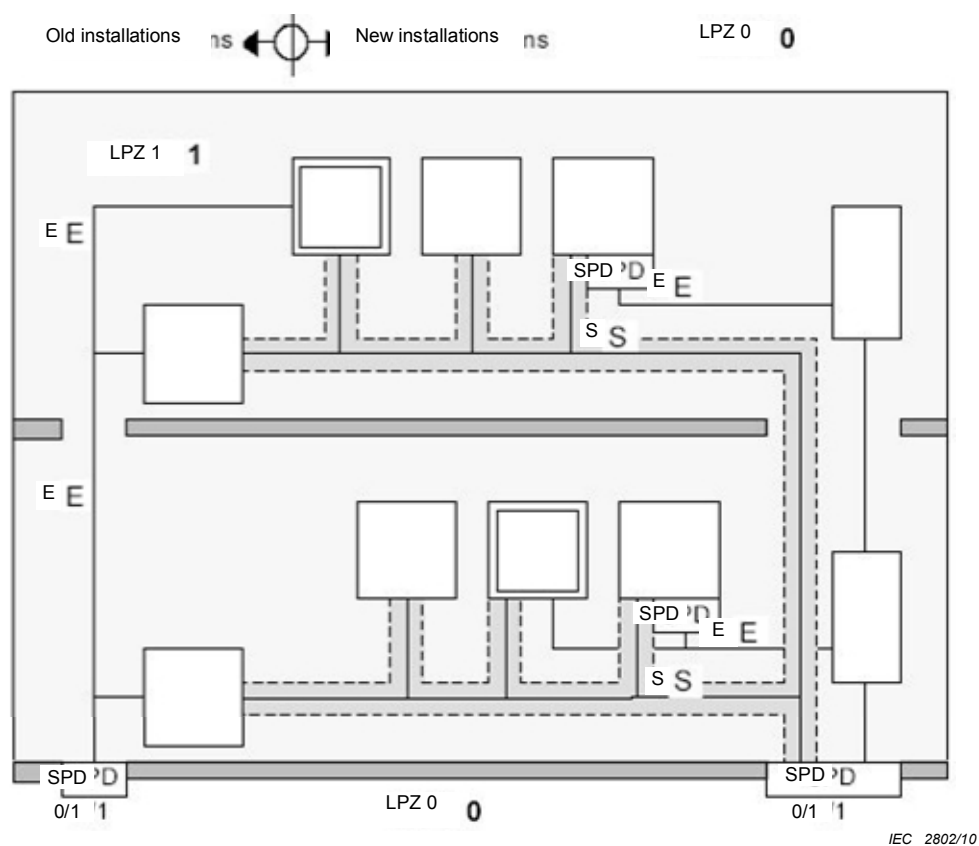
E   power lines
S   signal lines

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

IEC 2803/10

Key

E   power lines
S   signal lines

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

Key
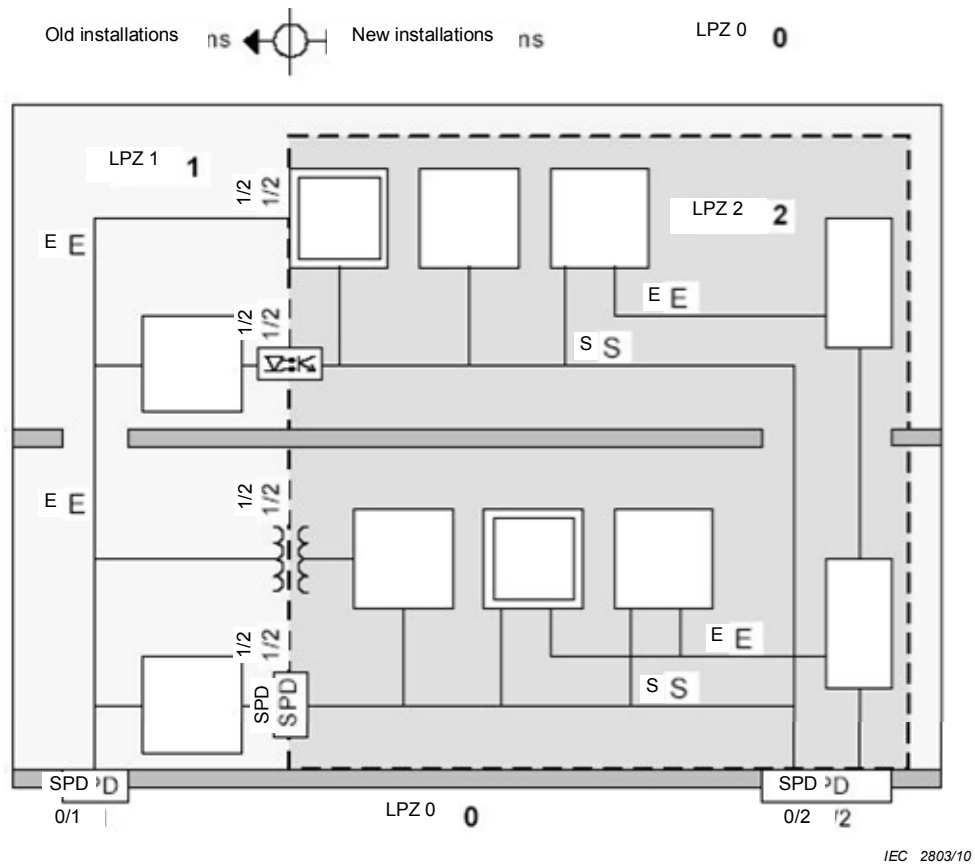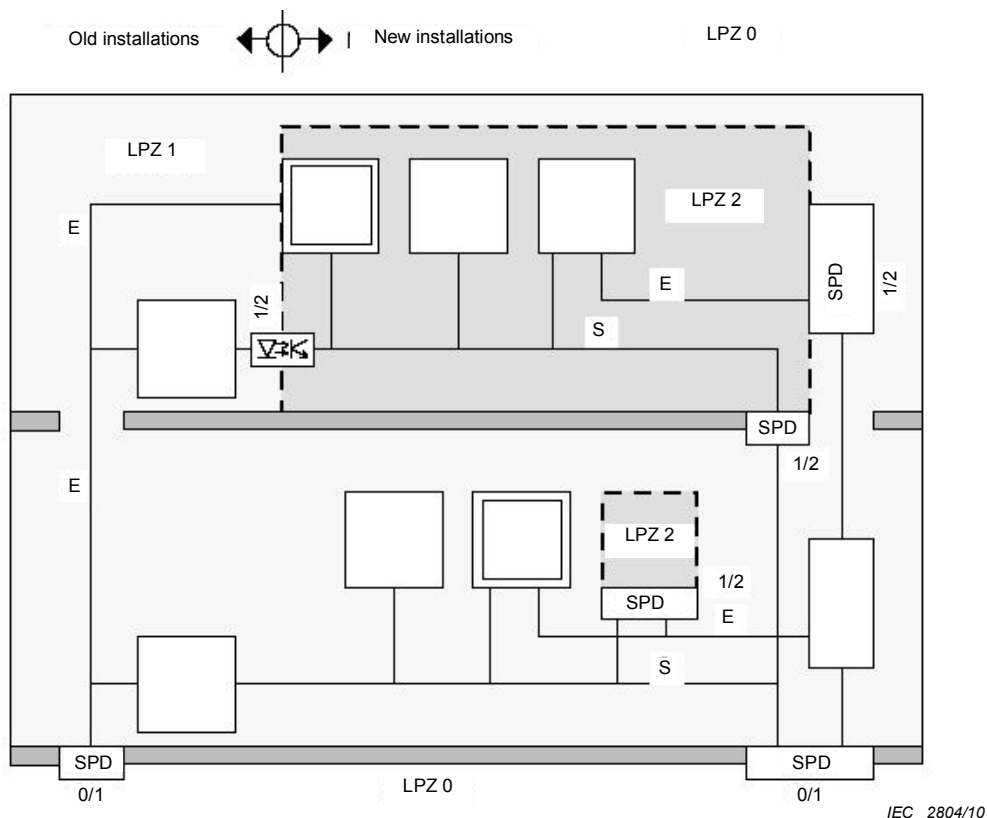
E   power lines
S   signal lines

