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A Guide to BS EN 62305 Protection Against Lightning

3rd edition

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A Guide to BS EN 62305 Protection Against Lightning

Lightning Theory
Risk Assessment
Structural Lightning Protection
Electronic Systems Protection

Intended for:

Lightning protection contractors, architects, consultants, specifiers, building services engineers, electrical contractors, facilities managers and any other parties responsible for or interested in the protection of structures and electronic systems from lightning.

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Author's note

This publication has been produced as an informative guide for designers, engineers, architects, consultants and contractors, with the following aims:

- To briefly explain the theory and phenomenon of lightning
- To précis, and simplify where possible the four parts of British Standard BS EN 62305 Protection against lightning
- To provide an introduction to the transient overvoltage protection requirements defined within BS 7671
- To outline the importance of lightning protection component performance to IEC 62561, the new product standard which is replacing BS EN 50164

In conjunction with our other technical material, such as CPD accredited seminars and commercial risk assessment software, this guide has been developed to improve understanding of lightning protection and to help industry professionals navigate through BS EN 62305 in a practical and cost effective manner.

All standards are open to individual interpretation. This guide therefore reflects Furse's own views on good practice and it is not the intention that these views replace, in any way, the recommendations contained in the BS EN 62305 series, but rather to be read in conjunction with the standard.

We hope you find this guide useful and should you require assistance or advice, please do not hesitate to contact Furse on +44 (0)115 964 3700.

New standards on lightning protection

The UK is one of the 28 countries with membership of CEN (Comité Européen de Normalisation), which focuses on ensuring harmonisation of design and application standards throughout its member states.

The electrical arm of CEN is CENELEC (CLC), and it is this committee which is responsible for compiling and producing standards relevant to lightning protection.

In 2006, a four-part suite of standards on lightning protection was compiled by CENELEC under the reference number 62305 series.

The UK's British Standards Institution (BSI) adopted this CENELEC standard as its own British Standard (with minor amendments), and introduced BS EN 62305 in August 2006. For a finite period BS EN 62305 ran in parallel with its predecessor on lightning protection, BS 6651, but as of September 2008, BS EN 62305 has been the only standard in force.

BS EN 62305 considers lightning protection in much greater depth and detail than its predecessor, containing approximately four times as much information as BS 6651 within its four parts.

Additionally, in two key areas, Part 2: Risk management and Part 4: Electrical and electronic systems within structures, it is radically different:

- Part 2: presents risk management in much greater detail and complexity than BS 6651 and defines a single risk assessment process for protection against physical damage to structures, life hazard, and protection of electronic systems
- Part 4: which essentially embodies Annex C of BS 6651 but with a new zonal concept, is now a key part of the core BS EN 62305 standard with implementation driven by Part 2

It is this single risk assessment process which now ensures that those involved in lightning protection consider all potential risks. Essentially, structural lightning protection and electronic systems protection cannot now be considered in isolation.

BS EN 62305 has now been in force for over five years. As with all CENELEC standards, it has been subject to technical review (completed 2011 - 2012) to ensure currency and accuracy of the information provided.

This review process has culminated in the publication of updates to Parts 1, 3, and 4 in 2011, and to Part 2 in mid 2013.

This guide has therefore been revised in this edition to reflect the changes made to the standard, with all updates clearly highlighted.

1. Introduction to lightning protection

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1. Introduction to lightning protection

Benjamin Franklin (1707 - 1790) is generally considered to be the father of modern Lightning Protection theory. His celebrated kite experiment proving for the first time that storm clouds generate, hold and discharge static electricity.

1.1 Characteristics of lightning

Formation of storm clouds

Lightning is formed as a result of a natural build-up of electrical charge separation in storm clouds.

There are two types of storm clouds, which generate a static electrical charge, heat storms and frontal storms.

The heat or convective storm (Figure 1.1) predominates in tropical regions and mountainous areas.

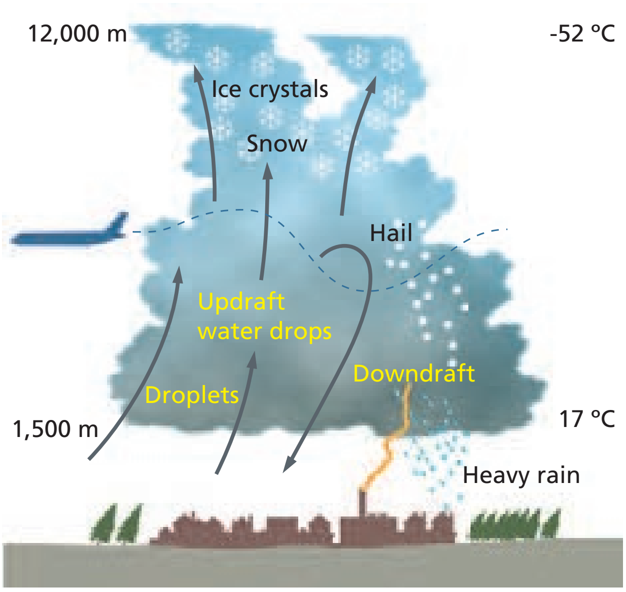

Figure 1.1: Heat storm

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On a hot day, warm air rises from warm ground and is replaced by cooler air drifting down. The convection process progressively cools the rising air to form clouds, first as water droplets and then at greater heights as ice crystals.

In this way, a single or multiple cloud 'cell' is formed, the top of which may reach a height of 12 km.

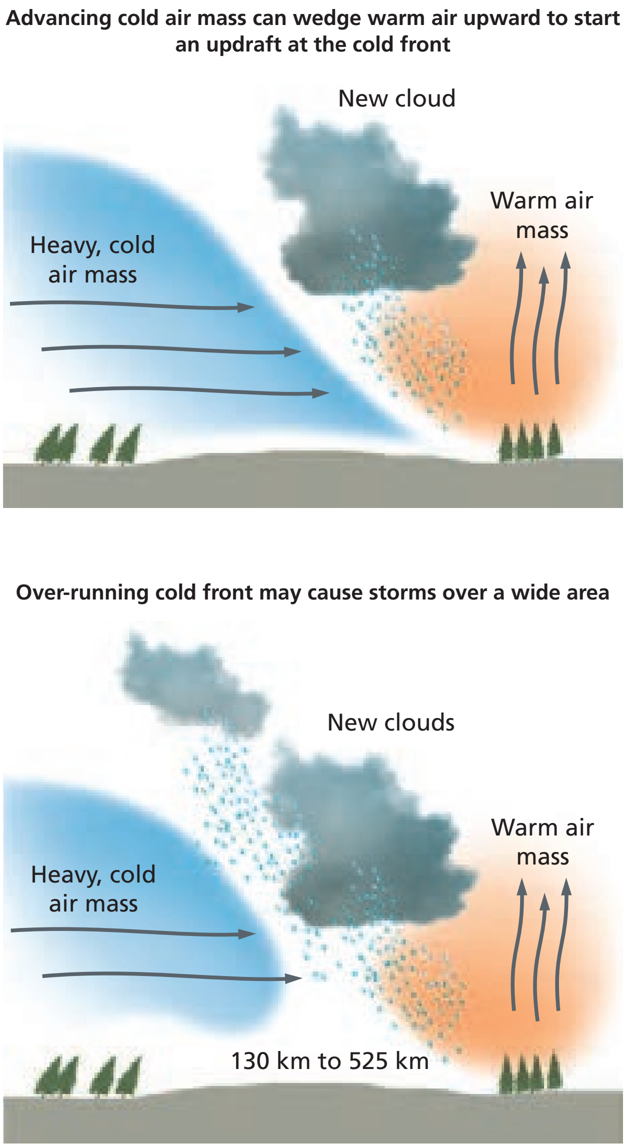

Figure 1.2: Frontal storm

Frontal storms (Figure 1.2), which predominate in temperate regions, are caused by the impact of a front of cold air on a mass of warm moist air, which is lifted above the advancing cold front.

As the warm air rises the process described above is repeated but the resulting cumulo-nimbus clouds may, in this case, extend over several tens of kilometres in width and contain a large number of individual cells with heights of between 7.5 km and 18 km.

Charge separation

How many clouds form is well understood. How the cloud separates its charge is not. Many theories have been put forward but everyone seems to agree that in a thunder-cloud, ice crystals become positively charged while water droplets carry a negative charge.

The distribution of these particles normally gives rise to a negative charge building up at the base of the cloud (Figure 1.3).

This build-up at the cloud base gives rise to a positive build-up of charge on the ground. The ground can be as little as 1 km away from the cloud base.

The build-up continues until the voltage difference between the cloud base and the ground becomes so great that it causes a breakdown of the air's resistance, thus creating a lightning discharge.

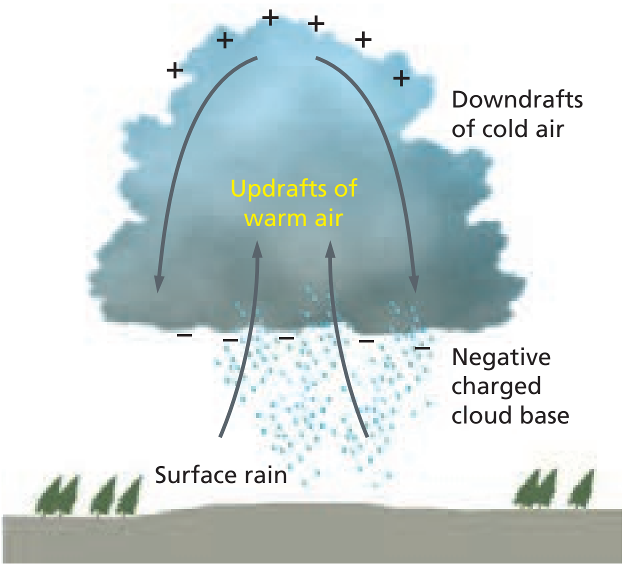

Figure 1.3: Charge build up in thundercloud

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Lightning discharges

The first stage of this discharge is the development of a stepped downward leader within the cloud, which moves towards the ground. This downward movement continues in approximately 50 m steps. It is not visible to the naked eye. When the stepped leader is near the ground (Figure 1.4) its relatively large negative charge induces even greater amounts of positive charge on the earth beneath it, especially on objects projecting above the earth's surface.

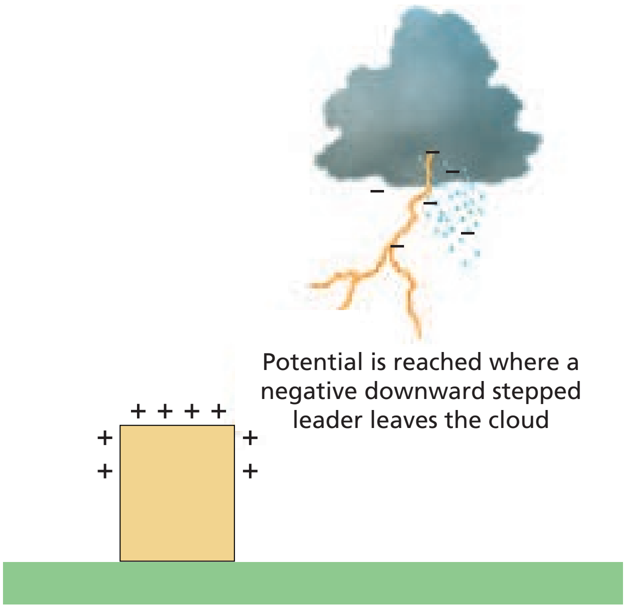

Figure 1.4: Development of the downward stepped leader

Since these opposite charges attract each other, the large positive charge attempts to join the downward moving stepped leader by forming an upward moving streamer (Figure 1.5). The two meet and form a complete conducting path along which a massive current attempts to flow in order to equalize the difference in potential between cloud and ground. This is termed the "return stroke" (Figure 1.6) and is the bright lightning flash we see.

The lightning discharge described is the most common seen by man and is termed a negative descending stroke. Several variations can occur, ie from mountain peaks or from structures. In these situations a positive leader channel may start upward from the mountain peak due to the intense concentration of positive charge at that point.

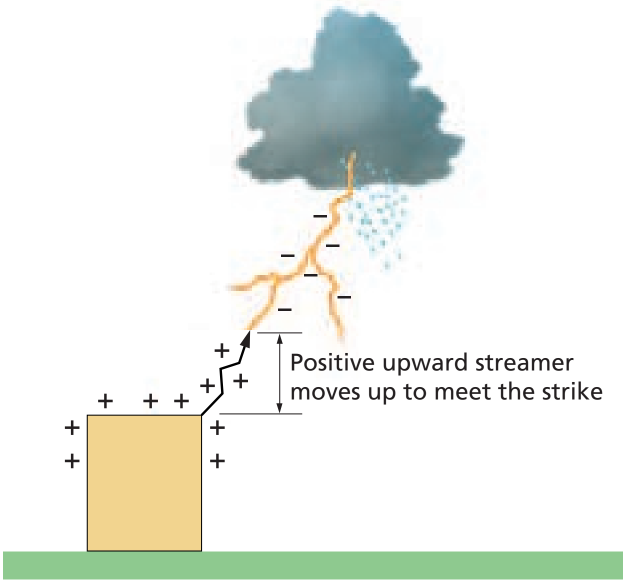

Figure 1.5: Development of the downward stepped leader and upward streamer

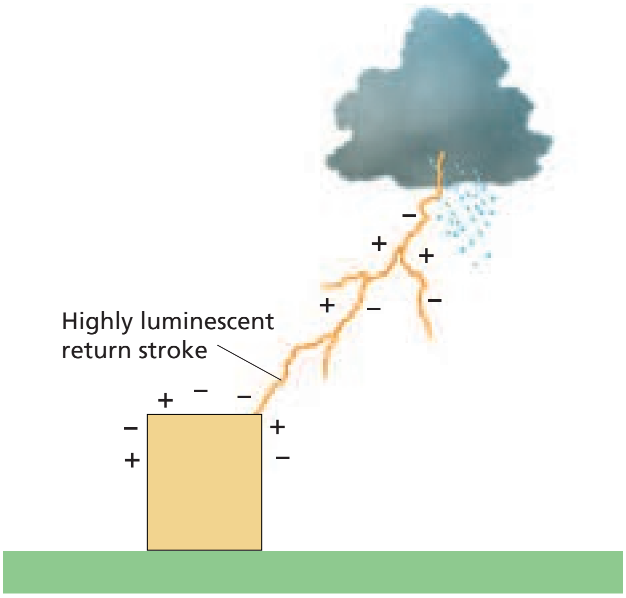

Figure 1.6: Return stroke

Lightning strokes

As well as different types of lightning discharge, different strokes also occur. No two lightning strokes are the same.

Air discharges emerge from the cloud but do not reach the ground. They can run horizontally for many kilometres. Sometimes they re-enter the cloud base further on, in which case they are regarded as cloud-to-cloud discharges.

Cloud flashes take place inside the thundercloud so that only a diffused flickering is seen. These are more numerous than flashes to the ground and a ratio of 6:1 or more is thought probable.

1.2 Transient overvoltages (surges)

Structural lightning protection conforming to BS EN 62305 is designed to protect the fabric of the building against lightning damage. It is not intended to, and will not, protect electronic equipment against the secondary effects of lightning.

By 'electronic equipment' we mean any piece of equipment that incorporates sensitive electronic components: computers, telecommunication equipment, PBX, control and instrumentation systems, programmable logic controllers.

Guidance on the protection of electronic systems is provided in Part 4 of the BS EN 62305 standard. This includes:

- An explanation of how lightning causes transient overvoltages (surges) and the effects they can have on electronic equipment
- Guidance on the need for protection (in accordance with the risk assessment)
- Methods of protection - these include bonding, location of equipment and cabling and the use of transient overvoltage (surge) protectors
- Advice on the selection of appropriate protectors

A transient overvoltage is a short duration surge in voltage between two or more conductors, see Figure 1.7. Lasting from microseconds to milliseconds large transient overvoltages can be caused by the secondary effects of lightning (transients can also be caused by electrical switching of large inductive loads such as air-conditioning units and lifts).

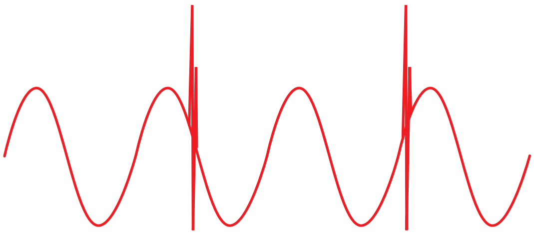

Figure 1.7: Transient overvoltage

Transient overvoltages caused by lightning can reach magnitudes of 6,000 Volts in a well-insulated power distribution system. This is over 8 times the level tolerated by many electronic systems.

Lightning doesn't have to strike the building to cause destructive transient overvoltages. The secondary effects of lightning can cause transient overvoltages by:

- Electromagnetic pick-up (inductive coupling)
- Differences in potential, between two connected earths (resistive coupling)

Lightning discharges give rise to an electromagnetic field (see Figure 1.8).

If power or data communications lines pass through this electromagnetic field a voltage will be picked up by, or induced onto this line.

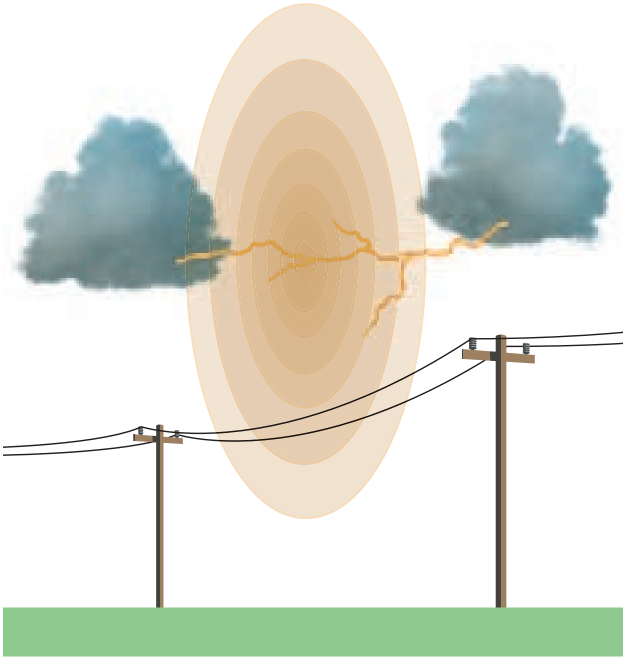

Figure 1.8: Cloud to cloud discharge - inductive coupling

Figure 1.9 shows two buildings. Each contains electronic equipment, which is connected to earth through its mains power supply. A data communication line connects the two pieces of equipment and hence the two separate earths.

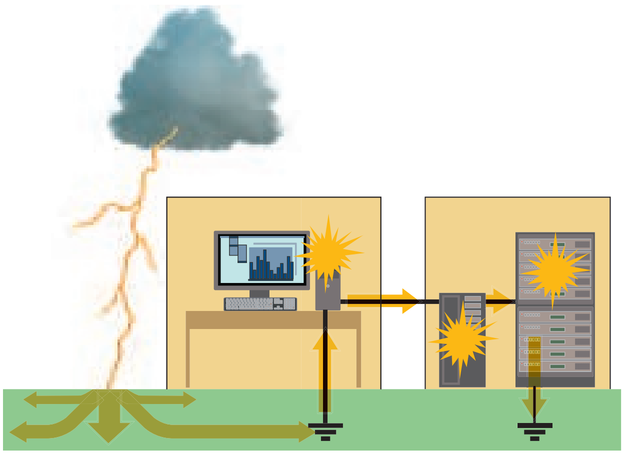

Figure 1.9: Nearby indirect lightning strike - resistive coupling

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A nearby lightning strike will inject a massive current into the ground. The current flows away from the strike point - preferentially through the path of least resistance. The earth electrode, electrical cables and the circuitry of the electronic equipment (once damaged), are all better conductors than soil. As the current attempts to flow, devastating transient overvoltages occur across the sensitive components of the equipment.

In both cases a transient overvoltage will appear across components within equipment at each end of the line - the consequences can be disastrous:

- Disruption and data corruption
- Degradation of components, shortening equipment lifetime
- Physical damage

All resulting in unnecessary systems downtime.

These destructive transient overvoltages can be conducted into electronic equipment by:

- Mains power supplies
- Data, signal and communications lines

Transient overvoltage protectors should be installed on both mains power supplies and data, signal and communications lines.

Mains power supplies should be protected

- At the main incomer or main low voltage power distribution board
- On outgoing power supplies
- Locally to key pieces of equipment eg: computers

Data, signal and communications lines

- Protect all lines coming into the building
- Protect all lines leaving the building

Requirements for a transient (surge) protection device:

- A low 'let-through' voltage (this is the voltage which gets past the protector, reaching sensitive equipment)
- This performance should be provided with respect to all combinations of conductors ie in the case of power cables, phase to phase, phase to neutral, phase to earth etc
- Should not impair the normal operation of the system

What transient overvoltages are not!

Transient overvoltages are by definition a very specific form of disturbance. It is therefore worth briefly outlining other forms of electrical disturbance in order to understand what transient overvoltages are not!

Most of these disturbances can be represented as an aberration to the normal mains power supply, shown in Figure 1.10a.

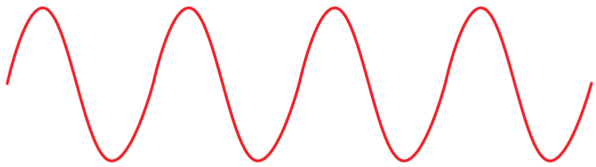

Figure 1.10a: Normal mains power supply

'Outage', 'power cut' and 'blackout' are all terms applied to total breaks in the supply lasting from several milliseconds to many hours. See Figure 1.10b. Very short breaks, which cause lights to flicker, may be sufficient to crash computers and other sensitive electronic equipment.

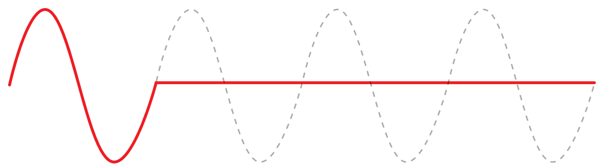

Figure 1.10b: Power cut

'Undervoltages' or 'brownouts' are sustained reductions in the supply voltage, lasting anything from a few seconds. See Figure 1.10c.

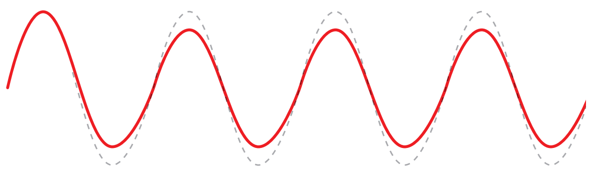

Figure 1.10c: Undervoltage

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'Overvoltages' are sustained increases in the supply voltage, lasting anything over a few seconds. See Figure 1.10d.

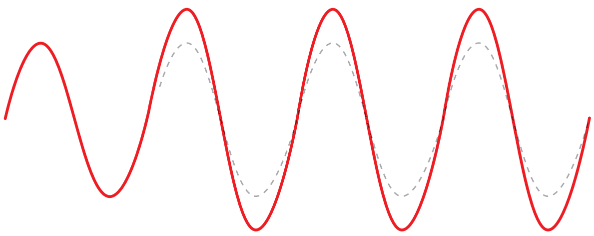

Figure 1.10d: Overvoltage

'Sags' or 'dips' are decreases in the supply voltage, lasting no more than a few seconds. See Figure 1.10e.

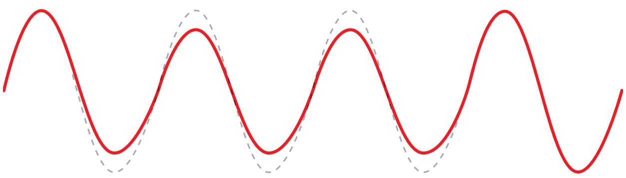

Figure 1.10e: Sag

'Swells' (also called 'surges') are increases in the supply voltage, lasting no more than a few seconds. See Figure 1.10f.

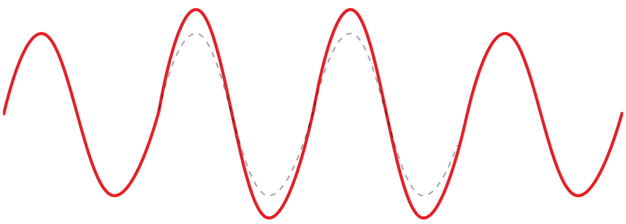

Figure 1.10f: Swell

Electrical noise or radio frequency interference (RFI) is a continuous high frequency (5 kHz or more) distortion of the normal sine wave. See Figure 1.10g.

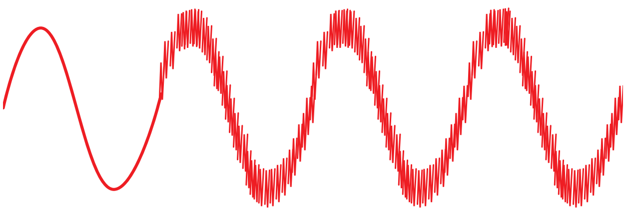

Figure 1.10g: Radio frequency interference

Harmonics are a continuous distortion of the normal sine wave, at frequencies of up to 3 kHz. See Figure 1.10h.

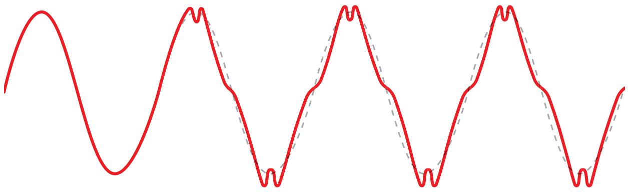

Figure 1.10h: Harmonics

Nuclear electromagnetic pulse (NEMP), or electromagnetic pulse (EMP), are pulses of energy caused by nuclear explosions and intense solar activity. NEMP or EMP transients are much quicker (a faster rise time) than commonly occurring transients. See Figure 1.10i.

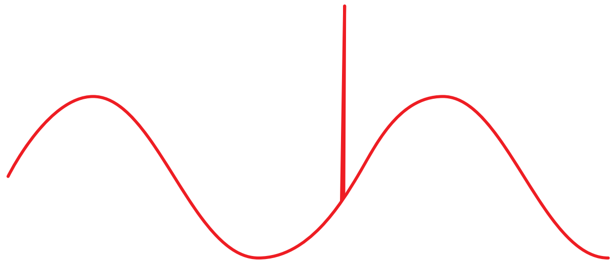

Figure 1.10i: Nuclear electromagnetic pulse

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1.3 Lightning protection standard BS EN 62305

The British Standard European Norm (BS EN) 62305 Series consists of four distinct parts, under the general title "Protection against lightning".

These four parts constitute a much more thorough view on protection against lightning, when assessed against the previous Standard BS 6651.

Part 1: General principles

BS EN 62305-1 (part 1) is an introduction to the other parts of the standard and essentially describes how to design a Lightning Protection System (LPS) in accordance with the accompanying parts of the standard.

Part 2: Risk management

BS EN 62305-2 (part 2) risk management approach, does not concentrate so much on the purely physical damage to a structure caused by a lightning discharge, but more on the risk of loss of human life (including permanent injury), loss of service to the public, loss of cultural heritage and economic loss.

Part 3: Physical damage to structures and life hazard

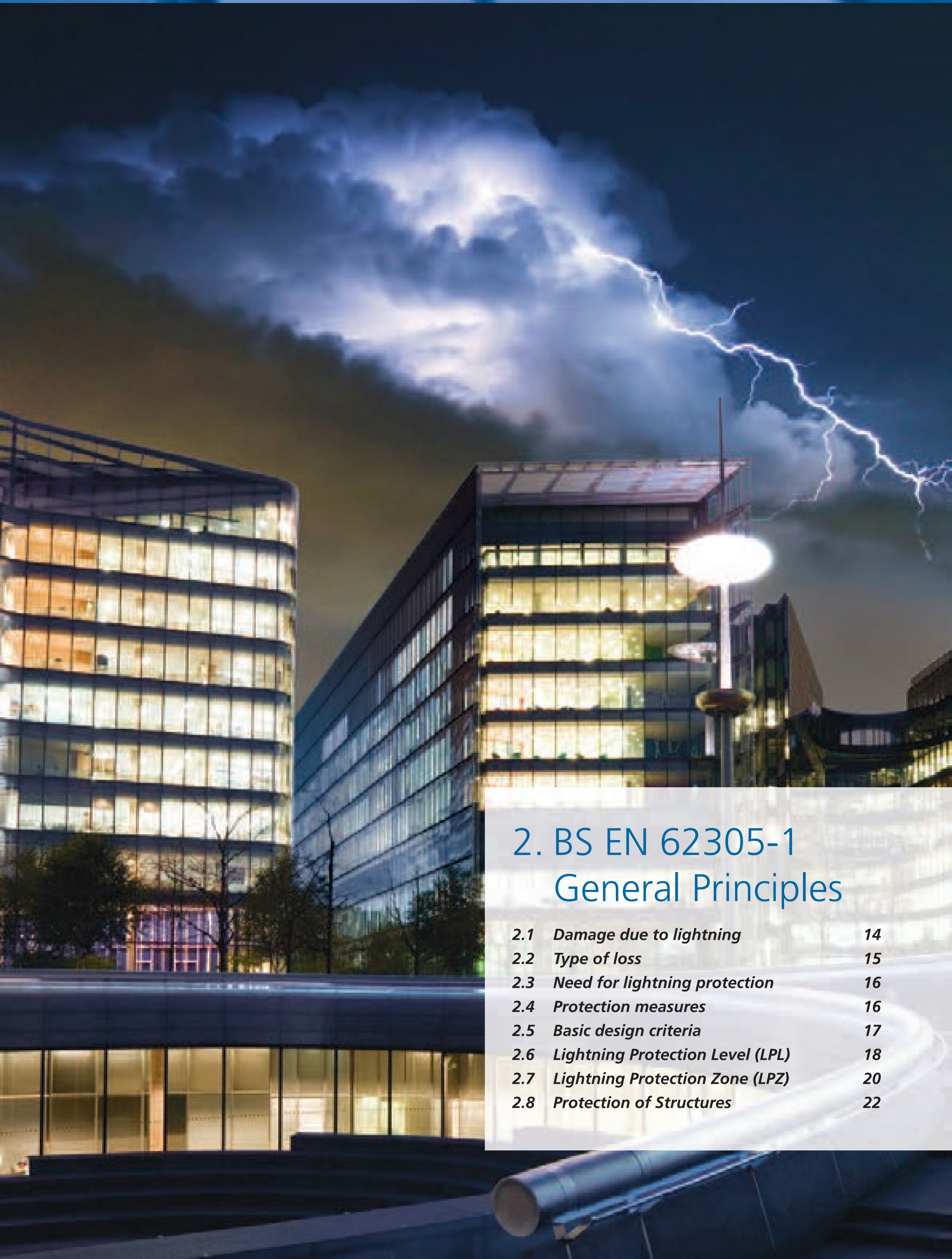
BS EN 62305-3 (part 3) relates directly to the major part of BS 6651. It differs from BS 6651 in as much that this new part has four Classes or protection levels of Lightning Protection System (LPS), as opposed to the basic two (ordinary and high-risk) levels in BS 6651.

Part 4: Electrical and electronic systems within structures

BS EN 62305-4 (part 4) covers the protection of electrical and electronic systems housed within structures. This part essentially embodies what Annex C in BS 6651 conveyed, but with a new zonal approach referred to as Lightning Protection Zones (LPZs). It provides information for the design, installation, maintenance and testing of Surge Protection Measures (SPM) for electrical/electronic systems within a structure.

! BS EN 62305 update

The 2006 version of BS EN 62305 was originally intended to be a five part set. However, the planned fifth part 'Services', whilst originally intended, was ultimately never published as part of the series. As the original BS EN 62305:2006 standard has now undergone technical review, any references to this Part 5 have been removed prior to the publishing of the revised standard. Any aspects relevant to Telecoms are covered in the appropriate ITU standards.



2. BS EN 62305-1 General Principles

2.1	*Damage due to lightning*	*14*
2.2	*Type of loss*	*15*
2.3	*Need for lightning protection*	*16*
2.4	*Protection measures*	*16*
2.5	*Basic design criteria*	*17*
2.6	*Lightning Protection Level (LPL)*	*18*
2.7	*Lightning Protection Zone (LPZ)*	*20*
2.8	*Protection of Structures*	*22*

2. BS EN 62305-1 General principles

This opening part of the BS EN 62305 suite of standards introduces the reader to the other parts of the standard.

It defines by its five annexes the lightning current parameters that are used to design and then select the appropriate protection measures detailed in the other parts.

2.1 Damage due to lightning

Within Part 1, the initial focus is on the damage that can be caused by lightning. This is sub-divided into:

- Damage to a structure (including all incoming electrical overhead and buried lines connected to the structure)
- Damage to a service (service in this instance being the service lines which form part of telecommunication, data, power, water, gas and fuel distribution networks)

Damage to a structure is further subdivided into sources of damage and types of damage.

Source of damage

The possible sources of damage, as highlighted in Figure 2.1 right, are:

S1 **Flashes to the structure**

S2 **Flashes near to the structure**

S3 **Flashes to the lines connected to the structure**

S4 **Flashes near to the lines connected to the structure**

Type of damage

Each source of damage may result in one or more of three types of damage.

The possible types of damage are identified as follows:

D1 **Injury of 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 Lightning Electromagnetic Impulse (LEMP)**

This wider approach of taking into account the specific services (power, telecom and other lines) that are connected to the structure identifies that fire and/or an explosion could occur as a result of a lightning strike to or near a connected service line (these being triggered by sparks due to overvoltages and partial lightning currents that are transmitted via these connected lines). This in turn could have a direct bearing on the specific types of loss as defined in the next section.

This approach is then amplified in BS EN 62305-2 Risk management.

2.2 Type of loss

The following types of loss may result from damage due to lightning:

L1 **Loss of human life (including permanent injury)**

L2 **Loss of service to the public**

L3 **Loss of cultural heritage**

L4 **Loss of economic value (the structure, its contents, and loss of activity)**

NOTE: L4 relates to the structure and its contents; to the service and the loss of activity, due to the loss. Typically, loss of expensive and critical equipment that may be irretrievably damaged due to the loss of the power supply or data/telecom line. Similarly the loss of vital financial information for example that could not be passed onto clients of a financial institution due to damage, degradation or disruption of internal IT hardware caused by lightning transients. The relationships of all of the above parameters are summarized in Table 2.1.

Point of strike	Source of damage	Type of damage	Type of loss
Structure	S1	D1 D2 D3	L1, L4** L1, L2, L3, L4 L1*, L2, L4
Near a structure	S2	D3	L1*, L2, L4
Lines connected to the structure	S3	D1 D2 D3	L1, L4** L1, L2, L3, L4 L1*, L2, L4
Near a line	S4	D3	L1*, L2, L4

* Only for structures with risk of explosion and for hospitals or other structures where failures of internal systems immediately endangers human life.
** Only for properties where animals may be lost.

Table 2.1: Damage and loss in a structure according to different points of lightning strike (BS EN 62305-1 Table 2)

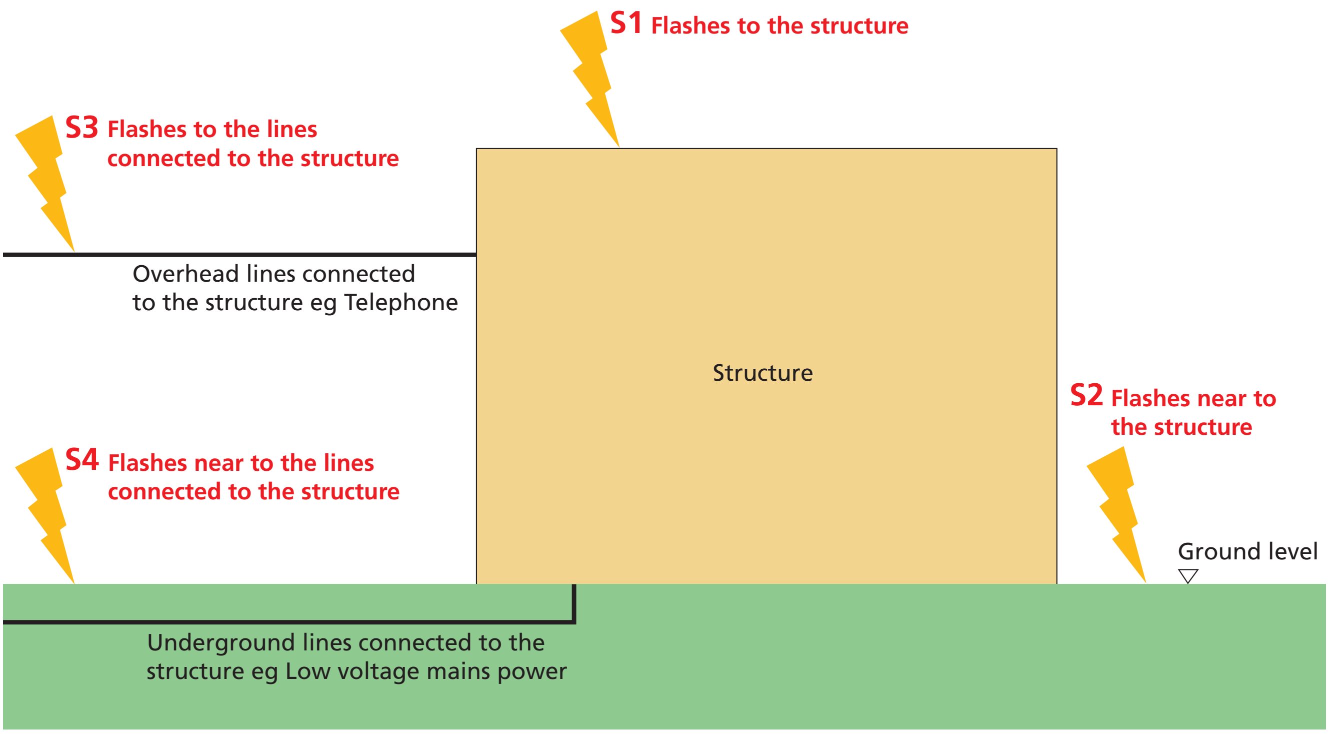


Figure 2.1: Sources of damage

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2.3 Need for lightning protection

The foregoing information is classifying the source and type of damage along with categorising the type of loss that could be expected in the event of a lightning strike.

This ultimately leads on to the important aspect of defining risk.

In order to evaluate whether lightning protection of a structure and/or its connected service lines is needed, a risk assessment is required to be carried out.

The following risks have been identified, corresponding to their equivalent type of loss.

R_1 **Risk of loss of human life (including permanent injury)**

R_2 **Risk of loss of service to the public**

R_3 **Risk of loss of cultural heritage**

Protection against lightning is required if the risk R (whether this be R_1, R_2 or R_3) is greater than the tolerable risk R_T.

Conversely if R is lower than R_T then no protection measures are required.

R_1 - **Risk of loss of human life (including permanent injury)** is by far the most important risk to consider, and as such the examples and subsequent discussions relating to BS EN 62305-2 Risk management will focus largely on R_1.

R_2 - **Risk of loss of service to the public** may initially be interpreted as the impact/implications of the public losing its gas, water or power supply. However the correct meaning of loss of service to the public lies in the loss that can occur when a service provider (whether that be a hospital, financial institution, manufacturer etc) cannot provide its service to its customers, due to lightning inflicted damage. For example, a financial institution whose main server fails due to a lightning overvoltage occurrence will not be able to send vital financial information to all its clients. As such the client will suffer a financial loss due to this loss of service as they are unable to sell their product into the open market.

R_3 - **Risk of loss of cultural heritage** covers all historic buildings and monuments, where the focus is on the loss of the structure itself.

Additionally it may be beneficial to evaluate the economic benefits of providing protection to establish if lightning protection is cost effective. This can be assessed by evaluating R_4 - **risk of loss of economic value**. R_4 is not equated to a tolerable level risk R_T but compares, amongst other factors, the cost of the loss in an unprotected structure to that with protection measures applied.

2.4 Protection measures

This section highlights the protection measures that can be adopted to reduce the actual risk of damage and loss in the event of a lightning strike to or near a structure or connected service line.

- Electric shock due to step and touch voltages generated from a lightning strike could cause injury to humans (and animals) both inside as well as in the close vicinity of the structure (approximately 3 m). Possible protection measures include adequate insulation of exposed conductive parts that could come in contact with the person. Creating an equipotential plane by means of a meshed conductor earthing arrangement would be effective in reducing the step voltage threat. Additionally, it is good practice to provide warning notices and physical restrictions where possible.
- Equally, artificially increasing the surface resistivity of the soil (typically, a layer of tarmac or stones) outside the structure may reduce the life hazard. Equipotential bonding of the connected service lines at the entrance point of the structure would benefit anyone located inside the structure.
- To reduce the physical damage caused by a lightning strike to a structure, a Lightning Protection System (LPS) would need to be installed, details of which are given in BS EN 62305-3.
- Damage, degradation or disruption (malfunction) of electrical and electronic systems within a structure is a distinct possibility in the event of a lightning strike. Possible protection measures against equipment failure include:
  a) Comprehensive earthing and bonding
  b) Effective shielding against induced Lightning Electromagnetic Impulse (LEMP) effects
  c) The correct installation of coordinated Surge Protective Devices (SPDs) which will additionally ensure continuity of operation
  d) Careful planning in the routeing of internal cables and the suitable location of sensitive equipment
  e) The appropriate installation of isolating interfaces such as isolation transformers, or fibre optic cables

  These measures in total are referred to as Surge Protection Measures (SPM) - see BS EN 62305-4.

The selection of the most suitable protection measures to reduce the actual risk (whether that be R_1, R_2 or R_3) below the tolerable risk R_T when applied to a particular structure and/or any connected service line is then made by the lightning protection designer.

Details of the methodology and criteria for deciding the most suitable protection measures is given in BS EN 62305-2 Risk management.

BS EN 62305 update

In the 2006 edition of BS EN 62305, protection measures for electrical and electronic systems were referred to as a LEMP Protection Measures System (LPMS). In the current edition however, this has been amended to Surge Protection Measures (SPM). Note, in the standard the actual term used is LEMP Protection Measures, although the more generic and industry recognized term, 'surge', is the basis for the acronym and is therefore used here.

Furthermore, with regard to protection measures, isolating interfaces may now be incorporated as part of the SPM system.

2.5 Basic design criteria

The ideal lightning protection for a structure and its connected service lines would be to enclose the structure within an earthed and perfectly conducting metallic shield (box), and in addition provide adequate bonding of any connected service lines at the entrance point into the shield. This in essence would prevent the penetration of the lightning current and the induced electromagnetic field into the structure.

However, in practice it is not possible or indeed cost effective to go to such lengths. The standard thus sets out a defined set of lightning current parameters where protection measures, adopted in accordance with its recommendations, will reduce any damage and consequential loss as a result of a lightning strike. This reduction in damage and consequential loss is valid provided the lightning strike parameters fall within the defined limits.

BS EN 62305 update

Note, the latest edition of the standard makes clear that LPS design and installation should be conducted by well trained and expert LPS designers and installers.

Additionally, design of SPM should be conducted by experts in lightning and surge protection who possess a broad knowledge of EMC and installation practices.

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2.6 Lightning Protection Level (LPL)

Four protection levels have been determined based on parameters obtained from previously published Conference Internationale des Grands Reseaux Electriques (CIGRE) technical papers. Each level has a fixed set of maximum and minimum lightning current parameters.

Maximum lightning current parameters

Table 2.2 identifies the maximum values of the peak current for the first short stroke for each protection level.

LPL	I	II	III	IV
Maximum current (kA)	200	150	100	100

Table 2.2: Lightning current for each LPL based on 10/350 μs waveform

The maximum values have been used in the design of products such as lightning protection components and SPDs.

For the current capability design of lightning current SPDs, it is assumed that 50% of this current flows into the external LPS/earthing system and 50% through the service lines within the structure.

Should the service line consist solely of a three-phase power supply (4 lines, 3 phases and neutral) then the following design currents could be expected:

LPL	I	II	III	IV
Current per mode (kA)	25	18.75	12.5	12.5

Table 2.3: Current capability of lightning current SPDs based on 10/350 μs waveform

This is the extreme case and in reality, multiple connected service lines (including telecommunication, data, metallic gas and water) are typically present which further divide and hence reduce the currents, as they are shared amongst the different service lines.

This will be further clarified in BS EN 62305-4 Electrical and electronic systems within structures starting on page 67.

Minimum lightning current parameters

The minimum values of lightning current are used to derive the rolling sphere radius for each level. There is a relationship between the minimum peak current and the striking distance (or in other words the rolling sphere radius) that can be expressed as:

$$r = 10 \times I^{0.65} \qquad (2.1)$$

Where: r = radius of rolling sphere (m)

I = minimum peak current (kA)

For example, for LPL I:

$$r = 10 \times 3^{0.65}$$

$$r = 20.42 \text{ m}$$

The calculated and adopted values for all four LPLs are shown in Table 2.4.

LPL	I	II	III	IV
Minimum current (kA)	3	5	10	16
Calculated radius of rolling sphere (m)	20.42	28.46	44.67	60.63
Adopted radius of rolling sphere (m)	20	30	45	60

Table 2.4: Radius of rolling sphere for each LPL

Tables 3, 4 and 5 of BS EN 62305-1 assign maximum and minimum values of peak current alongside a weighted probability for each designated lightning protection level.

So we can state that:

- LPL I can see a range of peak current from 3 kA to 200 kA with a probability that:

  99% of strikes will be lower than 200 kA
  99% of strikes will be higher than 3 kA
- LPL II can see a range of peak current from 5 kA to 150 kA with a probability that:

  98% of strikes will be lower than 150 kA
  97% of strikes will be higher than 5 kA
- LPL III can see a range of peak current from 10 kA to 100 kA with a probability that:

  97% of strikes will be lower than 100 kA
  91% of strikes will be higher than 10 kA
- LPL IV can see a range of peak current from 16 kA to 100 kA with a probability that:

  97% of strikes will be lower than 100 kA
  84% of strikes will be higher than 16 kA

It is worthwhile at this juncture to give a simple explanation of the parameters of lightning current.

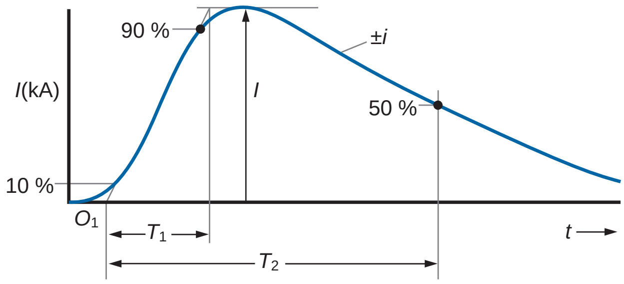
Two basic types of lightning flashes (or discharges) exist:

- Down flashes initiated by a downward leader from the cloud to earth. Most of these occur in flat territory and to structures of low to modest height
- Upward flashes initiated by an upward leader from an earthed structure to the cloud. This type of event occurs with tall or exposed structures

A lightning current consists of one or more different strokes.

Short strokes have a duration less than 2 milliseconds (ms) and long strokes have a duration greater than 2 ms.

The initial or first short stroke from a lightning discharge can be depicted by the waveform illustrated in Figure 2.2a.



O_1 = virtual origin
I = peak current
T_1 = front time (10 μs)
T_2 = time to half value (350 μs)

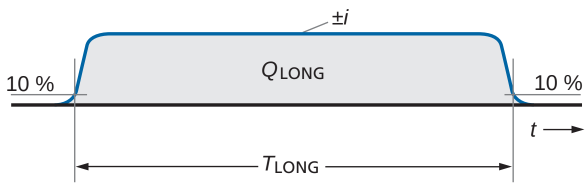
Figure 2.2a: Short stroke parameters

The waveform shown is 10/350 microsecond (μs) where the rise time is 10 μs and the time to reach its half value is 350 μs.

The characteristics of a long stroke are depicted by the waveform illustrated in Figure 2.2b.

Downward flashes which represent the majority of lightning discharges can consist of an initial short stroke followed by a series of subsequent short strokes (normally of lesser magnitude than the first) or an initial short stroke followed by a combination of long and subsequent short strokes.

See Annex A of BS EN 62305-1 for more details.



T_{long} = long stroke duration
Q_{long} = long stroke charge

Figure 2.2b: Long stroke parameters

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2.7 Lightning Protection Zone (LPZ)

The Lightning Protection Zone (LPZ) concept was introduced in BS EN 62305, particularly to assist in determining the Surge Protection Measures (SPM) required within a structure.

The LPZ concept as applied to the structure is illustrated in Figure 2.3 and expanded upon in BS EN 62305-3.

The LPZ concept as applied to SPM is illustrated in Figure 2.4 and expanded upon in BS EN 62305-4.

The general principle is that the equipment requiring protection should be located in an LPZ whose electromagnetic characteristics are compatible with the equipment stress withstand or immunity capability.

In general the higher the number of the zone (LPZ 2; LPZ 3 etc) the lower the electromagnetic effects expected. Typically, any sensitive electronic equipment should be located in higher numbered LPZs and be protected by its relevant SPM.

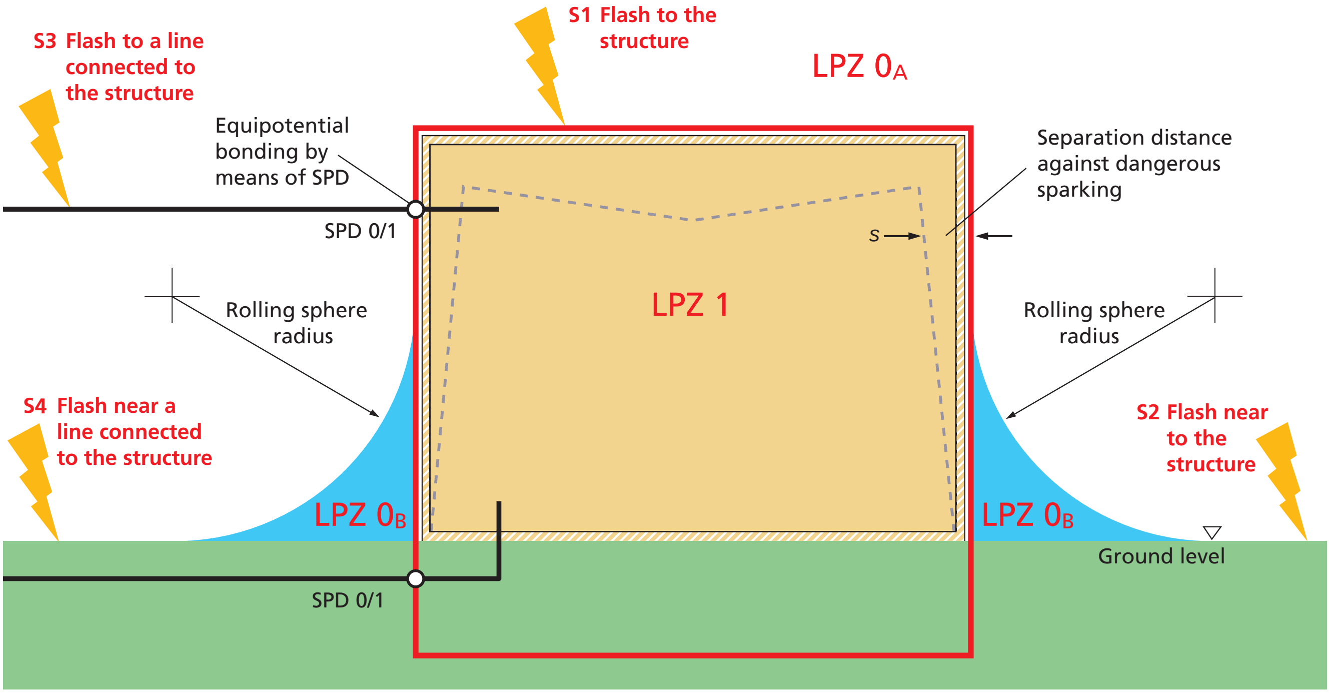

Figure 2.3: LPZ defined by an LPS

⌖	Lightning equipotential bonding (SPD)
LPZ 0_A	Direct flash, full lightning current
LPZ 0_B	No direct flash, partial lightning or induced current
LPZ 1	Protected volume inside LPZ 1 must respect separation distance

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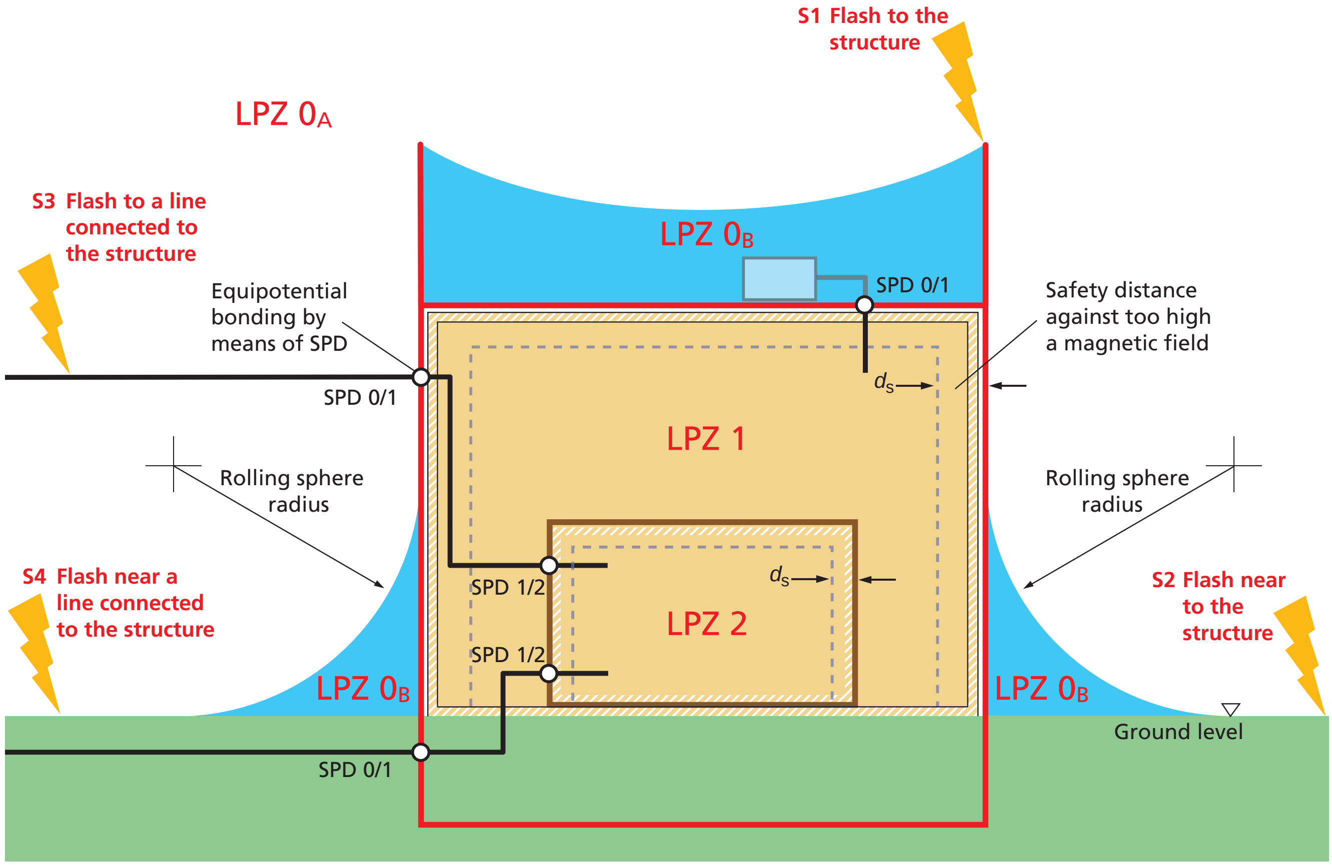

Figure 2.4: LPZ defined by protection measures against LEMP

LPZ 0_A Direct flash, full lightning current, full magnetic field
LPZ 0_B No direct flash, partial lightning or induced current, full magnetic field
LPZ 1 No direct flash, partial lightning or induced current, damped magnetic field
LPZ 2 No direct flash, induced currents, further damped magnetic field
Protected volumes inside LPZ 1 and LPZ 2 must respect safety distances d_s

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2.8 Protection of structures

An LPS consists of external and internal lightning protection systems. It has four Classes of LPS (I, II, III and IV) which are detailed in BS EN 62305-3.

