



# **BEAMA Guide to Surge Protection Devices (SPDs): selection, application and theory**



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**Companies involved in the preparation of this Guide**



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## **BEAMA Guide to Surge Protection Devices (SPDs): selection, application and theory**

### **Introduction**

This publication is intended as a practical guide:

- For designers, specifiers and installers to enable them to comply with surge protection requirements in BS 7671 Requirements for Electrical Installations – IET Wiring Regulations – Seventeenth Edition.
- To assist those involved in the use of these standards in selecting, erecting and testing and verification of Surge Protection Devices in accordance with BS 7671, supported by current lightning and surge protection standards.

BEAMA is the long established and respected trade association for the electrotechnical sector. The association has a strong track record in the development and implementation of standards to promote safety and product performance for the benefit of manufacturers and their customers.

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# Terminology and Definitions

The following common terminologies, as recognised by BS EN 61643, are used throughout SPD specifications in order to aid correct selection and are defined as follows:

---

**Nominal Voltage  $U_0$**  is the line voltage to Earth a.c. voltage of the mains system (derived from the nominal system voltage) for which the SPD is designed.  $U_0$  is the voltage by which the power system is designated – e.g. 230V.

---

**Maximum Continuous Operating Voltage  $U_c$**  is the maximum RMS voltage that may be continuously applied to the SPD's mode of protection e.g. phase to neutral mode. This is equivalent to the SPD's rated peak voltage.

---

**Temporary Overvoltage  $U_T$**  is the stated test value of momentary voltage increase or overvoltage that the power SPD must withstand safely for a defined time. Temporary overvoltages, typically lasting up to several seconds, usually originate from switching operations or wiring faults (for example, sudden load rejection, single-phase faults) as well as mains abnormalities such as ferro-resonance effects and harmonics.

---

**Impulse Current  $I_{imp}$**  is defined by three parameters, a current peak with a charge and a specific energy typically simulated with the 10/350 $\mu$ s waveform to represent partial lightning currents. This waveform is used, with peak  $I_{imp}$  current value stated, for the mains Type 1 SPD Class I test and typically for data/telecom SPD Test Category D.

---

**Nominal Discharge Current  $I_{nspd}$**  is a defined nominal peak current value through the SPD, with an 8/20 $\mu$ s current waveshape. This is used for classification of mains SPDs (Class II test) and also for preconditioning of SPDs in Class I and Class II tests.

---

**Maximum Discharge Current  $I_{max}$**  is the peak current value through the SPD, with an 8/20 $\mu$ s waveshape.  $I_{max}$  is declared for mains Type 2 SPDs in accordance to the test sequence of the Class II operating duty test. In general,  $I_{max}$  is greater than  $I_{nspd}$ .

---

**Combined Impulse Test with Open Circuit Voltage  $U_{oc}$  is a hybrid 1.2/50 $\mu$ s voltage test combined with an 8/20 $\mu$ s current.** The test is performed using a combination wave generator where its open circuit voltage is defined as  $U_{oc}$ , typically 6kV 1.2/50 $\mu$ s for the mains Class III test and up to 4kV 1.2/50 $\mu$ s for signal/telecom Test Category C. With an impedance of 2 Ohm, the generator also produces a peak short circuit current (sometimes referred to as  $I_{sc}$ ) at half the value of  $U_{oc}$  (3kA 8/20 $\mu$ s for the mains Class III test and up to 2kA 8/20 $\mu$ s for signal/telecom Test Category C). With both voltage and current test waveforms, the combined impulse test is designed to stress all technologies used within SPDs.

---

**Voltage Protection Level  $U_p$**  is the key parameter that characterises the performance of the SPD in limiting the transient overvoltage across its terminals. A low protection level value (also known as let-through voltage) is therefore particularly critical for the effective protection and continued operation of electronic equipment. The peak voltage protection level  $U_p$  is declared when the SPD is tested with its stated nominal discharge current  $I_n$  (or the peak current ( $I_{peak}$ ) of  $I_{imp}$ ) and is also declared when the SPD is subject to combined impulse test (mains Class III test for Type 3 SPDs) as well as data/telecom Test Categories C and B.

---

**'Modes'** refer to the combinations of conductors in which transient overvoltages occur. Lightning transients are generally disturbances with respect to Earth (common mode), whilst switching transients are disturbances between line/phase and neutral (differential mode). During propagation mode conversion can occur (e.g. as a result of flashover). Hence transients can exist simultaneously between any combination of conductors.

---







# I. Overview

Electronic systems now pervade almost every aspect of our lives, from the work environment, through filling the car 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 ‘increased exponentially’ during the last two decades. Not only are there more systems in existence, the physical size of the electronics involved has reduced considerably. This reduction in size means less energy is required to damage components.

The operation of electronic systems can be severely affected by lightning activity during ‘thunder’ storms or electrical switching events. Both can cause very short duration increases in voltage on mains power and/or data communication/signal/telephone lines, with potentially devastating consequences. These increases in voltages are called surges or transient overvoltages. All sorts of electronic equipment are at risk such as

- computers
- building management systems
- PABX telephone exchanges
- CCTV equipment
- fire and burglar alarms
- uninterruptible power supplies
- programmable logic controllers (PLCs)
- plant sensors, telemetry and data acquisition equipment
- weighbridge installations

A lightning surge is severe enough to present a risk of loss of life through fire and/or electric shock hazards through a dangerous flashover. This can occur when the surge voltage exceeds the withstand rating of the cable insulation or equipment

The home environment has also evolved; everyday activities rely on electronic equipment. Products such as plasma televisions, home theatre equipment, alarms, microwaves and washing machines are all vulnerable to voltage surges. Protecting all home electronic equipment is simple with the qualified installation of a surge protection device

Products such as LCD screens, computer networks, data servers and industrial equipment including PLCs provide essential services now crucial to business operational productivity. Protection against the effects of voltage surges in business today is no longer an option, it has become a necessity.

## **Circuit breakers/fuses are not designed to provide overvoltage protection**

Fuses and circuit breakers (aka Overcurrent Protective Devices (OCPDs)) are designed to protect your home, business, equipment, and possibly even your life from an event such as a short circuit or overload.

The Surge Protective Device (hereafter referred to as an SPD) is specifically designed to protect equipment from events such as extremely short duration high voltage spikes. These voltage spikes

or transients are everyday occurrences, and can be caused by anything from switching on a lamp to a lightning storm. Most spikes are of low energy. Some spikes could possibly cause irreparable damage to equipment if no SPD is installed to redirect the harmful voltage away from the equipment.

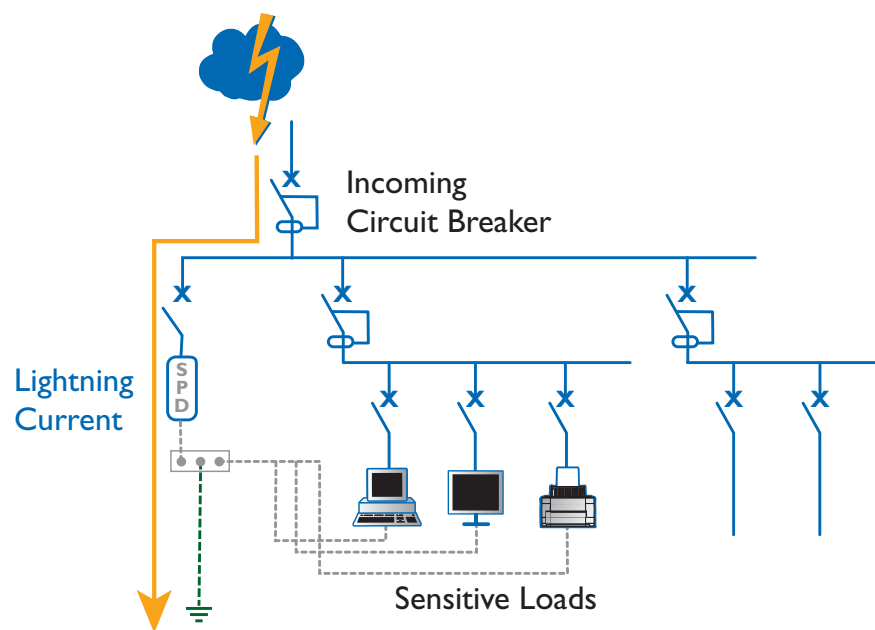
## 1.1 Surge Protection Devices (SPDs)

**A Surge Protection Device (SPDs)** is a component of the electrical installation protection system. This device is connected to the power supply in parallel with the loads (circuits) that it is intended to protect (see Fig. 1). It can also be used at all levels of the power supply network. This is the most commonly used and most practical type of overvoltage protection.

### Principle of Surge Protection Operation

SPDs are designed to limit transient overvoltages due to lightning or switching and divert the associated surge currents to earth, so as to limit these overvoltages to levels that are unlikely to damage the electrical installation or equipment.

**Figure 1:**  
Principle of protection  
system in parallel



## 1.2 Types of Surge Protection Devices

There are three types of SPD according to international standards:

- **Type 1 SPD – Protection Against Transient Overvoltages due to Direct Lightning Strokes**

The Type 1 SPD is recommended to protect electrical installations against partial lightning currents caused by direct lightning strokes. It can discharge the voltage from lightning spreading from the earth conductor to the network conductors.

Type 1 SPD is characterised by a **10/350µs** current wave.

- **Type 2 SPD – Protection Against Transient Overvoltages due to Switching and Indirect Lightning Strokes**

The Type 2 SPD is the main protection system for all low voltage electrical installations. Installed in each electrical switchboard, it prevents the spread of overvoltages in the electrical installations and protects the loads.

Type 2 SPD is characterised by an **8/20µs** current wave.

- **Type 3 SPD – Local Protection for Sensitive Loads**

These SPDs have a low discharge capacity. They must therefore only be installed as a supplement to Type 2 SPD and in the vicinity of sensitive loads. They are widely available as hard wired' devices (frequently combined with Type 2 SPDs for use in fixed installations) However they are also incorporated in

- Surge protected socket outlets
- Surge protected portable socket outlets
- Telecoms and Data protection

**2a Type 1**



**2b Type 2**



**2c Type 3**



Note 1 : – Combinations of SPD types are available as a single unit.

## **1.3 Requirements within the Wiring Regulations**

The IET Wiring Regulations (BS 7671- Requirements for Electrical Installations) define the requirements for a safe electrical installation. Part of the criteria is adequate protection for both people and equipment from transient over voltages of atmospheric origin transmitted via the supply distribution system and against switching overvoltages

Section 443 – Protection against overvoltages of atmospheric origin or due to switching

Section 534 – Devices for protection against overvoltage

## 2. Transient overvoltages (surges)

### 2.1 What are transient overvoltages (surges)?

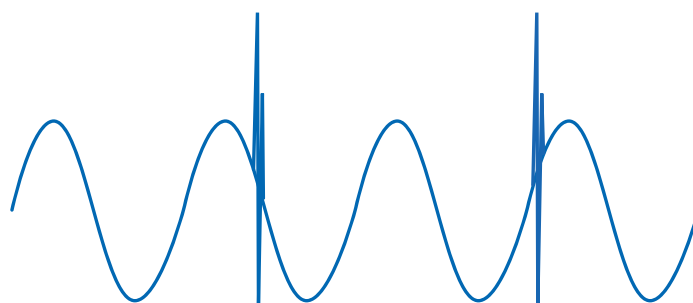
A transient overvoltage or surge is a short duration increase in voltage measured between two or more conductors.

In this context short means anything from microseconds (millionths of a second) to a few milliseconds (thousandths of a second) in duration.

The increase in voltage will vary from a few volts to thousands of volts.

This voltage exists between two or more conductors. For a mains power supply, these conductors would be the line/phase, neutral and earth. For data, telecom and signal lines, these conductors would be line(s) and earth/screen.

**Figure 2:**  
Transient  
overvoltages  
(surges)



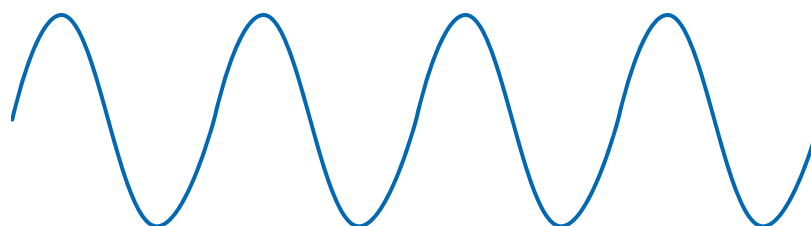
'Transient overvoltage', is technically and descriptively the best terminology. However, transients are also referred to as surges, spikes and glitches. The term 'surge', though widely used, should be used with caution. In some parts of the world, the UK amongst them, surge is used by the electricity supply industry to refer to a sustained overvoltage of several cycles duration.

### 2.2 Other types of electrical disturbance

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!

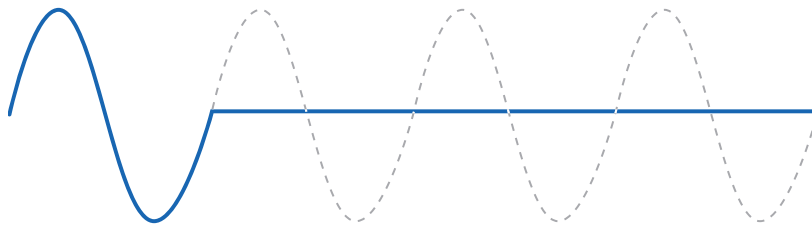
Most of these disturbances can be represented as a serious deviation of the normal mains power supply as shown by Figure 3 below.

**Figure 3:**  
Normal Mains Supply  
Waveform



### 2.2.1 'Outage'

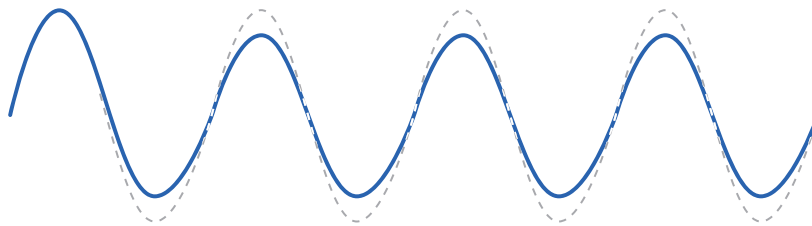
'Outage', 'power cut' and 'blackout' are all terms applied to total breaks in the supply lasting from several milliseconds to many hours. Very short breaks, which cause lights to flicker, may be sufficient to cause computers and other sensitive electronic equipment to 'crash'



**Figure 4:**  
Outage

### 2.2.2 Undervoltages

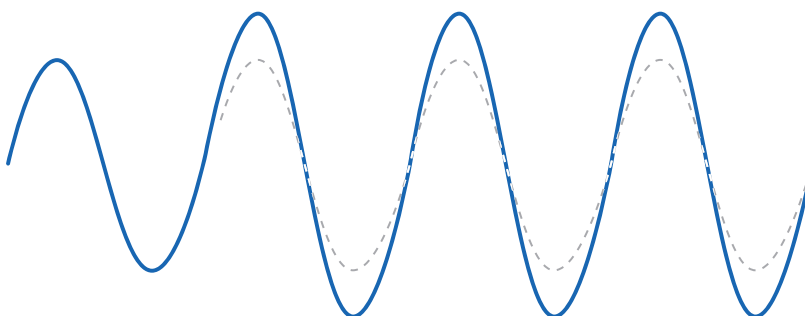
'Undervoltages' or 'brownouts' are sustained reductions in the supply voltage, lasting anything over a few seconds.