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

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

Figure B.2b shows that in an unshielded LPZ 1, new equipment 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 system. 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 the service entrance. It may also require additional Class II "double insulation" of the equipment.

Figure B.2c shows the installation of a large integral LPZ 2 inside of LPZ 1, to accommodate the new internal 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 of LPZs 0/1) and subsequently at the boundary of LPZ 2 (transition of LPZs 1/2), should be coordinated in accordance with IEC 61643-12. On the right hand side, the SPDs installed at the boundary of LPZ 1 should be selected for a direct transition of LPZs 0/2 (see C.3.5).

Figure B.2d shows the creation of two smaller LPZs (LPZs 2) inside LPZ 1. Additional SPDs for power as well as for signal lines at the boundary of each LPZ 2 should be installed. These SPDs should be coordinated with the SPDs at the boundary of LPZ 1 in accordance with IEC 61643-12.

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 internal 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 should be integrated into the bonding network, but the PEN conductor should 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 by surge protective devices

To limit conducted surges due to lightning on electrical lines, SPDs should be installed at the entry to any inner LPZ (see Figure B.2 and Figure B.8, No.3).

In buildings with uncoordinated SPDs, damage to the internal 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.10   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 insulated equipment (i.e. double insulation without a PE-conductor),

– isolation transformers,

– metal-free fibre optic cables,

– optical couplers.

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 that they are 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.11 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 damage. Furthermore, routing electrical and signal lines adjacent to one another can avoid large loops (see Figure B.8, No. 8);

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

– using metal cable ducts or bonded metal plates – the separate metal sections should be electrically well interconnected and the overall length bonded at either end. 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) [6].

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 tri-axial cables can be advantageous.
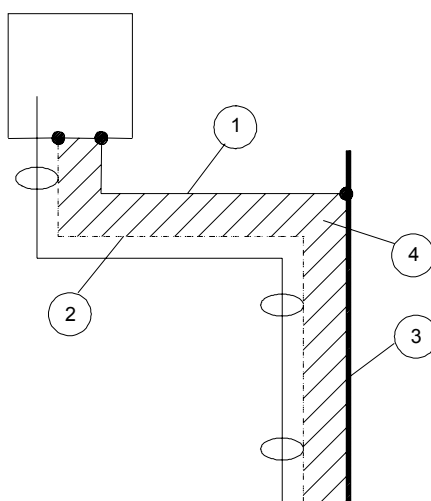
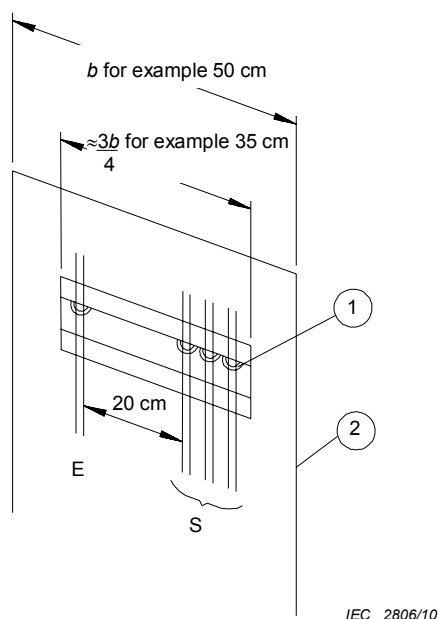*IEC   2805/10*

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 the 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.12   Protection measures for externally installed equipment

B.12.1   General

Examples of externally installed equipment include: 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 in external positions on structures, masts and process vessels.

B.12.2   Protection of 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 flashes (see Figure B.5).

On tall structures the rolling sphere method (see IEC 62305-3) should be applied, to determine if the equipments installed on the top or sides of the building are possibly subject to a direct flash. 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 a lightning flash. Others 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.