The function of the external system is to intercept the strike, conduct and disperse it safely to earth.

The function of the internal systems is to prevent dangerous sparking from occurring within the structure as this can cause extensive damage and fires.

This is achieved by equipotential bonding or ensuring that a "separation distance" or in other words a sufficient electrical isolation is achieved between any of the LPS components and other nearby electrically conducting material.

Protection of internal systems within a structure can be very effectively achieved by the implementation of an SPM system detailed in BS EN 62305-4.

3. BS EN 62305-2 Risk management

3.1	*Perception of risk*	*24*
3.2	*Risk management procedure*	*25*
3.3	*UK and world maps*	*30*

3. BS EN 62305-2 Risk management

BS EN 62305-2 drives the correct implementation of BS EN 62305-3 and BS EN 62305-4.

The method adopted for the implementation of managing risk relevant to lightning protection is significantly more extensive and in depth than that of BS 6651. Many more parameters are taken into consideration.

3.1 Perception of risk

Although the aim of the CENELEC EN 62305-2 was to impart a common set of parameters for use by every country that belongs to CENELEC, it became apparent that widely differing lightning activity from country to country coupled with each country's interpretation and perception of risk made it very difficult to obtain a common consensus of meaningful results.

It was therefore decided to include an opening paragraph in Annex 'C' which permitted each and every National Committee to assign relevant parameters most applicable to their country.

The BSI technical committee (GEL/81) responsible for BS EN 62305-2 have modified certain tables within this part of the standard to reflect the UK's views.

As the rules within CENELEC preclude the deletion of tables and relevant notes, it was decided to add a series of National Annexes prefixed NB, NC, NE and NF and locate them at the end of the CENELEC Annexes.

Thus anyone wishing to employ the 'UK parameters' should follow the National Annexes NB, NC, and NE in preference to Annex B, C and E. Additionally Annex NF relates to the inclusion of other national parameters and information. These National Annex tables are highlighted later in this guide.

One of the first changes to realise is that this new approach to risk management looks at risk in a far broader sense than merely the physical damage that can be caused to a structure by a lightning discharge.

3.2 Risk management procedure

The risk management procedure is illustrated by the flow diagram shown in Figure 3.1.

The process for determining the risk of lightning inflicted damage to a structure and its contents, is somewhat involved when considering all the factors that need to be taken into account.

The designer initially identifies the types of loss that could result from damage due to lightning. The main aim of the procedure is to determine the risk R of each type of loss identified.

Next the designer identifies the tolerable risk R_T for each loss identified.

The risk process then takes the designer through a series of calculations using relevant formulae to determine the actual risk R for the structure under review. The designer must ascertain various weighting factors relative to the structure from his client along with various assigned values from the appropriate tables in Annexes A, NB and NC of BS EN 62305-2.

The calculated risk R is then compared to its corresponding value of R_T.

If the result shows $R \leqslant R_T$ then the structure is adequately protected for a particular type of loss.

If the result shows $R > R_T$ then the structure is not adequately protected for the type of loss, therefore protection measures need to be applied. These protection measures are determined from relevant tables given in BS EN 62305-2 (typically tables NB.2, NB.3 and NB.7).

The aim, by a series of trial and error calculations is to ultimately apply sufficient protection measures until the risk R is reduced below that of R_T. The following expands on the various risk components, factors and formulae that contribute to the compilation of risk R.

Identification of relevant losses

The types of loss that could result from damage due to lightning must be identified for the structure. *The possible types of loss were previously discussed on page 15, 2.2 Type of loss.*

For each type of loss there is a corresponding risk attributed to that loss:

- R_1 risk of loss of human life (including permanent injury)
- R_2 risk of loss of service to the public
- R_3 risk of loss of cultural heritage
- R_4 risk of loss of economic value

Hereafter the primary risks will be referred to collectively as R_n where the subscript n indicates 1, 2, 3 or 4 as described above.

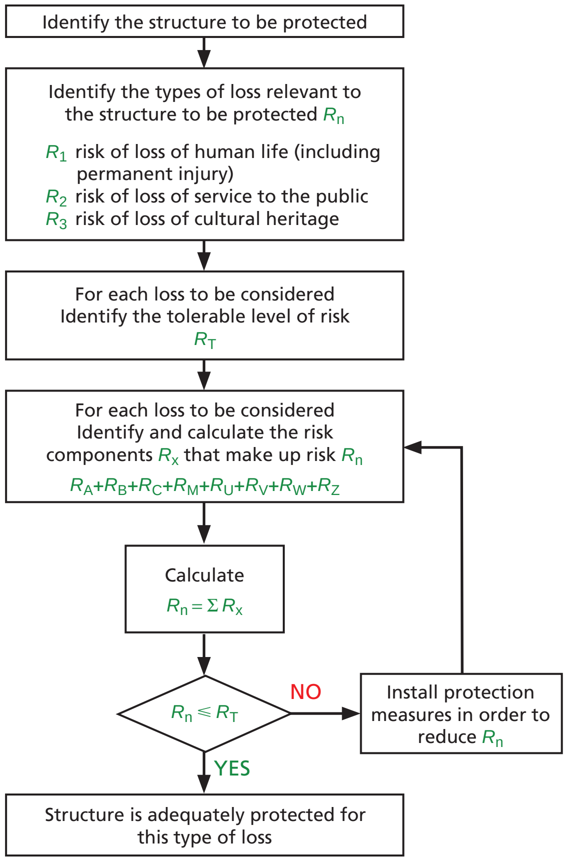

Figure 3.1: Procedure for deciding the need for protection (BS EN 62305-1 Figure 1)

Identification of tolerable risk R_T

Once a primary risk R_n has been identified, it is then necessary to establish a tolerable level R_T for that risk. Relevant values of tolerable risk are given in BS EN 62305-2 and shown below in Table 3.1. It should be noted that there is no tolerable risk for R_4 the loss of economic value.

Types of loss	R_T /annum
Loss of human life or permanent injuries	1×10^{-5}
Loss of service to the public	1×10^{-4}
Loss of cultural heritage	1×10^{-4}

Table 3.1: Values of tolerable risk R_T (BS EN 62305-2 Table NF.1)

If the calculated risk R_n is less than or equal to its corresponding value of R_T then the structure does not need any protection.

If however, the risk R_n is greater than R_T then protection is required and further calculations are needed to determine exactly what protection measures are required to bring the value below that of R_T.

Identification of risk components R_X

Each primary risk is composed of several risk components. Each risk component relates to a different relationship between source of damage (S1, S2, S3 and S4) and type of damage (D1, D2 and D3), such that:

$$R_1 = R_{A1} + R_{B1} + R_{C1}{}^{1)} + R_{M1}{}^{1)} + R_{U1} + R_{V1} + R_{W1}{}^{1)} + R_{Z1}{}^{1)} \quad (3.1)$$

$$R_2 = R_{B2} + R_{C2} + R_{M2} + R_{V2} + R_{W2} + R_{Z2} \quad (3.2)$$

$$R_3 = R_{B3} + R_{V3} \quad (3.3)$$

$$R_4 = R_{A4}{}^{2)} + R_{B4} + R_{C4} + R_{M4} + R_{U4}{}^{2)} + R_{V4} + R_{W4} + R_{Z4} \quad (3.4)$$

1) Only for structures with risk of explosion and for hospitals with life-saving electrical equipment or other structures when failure of internal systems immediately endangers human life.

2) Only for properties where animals may be lost.

Risk components R_A, R_B, R_C, R_M, R_U, R_V, R_W and R_Z are all attributed to lightning flashes either to, or near the structure or the service lines supplying the structure. They can involve injuries caused by electric shock, physical damage caused by dangerous sparking and failure of internal systems. Each risk component is defined in Table 3.2 and illustrated in Figure 3.2 below.

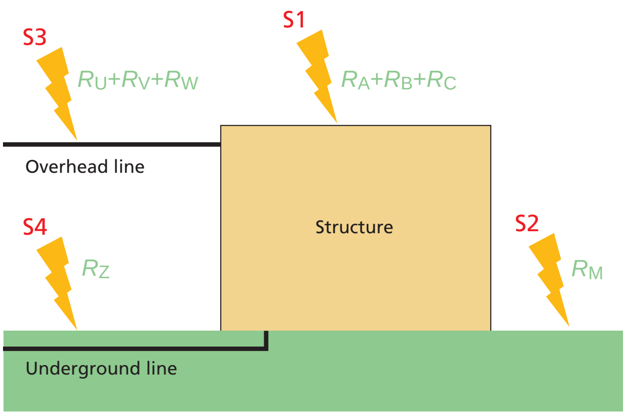

Figure 3.2: Risk components related to source of damage

R_X	Source of damage(1)	Type of damage(1)
R_A	Flashes to the structure (S1)	Injury to living beings by electric shock (D1)
R_B	Flashes to the structure (S1)	Physical damage caused by dangerous sparking inside the structure (D2)
R_C	Flashes to the structure (S1)	Failure of internal systems caused by LEMP (D3)
R_M	Flashes near the structure (S2)	Failure of internal systems caused by LEMP (D3)
R_U	Flashes to a service line connected to the structure (S3)	Injury to living beings by electric shock (D1)
R_V	Flashes to a service line connected to the structure (S3)	Physical damage caused by dangerous sparking inside the structure (D2)
R_W	Flashes to a service line connected to the structure (S3)	Failure of internal systems caused by LEMP (D3)
R_Z	Flashes near a service line connected to the structure (S4)	Failure of internal systems caused by LEMP (D3)

(1) For explanation of Source and Type of damage, see page 14.

Table 3.2: Risk components R_X

Each primary risk can also be expressed with reference to the source of damage. *See page 14, Source of damage.*

Thus R_n can be split into two basic components for each loss.

$$R_n = R_D + R_I \quad (3.5)$$

Where:

R_D (direct) relates to risk components attributable to flashes to the structure (S1).

R_I (indirect) relates to risk components attributable to flashes near the structure, to the lines connected to the structure and near the lines connected to the structure (S2, S3 and S4).

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These direct and indirect risk components can be further expressed by their own individual risk components viz.

$$R_D = R_A{}^{2)} + R_B + R_C{}^{1)} \quad (3.6)$$

$$R_I = R_M{}^{1)} + R_U + R_V + R_W{}^{1)} + R_Z{}^{1)} \quad (3.7)$$

1) Only for structures with risk of explosion and for hospitals with life-saving electrical equipment or other structures when failure of internal systems immediately endangers human life.

2) Only for properties where animals may be lost.

The generic equation for evaluating each risk component is:

$$R_X = N_X \times P_X \times L_X \quad (3.8)$$

Where:

N_X is the annual number of dangerous events

P_X is the probability of damage to a structure

L_X is the amount of loss to a structure

Thus:

$$R_A = N_D \times P_A \times L_A \quad (3.9)$$

$$R_B = N_D \times P_B \times L_B \quad (3.10)$$

$$R_C = N_D \times P_C \times L_C \quad (3.11)$$

$$R_M = N_M \times P_M \times L_M \quad (3.12)$$

$$R_U = (N_L + N_{DJ}) \times P_U \times L_U \quad (3.13)$$

$$R_V = (N_L + N_{DJ}) \times P_V \times L_V \quad (3.14)$$

$$R_W = (N_L + N_{DJ}) \times P_W \times L_W \quad (3.15)$$

$$R_Z = N_I \times P_Z \times L_Z \quad (3.16)$$

The values of N_X, P_X and L_X are determined from parameters/formulae contained within BS EN 62305-2.

Annex A provides information on how to assess the annual number of dangerous events (N_X).

Annex NB provides the necessary detail to assess the probability of damage to a structure (P_X).

Annex NC helps to assess the amount of loss to a structure (L_X).

Number of dangerous events N_X

The number of dangerous events experienced by a structure or service line(s) is a function of their collection areas and the lightning activity in the vicinity.

Collection area

The physical dimensions of the structure are used to determine the effective collection area of the structure.

The collection area is based on a ratio of 1:3 (height of structure : horizontal collection distance). See Figure 3.3.

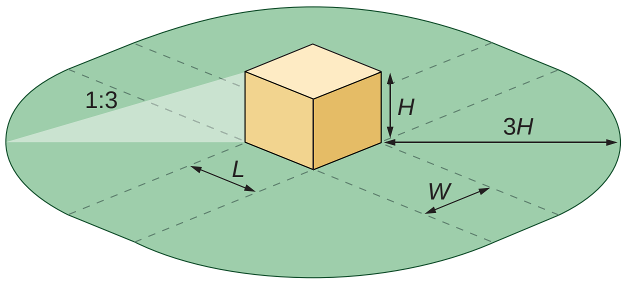

Figure 3.3: Definition of collection area

The collection area in BS 6651 was based on a 1:1 ratio so there is a significant increase in area taken into account in the BS EN 62305 assessment procedure.

For a simple box shaped structure, the collection area can be determined by:

$$A_d = (L + W) + (6 \times H(L + W)) + (9 \times \pi \times H^2) \quad (3.17)$$

Where:

A_d is the collection area of an isolated structure in square metres

L is the length of structure in metres

W is the width of structure in metres

H is the height of structure in metres

For structures of a more complex shape it may be necessary to determine the collection area graphically or by the use of computer software.

In the case of overhead lines entering the structure, the physical dimensions of the lines are used to determine the effective collection area. The physical dimensions and the local soil resistivity are used to determine the effective collection area of buried lines.

So the collection area of flashes striking a line is determined by:

$$A_L = 40 \times L_L \qquad (3.18)$$

Similarly the collection area of flashes striking near a line is determined by:

$$A_I = 4{,}000 \times L_L \qquad (3.19)$$

Where:

A_L is the collection area for flashes striking a line in square metres

A_I is the collection area for flashes striking near a line in square metres

L_L is the length of line section in metres

All of the relevant collection areas are illustrated in Figure 3.4.

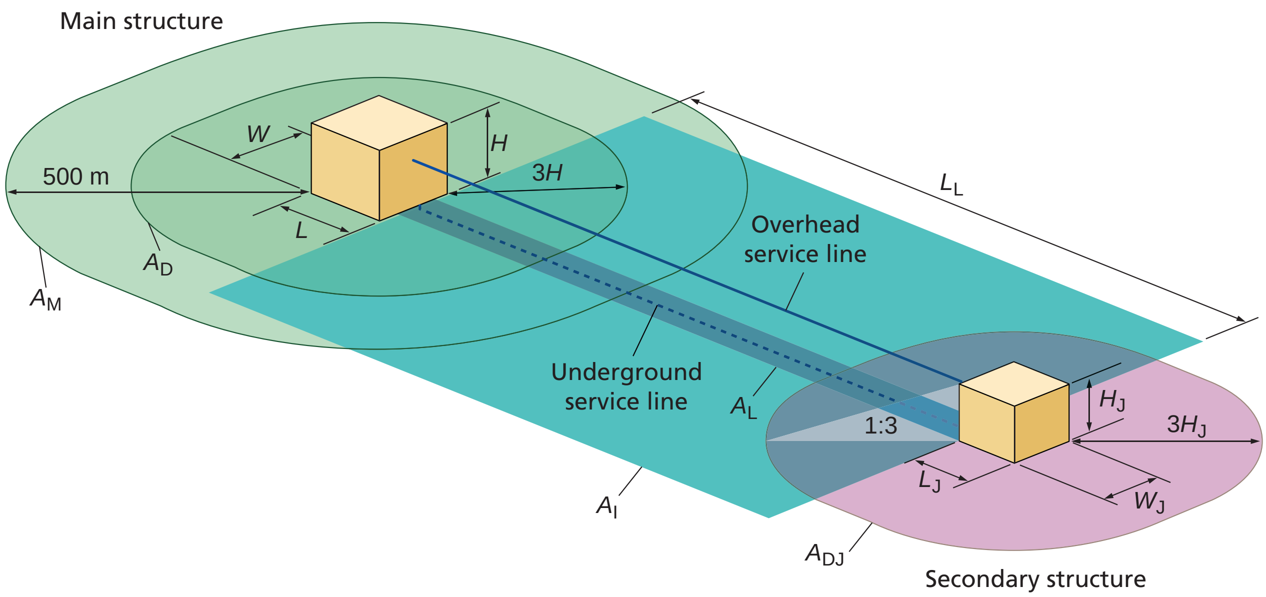

Figure 3.4: Collection areas

Flash density

Clearly, the amount of local lightning activity is of paramount importance when assessing the risk to a structure. Flash density is the measure of the number of lightning flashes to earth per square kilometre, per annum, the higher the number the greater the lightning activity. Hence, areas of intense lightning such as equatorial regions of the world will see a far greater risk of lightning inflicted damage than those in more temperate regions.

There is a correlation between the number of thunderstorm days per annum and the flash density. This can be expressed thus

$$N_G = 0.04 \times T_D^{1.25} \quad (3.20)$$

Where:

N_G is the flash density in strikes to ground per kilometre square per year

T_D is the number of thunderstorm days per year

BS EN 62305-2 Annex A approximates this relationship, for temperate regions, to

$$N_G \approx 0.1 \times T_D \quad (3.21)$$

BS 6651 had a flash density map and a world thunderstorm days map along with an accompanying table. The maps have been transferred to BS EN 62305-2, and also illustrated in this guide. See Figure 3.5 and Figure 3.6. Table 3.3 shows the relationship between N_G and T_D based upon Equation (3.20) above.

Other weighting factors that need to be determined are:

a) The location factor (the structure's relative location with respect to other surrounding or isolated objects - see BS EN 62305-2 Table A.1)

b) The environmental factor (urban or suburban location - see BS EN 62305-2 Table A.4)

c) The transformer factor (is the section of line(s) fed via a transformer or only the LV supply - see BS EN 62305-2 Table A.3)

The number of dangerous events can now be determined for each specific risk component, ie:

N_D is the average annual number of dangerous events for the structure

N_{DJ} is the average annual number of dangerous events for a structure adjacent and connected by a line to the structure

N_M is the average annual number of dangerous events due to flashes near to the structure

N_L is the average annual number of dangerous events due to flashes to a line connected to the structure

N_I is the average annual number of dangerous events due to flashes near to a line connected to the structure

For example in order to determine component risks R_U, R_V or R_W (see Equation 3.13, Equation 3.14 and Equation 3.15):

$$N_L = N_G \times A_L \times C_I \times C_E \times C_T \times 10^{-6} \quad (3.22)$$

And

$$N_{DJ} = N_G \times A_{DJ} \times C_{DJ} \times C_T \times 10^{-6} \quad (3.23)$$

Where:

N_L is the number of dangerous events due to flashes to a line

N_{DJ} is the number of dangerous events due to flashes to a structure connected to the far end of the line

N_G is the flash density in strikes to ground per kilometre square per year

C_E is the environmental factor

C_{DJ} is the location factor of an isolated adjacent structure

C_T is the correction factor for a HV/LV transformer on the line

A_{DJ} is the collection area of an isolated adjacent structure in square metres

A_L is the collection area for flashes striking a line in square metres

Thunderstorm days per year (T_D)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Flashes per km² per year (N_G)	0.30	0.71	1.18	1.69	2.24	2.81	3.41	4.02	4.66	5.32	5.99	6.68	7.38	8.10	8.83	9.57	10.32	11.09	11.86	12.65

Table 3.3: Relationship between thunderstorm days per year and lightning flashes per square kilometre per year

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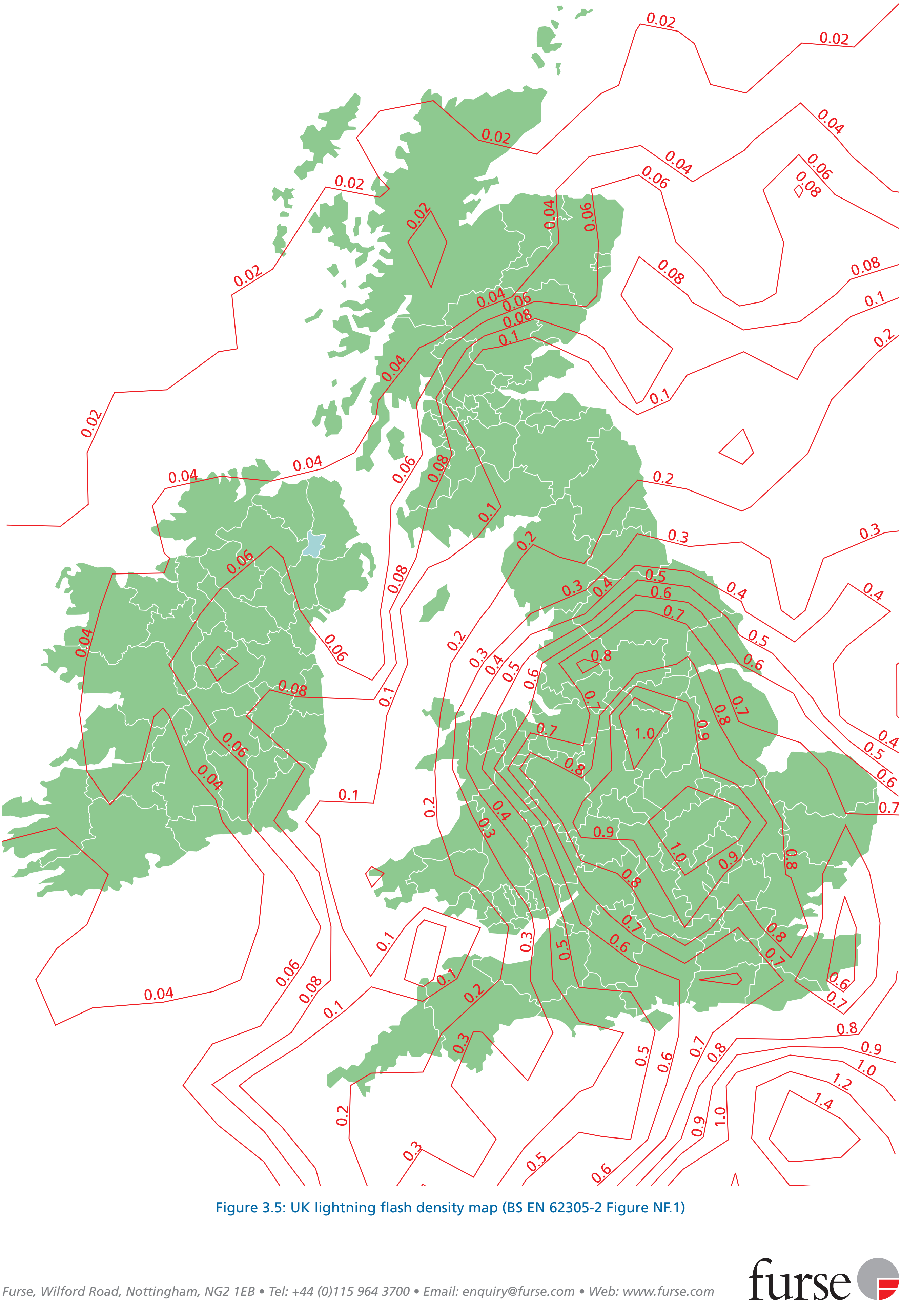

Figure 3.5: UK lightning flash density map (BS EN 62305-2 Figure NF.1)

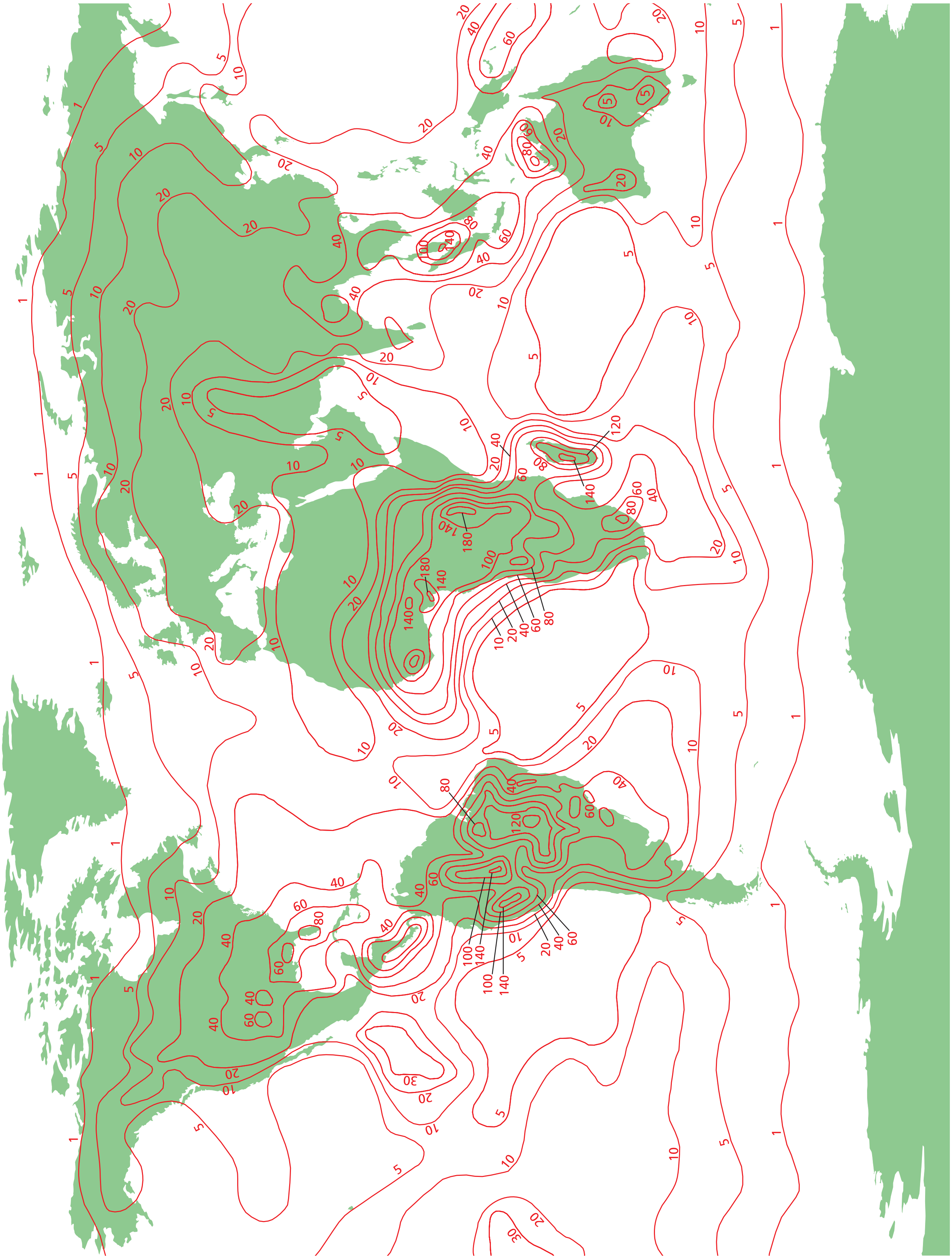

Figure 3.6: World Thunderstorm days map (BS EN 62305-2 Figure NF.2)

Probability of damage P_X

The probability of a particular type of damage occurring within a structure is determined, and if necessary reduced, by the choice of characteristics and protection measures given in Annex NB of BS EN 62305-2.

Shown below are some of the relevant tables from BS EN 62305-2 that should be used in order to determine the probability of damage.

The ultimate protection measures proposed by the designer should reflect the most suitable technical and economic solution.

P_X	Source of damage(1)	Type of damage(1)	Reduction of probability
P_A	S1	D1	By protection measures against electric shock. BS EN 62305-2 Table NB.1
P_B	S1	D2	By Class of lightning protection system (LPS) installed. BS EN 62305-2 Table NB.2
P_C	S1	D3	By coordinated SPD protection. BS EN 62305-2 Table NB.3
P_M	S2	D3	By adopted Surge Protection Measures (SPM), according to a factor P_{MS}. BS EN 62305-2 Table NB.5
P_U	S3	D1	By characteristics of the service shield, the impulse withstand voltage of internal systems connected to the service and the presence or otherwise of service entrance SPDs. BS EN 62305-2 Table NB.6, NB.7 & NB.8
P_V	S3	D2	
P_W	S3	D3	By characteristics of the service shield, the impulse withstand voltage of internal systems connected to the service and the presence or otherwise of coordinated SPDs. BS EN 62305-2 Table NB.8 & NB.9
P_Z	S4	D3	

(1) For explanation of Source and Type of damage, see page 14.

Table 3.4: Probability of damage P_X

The LPS designer should consult Tables NB.3 and NB.7 of BS EN 62305-2 when considering the need for protection measures in the form of equipotential bonding SPDs (P_{EB} to Table NB.7) and/or coordinated SPDs (P_{SPD} to Table NB.3). He or she will then decide on the appropriate choice of SPD level as part of the risk procedure. The information presented within Table NB.3 is shown here (Table NB.7 is comparable).

LPL	SPD	P_{SPD}
No coordinated SPD protection		1
III-IV	III-IV	0.05
	III-IV* (note 2)	0.005
II	II	0.02
	II* (note 2)	0.002
I	I	0.01
	I* (note 2)	0.001

NOTE 1 A coordinated SPD system is effective in reducing P_C only in structures protected by an LPS or structures with continuous metal or reinforced concrete framework acting as a natural LPS, where bonding and earthing requirements of BS EN 62305-3 are satisfied.

NOTE 2 Smaller values of P_{SPD} are possible where SPDs have lower voltage protection levels (U_P) that further reduce the risk of injury to living beings, physical damage and failure of internal systems. Such SPDs are always required to ensure the protection and continuous operation of critical equipment. SPDs with low voltage protection levels also take account of the additive inductive voltage drops along the connecting leads of SPDs.

Unless stated, the susceptibility level (of equipment) is assumed to be twice its peak operating voltage. In this respect, installed SPDs with a voltage protection level greater than the susceptibility level but less than the impulse withstand voltage U_W (of equipment), equate to the standard value of P_{SPD} whereas installed SPDs with a voltage protection level less than the susceptibility level equate to the enhanced value (ie SPDs denoted by *).

For example, in the case for a 230 V mains supply an SPD fitted at the service entrance (for lightning equipotential bonding) should have a voltage protection level of no more than 1600 V (4 kV withstand at the entrance of the installation, 20% margin and a factor of 2 for the worse case doubling voltage as per IEC 61643-12: ((4 kV x 0.8)/2 = 1600 V) when tested in accordance with BS EN 61643 series. Downstream SPDs (those that are located within another lightning protection zone) fitted as part of a coordinated set to ensure operation of critical equipment should have a voltage protection level of no more than 600 V ((1.5 kV x 0.8)/2) when tested in accordance with BS EN 61643 series (Class III test).

NOTE 3 The LPL governs the choice of the appropriate structural Lightning Protection System (LPS) and Surge Protection Measures (SPM), one option of which can include a set of coordinated SPDs. Typically, an LPS class II would require SPD II. If the indirect risk (R_I) was still greater than the tolerable risk (R_T) then SPD II* should be chosen.

When a risk assessment indicates that a structural LPS is not required, service lines connected to the structure (S3) are effectively protected against direct strikes when SPD III-IV or SPD III-IV* protection measures are applied.

Table 3.5: Value of the probability P_{SPD} as a function of LPL for which SPDs are designed (BS EN 62305-2 Table NB.3)

Table NB.3 of BS EN 62305-2 (see Table 3.5) has been expanded and notes added to give the designer the option of choosing an SPD that has superior protection capabilities - typically lower voltage protection levels.

This will ensure that critical equipment housed within the structure has a much greater degree of protection and thus continued operation. This is essential for minimizing downtime, a major factor in economic loss.

BS EN 62305 update

As per page 32, within the updated BS EN 62305-2 Table NB.3 is now supplemented by Table NB.7 to enable separate selection of coordinated SPDs (P_{SPD}) and equipotential bonding SPDs (P_{EB}). Table NB.3 refers to coordinated SPDs and Table NB.7 to equipotential bonding SPDs. The figures and notes to both tables are comparable, hence Table NB.3 only is shown here.

As illustrated in BS EN 62305-1, the Lightning Protection Level (LPL) is defined between a set of maximum and minimum lightning currents. *This is explained in depth on pages 18 - 19, Lightning Protection Level (LPL).*

The design parameters of SPDs included within the SPM levels *(see page 16, Protection measures)* should match the equivalent LPL.

Thus for example, if an LPL II is chosen (equivalent to a structural LPS Class II) then an SPD II should also be chosen. If the indirect risk is too high when using the standard SPD (eg SPD II) then the designer needs to select SPDs with a superior protection level to bring the actual risk below the tolerable risk. This can be achieved within the calculation by using SPD * (eg SPD II*).

The value of the probability that a lightning flash near a structure will cause failure of internal systems P_M is a function of the adopted Surge Protection Measures (SPM). The reduction of the probability is dependant upon screening effectiveness, internal wiring characteristics, equipment withstand and the presence or otherwise of coordinated SPDs.

Thus, when coordinated SPD protection is to be provided, the value of P_M - probability that a flash near a structure will cause failure of internal systems - is given by the product of P_{MS} and P_{SPD}:

$$P_M = P_{SPD} \times P_{MS} \qquad (3.24)$$

Where:

$$P_{MS} = (K_{S1} \times K_{S2} \times K_{S3} \times K_{S4})^2 \qquad (3.25)$$

Where:

K_{S1} relates to the screening effectiveness of the structure

K_{S2} relates to the screening effectiveness of internal shielding where present

K_{S3} relates to the characteristics of internal wiring

K_{S4} relates to the impulse withstand of the system to be protected

The following table is included to assist with the determination of K_{S1} and K_{S2} and ultimately P_{MS}.

Description of the shielding arrangement	K_{S1} or K_{S2}
Non conducting - timber, masonry structure and cladding	1
Non conducting with LPS Class IV, III, II or I	1
Non conducting cladding with conductive frame	0.6
Conducting cladding with conductive frame - typical opening - non conducting door	0.25
Conducting cladding with conductive frame - typical opening - windows	0.12
Conducting cladding with conductive frame - typical opening - small windows	0.06
Conducting cladding with conductive frame - 100 mm max opening	0.01
Conducting cladding with conductive frame - 10 mm max opening	0.001
Structure fully clad with metal - no openings	0.0001

Table 3.6: Typical values of K_{S1} or K_{S2}

The table merely expands the relationship:

$$K_{S1} = 0.12 \times w_{m1} \qquad (3.26)$$

$$K_{S2} = 0.12 \times w_{m2} \qquad (3.27)$$

Where w_{m1} and w_{m2} are the mesh width of the spatial shield (ie the spacing of the reinforcing bars or the steel stanchions within the walls of the structure).

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If the structure is a simple building with only external reinforced walls, then K_{S1} would be determined by the appropriate spacing of the reinforcing as shown in Table 3.6. Because no internal reinforced walls (or spatial screening) was present then K_{S2} = 1.

If however the building had internal as well as external reinforced walls then both K_{S1} and K_{S2} would be determined from Table 3.6 depending on their relevant spacing of the reinforcement (screening).

K_{S3} relates to the details of the wiring inside the structure. If details such as the presence of shielding and cable routeing arrangement is known at the time of carrying out the calculation (and in reality this is highly unlikely in most practical cases) then a low value of K_{S3} may be assigned. If specific details of the cable and its routeing within the structure is unknown then K_{S3} = 1 would need to be assigned.

K_{S4} relates to the rated impulse withstand voltage of the system. Table 3.7 shows the relationship between various impulse withstand voltages (U_W) and K_{S4}.

Impulse withstand voltage U_W (kV)	K_{S4}
6	0.167
4	0.25
2.5	0.4
1.5	0.67
1	1

If there is equipment with different impulse withstand levels in the internal system of the structure, K_{S4} shall correspond with the lowest withstand level.

Table 3.7: Typical values of K_{S4}

Amount of loss in a structure L_X

The lightning protection designer should evaluate and fix the values of the mean relative amount of loss L_X. Guidance on the determination of loss L_X for a particular type of damage *(see page 14, Type of damage)* can be found in Annex NC of BS EN 62305-2.

For example in order to determine component losses L_A and L_B in relation to the risk of loss of human life (including permanent injury) R_1 in a structure treated as a single zone

$$L_A = r_t \times L_T \times \frac{t_z}{8760} \quad (3.28)$$

and

$$L_B = r_p \times r_f \times h_z \times L_F \times \frac{t_z}{8760} \quad (3.29)$$

Where:

- r_t is a factor reducing the loss of human life (including permanent injury) depending on the type of soil (see Table NC.3)
- r_p is a factor reducing the loss due to physical damage depending on the provisions taken to reduce the consequences of fire (see Table NC.4)
- r_f is a factor reducing the loss due to physical damage depending on the risk of fire of the structure (see Table NC.5)
- h_z is a factor increasing the loss due to physical damage when a special hazard is present (see Table NC.6)
- L_T is the loss due to injury by electric shock
- L_F is the loss due to physical damage
- L_O (not shown above but required for R_2 calculations) refers to the loss related to failure of internal systems

The following tables (3.8, 3.9 and 3.10) which are taken from Annex NC of BS EN 62305-2, have been modified for clarity and to reflect the UK committee's (GEL/81) interpretation relative to the assessment of the amount of loss in a structure.

Typical mean values of L_T, L_F and L_O for use when the determination of n_p, n_t and t_p is uncertain or difficult to predict are given in Table NC.1. See Table 3.8 on page 35.

BS EN 62305 update

Within the new version of BS EN 62305, reference to 'touch and step voltages' has predominantly been updated to the more commonly recognized term 'electric shock'.

Type of structure	L_T
All types	0.01

Type of Structure	L_F
Airport Building	0.75
Base Station	0.04
Block of Flats	1.00
Cathedral	0.50
Church	0.08
Civic Building	0.33
Commercial Building/Office Block	0.42
Commercial Centre	0.33
Departmental Store	0.42
Factory	0.75
Farm Building	1.00
Fuel/Service Station	0.67
Gas Compound	0.33
Halls of Residence	1.00
Hospital	1.00
Hotel	1.00
Industrial Warehouse	0.42
Large House	1.00
Leisure Centre	0.67
Medical Centre	0.33
Museum	0.42
Nursing/Children's Home	1.00
Oil Refinery/Chemical Plant	1.00
Police/Fire/Ambulance Station	1.00
Power Station	0.33
Prison	1.00
Railway Station	0.75
Ruin	0.04
School	0.33
Shops/Shopping Centre	0.50
Sports Stadium	0.04
Substation	0.33
Telephone Exchange	0.33
Theatre	0.21
University	0.42
Water Treatment Works	0.33
Wind Farm	0.04
Others	0.33

Type of structure	L_O
Intensive care unit and operation block of hospital	0.001
Other parts of hospital	0.33
Risk of explosion	0.1

Table 3.8: Typical mean values of L_T, L_F and L_O (BS EN 62305-2 Table NC.2)

NOTE 1 The above values of L are generic in nature, different specific values may be assigned, depending on the individual merits of each structure.

NOTE 2 The values of L are based on the assumption that the structure is treated as a single zone and the total numbers of persons in the structure are all in the zone. The time in hours (h) per year for which the persons are present has been evaluated for each individual case.

For example:

Total number of persons in the structure	=	200 (n_t)
Number of persons in the zone	=	200 (n_z)
Number of hours per day spent in the office:		10 h
Therefore t_z = 10 h x 365 days	=	3 650 h

$$L = \frac{n_z}{n_t} \times \frac{t_z}{8760} \quad (3.30)$$

$$L = \frac{200}{200} \times \frac{3650}{8760} \qquad L = 0.42$$

NOTE 3 If further evaluation of L is required for a structure that is split into several zones, then the formula given in Table NC.1 should be applied.

NOTE 4 In case of a structure with risk of explosion, the values for L_F and L_O may need a more detailed evaluation, considering the type of structure, the risk of explosion, the zone concept of hazardous areas and the measures to meet the risk.

Risk	Amount of risk	r_f	Type of structure[a]
Explosion	Zones 0, 20 and solid explosive	1	Petrochemical plant, ammunition store, gas compound, paper mill
	Zones 1, 21	10^{-1}	
	Zones 2, 22	10^{-3}	
Fire	High	10^{-1}	Paper mill, industrial warehouse with flammable stock
	Ordinary	10^{-2}	Office, school, theatre, hotel, museum, shop
	Low	10^{-3}	Sports stadium, railway station, telephone exchange
Explosion or fire	None	0	

[a] List of structures and Risk suggested are merely typical and not exhaustive.

Table 3.9: Values of reduction factor r_f depending on risk of fire of structure (BS EN 62305-2 Table NC.5)

Service provider	L_F	L_O
Gas, water, power, communications, government, health, financial, manufacturing, retail, residential, leisure	0.1	0.01

NOTE: All the above institutions/industries are service providers to the public and need to be considered when calculating R_2 - risk of loss of service to the public

Table 3.10: Typical mean value of L_F and L_O (BS EN 62305-2 Table NC.8)

Commentary

If the risk evaluation demands that a structural LPS is required (ie R_D is greater than R_T) then equipotential bonding or lightning current SPDs are always required for any metallic electrical service entering the structure (typically power and telecom lines). Mains Type 1 SPDs and Signal/Telecom Category D SPDs (both tested with a 10/350 μs waveform) are necessary to divert the partial lightning currents safely to earth and limit the transient overvoltage to prevent possible flashover. They are therefore an integral part of the structural LPS and typically form the first part of a coordinated SPD set for effective protection of electronic equipment. *For further details see page 71, Earthing and bonding.*

If the risk evaluation shows that a structural LPS is not required (ie R_D is less than R_T) but there is an indirect risk R_I (ie R_I is greater than R_T), any electrical services feeding the structure via an overhead line will require lightning current SPDs. For mains Type 1 SPDs the surge current rating per mode of protection is 12.5 kA 10/350 μs (see Table 2.3 on page 18) and for signal/telecom SPDs the surge current rating per mode of protection is 2.5 kA 10/350 μs.

For underground electrical service lines connected to the structure, protection is achieved with overvoltage or mains Type 2 SPDs and signal/data Category C SPDs (both tested with an 8/20 μs waveform in accordance with BS EN 61643 standard series on SPDs). See Table 5.3 on page 75.

Such underground electrical service lines are not subject to direct lightning currents and therefore do not transmit partial lightning currents into the structure.

Underground electrical service lines therefore do not have a requirement for lightning current SPDs where no structural LPS is present - overvoltage SPDs are sufficient here. *For further details see page 74, Structural LPS not required.*

Alternatively, the structure in question may need both structural LPS and a fully coordinated set of SPDs to bring the risk below the tolerable level R_T. This is a significant deviation from that of BS 6651.

BS EN 62305 series now treats the aspect of internal protection (lightning current and overvoltage protection) as an important and integral part of the standard and devotes Part 4 to this issue. This is due to the increasing importance given to the protection against LEMP (Lightning Electromagnetic Impulse), which can cause immeasurable and irreparable damage (as well as disastrous consequential effects) to the electrical and electronic systems housed within a structure.

Although R_1, risk of loss of human life (including permanent injury) concentrates on the effects that fire and explosion can have upon us, it does not highlight or cover in any detail the effects the electromagnetic impulse will have on equipment housed within the structure.

We now need to consider R_2 risk of loss of service to the public, to identify the protection measures required to prevent any potential damage to equipment (typically main frame computers, servers etc) and perhaps more importantly the disastrous consequential effects that could occur to a business if vital IT information was permanently lost.

When considering R_I (indirect) within R_2, it is the inclusion of coordinated SPDs - to assist in reducing R_I - that will provide the solution for protection as well as limiting any consequential losses from electromagnetic impulses.

It is worthwhile to add a little clarification of exactly what is meant by coordinated SPDs here. *It will be expanded upon in the section BS EN 62305-4, Electrical and electronic systems within structures starting on page 67.*

Coordinated SPDs simply means a series of SPDs installed in a structure (from the equipotential bonding or lightning current SPD at the service entrance through to the overvoltage SPD for the protection of the terminal equipment) should compliment each other such that all LEMP effects are completely nullified.

This essentially means the SPDs at the interface between outside and inside the structure will deal with the major impact of the lightning discharge ie the partial lightning current from an LPS and/or overhead lines. Any resultant overvoltage will be controlled to safe levels by coordinated downstream overvoltage SPDs.

A coordinated set of SPDs should effectively operate together as a cascaded system to protect equipment in their environment. For example the lightning current SPD at the service entrance should sufficiently handle the majority of surge energy, thus leaving the downstream overvoltage SPDs to control the overvoltage. Poor coordination could mean that an overvoltage SPD is subjected to an excess of surge energy placing both itself and connected equipment at risk from damage.

Furthermore, voltage protection levels or let-through voltages of installed SPDs must be coordinated with the insulation withstand voltage of the parts of the installation and the immunity withstand voltage of electronic equipment.

Spatial shielding (ie the mesh spacing of the reinforcing within the structure), along with the cable length (of the connected services) and the height of the structure will also have a direct influence on R_I.

There is a further illustration in the worked examples *(see Design examples section starting on page 91)* that shows the implementation of risk R_2.

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4. BS EN 62305-3 Physical damage to structures and life hazard

4.1 Lightning Protection System (LPS) 38

4. BS EN 62305-3 Physical damage to structures and life hazard

This part of the suite of standards deals with protection measures in and around a structure and as such relates directly to the major part of BS 6651.

The main body of this part of the standard gives guidance on the classification of a Lightning Protection System (LPS), external and internal LPS and maintenance and inspection programmes. There are five Annexes and Annex E especially will be useful to anyone involved in the design, construction, maintenance and inspection of LPS. To make it easier to cross reference the document, a specific clause reviewed in Annex E corresponds to the same numbered clause in the main text. For example clause 4.3 in the main text - Reinforced concrete structures - is also expanded upon in E4.3.

There are also many sketches and tables throughout the document to facilitate the reader's interpretation and understanding.

4.1 Lightning Protection System (LPS)

Lightning Protection Level (LPL) has been designated and identified in BS EN 62305-1. Four levels of LPS are defined in this part of the standard and correspond to the LPLs in Table 4.1.

LPL	Class of LPS
I	I
II	II
III	III
IV	IV

Table 4.1: Relation between Lightning Protection Level (LPL) and Class of LPS (BS EN 62305-3 Table 1)

The choice of Class of LPS to be installed is governed by the result of the risk assessment calculation. Thus it is prudent to carry out a risk assessment every time to ensure a technical and economic solution is achieved.

External LPS design considerations

The lightning protection designer must initially consider the thermal and explosive effects caused at the point of a lightning strike and the consequences to the structure under consideration. Depending upon the consequences the designer may choose either of the following types of external LPS:

- Isolated
- Non-isolated

An Isolated LPS is typically chosen when the structure is constructed of combustible materials or presents a risk of explosion. Conversely a non-isolated system may be fitted where no such danger exists.

An external LPS consists of:

- Air termination system
- Down conductor system
- Earth termination system

These individual elements of an LPS should be connected together using appropriate lightning protection components (LPC) complying with BS EN 50164 or IEC 62561 series. This will ensure that in the event of a lightning current discharge to the structure, the correct design and choice of components will minimize any potential damage. *The requirements of the IEC 62561 series of standards, which is replacing BS EN 50164, are discussed in Section 8, starting on page 125.*

Air termination system

The role of an air termination system is to capture the lightning discharge current and dissipate it harmlessly to earth via the down conductor and earth termination system. Thus it is vitally important to use a correctly designed air termination system.

BS EN 62305-3 advocates the following, in any combination, for the design of the air termination.

- Air rods (or finials) whether they are free standing masts or linked with conductors to form a mesh on the roof. See Figure 4.1a.
- Catenary (or suspended) conductors, whether they are supported by free standing masts or linked with conductors to form a mesh on the roof. See Figure 4.1b.
- Meshed conductor network that may lie in direct contact with the roof or be suspended above it (in the event that it is of paramount importance that the roof is not exposed to a direct lightning discharge). See Figure 4.1c.

The standard makes it quite clear that all types of air termination systems that are used shall meet the positioning requirements laid down in the body of the standard. It highlights that the air termination components should be installed on corners, exposed points and edges of the structure.

The three basic methods recommended for determining the position of the air termination systems are:

- The rolling sphere method
- The protective angle method
- The mesh method

Each of these positioning and protection methods will be discussed in more detail in the following sections.

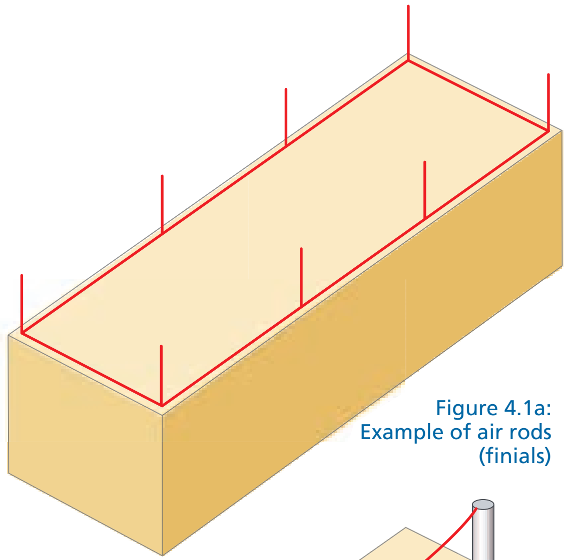

Figure 4.1a:
Example of air rods (finials)

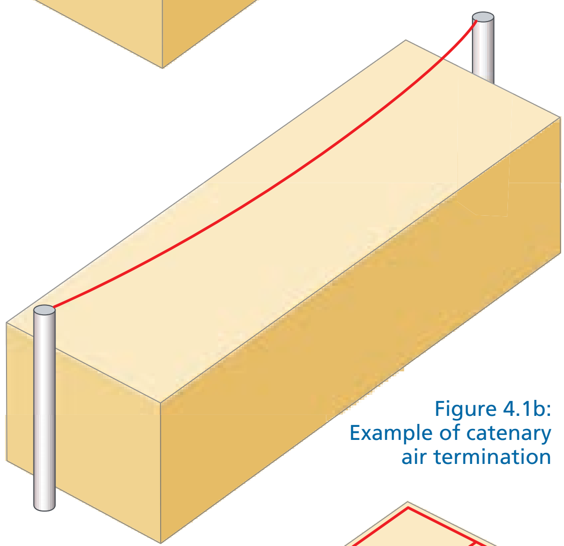

Figure 4.1b:
Example of catenary air termination

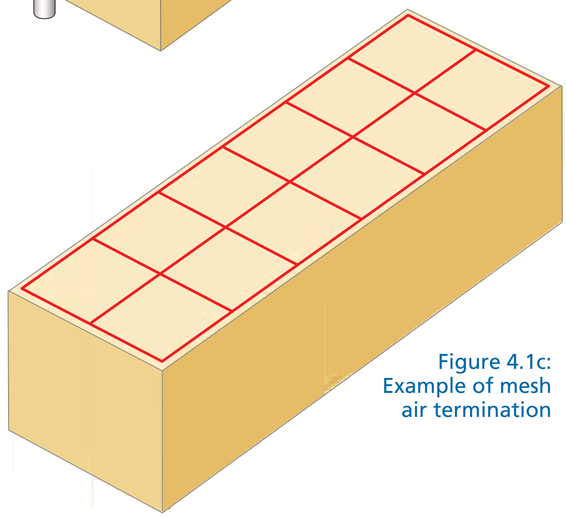

Figure 4.1c:
Example of mesh air termination

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Rolling sphere method

Given the lightning process already described in Introduction to lightning protection starting on page 6, it is logical to assume that a lightning strike terminates on the ground (or on structures) at the point where the upward streamer was originally launched.

These streamers are launched at points of greatest electric field intensity (see Figure 4.2a) and can move in any direction towards the approaching downward leader. It is for this reason that lightning can strike the side of tall structures rather than at their highest point.

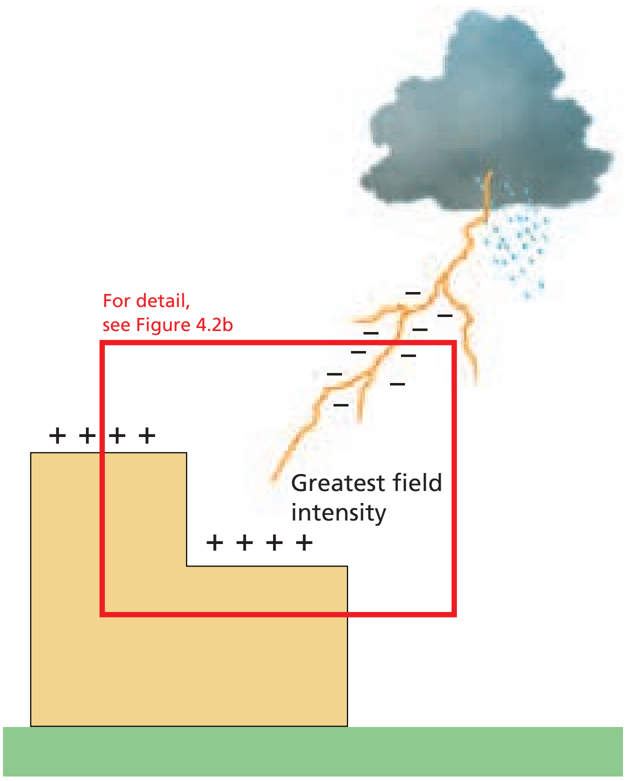

Figure 4.2a: Development of downward leader/striking distance

The position of the greatest field intensity on the ground and on structures will be at those points nearest to the end of the downward leader prior to the last step. The distance of the last step is termed the striking distance and is determined by the amplitude of the lightning current. For example, points on a structure equidistant from the last step of the downward leader are equally likely to receive a lightning strike, whereas points further away are less likely to be struck (see Figure 4.2b). This striking distance can be represented by a sphere with a radius equal to the striking distance.

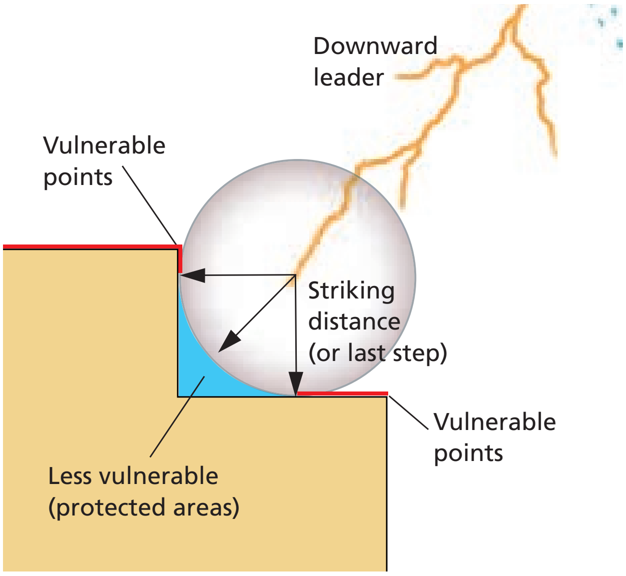

Figure 4.2b: Development of downward leader/striking distance

This hypothesis can be expanded to explain why corners of structures are vulnerable to lightning strikes. Figure 4.3 illustrates a sphere rolling over the surface of the building. The dotted line represents the path of the centre of the sphere as it is rolled over the building. The radius of the sphere is the striking distance, or last step of the lightning discharge. Thus it can be clearly seen that the corners are exposed to a quarter of the circular path of the sphere. This means that if the last step falls within this part of the circular path it will terminate on the corner of the building.