**Figure 5:**  
Undervoltages

### 2.2.3 Overvoltages

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

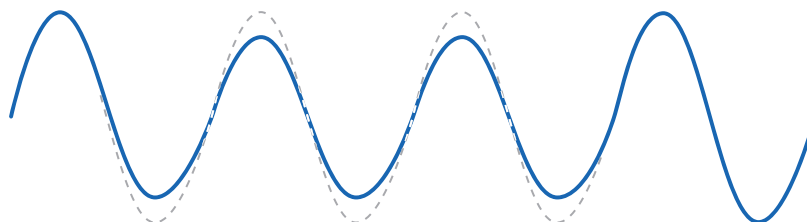


**Figure 6:**  
Overvoltages

#### 2.2.4 'Sags'

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

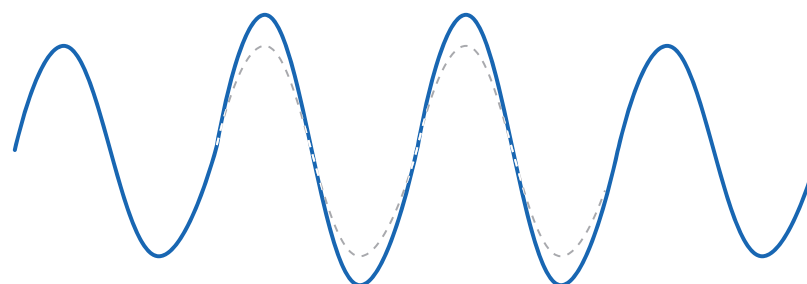
**Figure 7:**  
'Sags'



#### 2.2.5 'Swells'

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

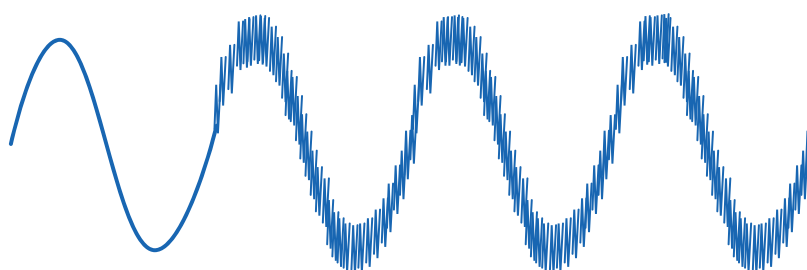
**Figure 8:**  
'Swells'



#### 2.2.6 Radio Frequency Interference

Electrical noise or Radio Frequency Interference (RFI), is a continuous high frequency (5kHz or more) distortion of the normal sine wave.

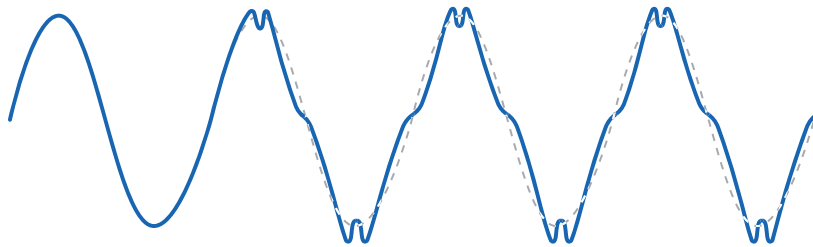
**Figure 9:**  
Radio Frequency  
Interference





### 2.2.7 Harmonics

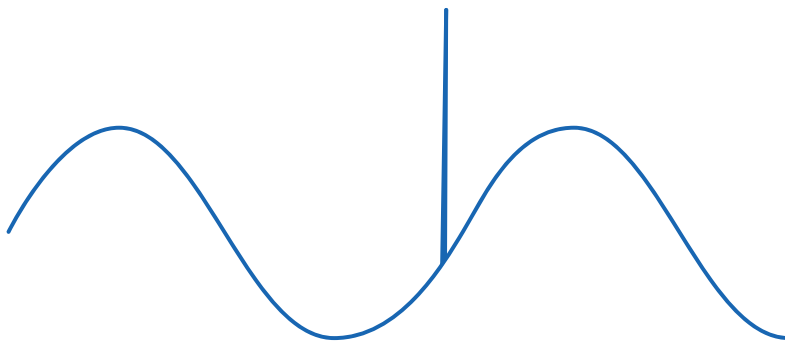
Harmonics are a continuous distortion of the normal sine wave, at frequencies of up to 3kHz.



**Figure 10:**  
Harmonics

### 2.2.8 NEMP/EMP

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 (as faster rise time) than commonly occurring transients.



**Figure 11:**  
NEMP/EMP

### 2.2.9 Electrostatic Discharge

ElectroStatic Discharge (ESD) is a different phenomenon. Unlike the above these do not tend to be transmitted on power or data lines. An electrostatic charge is generated by two insulating objects being rubbed together. A charged object will discharge when it comes into contact with a conducting object. A common example of the charging mechanism could be someone walking over a synthetic carpet. The discharge would occur when the electrically charged person touches a door handle or computer keyboard.

### 2.2.10 Electromagnetic Interference

ElectroMagnetic Interference (EMI) is a very broad term referring to system interference.

ElectroMagnetic Compatibility (EMC) is a philosophy referring to attempts to prevent EMI. EMC practice dictates that potential sources of interference are designed so as not to affect equipment, and that potential victim equipment is designed to be immune from potential source of interference. Lightning cannot be prevented at source, and cannot be fully protected against with EMC.

## 3. Transient overvoltage damage

Transient overvoltages are generally caused by lightning and/or electrical switching events. Transient overvoltages can be generated by lightning, (through resistive, inductive or capacitive coupling) or by electrical switching events. About 35% of all transients come from outside the facility from such sources as lightning, utility grid switching, switching large capacitor banks on the utility lines, electrical accidents or heavy motors or loads from nearby industry. The remaining 65% are generated inside our homes and facilities and come from such unsuspected sources as microwave ovens, laser printers and copiers, electric motors, electrical appliances and even lights being switched on or off.

### 3.1 By lightning

Lightning activity can cause transient overvoltages on both mains power supplies and data communication, signal or telephone lines.

Lightning discharges are claimed to have currents of up to half a million amperes (A), although 200 kA is an accepted upper limit within present standards for lightning protection. Were lightning to hit a building without a structural lightning protection scheme, this current would seek a path to earth through the building and its fabric – in an erratic and unpredictable manner. The building is likely to be damaged and may even catch fire. Although transient overvoltages will occur, this may be just one aspect of extensive damage to the building and its contents.

If however, lightning strikes a building with structural lightning protection the lightning will travel to earth in a predetermined manner.

Lightning can cause transient overvoltages through

- direct strikes to incoming electrical services
- ‘indirect’ strikes, which are coupled into electrical services through resistive, inductive and capacitive effects.

#### 3.1.1. Direct strikes

**Direct strikes to High Voltage (HV) power cables.** Strikes to HV overhead power lines are quite common. It is often thought that the high voltage to low voltage transformer action eliminates the resultant transient overvoltages. This is not so. Although transformers protect against transient overvoltages between line and earth, line to line transients pass through unattenuated.

When HV lines are struck by lightning they flashover to earth. One line will flashover before the others, converting a line to earth transient into one between line and line – these will easily pass through the transformer.

Also, capacitance between the transformer’s windings provides transients between any combination of conductors with a high frequency path through the transformer. This could have the effect of increasing the size of existing line to line transients, as well as providing a path through the transformer for line to earth transients.

**Direct strikes to Low Voltage (LV) power cables or telephone lines.** When lightning hits LV overhead power cables or telephone lines, most of the current travels to earth as a result of line flashover to ground. A relatively small (but devastating) portion of the lightning current is transmitted along the cable or line to electronic equipment.

### 3.1.2 Indirect strikes

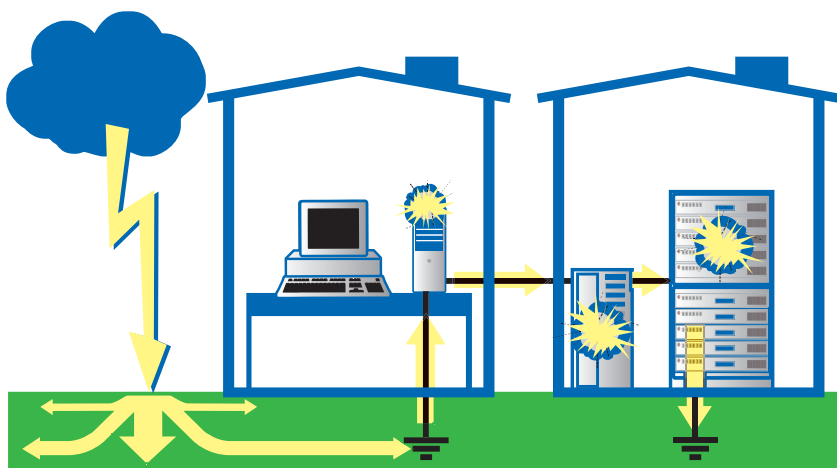
#### 3.1.2.1 Resistive coupling

**Resistive coupling** is the most common cause of transient overvoltages and it will affect both underground and overhead lines. Resistively coupled transients occur when a lightning strike raises the electrical potential of one or more of a group of electrically interconnected buildings (or structures).

Common examples of electrical interconnections are

- power feeds from substation to building
- building to building power feeds
- power supplies from the building to external lightning, CCTV or security equipment
- telephone lines from the exchange to the building
- between building telephone lines
- between building LANs or data communication lines
- signal or power lines from a building to external or field based sensors

Figure 12 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 12:**  
Potential current  
path in buildings  
connected through  
data communication  
lines

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 are present across the sensitive components of the equipment.

Resistively coupled transients can occur when separately earthed structures are only metres apart. Resistive coupling will affect both underground and overhead cables.

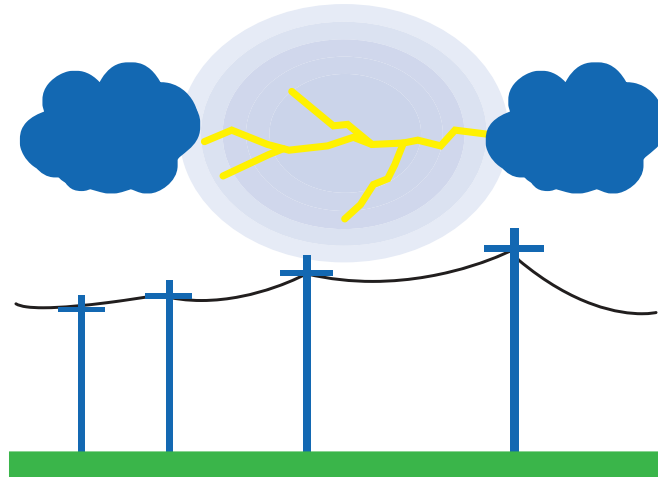
Note: SPDs for data communication signal and telephone lines ('Lightning Barriers') are fitted into the line (i.e. in series). This introduces a small impedance into the line and a capacitance across the line. For twisted pair signalling below 1 MHz, this generally causes no problems. However, at higher frequencies this impedance and capacitance would cause problems. Protectors for these systems need to be specially designed to have lower line capacitance and impedance. For impedance matched systems (e.g. coaxially wired computer networks such as Ethernet) it is essential that the protector is impedance matched, in order to avoid reflections.

### 3.1.2.2 Inductive coupling

**Inductive coupling** is a magnetic field transformer effect between lightning and cables.

A lightning discharge is an enormous current flow and whenever a current flows, an electromagnetic field is created around it. If power or data cabling passes through this magnetic field, then a voltage will be picked up by, or induced onto it.

**Figure 13:**  
*Inductive coupling*



### 3.1.2.3 Capacitive coupling

Where long lines are well isolated from earth (e.g. via transformers or opto-isolators) they can be pulled up to high voltages by capacitance between them and charged thunder clouds. If the voltage on the line rises beyond the breakdown strength of the devices at each end (e.g. the opto-isolators) they will be damaged.

## 3.2 By electrical switching events

Transient overvoltages caused by electrical switching events are very common and can be a source of considerable interference. Current flowing through a conductor creates a magnetic field in which energy is stored. When the current is interrupted or switched off, the energy in the magnetic field is suddenly released. In an attempt to dissipate itself it becomes a high voltage transient. The more stored energy, the larger the resulting transient. Higher currents and longer lengths of conductor, both contribute to more energy stored and subsequently released. This is why inductive loads such as motors, transformers and electrical drives are all common causes of switching transients

## 3.3 By transient overvoltage

Nearly all electronic components and circuits suffer transient overvoltages damage in the same way. There are two main physical mechanisms at work, overheating and insulation failure – both are made much worse by the subsequent power follow-on.

Let us consider a simple resistor made from a coil of resistance wire. During transient activity the current flowing through the wire, will cause degradation to occur. A little more heat and the wire will vaporize – destroying the component. Heat failure, such as this, is common in fuses, printed circuit board tracks, forward biased semiconductor junctions and the like.

In addition to heating, the current flow causes a voltage to be generated across the wire. If the voltage difference becomes high enough to pierce the wire insulation and breakdown the air gap, flashover occurs. This form of failure is common with reverse biased semiconductor junctions, capacitors, transformers, motor windings and such like.

For example, consider a transformer winding and an earthed lamination. If a small transient voltage is present between the winding and earth, no current flows and no heating occurs. However, if a larger transient voltage is present, flashover or insulation breakdown occurs, and a transient current

flows through the transformer, causing heating, burning and arcing. In a minor case the transformer would be able to continue operation after the event. The next transient would find it much easier to flashover the now degraded insulation. The process could then continue until a catastrophic short circuit failure occurs. In severe cases the first transient will be terminal!

When components connected across power supplies fail, the majority of the physical damage (charring, burning or explosion) is the result of the follow-on current. This occurs when the power current flows down the damage path created by the transient overvoltage.

It should be noted that integrated circuits are collections of components and inter-connections. Their inter-connections behave like PCB tracks and its components include forward biased or reverse biased junctions, resistors and capacitors.