LPZ 0_A

r

LPZ 0_B

LPZ 1

SPD

r
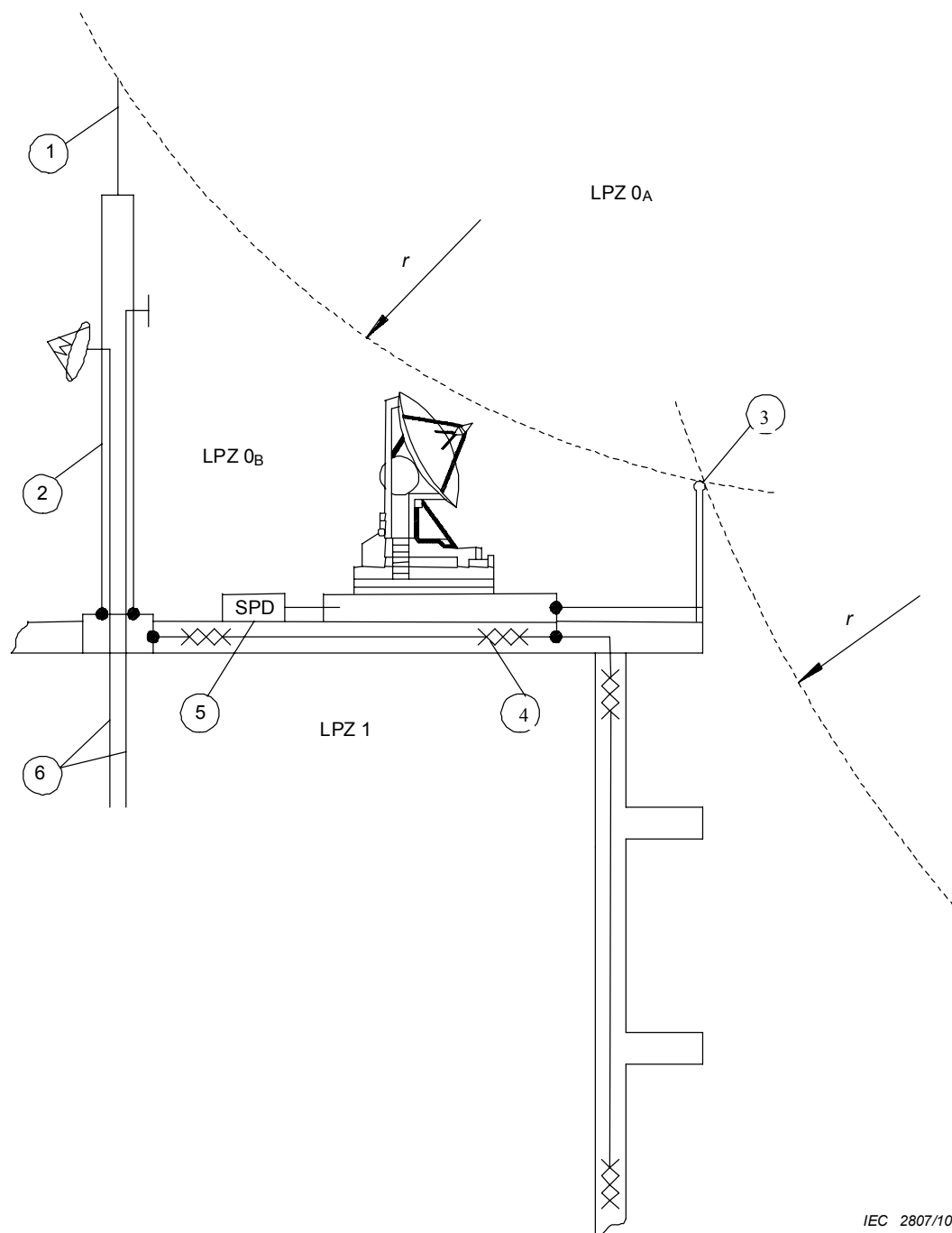
IEC   2807/10

Key

1   lightning rod
2   steel mast with antennas
3   hand rails
4   interconnected reinforcement
5   line coming from LPZ 0_B needs an 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

B.12.3   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).

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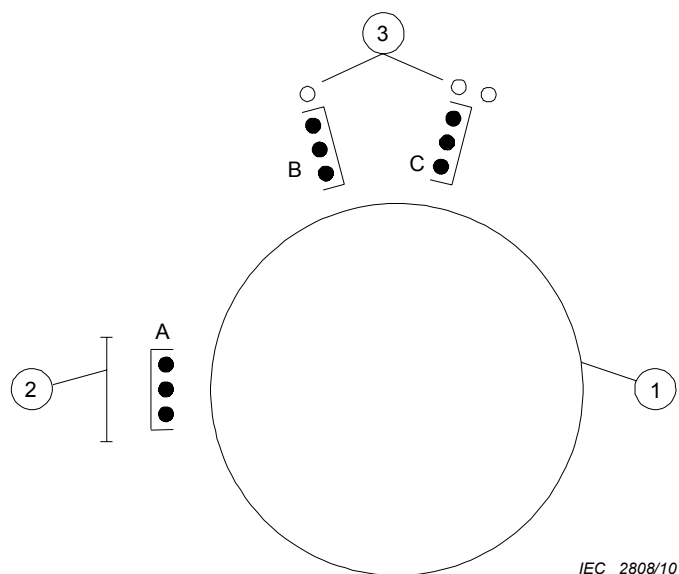
Key

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

IEC 2809/10

Key

1   ideal positions for cables in corners of L-girders
2   alternative position for bonded cable tray within the mast
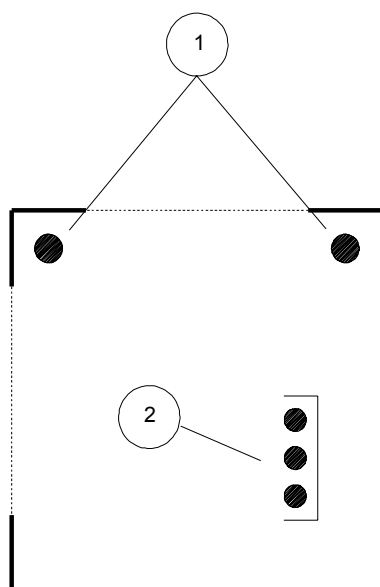
Figure B.7 – Ideal positions for lines on a mast (cross-section of steel lattice mast)

B.13   Improving interconnections between structures

B.13.1   General

Lines interconnecting separate structures are either

– isolating (metal-free fibre optic cables), or

– metallic (e.g. wire pairs, multicores, waveguides, 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.13.2   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.13.3   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. In this case:

– the required bonding, directly or via an 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.