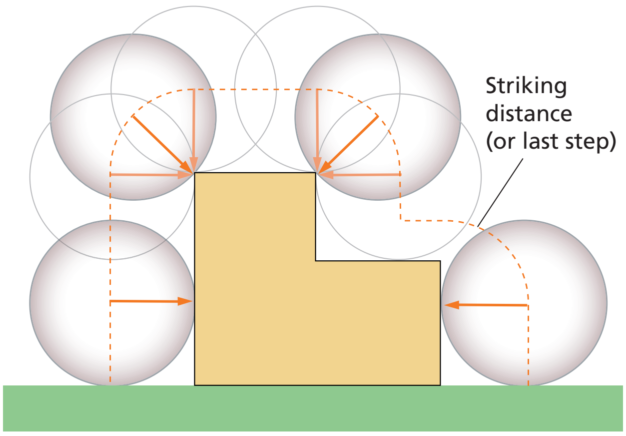

Figure 4.3: Striking distance (last step)

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Since the downward leader can approach from any direction, all possible approach angles can be simulated by rolling an imaginary sphere all around and over the structure to be protected, right down to the ground. Where the sphere touches the structure lightning protection would be needed. Using the same logic, the areas where the sphere does not touch the structure (see shaded area in Figure 4.2b) would be deemed to be protected and would not require protection.

The Rolling Sphere method is a simple means of identifying areas that need protection, taking into account the possibility of side strikes to the structures. The basic concept of applying the rolling sphere to a structure is illustrated in Figure 4.4.

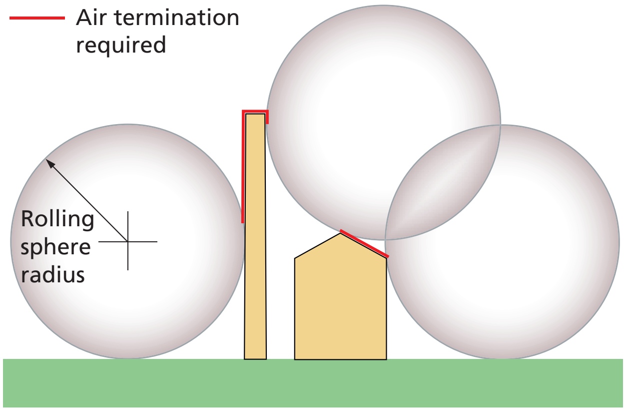


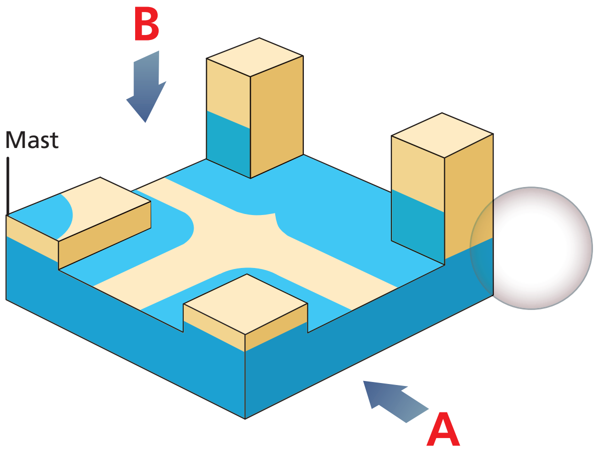
Figure 4.4: Application of the rolling sphere method

The rolling sphere method was used in BS 6651, the only difference being that in BS EN 62305 there are different radii of the rolling sphere that correspond to the relevant Class of LPS (see Table 4.2).

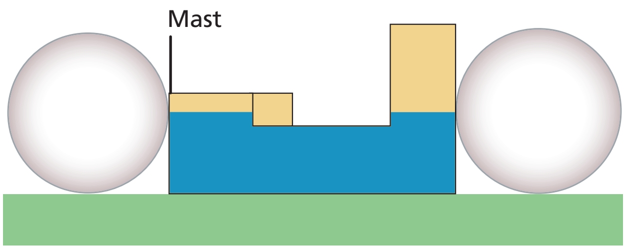
Class of LPS	Rolling sphere radius *r* (m)
I	20
II	30
III	45
IV	60

Table 4.2: Maximum values of rolling sphere radius corresponding to the Class of LPS

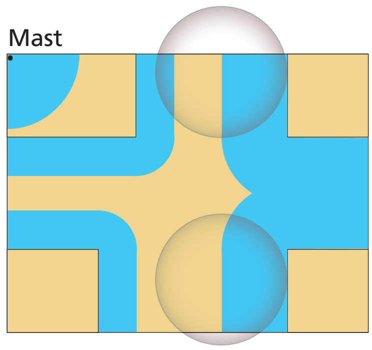
This method is suitable for defining zones of protection for all types of structures, particularly those of complex geometry. An example of such an application is shown in Figure 4.5.



All yellow areas and the mast should be assessed for the need for air terminations



View on arrow **A**



View on arrow **B**

Figure 4.5: Application of the rolling sphere method to a structure of complex geometry

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Application of protection using the rolling sphere method

Once the areas of the structure requiring protection have been identified using the rolling sphere, an air termination network can be designed. The air termination network can comprise any combination of the three systems described on page 39, External LPS design considerations. Reapplying the rolling sphere can show the effectiveness of the design produced.

Air rods or free standing masts

Air rods or free standing masts can be used to keep the rolling sphere away from the structure to be protected. If correctly dimensioned, air rods or free standing masts will ensure that the sphere does not come into contact with any part of the structure's roof.

If the system must be isolated from the structure then a free standing mast could be employed. See Figure 4.6. Clearly this arrangement is only suitable for smaller structures or isolated pieces of equipment. The separation distance *s* indicated on Figure 4.6 ensures isolation between the LPS and the structure. *The method of determining the separation distance is dealt with on page 64, Separation (isolation) distance of the external LPS.*

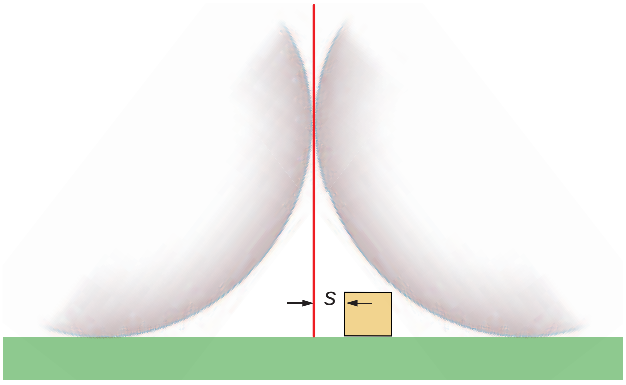

Figure 4.6: Application of the rolling sphere to an isolated free standing mast

If the system does not need to be isolated from the structure then air rods fitted to the roof of the structure could be employed. See Figure 4.7a.

The height of the air rods utilized is now a function of the rolling sphere radius (Class of LPS) and the spacing between the air rods.

If the rods are arranged in a square it is the distance between two diagonally opposite rods (see Figure 4.7c) rather than two adjacent rods (see Figure 4.7b) that must be considered when determining the penetration depth of the rolling sphere.

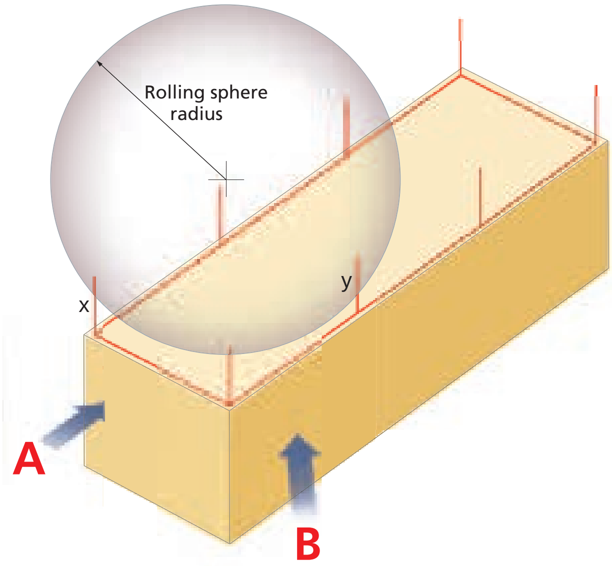

Figure 4.7a: Application of the rolling sphere to air rods in a non-isolated system

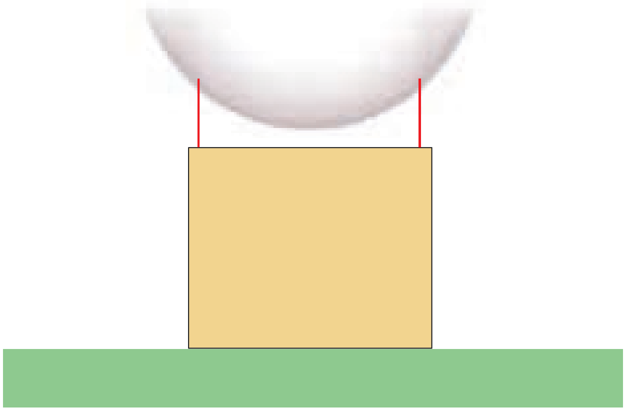

Figure 4.7b: View on arrow **A**

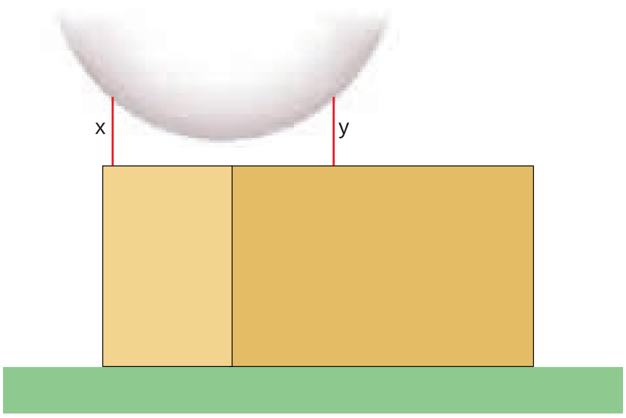

Figure 4.7c: View on arrow **B**

Catenary (or suspended) conductors

As with a free standing mast, catenary conductors can be used to keep the rolling sphere away from the structure to be protected. One or more catenary conductors may be utilized to ensure that the sphere does not come into contact with any part of the structure's roof.

If the system is required to be isolated from the structure then a conductor suspended between two free standing masts may be employed. See Figure 4.8. This arrangement is suitable for small sensitive structures such as explosive stores. Once again the separation distance (*s*) indicated on Figure 4.8c should be ensured.

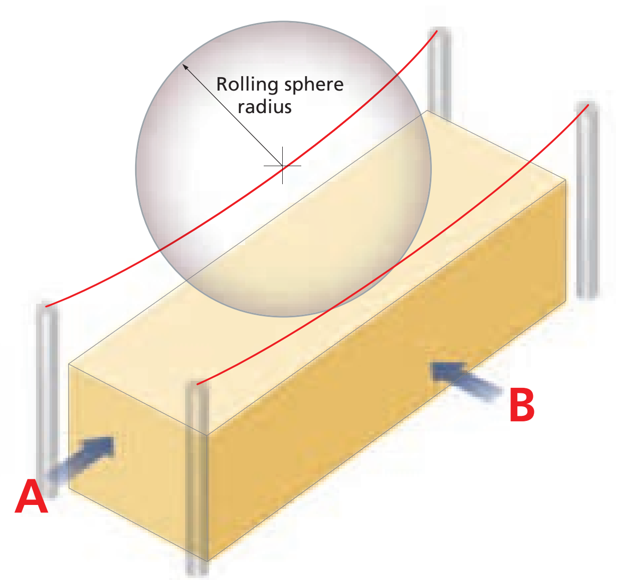

Figure 4.8a: Application of the rolling sphere to catenary conductors forming an isolated system

In a non isolated system, a catenary conductor may be used to protect larger items of roof mounted equipment from a direct strike. See Figure 4.10.

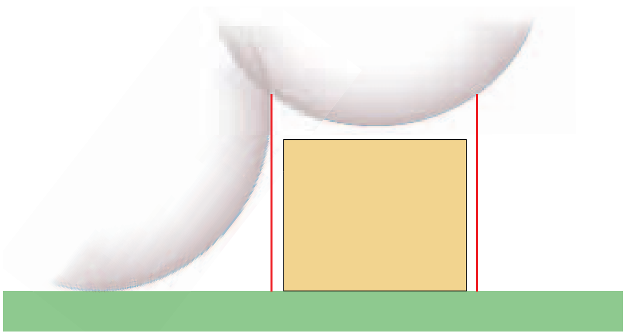

Figure 4.8b: View on arrow **A**

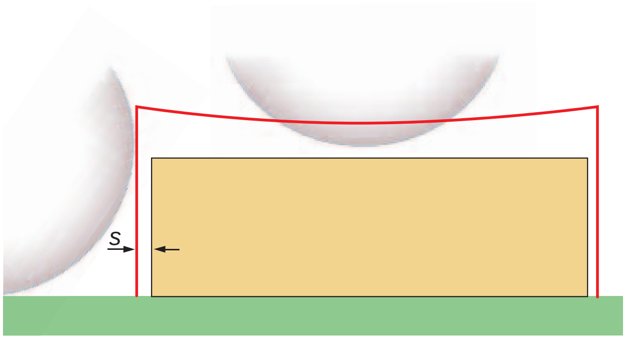

Figure 4.8c: View on arrow **B**

Unlike individual air rods arranged in a square, it is simply the distance between the two parallel conductors (see Figure 4.8b and Figure 4.10) that must be considered when determining the penetration depth of the rolling sphere.

Meshed conductor network

If the rolling sphere principle is used in conjunction with a meshed conductor network, the mesh must be mounted at some distance above the roof, to ensure the rolling sphere does not touch its surface (Figure 4.9).

In a similar way to the catenary conductors, the penetration distance of the sphere below the level of the mesh is determined by the distance between parallel mesh conductors. See Figure 4.10.

From all the previous design scenarios it is clear that the rolling sphere can penetrate a certain distance into the space below the air termination network.

This distance, known as the penetration distance, can be determined graphically or by calculation.

The penetration distance p into the space between two air termination conductors can be determined using Equation 4.1.

$$p = r - \sqrt{r^2 - \left(\frac{d}{2}\right)} \quad (4.1)$$

Where:

p = penetration distance (m)

r = rolling sphere radius (m)

d = distance between two points on an air termination network (m)

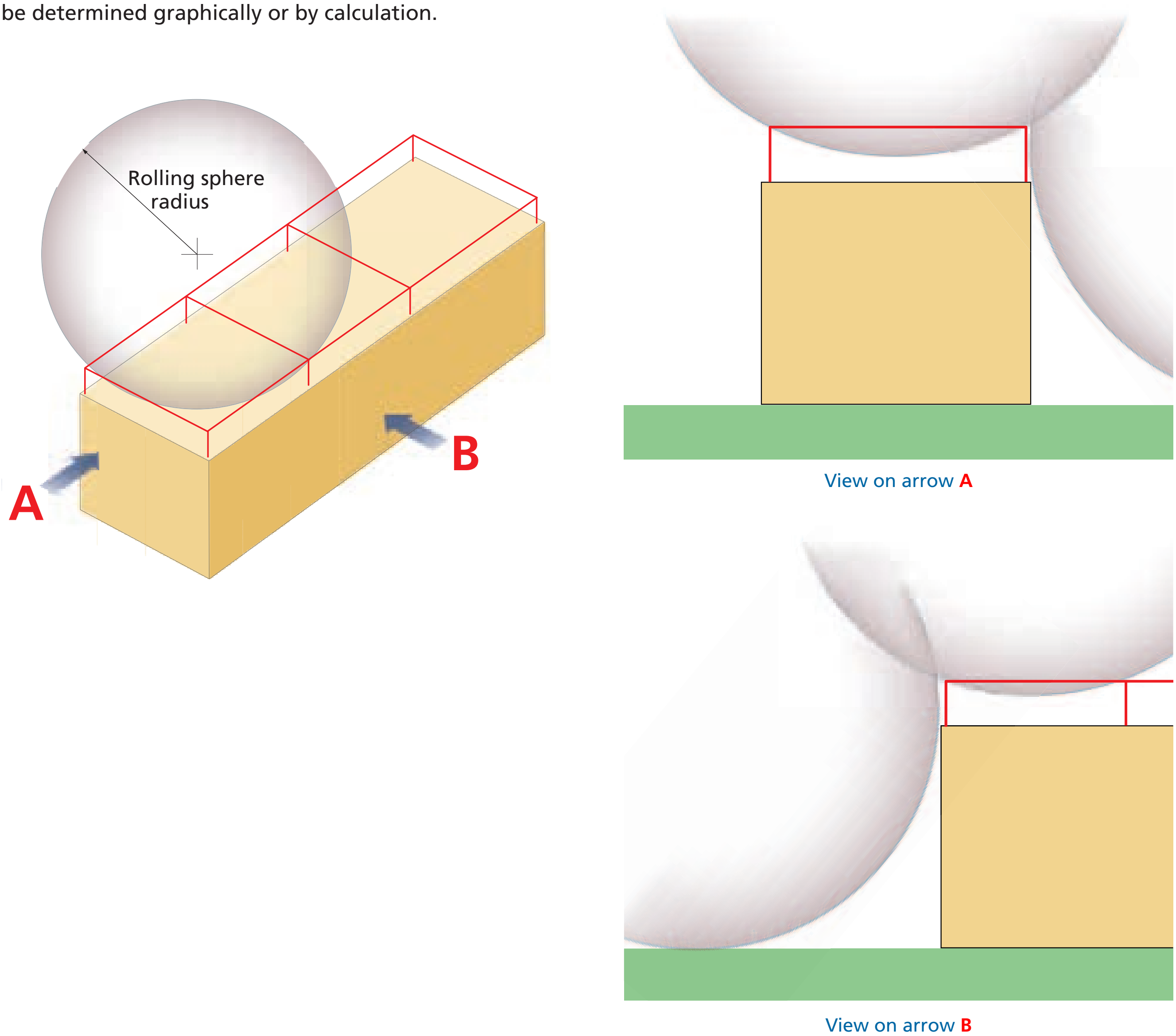

Figure 4.9: Application of the rolling sphere to elevated meshed conductors forming a non-isolated system

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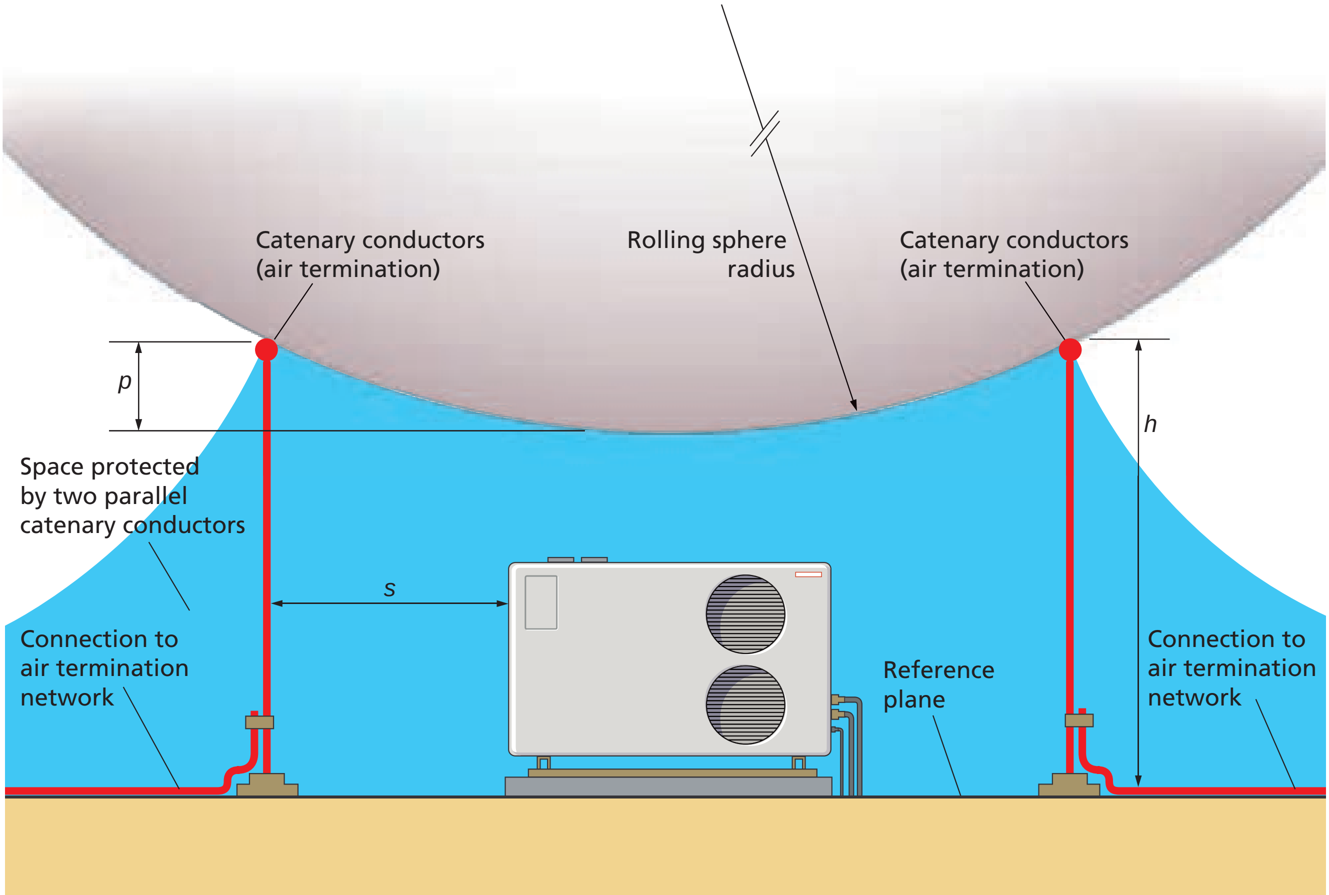


h	Physical height of catenary conductors above the reference plane
s	Separation distance
p	Penetration distance of the rolling sphere

Figure 4.10: Application of the rolling sphere to two parallel catenary conductors in a non-isolated system

For example, with reference to Equation 4.1, the penetration distance of the rolling sphere is determined as per the following calculation.

If we assume a Level II LPS (see Table 4.2), distance between the two catenary conductors is 2 metres and their height is 1 metre, so:

$$p = r - \sqrt{r^2 - \left(\frac{d}{2}\right)}$$

$$p = 30 - \sqrt{30^2 - \left(\frac{2}{2}\right)}$$

$$p = 30 - \sqrt{900 - 1}$$

$$p = 30 - \sqrt{899}$$

$$p = 30 - 29.98$$

$$p = 0.02 \text{ m}$$

If the height of the rooftop plant is 0.7 m and the height to the rolling sphere is 0.98 m (1 m – 0.02 m) then the item of plant is adequately protected.

The protective angle method

The protective angle method is a mathematical simplification of the rolling sphere method (see Figure 4.12). The protective angle is derived by initially rolling a sphere up to a vertical air termination eg an air rod (AB). A line is then struck from the point where the sphere touches the air rod (A) down to the reference plane (D), finishing at point C. The line must bisect the sphere (circle) such that the areas (shaded) of over and under estimation of protection (when compared to the rolling sphere method) are equal. The angle created between the tip of the vertical rod (A) and the projected line is termed the protective angle alpha (α).

The above procedure was applied to each Class of LPS using its corresponding rolling sphere. The protective angle afforded by an air rod located on a reference plane can be determined from Figure 4.11 or Table 4.3.

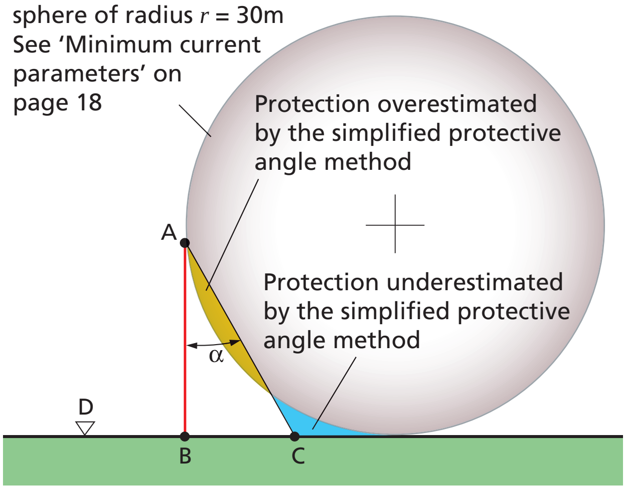
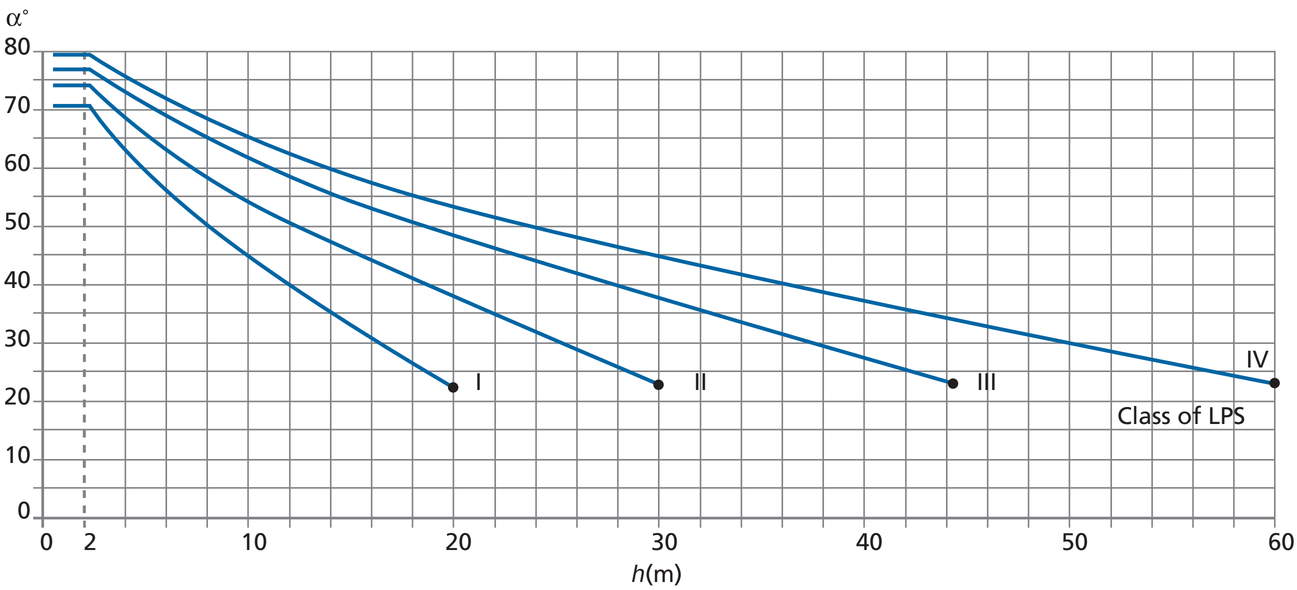


Figure 4.12: Derivation of the protective angle



Note 1 Not applicable beyond the values marked with •
Only rolling sphere and mesh methods apply in these cases

Note 2 *h* is the height of air-termination above the reference plane of the area to be protected

Note 3 The angle will not change for values of *h* below 2 m

Figure 4.11: Determination of the protective angle (BS EN 62305-3 Table 2)

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Height of air rod above reference plane (m)	LPS Class IV		LPS Class III		LPS Class II		LPS Class I	
	Angle (deg)	Radius (m)	Angle (deg)	Radius (m)	Angle (deg)	Radius (m)	Angle (deg)	Radius (m)
1	78.7	5.0	76.3	4.1	73.2	3.3	70.0	2.7
2	78.7	10.0	76.3	8.2	73.2	6.6	70.0	5.5
3	76.7	12.7	74.1	10.5	70.1	8.3	66.3	6.8
4	74.7	14.6	72.0	12.3	67.1	9.5	62.6	7.7
5	72.8	16.1	69.9	13.6	64.4	10.4	59.1	8.4
6	71.0	17.4	67.9	14.8	62.0	11.3	55.9	8.9
7	69.3	18.5	66.0	15.7	59.7	12.0	53.0	9.3
8	67.7	19.5	64.3	16.6	57.6	12.6	50.2	9.6
9	66.2	20.4	62.6	17.4	55.6	13.2	47.7	9.9
10	64.7	21.2	61.1	18.1	53.8	13.6	45.2	10.1
11	63.4	21.9	59.6	18.7	52.0	14.1	42.8	10.2
12	62.1	22.6	58.2	19.3	50.3	14.4	40.4	10.2
13	60.8	23.3	56.8	19.8	48.6	14.8	38.1	10.2
14	59.6	23.9	55.4	20.3	47.0	15.0	35.8	10.1
15	58.4	24.4	54.1	20.7	45.4	15.2	33.6	10.0
16	57.3	24.9	52.8	21.1	43.8	15.3	31.4	9.8
17	56.2	25.4	51.5	21.4	42.3	15.4	29.2	9.5
18	55.2	25.9	50.3	21.7	40.6	15.4	27.1	9.2
19	54.2	26.3	49.1	21.9	39.2	15.5	24.9	8.8
20	53.2	26.7	47.9	22.1	37.7	15.5	22.8	8.4
21	52.3	27.1	46.6	22.2	36.3	15.4		
22	51.3	27.5	45.5	22.4	34.8	15.3		
23	50.5	27.9	44.3	22.4	33.4	15.1		
24	49.6	28.2	43.1	22.5	31.9	15.0		
25	48.8	28.5	42.0	22.5	30.5	14.7		
26	48.0	28.8	40.9	22.5	29.0	14.4		
27	47.2	29.1	39.8	22.5	27.5	14.0		
28	46.4	29.4	38.7	22.5	25.9	13.6		
29	45.6	29.6	37.7	22.4	24.4	13.1		
30	44.8	29.8	36.7	22.3	22.8	12.6		
31	44.1	30.0	35.7	22.3				
32	43.3	30.2	34.7	22.1				
33	42.6	30.3	33.7	22.0				
34	41.8	30.4	32.8	21.9				
35	41.1	30.5	31.8	21.7				
36	40.3	30.6	30.9	21.5				
37	39.6	30.6	29.9	21.3				
38	38.8	30.6	29.0	21.1				
39	38.1	30.6	28.1	20.8				
40	37.3	30.5	27.2	20.5				
41	36.6	30.4	26.2	20.2				
42	35.9	30.3	25.3	19.9				
43	35.1	30.2	24.4	19.5				
44	34.4	30.1	23.5	19.2				
45	33.6	29.9	23.5	19.6				
46	32.9	29.8						
47	32.2	29.6						
48	31.5	29.4						
49	30.7	29.1						
50	30.0	28.9						
51	29.3	28.6						
52	28.5	28.3						
53	27.8	28.0						
54	27.1	27.6						
55	26.4	27.3						
56	25.7	26.9						
57	24.9	26.5						
58	24.2	26.1						
59	23.5	25.7						
60	22.8	25.2						

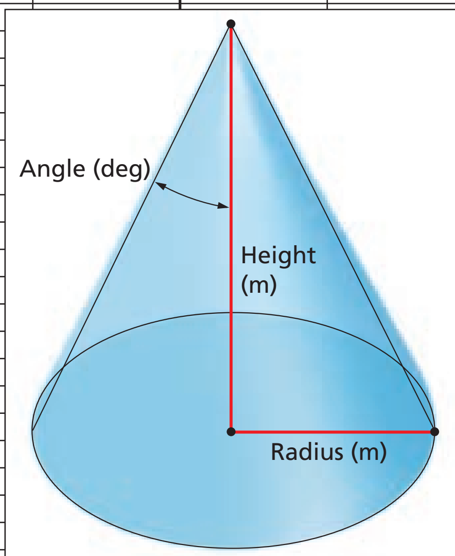

Table 4.3: Simple determination of the protective angle

Note 1 in Figure 4.11 identifies the restrictions when using the protective angle method for the air termination system design. When the structure/air rod/mast, relative to the reference plane, is greater in height than the appropriate rolling sphere radius, the zone of protection afforded by the protection angle is no longer valid (see Figure 4.13).

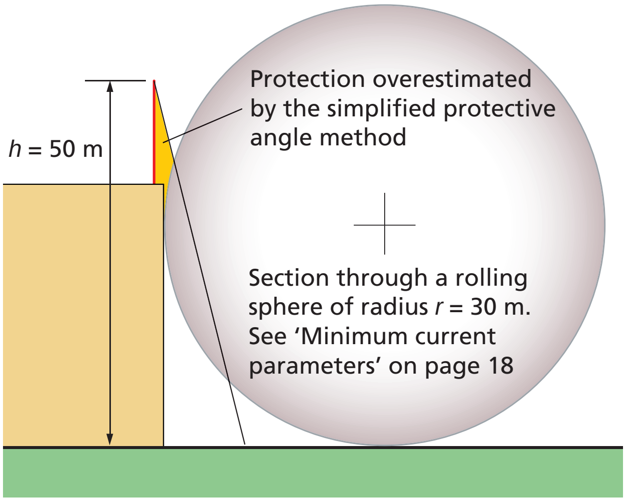

Figure 4.13: Limitation of the use of the protective angle method

For example if the design was to a structural LPS Class II, and the structure's height was 50 m, then using the appropriate rolling sphere of 30 m radius would leave the upper 20 m needing lightning protection. If an air rod or a conductor on the edge of the roof was installed then a zone of protection angle could not be claimed because the rolling sphere had already identified that the upper 20 m was not protected.

Thus the protective angle method is only valid up to the height of the appropriate rolling sphere radius.

The protective angle afforded by an air rod is clearly a three dimensional concept. See Figure 4.14. Therefore a simple air rod is assigned a cone of protection by sweeping the line AC at the angle of protection a full 360° around the air rod.

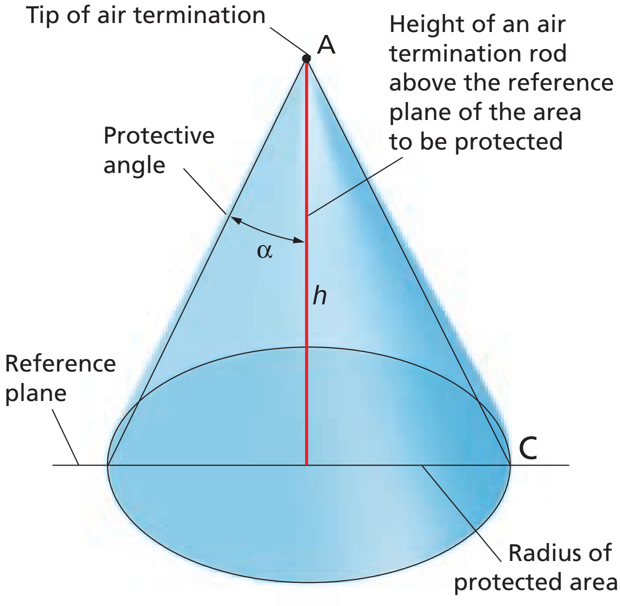

Figure 4.14: The protective angle method for a single air rod

The above concept can be extended to a catenary conductor. See Figure 4.15. At each end of the catenary conductor (A) a cone of protection is created relative to height *h*. A similar cone is created at every point along the suspended conductor. It should be noted that any sag in the suspended conductor would lead to a reduction in the zone of protection at the reference plane. This produces an overall 'dog bone' shape at the reference plane.

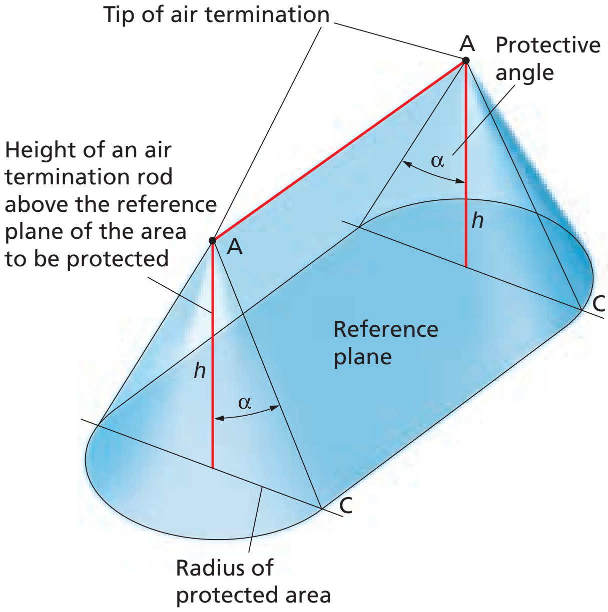

Figure 4.15: The protective angle method for a catenary conductor

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Varying the protection angle is a change to the simple 45° zone of protection afforded in most cases in BS 6651. Furthermore this standard uses the height of the air termination system above the reference plane, whether that be ground or roof level. See Figure 4.16.

The protective angle method is suitable for simple shaped buildings.

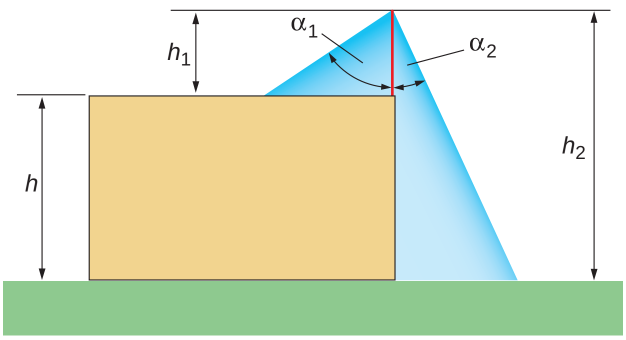


Figure 4.16: Effect of the height of the reference plane on the protection angle

Application of protection using the protective angle method

Unlike the rolling sphere, the protective angle method is not used to determine which parts of a structure require protection. It is however used in a similar way to the rolling sphere to show the effectiveness of the designed protection system.

Air rods or free standing masts

The effectiveness of an isolated free standing mast used to protect a small object can be proven by the protective angle method. See Figure 4.17.

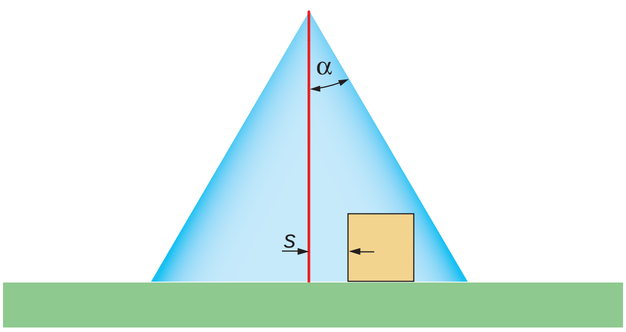


Figure 4.17: Application of the protection angle to an isolated free standing mast

Once again if the system does not need to be isolated from the structure then air rods fitted to the roof of the structure could be employed. See Figure 4.18a.

The height of the air rods utilized is now a function of the protection angle (Class of LPS), the spacing between the air rods and the height above a particular reference plane. See Figure 4.18b.

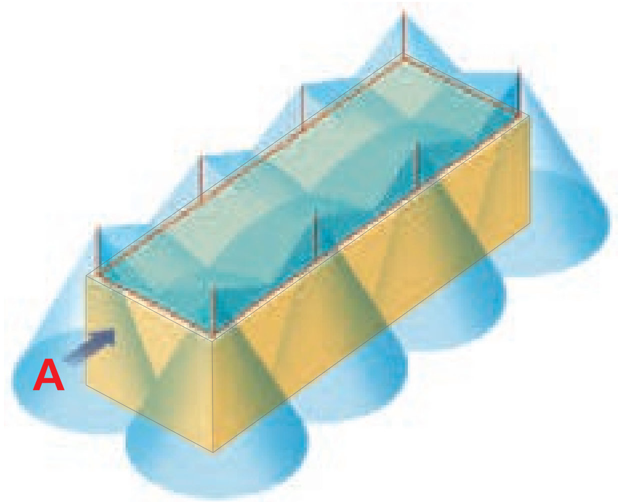


Figure 4.18a: Application of the protective angle method to air rods in a non-isolated system

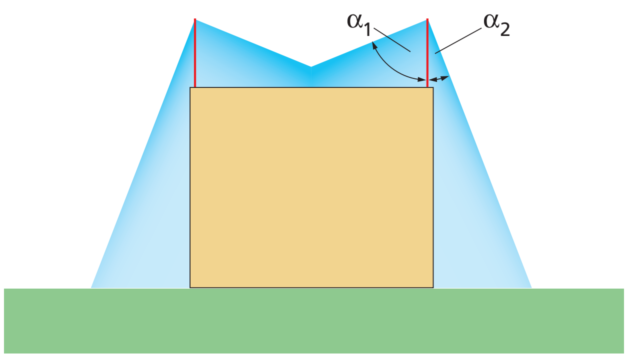
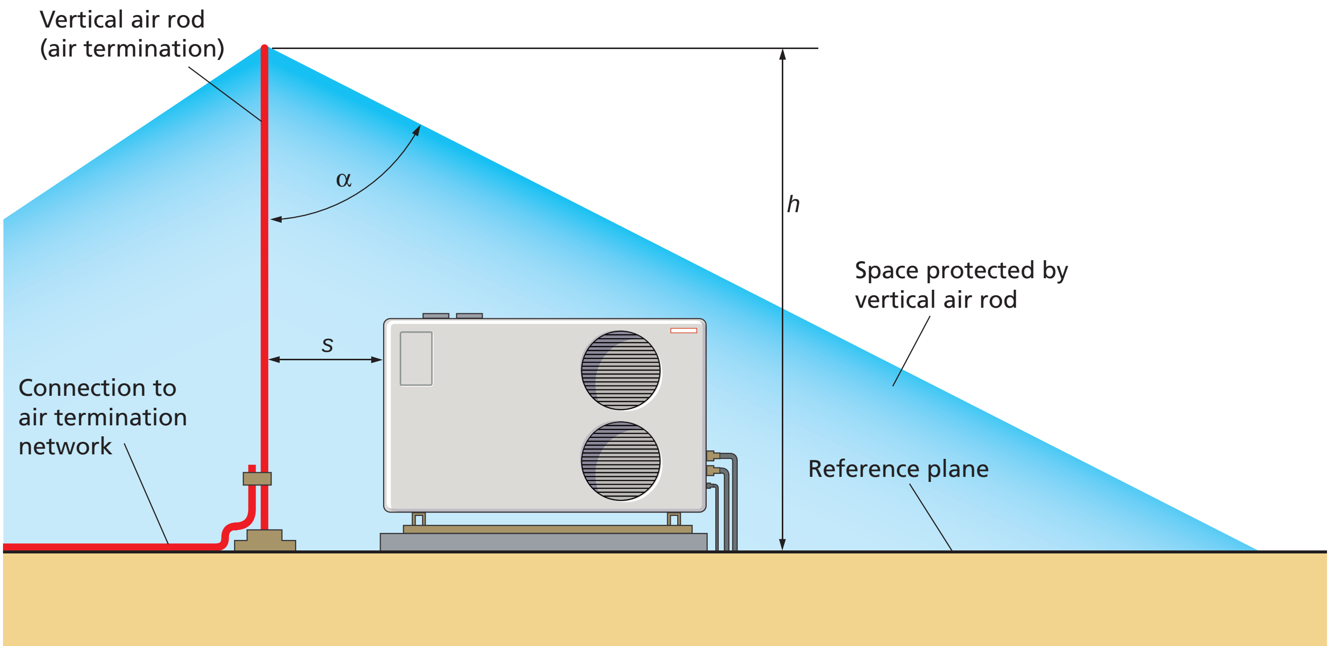


Figure 4.18b: View on arrow **A**

In a non-isolated system, an air rod (or multiple air rods) may be used to protect larger items of roof mounted equipment from a direct strike. See Figure 4.19.



h	Physical height of air rod above the reference plane
α	Protective angle (alpha)
s	Separation distance

Figure 4.19: Application of the protective angle method to an air rod in a non-isolated system

Catenary (or suspended) conductors

One or more catenary conductors may be utilized to provide a zone of protection over an entire structure. See Figure 4.20.

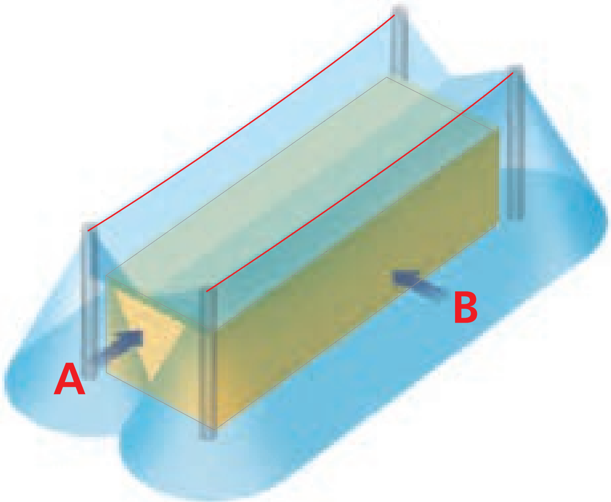


Figure 4.20a: Application of the protective angle method to catenary conductors forming an isolated system

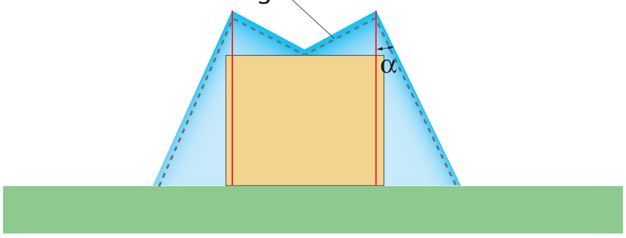


Figure 4.20b: View on arrow **A**

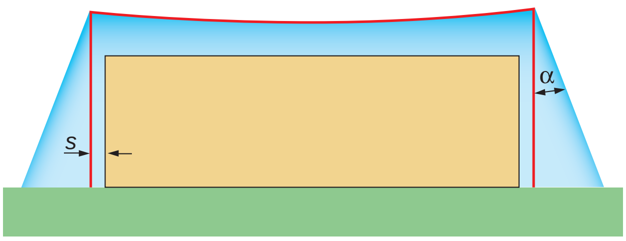
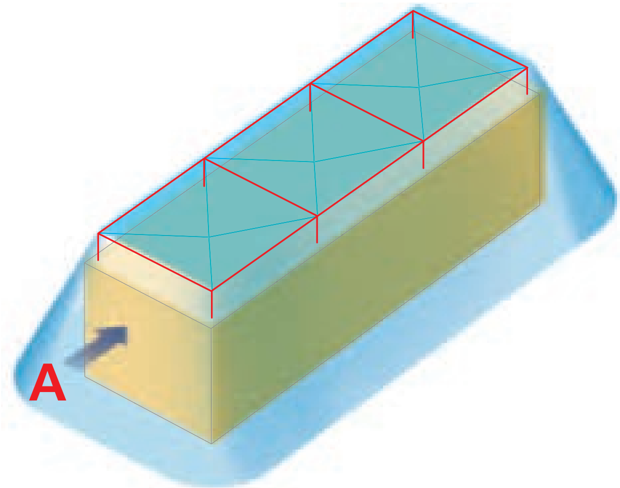
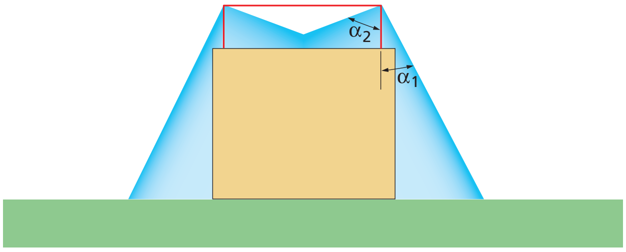


Figure 4.20c: View on arrow **B**

Meshed conductor network

As with the rolling sphere method a meshed conductor network must be mounted at some distance above the roof. This is in order to provide an effective zone of protection using the protective angle method. See Figure 4.21.





View on arrow **A**

Figure 4.21: Application of the protective angle method to elevated meshed conductors forming a non-isolated system

The mesh method

This is the method that was most commonly used in BS 6651. Again, four different air termination mesh sizes are defined and correspond to the relevant Class of LPS (see Table 4.4).

Class of LPS	Mesh size *W* (m)
I	5 x 5
II	10 x 10
III	15 x 15
IV	20 x 20

Table 4.4: Maximum values of mesh size corresponding to the Class of LPS

This method is suitable where plain surfaces require protection if the following conditions are met:

- Air termination conductors must be positioned at roof edges, on roof overhangs and on the ridges of roofs with a pitch in excess of 1 in 10 (5.7º)
- No metal installation protrudes above the air termination system

As in BS 6651, this standard permits the use of conductors (whether they be fortuitous metalwork or dedicated LP conductors) under the roof. Vertical air rods (finials) or strike plates should be mounted above the roof and connected to the conductor system beneath. The air rods should be spaced not more than 10 m apart and if strike plates are used as an alternative, these should be strategically placed over the roof area not more than 5 m apart.

As modern research on lightning inflicted damage has shown, the edges and corners of the roofs are most susceptible to damage.

So on all structures particularly with flat roofs, the perimeter conductors should be installed as close to the outer edges of the roof as is practicable.

Non-conventional air termination systems

A lot of technical (and commercial) debate has raged over the years regarding the validity of the claims made by the proponents of such systems. This topic was discussed extensively within the technical working groups that compiled this standard. The outcome was to remain with the information housed within this standard. BS EN 62305-3 states unequivocally that the volume or zone of protection afforded by the air termination system (eg air rod) shall be determined only by the real physical dimension of the air termination system. Typically if the air rod is 5 m tall then the only claim for the zone of protection afforded by this air rod would be based on 5 m and the relevant Class of LPS and not any enhanced dimension claimed by some non-conventional air rods.

BS EN 62305 update

The use of non-conventional air termination systems was covered in Annex A (normative) of BS EN 62305-3:2006. However the position regarding use of these systems (or in effect their non-use as specified above) has been reinforced in the 2011 version of BS EN 62305-3, by repeating the relevant statements in the main body of the standard.

There is no other standard being contemplated to run in parallel with this standard.

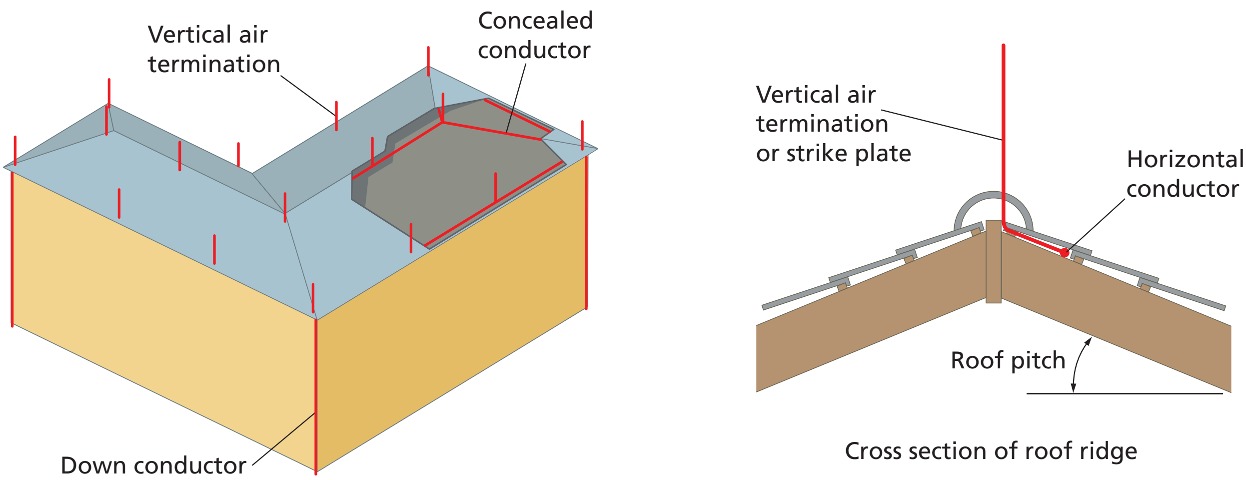


Figure 4.22: Concealed air termination network

Tall structures

As modern construction techniques improve, the height of structures is increasing. Super structures taller than 1 km in height are now being constructed.

One of the major protection measures required is to ensure adequate protection is afforded to the upper sides of these super structures to minimize any protection damage from side flashes to the structure.

BS EN 62305 update

BS EN/IEC 62305-3:2011 now covers this topic in detail.

Research has shown that it is the upper 20% of the structure that is most vulnerable to side strikes and potential damage.

This uppermost 20% of a structure taller than 60 m, and any equipment installed thereon, shall now incorporate protection against side flashes, especially at corners, points and edges of surfaces, meeting at least the requirements of LPL IV.

For calculation purposes, the LPS designer should consider the full height of the structure, minus 60 m, and then derive 20% from the remainder. That uppermost portion of the structure must be protected.

Protection measures may include air terminals, down conductors and where appropriate, use of fortuitous metalwork on or within the structure.

Equipotential bonding is another important aspect and with these particular structures it is vital to utilize the vast fortuitous metalwork present both in the concrete encased steel as well as the metallic cladding adorning it.

Natural components

When metallic roofs are being considered as a natural air termination arrangement, BS 6651 provided guidance on the minimum thickness and type of material under consideration. BS EN 62305-3 gives similar guidance as well as additional information if the roof has to be considered puncture proof from a lightning discharge. Table 4.5 refers.

Class of LPS	Material	Thickness(1) t (mm)	Thickness(2) t' (mm)
I to IV	Lead	-	2.0
	Steel (stainless, galvanized)	4	0.5
	Titanium	4	0.5
	Copper	5	0.5
	Aluminium	7	0.65
	Zinc	-	0.7

(1) Thickness t prevents puncture, hot spot or ignition.
(2) Thickness t' only for metal sheets if it is not important to prevent puncture, hot spot or ignition problems.

Table 4.5: Minimum thickness of metal sheets or metal pipes in air termination systems (BS EN 62305-3 Table 3)

Figure 4.23: Petronas Towers, Malaysia

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Down conductors

Down conductors should within the bounds of practical constraints take the most direct route from the air termination system to the earth termination system.

The lightning current is shared between the down conductors. The greater the number of down conductors, the lesser the current that flows down each. This is enhanced further by equipotential bonding to the conductive parts of the structure.

Lateral connections either by fortuitous metalwork or external conductors made to the down conductors at regular intervals (see Table 4.6) are also encouraged.

The down conductor spacing corresponds with the relevant Class of LPS.

Class of LPS	Typical distances (m)
I	10
II	10
III	15
IV	20

Table 4.6: Typical values of the distance between down conductors according to the Class of LPS (BS EN 62305-3 Table 4)

Arrangement	Tape and stranded conductors (mm)	Round solid conductors (mm)
Horizontal conductors on horizontal surfaces	1,000	1,000
Horizontal conductors on vertical surfaces	500	1,000
Vertical conductors from the ground to 20 m	1,000	1,000
Vertical conductors from 20 m and thereafter	500	1,000

This table does not apply to built-in type fixings which may require special considerations. Assessment of environmental conditions (ie expected wind load) shall be undertaken and fixing centres different from those recommended may be found to be necessary.

Table 4.7: Suggested conductor fixing centres (BS EN 62305-3 Table E.1)

BS EN 62305 update

Note that Table 4.7 now includes 1,000 mm fixing centres for tape and stranded conductors fixed to horizontal surfaces. This is a correction in the 2011 version of BS EN 62305-3 (from the 500 mm fixing centres stated in BS EN 62305:2006).