A third form of failure is not due to a physical mechanism, but the incorrect operation of systems caused by transients. In power supplies and power conversion equipment, two semiconductor devices are often connected in series across a supply to form the arm of the bridge. The two devices must never be on simultaneously. However, transient overvoltages can cause them to trigger at the wrong time, short circuiting the supply, with devastating consequences.

### **3.4 The problems caused by transient overvoltages**

Transient overvoltages, whether caused by lightning or by electrical switching, have similar effects: disruption, degradation, damage and downtime.

#### **3.4.1 Disruption**

Although no physical damage is caused, the logic or analogue levels of the systems' are upset, causing

- data loss
- data and software corruption
- unexplained computer crashes
- lock-ups
- the unwanted tripping of Residual Current Devices (RCDs)

The system can be reset (often just by switching off and on) and will then function normally. Much of this nuisance may go unreported.

#### **3.4.2 Degradation**

This is somewhat more serious. Long term exposure to lower level transient overvoltages will, unknown to the user, degrade electronic components and circuitry reducing the equipment's expected life and increasing the likelihood of failures.



**Figure 14**  
Damage

### 3.4.3 Damage

Large transient overvoltages can cause damage to components, circuit boards and I/O cards. Severe transient overvoltages can physically manifest themselves through burnt-out circuit boards, however, ordinarily damage is less spectacular (see Fig 15). Similar degradation can occur to the silicon dioxide insulation in integrated circuits (or microchips). Only in most severe cases do we see ruptured cases, charring and fire. In fact much of this more spectacular damage is caused by power follow-on and not by the transient.

When a transient overvoltage causes a short circuit failure, this can create a path for the power supply. Consider a component connected to line and neutral on a mains power supply, failing under short-circuit conditions as a result of a transient. At this point no outward signs of damage exist. Current flows into the short circuit and continues until a protective device operates or the component fails, sometime spectacularly. This also explains why it is often difficult to tell how big a transient overvoltage was by looking at the damage it caused.

### 3.4.4 Downtime

Unnecessary disruption, component degradation and damage all result in equipment and systems downtime, which means

- staff unable to work
- staff overtime
- senior managers and technical specialists unnecessarily tied-up problem solving
- lost data which may result in
  - lost productivity
  - delays to customers
  - lost business

#### Example 1 – Switching transients

An engineering company invested heavily in a networked Computer Aided Design (CAD) system. However, the system's many advantages were overshadowed by the all too regular problems it suffered. The system would crash unexpectedly, sometimes hours of work were lost or corrupted and circuit failures seemed to be almost a monthly event. At first, these were assumed to be just 'teething troubles'. But as time went on, and design work slipped further behind schedule, relations with the system's supplier became increasingly difficult. Only when one of the engineering team read an article in a professional journal, did they realise that the problem might not be the system, but the environment. They soon observed that the system's failures coincided with the operation of a large drawing copying machine. The operation of this equipment lead to switching transients appearing on the mains supply to the CAD system.

#### Example 2 – Lightning strike to research centre

A lightning strike to a research campus had widespread effects. The PBX telephone exchange was rendered almost totally inoperable, with 80% of the external telephone lines taken out of commission. The pattern of damage clearly indicated induced transient overvoltages on the incoming telephone lines. Elsewhere, there was extensive damage to computer equipment in the admin block, which was closest to the strike point. This equipment was networked to equipment in neighbouring buildings where transceivers, repeaters and some terminals were damaged – indicative of resistively coupled transient overvoltages.

#### Example 3 – Lightning strike to office block

When lightning struck an office block, its structural lightning protection ensured that the lightning current was carried safely to earth – without damage to the building or its occupants. However, sizeable transient overvoltages were induced on to the mains power supply within the building. Costly damage was suffered to the building management system, its UPS, the door entry system, the telephone exchange, and a large number of computer terminals. Over subsequent months, there were a number of failures to pieces of equipment apparently undamaged during the initial incident – suggesting component degradation had occurred.



## 4. BS EN 62305 Protection against lightning

The BS EN 62305 standard series specifically cover the protection against lightning to structures, their contents, persons and livestock.

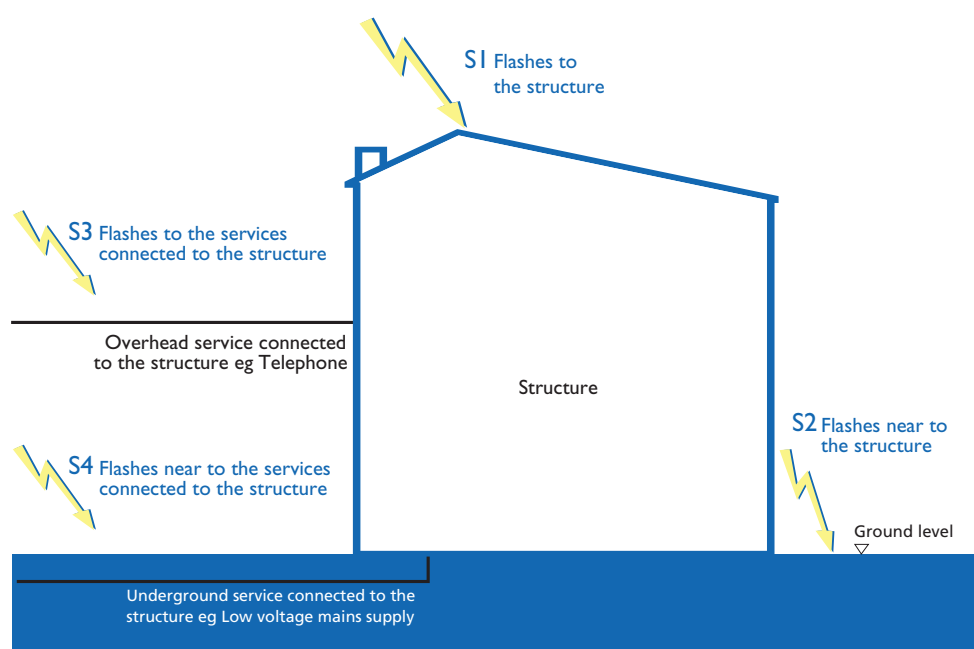
BS EN 62305 accepts that we now live in the electronic age, making LEMP (Lightning Electromagnetic Impulse) protection for electronic and electrical systems an integral part of the standard through BS EN 62305-4. LEMP is the term given to the overall electromagnetic effects of lightning, including conducted surges (transient overvoltages and currents) and radiated electromagnetic field effects.

BS EN 62305 – 4 categorises the source of damage, type of damage and the type of loss

### 4.1 Sources of damage

Damage that can be caused by lightning 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 part of telecommunication, data, electrical supply, water, gas and fuel distribution networks).



**Figure 15:**  
Different areas of lightning strike

### 4.2 Types 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 persons or livestock due to step and touch voltages**

**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** (these being triggered by sparks due to overvoltages and partial lightning currents that are transmitted via these connected services). This in turn could have a direct bearing on the specific types of loss.

### 4.3 Types of loss

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

**L1 Loss of human life**

**L2 Loss of service to the public**

**L3 Loss of cultural heritage**

**L4 Loss of economic value**

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 summarised in Table 1.

**Table 1:**  
Types of loss

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
Service connected to the structure	S3	D1 D2 D3	L1, L4** L1, L2, L3, L4 L1*, L2, L4
Near a service	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.

LEMP damage is so prevalent that it is identified as one of the specific types (D3) against which protection should be provided and can occur from ALL strike points to the structure or connected services – direct or indirect. This extended approach also takes into account the danger of fire or explosion associated with services connected to the structure, e.g. power, telecoms and other metallic lines.

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 lightning protection system (LPS) and a fully coordinated set of SPDs to bring the risk below the accepted tolerable levels defined within the standard. BS EN 62305 makes it clear that structural lightning protection must no longer be considered in isolation from transient overvoltage/surge protection and given that lightning from all strikes points, direct or indirect, to the structure or connected services creates a risk from transients, SPDs are a vital means of protection whether structural lightning protection is present or not.

## 4.4 Lightning protection and BS 7671 Wiring Regulations

Our reliance as a society on electronic equipment has increased dramatically over the last two decades; hence BS EN 62305 has specifically recognised the protection of such equipment within a normative part BS EN 62305-4 which states:

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

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

Section 443 of the Wiring Regulations is based upon a CENELEC Harmonisation Document published before BS EN 62305-4. This had led to the misconception that protection against lightning based on the ‘Thunderstorm days’ approach of Section 443 is sufficient.

The use of ‘thunderstorm days’ as the sole criterion of tolerable risk is a significant deviation from BS EN 62305 which uses many other factors in its risk assessment. The IEC is currently reviewing Section 443 of IEC 60364 to realign it with IEC 62305. It is recommended that the full risk assessment approach of BS EN 62305 is followed instead of Section 443 whilst this process is taking place to ensure all risk factors are taken into account.

## 4.5 Characterising transient currents and voltages

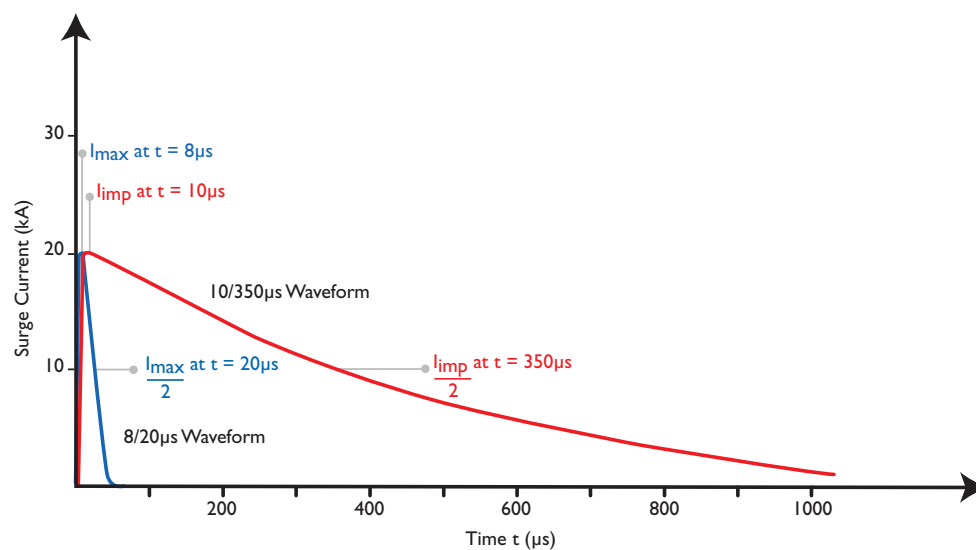
### 4.5.1 Current and voltage waveforms

BS EN 62305 takes account of protection measures on metallic service lines (typically power, signal and telecom lines) using transient overvoltage or Surge Protection Devices (SPDs) against both direct lightning strikes as well as the more common indirect lightning strikes and switching transients. Standards such as the BS EN 61643 series define the characteristics of lightning currents and voltages to enable reliable and repeatable testing of SPDs (as well as lightning protection components). Although these waveforms may differ from actual transients, the standardized forms are based upon years of observation and measurement (and in some cases simulation). In general they provide a fair approximation of the real world transient.

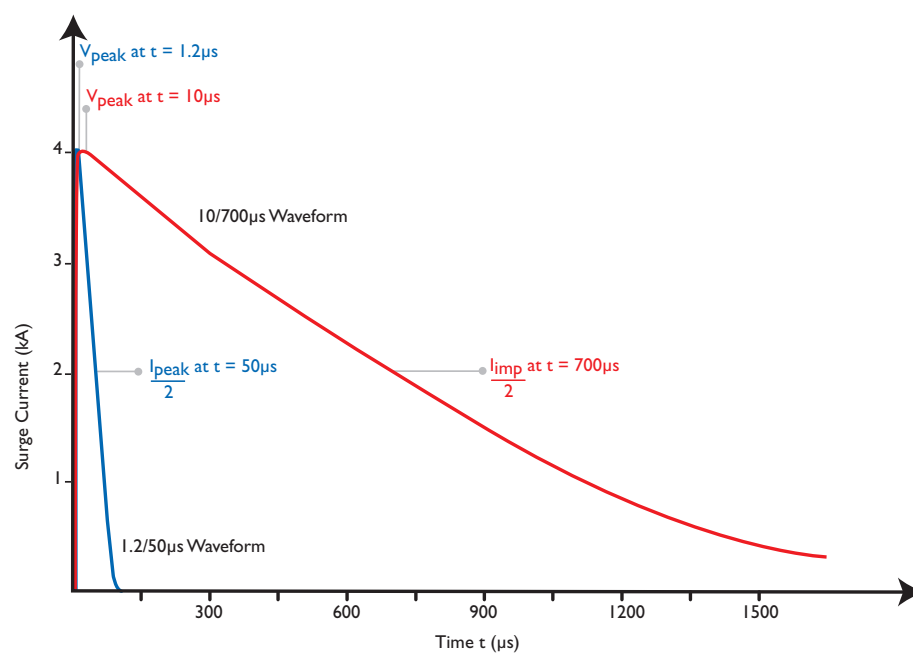
Transient waveforms have a fast rising edge and a longer tail. They are described through their peak value (or magnitude), rise time and their duration (or fall time). The duration is measured as the time taken for the test transient to decay to half its peak value.

The figures below illustrate the common current and voltage waveforms that are used to test SPDs for mains, signal and telecom lines.