B.14   Integration of new internal systems into existing structures

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

Figure B.8 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.
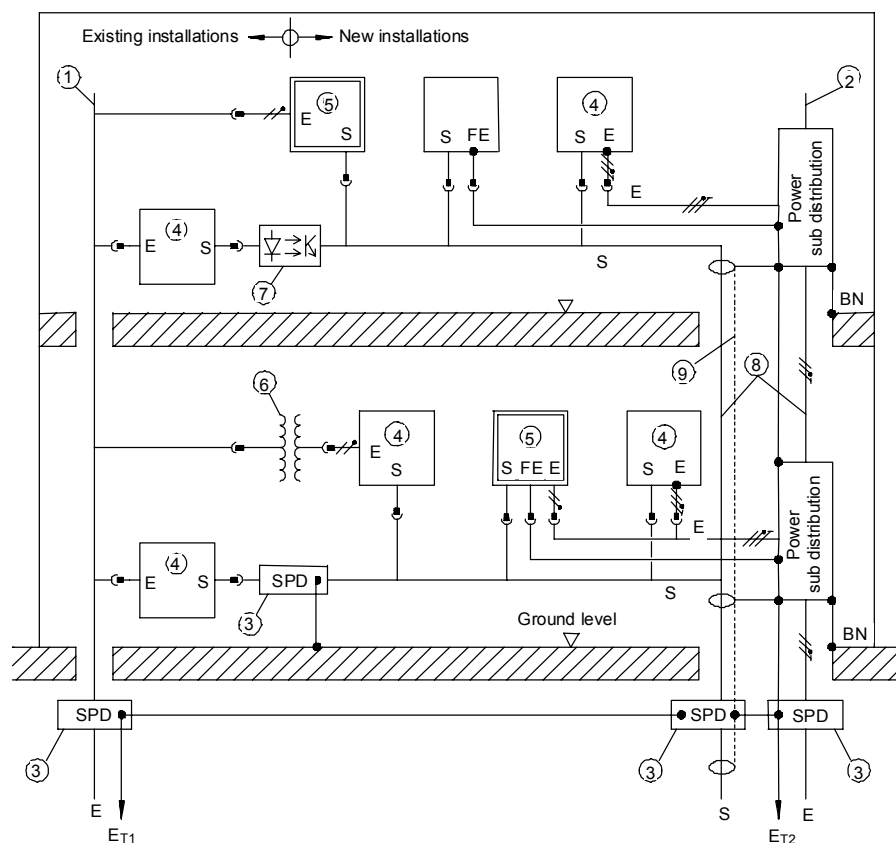
Key

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)	E_T	earth-termination system
4	class I standard insulation	BN	bonding network
5	class II double insulation without PE	PE	protective earthing conductor
6	isolation transformer	FE	functional earthing conductor (if any)
7	opto-coupler or fibre optic cable	∥⊤	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.8 – Upgrading of the SPM in existing structures

B.15   Overview of possible protection measures

B.15.1   Power supply

Existing mains supply (see Figure B.8, 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.8, No. 2) is installed, type TN-S is strongly recommended.

B.15.2   Surge protective devices

To control conducted surges on lines, SPDs should be installed at the entry into any LPZ and possibly at the equipment to be protected (see Figure B.8, No.3 and Figure B.2).

B.15.3   Isolating interfaces

To avoid interference, isolating interfaces between existing and new equipment can be used: Class II insulated equipment (see Figure B.8, No. 5), isolation transformers (see Figure B.8, No. 6), fibre optic cables or optical couplers (see Figure B.8, No. 7).

B.15.4   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.8, 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.8. No. 9), is also recommended. All these shields should 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.15.5   Spatial shielding

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

An LPZ 1 created by a normal external LPS in accordance with 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 should be upgraded (see Clause B.4).

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

B.15.6   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 an LPZ should be bonded directly, or via a suitable SPD, as closely as possible to the boundary of the LPZ.

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

B.16   Upgrading a power supply and cable installation inside the structure

The power distribution system in older structures (see Figure B.8, No. 1) is very often TN-C. Interference at 50/60 Hz arising from the connection of earthed signal lines with the PEN conductor can be avoided by

– isolating interfaces using class II electrical equipment or double insulated transformers. This can be a solution if there is only a small amount of electronic equipment (see Clause B.5),
– changing the power distribution system to a TN-S (see Figure B.8 No. 2). This is the recommended solution, especially for extensive systems of electronic equipment.

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

Annex C

(informative)

Selection and installation of a coordinated SPD system

C.1   Introduction

Lightning flashes to a structure (source of damage S1), near the structure (S2), to a service connected to the structure (S3) and near a service connected to the structure (S4) can cause failures or malfunction of internal systems (see 5.1 of IEC 62305-1:2010).

This annex provides information on the selection and installation of a coordinated SPD system. Additional information may be found in IEC 61643-12 and IEC 60364-5-53 which deal with protection against overcurrent and the consequences in the case of an SPD failure.

The failure due to surges exceeding the immunity level of electronic equipment is not covered within the scope of the IEC 62305 series. The reader is referred to IEC 61000-4-5 for treatment of this subject.

However, lightning surges frequently cause failure of electrical and electronic systems due to insulation breakdown or when overvoltages exceed the equipment's common mode insulation level.

Equipment is protected if its rated impulse withstand voltage U_W at its terminals (common mode withstand voltage) is greater than the surge overvoltage between the live conductors and earth. If not, an SPD must be installed.

Such an SPD will protect the equipment if its effective voltage protection level $U_{P/F}$ (the protection level U_P obtained when the nominal discharge current I_n flows added to the inductive voltage drop ΔU of the connecting conductors) is lower than U_W It should be noted that if the discharge current which occurs at the point of installation of the SPD exceeds the designated I_n of the SPD, the protection level U_P will be higher, and $U_{P/F}$ may exceed the equipment's withstand level U_W. In this case the equipment is no longer protected. It follows that the nominal current I_n of the SPD should be selected to be equal to, or higher, than the discharge lightning current which can be expected at this point of installation.

The probability that an SPD with $U_{P/F} \leq U_W$ does not adequately protect the equipment for which it is intended, is equal to the probability that the discharge current at the point of installation of this SPD exceeds the current at which U_P was determined.

Evaluation of the currents expected at various points in the installation is given in Annex E of IEC 62305-1:2010, and is based on the LPL determined using IEC 62305-2. A complete analysis of current sharing is required when considering the S1 event. Annex D of this standard provides additional information.

It should also be noted, that selecting an SPD with a lower value U_P (compared to the equipment's U_W) results in a lower stress to the equipment that may result not just in a lower probability of damage, but also a longer operating life.