There should always be a minimum of two down conductors distributed around the perimeter of the structure. Down conductors should wherever possible be installed at each exposed corner of the structure as research has shown these to carry the major part of the lightning current.

Down conductors should not be installed in gutters or down spouts even if they are insulated due to the risk of corrosion occurring.

Fixing centres for the air termination and down conductors are shown in Table 4.7.

Numerous illustrations are given in Annex E of the positioning and relevant use of natural conductors (fortuitous metalwork) as down conductors and lateral conductors and equipotential bonding, all elements contributing to a more effective LPS.

Sometimes it is not possible to install down conductors down a particular side of a building due to practical or architectural constraints. On these occasions more down conductors at closer spacings on those sides that are accessible should be installed as a compensating factor.

The centres between these down conductors should not be less than one third of the distances given in Table 4.6.

A test joint should be fitted on every down conductor that connects with the earth termination. This is usually on the vertical surface of the structure, sufficiently high to minimize any unwanted third party damage/interference. Alternatively, the test or disconnection point can be within the inspection chamber that houses the down conductor and earth rod. The test joint should be capable of being opened, removed for testing and reconnected. It shall meet the requirements of BS EN 50164-1 or IEC/BS EN 62561-1.

Similar to BS 6651, this standard permits the use of an aesthetic covering of PVC or protective paint over the external LP conductors. (See clause E.5.3.4.1 of BS EN 62305-3).

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Structure with a cantilevered part

As with BS 6651, BS EN 62305-3 addresses the potential problem associated with a person, standing under the overhang of a cantilevered structure during a thunderstorm.

The problem is illustrated in Figure 4.24.

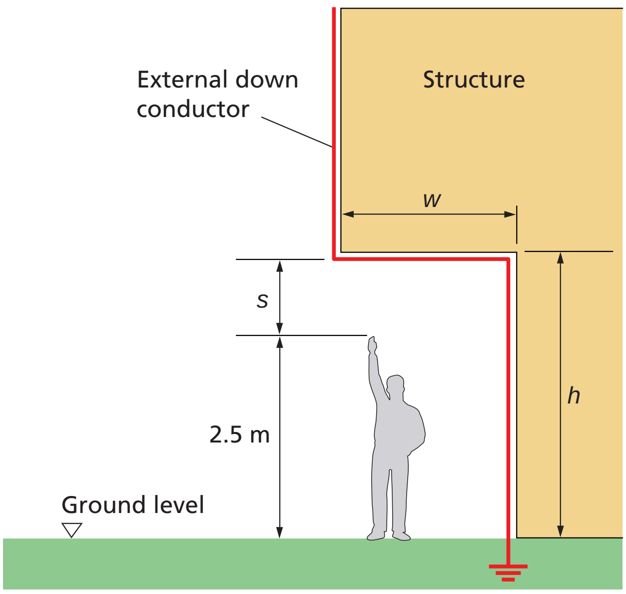


Figure 4.24: Cantilevered structure

To reduce the risk of the person becoming an alternative path for the lightning current to that of the external down conductors, then the following condition should be satisfied:

$$h > 2.5 + s \qquad (4.2)$$

Where:

h = Height of the overhang (in metres)

s = Required separation distance calculated in accordance with Section 6.3 of BS EN 62305-3

The separation distance s is covered in more detail on page 64, Separation (isolation) distance of the external LPS. For the purpose of determining h, the separation distance can be determined by using Equation 4.3.

$$s = \frac{k_i}{k_m} \times k_c \times l \qquad (4.3)$$

Where:

k_i = 0.08 for LPS Class I (see Table 4.13)

k_m = 1 for air (see Table 4.14)

k_c = 0.66 for 2 down conductors (see Table 4.15)

l = $w + h$

$$h - 2.5 = \frac{k_i}{k_m} \times k_c \times (w + h)$$

$$h - 2.5 = \frac{0.08}{1} \times 0.66 \times (w + h)$$

$$h - 2.5 = 0.0528 \times (w + h)$$

$$w = 18.94 \times (0.9472 \times h - 2.5)$$

$$w \approx 19 \times (h - 2.5)$$

So for a height h, the maximum width w of the overhang should be:

Height of overhang ***h*** (m)	Width of overhang ***w*** (m)
3	9.5
3.5	19
4.0	28.5
4.5	38
5	47.5

Table 4.8: Maximum allowable cantilever for LPL I

The above is based on 2 external, equally spaced down conductors and a Type A earthing arrangement. If the above conditions cannot be fulfilled, consideration should be given to increasing the number of down conductors, or alternatively, routeing the down conductors internally. The requirement of the separation distance would still need to be satisfied.

Natural components

The philosophy of the design, like BS 6651, encourages the use of fortuitous metal parts on or within the structure, to be incorporated into the LPS.

Where BS 6651 required electrical continuity when using reinforcing bars located in concrete structures, so too does BS EN 62305-3. Additionally, it states that the vertical reinforcing bars are welded, or clamped with suitable connection components or overlapped a minimum of 20 times the rebar diameter. This is to ensure that those reinforcing bars likely to carry lightning currents have secure connections from one length to the next.

If the reinforcing bars are connected for equipotential bonding or EMC purposes then wire lashing is deemed to be suitable.

Additionally, the reinforcing bars - both horizontal and vertical - in many new structures will be so numerous that they serve as an electromagnetic shield which goes some way to protecting the electrical and electronic equipment from interference caused by lightning electromagnetic fields.

When internal reinforcing bars are required to be connected to external down conductors or earthing network either of the arrangements shown in Figure 4.25 is suitable. If the connection from the bonding conductor to the rebar is to be encased in concrete then the standard recommends that two clamps are used, one connected to one length of rebar and the other to a different length of rebar. The joints should then be encased by a moisture inhibiting compound such as Denso tape.

If the reinforcing bars (or structural steel frames) are to be used as down conductors then electrical continuity should be ascertained from the air termination system to the earthing system. For new build structures this can be decided at the early construction stage by using dedicated reinforcing bars or alternatively to run a dedicated copper conductor from the top of the structure to the foundation prior to the pouring of the concrete. This dedicated copper conductor should be bonded to the adjoining/adjacent reinforcing bars periodically.

If there is doubt as to the route and continuity of the reinforcing bars within existing structures then an external down conductor system should be installed. These should ideally be bonded into the reinforcing network at the top and bottom of the structure.

BS EN 62305-3 gives further guidance regarding the electrical continuity of steel reinforced concrete by stating a maximum overall electrical resistance of 0.2 ohm. This should be achieved when measuring the electrical continuity from the top of the structure down to its foundations.

! BS EN 62305 update

On many occasions it is impractical to test electrical continuity of steel reinforced concrete from the top of the structure.

BS EN 62305-3:2011 therefore permits individual testing at each section/level. From these results the total resistance can be calculated and would be adequate so long as the overall electrical resistance was lower than 0.2 ohm. Alternatively, an external down conductor system can be employed.

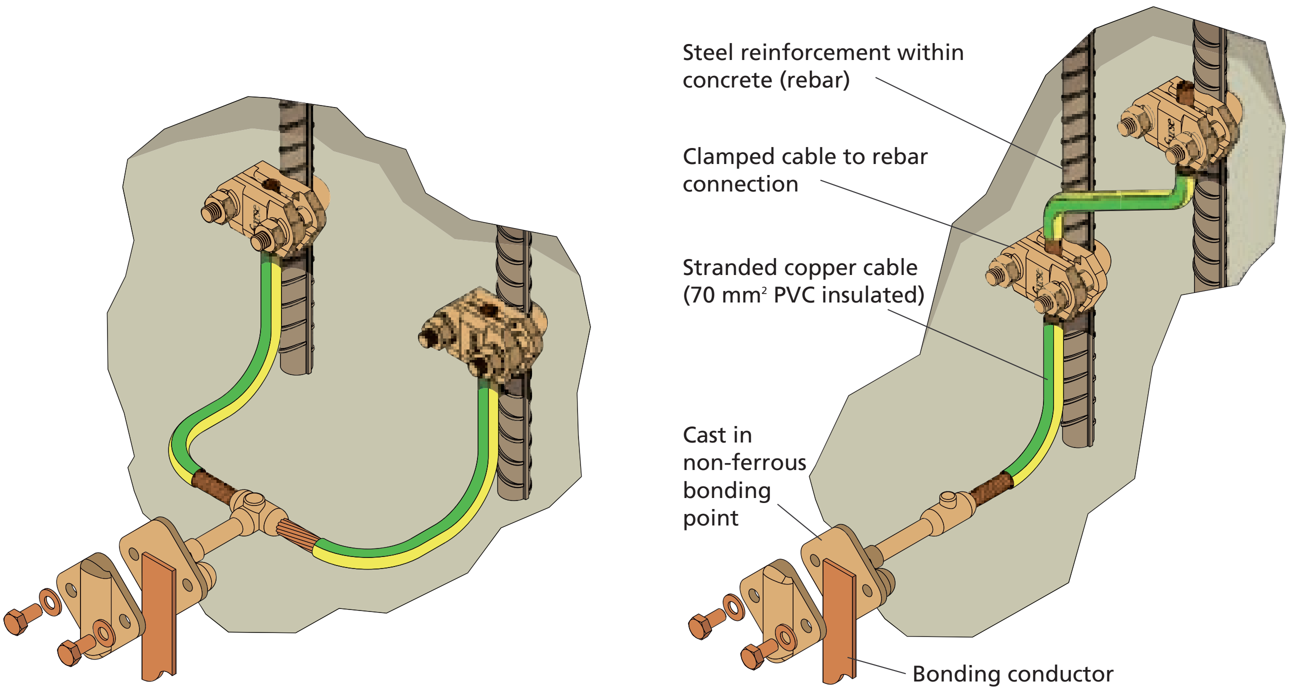


Figure 4.25: Typical methods of bonding to steel reinforcement within concrete

Although BS 6651 advocated the use of reinforcing for equipotential bonding, BS EN 62305 emphasizes its importance. It encourages a meshed connection conductor network (see E4.3.8 of BS EN 62305-3), even to the extent of utilizing dedicated ring conductors installed inside or outside the concrete on separate floors of the structure, at intervals not greater than 10 m. Foundation earth termination systems usually found in large structures and industrial plants are also encouraged.

Earth termination system

The earth termination system is vital for the dispersion of the lightning current safely and effectively into the ground. Although lightning current discharges are a high frequency event, at present most measurements taken of the earthing system are carried out using low frequency proprietary instruments. The standard advocates a low earthing resistance requirement and points out that can be achieved with an overall earth termination system of 10 ohms or less.

In line with BS 6651, the standard recommends a single integrated earth termination system for a structure, combining lightning protection, power and telecommunication systems. The agreement of the operating authority or owner of the relevant systems should be obtained prior to any bonding taking place.

Three basic earth electrode arrangements are used.

- Type A arrangement
- Type B arrangement
- Foundation earth electrodes

Type A arrangement

This consists of horizontal or vertical earth electrodes, connected to each down conductor fixed on the outside of the structure. This is in essence the earthing system used in BS 6651, where each down conductor has an earth electrode (rod) connected to it.

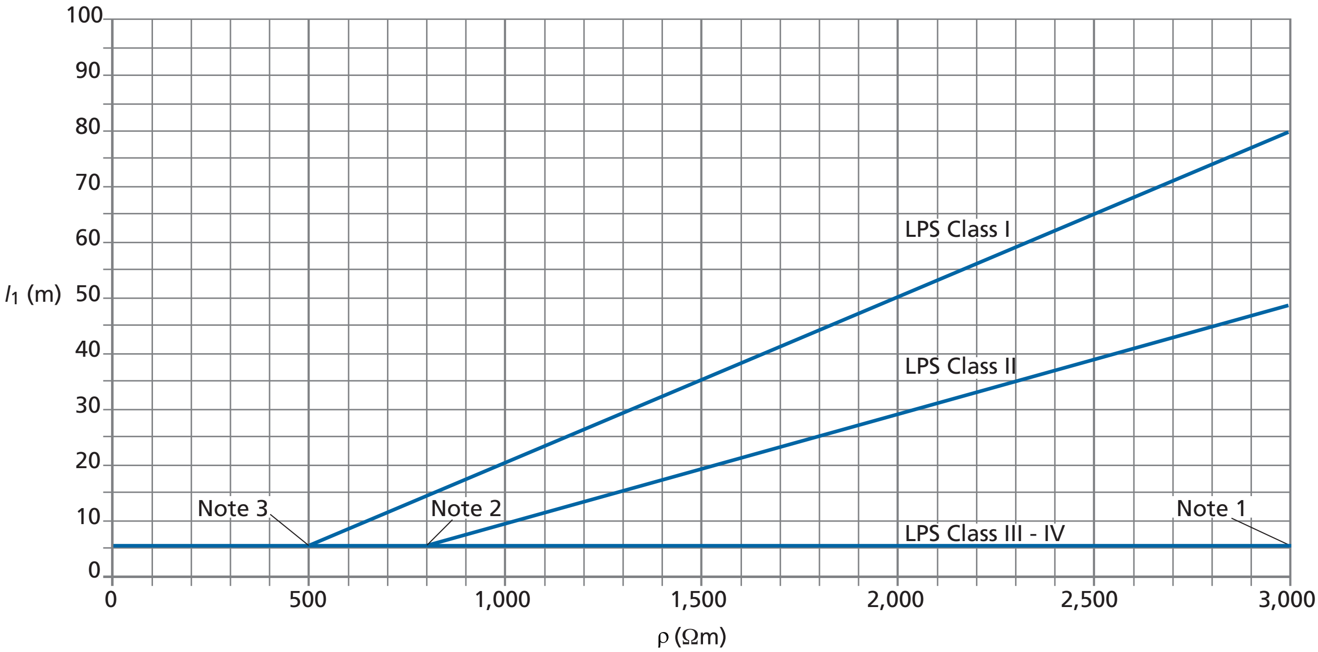
BS EN 62305 update

BS EN 62305-3:2011 makes clear that the total number of earth electrodes shall be not less than two, with one earth electrode installed per down conductor of the LPS.

The minimum length for a horizontal or vertical electrode is determined from Figure 4.26 (Figure 3 of BS EN 62305-3).

In the case of vertical electrodes (rods) when used in soils of resistivity 500 ohms metres or less, then the minimum length of each rod shall be 2.5 m. However, the standard states that this minimum length can be disregarded provided that the earth resistance of the overall earth termination system is less than 10 ohms.

Conversely, if the 10 ohm overall value cannot be achieved with 2.5 m long earth rods, it will be necessary to increase the length of the earth rods or combine them with a Type B ring earth electrode until a 10 ohm overall value is achieved.



Note 1 For LPS Class III and IV l_1 is independent of soil resistivity
Note 2 For LPS Class II l_1 is fixed for soil resistivities below 800 Ωm
Note 3 For LPS Class I l_1 is fixed for soil resistivities below 500 Ωm

Figure 4.26: Minimum length of earth electrode

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It further states that the earth electrodes (rods) shall be installed such that the top of each earth rod is at least 0.5 m below finished ground level. The electrodes (rods) should be distributed around the structure as uniformly as possible to minimize any electrical coupling effects in the earth.

From a practical point of view this means that the top 0.5 m from ground level down would need to be excavated prior to commencing the installation of the earth rod.

Another way of fulfilling this earthing requirement would be to drive the required extensible earth rods from ground level and complete the installation by driving an insulated section of earth rod that was connected to these earth rods and was terminated at ground level.

The following table gives an indication of how many earth rods would be required to achieve 10 ohms or less for varying soil resistivities. As the most popular size of earth rod used in many countries is 1.2 m (4 ft) or multiples thereof, the values are based on a 2.4 m (2 x 4 ft) length of earth rod electrode.

Resistivity (ohm m)	Number of earth rods	Length of earth rod (m)
500	50	2.4
400	38	2.4
300	28	2.4
200	18	2.4
100	8	2.4
50	3	2.4

Table 4.9: Earth rods required to achieve 10 ohms

Potential corrosion, soil drying out, or freezing is also considered with regard to achieving a stabilized earth resistance value of the earth rod. In countries where extreme weather conditions are found, for every vertical electrode (rod) the standard recommends that 0.5 m should be added to each length, to compensate for the detrimental effect from some of the extreme seasonal soil conditions that are likely to be encountered.

BS EN 62305 update

Note that BS EN 62305-3:2011 now includes a waiver regarding the requirement that the top of each earth rod is at least 0.5 m below finished ground level. Now, where the earth electrode is installed within an inspection housing, which is in turn located in high resistance paving or adjoining concrete, then the 0.5 m depth requirement can be disregarded.

Type B arrangement

This arrangement is essentially a ring earth electrode that is sited around the periphery of the structure and is in contact with the surrounding soil for a minimum 80% of its total length (ie 20% of its overall length may be housed in say the basement of the structure and not in direct contact with the earth).

The minimum length of the ring earth electrode is also determined from Figure 4.26 (Figure 3 of BS EN 62305-3). For soil of resistivity 500 ohm metres or less, the minimum length of electrode shall be 5 m. The mean radius of the area enclosed by the ring earth electrode is also taken into account to determine whether additional horizontal or vertical electrodes are required. In reality provided the structure is not smaller than 9 m x 9 m and the soil resistivity is less than 500 ohm metres then the ring electrode will not need to be augmented with additional electrodes. Medium/large size structures will automatically have a ring electrode greater in length than 5 m.

The ring electrode should preferably be buried at a minimum depth of 0.5 m and about 1 m away from the external walls of the structure.

Where bare solid rock conditions are encountered, the Type B earthing arrangement should be used.

The Type B ring earth electrode is highly suitable for:

- Conducting the lightning current safely to earth
- Providing a means of equipotential bonding between the down conductors at ground level
- Controlling the potential in the vicinity of conductive building wall
- Structures housing extensive electronic systems or with a high risk of fire

BS EN 62305 update

Note, BS EN 62305-3:2011 now clarifies that a Type B earthing arrangement should be fully interconnected throughout its entire length, even though 20% may be housed in the basement of a structure.

Foundation earth electrodes

This is essentially a Type B earthing arrangement. It comprises conductors that are installed in the concrete foundation of the structure. If any additional lengths of electrodes are required they need to meet the same criteria as those for Type B arrangement. Foundation earth electrodes can be used to augment the steel reinforcing foundation mesh. Earth electrodes in soil should be copper or stainless steel when they are connected to reinforcing steel embedded in concrete, to minimize any potential electrochemical corrosion.

Earthing - General

A good earth connection should possess the following characteristics:

- Low electrical resistance between the electrode and the earth. The lower the earth electrode resistance the more likely the lightning current will choose to flow down that path in preference to any other, allowing the current to be conducted safely to and dissipated in the earth.
- Good corrosion resistance. The choice of material for the earth electrode and its connections is of vital importance. It will be buried in soil for many years so has to be totally dependable.

Soil Conditions

Achieving a good earth will depend on local soil conditions. A low soil resistivity is the main aim and factors that affect this are:

- Moisture content of the soil
- Chemical composition of the soil, eg salt content
- Temperature of the soil

The following tables illustrate the effect these factors have on the soil resistivity.

Moisture content % by weight	Resistivity (Ωm)	
	Top soil	Sandy loam
0	10 x 10^6	10 x 10^6
2.5	2,500	1,500
5	1,650	430
10	530	185
15	310	105
20	120	63
30	64	42

Table 4.10: Effect of moisture on resistivity

Added salt (% by weight of moisture)	Resistivity (Ωm)
0	107
0.1	18
1	4.6
5	1.9
10	1.3
20	1.0

Table 4.11: Effect of salt on resistivity (based on sandy loam, 15.2% moisture)

Although Table 4.11 quotes figures for salt laden soil, it is now deemed bad practice to use salt as a chemical means of reducing soil resistivity, because of its very corrosive nature. Salt along with other chemicals, has the disadvantage of leaching out of the surrounding soil after a period of time, thus returning the soil to its original resistivity.

Temperature		Resistivity (Ωm)
°C	°F	
20	68	72
10	50	99
0	32 (water)	138
0	32 (ice)	300
-5	23	790
-15	14	3,300

Table 4.12: Effect of temperature on resistivity (based on sandy loam, 15.2% moisture)

It should be noted that, if the soil temperature decreases from +20 °C to -5 °C, the resistivity increases more than ten times.

Resistance to earth

Once the soil resistivity has been determined and an appropriate type earth electrode system chosen, its resistance to earth can be predicted by using the typical formulae listed below:

For horizontal strip electrode (circular or rectangular section)

$$R = \frac{\rho}{2\pi L}\left[\log_e\left(\frac{2L^2}{wh}\right) + Q\right] \qquad (4.4)$$

or for vertical rods

$$R = \frac{\rho}{2\pi L}\left[\log_e\left(\frac{8L}{d}\right) - 1\right] \qquad (4.5)$$

Where:

R = Resistance in ohms

ρ = Soil resistivity in ohm metres (Ωm)

L = Length of electrode in metres

w = Width of strip or diameter of circular electrode in metres

d = Diameter of rod electrode in metres

h = Depth of electrode in metres

Q = Coefficients for different arrangements
for rectangular section, Q = -1
for circular section, Q = -1.3

Earth electrode testing

BS 6651 was quite clear in its methodology statement relating to the testing of the lightning protection earthing system surrounding a building.

Unfortunately, in BS EN 62305-3 clause E.7.2.4, we believe this to be somewhat vague in its intent.

Our interpretation of this clause when applied to Type A arrangement is that with the test link removed and without any bonding to other services etc, the earth resistance of each individual earth electrode should be measured.

With the test links replaced the resistance to earth of the complete lightning protection is measured at any point on the system. The reading from this test should not exceed 10 ohms. This is still without any bonding to other services.

If the overall earth reading is greater than 10 ohms then the length of the earth rod electrode should be increased by the addition of further sections to the extensible earth rod. (Typically, add another section of earth rod to increase its length from 2.4 m to 3.6 m).

Similar to BS 6651, there is a statement to the effect that if the building is located on rocky soil then the 10 ohm requirement is not applicable.

Internal LPS design considerations

The fundamental role of the internal LPS is to ensure the avoidance of dangerous sparking occuring within the structure to be protected. This could be due, following a lightning discharge, to lightning current flowing in the external LPS or indeed other conductive parts of the structure and attempting to flash or spark over to internal metallic installations.

Carrying out appropriate equipotential bonding measures or ensuring there is a sufficient electrical insulation distance between the metallic parts can avoid dangerous sparking between different metallic parts.

Lightning equipotential bonding

Equipotential bonding is simply the electrical interconnection of all appropriate metallic installations/parts, such that in the event of lightning currents flowing, no metallic part is at a different voltage potential with respect to another. If the metallic parts are essentially at the same potential then the risk of sparking or flashover is nullified.

This electrical interconnection can be achieved by natural/fortuitous bonding or by using specific bonding conductors that are sized according to Tables 8 and 9 of BS EN 62305-3.

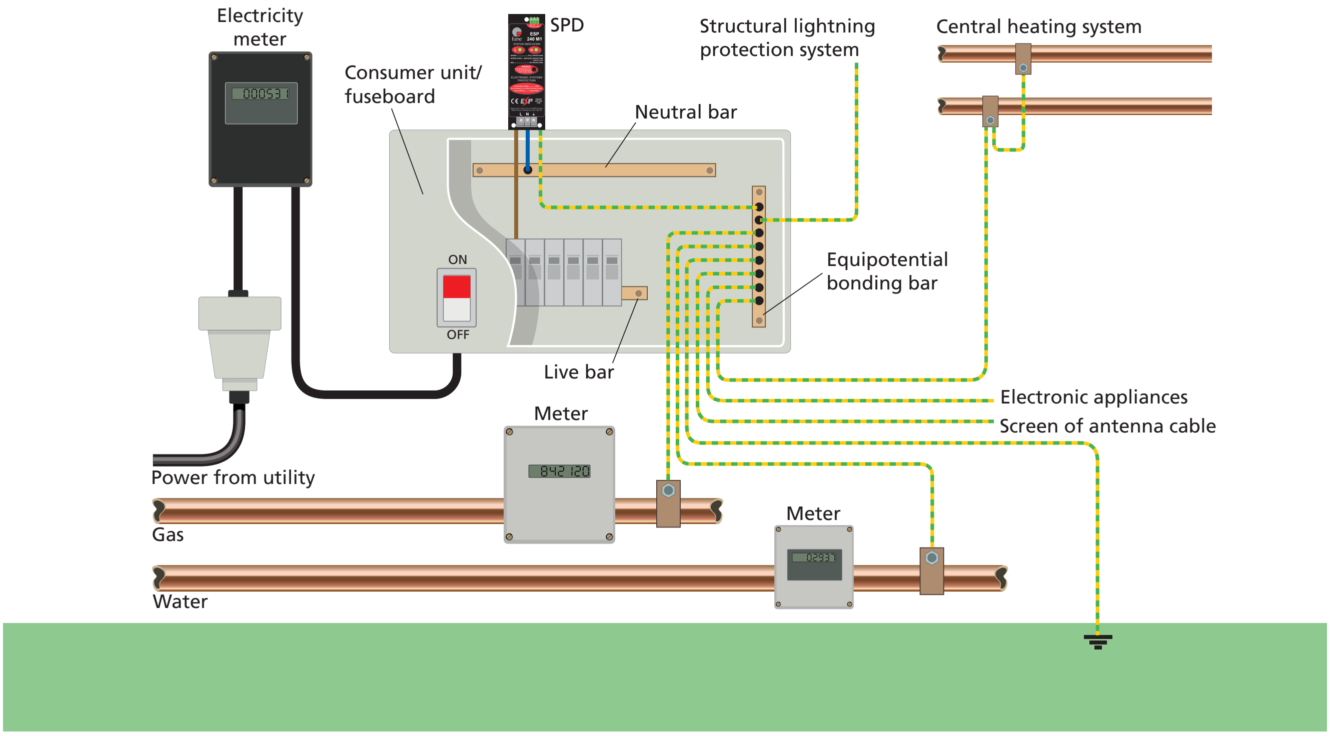

Figure 4.27: Example of main equipotential bonding

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Bonding can also be accomplished by the use of Surge Protective Devices (SPDs) or Isolating Spark Gaps (ISGs) where the direct connection with bonding conductors is not suitable. SPDs must be installed in such a way that they are readily accessible and visible for inspection purposes.

Prior to carrying out any lightning equipotential bonding that involves telecom networks and power utility cables, permission should be obtained from the operator of these systems to ensure there are no conflicting requirements.

For structures taller than 30 m, the standard recommends that equipotential bonding is carried out at basement/ground level and then every 20 m thereafter. A sufficient electrical insulation or 'separation' distance should always be maintained between the appropriate metallic installations/parts.

Wherever protection of internal systems against overvoltages caused by a lightning discharge requires SPDs, these shall conform to BS EN 62305-4. This topic is covered in greater detail in Section 5 of this guide.

Figure 4.27 (based on BS EN 62305-3 fig E.45) shows a typical example of an equipotential bonding arrangement. The gas, water and central heating system along with the external LPS are all bonded directly to the equipotential bonding bar located inside but close to an outer wall near ground level. The power cable is bonded via a suitable SPD, downstream from the electric meter, to the equipotential bonding bar. This bonding bar should be located close to the main distribution board (MDB) and also closely connected to the earth termination system with short length conductors. In larger or extended structures several bonding bars may be required but they should all be interconnected with each other.

The screen of any antenna cable along with any shielded power supply to electronic appliances being routed into the structure should also be bonded at the equipotential bar. Further guidance relating to equipotential bonding, meshed interconnection earthing systems and SPD selection is given in BS EN 62305-4 and the relevant section of this guide.

Lightning equipotential bonding for external LPS

In the case of equipotential bonding of an external LPS the installation should be carried out in the basement or at ground level of the structure. The bonding conductor should have a direct connection to an earth bonding bar which in turn should be connected to the earth termination system.

! BS EN 62305 update

BS EN 62305-3:2011 makes clear that equipotential bonding of an external LPS should be connected to and integrated with all other equipotential bonding in the structure.

If gas or water pipes entering the structure have insulated inserts incorporated into them, then these insulated sections should be bridged by suitably designed SPDs. Agreement with the relevant utility should be sought prior to installation.

Lightning equipotential bonding for external conductive parts should be carried out as near to the point of entry into the structure as possible. If direct bonding is not acceptable then suitably designed ISGs should be used.

When and if the risk assessment calculation indicates that a LPS is not required, but that equipotential bonding SPDs are, then the earth termination system of the low voltage electrical installation can be utilized.

Lightning equipotential bonding for internal systems

If the conductors within the structure have an outer screening or are installed within metal conduits then it may be sufficient to only bond these screens and conduits.

However, this may not avoid failure of equipment due to overvoltages. In this case coordinated SPDs designed and installed in accordance with BS EN 62305-4 should be used.

If these internal conductors are neither screened or located in metal conduits, they should be bonded using suitably designed SPDs.

Equipotential bonding of external service lines

Ideally, all metallic service lines along with the power, data and telecom supplies should enter the structure near ground level at one common location. Equipotential bonding should be carried out as close as possible to the entry point into the structure.

If the cables (power, telecom etc) entering the structure are of a shielded construction, then these shields should be connected directly to the equipotential bonding bar. The other 'live' cores should be bonded via suitable SPDs.

If the metallic and electrical service lines enter the structure at different locations and thus several bonding bars are required, these bonding bars should be connected directly to the earth termination system, which preferably should be a ring (Type B) earth electrode arrangement.

If a Type A earth electrode arrangement is used then the bonding bars should be connected to an individual earth electrode (rod) and additionally interconnected by an internal ring conductor.

If the service lines enter the structure above ground level, the bonding bars should be connected to a horizontal ring conductor either inside or outside the outer wall and in turn be bonded to the external down conductors and reinforcing bars of the structure.

Where structures are typically computer centres or communication buildings where a low induced electromagnetic field is essential, then the ring conductors should be bonded to the reinforcing bars approximately every 5 metres.

Protection measures for roof mounted equipment containing electrical equipment

This is an issue that has already caused some debate. If he/she were to apply the guidance from BS 6651 the designer/installer would bond the metallic, roof mounted casing into the mesh air termination system and accept that if the metallic casing suffered a direct lightning strike, then the casing, if not sufficiently thick, could be punctured.

What it did not address to any great degree was the solution to the possibility of partial lightning currents or induced overvoltages entering into the structure, via any metallic service lines that were connected to the roof mounted equipment.

BS EN 62305-3 significantly elaborates this topic. Our interpretation of the lightning protection requirements can be summarized by the flow chart shown in Figure 4.28.

There are several scenarios that can occur:

a) If the roof mounted equipment is not protected by the air termination system but can withstand a direct lightning strike without being punctured, then the casing of the equipment should be bonded directly to the LPS. If the equipment has metallic service lines entering the structure (gas, water etc) that can be bonded directly, then these should be bonded to the nearest equipotential bonding bar. If the service line cannot be bonded directly (power, telecom, cables) then the 'live' cores should be bonded to the nearest equipotential bonding bar, via suitable lightning current SPDs (mains Type 1 SPD, signal/telecom Category D tested SPD, both tested with a 10/350 µs waveform).

b) If the roof mounted equipment cannot withstand a direct lightning strike then a separation (ie isolation) distance needs to be calculated (explained in more detail, later in this section). If this separation distance can be achieved, (ie there is sufficient space on the roof) then an air rod or suspended conductor should be installed (see Figure 4.19). This should offer sufficient protection via the protective angle or rolling sphere method and is so spaced from the equipment, such that it complies with the separation distance. This air rod/suspended conductor should form part of the air termination system. If the equipment has metallic service lines entering the structure (gas, water etc) that can be bonded directly, then these should be bonded to the nearest equipotential bonding bar. If the other electrical service lines do not have an effective outer core screen, then consideration should be given to bonding to the nearest equipotential bonding bar, via overvoltage SPDs (mains Type 2 SPD, signal/telecom Category C tested SPD, both tested with an 8/20 µs waveform).

   If the electrical service lines are effectively screened but are supplying electronic equipment, then again due consideration should be given to bonding, via overvoltage SPDs.

   If the electrical service lines are effectively screened but are not supplying electronic equipment, then typically SPDs would not be required.

c) If the roof mounted equipment cannot withstand a direct lightning strike, then again a separation distance needs to be calculated. If this separation distance cannot practically be achieved, (ie there is insufficient space on the roof) then an air rod or suspended conductor should be installed. This still needs to meet the protective angle or rolling sphere criteria but this time, there should be a direct bond to the casing of the equipment. Again, the air rod/suspended conductor should be connected into the air termination system.

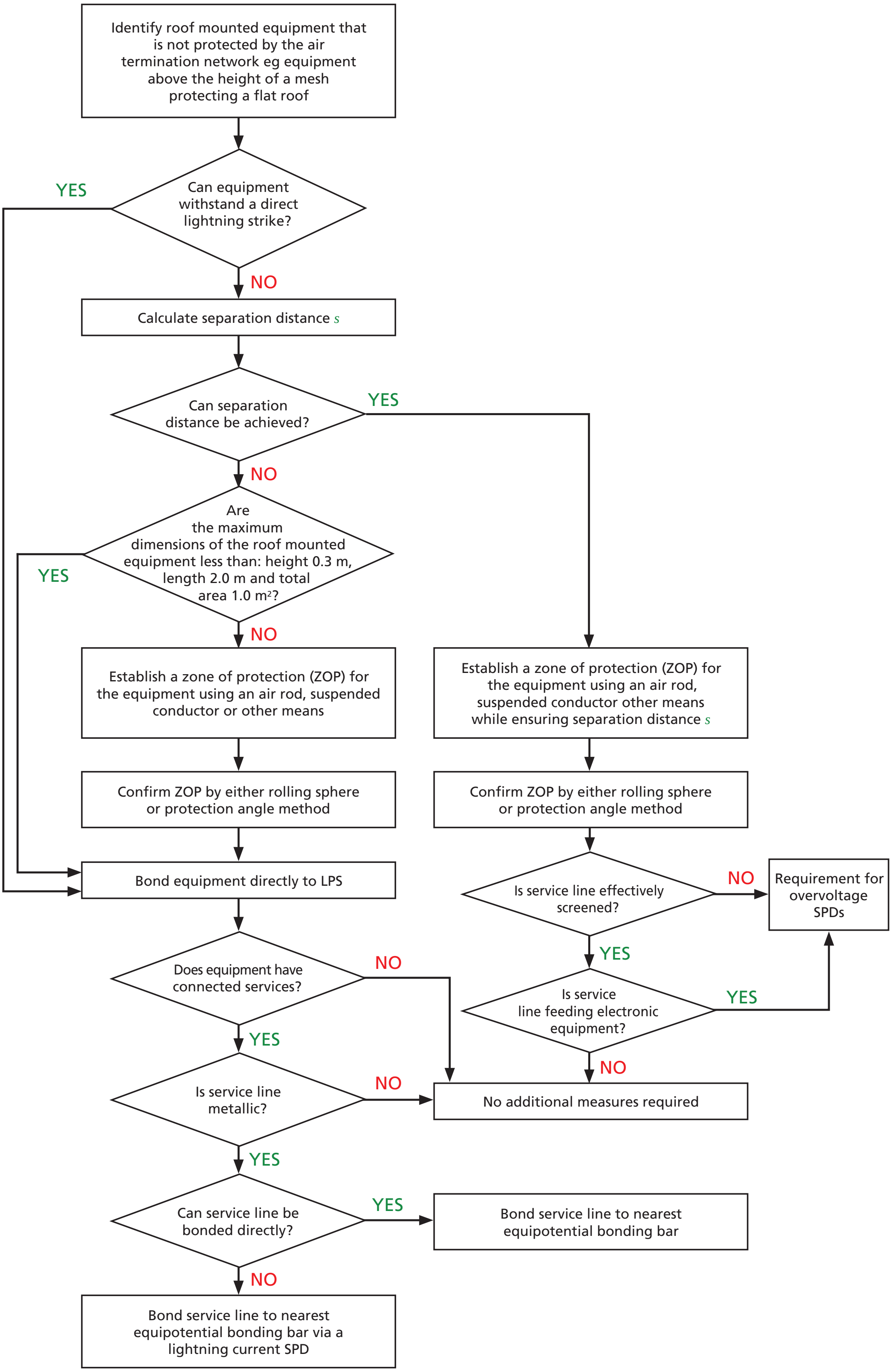


Figure 4.28: Protecting roof mounted equipment

If the equipment has metallic service lines entering the structure (gas, water etc) that can be bonded directly, then these should be bonded to the nearest equipotential bonding bar. If the service line cannot be bonded directly, (power, telecom, cables) then the 'live' cores should be bonded to the nearest equipotential bonding bar, via suitable lightning current SPDs.

The above explanation/scenarios are somewhat generic in nature and clearly the ultimate protection measures will be biased to each individual case.

We believe the general principle of offering air termination protection, wherever and whenever practical, alongside effective equipotential bonding and the correct choice of SPDs where applicable, are the important aspects to be considered when deciding on the appropriate lightning protection measures.

Separation (isolation) distance of the external LPS

A separation distance (ie the electrical insulation) between the external LPS and the structural metal parts is essentially required. This will minimize any chance of partial lightning current being introduced internally in the structure. This can be achieved by placing lightning conductors sufficiently far away from any conductive parts that have routes leading into the structure. So, if the lightning discharge strikes the lightning conductor, it cannot 'bridge the gap' and flash over to the adjacent metalwork.

BS EN 62305 update

BS EN 62305-3 now includes a simplified and detailed approach to calculating separation distance.

The simplified approach adopts the calculation proposed in the 2006 Edition (Equation 4.6a).

The detailed approach applies for LPS with meshed air termination, or interconnected ring conductors, since the conductors will have different values of current flowing down their lengths. Calculation follows Equation 4.6b. This detailed approach is suited to very large or complex structures.

For simplified calculation of separation distance:

$$s = \frac{k_i}{k_m} \times k_c \times l \qquad (4.6a)$$

For detailed calculation of separation distance:

$$s = \frac{k_i}{k_m} \times \left(k_{c1} \times l_1 + k_{c2} \times l_2 + ... + k_{cn} \times l_n\right) \qquad (4.6b)$$

Where:

- k_i Relates to the appropriate Class of LPS (see Table 4.13)
- k_m Is a partitioning coefficient relating to the separation medium (see Table 4.14)
- k_c Is a partitioning coefficient of the lightning current flowing in the down conductors (see Table 4.15)
- l Is the length in metres along the air termination or down conductor, from the point where the separation distance is to be considered, to the nearest equipotential bonding point

Class of LPS	k_i
I	0.08
II	0.06
III and IV	0.04

Table 4.13: Values of coefficient k_i (BS EN 62305-3 Table 10)

Material	k_m
Air	1
Concrete, bricks	0.5

When there are several insulating materials in series, it is good practice to use the lower value for k_m.
NOTE 2 In using other insulating materials, construction guidance and the value of k_m should be provided by the manufacturer.

Table 4.14: Values of coefficient k_m (BS EN 62305-3 Table 11)

Number of down conductors n	k_c
1 (only in the case of an isolated LPS)	1
2	0.66
3 and more	0.44

NOTE Values of Table 12 apply for all type B earthing arrangements and for type A earthing arrangements, provided that the earth resistance of neighbouring earth electrodes do not differ by more than a factor of 2. If the earth resistances of single earth electrodes differ by more than a factor of 2, k_c = 1 is to be assumed.

Table 4.15: Values of coefficient k_c (BS EN 62305-3 Table 12)

For example:

With reference to Figure 4.19, the required separation distance from the air rod to the air conditioning unit could be determined as follows.

If we assume: Number of down conductors = 4

Class of LPS = LPL II

Earthing arrangement = Type A

Length of air termination/down conductor to nearest equipotential bonding bar = 25 m

$$s = \frac{k_i}{k_m} \times k_c \times l \qquad (4.7)$$

Where:

k_i = 0.06 for LPS Class II (see Table 4.13)

k_m = 1 for air (see Table 4.14)

k_c = 0.44 (see Table 4.15)

l = 25 m

Therefore:

$$s = \frac{0.06}{1} \times 0.44 \times 25$$

$$s = 0.66 \text{ m}$$

Thus the air rod would need to be a minimum of 0.66 m away from the air conditioning unit to ensure that flashover did not occur in the event of a lightning discharge striking the air rod.

If the structure has a metallic framework, such as steel reinforced concrete, or structural steel stanchions and is electrically continuous, then the requirement for a separation distance is no longer valid. This is because all the steelwork is effectively bonded and as such an electrical insulation or separation distance cannot practicably be achieved.

Maintenance and inspection of the LPS

BS 6651 recommended the inspection and testing of the LPS annually.

BS EN 62305-3 categorizes visual inspection, complete inspection and critical systems complete inspection dependent on the appropriate LPL. See Table 4.16.

Protection level	Visual inspection (years)	Complete inspection (years)	Critical situations complete inspection (years)
I and II	1	2	1
III and IV	2	4	1

Lightning protection systems utilized in applications involving structures with a risk of explosion should be visually inspected every 6 months. Electrical testing of the installation should be performed once a year.
An acceptable exception to the yearly test schedule would be to perform the tests on a 14 to 15 month cycle where it is considered beneficial to conduct earth resistance testing over different times of the year to get an indication of seasonal variations.
Critical situations could include structures containing sensitive internal systems, office blocks, commercial buildings or places where a high number of people may be present.

Table 4.16: Maximum period between inspections of an LPS (BS EN 62305-3 Table E.2)

BS EN 62305 update

BS EN 62305-3:2011 Table E.2 (Table 4.17 above) now refers to 'critical situations' rather than 'critical systems'. This establishes clear inspection requirements where sensitive internal systems are present (such as in office blocks or commercial enterprises), or where there might be considered a higher risk due to a higher number of people being present.

All LPS systems should be inspected:

- During the installation of the LPS, paying particular attention to those components which will ultimately become concealed within the structure and unlikely to be accessible for further inspection
- After the LPS installation has been completed
- On a regular basis as per the guidance given in Table 4.16

Table 4.16 defines differing periods between visual and complete inspections where no specific requirements are identified by the authority having jurisdiction. In the case of the UK this would be covered by the Electricity at Work Regulations 1989, and as such current practice would be to inspect annually.

In addition the standard contains the following explicit statement that we believe applies to the UK:

"The LPS should be visually inspected at least annually".

Where adverse weather conditions occur, it may be prudent to inspect more regularly. Where an LPS forms part of a client's planned maintenance programme, or is a requirement of the builder's insurers, then the LPS may be required to be fully tested annually.

Additionally, the LPS should be inspected whenever any significant alterations or repairs have been carried out to the structure, or when it is known that the structure has been subjected to a lightning strike.

LPS exposed to mechanical stresses created by high winds and other such extreme environmental conditions should have a complete inspection annually.

Earthing systems should be reviewed and improved if the measured resistance between inspection testing shows marked increases in resistance. Additionally, all testing of the earthing system requirements should be fulfilled and all details logged in an inspection report.

The inspection should include the checking of all relevant technical documentation and a comprehensive visual inspection of all parts of the LPS along with the SPM system. Particular attention should be paid to evidence of corrosion or conditions likely to lead to corrosion problems.

The LPS should be maintained regularly, and the maintenance programme should ensure a continuous update of the LPS to the current issue of BS EN 62305.

If repairs to the LPS are found to be necessary these should be carried out without delay and not left until the next maintenance cycle.

Structures with a risk of explosion

Annex D of BS EN 62305-3 gives additional information with regard to LPS when applied to structures with a risk of explosion, including specific applications.

BS EN 62305 update

Whilst BS EN 62305-3:2006 required a minimum Class II structural LPS for a high risk structure, the 2011 version of the standard only stipulates that the LPS should be defined by risk assessment to BS EN 62305-2. Therefore any of the Classes of LPS (I-IV) may now prove appropriate.

A Type B earthing arrangement is preferred for all structures with a danger of explosion, with an earth resistance value as low as possible, but not greater than 10 ohms.

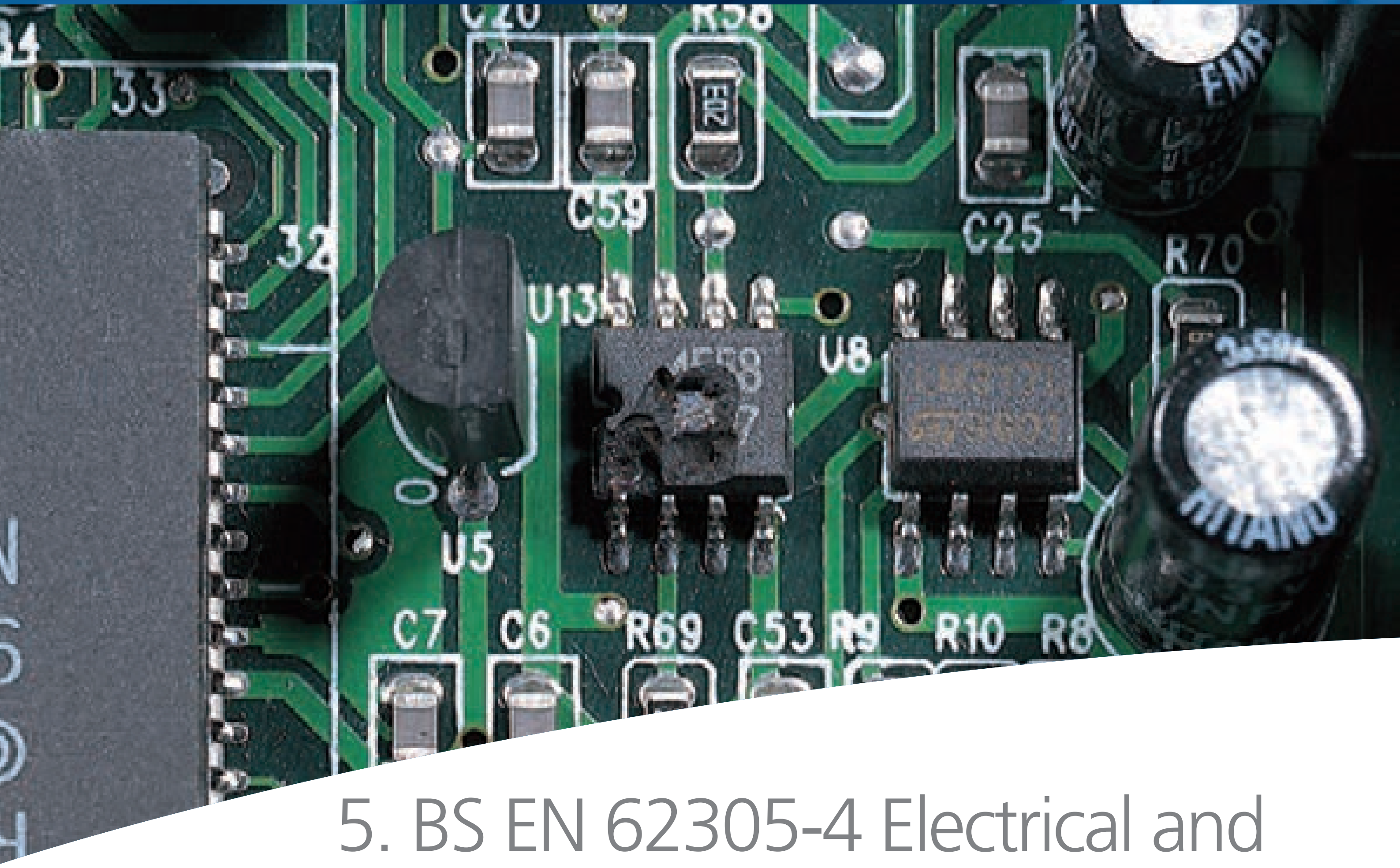
BS EN 62305 update

Note, within BS EN 62305-3:2011 Annex D, the DC resistance of any single object bonded to the LPS should not exceed 0.2 ohms.

For more specific and detailed information relating to structures containing hazardous and solid explosives material, it is strongly recommended that Annex D be read and expert opinion sought.

5. BS EN 62305-4 Electrical and electronic systems within structures

5.1	*Scope*	*69*
5.2	*Surge Protection Measures (SPM)*	*70*
5.3	*Protection using Surge Protective Devices (SPDs)*	*78*
5.4	*Summary*	*90*



5. BS EN 62305-4 Electrical and electronic systems within structures

Electronic systems now pervade almost every aspect of our lives, from the work environment, through filling the car with petrol and even shopping at the local supermarket. As a society, we are now heavily reliant on the continuous and efficient running of such systems.

The use of computers, electronic process controls and telecommunications has exploded during the last two decades. Not only are there more systems in existence, the physical size of the electronics involved have reduced considerably (smaller size means less energy required to damage circuits).

Although BS 6651 was released in 1985, it was not until 1992 that the subject of protection of electrical and electronic equipment against lightning was addressed.

Even in 1992 there was a 'stand still' on any national standard ie no additional technical information (unless it was on the grounds of safety) could be added without the consent and participation of CENELEC.

It was therefore decided by the technical committee that compiled BS 6651 (GEL/81) to add this very important topic as an informative annex and in this way, stayed within the CENELEC rules.

Consequently Annex C was introduced into BS 6651 only as a strong recommendation/guidance measure.

As a result protection was often fitted after equipment damage was suffered, often through obligation to insurance companies.

Annex C presented a separate risk assessment to that of structural protection in order to determine whether electronic equipment within the structure required protection.

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BS EN 62305-4 (Part 4) essentially embodies what Annex C in BS 6651 conveyed, but with a zonal approach referred to as Lightning Protection Zones (LPZ). It provides information for the design, installation, maintenance and testing of Surge Protection Measures (SPM) for electrical/electronic systems within a structure, to counter the effects of Lightning Electromagnetic Impulse (LEMP).

The term LEMP simply defines the overall electromagnetic effects of lightning that include conducted surges (both transient overvoltages and transient currents) as well as radiated electromagnetic field effects.

BS EN 62305-4 is an integral part of the complete standard. By integral we mean that following a risk assessment as detailed in BS EN 62305-2, the structure in question may need both a structural LPS and a fully coordinated set of transient overvoltage protectors (Surge Protective Devices or SPDs) to bring the risk below the tolerable level. This, in itself, is a significant deviation from that of BS 6651 and it is clear structural lightning protection can no longer be considered in isolation from transient overvoltage/surge protection.

To further stress the importance of BS EN 62305-4, damage type D3 Failure of internal systems due to LEMP is possible from all points of strike to the structure or service line - direct or indirect as shown in Table 2.1 (BS EN 62305-1 Table 2).

Protection of electronic systems from transient overvoltages can prevent:

- Lost or destroyed data
- Equipment damage
- Repair work for remote and unmanned stations
- Loss of production
- Health and safety hazards caused by plant instability, after loss of control
- Loss of life - protection of hospital equipment

Following introduction of BS EN 62305-4, industry recognition of the need to protect electronic systems against transient overvoltages has been steadily gaining ground, with both risk assessment principles and protection measures now also defined in additional standards, including the IET Wiring Regulations 17th Edition (BS 7671:2008+A1:2011).

For all countries where BS 7671 applies, the inclusion of transient overvoltage protection ensures that from 1st January 2012 all new electrical installations, as well as alterations and additions to existing installations, shall be risk assessed and, as appropriate, protected against this risk through application of suitable SPDs.

The requirements to meet BS 7671 are defined in Section 7 of this publication, starting on page 113.

5.1 Scope of BS EN 62305-4

BS EN 62305-4 gives guidance in order to be able to reduce the risk of permanent failures or damage to equipment due to LEMP. It does not directly cover protection against electromagnetic interference that may cause malfunction or disruption of electronic systems. Indeed, this also leads to downtime - the biggest cost to any industry.

As such, evaluating R_4 Risk of loss of economic value determines whether the economic benefits of providing lightning protection is cost effective against the physical loss of equipment, not the losses or downtime which are also due to the malfunction of equipment. In continuous processes even a small transient overvoltage can cause huge financial losses.

Similarly, this standard does not directly cover transients created by switching sources such as large inductive motors. Annex F of BS EN 62305-2 provides information on the subject of switching overvoltages.

Annex A of BS EN 62305-4 provides information for protection against electromagnetic interference, with further guidance being referenced to EMC standards such as the IEC 61000 series.

It is clearly recognized within BS EN 62305-4 that risk of failures or damage to equipment due to LEMP can be effectively countered through installation of Surge Protection Measures (SPM) within and around a structure.

A well designed SPM system can protect equipment and ensure its continual operation from all transient overvoltages, caused by both lightning and switching events.

BS EN 62305 update

Surge Protection Measures (SPM) is the updated reference within BS EN 62305 for measures previously referred to as a LEMP Protection Measures System (LPMS).

The acronym, SPM, is now used throughout this Guide to BS EN 62305. It is worth noting in the BS EN 62305 standard that the actual term used is LEMP Protection Measures, although the more generic and industry recognized term, 'surge', is the basis for the acronym and is therefore used in this publication.

5.2 Surge Protection Measures (SPM)

SPM are defined as the protection measures required to counter the effects of LEMP on internal systems.

There are several techniques, which can be used to minimize the lightning threat to electronic systems. Like all security measures, they should wherever possible be viewed as cumulative and not as a list of alternatives.

BS EN 62305-4 describes a number of measures to minimize the severity of transient overvoltages caused by lightning. These tend to be of greatest practical relevance for new installations.

Key and basic protection measures are:

- Earthing and bonding
- Electromagnetic shielding and line routeing
- Coordinated SPDs
- Use of isolating interfaces (eg fibre optic cables)

Further additional protection measures include:

- Extensions to the structural LPS
- Equipment location

These are explained and expanded upon in Extending structural lightning protection on page 88.

Selection of the most suitable SPM is made using the risk assessment in accordance with BS EN 62305-2 taking into account both technical and economic factors.

For example, it may not be practical or cost effective to implement electromagnetic shielding measures in an existing structure so the use of coordinated SPDs may be more suitable. Although best incorporated at the project design stage, SPDs can also be readily installed at existing installations.

SPM also have to operate and withstand the environment in which they are located considering factors such as temperature, humidity, vibration, voltage and current.

Annex B of BS EN 62305-4 provides practical information on SPM in existing structures.

Zoned protection concept

Protection against LEMP is based on a concept of the Lightning Protection Zone (LPZ) that divides the structure in question into a number of zones according to the level of threat posed by the LEMP.

The general idea is to identify or create zones within the structure where there is less exposure to some or all of the effects of lightning and to coordinate these with the immunity characteristics of the electrical or electronic equipment installed within the zone. Successive zones are characterized by significant reductions in LEMP severity as a result of bonding, shielding or use of SPDs.

Figure 5.1 illustrates the basic LPZ concept defined by protection measures against LEMP as detailed in BS EN 62305-4. Here equipment is protected against lightning, both direct and indirect strikes to the structure and service lines, using an SPM system.

This comprises spatial shields, bonding of incoming metallic service lines, such as water and gas, and the use of coordinated SPDs.

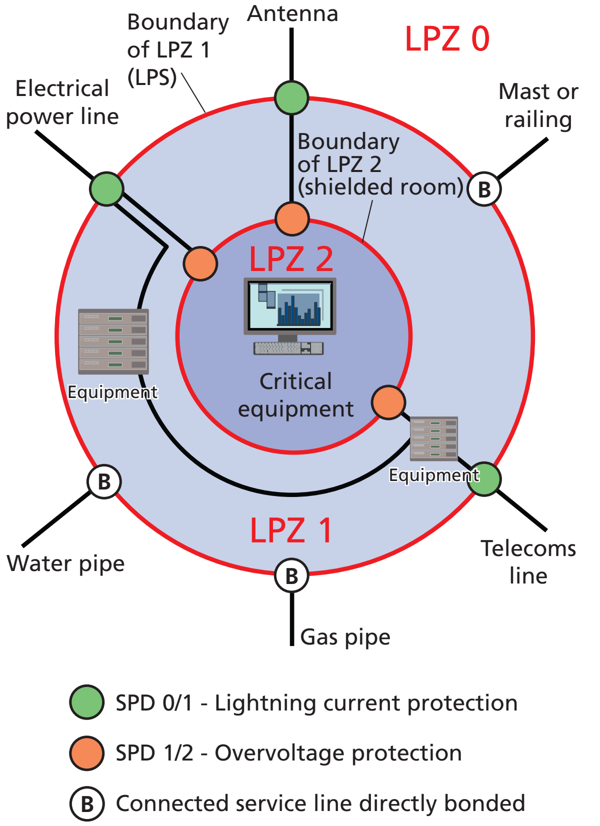

Figure 5.1: Basic LPZ concept - BS EN 62305-4

A spatial shield is the terminology used to describe an effective screen against the penetration of LEMP. An external LPS or reinforcing bars within the structure or room would constitute spatial shields.