**Figure 16:**  
Current waveform



**Figure 17:**  
Voltage waveform

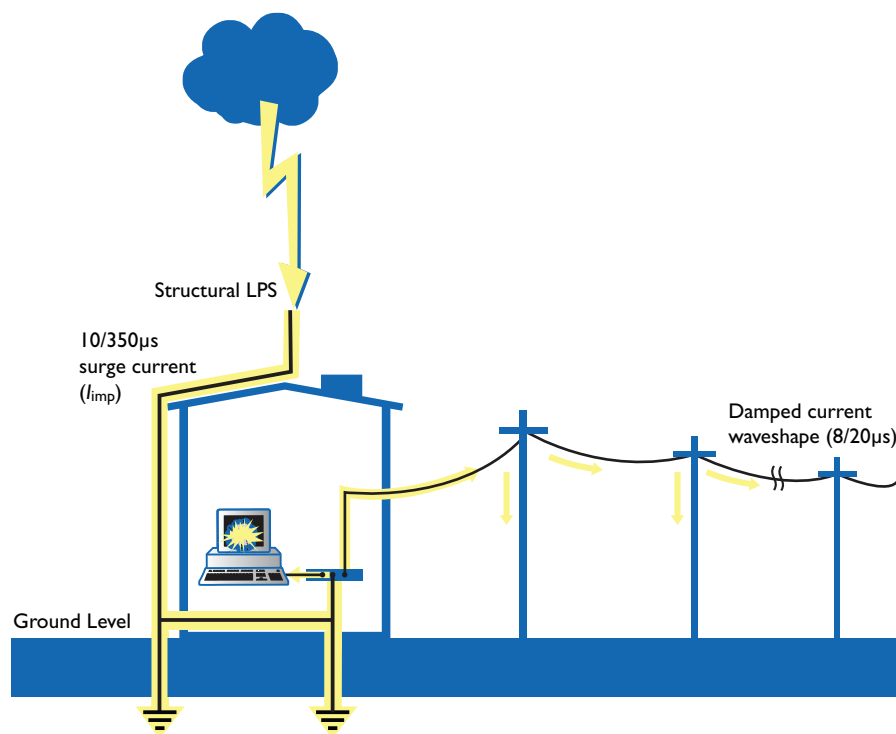


#### 4.5.2 Sources of damage

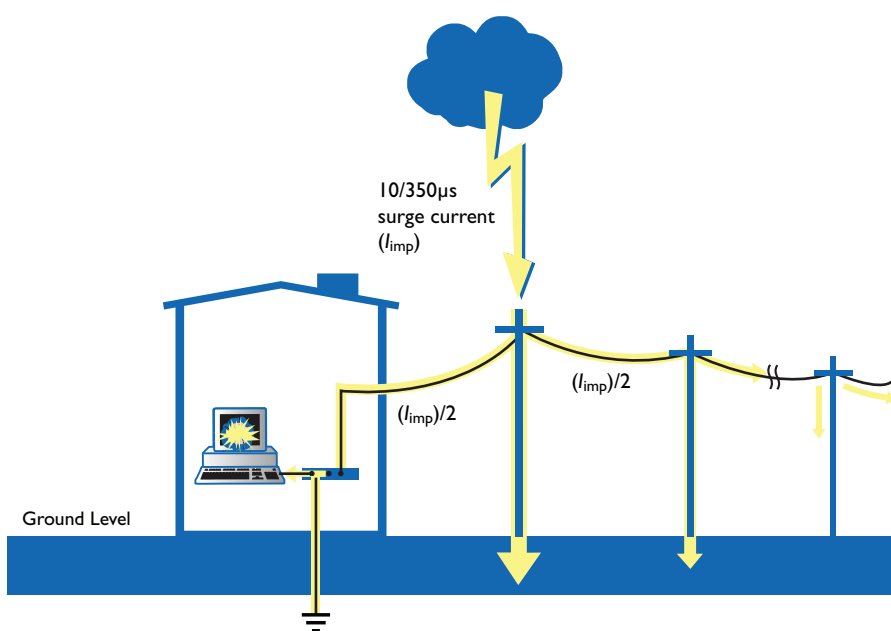
Lightning currents as a result of direct lightning strikes are represented by the simulated 10/350  $\mu\text{s}$  waveform with a fast rise time and long decay that replicates the high energy content of direct lightning.

#### 4.5.2.1 Direct strikes

Direct lightning can inject partial lightning currents of the 10/350 $\mu$ s waveform into a system where a structure with a structural Lightning Protection System receives a direct strike (Source S1) or where lightning directly strikes an overhead service line (Source S3).



**Figure 18:**  
Direct Strike to Structure

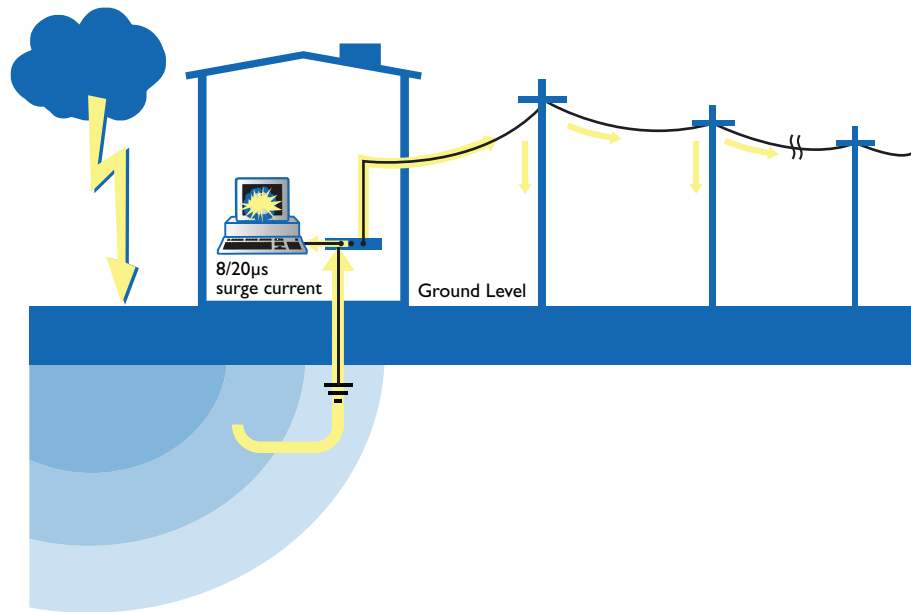


**Figure 19:**  
Direct Strike to nearby service

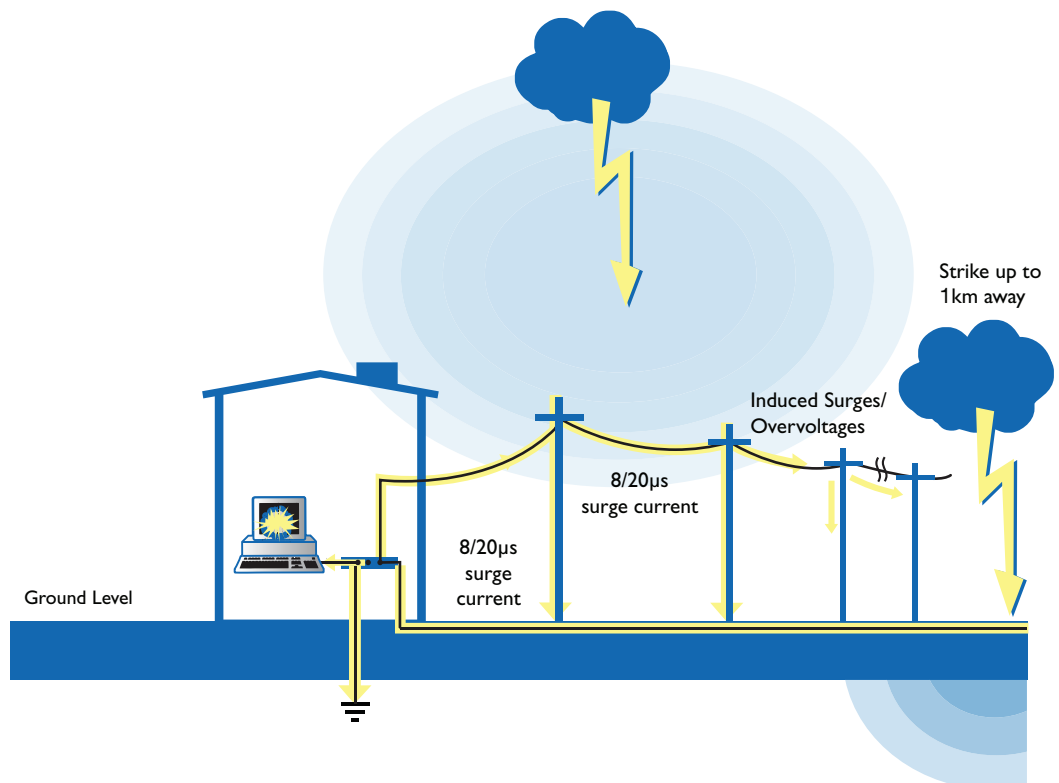
#### 4.5.2.2 Indirect strikes

Remote or indirect lightning flashes near the structure (Source S2) or near a connected service to the structure (Source S4) of up to 1km radius away (and hence far more common) are represented by the 8/20 $\mu$ s waveform. Induced surges from direct lightning flashes and switching sources are also represented by this waveform. With a much shorter decay or fall time relative to the 10/350 $\mu$ s waveform, the 8/20 $\mu$ s waveform presents significantly less energy (for an equivalent peak current) but is still devastating enough to damage electrical and electronic equipment.

**Figure 20:**  
Indirect Strike  
near Structure



**Figure 21:**  
Indirect Strike  
near Structure





BS EN 62305-1 recognises that failure of internal systems (Damage Type D3) due to Lightning Electromagnetic Impulse (LEMP) is possible from all points of strike to the structure or service – direct or indirect (all Sources: S1, S2, S3 and S4).

## 4.6 Surge Protection Measures (SPM)

NOTE: Surge Protection Measures (SPM) were previously known as LEMP Protection Measures Systems (LPMS) in BS EN 62305

There are several techniques, which can be used to minimise 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 defines this as a complete system of protection measures for internal systems against LEMP with the term Surge Protection Measures (SPM).

BS EN 62305-4 describes a number of measures to minimise the severity of transient overvoltages caused by lightning and electrical switching.

Key and basic protection measures are

- Earthing and bonding
- Electromagnetic shielding and line routing
- Coordinated Surge Protective Devices

Further additional protection measures include:

- Extensions to the structural LPS
- Equipment location
- Use of fibre optic cables (protection by isolation)

Note: For the purpose of this guide and its scope, protection measures utilising SPDs will only be considered. See BS EN 62305 for further details of all protection measures.

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

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. Ideally SPDs are best incorporated at the project design stage, although they can also be readily installed in existing installations.

To ensure continuous operation of critical systems even in the event of a direct strike, SPDs are essential and these must be suitably deployed, based on the source of surge and its intensity using the Lightning Protection Zones (LPZ) concept within BS EN 62305-4.

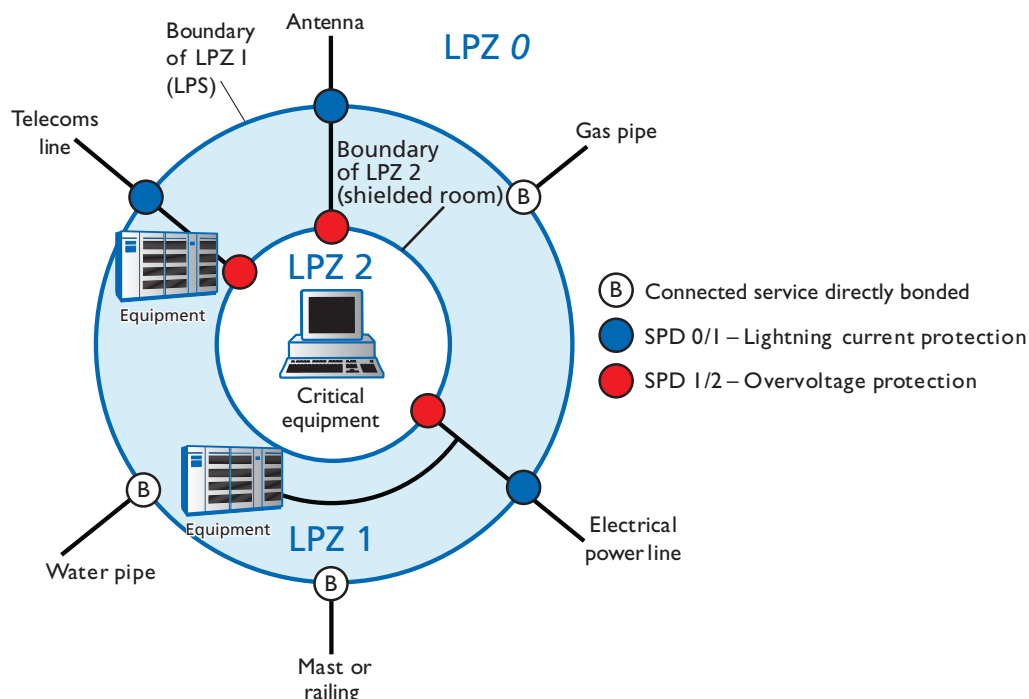
### 4.6.1 The Lightning Protection Zone (LPZ) concept

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 characterised by significant reductions in LEMP severity as a result of bonding, shielding or the use of SPDs.

Figure 22 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 services, with an SPM. This comprises spatial shields, bonding of incoming metallic services, such as water and gas, and the use of coordinated SPDs.

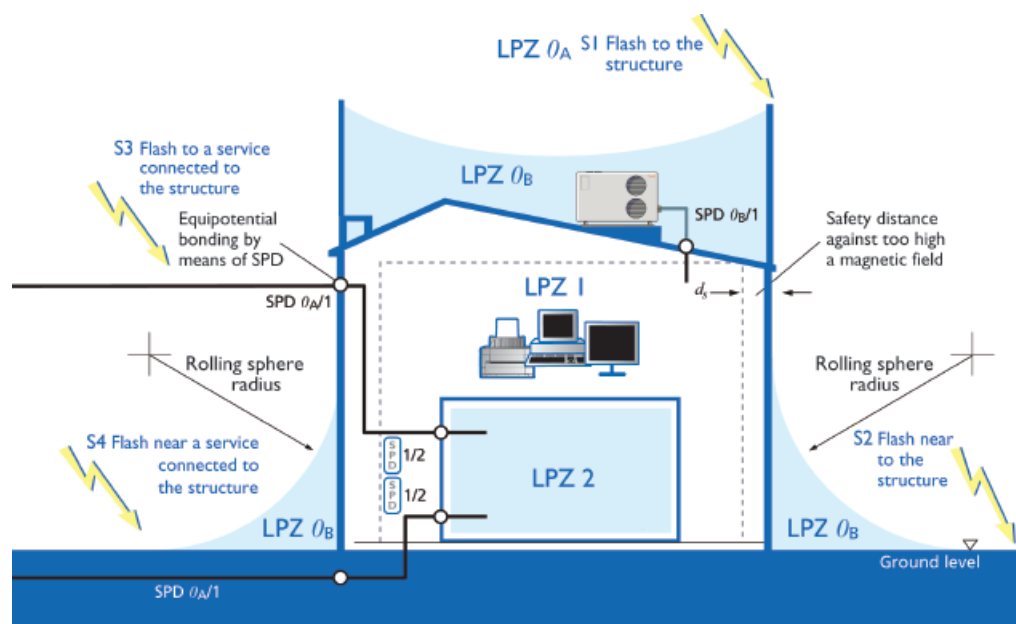
A spatial shield is the terminology used to describe an effective screen against the penetration of LEMP. An external LPS or conductive reinforcing bars within the structure or room would constitute spatial shields.

**Figure 22:**  
Lightning  
Protection Zones  
concept



The LPZs can be split into two categories (see Figure 23 below) – 2 external zones (LPZ 0A, LPZ 0B) 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.