Values of the probability P_{SPD} as a function of the LPL are given in Table B.3 of IEC 62305-1:2010.

NOTE   Values of P_{SPD} for SPDs providing better protection characteristics can be determined if the voltage vs current characteristic of the SPD is available.

Finally, the importance of applying SPD protection to both power and signal circuits is essential if an effective coordinated SPD system is to result.

C.2 Selection of SPDs

C.2.1 Selection with regard to voltage protection level

Selection of the proper voltage protection level of the SPD depends on

- the impulse withstand voltage U_W of the equipment to be protected,
- the length of the connecting conductors to the SPD,
- the length and the routing of the circuit between the SPD and the equipment.

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

- equipment connected to power lines in accordance with IEC 60664-1 and IEC 61643-12,
- equipment connected to telecom lines in accordance with IEC 61643-22, ITU-T K.20 [3], K.21[4] and K45 [5],
- other lines and equipment terminals in accordance with information obtained from the manufacturer.

NOTE 1   The protective 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's terminals will change accordingly.

NOTE 2   The voltage protective level U_P should be compared with the impulse withstand voltage U_W of the equipment, tested under the same conditions as the SPD (over voltage and over current waveform and energy, energized equipment, etc.). This matter is under consideration.

NOTE 3   Equipment may contain internal SPD components. The characteristics of these internal SPDs may affect the coordination.

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 C.1), can be assumed as being:

$U_{P/F} = U_P + \Delta U$ \qquad for voltage limiting type SPD(s);

$U_{P/F} = \max (U_P, \Delta U)$ \qquad for voltage switching type SPD(s).

NOTE 4   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 formulae may be needed.

When the SPD is installed at the line entrance into the structure, $\Delta U = 1$ kV per m length, should be assumed. When the length of the connection conductors is $\leq 0,5$ m, $U_{P/F} = 1,2 \times U_P$ can be assumed. When the SPD is carrying induced surges only, ΔU can be neglected.

During the operating state of an SPD, the voltage between the SPD terminals is limited to $U_{P/F}$ 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 $2 \times U_{P/F}$ and failure of equipment may result even if $U_{P/F} \leq U_W$.

Information on the connecting conductors, connecting configurations and fuse withstand levels for SPDs can be found in IEC 61643-12 and IEC 60364-5-53.

Moreover lightning flashes to the structure or to ground nearby the structure, can induce an overvoltage U_I in the circuit loop between the SPD and the equipment, that adds to $U_{P/F}$ and thereby reduces the protection efficiency of the SPD. Induced overvoltages increase with the 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).

NOTE 5   For evaluation of induced overvoltages U_I , Clause A.4 applies.

Internal systems are protected if

- they are energy coordinated with the upstream SPD(s), and
- one of the following three conditions is fulfilled:

1) $U_{P/F} \leq U_W$: when the circuit length between the SPD and the equipment is negligible (typical case of an SPD installed at equipment terminals);

2) $U_{P/F} \leq 0,8\ U_W$: when the circuit length is not greater than ten metres (typical case of SPD installed at a secondary distribution board or at a socket outlet);

NOTE 6   Where failure on internal systems may cause loss of human life or loss of service to the public doubling of voltage due to oscillations should be considered and the criteria $U_{P/F} \leq U_W /2$ is required..

3) $U_{P/F} \leq (U_W - U_I) / 2$: when the circuit length is more than ten metres (typical case of SPD installed at the line entrance into the structure or in some cases at the secondary distribution board).

NOTE 7   For shielded telecommunication lines, different requirements may apply due to the steepness of the wave front. Information on this effect is provided in Chapter 10 of the ITU-T lightning handbook [7].

If spatial shielding of the structure (or of the rooms) and/or line shielding (use of shielded cables or metallic cable ducts) are provided, induced overvoltages U_I are usually negligible and can be disregarded in most cases.
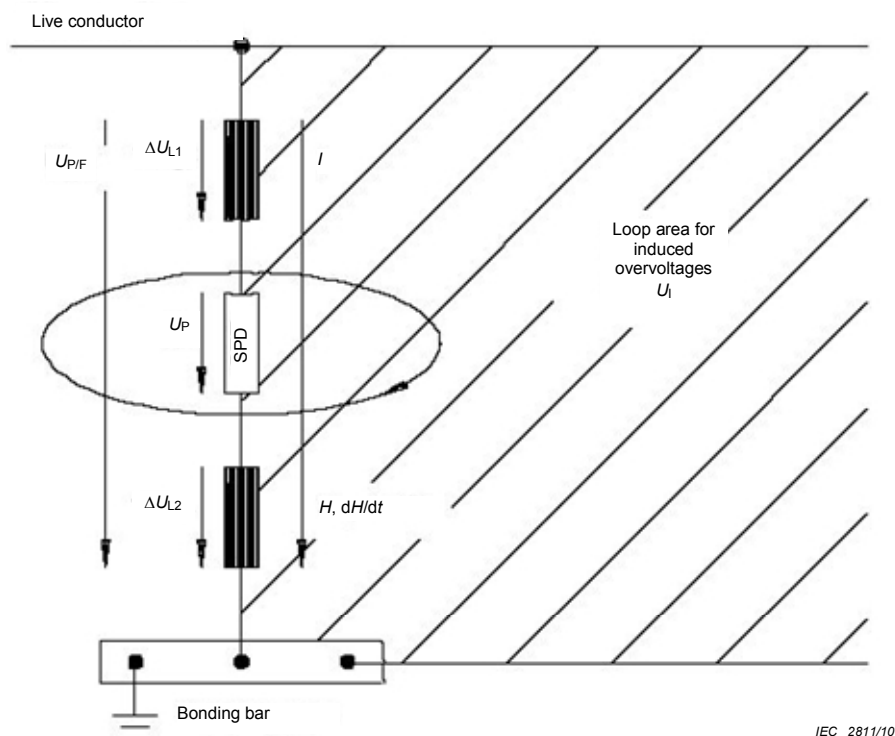
Key

I	partial lightning current
U_I	induced overvoltage
$U_{P/F} = U_P + \Delta U$	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

NOTE   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). That is, 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 than the protection level U_P of the SPD.

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

C.2.2   Selection with regard to location and to discharge current

SPDs should withstand the discharge current expected at their installation point in accordance with Annex E of IEC 62305-1:2010. The use of SPDs depends on their withstand capability, classified in IEC 61643-1 for power, and in IEC 61643-21 for telecommunication systems.