The LPZs can be split into two categories - 2 external zones (LPZ 0_A, LPZ 0_B) and usually 2 internal zones (LPZ 1, 2) although further zones can be introduced for a further reduction of the electromagnetic field and lightning current if required.

The various LPZs are explained below and by referring to Figure 2.4 on page 21.

External zones:

- LPZ 0_A is the area subject to direct lightning strokes and therefore may have to carry up to the full lightning current. This is typically the roof area of a structure. The full electromagnetic field occurs here.
- LPZ 0_B is the area not subject to direct lightning strokes and is typically the sidewalls of a structure. However the full electromagnetic field still occurs here and conducted partial or induced lightning currents and switching surges can occur here.

Internal zones:

- LPZ 1 is the internal area that is subject to partial lightning currents. The conducted lightning currents and/or switching surges are reduced compared with the external zones LPZ 0_A, LPZ 0_B as is the electromagnetic field if suitable shielding measures are employed. This is typically the area where service lines enter the structure or where the main power switchboard is located.
- LPZ 2 is an internal area that is further located inside the structure where the remnants of lightning impulse currents and/or switching surges are reduced compared with LPZ 1. Similarly the electromagnetic field is further reduced if suitable shielding measures are employed. This is typically a screened room or, for mains power, at the sub-distribution board area. Note, further additional internal zones (LPZ 3 … etc) may be required for protection of highly sensitive equipment.

This concept of zoning was also recognized by Annex C of BS 6651 and was defined by three distinct location categories with differing surge exposure levels (Category A, B and C).

Earthing and bonding

The basic rules of earthing are detailed in BS EN 62305-3.

A complete earthing system, as shown in Figure 5.2, consists of:

- The earth termination system dispersing the lightning current into the ground (soil)
- The bonding network, which minimizes potential differences and reduces the electromagnetic field

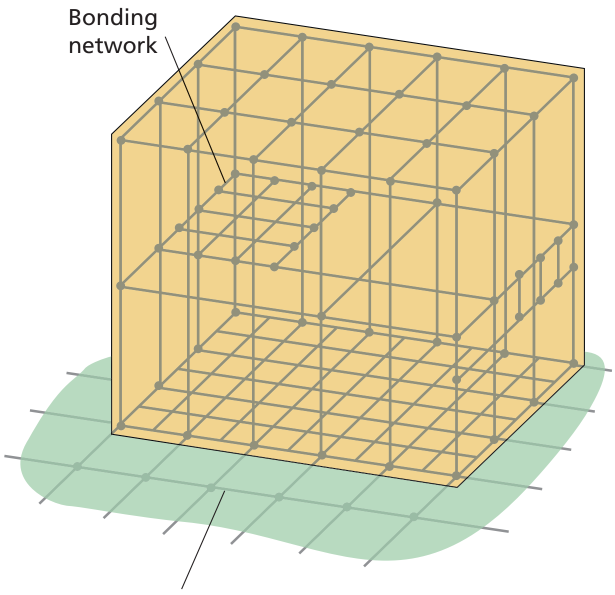

Figure 5.2: Example of a three-dimensional earthing system consisting of the bonding network interconnected with the earth termination system (BS EN 62305-4 Figure 5)

Improved earthing will achieve an area of equal potential, ensuring that electronic equipment is not exposed to differing earth potentials and hence resistive transients.

A "Type B" earthing arrangement is preferred particularly for protecting structures that house electronic equipment.

This comprises either a fully connected ring earth electrode external to the structure in contact with the soil for at least 80% of its total length or a foundation earth electrode. For a new build project that is going to house electronic systems, a Type B arrangement is strongly advised.

A low impedance equipotential bonding network will prevent dangerous potential differences between all equipment within internal LPZs. An equipotential bonding network also reduces the harmful electromagnetic fields associated with lightning.

All incoming service lines (metallic water and gas pipes, power and data cables) should be bonded to a single earth reference point. This equipotential bonding bar may be the power earth, a metal plate, or an internal ring conductor/partial ring conductor inside the outer walls of the structure.

Whatever form it takes, this equipotential bonding bar should be connected to the electrodes of the earthing system together with conductive parts of the structure forming a complete integrated meshed bonding network.

Metallic service lines such as gas and water should be directly bonded to the earth reference point at the boundary of the external LPZ 0_A and internal LPZ 1 - ie as close as possible to the point of entry of these service lines.

The armouring of metallic electrical services such as power and telecommunication lines can be directly bonded to the main earthing bar at the service entrance. However the live conductors within these service cables need to be equipotentially bonded at the service entrance through the use of SPDs.

The purpose of service entrance SPDs is to protect against dangerous sparking to minimize the risk of loss of life R_1.

Dangerous sparking can result in fire hazards as it presents a risk of flashover, where the voltage present exceeds the withstand rating of the cable insulation or equipment subjected to this overvoltage.

Throughout the BS EN 62305 standard series, such protectors are clearly termed equipotential bonding SPDs as their purpose is to prevent dangerous sparking only, in order to preserve life. They are not employed to protect electrical and electronic systems, which require the use of coordinated SPDs in accordance with the standard. These shall be discussed further in this guide.

BS EN 62305-4 clearly states that an LPS according to BS EN 62305-3 “which only employs equipotential bonding SPDs provides no effective protection against failure of sensitive electrical or electronic systems”.

It can therefore be concluded that as lightning equipotential bonding serves the purpose of protecting against dangerous sparking, the service entrance equipotential bonding SPD resides within this primary function and as such is an integral requirement of a structural LPS, in accordance with BS EN 62305-3.

Although the equipotental bonding SPD is the first part of a coordinated SPD set, it is appropriate to discuss their selection and application here due to their function.

Following a risk evaluation in accordance with BS EN 62305-2, the choice of suitable equipotential bonding SPDs is determined by a number of factors, which can be presented as follows:

- Is the structure in question protected with a structural LPS?
- What Class of LPS is fitted in accordance with the selected Lightning Protection Level (LPL)?
- What is the type of the earthing system installation - TN or TT?
- How many metallic service lines are there entering or leaving the structure?
- If an LPS is not required, are the service lines (such as power or telecom) entering the structure via an overhead line or an underground cable?

Partial lightning current (as defined by a 10/350 µs waveform) can only enter a system through either a structure’s LPS or an overhead line as both are subject to a direct strike. The long duration 10/350 µs waveform presents far greater energy (and therefore threat) to a system compared to an 8/20 µs waveform with an equivalent peak current.

Equipotential bonding SPDs that are designed to handle such 10/350 µs currents are also known as Lightning Current SPDs. Their primary function is to divert the partial lightning current safely to earth whilst sufficiently limiting the associated transient overvoltage to a safe level to prevent dangerous sparking through flashover.

There are industry standards, namely the BS EN 61643 series, which specifically cover the testing and application of SPDs.

Lightning current or equipotential bonding SPDs are defined as Type 1 SPDs for mains power within these standards. They are tested with a 10/350 µs impulse current, which is known as the Class I test. Signal/telecom lightning current SPDs are also tested with the 10/350 µs impulse current known as the Category D test.

Structural LPS required

When the risk calculation is evaluated in accordance with BS EN 62305-2 certain scenarios may arise which require further explanation.

If the risk evaluation demands that a structural LPS is required (ie R_D is greater than R_T) then equipotential bonding or lightning current SPDs are always required for any metallic electrical service line entering the structure (typically power and telecom lines where mains Type 1 SPDs and signal/data Category D tested SPDs are used respectively).

Table 5.1 shows the relationship between the LPL and the required maximum current handling of the equipotential bonding power line SPD. It is shown for the most common earthing arrangements TN-S or TN-C-S (where the neutral conductor is separated from earth).

LPL	Maximum current kA (10/350 µs)	Class of LPS	Maximum Type 1 SPD current kA per mode* (10/350 µs)
I	200	I	25
II	150	II	18.75
III/IV	100	III/IV	12.5

* Based on 3 phase TN-S or TN-C-S system: 4 conductors (L1, L2, L3, N) plus Earth - 4 modes to Earth

Table 5.1: Current handling requirement of SPDs

For the current capability design of lightning current SPDs, it is assumed that 50% of the maximum strike current flows into the external LPS/earthing system and 50% through the service lines within the structure as shown in Figure 5.3.

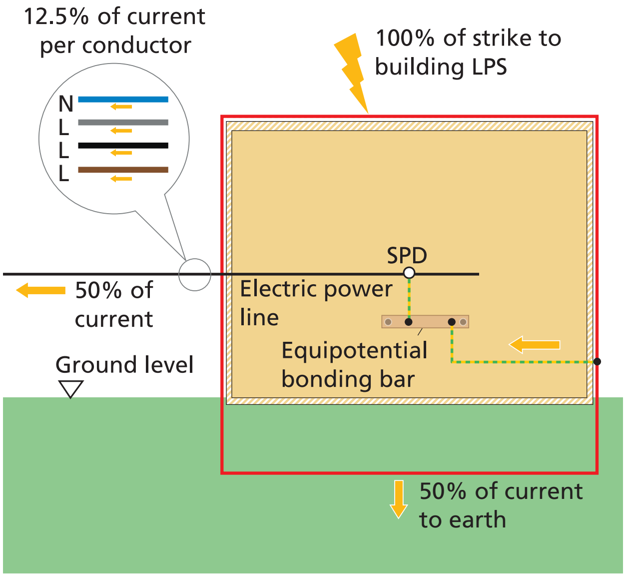

Figure 5.3: Simplified current division concept

Taking the worst case scenario, a strike of 200 kA and an incoming service line consisting solely of a three-phase power supply (4 lines, 3 phase conductors and neutral), 50% or 100 kA of the total partial lightning current is discharged through the power line. This is assumed to share equally between the 4 conductors within the power line, thus each SPD between line and earth and neutral and earth would be subject to 25 kA (ie 100 kA/4).

Similarly, for LPL II and III/IV the maximum Type 1 SPD current capabilities would be 18.75 kA (10/350 µs) and 12.5 kA (10/350 µs) respectively. In practice, 18.75 kA (10/350 µs) Type 1 SPDs are uncommon so 25 kA (10/350 µs) Type 1 SPDs cover both LPL I and II.

This worst case current of 25 kA (10/350 µs) is significantly higher than the worst case current of 10 kA (8/20 µs) presented within Annex C of BS 6651 (Location Category C-High).

This significant increase in magnitude of the design current capability raises, we believe, one or two debatable issues.

Would this 25 kA (10/350 µs) value of lightning current realistically be seen at a service entrance? This scenario is very rare - as indeed are the number of damaged SPDs installed at the service entrance designed and tested with an 8/20 µs current waveform and applied in accordance with BS 6651. This includes many countries in regions such as the Far East who have adopted BS 6651 over the years and have significantly higher lightning activity than most other countries throughout the world.

In reality, most structures have more than just one service line connected as shown in Figure 5.4. This figure illustrates how the lightning current is further divided. Again 50% of the full lightning current is dispersed into the earth. The remaining 50% is distributed on the basic assumption that each of the service lines carries an equal proportion of this current. In this example there are 4 service lines so each carries approximately 12.5% of the overall lightning current.

For a three-phase (4 wire) system, only 3.125% of the lightning current will be seen at each conductor. So for a worst case 200 kA (10/350 µs) direct strike to the structure, 100 kA goes straight into the earthing system and only 3.125% of the overall current is seen at each conductor ie 6.25 kA (10/350 µs). This is significantly lower than the 25 kA (10/350 µs), which occurs when there is lightning current of 200 kA (10/350 µs) and one three-phase (4 wire) power supply. This is in itself is a very rare event with a probability of occurrence of around 1%.

BS 6651 covered the more likely scenario of lightning induced damage to systems being caused by the more frequent but lower level indirect strikes near the structure or service line.

The BS EN 62305 standard presents a “belt and braces” approach covering the absolute worst case scenario, if specific information about a structure’s installation is unknown.

For example, it may not be known whether the gas or water service line at an installation is metallic. They could be non-conductive (ie plastic) which would therefore mean the power supply would see a significantly higher percentage of lightning current.

Unless the construction of the specific service lines is known, it should be assumed they are non-conductive to give a more conservative solution.

For such high partial lightning currents to flow, the conductor size of the power or telecom line would have to be substantial, as indeed would ancillary devices such as in-line over-current fuses.

Whilst main incoming power lines are generally substantial enough to carry partial lightning currents, telecommunication lines have significantly smaller cross-sectional areas.

Taking this factor into account, the worst case surge that could be expected on a two-wire telephone or data line is 2.5 kA (10/350 µs) per line (Category D test to BS EN 61643-21) to earth or 5 kA (10/350 µs) per pair.

Annex E of BS EN 62305-1 discusses the expected surge currents due to lightning flashes on both low voltage mains systems and telecommunication lines.

Table 5.2 (Tables E2 & E3, Annex E of BS EN 62305-1) details preferred values of lightning currents dependant on the LPL level and the type of service line (power or telecommunication). These values are more realistic in practice taking account of factors such as the line impedance and conductor cross-sectional area (as discussed previously). The preferred values of lightning currents for lightning flashes near the service line are of similar magnitude to those defined in the previous BS 6651 standard. These values therefore represent the most common lightning scenario in practice.

For direct lightning flashes to connected service lines, partitioning of the lightning current in both directions of the service line and the breakdown of insulation have also been taken into account.

System	Source of damage(1)	Current waveform (µs)	LPL III-IV (kA)	LPL II (kA)	LPL I (kA)
Low voltage lines	S3	10/350	5	7.5	10
	S4	8/20	2.5	3.75	5
	S2	8/20	0.1	0.15	0.2
	S1	8/20	5	7.5	10
Telecoms lines	S3	10/350	1	1.5	2
	S4	8/20	0.035	0.085	0.160
	S2	8/20	0.1	0.15	0.2
	S1	8/20	5	7.5	10

(1) Source of damage, see page 14

Table 5.2: Expected surge currents due to lightning flashes (BS EN 62305-1 Tables E2 & E3)

Structural LPS not required

If the risk evaluation shows that a structural LPS is not required (ie R_D is less than R_T) but there is an indirect risk R_I (ie R_I is greater than R_T), any electrical service lines feeding the structure via an overhead line will require lightning current SPDs.

For mains Type 1 SPDs the surge current rating per mode of protection is 12.5 kA 10/350 µs and for signal/telecom SPDs the surge current rating per mode of protection is 2.5 kA 10/350 µs.

For underground electrical service lines connected to the structure, protection is achieved with overvoltage or mains Type 2 SPDs and signal/data Category C SPDs (both tested with an 8/20 µs waveform in accordance with BS EN 61643 standard series on SPDs).

Such underground electrical service lines are not subject to direct lightning currents and therefore do not transmit partial lightning currents into the structure.

Underground electrical service lines therefore do not have a requirement for lightning current SPDs where no structural LPS is present - overvoltage SPDs are sufficient to provide effective protection.

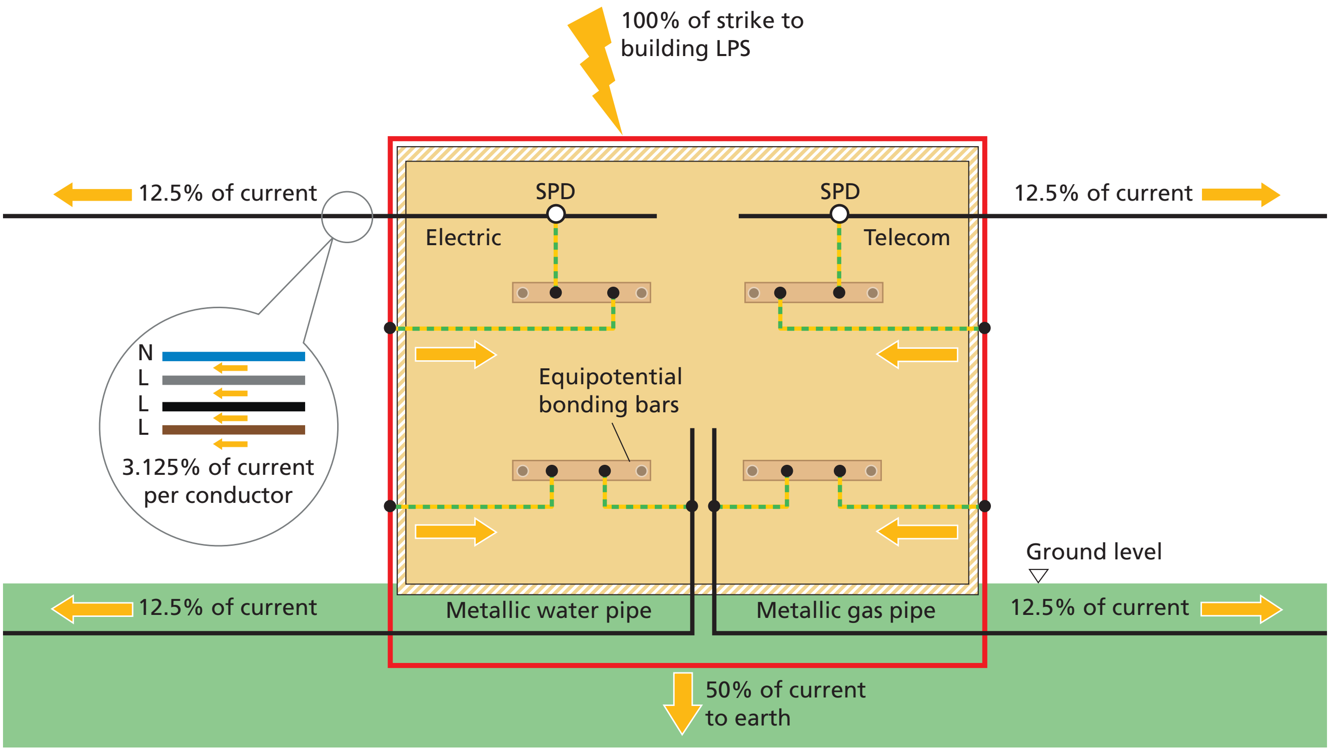

Figure 5.4: Current division concept for multiple service lines

SPDs - types, testing, location and application

Given that the live cores of metallic electrical service lines such as mains power, data and telecom cables cannot be bonded directly to earth wherever a line penetrates each LPZ, a suitable SPD is therefore needed.

The SPD's characteristics at the boundary of each given zone or installation location need to take account of the surge energy they are to be subject to as well as ensure the transient overvoltages are limited to safe levels for equipment within the respective zone.

Table 5.3 details the relationship between differing types of SPDs located at each LPZ boundary, their testing regimes and typical applications.

Enhanced performance SPDs - SPD*

Tables NB.3 and NB.7 of Annex NB, BS EN 62305-2 detail the use of improved performance SPDs to further lower the risk of damage. It should be clear that the lower the sparkover voltage, the lower the chance of flashover causing insulation breakdown, electric shock and possibly fire.

It therefore follows that SPDs that offer lower (and therefore better) voltage protection levels (U_P) further reduce the risks of injury to living beings, physical damage and failure of internal systems. *This subject is discussed in detail on page 79, Coordinated SPDs.*

SPD location/LPZ boundary

	LPZ 0/1	LPZ 1/2	LPZ 2/3
Typical SPD installation point	Service Entrance (eg Main distribution board or telecom NTP)	Sub-distribution board or telecom PBX frame	Terminal Equipment (eg socket outlet)
Mains Test Class/SPD Type[1]	I/1	II/2	III/3
Surge test waveform	10/350 current	8/20 current	Combination 8/20 current and 1.2/50 voltage
Typical peak test current (per mode)	25 kA[2]	40 kA	3 kA (with 6 kV)
Signal/Telecom Test Category[1]	D1[3]	C2[3]	C1
Surge test waveform	10/350 current	Combination 8/20 current and 1.2/50 voltage	Combination 8/20 current and 1.2/50 voltage
Typical peak test current (per mode)	2.5 kA	2 kA (with 4 kV)	0.5 kA (with 1 kV)

[1] Tests to BS EN 61643 series
[2] Peak current (per mode) for a 3 phase SPD to protect a TN-S mains system
[3] Test category B2 10/700 voltage waveform (also within ITU-T standards) up to 4 kV peak also permissible

Table 5.3: Test criteria and application of SPDs

Other considerations

Once an LPZ is defined, bonding is required for all metal parts and service lines penetrating the boundary of the LPZ. Bonding of service lines entering or leaving the structure (typically LPZ 1) needs to be in agreement and in accordance with the supply authorities.

All metal pipes, power and data cables should, where possible, enter or leave the structure at the same point, so that it or its armouring can be bonded, directly or via equipotential bonding SPDs, to the main earth terminal at this single point. This will minimize lightning currents within the structure.

If power or data cables pass between adjacent structures, the earthing systems should be interconnected, creating a single earth reference for all equipment. A large number of parallel connections, between the earthing systems of the two structures, are desirable - reducing the currents in each individual connection cable. This can be achieved with the use of a meshed earthing system.

Power and data cables between adjacent structures should also be enclosed in metal conduits, trunking, and ducts or similar. This should be bonded to both the meshed earthing system and also to the common cable entry point, at both ends.

To ensure a high integrity bond, the minimum cross-section for bonding components should comply with BS EN 62305-4. See Table 5.4.

Bonding component		Material	Cross-section (mm²)
Bonding bars (copper, copper coated or galvanized steel)		Cu, Fe	50
Connecting conductors from bonding bars to the earthing system or to other bonding bars		Cu Al Fe	16 25 50
Connecting conductors from internal metal installations to bonding bars		Cu Al Fe	6 10 16
Earthing conductors for SPD	Class I Class II Class III Other SPDs	Cu	16 6 1 1

Other material used instead of copper should have cross-section ensuring equivalent resistance

Table 5.4: Minimum cross-sections for bonding components (BS EN 62305-4 Table 1)

BS EN 62305 update

Note that as per Table 5.4, the cross-sectional areas of bonding components have been revised in BS EN 62305-4 to reflect commonly available sizes.

Electromagnetic shielding and line routeing

The ideal lightning protection for a structure and its connected service lines would be to enclose the structure within an earthed and perfectly conducting metallic shield (metallic box or Faraday Cage), and in addition provide adequate bonding of any connected service lines at the entrance point into the shield.

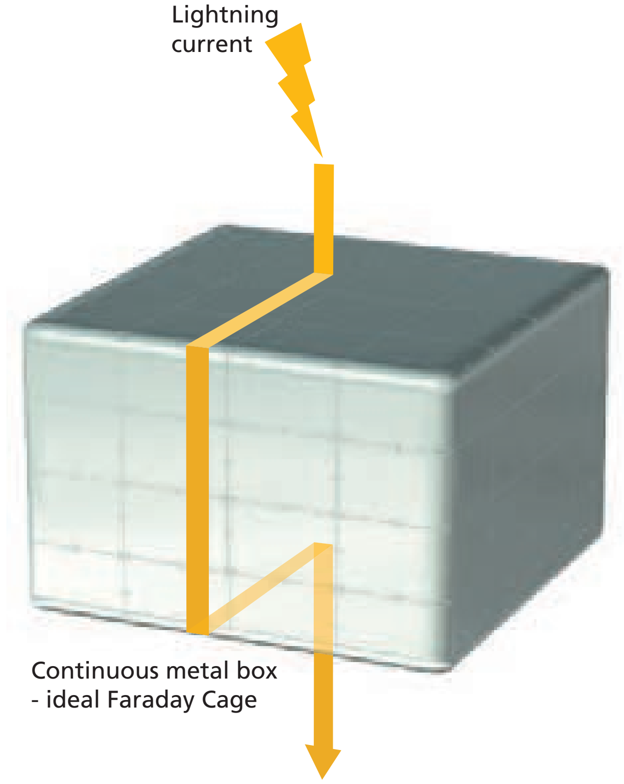

Figure 5.5: Ideal Faraday Cage

This, in essence, would prevent the penetration of the lightning current and the associated electromagnetic field into the structure. However, in practice it is not possible nor indeed cost effective to go to such measures.

Effective electromagnetic shielding can reduce the electromagnetic field and reduce the magnitude of induced internal surges. A metallic shield creates a barrier in the path of a propagating radiated electromagnetic wave, reflecting it and/or absorbing it.

Spatial shielding defines a protected zone that may cover:

- The complete structure
- A section of the structure
- A single room
- A piece of equipment by a suitable housing or enclosure

Spatial shields can take many forms and could be grid-like such as an external LPS or comprise the "natural components" of the structure itself such as steel reinforcement, as defined by BS EN 62305-3.

The spatial shield could also take the form of continuous metal - for example a metallic housing enclosing sensitive electronics. However grid-like spatial shields are advisable where it is more practical, cost effective and useful to protect a defined zone or volume of the structure rather than several individual pieces of equipment.

It therefore follows that spatial shielding should be planned at the early stages of a new build project as retro-fitting such measures to existing installations could result in significantly higher costs, practical installation implications with possible technical difficulties.

Grid-like spatial shields

Large volume shields of LPZs are created by the natural components of a structure such as the metal reinforcements in walls, ceilings and floors, the metal framework and possible metallic roof and facades. Cumulatively these components create a grid-like spatial shield as shown in Figure 5.6.

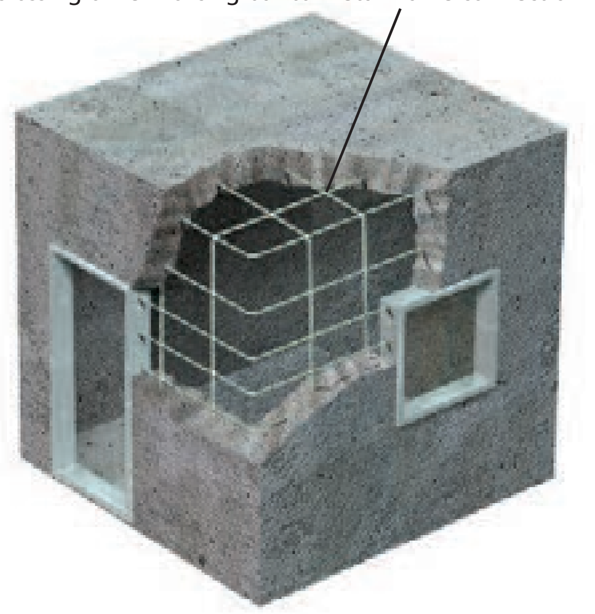

Figure 5.6: Large volume shield created by metal reinforcement within a structure (BS EN 62305-4 Figure A.3)

The spatial shielding of an LPZ, in accordance with BS EN 62305-4, only reduces the electromagnetic field inside an LPZ that is caused by lightning flashes to the structure or nearby ground.

In practice the performance of the spatial shield in reducing the induced electromagnetic field is greatly limited by the apertures in it. A more continuous shield will reduce the electromagnetic field threat. Effective shielding requires that the mesh dimensions be typically 5 m x 5 m or less.

Additionally, effective shielding can be accomplished with the fortuitous presence of the reinforcing bars within the walls/roof of the structure. Table 3.6 categorizes the various shielding arrangements when using K_{S1} as part of the risk evaluation.

Similarly K_{MS} *(see page 32, Probability of damage)* is a factor that is related to the screening effectiveness of the shields at the boundaries of the LPZs and is used to determine if a lightning flash near a structure will cause failure to internal systems.

Shielding in subsequent inner LPZs can be accomplished by either adopting further spatial shielding measures, for example a screened room, or through the use of metal cabinets or enclosure of the equipment.

Electronic systems should be located within a "safety volume" which respects a safe distance from the shield of the LPZ that carries a high electromagnetic field close to it. This is particularly important for the shield of LPZ 1, due to the partial lightning currents flowing through it. The equipment should not be susceptible to the field around it.

This subject is dealt with in detail within Annex A of BS EN 62305-4.

Cable routeing

Power, data, communication, signal and telephone cable systems may also be at risk from induced overvoltages within the structure.

These cable systems should not come into close proximity with lightning protection conductors, typically those located on or beneath the roof or on the side of structures (equipment location will be discussed later in this guide).

Additionally, cable systems should avoid being installed close to the shields of any LPZ within the structure.

Large area loops between mains power and data communication cable systems are, as a result of inductive coupling, effective at capturing lightning energy and should therefore be avoided. Figure 5.7 shows a large loop area created between power and data communication cabling.

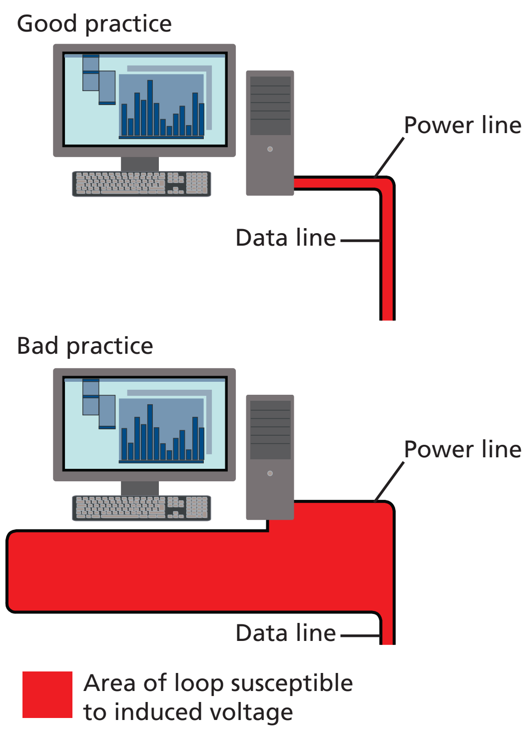

Figure 5.7: Loop areas

To minimize loop areas, mains power supply cables and data communication, signal, or telephone wiring should be run side by side, though segregated. The cables can be installed either in adjacent ducts or separated from each other by a metal partition inside the same duct.

The routeing or location of cable systems within effectively screened structures is less critical. However, adoption of the aforementioned precautions is good practice. For structures made from non-conducting materials the above practices are essential in order to minimize damage to equipment or data corruption.

Cable shielding

Shielding or screening of cable systems is another useful technique, which helps to minimize the pick-up and emission of electromagnetic radiation.

Power cables can be shielded by metallic conduit or cable trays, whilst data cables often incorporate an outer braid that offers effective screening.

The screen acts as a barrier to electric and electromagnetic fields. Its effectiveness is determined by its material and construction as well as by the frequency of the impinging electromagnetic wave.

For overvoltage protection purposes the screen should be bonded to earth at both ends, although there are instances, particularly in instrumentation, where single-end earthing is preferred to help minimize earth loops.

It should be noted that the shielding of external lines often is the responsibility of the network or service provider.

Material and dimensions of electromagnetic shields

Table 3 of BS EN 62305-3 details the requirements for the materials and dimensions of electromagnetic shields such as metallic cable trays and equipment enclosures. This is of particular importance at the boundary of LPZ 0 and LPZ 1 where the shield would be subject to carrying partial lightning currents.

5.3 Protection using Surge Protective Devices (SPDs)

Unlike shielding measures, Surge Protective Devices (SPDs) can easily and economically be retrofitted to existing installations.

In most practical cases, where a shield exists on a service cable, it is difficult to determine whether the shield (material and dimensions) is capable of handling the potential surge current.

Shields are primarily fitted to prevent residual interference, for example on signal lines. They are not employed with partial lightning currents in mind.

It is also impractical and often uneconomic to suitably re-shield the cable and where no shield exists on external lines.

In contrast suitable SPDs can be selected for the environment within which they will be installed.

For example, knowing the potential current exposure at the service entrance will determine the current handling capability of the applied SPD.

In simplistic terms, the function of an SPD is to divert the surge current to earth and limit the transient overvoltage to a safe level - see Figure 5.8. In doing so, SPDs prevent dangerous sparking through flashover and also protect equipment.

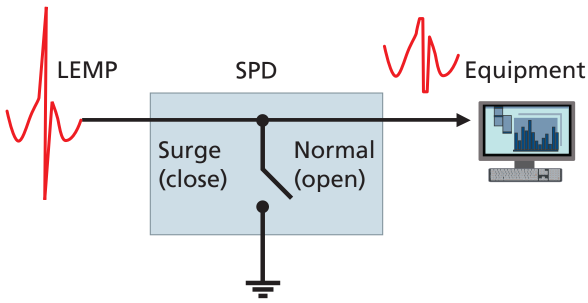

Figure 5.8: Principle of operation of an SPD

Transient overvoltages can occur between any combination of conductors - Live to Neutral, Live to Earth and Neutral to Earth for mains power supplies, and Line to Line, Line to Screen/Earth for data, telecom and signal lines.

In the event that a transient overvoltage exceeds the operating threshold of the SPD, the SPD should either:

- Conduct the energy to earth
- Distribute the energy to the other active conductor(s)

This is defined as common and differential mode protection, which is described in detail on pages 82-83.

An SPD must have the necessary capability to deal with the current levels and durations involved in the transient overvoltages to be expected at its point of installation.

This often translates in terms of installation to multiple SPDs sited at appropriate points on the electrical system, to capture high energy partial lightning currents at the service entrance, and downstream to protect sensitive and critical electronic systems.

Where multiple SPDs are installed, these should be coordinated in line with the requirements of BS EN 62305, and, where appropriate, the IET Wiring Regulations 17th Edition, BS 7671.

For a summary of the key requirements of the IET Wiring Regulations 17th Edition (BS 7671:2008 +A1:2011), see pages 113 to 122.

Coordinated SPDs

Coordinated SPDs simply means a series of SPDs installed in a structure (from the heavy duty lightning current SPD at the service entrance through to the overvoltage SPD for the protection of the terminal equipment) should compliment each other such that all LEMP effects are completely nullified.

Three types of SPD are defined within BS EN 62305 and associated standards for surge protection:

- **Type 1 SPDs (mains power)**
  Category D Tested SPDs (data, signal, telecoms)

  Recommended to protect electrical installations against partial lightning currents caused by direct lightning strokes. This SPD Type can discharge the voltage from lightning spreading from the earth conductor to the network conductors, protect against flashover and are often referred to as lightning current/equipotential bonding SPDs. Test Category B is also applicable for service entrance SPDs for data, signal and telecoms lines (See Table 5.3 on Page 75 for further details)

- **Type 2 SPDs (mains power)**
  Category C1 Tested SPDs (data, signal, telecoms)

  Overvoltage SPDs recommended for protection of the electrical installation against transient overvoltages caused by indirect lightning strokes and switching events

- **Type 3 SPDs (mains power)**
  Category C2 Tested SPDs (data, signal, telecoms)

  This SPD Type has a low discharge capacity and is for installation local to terminal equipment to protect sensitive or critial loads. They should only be installed as a supplement to Type 2 mains power or Category C1 Tested SPDs for data, signal and telecommunications lines

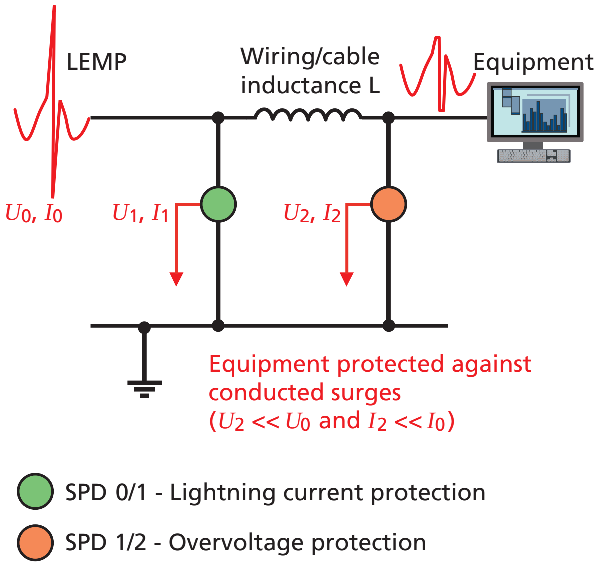

Figure 5.9: Principle of coordinated SPDs

It essentially means the SPDs at the interface between outside and inside the structure (SPD 0/1 for the transition between LPZ 0 to LPZ 1) will deal with the major impact of the LEMP (partial lightning current from an LPS and/or overhead lines). The resultant transient overvoltage will be controlled to safe levels by coordinated downstream overvoltage SPDs (SPD 1/2 for the transition between LPZ 1 to LPZ 2) - see Figure 5.9.

A coordinated set of SPDs should effectively operate together as a cascaded system to protect equipment in their environment.

For example the lightning current SPD at the service entrance should sufficiently handle the majority of surge energy, thus leaving the downstream overvoltage SPDs to control the overvoltage.

Coordination of SPDs is vital since overvoltages are not sufficiently attenuated downstream in the electrical installation. Poor coordination could mean that an overvoltage SPD is subjected to an excess of surge energy placing both itself and connected equipment at risk from damage.

Annex C of BS EN 62305-4 describes the principles and detailed theory of SPD coordination, which depends on factors such as SPD technologies, although in practice manufacturers of SPDs should supply installation guidance to ensure coordination is achieved.

Modern combined Type SPDs are classified with more than one Type, for example a combined Type 1+2+3 SPD for AC mains power supplies, as they effectively achieve the principle of coordination within a single protection unit.

Withstand voltage of equipment

The withstand voltage U_W is the maximum value of surge voltage which does not cause permanent damage through breakdown or sparkover of insulation. This is often referred to as the dielectric withstand.

For a power installation of nominal voltage 230/240 V, these withstand levels are defined by four overvoltage categories (IEC 60664 standard series) as shown in Table 5.5.

Category	Required minimum impulse withstand voltage (kV)	Typical location/ equipment
IV (equipment with very high overvoltage impulse)	6 kV	Electricity meter
III (equipment with high overvoltage impulse)	4 kV	Distribution board
II (equipment with normal overvoltage impulse)	2.5 kV	Sub-distribution board/ Electrical equipment
I (equipment with reduced overvoltage impulse)	1.5 kV	Socket outlet/ Electronic equipment

Table 5.5: Required minimum impulse withstand voltage for a 230/240 V system

Similarly the withstand levels of telecommunication equipment is defined in specific industry standards, (namely ITU-T K.20 and K.21 series).

The withstand voltage depends on the type of equipment, its sensitivity and where it is located within the electrical installation. This is termed as "insulation coordination" because the insulation characteristics of equipment must be coordinated with the equipment location within the installation.

For example an electricity meter has to have a minimum withstand voltage of 6 kV ie highest overvoltage impulse category IV as shown in Table 5.5. This is due to its proximity to the origin of the electrical installation upstream of the main distribution board.

The voltage protection levels or let-through voltages of installed SPDs must be coordinated with the insulation withstand voltage of equipment to prevent permanent damage.

Often, due to power supply authority regulations, the application of SPDs at the service entrance (typically the equipotential bonding Type 1 SPDs) cannot be installed upstream or before the electricity meter. Such SPDs are therefore fitted at the main distribution board.

As the main distribution board falls within overvoltage impulse category III (see Table 5.5), the installed mains Type 1 SPD must ensure that during lightning activity, the voltage protection level is well below the withstand value of 4 kV to prevent dangerous sparking through insulation breakdown caused by flashover.

Overvoltage or mains Type 2 SPDs are tested with an 8/20 µs waveform in accordance with the Class II test detailed within the BS EN 61643 standard on SPDs. Such devices are typically located at sub-distribution boards to control overvoltages, often residual voltages from the upstream coordinated mains Type 1 SPD.

Terminal equipment such as computers connected at socket outlets fall into the lowest overvoltage impulse category I (see Table 5.5) with a withstand voltage of 1.5 kV. An overvoltage mains Type 3 SPD (tested with the Class III test to BS EN 61643 which is a combination or hybrid waveform of 6 kV (1.2/50 µs voltage) and 3 kA (8/20 µs current) is typically employed at this location to prevent equipment from permanent damage. These SPDs also provide local protection by limiting overvoltages caused from switching operations, to safe levels.

The SPD's ability to survive and achieve a suitable protection level when installed clearly depends upon the size of the overvoltage to which it will be subjected. This, in turn, depends upon the SPD's location and its coordination with other SPDs fitted at the same installation.

Installation effects on protection levels of SPDs

Correct installation of SPDs is vital. Not just for the obvious reasons of electrical safety but also because poor installation techniques can significantly reduce the effectiveness of SPDs.

An installed SPD has its protection level increased by the voltage drop on its connecting leads. This is particularly the case for SPDs installed in parallel (shunt) on power installations.

Figure 5.10 illustrates the additive effects of the inductive voltage drop along the connecting leads (U_L) on the let-through voltage (voltage protection level U_P) of the SPD.

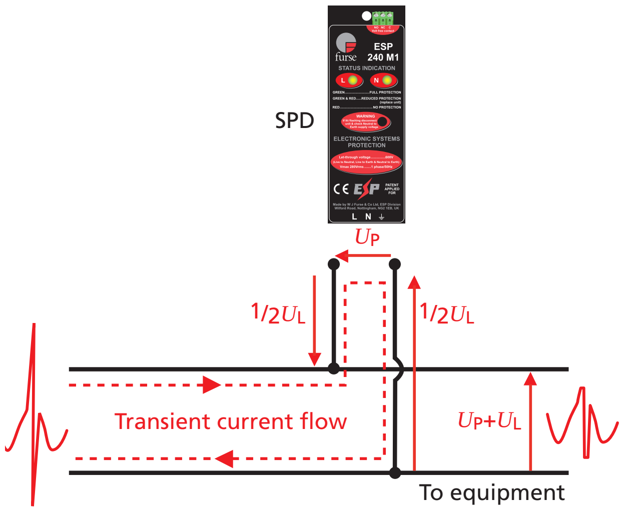

Figure 5.10: Let-through voltage of a parallel protector

In essence, the residual voltage transferred to the protected equipment will be the sum of the SPD's let-through voltage and the inductive voltage drop along the connecting leads (ie $U_L + U_P$).

Whilst the two voltages may not peak exactly at the same instant, for most practical purposes they may simply be added.

Inductance and hence inductive voltage drop is directly related to cable length.

To minimize the inductive voltage drop, lead lengths must be as short as possible (ideally 0.25 m but no more than 0.5 m).

Given the additive inductive voltage on connecting leads, it may be necessary to select an SPD with a lower let-through voltage U_P to achieve protection, for example by selecting an enhanced SPD (SPD* to BS EN 62305).

In addition to keeping connecting leads as short as possible, they should be tightly bound together over as much of their length as possible, using cable ties or spiral wrap.

This is very effective in cancelling inductance.

Inductance is associated with the electromagnetic field around a wire. The size of this field is determined by the current flowing through the wire as shown in Figure 5.11.

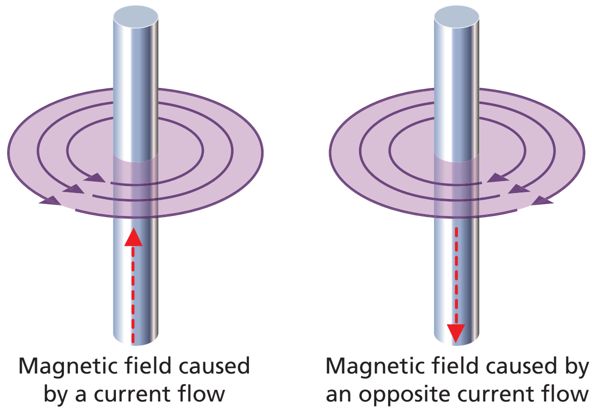

Figure 5.11: Electromagnetic field formation

A wire with the current flowing in the opposite direction will have an electromagnetic field in the opposite direction.

A parallel-connected SPD will, during operation, have currents going in and out of it in opposing directions and thus connecting leads with opposing electromagnetic fields as shown in Figure 5.12.

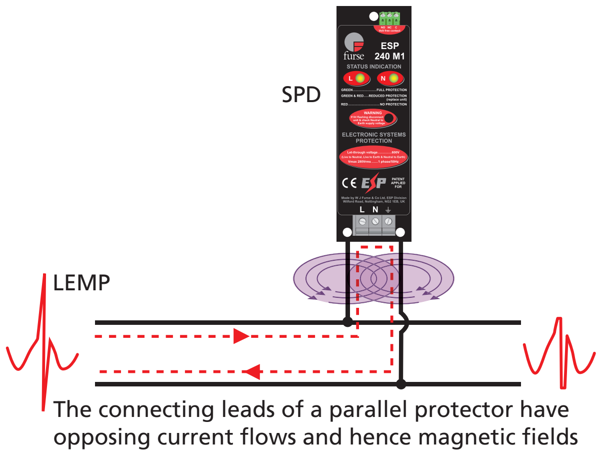

Figure 5.12: Opposing current flow

If the wires are brought close together, the opposing electromagnetic fields interact and cancel.

Since inductance relates to electromagnetic field it too tends to be cancelled. In this way, binding leads closely together reduces the voltage drop in cables.

Low current power (typically 16 A or less), data, signal and telecommunications tend to be installed in series (in-line) with the equipment they are protecting and are not affected by their connecting lead lengths.

However, the earthing of series SPDs must be kept as short as possible for similar reasons detailed above as shown in Figure 5.13.

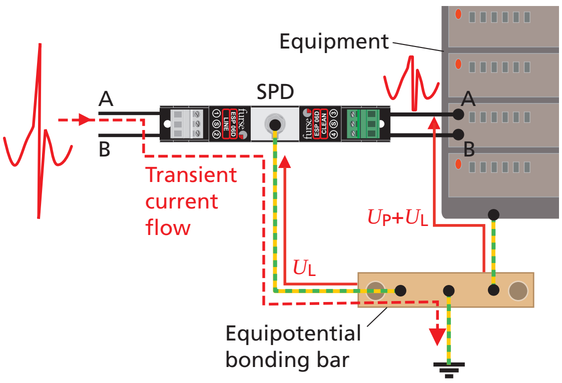

Figure 5.13: Series protector controlling a line to earth overvoltage

Earthing of all SPDs must be relative to the local earth of the equipment being protected.

Connecting leads of SPDs should have minimum cross-sections as given in Table 1 of BS EN 62305-4 (see Table 5.4). The size of connecting leads is associated with the test class related to the type of SPD.

Protective distance

Annex C (clause C.2.1) of BS EN 62305-4 identifies the subject of oscillation protective distance.

If the distance between an SPD and the equipment to be protected is too large, oscillations could lead to a voltage at the equipment terminals which is up to double the protection level of the SPD, U_P. This can cause a failure of the equipment to be protected, in spite of the presence of the SPD.

The acceptable or protective distance depends on the SPD technology, the type of system, the rate of rise of the incoming surge and the impedance of the connected loads. This doubling may occur if the equipment corresponds to a high impedance load or if the equipment is internally disconnected.

Oscillations may be disregarded for distances less than 10 m from the SPD. Some terminal equipment may have internal protective components for EMC purposes (for example Metal Oxide Varistors or MOVs) that will significantly reduce oscillations even at longer distances. However the upstream SPD to this equipment must coordinate with the protective component inside the equipment.

Note, protective distance also forms an important aspect of transient overvoltage protection to the IET Wiring Regulations, 17th Edition, BS 7671.

Common and differential mode surges

Cables typically consist of more than one conductor (core). 'Modes' refers to the combinations of conductors between which surges occur and can be measured. For example between phase and neutral, phase and earth and neutral and earth for a single-phase supply.

During a surge, all conductors will tend to move together in potential relative to their local earth.

This is a common mode surge and it occurs between phase conductors to earth and neutral conductor to earth on a power line or signal line to earth on a telecommunication or data line.

During propagation of the surge, mode conversion can occur, as a result of flashover.

As a result a difference in voltage can also exist between the live conductors (line to line).

This is a differential mode surge and it occurs between phases and phase conductors to neutral on a power line or signal line to signal line on a telecommunication or data line.

It is therefore clear that surges can exist between any pair of conductors, in any polarity, simultaneously.

Lightning transient overvoltages generally start as disturbances with respect to earth, whilst switching transient overvoltages start as disturbances between live/phase and neutral.

Both common and differential mode surges can damage equipment.

Common mode surges in general are larger than differential mode surges and result in flashover leading to insulation breakdown if the withstand voltage of the connected equipment (as defined by IEC 60664-1) is exceeded.

Equipotential bonding or lightning current SPDs protect against common mode surges. On a power supply for example, Type 1 SPDs protect between phases to earth, and neutral to earth on TN earthing systems to prevent dangerous sparking.

Terminal equipment tends to be more vulnerable to differential mode surges.

Downstream overvoltage SPDs protect against both common and differential mode surges - this is a significant advantage over sole protection measures such as shielding, which only provides a reduction in common mode surges.

The use of SPDs in this way also generally presents a more practical and often cost effective solution over shielding.

Figure 5.14 illustrates the interconnection of two separate LPZ 2s with a metallic signal line. A common LPZ is created through the use of bonded shielded cable ducts.

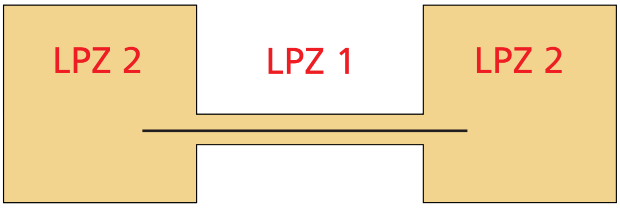

Figure 5.14: Interconnection of two LPZ 2s using shielded cables

Whilst this measure will prevent common mode surges, during propagation of the surge, mode conversion could occur and differential mode surges could pose a threat, particularly if the data system to be protected operates at very low voltages such as RS 485 systems of serial data transmission.

Figure 5.15 illustrates the same scenario, but protection is achieved with overvoltage SPDs (SPD 1/2). The use of SPDs in this way generally presents a more practical and often cost effective solution over shielding.

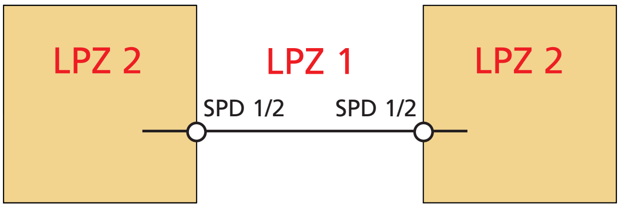

Figure 5.15: Interconnection of two LPZ 2s using SPDs

More importantly, SPDs protect against both common and differential mode surges (often termed as full mode protection), such that the equipment will be protected from damage and remain in continuous operation during surge activity.

Full mode protection is very important when considering the continual operation of equipment which considers protection levels often lower than the withstand voltage of equipment. These levels are referred to as the immunity withstand (or impulse immunity to BS 7671).

Immunity withstand of equipment

Protecting equipment from the risk of permanent failures or damage due to LEMP considers the withstand voltage U_W as defined by IEC 60664-1.

This standard considers insulation coordination for equipment within low voltage systems. During the insulation coordination test, within this standard, the equipment under test is de-energized.

Permanent damage is hardly ever acceptable, since it results in system downtime and expense of repair or replacement.

This type of failure is usually due to inadequate or no surge protection, which allows high voltages and excessive surge currents into the circuitry of the equipment, causing component failures, permanent insulation breakdown and hazards of fire, smoke or electrical shock. It is also undesirable, however, to experience any loss of function or degradation of equipment or system, particularly if the equipment or system is critical and must remain operational during surge activity.

Reference is made in BS EN 62305-4 to the IEC 61000 standard series for the determination of the immunity withstand from voltage and current surges for electronic equipment and systems.

The IEC 61000 series investigates the full range of possible effects of comparatively low current surges on electronic equipment and systems. The applied tests (specifically described in IEC 61000-4-5) evaluate the equipment's operational immunity capabilities by determining where a malfunction, error or failure may occur during energized operation.

The possible results of these tests applied to equipment ranges from normal operation to temporary loss of function as well as permanent damage and destruction of equipment and systems.

Simply stated, the higher the voltage level of a surge, the higher the likelihood of loss of function or degradation, unless the equipment has been designed to provide an appropriate surge immunity.

In general, surge immunity levels or susceptibility of equipment in accordance with IEC 61000-4-5 are lower than insulation withstand levels in accordance with IEC 60664-1.

Protection of SPDs against overcurrent

SPDs are designed to protect against overvoltages - extremely short duration high electrical spikes. They are not designed to counter abnormally high current flow, as could be expected as a result of a short-circuit.

Within the electrical installation, SPDs should be protected against short-circuit through the use of suitable overcurrent fuses (often referred to as Overcurrent Protective Devices - OCPDs).

The installation of OCPDs to protect a mains power SPD is shown in Figure 5.16 below. Overcurrent protection can be confusing in practice where mains power SPDs are concerned, since the majority of these SPDs are installed in parallel (shunt) with the supply and therefore the installed SPD is independent of the supply load current.

Parallel connected SPDs are passive devices and under normal operation do not draw any load current (excepting in some cases a negligible current if the SPD includes electronic status indication). In effect, the same SPD could be installed on a 100 A or 1000 A load supply.

The cross-sectional area of connecting leads to the SPD therefore does not have to be sized equivalent to the load current, only the surge current expected to be handled by the SPD (see Table 5.4 on page 75 for minimum cross-sectional area requirements to BS EN 62305-4).

Thus the OCPD selected should coordinate with the SPD, and vitally, discriminate from the upstream OCPD installed to protect the mains supply.

SPD manufacturers should give clear guidance for the correct rating of OCPDs in their SPD installation instructions.

BS EN 61643 requires SPD manufacturers to declare the maximum OCPD rating that can safely be used with their SPD. Within the SPD installation, it is important to ensure that the maximum OCPD rating declared by the SPD manufacturer is never exceeded. Since the OCPD is installed in-line with the SPD the maximum surge current of the SPD will also flow through the OCPD.

The OCPD rating declared by the manufacturer is selected as part of the SPD testing process to ensure that the full SPD pre-conditioning and operating duty tests, including the maximum SPD surge current test, do not cause the OCPD to operate.

However, the SPD manufacturer's declared OCPD rating does not take into account the need to discriminate the SPD OCPD from the upstream supply OCPD. IEC 61643-12 allows the use of OCPD ratings lower than the maximum OCPD declared by the manufacturer, so as to enable discrimination from the upstream supply OCPD.

Installers should therefore refer to OCPD manufacturer’s operating characteristics to ensure discrimination, particularly where an installation includes a mixture of OCPD types.

Where manufacturer’s operating characteristics of the upstream OCPD are not available, as a rule of thumb, the OCPD to the SPD should be rated nominally half the value of the immediate upstream OCPD.

Further information on use of OCPDs with SPDs is provided in Section 7 on BS 7671, see page 123.