**Figure 23:**  
Lightning protection  
zones split by category



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

## 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 without structural lightning protection. 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 or a roof with structural lightning protection. 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 services 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.

The general concept of zoning is not new. It was part of Annex C of BS 6651 “Protection of structures against lightning” and was defined by three distinct location categories with differing surge exposure levels, (Category A, B and C). These 3 location categories are still recognised within IEEE C62.41.1 standard series.

Note: BS 6651 has been superseded by BS EN 62305 and subsequently withdrawn.

## 4.7 SPD test parameters, types, location and application

Given that the live cores of metallic electrical services 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 likely to be subject to as well as ensure the transient overvoltages are limited to safe levels for equipment within the respective zone.

The following table details the standardized test waveforms with peak currents used to test SPDs

	LPZ 0/1	LPZ 1/2	LPZ 2/3
<b>Typical SPD Installation point</b>	Service Entrance (e.g. Main distribution board or telecom NTP)	Sub-distribution board or telecom PBX frame	Terminal Equipment (e.g. socket outlet)
<b>Mains Test Class/SPD Type (1)</b>	VI	IV2	IIV3
<b>Surge test waveform</b>	10/350 current	8/20 current	Combination 8/20 current and 1.2/50 voltage
<b>Typical peak test current (per mode)</b>	25kA (2)	40kA	3kA (with 6kV)
<b>Signal/Telecom Test Category (1)</b>	D1 (3)	C2 (3)	C1
<b>Surge test waveform</b>	10/350 current	Combination 8/20 current and 1.2/50 voltage	Combination 8/20 current and 1.2/50 voltage
<b>Typical peak test current (per mode)</b>	2.5kA	2kA (with 4kV)	0.5kA (with 1kV)

**Table 2:**  
Standardized test waveforms with peak currents used to test SPDs at each LPZ boundary

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

## 5. Types of Surge Protection Devices

BS EN 62305 deals with the provision of SPDs to protect against both the effects of high-energy direct lightning strikes and indirect lightning strikes plus switching transients.

- Direct lightning strikes are protected by lightning current or equipotential bonding SPDs (Mains Type 1 SPDs and Signal/Telecom SPDs to Test Category D)
- Indirect lightning strikes and switching transients are protected by transient overvoltage SPDs (Mains Type 2 and Type 3 SPDs and Signal/Telecom SPDs to Test Category C)

### 5.1 Lightning current or equipotential bonding SPDs

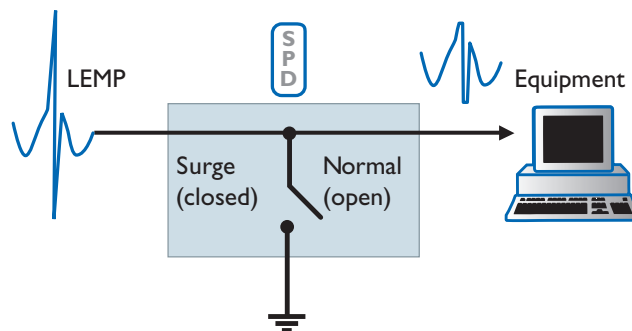
Designed to prevent dangerous sparking caused by flashover. Flashover is caused when the extremely high voltages associated with a direct lightning strike breaks down cable insulation. This can occur between the structural LPS and electrical services and presents a potential fire hazard and risk of electric shock.

### 5.2 Transient overvoltage SPDs

Designed to protect electrical/electronic equipment from the secondary effects of indirect lightning and against switching transients. SPDs should be installed at sub-distribution boards and at equipment level for critical equipment.

Although lightning current and transient overvoltage SPDs have two distinct functions, the concept of protection is the same. As figure 24 demonstrates in simplistic terms, the function of an SPD is to divert the surge current to earth and limit the overvoltage to a safe level. In doing so, SPDs prevent dangerous sparking through flashover and also protect equipment.

**Figure 24:**  
Basic concept  
of SPD operation



BS EN 62305 refers to the correct application of lightning current and transient overvoltage SPDs as a coordinated set where the service entrance lightning current SPD handles the majority of surge energy and prevents flashover whilst the downstream transient overvoltage SPDs ensure equipment protection by sufficiently limiting the overvoltages. Coordinated SPDs are covered in section 5.5 – it is important to first understand the need and application of the service entrance equipotential bonding SPD.

### 5.3 Equipotential bonding to BS EN 62305

It is fundamental to ensure the avoidance of dangerous sparking occurring within the structure to be protected. Following a lightning discharge, this could be due, to lightning current flowing in the external LPS or other conductive parts of the structure and attempting to flash or spark over to other 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.

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 one another. If the metallic parts are essentially at the same potential then the risk of sparking or flash over is nullified.

Note: BS EN 62305-3 details these requirements. This should not be confused with supplementary bonding for shock protection as required by BS 7671 the IET Wiring Regulations

As Figure 23 illustrates, all incoming services (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 main earthing terminal, a bonding ring conductor or a 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 extraneous conductive parts of the structure forming a complete integrated meshed bonding network.

Metallic services such as gas and water should be directly bonded to the earth reference point at the boundary of the external LPZ 0 and internal LPZ 1 – i.e. as close as possible to the point of entry of these services.

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 cannot be directly bonded to earth. Live cores therefore need to be connected at the service entrance through the use of equipotential bonding SPDs.

The purpose of service entrance SPDs is to protect against dangerous sparking thereby minimising the risk of loss of life (Risk R1 within BS EN 62305-2). 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 or equipment insulation 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. These SPDs also known in industry as lightning current SPDs, which are Class I tested to BS EN 61643 and hence are termed as Type 1 SPDs. However, the use of these Type 1 SPDs alone “provides no effective protection against failure of sensitive electrical or electronic systems”, to quote BS EN 62305 part 4, which is specifically dedicated to the protection of electrical and electronic systems within structures.

The effective protection of electrical and electronic systems from both lightning and switching transients requires the use of additional SPDs, namely Type 2 and Type 3 SPDs which further reduce the transient overvoltage to safe levels for equipment protection. Cumulatively Type 1, 2 and 3 SPDs are referred to as coordinated SPD set in accordance with the standard. Combined Type SPDs are classified with more than one Type, e.g. Type 1+2, Type 2+3 as they effectively achieve the principle of coordination within the single protection unit – the benefits of such SPDs as well as the concept of SPD coordination will be discussed later in this guide.

It can therefore be concluded that as lightning equipotential bonding serves the purpose of protecting against dangerous sparking, the service entrance equipotential bonding or lightning current SPD resides within this primary function and as such is an integral requirement of a structural LPS, in accordance with BS EN 62305-3. Lightning current or equipotential bonding SPDs are also used on overhead service lines feeding structures that are at risk from a direct strike.

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

### 5.4.1 Selecting appropriate equipotential bonding SPDs

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 – e.g. TN or TT
- How many metallic services are there entering or leaving the structure
- If an LPS is not required, are the services (such as power or telecom) entering the structure via an overhead line or an underground cable

#### 5.4.1.1 Requirements for equipotential bonding service entrance SPDs.

Partial lightning current (as defined by a 10/350µs 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 10/350µs waveform presents far greater energy (and therefore threat) to a system compared to an 8/20µs waveform with an equivalent peak current.

Equipotential bonding SPDs that are designed to handle such 10/350µs 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 10/350µs impulse current, which is known as the Class I test. Signal/telecom lightning current SPDs are also tested with the 10/350µs impulse current known as the Category D test.

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 then equipotential bonding or lightning current SPDs are always required for any metallic electrical service entering the structure (typically power and telecom lines where mains Type 1 SPDs and signal/data Category D tested SPDs are used respectively).

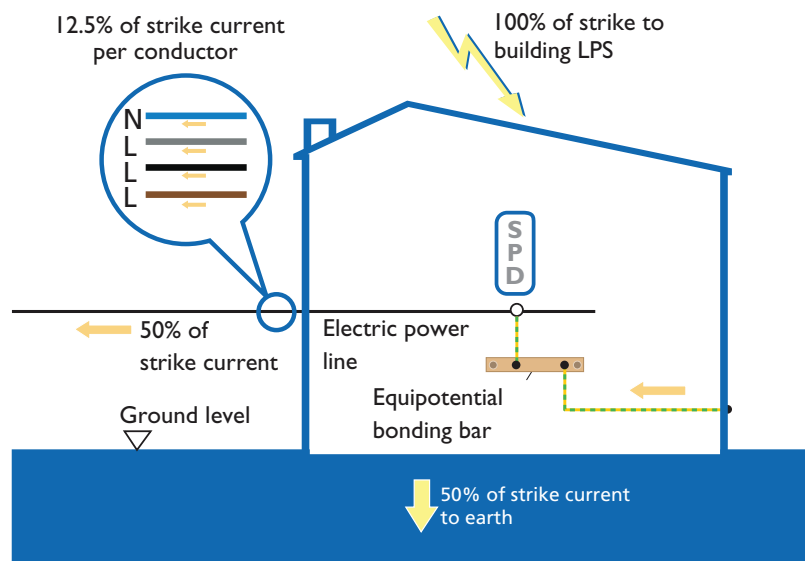
Table 3 shows the relationship between the Lightning Protection Level (LPL) of the structural LPS and the required maximum current handling of the equipotential bonding power line SPD. It is shown for the most common earthing arrangements TN-S or TN-C-S (where the neutral conductor is separated from earth).

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

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



- (1) 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 services within the structure as shown in Figure 25.

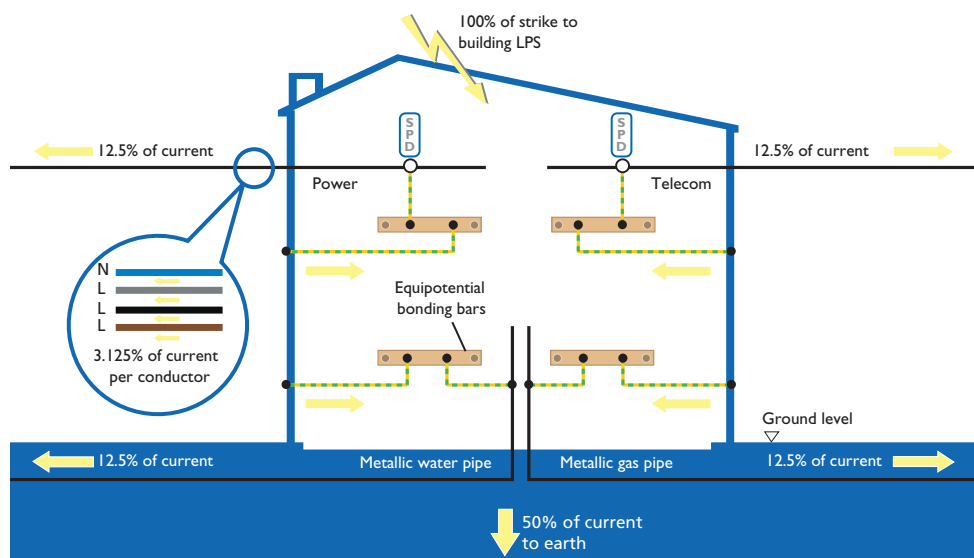


**Figure 25:**  
Simplified current  
division concept

Taking the worst case scenario, a strike of 200kA and an incoming service consisting solely of a three-phase power supply (4 lines, 3 phase conductors and neutral), 50% or 100kA of the total 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 25kA (ie  $100\text{kA}/4$ ).

Similarly, for LPL II and III/IV the maximum Type 1 SPD current capabilities would be 18.75kA (10/350 $\mu$ s) and 12.5kA (10/350 $\mu$ s) respectively. In practice, 18.75kA (10/350 $\mu$ s) Type 1 SPDs are uncommon so 25kA (10/350 $\mu$ s) Type 1 SPDs cover both LPL I and II. This worst case current of 25kA (10/350 $\mu$ s) is significantly higher than the worst case current of 10kA (8/20 $\mu$ s) presented within Annex C of BS 6651 (Location Category C-High).

In reality, most structures have more than just one service connected as shown in Figure 26. 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 services carries an equal proportion of this current. In this example there are 4 services so each carries approximately 12.5% of the overall lightning current.



**Figure 26:**  
Current division  
concept for  
multiple services

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 200kA (10/350µs) direct strike to the structure, 100kA goes straight into the earthing system and only 3.125% of the overall current is seen at each conductor i.e. 6.25kA (10/350µs). This is significantly lower than the 25kA (10/350µs), which occurs when there is lightning current of 200kA (10/350µs) and one three-phase (4 wire) power supply. Only one metallic service coming into a building is rare, as is a direct lightning strike. The two occurring together are very rare events 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.

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 at an installation is metallic. They could be non-conductive (i.e. plastic) which would therefore mean the power supply would see a significantly higher percentage of lightning current.

Unless the construction of the specific services 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 2.5kA (10/350µs) per line (Category D test to BS EN 61643-21) to earth or 5kA (10/350µs) per pair.

BS EN 62305-1 therefore discusses the expected surge currents due to lightning flashes on both low voltage mains systems and telecommunication lines as defined in Table 4. The preferred values of lightning currents are dependant on the LPL level and the type of service (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 are of similar magnitude to those defined in the previous BS 6651 standard. These values therefore represent the most common lightning scenario in practice.

**Table 4:**  
Expected surge  
currents due to  
lightning flashes (as  
per BS EN 62305-1)

System	Source of damage	Current waveform (µs)	LPL	
			III/IV (kA)	I/II (kA)
Low voltage lines	S3	10/350	5	10
	S4	8/20	2.5	5
	S1 or S2	8/20	0.1	0.2
Telecom lines	S3	10/350	1	2
	S4	Measured 5/300 Estimated 8/20	0.01 (0.05)	0.2 (0.1)
	S1 or S2	8/20	0.05	0.1

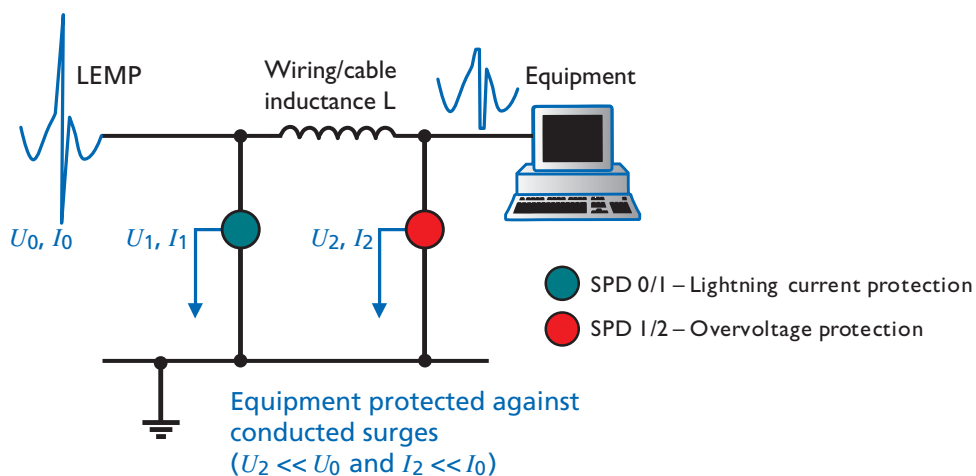
If the BS EN 62305 risk evaluation shows that a structural LPS is not required but there is an indirect risk any electrical services feeding the structure via an overhead line will require lightning current SPDs. For mains Type 1 SPDs the surge current rating per mode of protection is 12.5kA 10/350µs and for signal/telecom SPDs the surge current rating per mode of protection is 2.5kA 10/350µs.