The selection of an SPDs discharge current rating is influenced by the type of connection configuration and the type of power distribution network. More information on this may be found in IEC 61643-12 and IEC 60364-5-53.

SPDs should be selected in accordance with 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 should provide for the (partial) lightning current to be expected at this installation point based on the chosen LPL in accordance

with Clause E.2 (source of damage S1) and/or E.3.1 (source of damage S3) of IEC 62305-1:2010.

- **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 probability of failures of the SPD due to sources of damage S1 and S3 can be disregarded. The required nominal discharge current I_n of the SPD should provide for the surge level to be expected at the installation point based on the chosen LPL and related overcurrents, in accordance with E.3.2 of IEC 62305-1:2010.

NOTE 1   The risk of failures of the SPDs due to sources of damage S1 and S3 can be disregarded if the total number of direct flashes to structure (N_D) and to line (N_L) complies with the condition $N_D + N_L \le 0,01$.

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

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

  The required nominal discharge current I_n of the SPD should provide for the surge current to be expected at this point of the installation, based the chosen LPL and related overcurrents in accordance with Clause E.4 of IEC 62305-1:2010.

NOTE 2   An SPD having the characteristics of class I and class II tests may be used in this location.

- **SPD tested with a combination wave U_{OC} (class III 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 SPD due to sources of damage S1 and S3 can be disregarded. The required open circuit voltage rating U_{OC} of the SPD (from which the short-circuit current I_{SC} can be determined, since test class III is carried out using a combination wave generator with a 2 Ω impedance) should provide for the surge level to be expected at the installation point, based on the chosen LPL and related overcurrents,in accordance with Clause E.4 of IEC 62305-1:2010.

C.3   Installation of a coordinated SPD system

C.3.1   General

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

- location of the SPD;
- connecting conductors.

C.3.2   Installation location of SPDs

The location of the SPDs should comply with C.2.2 and is primarily affected by:

- the specific source of damage e.g. lightning flashes to a structure (S1), to a line (S3), to ground near a structure (S2) or to ground near 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 the SPD is to the entrance point of the incoming line, the greater the amount of equipment within the structure that will be protected by this SPD (economic advantage). Then the second criterion should be checked: the closer an SPD is to the equipment being protected, the more effective its protection will be (technical advantage).

C.3.3   Connecting conductors

The SPDs connecting conductors should have a minimum cross-sectional area as given in Table 1.

C.3.4   Coordination of SPDs

In a coordinated SPD system, cascaded SPDs need to be energy coordinated in accordance with IEC 61643-12 and/or IEC 61643-22. For this purpose, the SPD manufacturer should provide sufficient information as to how to achieve energy coordination between his different SPDs.

C.3.5   Procedure for installation of a coordinated SPD system

A coordinated SPD system should be installed as follows:

- At the line entrance into the structure (at the boundary of LPZ 1, e.g. at installation point MB) install SPD1 fulfilling the requirements of C.2.2.

- Determine the impulse withstand voltage U_W of internal systems to be protected.

- Select the voltage protection level U_{P1} of SPD 1.

- Check the requirements of C.2.1 are met.

If this requirement is met, the equipment is adequately protected by SPD 1. Otherwise, an additional SPD 2(s) is/are needed.

- If so required, closer to the equipment (at the boundary of LPZ 2, e.g. at the installation point SB or SA), install SPD 2 fulfilling the requirements of C.2.2 and energy coordinated with the upstream SPD 1 (see C.3.4).

- Select the protection level U_{P2} of SPD 2.

- Check the requirements of C.2.1 are met.

If this requirement is met, the equipment is adequately protected by SPD 1 and SPD 2.

- Otherwise, close to the equipment (e.g. at installation point SA socket), additional SPD 3(s) is/are needed fulfilling the requirements of C.2.2 and energy coordinated with the upstream SPD 1 and SPD 2 (see C.2.3),

- Check the condition $U_{P/F3} \leq U_W$ is fulfilled (see C.2.1).

Annex D
(informative)

Factors to be considered in the selection of SPDs

D.1   Introduction

I_{imp}, I_{max} and I_n, are test parameters used in the operating duty test for class I and class II tests. They are related to the maximum values of discharge currents, which are expected to occur at the LPL probability level at the location of installation of the SPD in the system. I_{max} is associated with class II tests and I_{imp} is associated with class I tests.

The preferred values for I_{imp}, Q, W/R, in accordance with the future IEC 61643-11 [8] are reproduced in Table D.1.
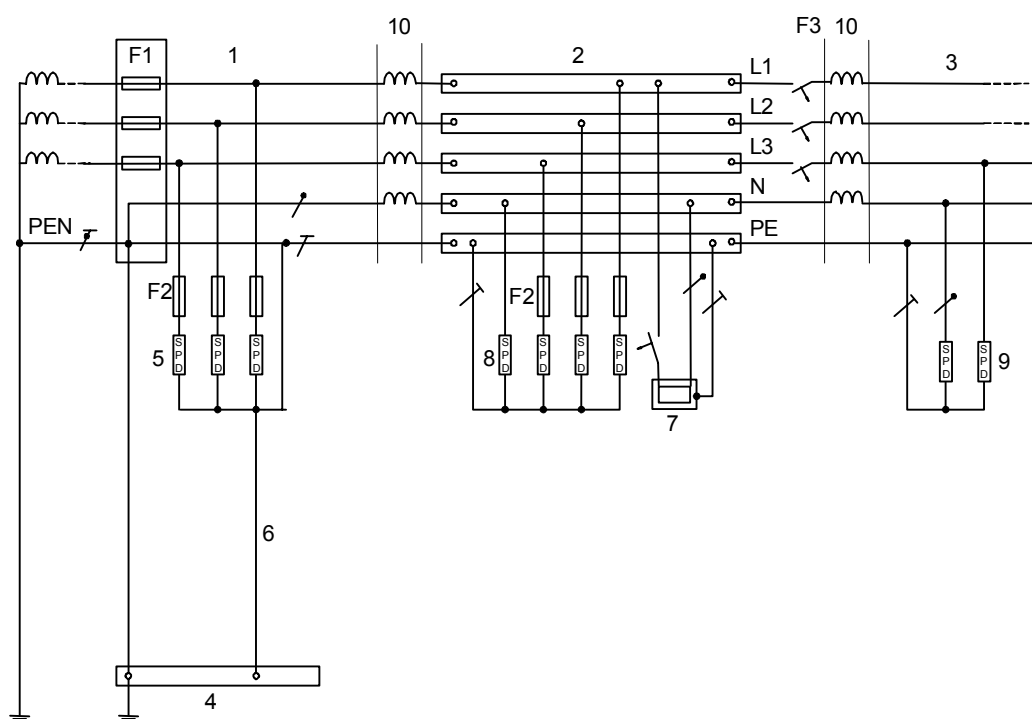
Table D.1 – Preferred values of I_{imp} [a]

I_{imp} [b] kA	1	2	5	10	12,5 [c]	20	25
Q (C)	0,5	1	2,5	5	6,25 [c]	10	12,5
W/R (kJ/Ω)	0,25	1	6,25	25	39 [c]	100	156

[a] Table D.1 refers to SPDs connected line to neutral (CT1 connection).