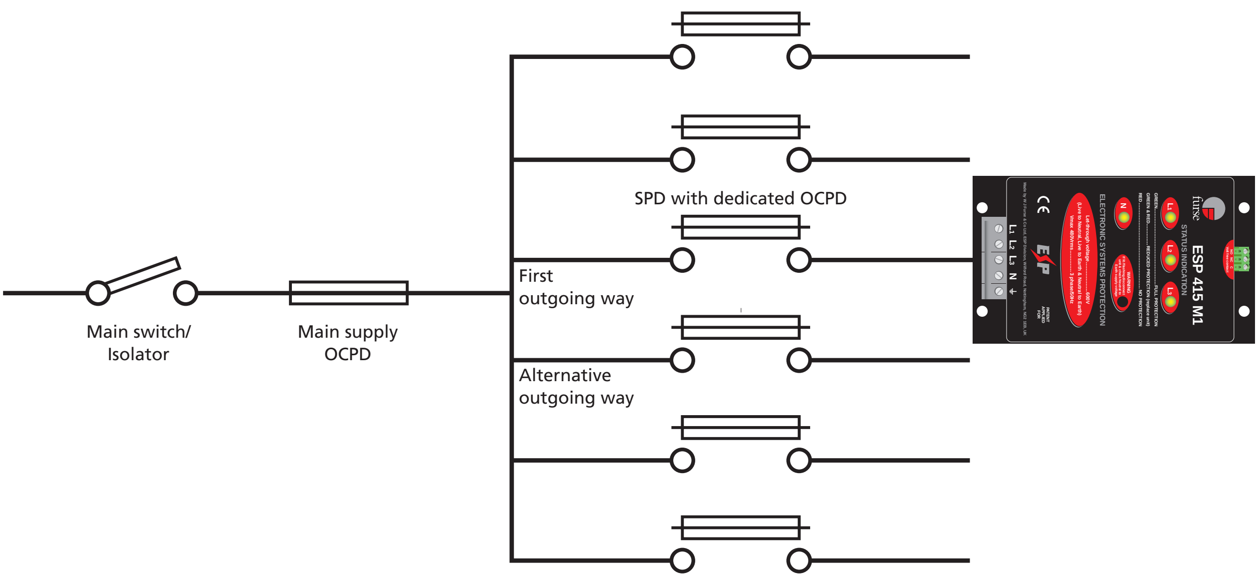

Figure 5.16: OCPD positioning and coordination with the SPD

Protection levels and enhanced SPDs

The choice of SPD to protect equipment and systems against surges will depend on the following:

- Withstand voltage
- Immunity withstand for critical equipment requiring continual operation
- Additive installation effects such as inductive voltage on the connecting leads of SPDs
- Oscillation protective distance

Each of the above points has been described independently in detail. However SPDs have to be applied with all of these factors in mind. Tables NB.3 and NB.7 of Annex NB, BS EN 62305-2 give guidance towards achieving this.

The tables detail the choice of a coordinated SPD set to the corresponding Lightning Protection Level in order to reduce the probability of failure of internal systems due to flashes to the structure, denoted as P_C.

The first point to note is that only coordinated SPD protection is suitable as a protection measure to reduce P_C for structures protected by an LPS with bonding and earthing requirements of BS EN 62305-3 satisfied. For each LPL, two types of SPDs are presented, SPD and SPD*. Both correspond to a probability value P_{SPD} or P_{EB}.

"Standard" SPDs offer protection levels below the withstand level of the equipment or system they protect. This is often 20% lower than the withstand value of equipment to take account of additive inductive volt drops on the connecting leads of SPDs. However, this value is still likely to be higher than the susceptibility value of equipment, in the case of overvoltage SPDs.

"Enhanced" SPD*s reduce P_{SPD} and P_{EB} by a factor of 10 as they have lower (better) voltage protection levels (U_P) or let-through voltages which goes some way to compensate against the additive inductive voltage of the connecting lead length and possible voltage doubling due to oscillation protective distance.

As the latter is dependent on, amongst other factors, SPD technology, typical SPD* designs help minimize such effects.

Lower (and hence better) protection levels further reduce the risks of injury to living beings, physical damage and failure of internal systems.

Equipotential bonding or lightning current SPD*s further lower the risk of damage as the lower the sparkover voltage, the lesser the chance of flashover causing insulation breakdown, electric shock and possibly fire.

For example, in the case of a 230 V mains supply an enhanced mains Type 1 SPD* fitted at the service entrance (for lightning equipotential bonding) should have a voltage protection level of no more than 1600 V when tested in accordance with BS EN 61643 series (Class I Test).

This value is derived as follows:

$$\frac{4\,kV \times 0.8}{2} = 1600\,V$$

Where:

- The withstand voltage for electrical apparatus at the main distribution board downstream of the electricity meter is 4 kV in accordance with IEC 60664-1
- A 20% margin is taken into account for the additive inductive volt drops on the connecting leads of SPDs
- A factor of 2 is taken into account for the worst case doubling voltage due to the oscillation protective distance

SPD*s of the overvoltage type (mains Type 2 and Type 3 and signal/telecom Category C tested) further ensure the protection and continuous operation of critical equipment, by offering low protection levels, in both common and differential modes, below the susceptibility (immunity) values of equipment.

Often the susceptibility level of equipment is unknown. Table NB.3 Note 2 and Table NB.7 Note 4 give further guidance that unless stated, the susceptibility level of equipment is assumed to be twice its peak operating voltage. For example, a single-phase 230 V power supply has a peak operating rating of 230 V x √2 x 1.1 (10% supply tolerance). This equates to a peak operating voltage of 358 V so the susceptibility level of terminal equipment connected to a 230 V supply is approximately 715 V.

This is an approximation and where possible the known susceptibility of equipment should be used.

The typical withstand voltage of such terminal equipment is 1.5 kV.

Similarly to take account of the additive inductive voltage of the connecting lead length and possible voltage doubling due to oscillation protective distance, enhanced overvoltage SPD*s should have a voltage protection level of no more than 600 V ((1.5 kV x 0.8)/2) when tested in accordance with BS EN 61643 series (Class III test).

Such an enhanced SPD* installed with short, bound connecting leads (25 cm) should achieve an installed protection level well below 715 V to ensure critical terminal equipment is protected and remains operational during surge activity.

All SPDs, particularly those with low protection levels, should also take account of supply fault conditions such as Temporary Over Voltages or TOVs as defined by BS EN 61643 standard series that are specific for SPDs.

From a risk perspective, the choice of using a standard SPD or enhanced SPD* is determined by Note 2 of Table NB.3 and Note 4 of Table NB.7.

The LPL governs the choice of the appropriate structural LPS and corresponding coordinated SPDs. Typically, an LPS Class I would require SPD I. If the indirect risk (R_I) was still greater than the tolerable risk (R_T) then SPD I* should be chosen.

Given the increased use of electronic equipment in all industry and business sectors and the importance of its continual operation, the use of enhanced SPD*s is always strongly advised. Enhanced SPD*s can also present a more economic solution to standard SPDs as described below.

Economic benefits of enhanced SPDs

For the SPM designer, there are considerations for the location of SPDs as detailed in Annex D of BS EN 62305-4.

For example, in the case of overvoltage SPDs, the closer the SPD is to the entrance point of an incoming line to an LPZ, the greater the amount of equipment within the structure is being protected by this SPD. This is an economic advantage.

However, the closer the overvoltage SPD is to the equipment it protects, the more effective the protection. This is a technical advantage.

Enhanced overvoltage SPDs (SPD*) that offer lower (better) voltage protection levels in both common and differential modes provide a balance of both economic and technical advantages over standard SPDs that have higher voltage protection levels and often only common mode protection. Less equates to more in such a case, as fewer SPDs are required which also saves on both installation time and costs.

An enhanced overvoltage SPD* can satisfy two test classes and hence be both mains Type 2+3 (or data Category C1+C2) within one unit. Such a unit offers a high 8/20 µs current handling with a low voltage protection level in all modes.

If the stresses at the entrance to an LPZ are not subject to partial lightning currents, such as an underground mains line, one such enhanced Type 2+3 SPD* may be sufficient to protect this LPZ from threats via this line.

Similarly enhanced mains Type 1+2 (or data Category D1+C2) SPD*s exist which handle both partial lightning current (10/350 µs) and offer low protection levels and so further reduce the risk of flashover.

Enhanced telecom, data and signal SPD*s can offer complete protection - namely Category D1+C2+C1 (SPD 0/1/2) within the same unit. Such SPDs utilize the principles of coordination within the unit itself - further details are provided in Annex C of BS EN 62305-4.

Although the typical design technologies of enhanced SPD*s help minimize voltage doubling effects (oscillation protection distance), care must be taken if there are sources of internal switching surges past the installation point of the enhanced SPD*. Additional protection may therefore be required.

Design examples of a complete system of Surge Protection Measures (SPM)

The following examples illustrate the simple combination of individual SPM to counter the effects of LEMP.

Example 1 - Power line entering the structure

Figure 5.17 illustrates the combined use of an external LPS, spatial shielding and the use of coordinated enhanced SPD*s as an SPM system.

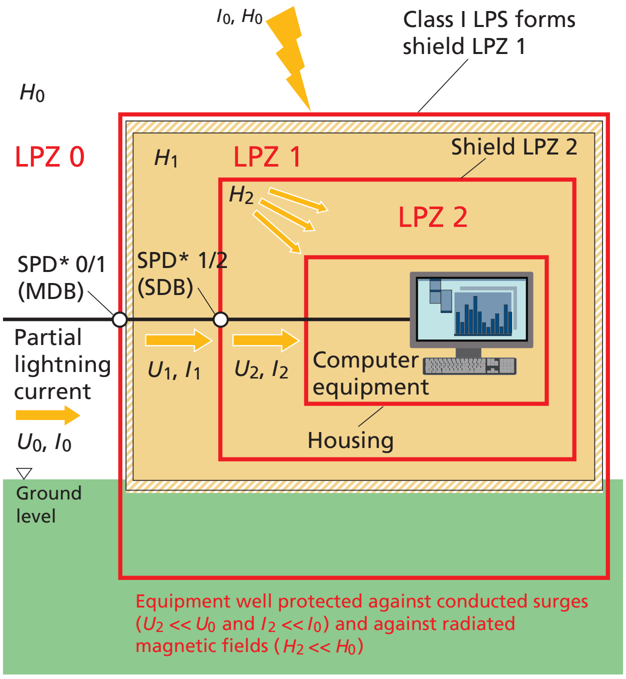

Figure 5.17: Protection example utilizing spatial shielding and coordinated enhanced SPD*s

The structure is protected by a Class I LPS with a 5 x 5 m air termination network (mesh) in conjunction with the metallic cladding fitted to the walls.

This acts as the suitable spatial shield and a reduction of LEMP severity is established, which defines the boundary of LPZ 1. The full (unattenuated) radiated electromagnetic field H_0 of LPZ 0 is reduced in severity, denoted by H_1 of LPZ 1.

As the equipment to be protected in this example is sensitive and its continual operation is necessary, a further reduction in radiated electromagnetic field H_1 is required. This is achieved by the spatial shielding of the room housing the equipment, which forms the boundary of successive zone LPZ 2.

The electromagnetic field H_1 of LPZ 1 is further reduced to H_2 of LPZ 2.

Whenever a metallic service line passes from one LPZ to another it needs to be bonded directly or via a suitable SPD. The power line in this example is protected at the Main Distribution Board (MDB) at the boundary of LPZ 0/1 by an enhanced Type 1 SPD* corresponding to the LPL determined by risk assessment. As a Class I LPS is fitted in this example and the supply is TN-S (4 lines, 3 phase conductors and neutral), the current handling capability of this enhanced Type 1 SPD* is 25 kA 10/350 µs between any two conductors.

The purpose of this enhanced equipotential bonding, lightning current Type 1 SPD* is to reduce the risk of dangerous sparking which may present a fire hazard. The surge voltage U_0 and partial lightning current I_0 of LPZ 0 is reduced to U_1 and I_1 of LPZ 1 respectively.

The use of a Type 1 SPD* alone is not sufficient to protect the equipment. An enhanced Type 2+3 SPD* is employed at the Sub-Distribution Board (SDB) at the boundary of LPZ 1/2 further reducing the surge voltage U_1 and surge current I_1 of LPZ 1 to U_2 and I_2 of LPZ 2.

This enhanced Type 2+3 SPD* (coordinated with enhanced Type 1 SPD*) provides protection in both differential and common mode which ensures the equipment remains continually operational and further removes the need of an additional SPD at the socket outlet local to the equipment. This could represent a significant cost saving. Typically a room may contain many pieces of sensitive equipment (for example an IT room) where each may have required an individual SPD at every local socket outlet, if a standard Type 2 SPD was used at the SDB.

Example 2 - Telecom line entering the structure

Figure 5.18 illustrates the combined use of line shielding with shielded equipment enclosures and the use of coordinated enhanced Category D1+C2+C1 SPD* (SPD 0/1/2).

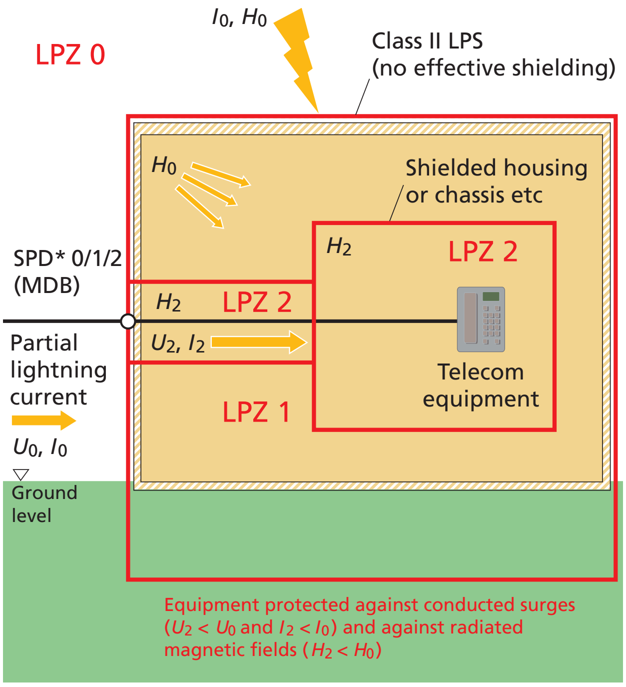

Figure 5.18: Protection example utilizing spatial shielding and an enhanced SPD*

A metallic telecom line enters the structure from zone LPZ 0; it therefore has to be protected by a suitable SPD. The enhanced Category D1+C2+C1 SPD* (SPD 0/1/2) employed offers complete coordinated protection (within the one unit) from partial lightning current I_0 and conducted surge U_0, significantly reducing their threat to I_2 and U_2 respectively.

A Class II LPS is fitted with a 10 m x 10 m air termination network (mesh) and down conductors at 10 m spacing. Such a system does not provide an effective spatial shield at the structure boundary LPZ 0/1. Effective shielding, in accordance with BS EN 62305-4, requires that the mesh width be typically no greater than 5 m. The full (unattenuated) radiated electromagnetic field H_0 of LPZ 0 is not reduced within the LPZ 1. However by bonding the shielding of the line together with the metallic housing of the equipment, a reduction in the radiated electromagnetic field H_0 to H_2 is achieved within LPZ 2.

Further design examples for a complete SPM system are discussed in BS EN 62305-4.

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Extending structural lightning protection

The benefit obtained from a spatial shield derived from the reinforcing bars or steel stanchions of a structure has been discussed and illustrated previously. In the same manner, if these fortuitous natural conductors are not present, or have a large grid network, then the choice of a higher Class of external structural LPS would certainly improve the protection measures afforded to electronic equipment housed within the structure.

Protecting exposed systems

Many systems incorporate elements installed outside or on the structure. Common examples of external system components include:

- Aerials or antennae
- Measurement sensors
- Parts of the air conditioning system
- CCTV equipment
- Roof mounted instruments (eg clocks)

Exposed equipment, such as this, is not only at risk from transient overvoltages caused by the secondary effects of lightning, but also from direct strikes.

A direct lightning strike must be prevented if at all possible. This can typically be achieved by ensuring that external equipment is within a zone of protection and where necessary is bonded to the structural lightning protection. For example CCTV cameras should be safely positioned within the zone of protection provided by the structure's lightning protection.

It may be necessary to include additional air termination points in the structure's lightning protection system, in order to ensure that all exposed equipment is protected.

For exposed parts of an air conditioning system for example, it is possible just to bond its metal casing on to the roof top lightning conductor grid providing the integrity of the metallic casing can handle the lightning current.

Where air termination points cannot be used, for example with ship aerials, the object should be designed to withstand a direct lightning strike or be expendable.

Exposed wiring should be installed in bonded metallic conduit or routed such that suitable screening is provided by the structure itself. For steel lattice towers the internal corners of the L-shaped support girders should be used.

Cables attached to masts should be routed within the mast (as opposed to on the outside) to prevent direct current injection.

Equipment location

Careful consideration should be given to the location of electronic equipment within a structure. It should not be located (where possible) near potential lightning current routes and the subsequent threat of induced transient overvoltages.

- Equipment should not be located on the top floor of the structure where it is adjacent to the structure's air termination system
- Similarly, equipment should not be located near to outside walls and especially corners of the structure, where lightning currents will preferentially flow
- Equipment should not be located close to tall, lightning attractive, structures such as masts, towers or chimneys. These tend to provide fewer routes to earth, causing very large currents to flow (in each route) and hence very large electromagnetic fields

The issue of equipment location can only be ignored if the structure has an effective spatial screen (typically, bonded metal clad roof and walls).

Fibre optic cable on structure to structure data links

Special care should be taken with the protection of data lines which:

- pass between separate structures
- travel between separate parts of the same structure (ie not structurally integral) and which are not bonded across. Examples include parts of a structure, which are separated by settlement gaps, or new wings that are linked by brick corridors

The use of fibre optic cable is the optimum method of protection for structure-to-structure data links. This will completely isolate the electronic circuits of one structure from the other, preventing all sorts of EMC problems including overvoltages. Annex B of BS EN 62305-4 refers to the use of fibre optic cables and regards it as protection by isolation interfaces.

Many fibre optic cables incorporate metal draw wires or moisture barriers and steel armouring. This can establish a conductive link between structures, defeating the object of using a fibre optic link. If this cannot be avoided the conductive draw wire, moisture barrier or armouring should be bonded to the main cable entry bonding bar as it enters each structure, or be stripped well back. No further bonding should be made to the fibre optic cable's 'metal'.

The cost of fibre optic cable makes it unattractive for low traffic data links and single data lines.

Example of a complete SPM system

An example of a complete SPM system is illustrated in Figure 5.19.

This shows the clear use of extensive equipotential bonding, shielding, the use of coordinated SPDs, equipment location and structural LPS (to protect roof-mounted equipment).

The structural LPS and natural/additional shielding create the various LPZs. All the cables, metalwork and metallic service lines that cross the perimeter of an LPZ should either be bonded directly or via suitable SPDs.

Note that the transformer on the High Voltage (HV) power supply is located within the structure. Appropriate protection measures on the HV side are often restricted by the supply authority. The problem is solved by extending LPZ 0 into LPZ 1 using suitably bonded metallic cable conduit and protecting the low voltage side with equipotential bonding mains Type 1 SPDs.

Management of the SPM system

As detailed in BS EN 62305-3, there is a requirement to routinely maintain and inspect a structural LPS to ensure its designed mechanical and electrical characteristics are not compromised during its intended service life.

It follows that the SPM system should also be routinely maintained and frequently inspected to confirm that its design and integrity ensures electrical and electronic systems are effectively protected.

Table 2 of BS EN 62305-4 details a management plan for new structures and for existing structures undergoing extensive changes. The successful execution of actions detailed in the plan requires the coordination and co-operation of architects, civil and electrical engineers along with lightning protection experts.

The design of the SPM system should be carried out during the structure's design stage and before construction commences in order to achieve a cost effective and efficient protection system.

Furthermore, pre-construction planning optimizes the use of the natural components of the structure and allows optimal selection for the cable systems and equipment location.

To carry out a retrofit to an existing structure, the cost of the SPM system is generally higher than that of the cost for new structures. However, it is possible to minimize costs by the correct choice of protection measures. For example it may not be practical or cost effective to implement electromagnetic spatial shielding measures in an existing structure so the use of coordinated SPDs may be more suitable.

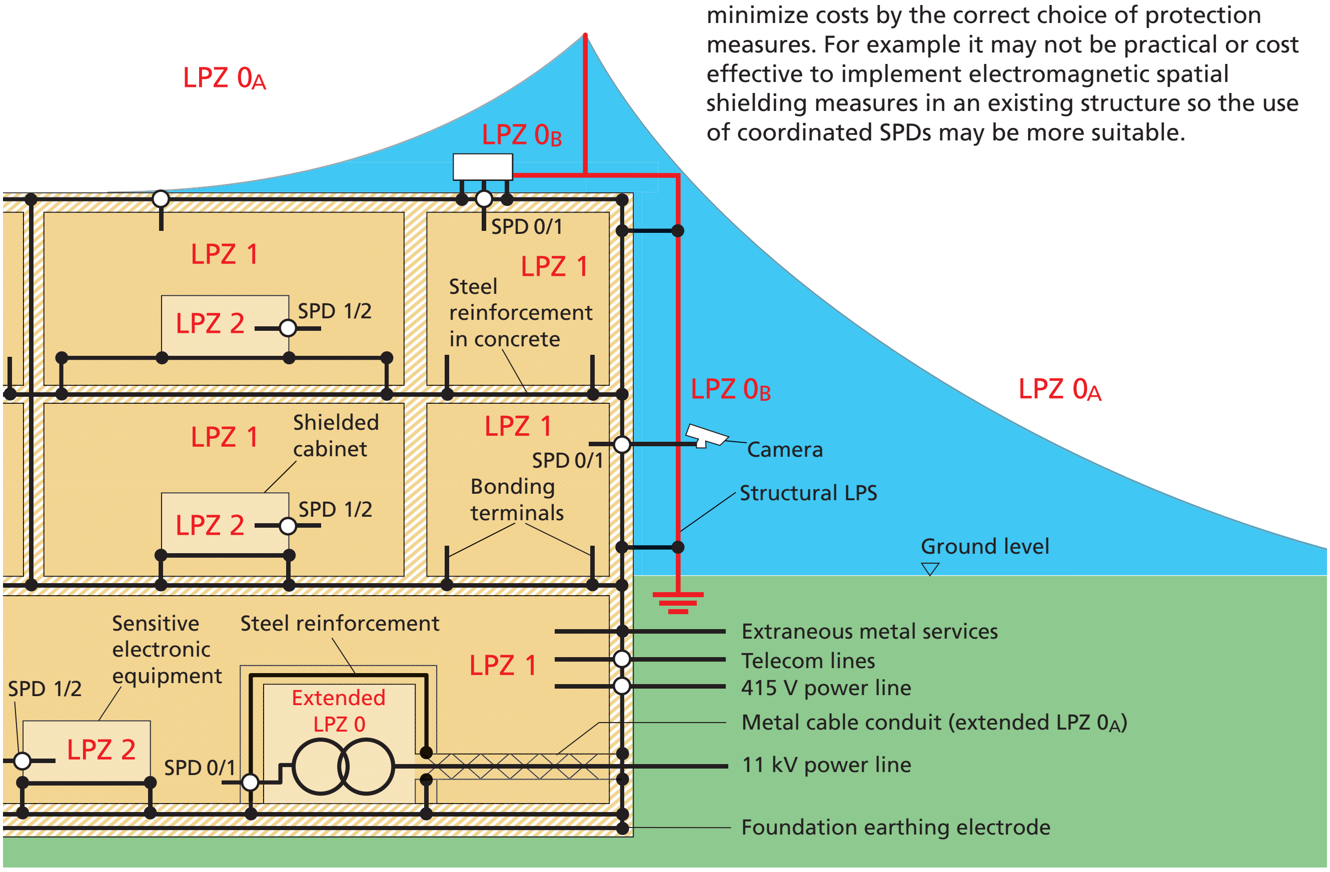

Figure 5.19: Example of a complete SPM system

Inspection and maintenance of the SPM system

The object of the inspection is to verify the following:

- The SPM system complies with the design
- The SPM system is capable of performing its design function
- Additional protection measures are correctly integrated into the complete SPM system

The inspection comprises checking and updating the technical documentation, visual inspections and test measurements.

Visual inspections are very important, and should verify, for example, if bonding conductors and cables shields are intact and appropriate line routeings are maintained.

A visual inspection should also verify that there are no alterations or additions to an installation, which may compromise the effectiveness of the SPM system. For example, an electrical contractor may add a power supply line to external CCTV cameras or car park lighting. As this line is likely to cross an LPZ, suitable protection measures (eg SPD) should be employed to ensure the integrity of the complete SPM system is not compromised.

Care should be taken to ensure that SPDs are re-connected to a supply if routine electrical maintenance such as insulation or “flash” testing is performed. SPDs need to be disconnected during this type of testing, as they will treat the insulation test voltage applied to the system as a transient overvoltage, thus defeating the object of the test.

As SPDs fitted to the power installation are often connected in parallel (shunt) with the supply, their disconnection could go unnoticed. Such SPDs should have visual status indication to warn of disconnection as well as their condition, which aids the inspection.

Inspections should be carried out:

- During the installation of the SPM system
- After the installation of the SPM system
- Periodically thereafter
- After any alteration of components relevant to the SPM system
- After a reported lightning strike to the structure

Inspections at the implementation stages of the SPM system are particularly important, as many of the measures to control LEMP, such as equipotential bonding, are no longer accessible after construction has been completed.

The frequency of the periodical inspections should be determined with consideration to:

- The local environment, such as the corrosive nature of soils and corrosive atmospheric conditions
- The type of protection measures employed

Following the inspections, all reported defects should be immediately corrected.

Successful management of the SPM system requires controlled technical and inspection documentation. The documentation should be continuously updated, particularly to take account of alterations to the structure that may require an extension of the SPM system.

5.4 Summary

Damage, degradation or disruption (malfunction) of electrical and electronic systems within a structure is a distinct possibility in the event of a lightning strike.

Some areas of a structure, such as a screened room, are naturally better protected from lightning than others and it is possible to extend the more protected zones by careful design of the LPS, direct equipotential bonding of metallic service lines such as water and gas, and equipotential bonding metallic electrical service lines such as power and telephone lines, through the use of equipotential bonding SPDs.

An LPS according to BS EN 62305-3 which only employs equipotential bonding SPDs provides no effective protection against failure of sensitive electrical or electronic systems. However it is the correct installation of coordinated SPDs that protect equipment from damage as well as ensuring continuity of its operation - critical for eliminating downtime.

Each of these measures can be used independently or together to form a complete SPM system. Careful planning of equipment location and cable routeing also help achieve a complete SPM system.

For effective protection of electronic equipment and systems, the SPM system requires continual, documented inspections and, where necessary, maintenance in accordance with a management plan for the system.

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6. Design examples

6.1 Introduction

The following section of this guide takes all the aforementioned information and leads the reader through a series of worked examples.

In Example 1 and 2 the long hand risk management calculations are explained. The results determine whether protection measures are required. The first example illustrates various possible solutions.

The next example takes the reader through a complete implementation of the design protection measures.

It takes the results from the risk calculation and shows how to carry out the requirements of BS EN 62305-3 for the structural aspects and additionally the necessary measures of BS EN 62305-4, for the protection of the electrical and electronic systems housed within the structure.

Finally, there is a third example where the evaluation of R_4 (economic loss) is reviewed and discussed.

The first is a simple example of a small country house located in Norfolk, England, and is treated as a single zone. R_1 - risk of loss of human life (including permanent injury) is evaluated.

The next example is an office building near King's Lynn in Norfolk.

In this example the structure is split into 5 distinct zones, where the risk components are calculated for each zone.

By splitting the structure into zones, the designer can pinpoint precisely where (if any) protection measures are required. R_1 and R_2 have been evaluated in this case to ascertain whether there is a risk of loss of human life (including permanent injury) (R_1) as well as illustrating the need for coordinated SPDs as part of the required protection measures (R_2).

The third example is a hospital situated in the south east of London and again is split into 4 distinct zones.

R_1 and R_4 (economic loss) are evaluated the latter of which confirms the cost effectiveness of installing lightning protection measures compared to the potential consequential losses that could be incurred, without any protection.

It will become obvious that this long hand method is both laborious and time consuming, particularly for those people involved in the commercial world of lightning protection.

Furse have therefore developed their own in-house software, which will carry out all the necessary calculations in a fraction of the time and will provide the designer with the optimum solution.

It will also become apparent to everyone who tackles the risk calculations that a lot of detailed information is required for both the structure and the service lines supplying the structure.

Typically, specific details relating to the characteristics of internal wiring (K_{S3}), the screening effectiveness of the structure (K_{S1}) and of shields internal to the structure (K_{S2}) are required to determine probability P_{MS}. Whether the internal wiring uses unshielded or shielded cables is another factor that is taken into consideration.

Clearly, the majority of times this information will simply not be available to the designer.

In these events the designer will choose the probability value of one (as given in the appropriate table), which will produce a more conservative solution.

The more accurate the details are, the more precise will be the recommended protection measures.

With the aid of the software it will be very easy and become routine in nature to automatically calculate the risks R_1 and R_2. If it is a listed building or has any cultural importance then R_3 can additionally be calculated at the same time.

When the designer has completed the risk assessment calculation, the proposed protection measures should be a reflection of the most suitable technical and economic solution.

BS EN 62305-3 and BS EN 62305-4 then give specific guidance on how to implement these measures.

6.2 Example 1: Country house

Consider a small country house (see Figure 6.1) near King's Lynn in Norfolk. The structure is situated in flat territory with no neighbouring structures. It is fed by an underground power line and overhead telecom line, both of unknown length. The dimensions of the structure are:

L = 15 m

W = 20 m

H = 6 m

In this specific example the risk of loss of human life (including permanent injury) R_1 in the structure should be considered.

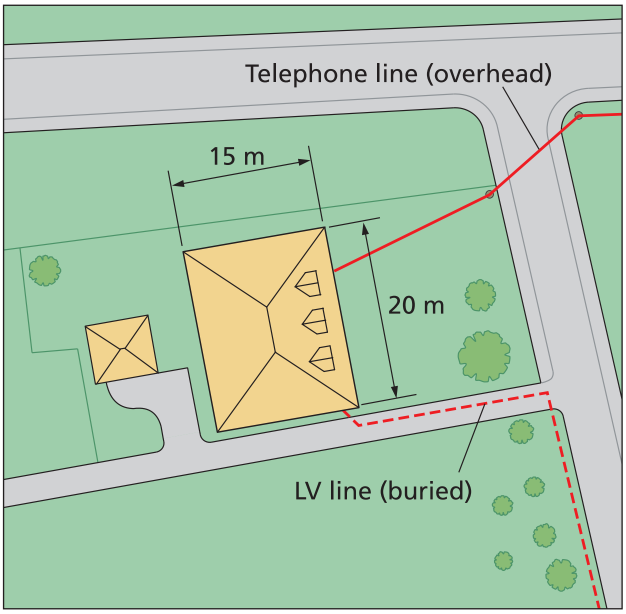

Figure 6.1: Country house

Assigned values

The following tables identify the characteristics of the structure, its environment and the lines connected to the structure.

- Table 6.1: Characteristics of the structure and its environment
- Table 6.2: Characteristics of incoming LV power line and connected internal equipment
- Table 6.3: Characteristics of incoming telecom line and connected internal equipment

The equation numbers or table references shown subsequently in brackets relate to their location in BS EN 62305-2.

Parameter	Comment	Symbol	Value
Dimensions (m)	-	L_B, W_B, H_B	15, 20, 6
Location factor	Isolated	C_D	1
Line environment factor	Rural	C_E	1
LPS	None	P_B	1
Shield at structure boundary	None	K_{S1}	1
Lightning flash density	1/km²/year	N_G	0.7

Table 6.1: Characteristics of the structure and its environment

Parameter	Comment	Symbol	Value
Length (m)	-	L_L	1,000
Installation type	Buried	-	-
Line type	LV power	C_T	1
Line shielding	None	P_{LD}	1
Internal wiring precaution	None	K_{S3}	1
Withstand of internal system (kV)	None	U_W	2.5
SPD Protection	None	P_{EB}	1

Table 6.2: Characteristics of incoming LV power line and connected internal equipment

Parameter	Comment	Symbol	Value
Length (m)	-	L_L	1,000
Installation type	Aerial	-	-
Line type	Telecoms	C_T	1
Line shielding	None	P_{LD}	1
Internal wiring precaution	None	K_{S3}	1
Withstand of internal system (kV)	None	U_W	1.5
SPD Protection	None	P_{EB}	1

Table 6.3: Characteristics of incoming telecom line and connected internal equipment

Definition of zones

The following points have been considered in order to divide the structure into zones:

- The type of floor surface is different outside to inside the structure
- The type of floor surface is common within the structure
- The structure is a unique fireproof compartment
- No spatial shields exist within the structure
- Both electrical systems are common throughout the structure

The following zones are defined:

- Z_1 (outside the building)
- Z_2 (inside the building)

If we consider that no people are at risk outside the building, risk R_1 for zone Z_1 may be disregarded and the risk assessment performed for zone Z_2 only.

Characteristics of zone Z_2 are reported in Table 6.4.

Parameter	Comment	Symbol	Value
Floor surface type	Wood	r_t	1 x 10^{-5}
Protection measures against step and touch voltage	None	PT_A PT_U	1 1
Risk of fire	Ordinary	r_f	1 x 10^{-2}
Special hazard	None	h_z	1
Fire protection	None	r_p	1
Shield internal to structure	None	K_{S2}	1
Internal power systems	Yes	Connected to LV power line	-
Internal telephone systems	Yes	Connected to telecom line	-
Loss by touch and step voltages	Yes	L_T	1 x 10^{-2}
Loss by physical damage	Yes	L_F	1

Table 6.4: Characteristics of Zone Z_2 (inside the building)

The actual risk is now determined in the following calculation stages based on the assigned values.

From this point on a subscript letter will be added to several factors relating to lines entering the structure. This subscript (P or T) will identify whether the factor relates to the Power or Telecom line.

Collection areas

Calculate the collection areas of the structure and the power and telecom lines.

a) Collection area of the structure A_D

$$A_D = L \times W + 6H(L + W) + \pi(3H)^2 \qquad \text{(E A.2)}$$

$$A_D = 15 \times 20 + 6 \times 6(15 + 20) + \pi(3 \times 6)^2$$

$$A_D = 300 + 1{,}260 + 1{,}018$$

$$A_D = 2{,}578\, m^2$$

b) Collection area of the power line $A_{L(P)}$

$$A_{L(P)} = 40 \times L_L \qquad \text{(E A.9)}$$

As length of the power line is unknown then assume L_L = 1000 m.

$$A_{L(P)} = 40 \times 1{,}000$$

$$A_{L(P)} = 40{,}000\, m^2$$

c) Collection area near the power line $A_{I(P)}$

$$A_{I(P)} = 4{,}000 \times L_L \qquad \text{(E A.11)}$$

$$A_{I(P)} = 4{,}000 \times 1{,}000$$

$$A_{I(P)} = 4{,}000{,}000\, m^2$$

d) Collection area of the telecom line $A_{L(T)}$

$$A_{L(T)} = 40 \times L_L \qquad \text{(E A.9)}$$

$$A_{L(T)} = 40 \times 1{,}000$$

$$A_{L(T)} = 40{,}000\, m^2$$

e) Collection area near the telecom line $A_{I(T)}$

$$A_{I(T)} = 4{,}000 \times L_L \quad \text{(E A.11)}$$

$$A_{I(T)} = 4{,}000 \times 1{,}000$$

$$A_{I(T)} = 4{,}000{,}000\, m^2$$

Number of dangerous events

Calculate the expected annual number of dangerous events (ie number of flashes).

a) Annual number of events to the structure N_D

$$N_D = N_G \times A_D \times C_D \times 10^{-6} \quad \text{(E A.4)}$$

$$N_D = 0.7 \times 2{,}578 \times 1 \times 10^{-6}$$

$$N_D = 0.0018$$

b) Annual number of events to the power line $N_{L(P)}$

$$N_{L(P)} = N_G \times A_{L(P)} \times C_{I(P)} \times C_{E(P)} \times C_{T(P)} \times 10^{-6} \quad \text{(E A.8)}$$

$$N_{L(P)} = 0.7 \times 40{,}000 \times 0.5 \times 1 \times 1 \times 10^{-6}$$

$$N_{L(P)} = 0.014$$

c) Annual number of events near the power line $N_{I(P)}$

$$N_{I(P)} = N_G \times A_{I(P)} \times C_{I(P)} \times C_{E(P)} \times C_{T(P)} \times 10^{-6} \quad \text{(E A.10)}$$

$$N_{I(P)} = 0.7 \times 40{,}000{,}000 \times 0.5 \times 1 \times 1 \times 10^{-6}$$

$$N_{I(P)} = 1.4$$

d) Annual number of events to the telecom line $N_{L(T)}$

$$N_{L(T)} = N_G \times A_{L(T)} \times C_{I(T)} \times C_{E(T)} \times C_{T(T)} \times 10^{-6} \quad \text{(E A.8)}$$

$$N_{L(T)} = 0.7 \times 40{,}000 \times 1 \times 1 \times 1 \times 10^{-6}$$

$$N_{L(T)} = 0.028$$

e) Annual number of events near the telecom line $N_{I(T)}$

$$N_{I(T)} = N_G \times A_{I(T)} \times C_{I(T)} \times C_{E(T)} \times C_{T(T)} \times 10^{-6} \quad \text{(E A.10)}$$

$$N_{I(T)} = 0.7 \times 4{,}000{,}000 \times 1 \times 1 \times 1 \times 10^{-6}$$

$$N_{I(T)} = 2.8$$

f) Annual number of events to the structure at end of power line $N_{DJ(P)}$

$$N_{DJ(P)} = N_G \times A_{DJ} \times C_{DJ} \times C_T \times 10^{-6} \quad \text{(E A.5)}$$

$$N_{DJ(P)} = 0.7 \times 0 \times 1 \times 1 \times 10^{-6}$$

$$N_{DJ(P)} = 0$$

g) Annual number of events to the structure at end of telecom line $N_{DJ(T)}$

$$N_{DJ(T)} = N_G \times A_{DJ} \times C_{DJ} \times C_T \times 10^{-6} \quad \text{(E A.5)}$$

$$N_{DJ(T)} = 0.7 \times 0 \times 1 \times 1 \times 10^{-6}$$

$$N_{DJ(T)} = 0$$

Assessment of probability of damage

a) Probability that a flash to a structure will cause injury to living beings by electric shock P_A

$$P_A = P_{TA} \times P_B \quad \text{(E NB.1)}$$

P_{TA} and P_B are determined from Tables NB.1 and NB.2 of Annex NB

$$P_A = 1 \times 1$$

$$P_A = 1$$

b) Probability that a flash to a structure will cause physical damage P_B

With reference to Table NB.2 of Annex NB. For a structure with no protection by an LPS, $P_B = 1$

c) Probability that a flash to a line will cause injury to living beings by electric shock P_U

$$P_U = P_{TU} \times P_{EB} \times P_{LD} \times C_{LD} \quad \text{(E NB.8)}$$

P_{TU} is determined from Table NB.6 of Annex NB. $P_{TU} = 1$

P_{EB} is determined from Table NB.7 of Annex NB. $P_{EB} = 1$ for both lines

P_{LD} is determined from Table NB.8 of Annex NB. $P_{LD} = 1$ for both lines

C_{LD} is determined from Table NB.4 of Annex NB. $C_{LD} = 1$ for both lines

$$P_U = 1 \times 1 \times 1 \times 1$$

$$P_U = 1 \quad \text{for both lines}$$

Probability that a flash to a line will cause physical damage P_V

$$P_V = P_{EB} \times P_{LD} \times C_{LD} \quad \text{(E NB.9)}$$

$$P_V = 1 \times 1 \times 1$$

$$P_V = 1 \quad \text{for both lines}$$

Expected annual loss of human life (including permanent injury)

Loss L_T defines losses due to injuries by electric shock inside or outside buildings.

Loss L_F defines losses due to physical damage applicable to various classifications of structures (eg hospitals, schools, museums).

$L_T = 1 \times 10^{-2}$ (See Table NC.2 - all types of structure)

$L_F = 1$ (See Table NC.2 - Large house)

In order to calculate the following loss factors the following should be noted:

NOTE 1. When a structure is treated as a single zone the ratio n_z / n_t should equate to a value of 1.

NOTE 2. Where the value of t_z is unknown, the ratio t_z / 8760 should equate to a value of 1.

a) Calculate loss related to injury of living beings L_A

$$L_A = r_t \times L_T \times \frac{n_z}{n_t} \times \frac{t_z}{8760} \quad \text{(E NC.1)}$$

$$L_A = 0.00001 \times 0.01 \times 1 \times 1$$

$$L_A = 1 \times 10^{-7}$$

b) Calculate loss in structure related to physical damage (flashes to structure) L_B

$$L_B = r_p \times r_f \times h_z \times L_F \times \frac{n_z}{n_t} \times \frac{t_z}{8760} \quad \text{(E NC.3)}$$

$$L_B = 1 \times 1 \times 0.01 \times 1 \times 1 \times 1$$

$$L_B = 1 \times 10^{-2}$$

c) Calculate loss related to injury of living beings (flashes to service line) L_U

$$L_U = r_t \times L_T \times \frac{n_z}{n_t} \times \frac{t_z}{8760} \quad \text{(E NC.2)}$$

$$L_U = 0.00001 \times 0.01 \times 1 \times 1$$

$$L_U = 1 \times 10^{-7}$$

d) Calculate loss in structure related to physical damage (flashes to service line) L_V

$$L_V = r_p \times r_f \times h_z \times L_F \times \frac{n_z}{n_t} \times \frac{t_z}{8760} \quad \text{(E NC.3)}$$

$$L_V = 1 \times 1 \times 0.01 \times 1 \times 1 \times 1$$

$$L_V = 1 \times 10^{-2}$$

Risk of loss of human life (including permanent injury) R_1

The primary consideration in this example is to evaluate the risk of loss of human life (including permanent injury) R_1. Risk R_1 is made up from the following elements/coefficients

$$R_1 = R_A + R_B + R_C{}^* + R_M{}^* + R_U + R_V + R_W{}^* + R_Z{}^* \quad \text{(E 1)}$$

* Only for structures with risk of explosion and for hospitals with life saving electrical equipment or other structures when failure of internal systems immediately endangers human life.

Thus, in this case

$$R_1 = R_A + R_B + R_{U(P)} + R_{V(P)} + R_{U(T)} + R_{V(T)}$$

a) Calculate risk to the structure resulting in shock to humans R_A

$$R_A = N_D \times P_A \times L_A \quad \text{(E 6)}$$

$$R_A = 0.0018 \times 1 \times 1 \times 10^{-7}$$

$$R_A = 1.8 \times 10^{-10} \quad \text{say } R_A = 0$$

b) Calculate risk to the structure resulting in physical damage R_B

$$R_B = N_D \times P_B \times L_B \quad \text{(E 7)}$$

$$R_B = 0.0018 \times 1 \times 1 \times 10^{-2}$$

$$R_B = 1.805 \times 10^{-5}$$

c) Calculate risk to the power line resulting in shock to humans $R_{U(P)}$

$$R_{U(P)} = \left(N_{L(P)} + N_{DJ(P)}\right) P_U \times L_U \quad \text{(E 10)}$$

$$R_{U(P)} = \left(0.014 + 0\right) \times 1 \times 1 \times 10^{-7}$$

$$R_{U(P)} = 1.4 \times 10^{-9} \quad \text{say } R_{U(P)} = 0$$

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d) Calculate risk to the power line resulting in physical damage $R_{V(P)}$

$$R_{V(P)} = \left(N_{L(P)} + N_{DJ(P)}\right) P_V \times L_V \quad \text{(E 11)}$$

$$R_{V(P)} = \left(0.014 + 0\right) \times 1 \times 1 \times 10^{-2}$$

$$R_{V(P)} = 1.4 \times 10^{-4} \quad \text{or} \quad 14 \times 10^{-5}$$

e) Calculate risk to the telecom line resulting in shock to humans $R_{U(T)}$

$$R_{U(T)} = \left(N_{L(T)} + N_{DJ(T)}\right) P_U \times L_U \quad \text{(E 10)}$$

$$R_{U(T)} = \left(0.028 + 0\right) \times 1 \times 1 \times 10^{-7}$$

$$R_{U(T)} = 2.8 \times 10^{-9} \quad \text{say } R_{U(T)} = 0$$

f) Calculate risk to the telecom line resulting in physical damages $R_{V(T)}$

$$R_{V(T)} = \left(N_{L(T)} + N_{DJ(T)}\right) P_V \times L_V \quad \text{(E 11)}$$

$$R_{V(T)} = \left(0.028 + 0\right) \times 1 \times 1 \times 10^{-2}$$

$$R_{V(T)} = 2.8 \times 10^{-4} \quad \text{or} \quad 28 \times 10^{-5}$$

Thus:

$$R_1 = R_A + R_B + R_{U(P)} + R_{V(P)} + R_{U(T)} + R_{V(T)}$$

$$R_1 = 0 + 1.805 + 0 + 14 + 0 + 28$$

$$R_1 = 43.805 \times 10^{-5}$$

This result is now compared with the tolerable risk R_T for the risk of loss of human life (including permanent injury) R_1.

Thus:

$$R_1 = 43.805 \times 10^{-5} > R_T = 1 \times 10^{-5}$$

Therefore protection measures need to be instigated.

The overall risk R_1 may also be expressed in terms of the source of damage. *Source of damage, page 14.*

$$R = R_D + R_I$$

Where:

$$R_D = R_A + R_B$$

$$R_D = 0 + 1.805$$

$$R_D = 1.805$$

Thus:

$$R_D = 1.805 \times 10^{-5} > R_T = 1 \times 10^{-5}$$

Therefore protection measures against a direct strike to the structure need to be instigated.

And

$$R_I = R_{U(P)} + R_{V(P)} + R_{U(T)} + R_{V(T)}$$

Where:

$$R_I = 0 + 14 + 0 + 28$$

$$R_I = 42$$

Thus:

$$R_I = 42 \times 10^{-5} > R_T = 1 \times 10^{-5}$$

Therefore protection measures against an indirect strike to the structure need to be instigated.

Analysing the component results that make up R_1 we can see that $R_{V(T)}$ is by far the largest contributor to the actual risk R_1

Component $R_{V(T)}$ = 28 and R_1 = 43.805

Thus component $R_{V(T)}$ represents:

$$\left(\frac{28}{43.805}\right) \times 100\% = 63.9\% \text{ of } R_1$$

Component $R_{V(P)}$ is next significant contributor to R_1

Component $R_{V(P)}$ represents:

$$\left(\frac{14}{43.805}\right) \times 100\% = 31.9\% \text{ of } R_1$$

$R_{V(T)}$ and $R_{V(P)}$ represent 95.8% of reason why $R_1 > R_T$

Protection measures

To reduce the risk to the tolerable value the following protection measures could be adopted:

Solution A

To reduce R_D we should apply a structural Lightning Protection System and so reduce P_B from 1 to a lower value depending on the Class of LPS (I to IV) that we choose.

By the introduction of a structural Lightning Protection System, we automatically need to install service entrance lightning current SPDs at the entry points of the incoming telecom and power lines, corresponding to the structural class of LPS. This reduces $R_{V(T)}$ and $R_{V(P)}$ to a lower value, depending on the choice of Class of LPS. If we apply a structural LPS Class IV, we can assign P_B = 0.2

Thus:

$$R_B = N_D \times P_B \times L_B \quad \text{(E 22)}$$

$$R_B = 0.0018 \times 0.2 \times 1 \times 10^{-2}$$

$$R_B = 3.6 \times 10^{-6} \quad \text{or} \quad 0.36 \times 10^{-5}$$

Similarly we need to apply SPDs at the entrance point of the building for the power and telecom lines corresponding with the structural protection measure ie SPDs to LPL III-IV. We therefore assign P_{EB} = 0.05.

Thus:

$$R_{V(P)} = \left(N_{L(P)} + N_{DJ(P)}\right) P_V \times L_V \quad \text{(E 11)}$$

$$R_{V(P)} = \left(0.014 + 0\right) \times 0.05 \times 1 \times 10^{-2}$$

$$R_{V(P)} = 7 \times 10^{-6} \quad \text{or} \quad 0.7 \times 10^{-5}$$

Similarly:

$$R_{V(T)} = \left(N_{L(T)} + N_{DJ(T)}\right) P_V \times L_V \quad \text{(E 11)}$$

$$R_{V(T)} = \left(0.028 + 0\right) \times 0.05 \times 1 \times 10^{-2}$$

$$R_{V(T)} = 1.4 \times 10^{-5}$$

Risk	Value x 10^{-5}
R_A	≈0
R_B	0.36
$R_{U(P)}$	≈0
$R_{V(P)}$	0.7
$R_{U(T)}$	≈0
$R_{V(T)}$	1.4
Total	**2.46**

Risks > 1x10^{-5} are shown in red. Risks ≤ 1x10^{-5} are shown in green

Table 6.5: Summary of individual risks after first attempt at protection solution A

Thus:

$$R_1 = 2.46 \times 10^{-5} > R_T = 1 \times 10^{-5}$$

Therefore additional protection measures need to be instigated.

We now continue and fit a higher Class of LPS.

For the purposes of this example we will assume that we have already recalculated the risk using a structural LPS of Class III and it still exceeds the tolerable limit.

If we now apply a structural LPS of Class II, we can assign P_B = 0.05.

Thus:

$$R_B = N_D \times P_B \times L_B \quad \text{(E 7)}$$

$$R_B = 0.0018 \times 0.05 \times 1 \times 10^{-2}$$

$$R_B = 9.02 \times 10^{-7} \quad \text{or} \quad 0.09 \times 10^{-5}$$

We now need to apply SPDs to LPL II at the entrance point of the building for the power and telecom lines, to correspond with the structural protection measure. We therefore assign P_{EB} = 0.02.

Thus:

$$R_{V(P)} = \left(N_{L(P)} + N_{DJ(P)}\right) P_V \times L_V \quad \text{(E 11)}$$

$$R_{V(P)} = \left(0.014 + 0\right) \times 0.02 \times 1 \times 10^{-2}$$

$$R_{V(P)} = 2.8 \times 10^{-6} \quad \text{or} \quad 0.28 \times 10^{-5}$$

Similarly:

$$R_{V(T)} = \left(N_{L(T)} + N_{DJ(T)}\right) P_V \times L_V \quad \text{(E 11)}$$

$$R_{V(T)} = \left(0.028 + 0\right) \times 0.02 \times 1 \times 10^{-2}$$

$$R_{V(T)} = 5.6 \times 10^{-6} \quad \text{or} \quad 0.56 \times 10^{-5}$$

Risk	Value x 10^{-5}
R_A	≈0
R_B	0.09
$R_{U(P)}$	≈0
$R_{V(P)}$	0.28
$R_{U(T)}$	≈0
$R_{V(T)}$	0.56
Total	**0.93**

Risks > 1x10^{-5} are shown in red. Risks ≤ 1x10^{-5} are shown in green

Table 6.6: Summary of individual risks after second attempt at protection solution A

Thus:

$$R_1 = 0.93 \times 10^{-5} < R_T = 1 \times 10^{-5}$$

Therefore protection has been achieved.

Solution:

Install a structural LPS Class II along with service entrance SPDs to LPL II on both the incoming power and telecom lines (25 kA 10/350 μs per mode for mains Type 1 SPDs and 2.5 kA 10/350 μs per mode for telecom SPDs).

Solution B

An alternative approach would be to revisit the first attempt at solution A ie a structural LPS of Class IV. If we now use SPDs with superior protection characteristics (ie lower let-through voltage) we can apply SPDs to LPL III-IV* for both the telecom and power lines, ie we can assign P_{EB} = 0.005 (see Table NB.7).

Thus:

$$R_{V(P)} = (N_{L(P)} + N_{DJ(P)})P_V \times L_V \quad \text{(E 11)}$$

$$R_{V(P)} = (0.014 + 0) \times 0.005 \times 1 \times 10^{-2}$$

$$R_{V(P)} = 0.7 \times 10^{-6} \text{ or } 0.07 \times 10^{-5}$$

Similarly:

$$R_{V(T)} = (N_{L(T)} + N_{DJ(T)})P_V \times L_V \quad \text{(E 11)}$$

$$R_{V(T)} = (0.028 + 0) \times 0.005 \times 1 \times 10^{-2}$$

$$R_{V(T)} = 0.14 \times 10^{-5}$$

Risk	Value x 10^{-5}
R_A	≈0
R_B	0.36
$R_{U(P)}$	≈0
$R_{V(P)}$	0.07
$R_{U(T)}$	≈0
$R_{V(T)}$	0.14
Total	**0.57**

Risks > 1x10^{-5} are shown in red. Risks ≤ 1x10^{-5} are shown in green

Table 6.7: Summary of individual risks for protection solution B

Thus:

$$R_1 = 0.57 \times 10^{-5} < R_T = 1 \times 10^{-5}$$

Therefore protection has been achieved.

Solution:

Install a structural LPS Class IV along with service entrance SPDs to LPL III-IV* on both the incoming power and telecom lines (12.5 kA 10/350 μs per mode for mains Type 1 SPDs and 2.5 kA 10/350 μs per mode for telecom SPDs).

Solution C

If we maintain service entrance SPDs with the lower let-through voltage ie SPDs to LPL III-IV* on both the incoming telecom and power lines, but this time install an automatically operated alarm or extinguishing installation throughout the house then r_p can be reduced from no fire provision r_p = 1 to r_p = 0.2. No structural protection is installed.

Thus:

$$L_B = L_V = r_p \times r_f \times h_z \times L_F \quad \text{(E NC.3)}$$

$$L_B = L_V = 0.2 \times 0.01 \times 1 \times 1$$

$$L_B = L_V = 2 \times 10^{-3}$$

So:

$$R_B = N_D \times P_B \times L_B \quad \text{(E 7)}$$

$$R_B = 0.0018 \times 1 \times 2 \times 10^{-3}$$

$$R_B = 3.6 \times 10^{-6} \text{ or } 0.36 \times 10^{-5}$$

Similarly:

$$R_{V(P)} = (N_{L(P)} + N_{DJ(P)})P_V \times L_V \quad \text{(E 11)}$$

$$R_{V(P)} = (0.014 + 0) \times 0.005 \times 0.002$$

$$R_{V(P)} = 1.4 \times 10^{-7} \text{ or } 0.014 \times 10^{-5}$$

Similarly:

$$R_{V(T)} = (N_{L(T)} + N_{DJ(T)})P_V \times L_V \quad \text{(E 11)}$$

$$R_{V(T)} = (0.028 + 0) \times 0.005 \times 0.002$$

$$R_{V(T)} = 2.8 \times 10^{-7} \text{ or } 0.028 \times 10^{-5}$$

Risk	Value x 10^{-5}
R_A	≈0
R_B	0.36
$R_{U(P)}$	≈0
$R_{V(P)}$	0.014
$R_{U(T)}$	≈0
$R_{V(T)}$	0.028
Total	**0.402**

Risks > 1x10^{-5} are shown in red. Risks ≤ 1x10^{-5} are shown in green

Table 6.8: Summary of individual risks for protection solution C

Thus:

$R_1 = 0.402 \times 10^{-5} < R_T = 1 \times 10^{-5}$

Therefore protection has been achieved.

Solution:

Install an automatic fire alarm or extinguishing system at strategic points throughout the house and install structural service entrance SPDs to LPL III-IV* on both the incoming power and telecom lines.

Decision

As can be seen by this example of the Country house there are several “protection measure” solutions. One option is a structural LPS Class II combined with service entrance lightning current SPDs to LPL II on both incoming service lines.

Another solution is a structural LPS Class IV combined with service entrance lightning current SPDs to LPL III-IV* (ie with a lower let-through voltage) on both incoming service lines.

A third option is the installation of an automatic fire system in the house and the installation of service entrance SPDs to LPL III-IV* (ie with a lower let-through voltage) on both incoming service lines. According to table NC.4, an automatic system is either a sprinkler system, or a fire alarm which automatically dials out. In the case of the latter, it should only be treated as automatic if it is protected against overvoltages and the fire brigade can attend site within 10 minutes, something which is very difficult to guarantee.

All three solutions ensure that the actual risk R_1 is lower than the tolerable value R_T.