For underground electrical services 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 $\mu$ s waveform in accordance with BS EN 61643 standard series on SPDs). Such underground electrical services are not subject to direct lightning currents and therefore do not transmit partial lightning currents into the structure. Underground electrical services therefore do not have a requirement for lightning current SPDs where no structural LPS is present – overvoltage SPDs are sufficient to provide effective protection.

## 5.5. Coordinated SPDs

BS EN 62305-4 emphasises the use of coordinated SPDs for the protection of equipment within their environment. This simply means a series of SPDs whose locations and LEMP handling attributes are coordinated in such a way as to protect the equipment in their environment by reducing the LEMP effects to a safe level.

Figure 27 explains the concept of coordinated SPDs, using two SPDs fitted on the same installation for simplicity. The SPD (typically a lightning current SPD) 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). The surge current and voltage are further reduced by the downstream overvoltage SPD to safe levels for equipment protection including potential damage by switching sources, e.g. large inductive motors. Appropriate SPDs should be fitted wherever services cross from one LPZ to another.



**Figure 27**  
Principle of  
coordinated SPDs

A coordinated set of SPDs should therefore effectively operate together as a cascaded system to protect equipment in their environment. 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. Appropriate SPDs should be fitted wherever services cross from one LPZ to another.

BS EN 62305-4 describes the principles and detailed theory of SPD coordination, which depends on factors such as SPD technologies; although in practice reputable manufacturers of SPDs will provide installation guidance to ensure coordination is achieved.

Modern combined Type SPDs are classified with more than one Type, e.g. Type 1+2, Type 2+3 or data/telecom Test Cat D+C+B as they effectively achieve the principle of coordination within the single protection unit itself. These SPDs offer significant technical, practical and economic benefits. In order to appreciate these advantages, we need to first understand the factors that effect SPD performance and the design considerations needed to achieve protection.

## 6 Design considerations for SPD protection of equipment

To achieve optimum protection, the designer must take into account the following when choosing and applying SPDs

- withstand voltage of equipment to be protected
- immunity withstand voltage of equipment to be protected
- additional installation effects, such as voltage drop on connecting leads
- oscillation protective distance – if the distance from the SPD to the equipment is over 10m, oscillations could lead to a doubling of voltage

### 6.1 Withstand voltages

The withstand voltage 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.

There are defined voltages that equipment must be capable of withstanding in various system voltages and installation categories. For a power installation of nominal voltage 230/240V, these withstand levels are defined by four overvoltage categories (IEC 60664 standard series) as shown in the table below (also defined in Table 44.3 of BS 7671). The concept of overvoltage categories in low voltage systems is used for equipment energized directly from the low voltage mains.

Equipment Category	Required minimum impulse withstand voltage (kV)	Typical location/ equipment
IV (equipment with very high overvoltage impulse) withstand	6kV	Electricity meter
III (equipment with high overvoltage impulse) withstand	4kV	Distribution board
II (equipment with normal overvoltage impulse) withstand	2.5kV	Sub-distribution board/ Electrical equipment
I (equipment with reduced overvoltage impulse) withstand	1.5kV	Socket outlet/ Electronic equipment

**Table 5:**  
Required minimum impulse withstand voltage for a 230/240V system

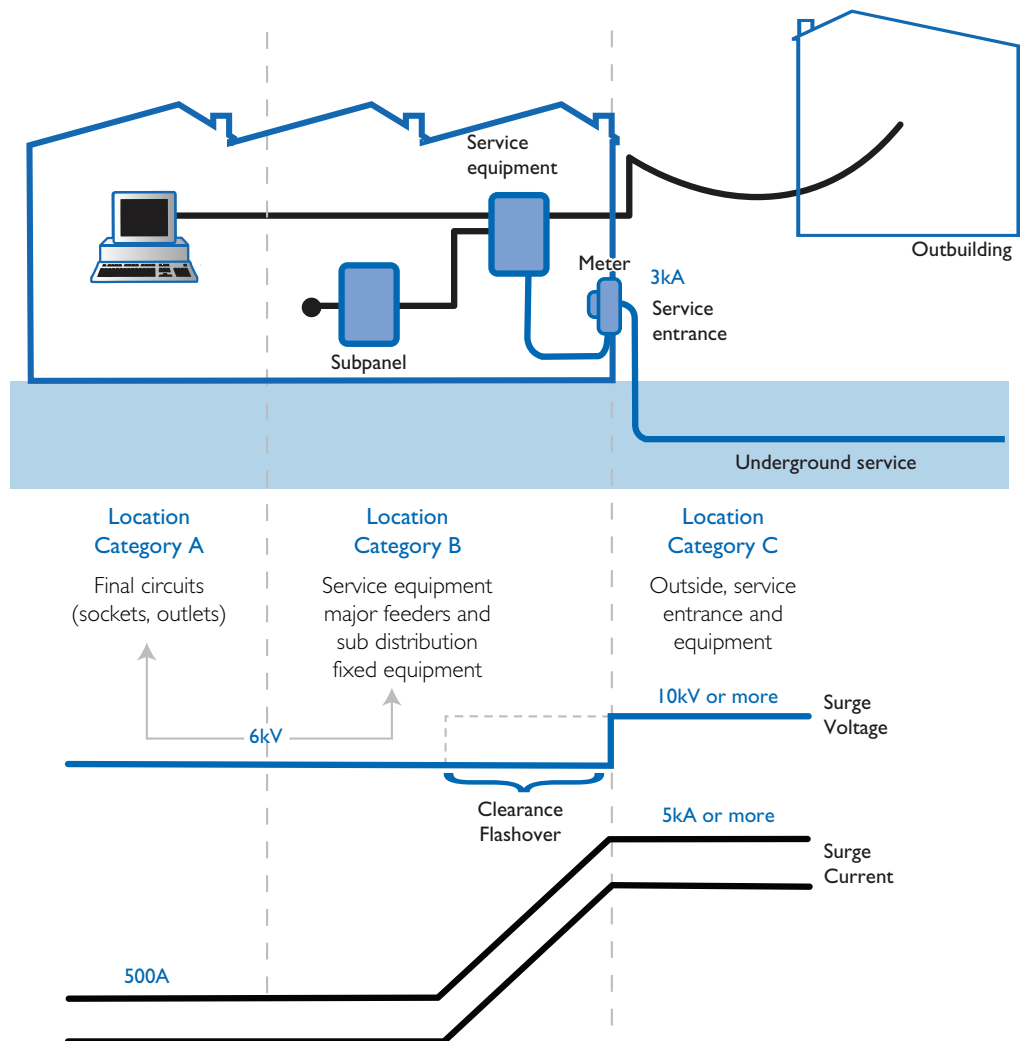
Similarly the withstand levels of telecommunication equipment is defined in specific industry standards, (namely ITU-T K.20 and K.21 series). The withstand voltage depends on the type of equipment, its sensitivity and where it is located within the electrical installation. This is termed as “insulation 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 6kV i.e. highest overvoltage impulse category IV as shown in Table 5. This is due to its proximity to the origin of the electrical installation upstream of the main distribution board where the threat presented (typically a lightning overvoltage) could be 6kV.

IEEE C62.41.1 2002 “Guide on the Surge Environment in Low-Voltage (1000V and Less) AC Power

Circuits” provides information about the magnitude of surge currents and voltages within an installation. The following figure illustrates a typical building to describe the scenario of surges impinging at the service entrance or generated within the building, exclusive of those associated with a direct lightning strike to the structure.

**Figure 28:**  
Concept of  
Location Categories  
(IEEE C62.41.1)



The concept of location category is based on the considerations of dispersion and propagation of surge currents and surge voltages. For surge currents presented at the service entrance of a building, the increasing impedance opposing (impeding) the flow of surge currents further into the building (with or without the crowbar effect of a flashover that can occur at the meter or in the service-entrance equipment) reduces the surge current that can be delivered along the branch circuits – typically from up to 3kA 8/20 at the service entrance and up to 500A at the end of the branch circuit (socket outlet).

In contrast, a voltage surge, with an amplitude below the point of flashover of clearances and presented at the service entrance of a building, can propagate, practically un-attenuated, to the end of a branch circuit when no low-impedance load (e.g. local SPD) is present along the branch circuit. This concurs with BS 7671 443.1.1 Note 3 which states 'Transient overvoltages transmitted by the supply distribution system are not significantly attenuated downstream in most installations'.

IEC 60664-1 'overvoltage categories have a probabilistic implication rather than the meaning of physical attenuation of the transient overvoltage downstream in the installation' – which again concurs with Note 3, 443.1.1 of BS 7671 which states – “Transient overvoltages transmitted by the supply distribution system are not significantly attenuated downstream in most installations”.

Probabilistic in this context simply means the probability of failure is based on the need or availability of equipment. It makes sense that an electricity meter needs to have a high availability and hence have a high voltage withstand rating (Category IV with the highest 6kV rating for a 230V nominal rating) given its location at or in the proximity of the origin of the electrical installation, upstream of the main distribution board where transient overvoltages are likely to be at a higher energy at the origin (see Table 44.3 and Table 44.4 Section 443 of BS 7671).

Even though transient overvoltages are not sufficiently attenuated downstream in most installations, terminal equipment installed downstream of the service entrance e.g. at the socket outlet is accepted to be subject to a higher risk or probability of failure as its availability is not generally as critical as the service entrance electricity meter. As such, terminal equipment (e.g. computers) have a reduced voltage withstand Category 1 (Table 44.3 and Table 44.4) with the lowest impulse withstand voltage of 1.5kV for a 230V nominal voltage. However Table 44.4 makes it clear if Category I equipment is to be connected to the fixed electrical installation, it must be protected against transient overvoltages. An SPD installed external to this equipment serves this purpose. In today's world where we are heavily dependent on such electronic equipment in our daily lives, the need to protect this equipment against transient overvoltages has become more apparent.

The withstand voltage values within Table 44.3 are the maximum ratings between live conductors and PE – this is referred to in Section 534 of BS 7671 as common mode protection (534.2.2 Note 1). Table 44.3 does not consider transient overvoltages which are also present between live conductors (e.g. live and neutral), referred to as differential mode protection by Section 534. Differential mode transients, also due to electrical switching events, which present particular problems for electronic equipment where their sensitive electronic components are connected between live conductors and hence SPDs with differential mode protection should be selected to protect such equipment.

The required minimum impulse withstand voltage Table 44.3 of BS 7671 therefore specifies its applicability to a **controlled voltage situation**, which implies that some surge-limiting device has been provided – presumably a typical SPD with characteristics matching the system voltage (e.g. 230/240V) in each case. Interestingly the wave shape specified for these voltages is the 1.2/50µs transient wave (see Figure 29 transient waveforms above). With such SPDs in place, the four "installation categories" are specified, each with decreasing voltage magnitude as the installation is further removed from the outdoor environment.

Therefore protection against transient overvoltages is not inherent if equipment has withstand values according to Table 44.3. Protection is achieved if the overvoltages presented are below the withstand values of the equipment as stated within Table 44.3 which will normally require a combination of equipment having the appropriate withstand voltage and correct selection of SPD(s).

We know that the function of the SPD is to limit the transient overvoltage and these 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.

Conventionally the main distribution board falls within overvoltage impulse category III (see Table 5), the installed mains Type 1 SPD must ensure that during lightning activity, the voltage protection level is well below the withstand value of 4kV to prevent dangerous sparking through insulation breakdown caused by flashover.

Overvoltage or mains Type 2 SPDs are tested with an 8/20 $\mu$ s 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 1.5kV. An overvoltage mains Type 3 SPD (tested with the Class III test to BS EN 61643 which is a combination or hybrid waveform of 6kV (1.2/50 $\mu$ s voltage) and 3kA (8/20 $\mu$ s 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 ability of an SPD to survive and achieve a suitable protection level when installed clearly depends upon the magnitude of the overvoltage it will be subjected to, this, in turn, depends upon its location and its coordination with other SPDs fitted as part of the same installation.

## 6.2 Installation effects on protection levels of SPDs

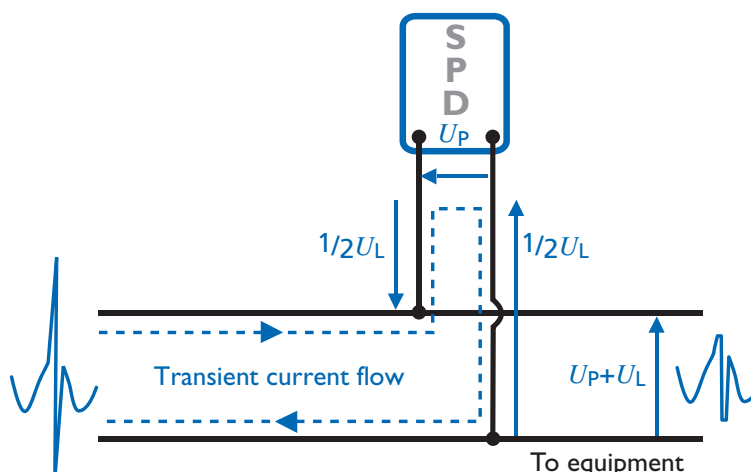
Correct installation of SPDs is vital. Not just for the obvious reasons of electrical safety but also because poor installation techniques can significantly reduce the effectiveness of SPDs.

### 6.2.1 Influence of SPD connecting lead lengths

The voltage drop on the connecting leads  $U_L$  of an installed SPD adds to the SPD's protection level  $U_P$  as seen by the equipment. This is particularly the case for SPDs installed in parallel (shunt) on power installations.