[b] In general I_{imp} is associated with longer waveshapes (for example 10/350 μs) than I_{max}.

[c] See IEC 60364-5-53:2001.

D.2   Factors determining the stress experienced by an SPD

The stress, which an SPD will experience under surge conditions, is a function of many complex and interrelated parameters. These include:

- location of the SPD(s) within the structure – See Figure D.1;

- method of coupling of the lightning strike to the facility (see Figure D.2) – for example, is this via a direct strike to the structure's LPS (S1), or via induction onto building wiring due to a nearby strike (S2), or services feeding the structure (S3 and S4);

- distribution of lightning currents within the structure – for example, what portion of the lightning current enters the earthing system, and what remaining portion seeks a path to remote earths via services which enter the structure such as the power distribution system, metallic pipes, telecom services, etc. and the equipotential bonding SPDs used on these;

- the resistance and inductance of services entering the structure, as these components effect the current peak value, I, and charge Q distribution ratios;

- additional conductive services connected to the facility – these will carry a portion of the direct lightning current and therefore reduce the portion which flows through the power distribution system via the lightning equipotential bonding SPD(s). Attention should be paid to the permanence of such services due to possible replacement by non-conductive parts;

- type of waveshape being considered – it is not possible to consider simply the peak current which the SPD will have to conduct under surge conditions, one also has to consider the waveshape of this surge (for example, 10/350 μs covering direct and partial lightning current, 8/20 μs covering induced lightning current) and the bulk charge Q;

- any additional structures which are interconnected to the primary structure via the power service, as these will also effect the current sharing distribution.


IEC 2812/10

Key

1 origin of the installation

2 distribution board

3 distribution outlet

4 main earthing terminal or bar

5 surge protective device, class I or II tested

6 earthing connection (earthing conductor) of the surge protective device

7 fixed equipment to be protected

8 surge protective device, class II tested

9 surge protective device, class II or class III tested

10 decoupling element or line length

F1, F2, F3 overcurrent protective disconnectors

NOTE   Refer to IEC 61643-12 for further information.

Figure D.1 – Installation example of test class I, class II and class III SPDs

IEC 2813/10
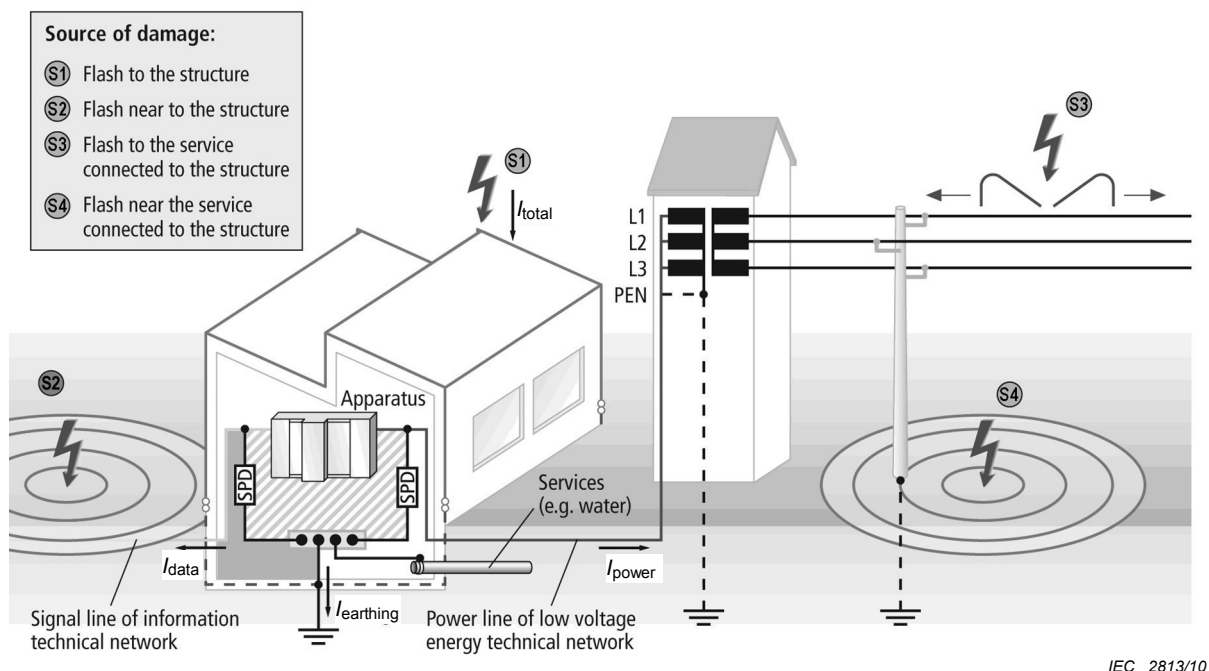
**Figure D.2 – Basic example for different sources of damage to a structure
and lightning current distribution within a system**

## D.3 Quantifying the statistical threat level to an SPD

D.3.1 General

Many attempts have been made to quantify the electrical environment and "threat level" which an SPD will experience at different locations within a facility. For example, for a service entrance SPD where a structural LPS is fitted, the threat level depends on the required LPL according to risk assessment for the involved structure in order to limit such risk to the tolerable value (see Clause 6 of IEC 62305-1:2010).

This standard postulates that under an LPL I the magnitude of a direct strike (S1) to the structure's LPS may be as high as 200 kA with a waveshape of 10/350 μs (see 8.1 and Annex A of IEC 62305-1:2010). However, whilst the SPDs should be selected to meet the required LPL identified by the risk assessment, there are further factors that would affect the magnitude of lightning current to which SPD is subjected.