However, the practical issues with the third option mean that the second option of a structural LPS Class IV with service entrance lightning current SPDs to LPL III-IV* is, in this case, the most economic solution.

SPD recommendations

Solution B was deemed to be the most cost effective and practical option, involving the installation of a structural LPS class IV, and service entrance SPDs on the incoming power and telecom lines.

As a structural LPS is required, all incoming cables should be fitted with service entrance lightning current SPDs to LPL III-IV*.

The enhanced or * category of SPD indicates that an SPD with a voltage protection level of no more than 1000 V should be used, based on a domestic consumer unit having a voltage withstand of 2.5 kV (see Table 3.5 Note 3, 3rd paragraph on page 32). The power supply is single phase, so an ESP 240 M1 (based on the partial lightning currents being shared between the power and telecom lines, see pages 73-74 and Figure 5.4 for more details on current division) should be installed at the consumer unit, on the load side of the main isolator, housed within a WBX 3 enclosure.

The telecom cable feeds a single BT socket. An ESP TN/JP fitted at the BT socket would offer the required level of protection.

6.3 Example 2: Office block

Consider a small five storey office block housing an insurance company (see Figure 6.2) near King's Lynn in Norfolk. The structure is situated in flat territory with a number of similarly sized neighbouring structures. It is fed by an underground power line 650 m long and underground telecom line of unknown length. The dimensions of the structure are:

L = 40 m

W = 20 m

H = 15 m

In this specific example the risk of loss of human life (including permanent injury) R_1 and loss of service to the public R_2 should be considered.

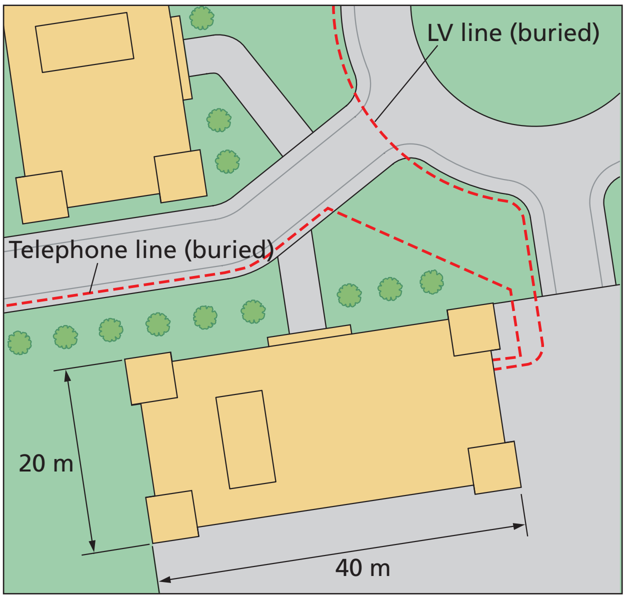

Figure 6.2: Office block

Assigned values

The following tables identify the characteristics of the structure, its environment and the lines connected to the structure.

- Table 6.9: Characteristics of the structure and its environment
- Table 6.10: Characteristics of incoming LV power line and connected internal equipment
- Table 6.11: Characteristics of incoming telecom line and connected internal equipment

The equation numbers or table references shown subsequently in brackets relate to their location in BS EN 62305-2.

Throughout this example a numerical subscript will be added to several factors. This subscript will identify the major risk to which the factors relate. For example loss L_T relating to the risk R_2 will be written as L_{T2}.

Parameter	Comment	Symbol	Value
Dimensions (m)	-	L_B, W_B, H_B	40, 20, 15
Location factor	Surrounded by objects same height or smaller	C_D	0.5
Line environment factor	Urban (buildings between 10 and 20 m)	C_E	0.1
LPS	None	P_B	1
Shield at structure boundary	None	K_{S1}	1
People present inside/outside the structure	Yes	n_t	200
Lightning flash density	1/km²/year	N_G	0.7

Table 6.9: Characteristics of the structure and its environment

Parameter	Comment	Symbol	Value
Length (m)	-	L_L	650
Line type	LV power	C_T	1
Line shielding	None	P_{LD}	1
Internal wiring precaution	None	K_{S3}	1
Withstand of internal system (kV)	None	U_W	2.5
SPD Protection	None	P_{EB}	1

Table 6.10: Characteristics of incoming LV power line and connected internal equipment

Parameter	Comment	Symbol	Value
Length (m)	-	L_L	1,000
Line type	Telecoms	C_T	1
Line shielding	None	P_{LD}	1
Internal wiring precaution	None	K_{S3}	1
Withstand of internal system (kV)	None	U_W	1.5
SPD Protection	None	P_{EB}	1

Table 6.11: Characteristics of incoming telecom line and connected internal equipment

Definition of zones

The following characteristics of the structure have been considered in order to divide it into zones:

- The type of floor surface is different in the entrance area, in the garden and inside the structure
- The structure is a unique fireproof compartment
- The archive within the structure is a unique fireproof compartment
- No spatial shields exist within the structure
- Both electrical systems are common throughout the structure

The following zones are defined:

- Z_1 - Entrance area to the building
  see Table 6.12
- Z_2 - Garden
  see Table 6.13
- Z_3 - Archive
  see Table 6.14
- Z_4 - Offices
  see Table 6.15
- Z_5 - Computer centre
  see Table 6.16

Parameter	Comment	Symbol	Value
Soil surface type	Marble	r_t	1×10^{-3}
Shock protection	None	P_{TA}	1
Loss by touch and step voltages	Yes	L_T	See Expected amount of loss pages 104-105
People potentially in danger in the zone	-	n_p	4

Table 6.12: Characteristics of Zone Z_1 (Entrance area)

Parameter	Comment	Symbol	Value
Soil surface type	Grass	r_t	1×10^{-2}
Shock protection	Fence	P_{TA}	0
Loss by touch and step voltages	Yes	L_T	See Expected amount of loss pages 104-105
People potentially in danger in the zone	-	n_p	2

Table 6.13: Characteristics of Zone Z_2 (Garden)

Parameter	Comment	Symbol	Value
Floor surface type	Linoleum	r_t	1×10^{-5}
Shock protection	None	P_{TU}	1
Risk of fire	High	r_f	0.5
Special hazard	Low panic	h_z	2
Fire protection	Automatic	r_p	0.2
Spatial shield	None	K_{S2}	1
Internal power systems	Yes	Connected to LV power line	-
Internal telephone systems	Yes	Connected to telecom line	-
Loss by touch and step voltages	Yes	L_T	See Expected amount of loss pages 104-105
Loss by physical damage	Yes	L_F	See Expected amount of loss pages 104-105
People potentially in danger in the zone	-	n_p	20 persons

Table 6.14: Characteristics of Zone Z_3 (Archive)

Parameter	Comment	Symbol	Value
Floor surface type	Linoleum	r_t	1×10^{-5}
Shock protection	None	P_{TU}	1
Risk of fire	Ordinary	r_f	0.01
Special hazard	Low panic	h_z	2
Fire protection	Manual	r_p	0.5
Spatial shield	None	K_{S2}	1
Internal power systems	Yes	Connected to LV power line	-
Internal telephone systems	Yes	Connected to telecom line	-
Loss by touch and step voltages	Yes	L_T	See Expected amount of loss pages 104-105
Loss by physical damage	Yes	L_F	See Expected amount of loss pages 104-105
People potentially in danger in the zone	-	n_p	160 persons

Table 6.15: Characteristics of Zone Z_4 (Offices)

Parameter	Comment	Symbol	Value
Floor surface type	Linoleum	r_t	1 x 10^{-5}
Shock protection	None	P_{TU}	1
Risk of fire	Ordinary	r_f	0.01
Special hazard	Low panic	h_z	2
Fire protection	Manual	r_p	0.5
Spatial shield	None	K_{S2}	1
Internal power systems	Yes	Connected to LV power line	-
Internal telephone systems	Yes	Connected to telecom line	-
Loss by touch and step voltages	Yes	L_T	See Expected amount of loss pages 104-105
Loss by physical damages	Yes	L_F	See Expected amount of loss pages 104-105
People potentially in danger in the zone	-	n_p	14 persons

Table 6.16: Characteristics of Zone Z_5 (Computer centre)

The actual risk is now determined in the following sections. Each risk component (where appropriate) is now calculated for each of the five zones. Long hand calculation stages already illustrated in Example 1 will not be repeated for this example. Results will be given in tabular form.

Collection areas

Calculate the collection areas of the structure and the power and telecom lines in accordance with Annex A of BS EN 62305-2. The calculated values are summarized in Table 6.17.

Symbol	Area (m²)
A_D	12,561.73
A_M	845,398.2
$A_{L(P)}$	26,000
$A_{L(T)}$	40,000
$A_{I(P)}$	2,600,000
$A_{I(T)}$	4,000,000

Table 6.17: Example 2 - Summary of collection areas

Number of dangerous events

Calculate the expected annual number of dangerous events (ie number of flashes) in accordance with Annex A of BS EN 62305-2. The calculated values are summarized in Table 6.18.

Symbol	Value
N_D	0.0044
N_M	0.5918
$N_{L(P)}$	0.0009
$N_{L(T)}$	0.0014
$N_{I(P)}$	0.091
$N_{I(T)}$	0.14

Table 6.18: Example 2 - Summary of dangerous events

Probability of damage

Ascertain the probability of each particular type of damage occurring in the structure in accordance with Annex NB of BS EN 62305-2. The values are summarized in Table 6.19.

Probability	Z_1	Z_2	Z_3	Z_4	Z_5
P_A	1	0	1	1	1
P_B	N/A	N/A	1		
$P_{U(P)}$	N/A	N/A	1		
$P_{V(P)}$	N/A	N/A	1		
$P_{U(T)}$	N/A	N/A	1		
$P_{V(T)}$	N/A	N/A	1		

Table 6.19: Example 2 - Summary of probabilities of damage

Expected amount of loss - Risk of loss of human life (including permanent injury)

Loss L_{T1} relates to losses due to injuries by electric shock voltages inside or outside buildings.

Loss L_{F1} relates to losses due to physical damage applicable to various classifications of structures (eg hospitals, schools, museums).

With reference to Table NC.2 of BS EN 62305-2 the following values have been chosen:

$L_{T1} = 1 \times 10^{-2}$ For external zones Z_1 and Z_2

$L_{T1} = 1 \times 10^{-2}$ For internal zones Z_3, Z_4 and Z_5

$L_{F1} = 0.42$ For an office block

These values relate to the structure as a whole. Therefore these losses must be apportioned between the individual zones of the structure, based upon the occupancy of each zone.

Values of L_x are determined for each individual zone using the equations shown in Table NC.1 or BS EN 62305-2. For example.

$$L_A = r_t \times L_T \times \frac{n_z}{n_t} \times \frac{t_z}{8760} \quad \text{(NC.1)}$$

It can be seen in Table 6.14 that zone Z_3 is occupied by 20 persons. As the time of occupancy is unknown the ratio t_z/8,760 is equated to 1 and therefore ignored.

Loss related to injury of living beings L_A in zone 3, for example is:

$$L_{A1} = r_t \times L_T \times \frac{n_z}{n_t}$$

$$L_{A1} = 0.00001 \times 0.01 \times \frac{20}{200}$$

$$L_{A1} = 1 \times 10^{-8}$$

The calculated values of the component losses are summarized in Table 6.20.

Probability	Z_1	Z_2	Z_3	Z_4	Z_5
L_{A1}	2.000 x 10^{-7}	1.000 x 10^{-6}	1.000 x 10^{-8}	8.000 x 10^{-8}	7.000 x 10^{-9}
L_{B1}	N/A	N/A	1.680 x 10^{-3}	3.360 x 10^{-3}	2.940 x 10^{-4}
L_{U1}	N/A	N/A	1.000 x 10^{-8}	8.000 x 10^{-8}	7.000 x 10^{-9}
L_{V1}	N/A	N/A	1.680 x 10^{-3}	3.360 x 10^{-3}	2.940 x 10^{-4}

Table 6.20: Example 2 - Summary of R_1 component losses

Expected amount of loss - Unacceptable loss of service to the public

Loss L_{F2} relates to losses due to physical damage applicable to various classifications of service provider (eg gas, water, financial, health etc).

Loss L_{O2} relates to losses due to failure of internal systems applicable to various classifications of service provider (eg gas, water, financial, health etc).

With reference to Table NC.8 of BS EN 62305-2 the following values have been chosen:

L_{F2} = 0.1 for a financial service provider

L_{O2} = 0.01 for a financial service provider

These values relate to the structure as a whole. Therefore these losses must be apportioned between the individual zones of the structure, based upon the service provided by each zone.

However in the absence of any information regarding the factors n_z, n_t and t, in each of the defined zones, the value chosen from Table NC.8 will be apportioned equally between the three internal zones of the structure. Zones 1 and 2 are not considered to contribute to the provision of and therefore the loss of service to the public. This effectively treats the structure as a single zone for this type of loss.

The calculated values of L_{F2} and L_{O2} are summarized in Table 6.21.

Zone	L_{F2}	L_{O2}
1 & 2	N/A	N/A
3 to 5	3.33 x 10^{-2}	3.33 x 10^{-3}

Table 6.21: Example 2 - Summary of annual losses

Loss related to injury of living beings in zone 3, for example is:

$$L_{B2} = r_p \times r_f \times L_{F2} \quad \text{(E NC.4)}$$

$$L_{B2} = 0.2 \times 0.1 \times 0.033$$

$$L_{B2} = 6.667 \times 10^{-4}$$

The calculated values of the component losses are summarized in Table 6.22.

Probability	Z_1	Z_2	Z_3	Z_4	Z_5
L_{B2}	N/A	N/A	6.667 x 10^{-4}	1.667 x 10^{-4}	1.667 x 10^{-4}
L_{C2}	N/A	N/A	3.333 x 10^{-3}	3.333 x 10^{-3}	3.333 x 10^{-3}
L_{M2}	N/A	N/A	3.333 x 10^{-3}	3.333 x 10^{-3}	3.333 x 10^{-3}
L_{V2}	N/A	N/A	6.667 x 10^{-4}	1.667 x 10^{-4}	1.667 x 10^{-4}
L_{W2}	N/A	N/A	3.333 x 10^{-3}	3.333 x 10^{-3}	3.333 x 10^{-3}
L_{Z2}	N/A	N/A	3.333 x 10^{-3}	3.333 x 10^{-3}	3.333 x 10^{-3}

Table 6.22: Example 2 - Summary of R_2 component losses

Risk of loss of human life (including permanent injury) R_1

The primary consideration in this example is to evaluate the risk of loss of human life (including permanent injury) R_1. Risk R_1 is made up from the following risk components:

$$R_1 = R_A + R_B + R_C{}^* + R_M{}^* + R_U + R_V + R_W{}^* + R_Z{}^* \quad (1)$$

* Only for structures with risk of explosion and for hospitals with life saving electrical equipment or other structures when failure of internal systems immediately endangers human life.

From this point on a subscript letter will be added to several factors relating to lines entering the structure. This subscript (P or T) will identify whether the factor relates to the Power or Telecom line.

Thus, in this case:

$$R_1 = R_{A1} + R_{B1} + R_{U1(P)} + R_{V1(P)} + R_{U1(T)} + R_{V1(T)}$$

Risk to the structure resulting in physical damages R_B in Zone 3 for example is:

$$R_{B1} = N_D \times P_B \times L_{B1} \quad \text{(E 7)}$$

$$R_{B1} = 0.0044 \times 1 \times 1.680 \times 10^{-3}$$

$$R_{B1} = 7.392 \times 10^{-6}$$

The calculated values are summarized in Table 6.23.

Risk	Z_1	Z_2	Z_3	Z_4	Z_5	Total
R_{A1}	8.793×10^{-10}	0	4.397×10^{-11}	3.517×10^{-10}	3.708×10^{-11}	1.306×10^{-9}
R_{B1}	N/A	N/A	7.386×10^{-6}	1.477×10^{-5}	1.293×10^{-6}	2.345×10^{-5}
$R_{U1(P)}$	N/A	N/A	9.100×10^{-12}	7.208×10^{-11}	6.370×10^{-12}	8.827×10^{-11}
$R_{U1(T)}$	N/A	N/A	1.400×10^{-11}	1.120×10^{-10}	9.800×10^{-12}	1.358×10^{-10}
$R_{V1(P)}$	N/A	N/A	1.529×10^{-6}	3.058×10^{-6}	2.675×10^{-7}	4.854×10^{-6}
$R_{V1(T)}$	N/A	N/A	2.352×10^{-6}	4.704×10^{-6}	4.116×10^{-7}	7.468×10^{-6}
Total	8.793×10^{-10}	0	1.127×10^{-5}	2.253×10^{-5}	1.972×10^{-6}	**3.577×10^{-5}**

Risks > 1×10^{-5} are shown in red. Risks ≤ 1×10^{-5} are shown in green

Table 6.23: Example 2 - Summary of R_1 component risks

This result is now compared with the tolerable risk R_T for risk of loss of human life (including permanent injury) R_1.

Thus:

$$R_1 = 3.577 \times 10^{-5} > R_T = 1 \times 10^{-5}$$

Therefore protection measures need to be instigated.

Risk of loss of service to the public R_2

The secondary consideration in this example is to evaluate the risk of loss of service to the public R_2. Risk R_2 is made up from the following risk components:

$$R_2 = R_B + R_C + R_M + R_V + R_W + R_Z \quad (2)$$

Thus, in this case:

$$R_2 = R_{B2} + R_{C2} + R_{M2} + R_{V2(P)} + R_{V2(T)} + R_{W2(P)} + R_{W2(T)} + R_{Z2(P)} + R_{Z2(T)}$$

Risk to the structure resulting in physical damage R_B in Zone 3 for example is:

$$R_{B2} = N_D + P_B + L_{B2} \quad \text{(E 7)}$$

$$R_{B2} = 0.0044 \times 1 \times 6.667 \times 10^{-4}$$

$$R_{B2} = 2.933 \times 10^{-6}$$

The calculated values are summarized in Table 6.24.

Risk	Z_1	Z_2	Z_3	Z_4	Z_5	Total
R_{B2}	N/A	N/A	2.931×10^{-6}	7.328×10^{-7}	7.328×10^{-7}	4.397×10^{-6}
R_{C2}	N/A	N/A	1.466×10^{-5}	1.466×10^{-5}	1.466×10^{-5}	4.397×10^{-6}
R_{M2}	N/A	N/A	1.052×10^{-3}	1.052×10^{-3}	1.052×10^{-3}	3.156×10^{-3}
$R_{V2(P)}$	N/A	N/A	6.067×10^{-6}	1.517×10^{-7}	1.517×10^{-7}	9.100×10^{-7}
$R_{V2(T)}$	N/A	N/A	9.333×10^{-7}	2.333×10^{-7}	2.333×10^{-7}	1.400×10^{-6}
$R_{W2(P)}$	N/A	N/A	3.033×10^{-6}	3.033×10^{-6}	3.033×10^{-6}	9.100×10^{-6}
$R_{W2(T)}$	N/A	N/A	4.667×10^{-6}	4.667×10^{-6}	4.667×10^{-6}	1.400×10^{-5}
$R_{Z2(P)}$	N/A	N/A	9.009×10^{-5}	9.009×10^{-5}	9.009×10^{-5}	2.703×10^{-4}
$R_{Z2(T)}$	N/A	N/A	2.310×10^{-4}	2.310×10^{-4}	2.310×10^{-4}	6.930×10^{-4}
Total	N/A	N/A	1.400×10^{-3}	1.397×10^{-3}	1.397×10^{-3}	**41.932×10^{-4}**

Risks > 1×10^{-4} are shown in red. Risks ≤ 1×10^{-4} are shown in green

Table 6.24: Example 2 - Summary of R_2 component risks

This result is now compared with the tolerable risk R_T for loss of service to the public R_2.

Thus:

$$R_2 = 41.932 \times 10^{-4} > R_T = 1 \times 10^{-4}$$

Therefore protection measures need to be instigated.

Protection Measures

To reduce the risks to the tolerable value the following protection measures could be adopted:

Solution A

To reduce R_{D1} we should apply a structural Lightning Protection System and so reduce P_B from 1 to a lower value depending on the Class of LPS (I to IV) that we choose.

By the introduction of a structural Lightning Protection System, we automatically need to install service entrance lightning current SPDs at the entry points of the incoming telecom and power lines, corresponding to the structural Class of LPS.

For a first attempt at reducing R_{D1} we will apply a structural LPS Class IV.

This reduces $R_{V(T)}$ and $R_{V(P)}$ to a lower value, depending on the choice of Class of LPS.

The re-calculated values relating to risk of loss of human life (including permanent injury) R_1 are summarized in Table 6.25.

Risk	Z_1	Z_2	Z_3	Z_4	Z_5	Total
R_{A1}	1.759 x 10^{-10}	0	8.793 x 10^{-12}	7.035 x 10^{-11}	6.155 x 10^{-12}	2.612 x 10^{-10}
R_{B1}	N/A	N/A	1.477 x 10^{-6}	2.955 x 10^{-6}	2.585 x 10^{-7}	4.690 x 10^{-6}
$R_{U1(P)}$	N/A	N/A	4.550 x 10^{-13}	3.640 x 10^{-12}	3.185 x 10^{-13}	4.414 x 10^{-12}
$R_{U1(T)}$	N/A	N/A	7.000 x 10^{-13}	5.600 x 10^{-12}	4.900 x 10^{-13}	6.790 x 10^{-12}
$R_{V1(P)}$	N/A	N/A	7.644 x 10^{-8}	1.529 x 10^{-7}	1.338 x 10^{-8}	2.427 x 10^{-7}
$R_{V1(T)}$	N/A	N/A	1.176 x 10^{-7}	2.352 x 10^{-7}	2.058 x 10^{-8}	3.734 x 10^{-7}
Total	1.759 x 10^{-10}	0	1.671 x 10^{-6}	3.343 x 10^{-6}	2.925 x 10^{-7}	**5.307 x 10^{-6}**

Risks > 1x10^{-5} are shown in red. Risks ≤ 1x10^{-5} are shown in green

Table 6.25: Example 2 - Summary of R_1 component risks for protection solution A

Thus:

$$R_1 = 0.531 \times 10^{-5} < R_T = 1 \times 10^{-5}$$

Therefore protection has been achieved with regard to risk of loss of human life (including permanent injury) R_1.

Risk R_2 is now recalculated based upon the protection measures applied above.

The re-calculated values relating to loss of service to the public R_2 are summarized in Table 6.26.

Risk	Z_1	Z_2	Z_3	Z_4	Z_5	Total
R_{B2}	N/A	N/A	5.862 x 10^{-7}	1.466 x 10^{-7}	1.466 x 10^{-7}	8.793 x 10^{-7}
R_{C2}	N/A	N/A	1.466 x 10^{-5}	1.466 x 10^{-5}	1.466 x 10^{-5}	4.397 x 10^{-5}
R_{M2}	N/A	N/A	1.052 x 10^{-3}	1.052 x 10^{-3}	1.052 x 10^{-3}	3.156 x 10^{-3}
$R_{V2(P)}$	N/A	N/A	3.033 x 10^{-8}	7.583 x 10^{-9}	7.583 x 10^{-9}	4.550 x 10^{-8}
$R_{V2(T)}$	N/A	N/A	4.667 x 10^{-8}	1.167 x 10^{-8}	1.167 x 10^{-8}	7.000 x 10^{-8}
$R_{W2(P)}$	N/A	N/A	3.033 x 10^{-6}	3.033 x 10^{-6}	3.033 x 10^{-6}	9.100 x 10^{-6}
$R_{W2(T)}$	N/A	N/A	4.667 x 10^{-6}	4.667 x 10^{-6}	4.667 x 10^{-6}	1.400 x 10^{-5}
$R_{Z2(P)}$	N/A	N/A	9.009 x 10^{-5}	9.009 x 10^{-5}	9.009 x 10^{-5}	2.703 x 10^{-4}
$R_{Z2(T)}$	N/A	N/A	2.310 x 10^{-4}	2.310 x 10^{-4}	2.310 x 10^{-4}	6.930 x 10^{-4}
Total	N/A	N/A	1.396 x 10^{-3}	1.396 x 10^{-3}	1.396 x 10^{-3}	**41.875 x 10^{-4}**

Risks > 1x10^{-4} are shown in red. Risks ≤ 1x10^{-4} are shown in green

Table 6.26: Example 2 - Summary of R_2 component risks for protection solution A

Clearly the application of a structural LPS and service entrance lightning current SPDs has had little effect on the major contributors to risk R_2 ie R_{M2} and R_{Z2}. With reference to Table 3.4, it can be seen that the reduction of probabilities P_M and P_Z is directly related to the presence or otherwise of a coordinated set of SPDs.

Therefore we will introduce a coordinated set of SPDs (corresponding to the structural Class LPS) to all internal systems connected to the incoming telecom and power lines to reduce components R_{M2} and R_{Z2}.

Initial calculations show that although the application of a coordinated set of SPD of LPL IV does reduce the components R_{M2} and R_{Z2}, the overall result is still slightly too high. The final solution is to use an enhanced coordinated set of SPDs fitted to equipment connected to the telecom line.

The re-calculated values relating to loss of service to the public R_2 are summarized in Table 6.27.

It should be noted that the use of an enhanced SPD on the service entrance of the telecom line (as part of a coordinated set) will give a further reduction in the risk of loss of human life (including permanent injury).

Risk	Z_1	Z_2	Z_3	Z_4	Z_5	Total
R_{B2}	N/A	N/A	5.862×10^{-7}	1.466×10^{-7}	1.466×10^{-7}	8.793×10^{-7}
R_{C2}	N/A	N/A	8.024×10^{-7}	8.024×10^{-7}	8.024×10^{-7}	2.407×10^{-6}
R_{M2}	N/A	N/A	2.013×10^{-5}	2.013×10^{-5}	2.013×10^{-5}	6.039×10^{-5}
$R_{V2(P)}$	N/A	N/A	3.033×10^{-8}	7.583×10^{-9}	7.583×10^{-9}	4.550×10^{-8}
$R_{V2(T)}$	N/A	N/A	4.667×10^{-9}	1.167×10^{-9}	1.167×10^{-9}	7.000×10^{-9}
$R_{W2(P)}$	N/A	N/A	1.517×10^{-7}	1.517×10^{-7}	1.517×10^{-7}	4.550×10^{-7}
$R_{W2(T)}$	N/A	N/A	2.333×10^{-8}	2.333×10^{-8}	2.333×10^{-8}	7.000×10^{-8}
$R_{Z2(P)}$	N/A	N/A	4.505×10^{-6}	4.505×10^{-6}	4.505×10^{-6}	1.351×10^{-6}
$R_{Z2(T)}$	N/A	N/A	1.155×10^{-6}	1.155×10^{-6}	1.155×10^{-6}	3.465×10^{-6}
Total	N/A	N/A	2.739×10^{-5}	2.692×10^{-5}	2.692×10^{-5}	**8.123×10^{-5}**

Risks > 1×10^{-4} are shown in red. Risks ≤ 1×10^{-4} are shown in green

Table 6.27: Example 2 - Summary of R_2 component risks for protection solution B

Thus:

$$R_2 = 0.812 \times 10^{-4} < R_T = 1 \times 10^{-4}$$

Therefore protection has been achieved with regard to loss of service to the public.

Decision

As can be seen by this example of the office block the application of protection measures to reduce the risk of loss of human life (including permanent injury) R_1 does not automatically ensure the reduction of other primary risks, in this case R_2.

The recommended solution is a structural LPS Class IV combined with service entrance lightning current SPDs to LPL III-IV on the incoming power line and to LPL III-IV* on the incoming telecom line.

In addition to this, a coordinated set of SPDs to the same LPLs above should be applied to all internal systems connected to the incoming telecom and power lines.

This solution ensures that the actual risks R_1 and R_2 are both lower than their tolerable value R_T.

LPS design

Consider further the office block described on page 102. The results after evaluating the risks R_1 and R_2 was the installation of a structural LPS Class IV combined with service entrance lightning current SPDs to LPL III-IV on both incoming service lines (to reduce R_1) and additionally a coordinated set of SPDs to LPL III-IV for power/SPDs to LPL III-IV* for telecoms (to reduce R_2). The design of these protection measures is detailed in the following sections.

The office block is of a 1950s construction. The building is of a traditional brick and block construction with a flat felted roof. The building dimensions and roof levels are shown in Figure 6.3.

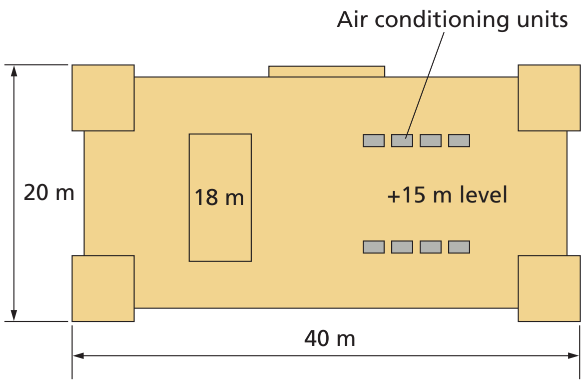

Figure 6.3 Example 2 - Office block dimensions

Air termination network

The type of construction allows a non-isolated type LPS to be fitted. The air termination network will be designed using the mesh method. According to Table 2 of BS EN 62305-3 a structure fitted with an LPS Class IV requires an air termination mesh with maximum dimensions of 20 m x 20 m. The air termination mesh is illustrated in Figure 6.4.

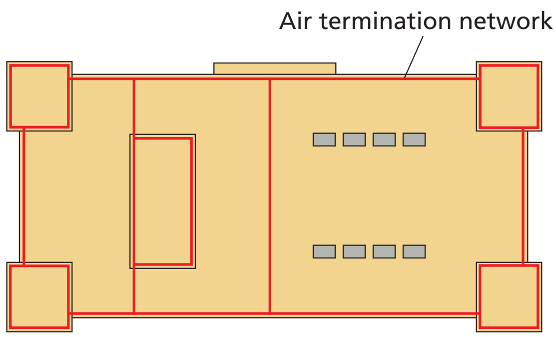

Figure 6.4 Example 2 - Air termination mesh

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The mesh method is suitable for the protection of plane surfaces only. The thickness of the metallic casing of the eight air conditioning (AC) units is sufficiently thin that in the event of a direct lightning strike, the casing could well be punctured. Therefore an LPZ 0_B should be created for the area of the air conditioning units, by means of vertical air rods using the protective angle method.

As a vertical air rod will be used to protect each air conditioning unit from a direct lightning discharge, an isolation/separation distance between the air conditioning unit and the air rod needs to be calculated. This separation distance, once calculated, will be used to ascertain if there is sufficient physical space between the air rod and the air conditioning unit. If there is sufficient space on the roof then the separation distance can be satisfied and as such no direct or partial lightning current should be transmitted into the structure via any mechanical service lines connected to the air conditioning unit. However, there is the possibility of induced LEMP entering the structure via any metallic service lines and as such a mains Type 2 overvoltage SPD (ESP 415 M1) should be installed and connected to the nearest equipotential bonding bar.

If, however, the separation distance cannot be achieved due to space restrictions on the roof then the air rod should be positioned to maintain the protective angle zone of protection afforded to the air conditioning unit and additionally the air rod should be bonded directly to the casing of the air conditioning unit. Although the air conditioning unit should not receive a direct lightning strike, it will in the event of a lightning discharge, carry partial lightning current via its casing and any connected metallic service lines into the structure. In this case a mains Type 1 lightning current SPD to LPL IV (ESP 415/III/TNS) should be installed and connected to the nearest equipotential bonding bar.

In order to establish the separation distance the following formula is used. *For more information see Separation (isolation) distance of the external LPS, page 64.*

$$s = \frac{k_i}{k_m} \times k_c \times l \qquad (4.5)$$

Two aspects have to be considered. Firstly the separation distance required from the edge of the roof down to ground level (separation distance A) ie l = 15 m. Secondly the separation distance required from the edge of the roof to the AC unit plus the height of the AC unit (separation distance B) ie l = 3 m + 0.75 m = 3.75 m.

Therefore, for separation distance A:

k_i = 0.04 (for LPS Class IV)

k_c = 1 (for 6 down conductors, Type A earthing arrangement with each earth rod having a dissimilar resistance value, ie differing by more than a factor of 2)

k_m = 0.5 (for building materials)

l = 15 m

So:

s = 1.2 m

And for separation distance B:

k_i = 0.04 (for LPS Class IV)

k_c = 1 (for 6 down conductors, Type A earthing arrangement with each earth rod having a dissimilar resistance value, ie differing by more than a factor of 2)

k_m = 0.5 (for building materials)

l = 3.75 m

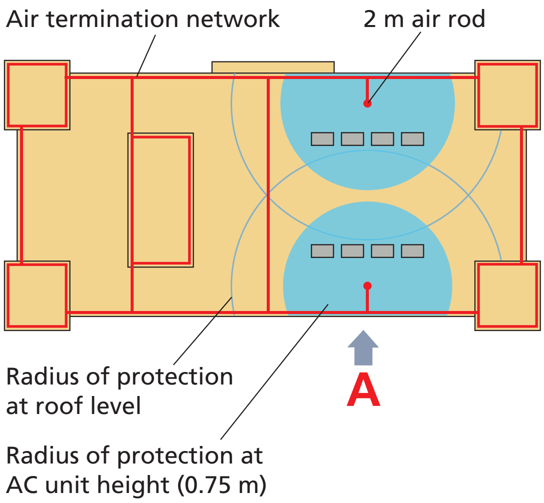
So:

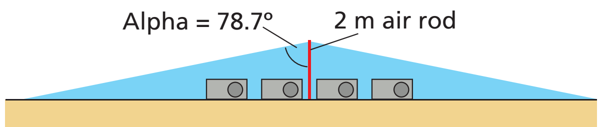
s = 0.3 m

Thus a separation distance of 1.5 m (1.2 m + 0.3 m) is required between the air rod and the air conditioning unit to prevent any possible flashover in the event of a lightning discharge striking the air rod.

In this case there is sufficient space to maintain a separation distance of 1.5 m between each air rod and each air conditioning unit. Additionally a mains Type 2 overvoltage SPD (ESP 415 M1) should be connected to the live cores of the electrical cables and connected to the nearest equipotential bonding bar.

The dimensions of each air conditioning unit are 1,000 mm x 400 mm x 750 mm high. Thus, if a 2 m air rod is placed (centrally) at least 1.5 m away from a bank of four units (see Figure 6.5), the protective angle of 78.7 degrees (see Table 4.3, LPS Class IV) produces a radius of protection (at roof level) of 10 m. Each of the four AC units falls within the zone of protection afforded by this air rod. Each air rod (one for each bank of AC units) is subsequently bonded into the mesh air termination system.





View on arrow **A**

Figure 6.5 Protection of air conditioning units

Down conductor network

According to Table 4 of BS EN 62305-3 a structure fitted with an LPS Class IV requires down conductors fitted at 20 m intervals around its perimeter. The perimeter at roof level is 128 m. Therefore 6.4 (say 6) down conductors are required.

Figure 6.6 illustrates the proposed locations of the down conductors.

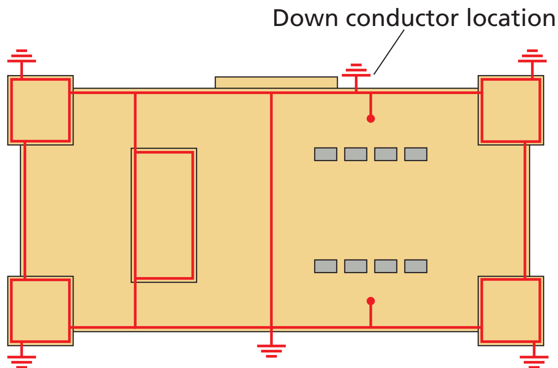


Figure 6.6 Down conductor locations

Earth termination network

We require an earth electrode resistance of 10 ohms or less and we have established that the local soil resistivity ρ is approximately 160 ohm metres.

For this example, as the designer we assume that the soil is suitable for deep driven rod electrodes (Type A arrangement). We can now calculate the depth of rod required to obtain the desired 60 ohms per down conductor to give an overall 10 ohms resistance.

Using Equation 4.2, for vertical rods

$$R = \frac{\rho}{2\pi L}\left[\log_e\left(\frac{8L}{d}\right) - 1\right]$$

Where:

R = Resistance in ohms

ρ = Soil resistivity in ohm metres

L = Length of electrode in metres

d = Diameter of rod in metres

Assume we use a standard ⅝" diameter rod (actual shank diameter 14.2 mm).

If we let L = 3.6 m and substitute to see what value of R is obtained

$$R = \frac{160}{2 \times \pi \times 3.6}\left[\log_e\left(\frac{8 \times 3.6}{0.0142}\right) - 1\right]$$

$$R = 46.814\,\Omega$$

Thus 3.6 m of extensible rods (3 x 1.2 m) can be used to obtain the desired resistance value of 60 ohms per down conductor and 10 ohms overall.

Equipotential bonding

The solution requires a structural LPS Class IV, with service entrance and coordinated SPDs to LPL III/IV for power, and to LPL III-IV* for telecom cables. We now need to look at these systems in more detail in order to select the correct SPDs.

SPDs - Structural LPS

The power supply is a three-phase system, connected to a TN-C-S earth. There is also a twenty pair telecom cable. We do not have details of the construction of the gas and water services, so we will assume they are non-metallic (eg plastic) to give us a more conservative solution. The structural LPS Class IV indicates that we can expect to see lightning current of up to 100 kA striking the building, of which 50 kA will dissipate into the ground, and the other 50 kA will be shared equally amongst the incoming service lines (ie power and telecom). This equates to each cable seeing 25 kA.

The power cable has three phases and a neutral (4 wires), which will each see 6.25 kA (25 kA/4). We therefore need a mains Type 1 lightning current SPD that can handle at least 6.25 kA 10/350 µs current per mode. An ESP 415/III/TNS is required to be installed at the Main Distribution Board (MDB) located near the service entrance (LPZ 1).

We now review the protection for the telecom line. We have already established that this cable could see up to 25 kA partial lightning current which is shared between the twenty pairs (ie 1.25 kA per pair). The cable terminates on a PBX within the IT/comms room, which also houses the distribution frame for the internal extensions. We can protect the twenty pairs, by fitting ESP K10T1 protectors to the two LSA-PLUS disconnection modules within the PBX where the incoming lines terminate. Although not ideal, we cannot fit protection prior to this point in LPZ 1, as the incoming lines belong to the service provider. In addition, there is a dedicated telephone line adjacent to the fire panel, which dials out in the event of an alarm. This line should be protected with an in-line ESP TN/BX hard-wired at the fire panel.

SPDs - Coordinated protection

We now need to consider overvoltage protection to the critical systems within the building. In this building we have the main IT/comms room on the first floor and the fire alarm panel, located just inside the main entrance to the building. Both the comms room and the fire panel are defined as being LPZ 2. The IT/comms room is fed by a three-phase MCB panel, which we protect with an ESP 415 M1, housed alongside the panel in a WBX 4 enclosure. The fire alarm panel should be protected with an ESP 240-5A/BX between the fused spur and the panel itself.

The twenty pair telecom cable is already fitted with ESP K10T1 devices and the dedicated telephone line to the fire panel, with an ESP TN/BX, to address the need for service entrance SPDs on these cables. While the risk assessment calls for coordinated protectors to be fitted on these lines, additional protection may not be required, as the high current handling and low protection levels afforded by these devices mean that they effectively offer coordinated protection of Categories D1, C2 and C1, within the same unit. Additional protection may be required at the terminal equipment if they are located at a distance (> 10 m) from the first point of protection and also if there are internal sources of switching transients such as air-conditioning units, lifts or similarly large inductive loads.

6.4 Example 3: Hospital

The illustration given in BS EN 62305-2 Annex NE of a hospital (Example NE.4) uses risk R_4 to prove the cost effectiveness of protection measures instigated to manage risk R_1.

It is a very time consuming and laborious method to ascertain the results by longhand calculation.

The process to ultimately arrive at a set of results is described in Annex D of BS EN 62305-2.

It is sufficient here to discuss the actual findings.

The two solutions or protection measures both show annual savings of £1,863 and £3,682 respectively.

What the overall economic decision of whether to provide protection measures (or not) does not address are the potential consequential losses.

The loss of critical electrical/electronic equipment through lightning inflicted damage can have enormous financial implications. Hospital equipment itself is highly specialist and expensive. The downtime to replace such bespoke equipment alone justifies adequate protection. In the worst general case scenario, companies may go out of business because of lost data or lost production.

If a finite figure could be applied to these losses then the annual saving of applying the protection measures could be many times that of £1,863 and £3,682.

It is sufficient to conclude that evaluating R_4 (the economic loss) is a very tortuous process and when the potential consequential losses are taken into account, there can be only one recommendation. Apply the recommended protection measures to the structure.

7. Transient overvoltage protection to BS 7671

7.1	*Risk assessment to BS 7671*	*115*
7.2	*Selection of SPDs to BS 7671*	*118*
7.3	*Installation of SPDs to BS 7671*	*119*
7.4	*Protection against overcurrent & SPD end of life conditions*	*123*

7. Transient overvoltage protection to BS 7671

Amendment 1 of the 17th Edition BS 7671 Wiring Regulations was published in July 2011, and came into effect on 1st January 2012 under the reference BS 7671:2008(+A1:2011).

A key update in the Amendment relates to Sections 443 and 534, which concern protection of electrical and electronic systems against transient overvoltages, either as a result of atmospheric origin (lightning) or electrical switching events.

Essentially, the Amendment requires all new electrical system designs and installations, as well as alterations and additions to existing installations as of 1st January 2012, to be assessed against transient overvoltage risk and, where necessary, protected using appropriate protection measures (in the form of SPDs).

Within BS 7671:

- Section 443 defines the criteria for risk assessment against transient overvoltages, considering the supply to the structure, risk factors and impulse withstand voltages of equipment
- Section 534 details the selection and installation of SPDs for effective transient overvoltage protection, including SPD Type, performance and coordination

It is worth bearing in mind that BS 7671 provides guidance only for the assessment and protection of electrical and electronic equipment intended to be installed on AC mains power supplies.

It does not include recommendations for other incoming metallic service lines, such as data, signal and telecommunications lines, which are a potential route through which transient overvoltages can enter into a structure.

For these lines, BS 7671 clearly points the reader back to BS EN 62305 and BS EN 61643 for guidance (see Note 5 in BS 7671 Clause 443.1.1).

Readers of this guide should be mindful of the need to protect all incoming metallic service lines against the risk of transient overvoltages.

Section 5 of this guide, detailing Part 4 of BS EN 62305, should therefore be cross-referenced as necessary for advice on protecting these lines.

7.1 Risk assessment to BS 7671

Section 443 establishes the criteria for risk assessment of transient overvoltages by considering:

- The supply connection to the structure
- External influences (thunderstorm days per year)
- Consequential levels of protection (risk of loss to human life, public service, commercial or industrial activity, groups of individuals or individuals)
- Defined impulse withstand voltages (U_w) of electrical equipment based on their location

In essence, following BS 7671 Section 443, protection against transient overvoltages is required where:

- The electrical supply to the installation is via an overhead metallic service line at risk from lightning, and
- The impulse withstand voltage (U_w) of electrical equipment does not meet the requirements of Tables 44.3 and 44.4 of BS 7671, or the level of transient overvoltage expected would exceed the withstand voltage stated in those tables, or
- The level of risk is determined by the external influences or by consequential levels of protection as being sufficient to warrant the installation of SPDs to counter transient overvoltages

Impulse withstand voltage (U_w) is the maximum value of surge voltage that an item of equipment can withstand before permanent damage through breakdown or sparkover of insulation.

The impulse withstand voltage of equipment depends on the equipment type, its sensitivity and where it is located within the electrical installation.

The required minimum impulse withstand voltage (U_w) per category of equipment for 230/240 V installations is defined in Tables 44.3 and 44.4 of BS 7671, as outlined in Tables 7.1 & 7.2 below.

Equipment at the origin of the installation, such as an electricity meter, or part of the fixed installation, requires a high level of availability within the electrical system and therefore this equipment has a high impulse withstand voltage (eg 6 kV for an electricity meter).

Equipment installed downstream of the service entrance, and especially where connected to final socket outlets, is not considered as critical to the supply and therefore has a lower impulse withstand voltage and falls into a lower category.

BS 7671 makes clear however through Note 3 of Section 443 that *'transient overvoltages transmitted by the supply distribution system are not significantly attenuated downstream in most installations'*.

Therefore, without the installation of protection measures (such as SPDs), downstream equipment connected to the electrical installation (ie Category II and I equipment) is deemed to remain at significant risk from transient overvoltages.

Whilst the rationale supporting Note 3 is not detailed within BS 7671 Section 443, guidance on attenuation of surges within low voltage electrical installations is provided within the IEEE C62.41.1 2002 'Guide to the Surge Environment in Low-Voltage (1000V and Less) AC Power Circuits'.

Nominal voltage of the installation	Required minimum impulse withstand voltage[1]			
	Category IV (equipment with very high impulse voltage)	Category III (equipment with high impulse voltage)	Category II (equipment with normal impulse voltage)	Category I (equipment with reduced impulse voltage)
230/240 V	6 kV	4 kV	2.5 kV	1.5 kV

[1] This impulse withstand voltage is applied between live conductors and PE.

Table 7.1: Minimum impulse withstand voltage to BS 7671 (Section 443, Table 44.3 - 230/240 V shown only)

Category	Example
I	Equipment intended to be connected to the fixed electrical installation where protection is external to the equipment, either in the fixed installation or between the fixed installation and the equipment. Examples of equipment are household appliances, portable tools and similar loads intended to be connected to circuits in which measures have been taken to limit transient overvoltages.
II	Equipment intended to be connected to the fixed electrical installation, e.g. household appliances, portable tools and similar loads, the protective means being either within or external to the equipment.
III	Equipment which is part of the fixed electrical installation and other equipment where a high degree of availability is expected, eg distribution boards, circuit-breakers, wiring systems and equipment for industrial uses, stationary motors with permanent connection to the fixed installation.
IV	Equipment to be used at or in the proximity of the origin of the electrical installation upstream of the main distribution board, eg electricity meter, primary overcurrent device, ripple control unit.

Table 7.2: Examples of various impulse category equipment (Section 443, Table 44.4)

Figure 7.1, taken from this Guide, describes the surge environment within a typical building which can be expected as a result of transient overvoltages either of atmospheric origin or from switching events (excluding direct strikes).

From the figure, voltage surges with an amplitude below the point of flashover of clearances, but still up to 6 kV, can be seen to propagate practically unattenuated to the end of a branch circuit when no low-impedance load (eg local SPD) is present on that circuit. Without the protection measure, electrical equipment connected to the branch circuit would inevitably risk damage.

Table 44.4 of BS 7671 therefore makes clear within its examples for Category II and I equipment that a means of protection against transient overvoltages should have been applied to counter this risk.

Indeed, following Table 44.4, the installation of Category I equipment, such as laptops and computers, should only be on *'circuits in which measures have been taken to limit transient overvoltages.'*

This requirement is further emphasized in the IET's Guidance Note 1 for BS 7671, which states in clause 3.9.4:

> *'Category I equipment ... has a required minimum impulse withstand voltage of 1.5 kV, for a nominal voltage of 230 V, and is not to be connected to the electricity supply without surge protection.'*

Tables 44.3 and 44.4 should therefore be viewed as defining the installation of electrical equipment in a controlled voltage situation, according to impulse withstand voltage (U_w), where the application of surge protection measures is presumed.

Protection against transient overvoltages is not inherent within the electrical system if installed electrical equipment meets the appropriate impulse withstand values given by Table 44.3, rather protection is achieved if the transient overvoltages presented at the electrical equipment are controlled below the equipment's impulse withstand, or if unknown, below the stated minimums.

The installation of a coordinated set of SPDs following Section 534 of BS 7671 and BS EN 62305 would achieve this requirement.

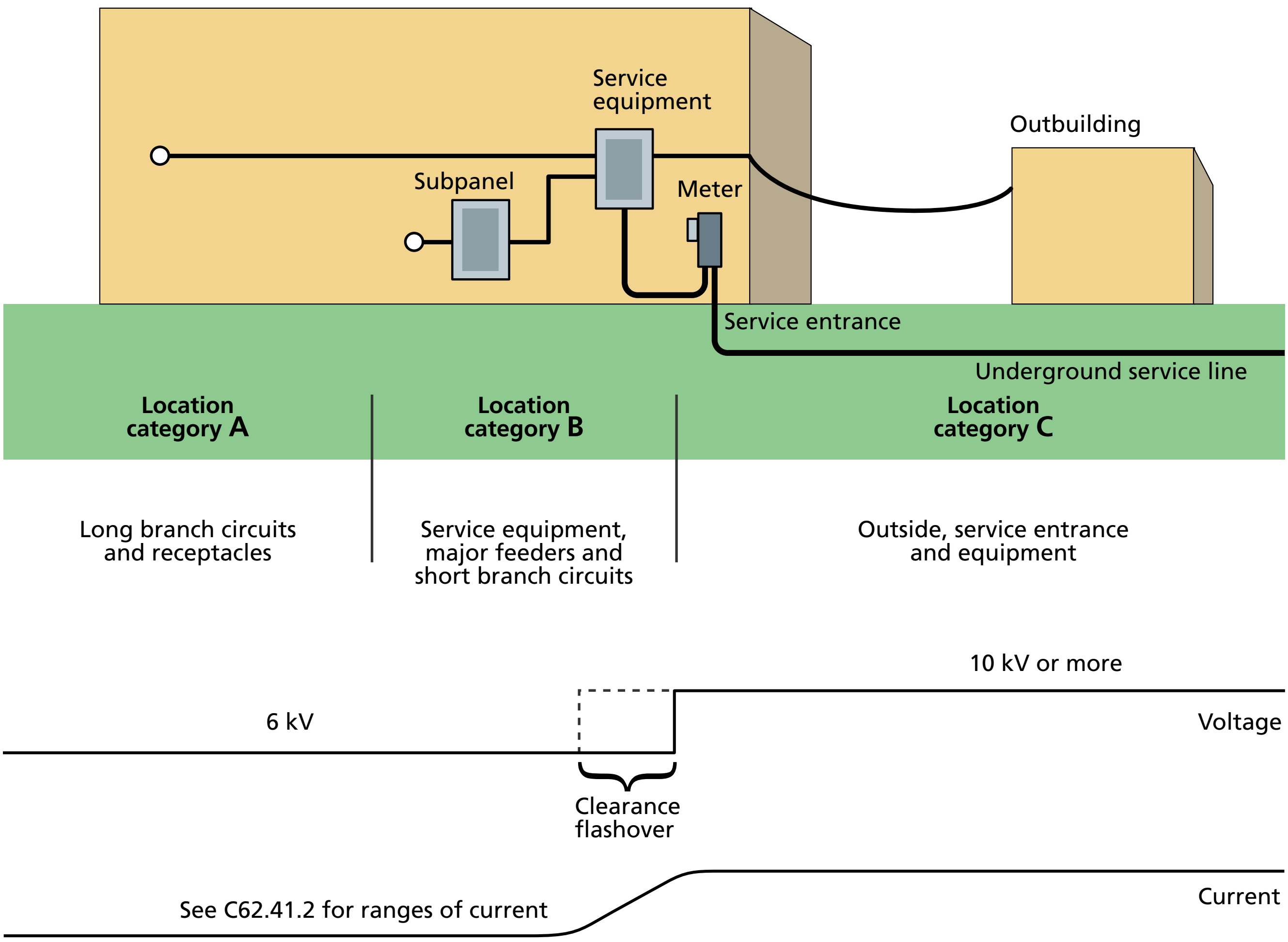


Figure 7.1: Attenuation of surges within low voltage electrical installations

External influences versus consequential levels of protection

Within Clause 443.2 of BS 7671, Arrangements for overvoltage control, two risk assessment methods are presented - risk by external influences or an assessment of risk based on consequential levels of protection.

The evaluation of risk by external influences is based upon AQ values for ceraunic levels or `thunderstorm days', with the critical time frame by which the need for protection measures is assessed being 25 thunderstorm days per year. The number of thunderstorm days in the UK currently falls under this target figure.

However, risk assessment by external influences should be viewed with caution.

Firstly, as previously described, where Category II and I equipment is connected to the electrical installation, the application of surge protection measures is implied by Table 44.4 of Section 443 within the individual Category examples. This requirement would cover a significant number of installations within the UK.

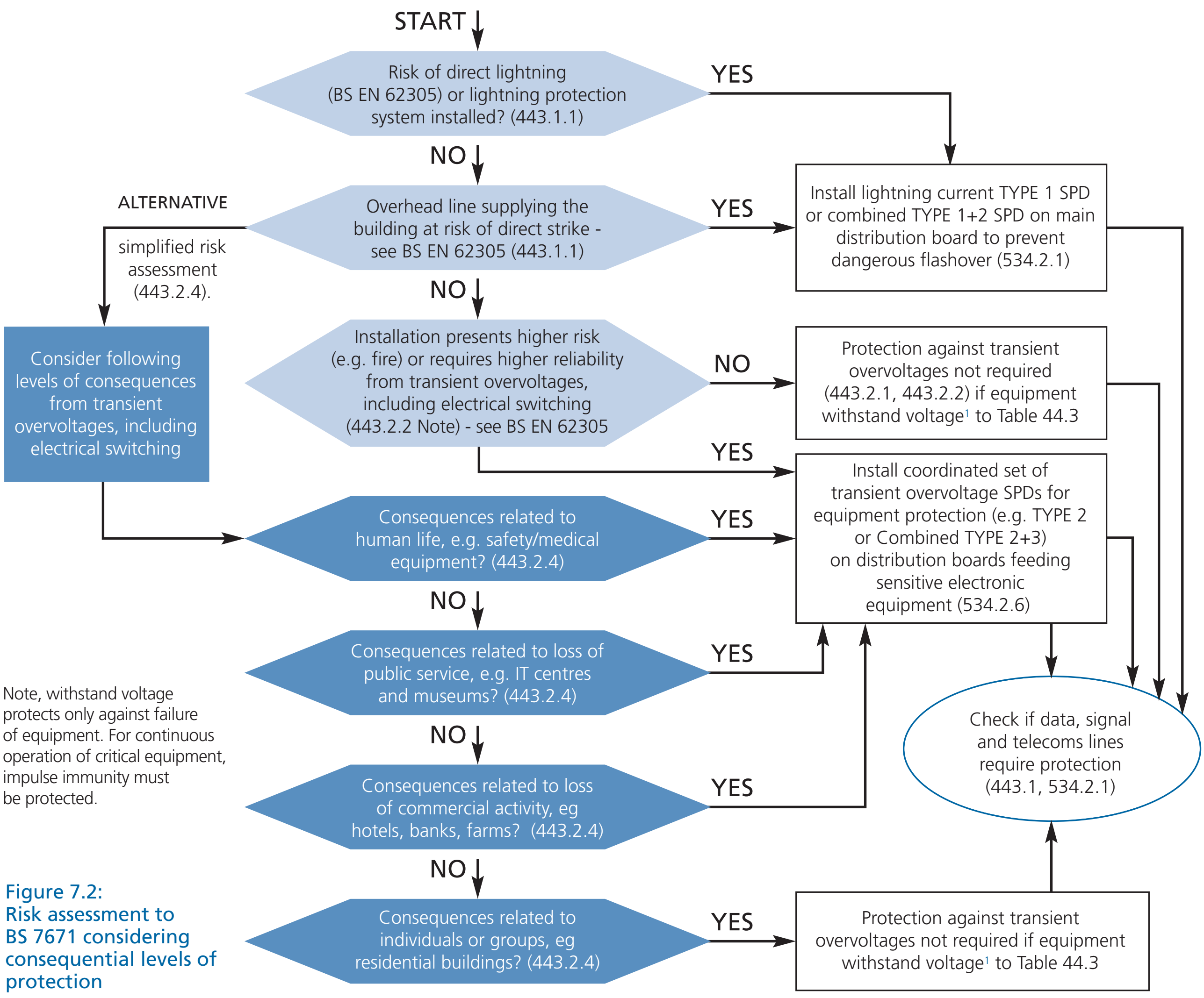
Secondly, following Clause 443.2.2 of BS 7671, where the electrical installation requires higher reliability or where higher risks (eg fire) are expected, the designer should undertake a comprehensive risk assessment in accordance with BS EN 62305-2.