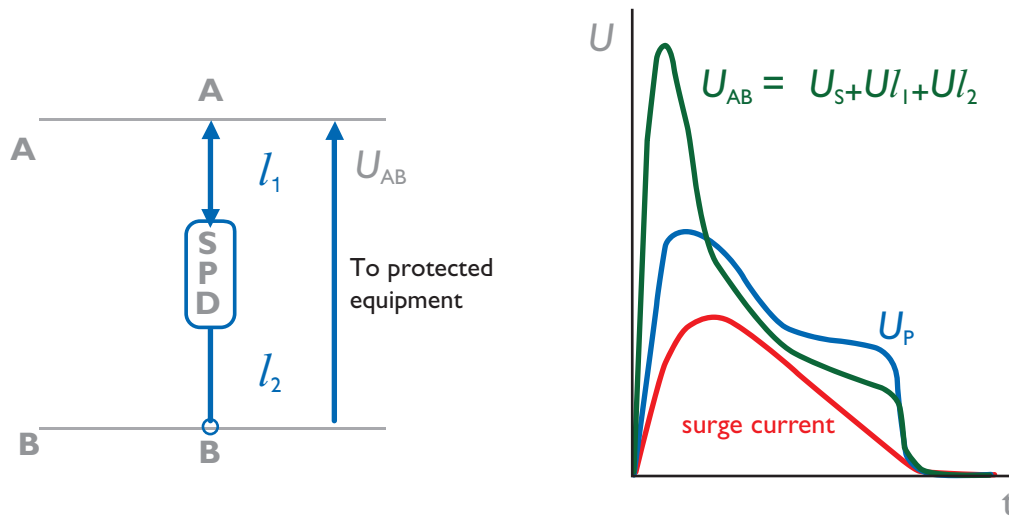
Figure 29 illustrates the additive effect of the inductive voltage drop ( $U_L$ ) along the connecting leads.

**Figure 29:**  
Additive effect of  
the inductive  
voltage drop to  
the SPD's  
protection level



Inductance and hence inductive voltage drop is directly related to cable length. To minimise the inductive voltage drop, lead lengths must be as short as possible (Section 534 BS 7671 states the total lead length should preferably not exceed 0.5m, but shall in no case exceed 1.0m).

Figure 30 shows the effect of the inductance of connecting leads on the voltage measured between connection points of the SPD during the impulse discharge current.



**Figure 30:**  
Influence of SPD  
connecting lead  
lengths

**Key:**

$U_{l1}, U_{l2}$  inductive voltage dropped on corresponding lead lengths  $l_1 + l_2$

$U_p$  Voltage at the SPD terminals during the surge

$U_{AB}$  Voltage between points A and B during the surge =  $U_p$  + voltage drop due to inductance  $U_{l1} + U_{l2}$

The residual voltage transferred to the protected equipment ( $U_{AB}$ ) will be the sum of the SPD voltage protection level  $U_p$  (relative to the applied surge current  $I_{surge}$ ) and the inductive voltage drop along the connecting leads ( $U_{l1} + U_{l2}$ ). The two voltages may not peak exactly at the same instant, but for most practical purposes, may simply be added. The inductive voltage drop can be calculated using the following formula:-

$$U_l = L \frac{di}{dt}$$

Inductance and hence inductive voltage drop is directly related to cable length. As a general rule, the lead inductance ( $L$ ) is assumed to be  $1 \mu\text{H/m}$ . This inductive voltage drop, when caused by an impulse current with a rate of rise of  $1 \text{ kA}/\mu\text{s}$  will be approximately  $1 \text{ kV/m}$  of lead length. Furthermore, if the steepness of  $di/dt$  (rate of change of current) is greater, this value will be increased.

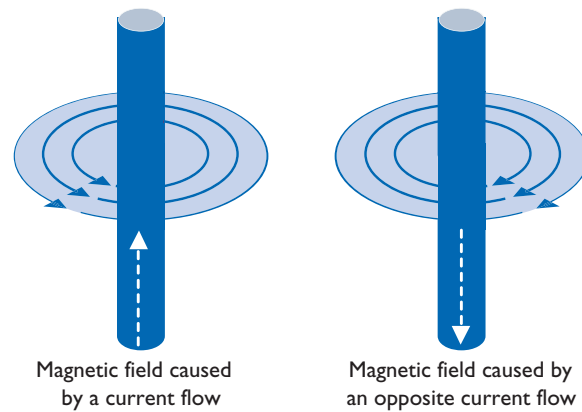
Therefore in order to achieve optimum overvoltage protection, connecting leads of SPDs shall be as short as possible, preferably not exceeding  $0,5 \text{ m}$  for the total lead length ( $l_1 + l_2$  see Figure 30). Therefore, given the additive inductive voltage on the connecting leads, it may be necessary to select an SPD with a lower voltage protection level  $U_p$  in order to provide the required level of protection.

In addition to keeping connecting leads short, 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 and hence inductive voltage dropped onto the connecting leads as explained below.

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 31.



**Figure 31:**  
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 or shunt installed 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 32 below.

**Figure 32:**  
Parallel or shunt  
installed SPD with  
closely bound  
connecting leads to  
cancel magnetic fields  
around the leads.

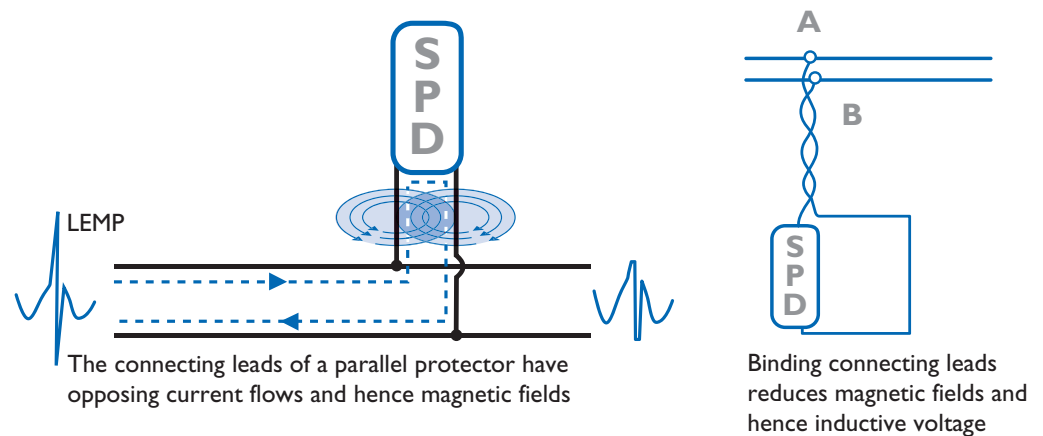
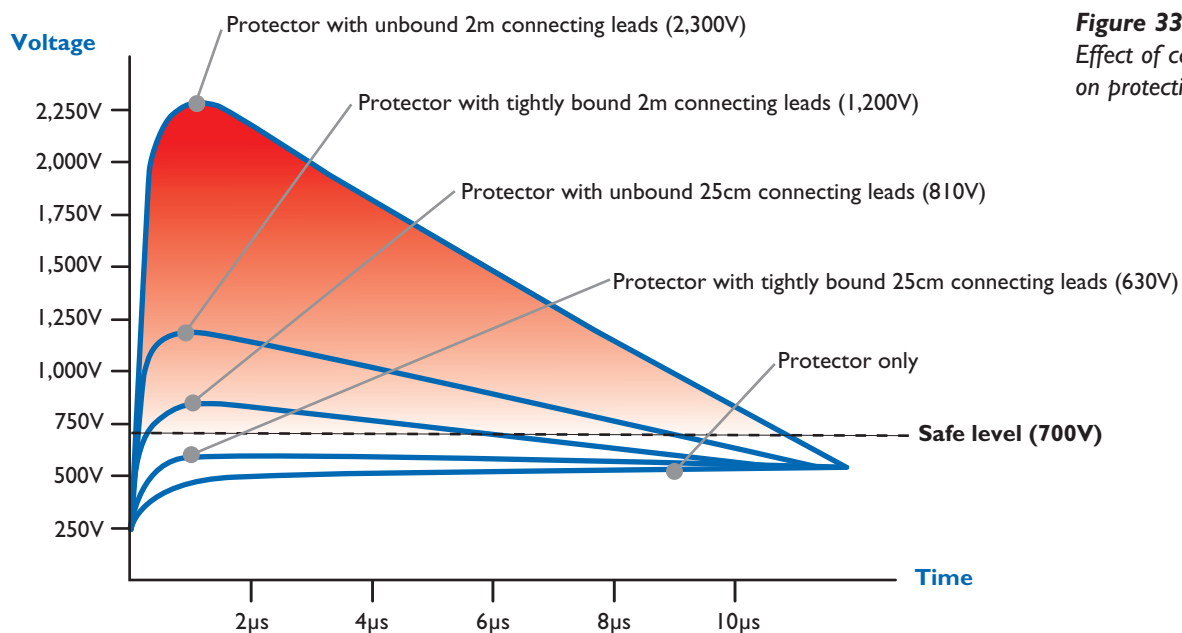


Figure 32 also illustrates a way to reduce the inductive voltage dropped on the connecting lead by placing the conductors in close proximity, through twisting or binding the connecting leads together. If the wires are brought close together, the opposing electromagnetic fields interact and cancel. Since inductance relates to electromagnetic field it too tends to be cancelled. In this way, binding leads closely together reduces the voltage drop in cables.

To illustrate the effects of long and unbound connecting leads we applied a 6kV/3kA combination wave surge test (Class III test to BS EN 61643-11) to a parallel installed SPD for a 230V mains power supply. In this example, the equipment to be protected has a susceptibility or immunity level of 700V. The SPD therefore has a protection level  $U_p$  of 600V when measured across its terminals with a 6kV/3kA surge test. If this protector is fitted with its recommended length (25 cm in this case) of bound connecting lead, the overall voltage of the SPD plus connecting leads is 630V as shown in Figure 33 graph. However the overall voltage doubles to 1,200V with unacceptably long, 2 m, bound connecting leads. If these connecting leads are left unbound, then the overall voltage rises to 810V with the recommended connecting leads (25 cm), and to 2,300V with the 2 m leads.



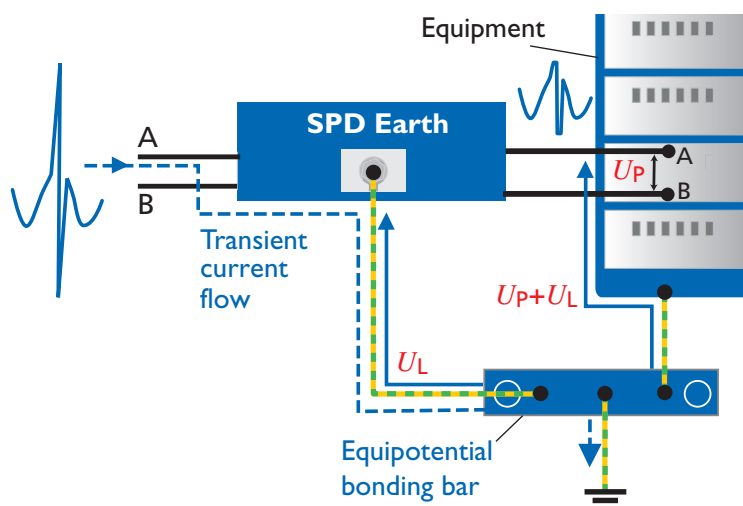
**Figure 33:**  
Effect of cable length  
on protection level

In practice protectors for mains power supplies are usually mounted on or in, power distribution boards. One problem which can occur is that the earth lead needs to be significantly longer than the phase and neutral connections and longer than 25cm. This can be alleviated through the use of two sets of connecting leads in one of two ways, as follows: -

For metal cabinets and enclosures one conductor should be closely connected to the metalwork of the assembly, whilst the other should be connected directly to the earth bar. This, in turn, should be connected directly to the metal of the assembly. Transient current can now flow through the metal back of the assembly. Since this is a plate and not a cable, it has the inherently useful property of having a low inductance, which helps to keep the let-through voltage low.

If this is not possible, two connections can be made to the earth bar. One of these should be within the set of bound conductors, whilst the other should be separate.

Low current SPDs for power (typically 16A or less), telecommunication, data and signal equipment are usually installed in series (in-line) with the equipment they are protecting and are not affected by length of their connecting leads. However, the earthing conductors of series SPDs must be kept as short as possible as shown in Figure 34, for reasons similar to those detailed above.



**Figure 34:**  
Series connected SPD

This type of series connected SPD behaves differently with line to line transients than with line to earth transients.

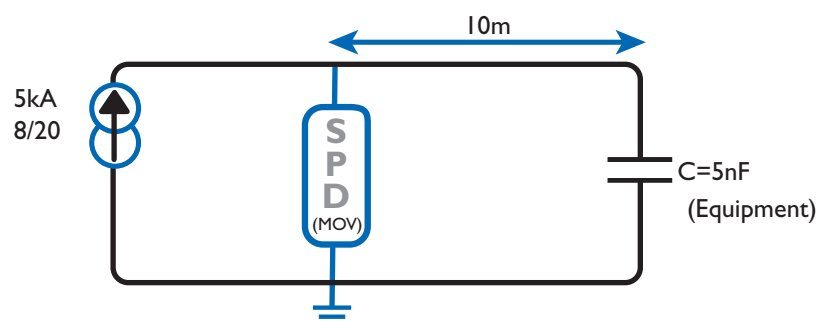
A line to line transient between A & B (see Figure 34) is reduced to a protection level of  $U_p$ . In this case there is no additional voltage ( $U_L$ ) from the earth lead.

However, for line to earth transients there will also be a voltage ( $U_L$ ) between the protector and earth. In this case the voltage reaching the equipment will be the protection level of the SPD ( $U_p$ ), plus the voltage associated with the connecting lead ( $U_L$ ).

### 6.2.2 Protective distance

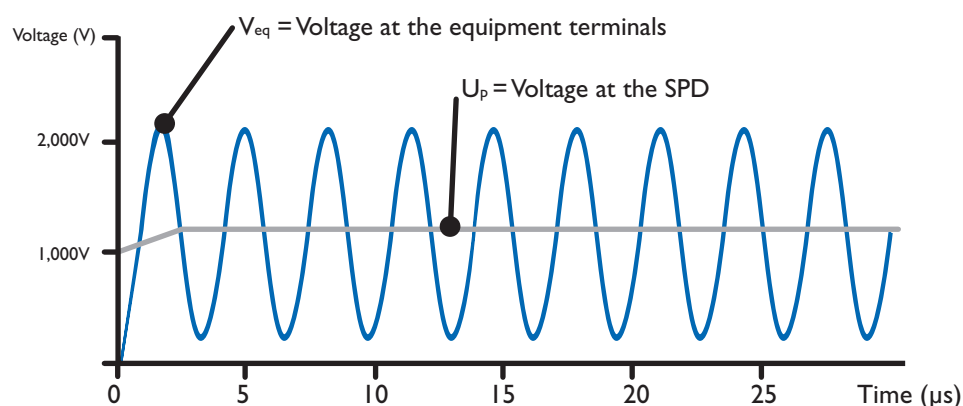
If the distance between a parallel installed SPD and the equipment to be protected is too large, oscillations could lead to a voltage at the equipment terminals which is up to double the protection level of the SPD,  $U_p$ . This can cause a failure of the equipment to be protected, in spite of the presence of the SPD. This is illustrated in Figure 35 and 36 below.