D.3.2 Installation factors effecting current distribution

When no specific calculation of current sharing (see Clause E.2 of IEC 62305-1:2010) is carried out, a general assumption is made that 50 % of this current is conducted to the building's earthing system, and 50 % returns via the equipotential bonding SPD(s). For LPL I, this implies that the portion of the initial 200 kA discharge experienced by each SPD, I_{imp}, is 25 kA for a three phase plus neutral power distribution system – see Figure D.3.
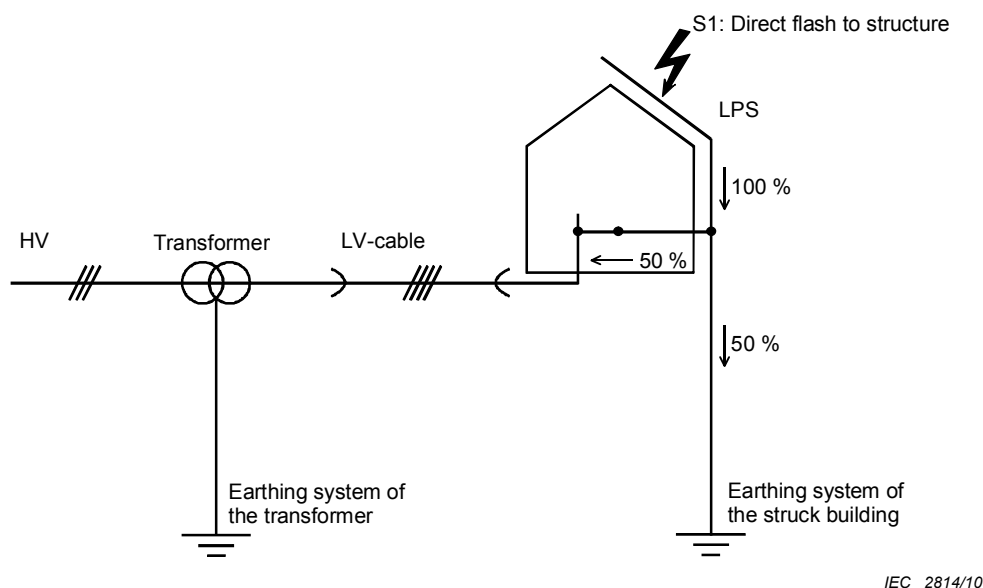
Figure D.3 – Basic example of balanced current distribution

If, however, three metallic services supply the structure, and the model of Clause E.2 of IEC 62305-1:2010 is adopted, the total current, I_{imp}, to each equipotential bonding SPD in the three-phase system becomes 8,3 kA.

The distribution of lightning current on a power distribution system is strongly influenced by the earthing practice of the services entering the structure. For example, in the TN-C system with its multiple-earthed neutral, a more direct and lower impedance path to earth is provided for lightning currents than in a TT system.

Simplified assumptions of current dispersion are useful in considering the possible threat level, which the SPD(s) may experience, but it is important to keep in context the assumptions being made. In addition, it has been assumed that the waveshape of this current component through the SPD(s) will be the same waveshape as the initial discharge, whereas in reality the waveshape may have been altered by the impedance of building wiring, etc.

Computer simulations can be a helpful tool in order to consider these factors for the correct selection of SPDs. In order to evaluate the lightning current dispersion for a complex system it is necessary to convert the real world system, as shown in the example of Figure D.2 into an equivalent electrical circuit diagram.

Many standards have sought rather to base their considerations of the threat level to which an SPD may be subject, on field experience collected over time. Table E.2 of IEC 62305-1:2010 is based mainly on field experience (see IEEE C62.41 series [9]).

D.3.3 Considerations in the selection of SPD ratings: I_{imp}, I_{max}, I_n, U_{OC}

From the above, it is apparent that the selection of the appropriate ratings I_{imp}, I_{max}, I_n and U_{OC} of an SPD depends on many complex and interconnected parameters.

It is important to keep in context that the risk of damage to internal systems within a structure due to surges arising from

– induced effects coupling power, phone and data lines (S4),
– LEMP effects of coupling from nearby strikes to the structure (S2),

may often be greater than those due to the effects of surges arising from direct strikes to the structure itself (S1) or to lines (S3).

Many buildings do not require protection against direct strikes to the structure or to incoming lines, and as such the requirement for test class I SPD(s) is not necessary, while a correctly designed test class II SPD system may be appropriate.

In general, the approach should be to use a test class I SPD where direct or partial lightning currents are involved (S1/S3) and a test class II/III SPD for induced effects (S2/S4).

When addressing such complexities, one needs to keep in mind that the most important aspect in selecting an SPD is its voltage limiting performance during the expected surge event, and the energy withstand (I_{imp}, I_{max}, I_n, U_{OC}) which it can handle (see NOTE 4 that follows Table B.7 in IEC 62305-2:2010).

At the expected I_n, an SPD with a limiting voltage lower than the withstand voltage of the equipment will ensure equipment protection, particularly considering external factors that create additive voltages (voltage drop on connecting leads, oscillations and induction phenomena). In contrast, an SPD with a withstand energy higher than that required at the point of installation may result only in a longer SPD operating life. However, an SPD with lower limiting voltage may be more susceptible to possible damage from temporary over voltages (TOV) if installed on poorly regulated power systems.

Bibliography

[1] IEC 60364-4-44, *Low-voltage electrical installations – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances*

[2] IEC 61000 (all parts), *Electromagnetic compatibility (EMC)*

[3] ITU-T Recommendation K.20:2008, *Resistibility of telecommunication equipment installed in a telecommunications centre to overvoltages and overcurrents*

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

[5] ITU-T Recommendation K.45:2003, *Resistibility of telecommunication equipment installed in the access and trunk networks to overvoltages and overcurrents*

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

[7] ITU-T Lightning handbook:1994, *The protection of telecommunication lines and equipment against lightning discharges – Chapter 10*

[8] IEC 61643-11: *Low-voltage surge protective devices – Part 11: Surge protective devices connected to low-voltage power distribution systems – Performance requirements and testing methods*

[9] IEEE C62.41:1991, *Recommended practice on surge voltages in low-voltage ac power circuits*

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