Since risk of fire is a natural consequence of insulation breakdown due to impulse withstand being exceeded, this clause essentially leads the system designer towards the more formal risk assessment approach, as defined by BS EN 62305.

The difference in approach between BS 7671 and BS EN 62305 stems from BS 7671 including the AQ values for ceraunic levels (thunderstorm days) which originated from the IEC 61024 standard for lightning protection 'Protection of structures against lightning'.

This IEC 61024 standard has however been superceded by BS EN 62305, which is identified as the current, applicable standard for lightning protection.

The use of thunderstorm days alone does not align to BS EN 62305 which considers a measured flash density, among many other factors (collection area of a structure, its environment, construction and use, screening and routeing of cables etc), to determine risk.



[1] Note, withstand voltage protects only against failure of equipment. For continuous operation of critical equipment, impulse immunity must be protected.

Figure 7.2: Risk assessment to BS 7671 considering consequential levels of protection

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Additionally, risk assessment to BS EN 62305 ensures that an LPS designer can determine a risk value based on type of loss (R_1 - R_3) directly comparable to defined tolerable risk values, in order to establish whether lightning protection is required. This method is significantly more comprehensive than the BS 7671 approach based on thunderstorm days.

As an alternative, BS 7671 provides the system designer with a risk assessment method in which consequential levels of protection are considered. This method aligns more closely to BS EN 62305 in that risk is based on potential loss.

Five consequential levels of protection are defined:

- Consequences related to human life (eg safety services, medical equipment etc)
- Consequences related to public services (eg loss of public services, IT centres, museums etc)
- Consequences related to commercial or industrial activity
- Consequences to groups of individuals
- Consequences to individuals

For consequences related to human life, public services or commercial or industrial activity, protection measures would always be required.

For consequences related to groups of individuals, or individuals, calculation of risk is based on the critical length of the incoming line to a defined formula in Clause 443.2.4. This formula is based on IEC 61662, and gives a worst case scenario considering the length of overhead supply lines (HV and LV), and underground unscreened supply lines to a structure, in relation to reduction factors.

Essentially, where the conventional length of the line (up to 1 km) exceeds the critical length defined by the formula, protection measures would be required.

Figure 7.2 provides an outline of the process for risk assessment to consequential levels of protection, and clarifies how this correlates to BS EN 62305, and the need to apply SPDs as protection measures following the requirements of Section 534.

The fact that the approaches to risk assessment differ between BS 7671 and BS EN 62305 is recognized by Section 443 Clause 443.1.1 Note 2, in that:

"This section takes into account the technical intent of HD 60364-4-443:2006, which was not fully aligned to BS EN 62305. The IEC are currently reviewing Section 443 and realigning it with IEC 62305"

Bearing this in mind, the system designer or electrical engineer considering overvoltage protection is recommended to select the more formal risk assessment process, to consequential loss, as per BS 7671 Clause 443.2.4 or to follow BS EN 62305 in determining risk, rather than assessment by external influences/thunderstorm days alone.

7.2 Selection of SPDs to BS 7671

The scope of Section 534 of BS 7671 is to achieve overvoltage limitation within AC power systems to obtain insulation coordination, in line with Section 443, and other standards, including BS EN 62305-4.

Overvoltage limitiation is achieved through installation of SPDs as per the recommendations in Section 534 (for AC power systems), and IEC/BS EN 62305-4 (for other power and data, signal or telecommunications lines).

Selection of SPDs should achieve the limitation of transient overvoltages of atmospheric origin, and protection against transient overvoltages caused by direct lightning strikes or lightning strikes in the vicinity of a building protected by a structural LPS.

SPD selection

SPDs should be selected according to the following requirements:

- Voltage protection level (U_P)
- Continuous operating voltage (U_C)
- Temporary overvoltages (U_{TOV})
- Nominal discharge current (I_{nspd}) and impulse current (I_{imp})
- Prospective fault current and the follow current interrupt rating

The most important aspect in SPD selection is its voltage protection level (U_P). The SPD's voltage protection level (U_P) must be lower than the impulse withstand voltage (U_w) of protected electrical equipment, or for continuous operation of critical equipment, its impulse immunity.

Where unknown, impulse immunity can be calculated as twice the peak operating voltage of the electrical system (ie approximately 715 V for 230 V systems).

Non-critical equipment connected to a 230/400 V fixed electrical installation (eg a UPS system) would require protection by an SPD with a U_P lower than Category II impulse withstand voltage (2.5 kV).

Sensitive equipment, such as laptops and PCs, would require additional SPD protection to Category I impulse withstand voltage (1.5 kV).

These figures should be considered as achieving a minimal level of protection. SPDs with lower voltage protection levels (U_P) offer much better protection, by:

- Reducing risk from additive inductive voltages on the SPD's connecting leads
- Reducing risk from voltage oscillations downstream which could reach up to twice the SPD's U_P at the equipment terminals
- Keeping equipment stress to a minimum, as well as improving operating lifetime

In essence, an enhanced SPD (SPD* to BS EN 62305) would best meet the selection criteria, as such SPDs offer voltage protection levels (U_P) considerably lower than standard SPDs and thereby are more effective in achieving a protective state.

The other requirements stipulated by BS 7671 to be considered in selection of SPDs are covered in Table 7.3, below. This information is generally available from manufacturers' product datasheets.

Lightning impulse current (I_{imp}) is only relevant where a Type 1 SPD is required, ie where a building is at risk from a direct lightning strike and therefore includes a structural LPS, or is at risk from a direct lightning strike to a connected overhead metallic service line.

In other cases, nominal discharge current (I_{nspd}) applies (note I_{nspd} is referred to as I_n in BS EN 62305). In these cases a Type 2 and Type 3 SPD (or combined Type 2+3 SPD) should be applied.

As per BS EN 62305, All SPDs installed to meet the requirements of BS 7671 shall conform to the product and testing standard BS EN 61643.

7.3 Installation of SPDs to BS 7671

As stated previously, BS 7671 recognizes that *'transient overvoltages are not significantly attenuated downstream in most installations'* and therefore recommends SPD installation at a number of key locations, including:

- At the service entrance/as close as possible to the origin of the installation (usually in the main distribution board after the electricity meter)
- Downstream as close as practicable to sensitive and critical equipment (sub-distribution board level or local to the equipment)

Where two or more SPDs are installed, these should form a coordinated set, as per BS EN 62305-4.

Essentially, following clauses 534.1, 534.2.1 and 534.2.2 of BS 7671, SPD application and coordination would follow the Lightning Protection Zone (LPZ) concept described in BS EN 62305-4, with SPDs defined by Type according their location and the level of protection required.

Selection criteria	Requirement (for TN & TT installations)[1]
Continuous operating voltage U_C	For TN-C-S, TN-S or TT installations the maximum continuous operating voltage of the SPD shall be equal or greater than: - 1.1 x the nominal a.c rms line voltage of the low voltage system (L-N and L-PE connections) - 1 x the nominal a.c rms line voltage of the low voltage system (N-PE connection).
Temporary overvoltages U_{TOV}	The SPD shall be selected and installed according to manufacturer's instructions.
Nominal discharge current I_{nspd}	SPD selection shall be according to their withstand capability as classified in BS EN 61643-11 or BS EN 61643-21 as appropriate, with I_{nspd} not lower than 5 kA (8/20 μs waveform). For SPDs designed with a 3+1 configuration for TT installations (Connection Type 2 to BS 7671), I_{nspd} on the N-PE connection shall not be lower than 20 kA 8/20 μs (3-phase) or 10 kA 8/20 μs (single phase).
Impulse current I_{imp}	Impulse current I_{imp} need only be considered where a Type 1 SPD is installed as part of a structural lightning protection system, or to protect against risk from direct lightning stokes to an overhead line. In these circumstances the impulse current I_{imp} of the SPD shall be appropriate to its location in the installation, calculated according to BS EN 62305-4. - If I_{imp} **cannot** be calculated, the SPD's withstand shall not be less than 12.5 kA 10/350 μs per mode For SPDs designed with a 3+1 configuration for TT installations (Connection Type 2), I_{imp} on the N-PE connection shall not be less than 50 kA 10/350 μs (3-phase) or 25 kA 10/350 μs (single phase). This applies whether the 3+1 configuration is within a single SPD or devised from a modular SPD arrangement.
Prospective fault current	The short circuit withstand of the SPD combined with the overcurrent protective device (OCPD) shall be equal to or higher than the maximum prospective fault current expected at the point of installation.
Follow current interrupt rating	Follow current interrupt rating only applies where the SPD includes a voltage switching device such as a gas discharge tube. - For L-N, it shall be equal or higher than the fault current expected at the point of installation. - For N-PE in TN & TT installations, it shall be equal to or greater than 100 A.

[1] For IT installations, please refer to BS 7671.

Table 7.3: Requirements for SPD selection

The SPDs selected should have sufficient surge withstand capability for their location, and deliver a voltage protection level (U_P) lower than the impulse withstand voltage of connected equipment (or impulse immunity of critical equipment).

Application of a single SPD at the origin of the installation may suffice to achieve protection, where:

- The installed equipment has sufficient overvoltage withstand, and is close to the distribution board (within 10 metres)
- The SPD provides sufficient modes of protection - sensitive equipment requires both common and differential mode protection

Where the protective distance between the SPD and equipment is greater than 10 m, additional downstream SPDs should be applied to counter risk of voltage oscillations within the electrical system.

These voltage oscillations could effectively double the overvoltage to which terminal equipment is subjected.

SPDs installed local to equipment would also provide protection against switching transients which could occur within the structure, from loads positioned after the SPD at the origin of the installation.

Common and differential mode protection

Since transient overvoltages can occur between all conductors (or modes), ie between L-PE, N-PE (common mode) and L-N (differential mode), BS 7671 recognizes that sensitive electronic systems require both common and differential mode protection (Clause 534.2.2 Note 1).

Selecting and installing an SPD with Full Mode capability, as well as a good voltage protection level U_P in all such modes, would therefore provide the highest level of protection to the electrical system.

Types of SPD

Clause 534.1 defines application of SPDs according to the LPZ concept in BS EN 62305-4, considering the use of Type 1, Type 2 or Type 3 SPDs as appropriate for effective protection against transient overvoltages.

Type 1 SPDs, often referred to as lightning current/ equipotential bonding SPDs, are designed to prevent dangerous sparking caused by flashover where the extremely high voltages from a direct lightning strike have broken down cable insulation. Dangerous sparking and flashover present a risk of fire and electric shock, and therefore life hazard.

Type 1 SPDs should be installed at the origin of the installation.

Their installation is required where:

- A structural LPS is installed, or
- An overhead metallic service line at risk from a direct lightning strike is connected to a building

Type 1 SPDs are designed to protect life in the event of a direct lightning strike to a structure and not to provide protection to electronic systems, which equally may be damaged and degraded by transient overvoltages from indirect lightning.

For the purpose of protecting sensitive and critical electronic systems, Type 2 and/or Type 3 SPDs need to be applied.

These SPD Types protect against transient overvoltages from indirect lightning (ie of atmospheric origin, caused by resistive or inductive coupling of lightning energy on to metallic service lines), or from electrical switching events.

Following BS 7671 Clause 534.2.1, Type 1 or Type 2 SPDs may be installed at the origin of the installation, and Type 2 or Type 3 SPDs may be installed close to the equipment needing protection.

In effect and in accordance with the LPZ concept of BS EN 62305, this would lead to application of Type 1, 2 and 3 SPDs throughout an installation where there is risk from direct lightning, and Type 2 and Type 3 SPDs where there is a risk from indirect lightning. For economic reasons, the use of combined Type SPDs may prove beneficial.

Connection of SPDs

Section 534 contains a number of requirements for the connection and position of SPDs dependent on the type of supply and system earthing.

Two Connection Types are defined (Figures 53.1 and 53.2 of Section 534):

- An SPD configuration based on Connection Type 1 (CT 1) (see Figure 7.3) is typically used for TN-S, TN-C-S systems as well as TT earth arrangements where the SPD is fitted on the load side of the Residual Current Device (RCD)
- An SPD configuration based on Connection Type 2 (CT 2) (see Figure 7.4) is required for TT systems, where the SPD is installed on the supply side of the RCD (often referred to as a '3+1' arrangement)

Installation of SPDs with regard to Residual Current Devices (RCDs)

Ideally, SPDs should be installed upstream of the RCD to avoid nuisance tripping.

However, where this is not possible and the SPD is installed on the load side of the SPD, BS 7671 Clause 534.6 defines the requirement for installation of a time delayed type RCD with an immunity to surge current of at least 3 kA 8/20.

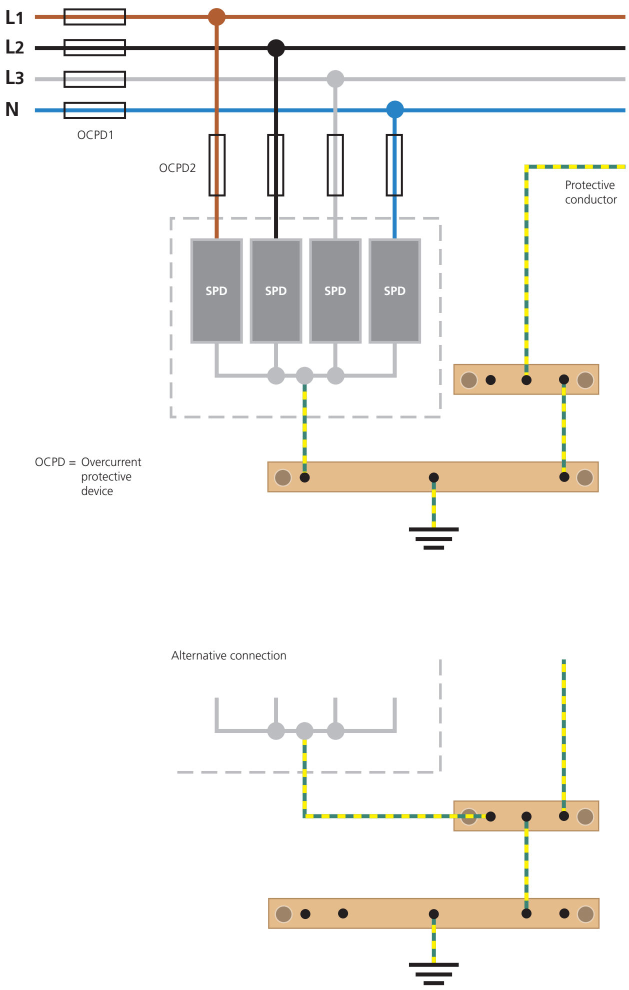

Figure 7.3: Connection Type 1 (CT 1) to BS 7671

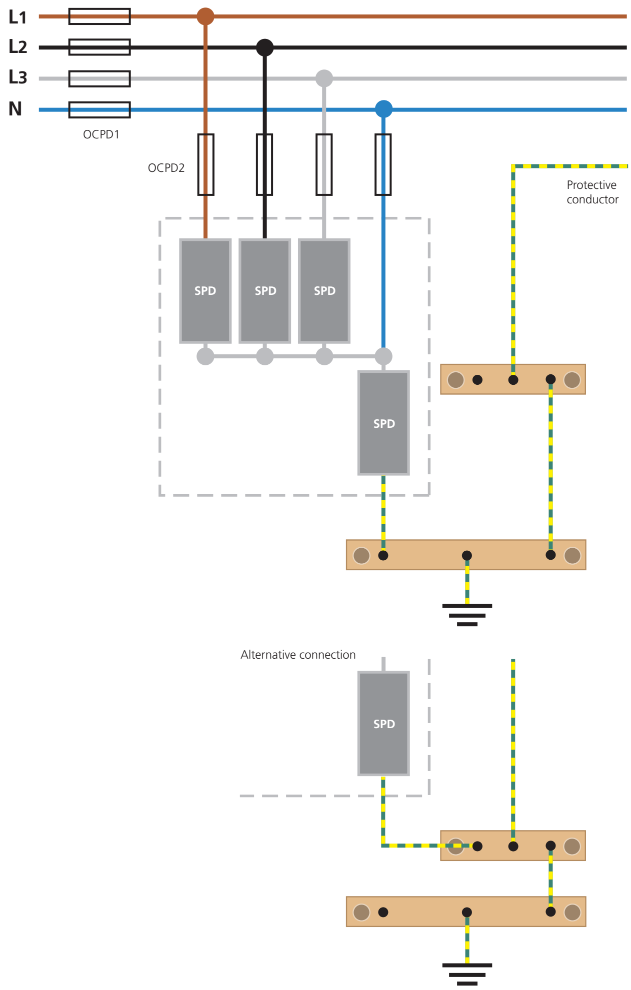

Figure 7.4: Connection Type 2 (CT 2) to BS 7671

An S-type RCD would meet this requirement.

Fault protection integrity for TN systems is achieved through correct operation of the Overcurrent Protective Device (OCPD) on the supply side of the SPD. For TT systems, fault protection integrity is achieved via the RCD (Clause 534.2.5).

In general, TT systems require special attention because they normally have higher impedances which reduce earth fault currents and increase disconnection times of OCPDs. Therefore in order to meet the requirements for safe disconnection times, RCDs are used for earth fault protection.

The SPD arrangement in CT 2 is configured such that the SPDs are applied between the live conductors (L-N) rather than between live and protective conductor (L-PE, N-PE).

Should the SPD become defective it would create a short circuit current rather than an earth fault current and as such would ensure that the OCPD in-line with the SPD safely operates in the required disconnection time. The RCD being on the load side of the SPD would not operate should the SPD become defective.

A higher energy SPD is used between neutral and protective conductor. This higher energy SPD (typically a spark-gap for a Type 1 SPD) is required as lightning currents arise towards the protective conductor and as such this higher energy SPD sees up to four times the surge current of the SPDs connected between the live conductors.

Clause 534.2.3.4.3 of BS 7671 therefore advises that the SPD between neutral and protective conductor is rated at 4 times the magnitude of the SPD between the live conductors. Thus, only if the impulse current I_{imp} cannot be calculated, a minimum value N-PE of 50 kA 10/350 µs is stipulated for a 3-phase CT 2 installation - four times the 12.5 kA requirement between the live conductors.

For a CT 1 installation, the minimum SPD connection requirements at or near the origin of a TN-C-S system as per BS 7671 Fig 16.A illustrates a Type 1 SPD being required between live and PE conductors - the same as required for a TN-S system. Therefore, as far as Section 534 is concerned, TN-C-S systems are to be treated the same as TN-S systems for the selection and installation of SPDs.

Critical length of connecting conductors

An installed SPD will always present a higher let-through voltage to equipment compared with the voltage protection level (U_P) stated on a manufacturer's data sheet, due to additive inductive voltage drops across the conductors on the SPD's connecting leads.

Therefore, for maximum transient overvoltage protection the SPDs connecting conductors must be kept as short as possible.

BS 7671 Clause 534.2.9 defines that for SPDs installed in parallel (shunt), the total lead length between line conductors, protective conductor and SPD preferably should not exceed 0.5 m (see Figure 7.5), and never exceed 1 m. Current loops should be avoided.

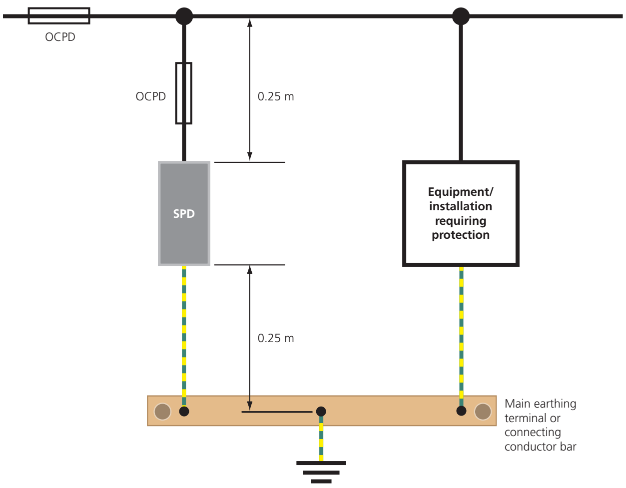

Figure 7.5: Total lead length for SPDs installed in parallel

For SPDs installed in-line (series), the lead length between the protective conductor and SPD preferably should not exceed 0.5 m (see Figure 7.6), and never exceed 1 m.

Poor installation can significantly reduce effectiveness of SPDs. Therefore, keeping connecting leads as short as possible is vital to maximize performance, and minimize additive inductive voltages.

Best practice cabling techniques, such as binding together connecting leads over as much of their length as possible, using cable ties or spiral wrap, is highly effective in cancelling inductance.

The combination of an SPD with low voltage protection level (U_P), and short, tightly bound connecting leads will lead to an optimum controlled installation meeting the requirements of BS 7671.

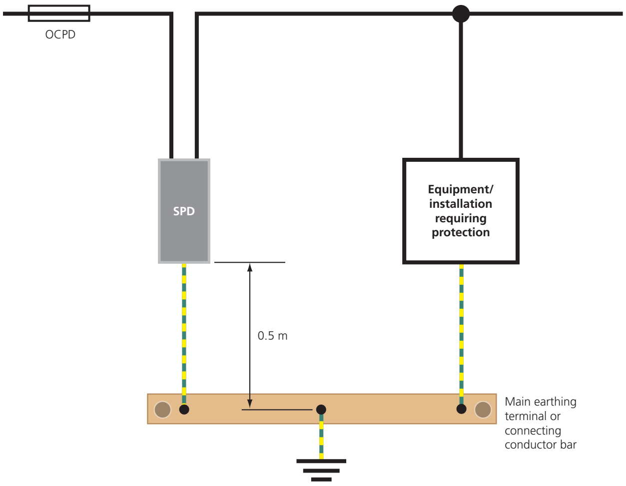

Figure 7.6: Total lead length for SPDs installed in series

Cross-sectional area of connecting conductors

Following BS 7671, the cross-sectional area of the SPD's connecting conductors shall be:

- Not less than 4 mm^2 copper (or equivalent) if the cross-sectional area of the line conductors is greater than or equal to 4 mm^2, or
- Not less than that of the line conductors, where the line conductors have a cross-sectional area less than 4 mm^2
- For Type 1 SPDs, a minimum of 16 mm^2 copper or equivalent, where a structural LPS is installed

These cross-sectional area values are based on the surge current that these SPD connecting leads need to handle, not the supply current.

However, in the event of a short circuit, for example due to the end of life condition of the SPD, the connecting leads to the SPD would need to be protected by a suitable Overcurrent Protective Device (OCPD) - see Section 7.4.

7.4 Protection against overcurrent & SPD end of life conditions

SPDs tested to BS EN 61643 are designed to fail safely when the SPD has reached its natural end of life.

Once this occurs the SPD's internal thermal disconnector will isolate the SPD from the mains supply. The fault condition is overload.

There are also remote conditions which may cause an SPD to fail during its lifetime, which would trigger a short circuit fault. These are:

- The SPD's maximum surge discharge capacity is exceeded, resulting in a strong short circuit. In practice SPDs' surge components such as MOVs are inherently rugged and conservatively rated, and thus exhibit a very low failure rate
- A fault due to the distribution system (neutral/ phase switchover, neutral disconnection) causing phase imbalance leading to temporary overvoltage (U_{TOV}) conditions, subjecting the SPD to operate at steady-state voltages well beyond its nominal voltage ratings U_{nspd}

In these circumstances the SPD's internal thermal disconnector does not have time to warm up and hence, to operate.

The electrical installation must be protected from damage resulting from these types of fault.

BS 7671 defines requirements to ensure that fault protection shall remain effective in the protected installation even in the case of failure of SPDs.

Therefore an SPD needs to be protected against short circuit through the use of an appropriate OCPD capable of eliminating the short-circuit.

The question of overcurrent protection is often confusing in practice where mains power SPDs are concerned, as the vast majority are installed in parallel (shunt) with the supply and the installed SPD itself is therefore independent of the supply load current.

Hence, the cross-sectional area of connecting leads to the SPD do not have to be sized equivalent to the load current. The minimum cross-sectional areas stipulated by BS 7671 are based on the surge current that these SPD connecting leads need to handle. However, in the event of a short circuit, the connecting leads to the SPD would need to be protected by the OCPD.

Where an SPD is installed at the main intake switch panel or a distribution board it should have a separate OCPD to that of the main supply, depending on the maximum prospective current at the point of installation.

In effect, the SPD should have a dedicated OCPD installed in-line on its connecting leads, ensuring that this OCPD to the SPD discriminates with the upstream OCPD of the main supply (see Figure 7.7).

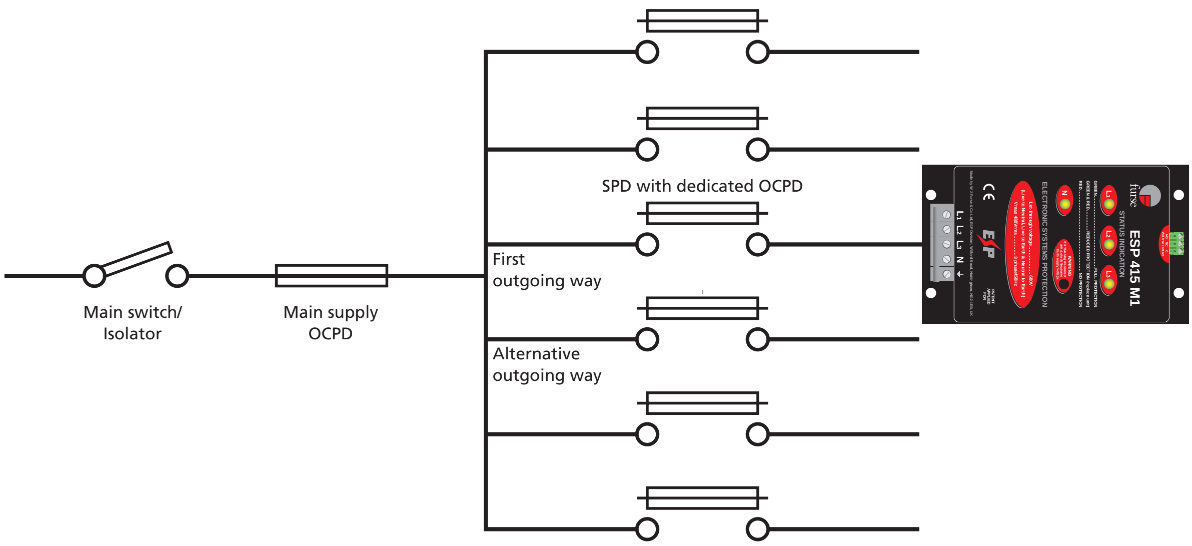

Figure 7.7: OCPD positioning and coordination with the SPD

To determine the capacity of the in-line OCPD to protect the cable to the SPD, Equation 7.1 (as per BS 7671) may be used:

$$I^2t \leq k^2S^2 \quad (7.1)$$

Where:

I^2t relates to the OCPD (this rating can be obtained from OCPD manufacturer data as the total I^2t rating)

k^2S^2 indicates the thermal capacity of the cable, where k is obtained from BS 7671 (or cable manufacturer data) and S is the cable cross-sectional area)

For the connecting cable not to be damaged, the Total I^2t rating of the OCPD must not exceed the k^2S^2 rating of the connecting cable.

By way of example, consider that a typical Type 2 SPD with a peak surge current 40 kA 8/20µs is likely to state a maximum OCPD rating of 125 A and may recommend the use of 10 mm² cable.

A typical 125 A high rupture capacity (HRC) OCPD has a total I^2t rating of approximately 85,000 A²s, and for general purpose cable (70 °C PVC), k is typically 115 (available from cable manufacturer data or BS 7671).

In effect:

$$I^2t = 85{,}000 \text{ A}^2\text{s}$$

$$k^2S^2 = (115 \times 115) \times (10 \times 10)$$

$$k^2S^2 = 1{,}322{,}500$$

From the calculation, it is clear that k^2S^2 at 1,322,500 is significantly in excess of the 85,000 A²s of the cable.

Therefore the OCPD will always protect the 10 mm² cable in the remote event of a short circuit. It is worth noting also that the minimum cross-sectional area of cable required by BS 7671 for a Type 2 SPD, 4 mm², would also be protected by the manufacturer's maximum stated 125 A OCPD.

SPD Manufacturers should provide clear guidance for the selection of the correct ratings of OCPDs in their SPD installation instructions.

The OCPD must be coordinated with the SPD to ensure reliable operation and continuity of service. The OCPD, being in-line with the SPD, must withstand the surge current whilst limiting its residual voltage, and most importantly the OCPD must ensure effective protection against all types of overcurrents.

In accordance with BS EN 61643 SPD product test standards, SPD manufacturers have to declare the maximum OCPD rating that can safely be used with their SPD.

The OCPD rating is selected as part of the SPD testing process to ensure that the full SPD preconditioning and operating duty tests, including the maximum SPD surge current test, do not cause the OCPD to operate.

It is important to ensure that the maximum OCPD rating delared by the SPD manufacturer is never exceeded. However, the maximum OCPD value declared by the SPD manufacturer does not consider the need to discriminate the SPD's OCPD from that of the upstream supply.

Selection of the appropriate OCPD in-line with the SPD must ensure sufficient discrimination with the upstream OCPD of the main supply load.

Installers should refer to OCPD manufacturers' operating characteristics to ensure discrimination, particularly where an installation includes a mixture of types of OCPD. However, as a general rule of thumb, the OCPD for the SPD should be rated at approximately half the value of the upstream supply OCPD.

8. IEC/BS EN 62561 Lightning Protection System Components (LPSC)

8.1 Performance requirements to IEC/BS EN 62561 *127*

8. IEC/BS EN 62561 Lightning Protection System Components (LPSC)

IEC/BS EN 62561 Lightning Protection System Components (LPSC) is a series of standards governing lightning protection component quality and performance, introduced to be the direct replacement of BS EN 50164.

Figure 8.1: Environmental ageing chamber for salt mist and humid sulphurous atmosphere ageing

Selecting appropriately tested and proven components is vital to ensure long term safety is achieved.

LPS designers and those parties responsible for the management and maintenance of such systems need to be assured that the LPSC selected - the air terminals, conductors, connectors, fasteners and earth electrodes etc - will meet the highest levels of performance when it comes to durability, long term exposure to the environmental elements and perhaps most importantly of all, the ability to dissipate the lightning current safely and harmlessly to earth.

For LPS installers, the correct choice in terms of the material, configuration and dimensions of LPSC is essential when linking the various elements of an LPS together for simplicity in installation, and critically, to achieve the effective, fully connected channel through which lightning current can pass to earth.

The IEC/BS EN 62561 series has been compiled with these needs very much in mind.

LPSC which conform to this series of standards offer the assurance that their design and manufacture is suitable for use in LPS installations which meet the requirements of IEC/BS EN 62305.

Currently, there are seven parts to the IEC/BS EN 62561 series of standards, as follows:

- IEC/BS EN 62561-1:2012 Lightning protection system components (LPSC) Part 1: Requirements for connection components
- IEC/BS EN 62561-2:2012 Lightning protection system components (LPSC) Part 2: Requirements for conductors and earth electrodes
- IEC/BS EN 62561-3:2012 Lightning protection system components (LPSC) Part 3: Requirements for isolating spark gaps (ISG)
- IEC 62561-4:2010/BS EN 62561-4:2011 Lightning protection system components (LPSC) Part 4: Requirements for conductor fasteners
- IEC/BS EN 62561-5:2011 Lightning protection system components (LPSC) Part 5: Requirements for earth electrode inspection housings and earth electrode seals
- IEC/BS EN 62561-6:2011 Lightning protection system components (LPSC) Part 6: Requirements for lightning strike counters (LSC)
- IEC 62561-7:2011/BS EN 62561-7:2012 Lightning protection system components (LPSC) Part 7: Requirements for earth enhancing compounds

Each part correlates to the previous BS EN 50164 series for lightning protection components.

The IEC/BS EN 62561 series will fully replace this existing BS EN 50164 series, with all parts of the outgoing series being withdrawn by early 2015.

Figure 8.2: Environmental ageing chamber for ammonia atmosphere ageing

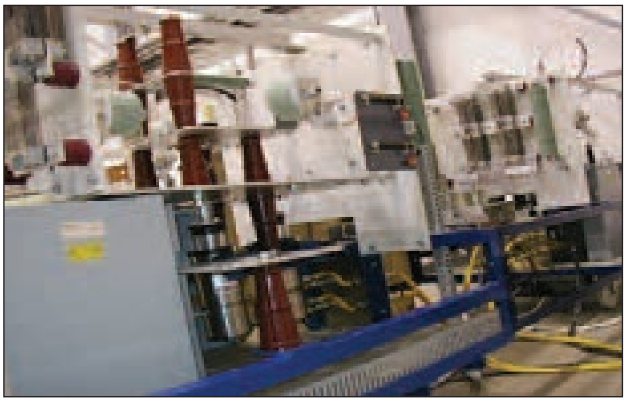

Figure 8.3: 100 kA impulse current generator

8.1 Performance requirements to IEC/BS EN 62561

The various testing and performance requirements for LPSC conforming to each part of the IEC/BS EN 62561 series are outlined in this section.

Tests performed during the course of IEC/BS EN 62561 product testing are defined as ‘Type Tests’. Products, once proven, would not require retesting unless material, design, or manufacturing changes are made which might affect product performance in-situ.

IEC/BS EN 62561-1 specifies the requirements and tests for metallic connection components which form part of an LPS, such as connectors, test joints, flexible and expansion bonds, and other bridging components.

It is a performance specification and attempts to simulate actual installation conditions.

The connection components are configured and tested to create the most onerous application. A pre-conditioning or environmental exposure initially takes place (see Figure 8.1 and Figure 8.2) followed by three 100 kA electrical impulses, which simulate the lightning discharge (see Figure 8.3).

A pre- and post-measuring/installation torque is applied to each component as part of the test regime along with initial and post resistance measurements either side of the electrical impulses.

The tests are carried out on three specimens of the components. The conductors and specimens are prepared and assembled in accordance with the manufacturer’s instructions, eg recommended tightening torques. A typical test arrangement is illustrated in Figure 8.4.

For connection components used above ground, the specimens are subject to a salt mist treatment for three days, followed by exposure to a humid, sulphurous atmosphere for seven days.

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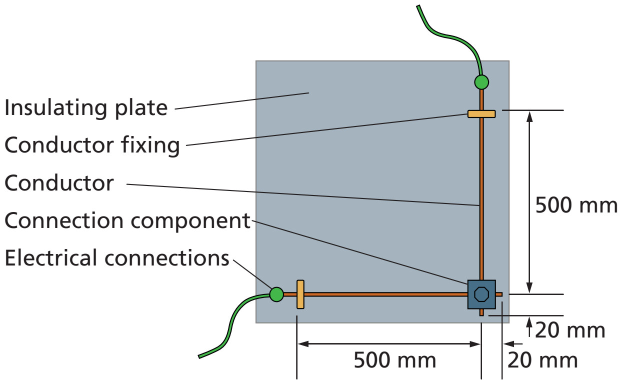

Figure 8.4: Arrangement of specimen for a typical cross-connection component

Figure 8.6: Test/junction clamp (CN105-H)

For specimens made of copper alloy with a copper content of less than 80%, a further one day of ammonia atmosphere treatment is added.

A range of pre-conditioned Furse components alongside an off-the-shelf original are shown in Figures 8.5 to 8.12.

Figure 8.7: Air rod base (SD105-H)

Figure 8.5: Square tape clamp (CT105-H)

Figure 8.8: Two hole earth point (PC115-FU)

Figure 8.9: Type 'B' bond (Part no BN005)

Figure 8.10: Type 'B' bond (Part no BN105)

Figure 8.11: Square clamp (Part no CS610)

The electrical impulse test is particularly onerous. The following photographs (Figure 8.12) show a Furse connection component before and after the electrical impulses. Poorly designed components would have been thrown from the conductors by the enormous electromagnetic forces created.

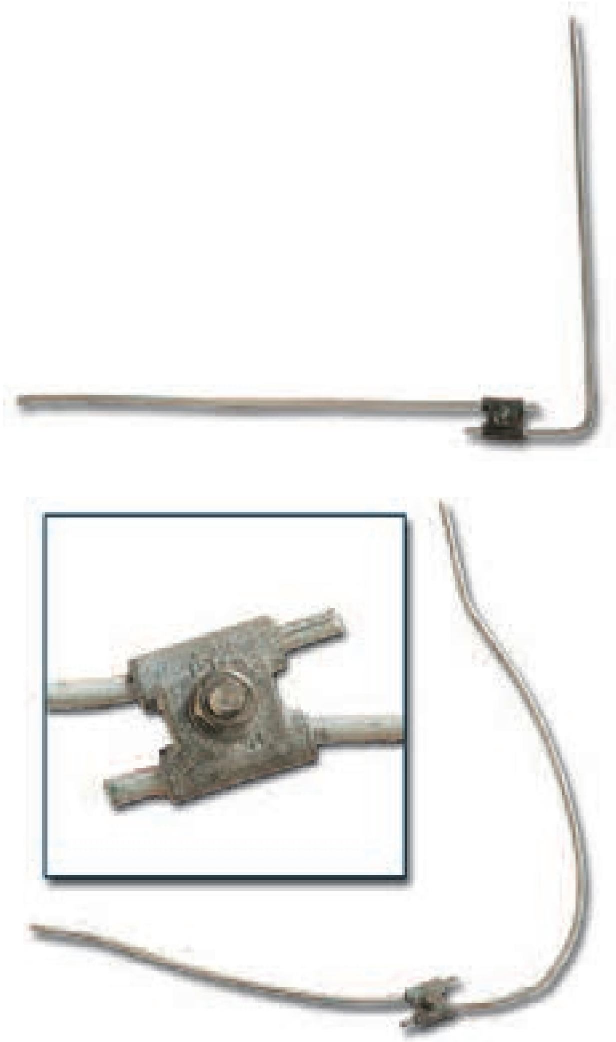

Figure 8.12: Effects of the electrical impulse test

Furse product tests are undertaken by an independent laboratory.

The Research Development and Certification Centre - High Voltage and High Current Testing Laboratory - is accredited by the American Association for Laboratory Accreditation (A2LA).

IEC/BS EN 62561-2 is both a design and in parts a performance specification.

It lists down the conductor and earth electrode types suitable for use in lightning protection and earthing applications, and defines their tests and requirements.

Tables 6 and 7 of BS EN 62305-3 are essentially copied from IEC/BS EN 62561-2 with minor modifications. Additionally, Tables 2 and 4 from IEC/BS EN 62561-2 give information relating to the mechanical and electrical requirements of the conductors and earth electrodes to be used in LPS.

The standard also defines test criteria for tensile strength, bend, adhesion of galvanized or copper coatings, electrical resistivity and environmental performance.

IEC/BS EN 62561-3 covers the requirements for isolating spark gaps (ISG) when used in an LPS.

A typical application of an ISG would be when certain metal installations need to be isolated from the nearby external down conductors to prevent any potential corrosion cells being created. The ISG would bridge across both components and in the event of a lightning current discharge would then conduct and link both components electrically.

Tests within this standard determine electrical performance and lightning current carrying capability to ensure the ISG operates satisfactorily under normal service conditions.

IEC/BS EN 62561-4 defines the performance and testing requirements for conductor fasteners, which have been designed to clamp and support the air termination and down conductor network.

The standard lists the conductor fastener types suitable for lightning protection applications, and establishes performance parameters in terms of product quality, mechanical strength and environmental (corrosion/UV) or impact resistance.

Testing procedures are established to ensure safe, acceptable performance of the component when subjected to mechanical, environmental and lightning discharge stress.

IEC/BS EN 62561-5 establishes the requirements for earth electrode inspection housings (inspection pits) and earth electrode seals.

In addition to defining construction and marking requirements, the standard defines load testing of earth electrode inspection housings, and a seal test of the complete earth electrode seal assembly, to ensure watertight performance in application.

IEC/BS EN 62561-6 details the requirements for lightning strike counters (LSC) - products intended to count the number of lightning strike events/lightning current flowing through either an LPS conductor or conductor to which an SPD is connected.

Tests include environmental (if sited externally), mechanical, corrosion, ingress & impact protection and electrical performance.

IEC/BS EN 62561-7 covers the requirements for earth enhancing compounds, often included in earth termination systems to produce a low resistance to earth.

These products are tested to ensure they are chemically inert and do not pollute the surrounding environment, are non-corrosive to the earth electrode, as well as achieve a low earth resistance.

9. Glossary

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Glossary

For the purpose of this guide, the following definitions apply:

Air termination system
Part of an external Lightning Protection System using metallic elements such as rods, mesh conductors or catenary wires which is intended to intercept lightning flashes.

Average steepness of the short stroke current
Average rate of change of current within a time interval $t_2 - t_1$. It is expressed by the difference $i(t_2) - i(t_1)$ of the values of the current at the start and at the end of this interval, divided by $t_2 - t_1$.

Bonding bar
Metal bar on which metal installations, external conductive parts, electric power and telecommunication lines and other cables can be bonded to a Lightning Protection System.

Bonding conductor
Conductor connecting separated conducting parts to a Lightning Protection System.

Bonding network
Interconnecting network of all conductive parts of the structure and of internal systems (live conductors excluded) to the earth termination system.

Class of LPS
Number denoting the classification of a Lightning Protection System (LPS) according to the lightning protection level for which it is designed.

Combination type SPD
Surge Protective Device (SPD) that incorporates both voltage switching and voltage limiting type components and which may exhibit voltage switching, voltage limiting or both voltage switching and voltage limiting behaviour, depending upon the characteristics of the applied voltage (BS EN 61643-11).

Connecting component
Part of an external Lightning Protection System, which is used for the connection of conductors to each other or to metallic installations.

Conventional earth impedance
Ratio of the peak values of the earth termination voltage and the earth termination current, which in general, do not occur simultaneously.

Coordinated SPD protection
Set of Surge Protective Devices (SPDs) properly selected, coordinated and installed to reduce failures of electrical and electronic systems.

Dangerous event
Lightning flash to the object to be protected or near the object to be protected.

Dangerous sparking
Electrical discharge due to lightning, which causes physical damage in the structure to be protected.

Down conductor system
Part of an external Lightning Protection System which is intended to conduct lightning current from the air termination system to the earth termination system.

Downward flash
Lightning flash initiated by a downward leader from cloud to earth. A downward flash consists of a first short stroke, which can be followed by subsequent short strokes. One or more short strokes may be followed by a long stroke.

Duration of long stroke current (T_{long})
Time duration during which the current in a long stroke is between the 10% of the peak value during the increase of the continuing current and 10% of the peak value during the decrease of the continuing current.

Earthing electrode
Part or a group of parts of the earth termination system, which provides direct electrical contact with the earth and disperses the lightning current to the earth.

Earthing system
Complete system combining the earth termination system and the bonding network.

Earth termination system
Part of an external Lightning Protection System which is intended to conduct and disperse lightning current into the earth.

Earth termination voltage
Potential difference between the earth termination system and the remote earth.

Electrical system
System incorporating low voltage power supply components and possibly electronic components.

Electromagnetic shield
Closed metallic grid-like or continuous screen enveloping the object to be protected, or part of it, used to reduce failures of electrical and electronic systems.

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

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External conductive parts
Extended metal items entering or leaving the structure to be protected such as pipe works, cable metallic elements, metal ducts, etc which may carry a part of the lightning current.

External lightning protection system
Part of the Lightning Protection System consisting of an air termination system, a down conductor system and an earth termination system. Typically these parts are outside the structure.

External LPS isolated from the structure to be protected
Lightning Protection System (LPS) whose air termination system and down conductor system are positioned in such a way that the path of the lightning current has no contact with the structure to be protected. In an isolated Lightning Protection System dangerous sparks between the Lightning Protection System and the structure are avoided.

External LPS not isolated from the structure to be protected
Lightning Protection System (LPS) whose air termination system and down conductor system are positioned in such a way that the path of the lightning current can be in contact with the structure to be protected.

Failure current (I_a)
Minimum peak value of lightning current that will cause damage in a line.

Failure of electrical and electronic system
Permanent damage of electrical and electronic system due to LEMP.

Fixing component
Part of an external Lightning Protection System, which is used to fix the elements of the Lightning Protection System to the structure to be protected.

Flash charge (Q_{flash})
Time integral of the lightning current for the entire lightning flash duration.

Flash duration (T)
Time for which the lightning current flows at the point of strike.

Foundation earthing electrode
Reinforcing steel of foundation or additional conductor embedded in the concrete foundation of a structure and used as an earthing electrode.

Grid-like spatial shield
Electromagnetic shield characterized by openings. For a building or a room, it is preferably built by interconnected natural metal components of the structure (eg rods of reinforcement in concrete, metal frames and metal supports).

Injuries of living beings
Injuries, including loss of life, to people or to animals due to electric shock, fire or explosion caused by lightning.

Interconnected reinforcing steel
Steelwork within a concrete structure, which is considered electrically continuous.

Internal lightning protection system
Part of the Lightning Protection System consisting of lightning equipotential bonding and compliance with the separation distance within the structure to be protected.

Internal system
Electrical and electronic systems within a structure.

Lightning current (i)
Current flowing at the point of strike.

Lightning Electromagnetic Impulse (LEMP)
Electromagnetic effects of lightning current via resistive, inductive and capacitive coupling which create surges and electromagnetic fields.

Lightning Equipotential Bonding (EB)
Bonding to the Lightning Protection System of separated metallic parts, by direct conductive connections or via surge protective devices, to reduce potential differences caused by lightning current.

Lightning flash near an object
Lightning flash striking close enough to an object to be protected that it may cause dangerous overvoltages.

Lightning flash to an object
Lightning flash striking an object to be protected.

Lightning flash to earth
Electrical discharge of atmospheric origin between cloud and earth consisting of one or more strokes.

Lightning protection designer
Specialist competent and skilled in the design of a Lightning Protection System.

Lightning protection installer
Person competent and skilled in the installation of a Lightning Protection System.

Lightning Protection Level (LPL)
Number related to a set of lightning current parameters' values relevant to the probability that the associated maximum and minimum design values will not be exceeded in naturally occurring lightning. Lightning protection level is used to design protection measures according to the relevant set of lightning current parameters.

Lightning Protection System (LPS)
Complete system used to reduce physical damage due to lightning flashes striking a structure. It consists of both external and internal lightning protection systems.

Lightning Protection Zone (LPZ)
Zone where the lightning electromagnetic environment is defined. The zone boundaries of an LPZ are not necessarily physical boundaries (eg walls, floor and ceiling).

Lightning protective cable
Special cable with increased dielectric strength, whose metallic sheath is in continuous contact with the soil either directly or by the use of conducting plastic covering.

Lightning protective cable duct
Cable duct of low resistivity in contact with the soil (for example, concrete with interconnected structural steel reinforcements or a metallic duct).

Lightning stroke
Single electrical discharge in a lightning flash to earth.

Long stroke
Part of the lightning flash which corresponds to a continuing current. The duration time T_{long} (time from the 10% value on the front to the 10% value on the tail) of this continuing current is typically more than 2 ms and less than 1 second.

Long stroke charge (Q_{long})
Time integral of the lightning current in a long stroke.

Loss (L_x)
Mean amount of loss (humans and goods) consequent to a specified type of damage due to a dangerous event, relative to the value (humans and goods) of the object to be protected.

Metal installations
Extended metal items in the structure to be protected, which may form a path for lightning current, such as pipework, staircases, elevator guide rails, ventilation, heating and air conditioning ducts, and interconnected reinforcing steel.

Multiple strokes
Lightning flash consisting on average of 3 - 4 strokes, with typical time interval between them of about 50 ms (events having up to a few tens of strokes with intervals between them ranging from 10 ms to 250 ms have been reported).

"Natural" component of LPS
Conductive component installed not specifically for lightning protection which can be used in addition to the Lightning Protection System (LPS) or in some cases could provide the function of one or more parts of the Lightning Protection System (LPS).

Examples of the use of this term include:
- "natural" air termination;
- "natural" down conductor;
- "natural" earthing electrode.

Node
Point on a service line at which surge propagation can be assumed to be neglected. Examples of nodes are a point on a power line branch distribution at a HV/LV transformer, a multiplexer on a telecommunication line or Surge Protective Device (SPD) installed along the line.

Number of dangerous events due to flashes near a line (N_I)
Expected average annual number of dangerous events due to lightning flashes near a line.

Number of dangerous events due to flashes near a structure (N_M)
Expected average annual number of dangerous events due to lightning flashes near a structure.

Number of dangerous events due to flashes to a line (N_L)
Expected average annual number of dangerous events due to lightning flashes to a line.

Number of dangerous events due to flashes to a structure (N_D)
Expected average annual number of dangerous events due to lightning flashes to a structure.

Object to be protected
Structure or line to be protected against the effects of lightning.

Peak value (I)
Maximum value of the lightning current.

Physical damage
Damage to a structure (or to its contents) or to a line due to mechanical, thermal, chemical or explosive effects of lightning.

Pipes
Piping intended to convey a fluid into or out of a structure, such as gas pipe, water pipe, oil pipe.

Point of strike
Point where a lightning flash strikes the earth, or a protruding object (eg structure, Lightning Protection System, service line, tree, etc). A lightning flash may have more than one point of strike.

Power lines
Transmission lines feeding electrical energy into a structure to power electrical and electronic equipment located there, such as low voltage (LV) or high voltage (HV) electric mains.

Probability of damage (P_X)
Probability that a dangerous event will cause damage to or in the object to be protected.

Protection measures
Measures to be adopted in the object to be protected to reduce the risk.

Rated impulse withstand voltage (U_W)
Impulse withstand voltage assigned by the manufacturer to the equipment or to a part of it, characterising the specified withstand capability of its insulation against overvoltages. For the purpose of BS EN 62305, only withstand voltage between live conductors and earth is considered. [IEC 60664-1:2002]

Ring conductor
Conductor forming a loop around the structure and interconnecting the down conductors for distribution of lightning current among them.

Ring earthing electrode
Earthing electrode forming a closed loop around the structure below or on the surface of the earth.

Risk (R)
Value of probable average annual loss (humans and goods) due to lightning, relative to the total value (humans and goods) of the object to be protected.

Risk component (R_X)
Partial risk depending on the source and the type of damage.

Rural environment
Area with a low density of buildings. "Countryside" is an example of a rural environment.

Separation distance
Distance between two conductive parts at which no dangerous sparking can occur.

Service line to be protected
Service line connected to a structure for which protection is required against the effects of lightning in accordance with this standard.

The service line to be protected comprises the physical connection between:

- the switch telecommunication building and the user's building or two switch telecommunication buildings or two user's buildings, for the telecommunication (TLC) lines;
- between the switch telecommunication building or the user's building and a distribution node, or between two distribution nodes for the telecommunication (TLC) lines;
- the high voltage (HV) substation and the user's building, for the power lines;
- the main distribution station and the user's building, for pipes.

Shielding wire
Metallic wire used to reduce physical damage due to lightning flashes to a line.

Short stroke
Part of the lightning flash which corresponds to an impulse current. This current has a time to the half value T_2 typically less than 2 ms.

Short stroke charge (Q_{short})
Time integral of the lightning current in a short stroke.

SPD tested with a combination wave
Surge Protective Devices (SPDs) that withstand induced surge currents with a typical waveform 8/20 µs and require a corresponding impulse test current I_{sc}. For power lines a suitable combination wave test is defined in the Class III test procedure of BS EN 61643-11 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.

SPD tested with (I_{imp})
Surge Protective Devices (SPDs) which withstand the partial lightning current with a typical waveform 10/350 µs require a corresponding impulse test current I_{imp}. For power lines, a suitable test current I_{imp} is defined in the Class I test procedure of BS EN 61643-11.

SPD tested with (I_n)
Surge Protective Devices (SPDs) which withstand induced surge currents with a typical waveform 8/20 µs require a corresponding impulse test current I_n. For power lines a suitable test current I_n is defined in the Class II test procedure of BS EN 61643-11.

Specific energy (W/R)
Time integral of the square of the lightning current for the entire flash duration; it represents the energy dissipated by the lightning current in a unit resistance.

Specific energy of short stroke current
Time integral of the square of the lightning current for the duration of the short stroke. The specific energy in a long stroke current is negligible.

Structure to be protected
Structure for which protection is required against the effects of lightning in accordance with BS EN 62305. A structure to be protected may be a part of a larger structure.

Structures dangerous to the environment
Structures which may cause biological, chemical and radioactive emission as a consequence of lightning (such as chemical, petrochemical, nuclear plants, etc).

Structures with risk of explosion
Structures containing solid explosive materials or hazardous zones as determined in accordance with IEC 60079-10 and IEC 61241-10. For the purposes of BS EN 62305 structures with hazardous zones type 0 or containing solid explosive materials are considered.

Suburban environment
Area with a medium density of buildings. "Town outskirts" is an example of a suburban environment.

Surge
Transient wave appearing as overvoltage and/or overcurrent caused by LEMP. Surges caused by LEMP can arise from (partial) lightning currents, from induction effects in installation loops and as a remaining threat downstream of a Surge Protective Device (SPD).

Surge Protective Device (SPD)
Device that is intended to limit transient overvoltages and divert surge currents. It contains at least one non-linear component (see BS EN 61643 series).

Surge Protection Measures (SPM)
Measures taken to protect internal systems against the effects of LEMP, as part of overall lightning protection.

Telecommunication lines
Transmission medium intended for communication between equipment that may be located in separate structures, such as phone line and data line.

Test joint
Joint designed to facilitate electrical testing and measurement of Lightning Protection System components.

Time to peak value of short stroke current (t_1)
Virtual parameter defined as 1.25 times the time interval between the instants when the 10% and 90% of the peak value are reached.

Time to half value of short stroke current (t_2)
Virtual parameter defined as the time interval between the virtual origin O_1 and the instant at which the current has decreased to half the peak value.

Tolerable risk (R_T)
Maximum value of the risk, which can be tolerated for the object to be protected.

Upward flash
Lightning flash initiated by an upward leader from an earthed structure to cloud. An upward flash consists of a first long stroke with or without multiple superimposed short strokes. One or more short strokes may be followed by a long stroke.

Urban environment
Area with a high density of buildings or densely populated communities with tall buildings. "Town centre" is an example of an urban environment.

Virtual origin of short stroke current (O_1)
Point of intersection with time axis of a straight line drawn through the 10% and the 90% reference points on the stroke current front; it precedes by $0.1T_1$ that instant at which the current attains 10% of its peak value.

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. 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". A voltage switching device has a discontinuous voltage/current characteristic. (BS EN 61643-11)

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. Common examples of components used as non-linear devices are varistors and suppressor diodes. These SPDs are sometimes called "clamping type". A voltage-limiting device has a continuous voltage/current characteristic. (BS EN 61643-11)

Zone of a structure (Z_S)
Part of a structure with homogeneous characteristics where only one set of parameters is involved in assessment of a risk component.

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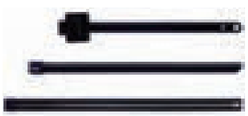

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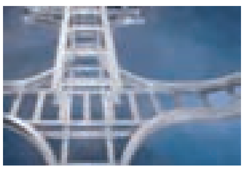

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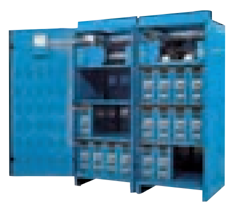

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