**Figure 35:**  
Large distance  
between SPD  
and equipment



When a surge is applied (in this case a 5kA 8/20 surge) the equipment's capacitance together with the long inductive cable distance create a voltage doubling as shown in Figure 36.

**Figure 36:**  
Voltage doubling  
due to equipment  
capacitance and  
long inductive  
cable distance



The 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 cable runs of less than 10m 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.

For more information, Annex D of BS EN 62305-4 and IEC 61643-12 both provide further information on the subject of oscillation protection distance.

### 6.2.3 Common and differential mode surges

Composite cables consist of more than one 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 cores will tend to move together in potential relative to their local earth. This is a common mode surge and it occurs between phase cores to earth and neutral core 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 cores (line to line). This is a differential mode surge and it occurs between phases and phase cores 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 cores, in any polarity, simultaneously.

Lightning transient overvoltages generally start as disturbances with respect to earth, whilst switching transient overvoltages start as disturbances between line/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 live/phase 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 more cost effective solution over shielding.

SPDs that protect against both common and differential mode surges (often termed as full mode protection), ensure the equipment will be protected from damage and remain available for continuous operation during surge activity.

Full mode protection is very important when considering the continuous operation of equipment which considers protection levels often lower than the withstand voltage of equipment. These levels are referred to as the immunity withstand.

### 6.2.4 Immunity withstand of equipment

Protecting equipment from the risk of permanent failures or damage due to surges considers the withstand voltage  $U_w$  as defined by IEC 60664-1 (see Table 44.3 as seen in Section 44.3 of BS 7671). 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-energised.

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 potential fire, smoke and/or electric shock hazards. 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 immunity withstand from voltage and current surges for electronic equipment and systems.

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.

## 7 Enhanced SPDs referred to in BS EN 62305

### 7.1 Protection levels and enhanced SPDs

“Standard” SPDs may 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” SPDs reduce the probability of failure of internal systems by a factor of 10 as they have lower (better) voltage protection levels or let-through voltages (See BS EN 62305 Table NB.3). This 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 minimise 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 SPDs 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 230V mains supply a Type 1 SPD fitted at the service entrance (for lightning equipotential bonding) should have a voltage protection level of no more than 1600V when tested in accordance with BS EN 61643 series (Class I Test).

This value is derived as follows:

$$((4\text{kV} \times 0.8)/2) = 1600\text{V}$$

Where:

- The withstand voltage for electrical apparatus at the main distribution board downstream of the electricity meter is 4kV 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

SPDs 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. See section 6.2.4 for more details.

Often the susceptibility level of equipment is unknown. BS EN 62305 Table NB.3, note 3 gives further guidance that unless stated, the susceptibility level of equipment is assumed to be twice its peak operating voltage.

For example, a single-phase 230V power supply has a peak operating rating of  $230\text{V} \times \sqrt{2} \times 1.1$  (10% supply tolerance). This equates to a peak operating voltage of 358V so the susceptibility level of terminal equipment connected to a 230V supply is approximately 715V. This is an approximation and where possible the known susceptibility of equipment should be used. The typical withstand voltage of such terminal equipment is 1.5kV.

Similarly to take account of the additive inductive voltage of the connecting lead length and possible voltage doubling due to oscillation protective distance, overvoltage SPDs should have a voltage protection level of no more than 600V  $((1.5\text{kV} \times 0.8)/2)$  when tested in accordance with BS EN 61643 series (Class III test).

Such an SPD installed with short, bound connecting leads (25cm) should achieve an installed protection level well below 715V 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 (TOVs) as defined by BS EN 61643 standard series that are specific for SPDs.

From a risk perspective, the choice of using a standard or enhanced SPD can be determined by Note 4 of Table NB.3 of BS EN 62305. 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 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 SPDs is always strongly advised. Enhanced SPDs can also present a more economic solution to standard SPDs as described below.

## 7.2 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 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 cost.

Overvoltage SPDs can satisfy two test classes and hence be both mains combined Type 2+3 (or data Category C1+C2) within one unit. Such units offer a high 8/20 $\mu$ s 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 combined Type 2+3 SPD may be sufficient to protect this LPZ from threats via this line. Similarly enhanced mains combined Type 1+2 (or data Category D1+C2) SPDs exist which handle both partial lightning current (10/350 $\mu$ s) and offer low protection levels and so further reduce the risk of flashover.

Telecom, data and signal SPDs can offer complete protection – namely Category D1+C2+C1 within the same unit. Such SPDs utilise 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 SPDs help minimise voltage doubling effects (oscillation protection distance), care must be taken if there are sources of internal switching surges generated downstream of the installation point of the SPD. Additional protection may therefore be required.

## 8 Protection of SPDs

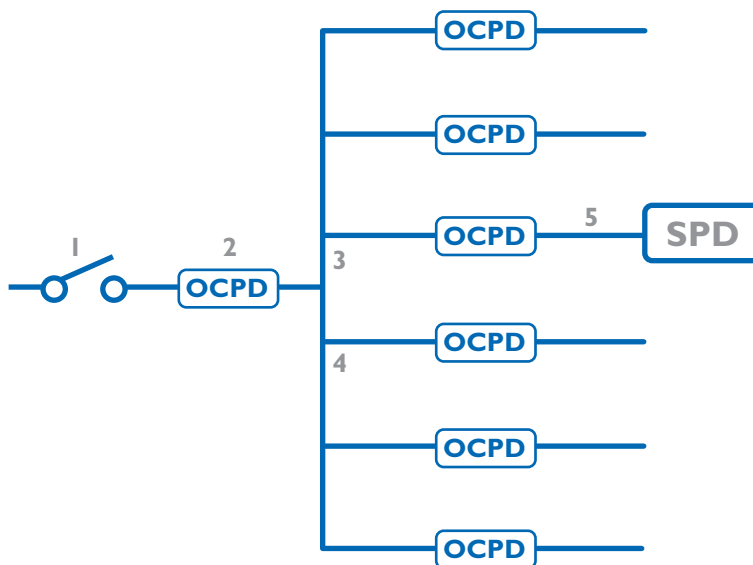
### 8.1 Protection against overcurrent and consequences of SPDs end of life

BS 7671 Section 534 requires installed SPDs to be protected against short-circuit through the use of over current protective devices (OCPDs). Reputable manufacturers of SPDs provide clear guidance for the selection of the correct ratings of OCPDs in their SPD installation instructions.

The subject of overcurrent protection of SPDs is often confusing in practice where mains power SPDs are concerned, given that the vast majority of these SPDs are installed in shunt or parallel with the supply and the installed SPD itself is therefore independent of the supply load current. The same SPD could therefore be used on a 100A supply load or a 1000A supply load and hence the cross-sectional area of the connecting leads to SPDs therefore does not have to be sized equivalent to the load current.

Section 534 advises that SPD connecting cables have minimum cross-sectional areas of 16mm<sup>2</sup> (copper) for the high energy Type 1 SPD and 4mm<sup>2</sup> (copper) for Type 2 and Type 3 SPDs if the cross-sectional area of the line conductors is  $\geq 4\text{mm}^2$ , or not less than that of the line conductor, where the line conductors have a cross-sectional area less than 4mm<sup>2</sup>. These cross-sectional area values are based on the surge current that these SPD connecting leads need to carry, not the supply load current. However in the event of a short-circuit due to say the end-of-life condition of the SPD, the connecting leads to the SPD need to be protected by a suitable OCPD.

Parallel connected SPDs are passive devices and under normal operation do not draw any load current although a negligible current is drawn if the SPD has electronic status indication). In the event of an overload fault condition, BS EN 61643 SPD product test standards require mains power SPDs to have internal overload protection (typically a thermal disconnection). The connecting conductors to SPDs therefore need only be protected against short-circuit fault conditions by the use of an OCPD in-line with the connecting cables as shown in the figure below.



**Key:**

1. main switch/isolator
2. main supply OCPD
3. preferred outgoing way (closest to incomer)
4. alternative outgoing way for SPD with dedicated OCPD
5. SPD with dedicated OCPD

**Figure 37:**  
Optimal positioning  
of parallel SPD with  
dedicated OCPD



Although SPD manufacturers recommend ratings of the OCPD and connecting cables according to BS 7671, it is useful to explain how the connecting cable to the SPD is protected by the in-line OCPD using the following equation.

$$I^2t = k^2S^2,$$

Where;

$I^2t$  relates to OCPD (this rating can be readily obtained from OCPD manufacturer's data as 'Total  $I^2t$ ' rating+.

$k^2S^2$  indicates the thermal capacity of the cable where  $k$  is obtained from BS 7671 or cable manufacturer's data and  $S$  is the nominal cross-sectional area of the cable in  $\text{mm}^2$

If the connecting cable is not to be damaged, the Total  $I^2t$  of the OCPD must not exceed  $k^2S^2$  rating of the connecting cable;

For example, a typical (industry common) Type 2 SPD with a peak surge current of 40kA 8/20 is likely to state a maximum OCPD rating of 125A and may recommend 10mm<sup>2</sup> connecting cables.

A typical 125A high rupture capacity HRC OCPD has a total  $I^2t$  rating of approximately 85,000A<sup>2</sup>s (taken from OCPD manufacturer's data, three-phase 415V).

For general purpose cable (70 deg°C PVC),  $k$  is typically 115 (taken from cable manufacturer data or BS 7671)

So  $k^2S^2$  would be equal to 1,322,500 – this is significantly greater than the 85,000A<sup>2</sup>s rating so the OCPD will always protect the 10mm<sup>2</sup> cable in the remote event of a short circuit. It is worth noting that the Section 534 minimum 4mm<sup>2</sup> connecting cable for Type 2 SPDs ( $k^2S^2$  of 211,600) would be protected by the manufacturer's maximum 125A OCPD.

## 8.2 Design considerations for protection of SPDs

### 8.2.1 SPD and OCPD coordination/discrimination

The OCPD and SPD should be co-ordinated to ensure correct operation. It is important that discrimination between the SPD OCPD and upstream OCPDs is achieved in all installations.

BS EN 61643 SPD product standard requires SPD manufacturers to declare the maximum OCPD ratings that can safely be used with their SPDs. As the OCPD is installed in-line with the SPD, the maximum surge current of the SPD will also flow through the OCPD. Therefore the OCPD rating 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 – resulting in a tested combination of SPD and OCPD.

It is important to ensure that the maximum OCPD rating declared by the SPD manufacturer is never exceeded. It is often thought albeit erroneously, that in order to get the maximum surge current rating of the SPD, the maximum OCPD value declared by the SPD manufacturer should be used irrespective of the discrimination of this OCPD with upstream OCPDs. Therefore it is important that the SPD's OCPD is selected so as to discriminate with the upstream OCPD.

For example, a supply with a 100A OCPD fitted may have a downstream Type 2 SPD incorrectly fitted with the manufacturer's maximum recommended 125A OCPD. A suitable OCPD should be selected for installation in-line with the SPD to ensure that discrimination is achieved with the upstream supply OCPD.

Installers should 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 for the upstream OCPD are not available, for example a retrofit installation, it may be safely assumed that the OCPD for the SPD should be rated at half the nominal value of the immediate upstream OCPD.

IEC 61643-12 allows the use of OCPD ratings lower than the maximum OCPD declared by the manufacturer of the SPD and explains further details that “when co-ordinating SPDs with an OCPD (or RCD), it is recommended that, at the nominal discharge current  $I_{nspd}$ , this OCPD (or RCD) shall not operate. However, at current higher than  $I_{nspd}$ , it is normally acceptable for the OCPD device to operate.”

$I_{nspd}$  is the nominal value of surge current and is typically half the value of the peak surge current rating ( $I_{max}$  to BS EN61643). Section 534 requires a minimum  $I_{nspd}$  of 5kA 8/20 for each SPD mode of protection on the common CT1 configuration (534.2.3.4.1). This magnitude of surge current is realistic in practice and small OCPD ratings (approximately 20A) should allow this current to flow without operating hence SPD installers should not be too concerned that OCPD devices will not frequently operate during surge activity.

### 8.3 SPDs and residual current devices RCDs

Where the power distribution system incorporates RCDs transient activity could cause RCDs to operate and hence loss of supply. SPDs should wherever possible be installed upstream of RCDs to prevent unwanted tripping caused by transient overvoltages.

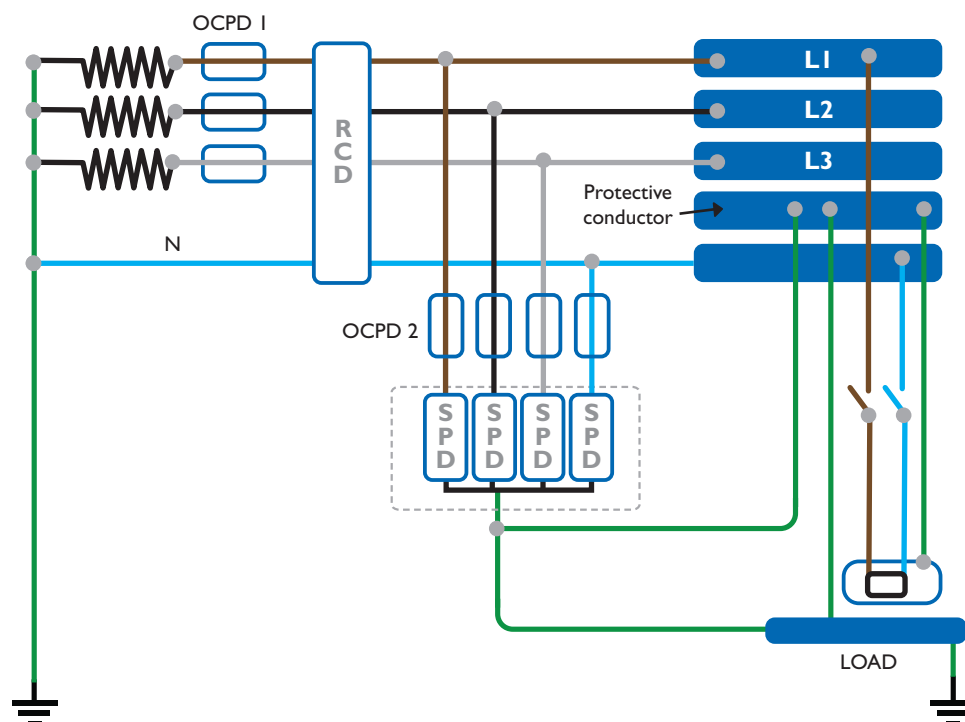
**Where SPDs are installed in accordance with BS 7671 534.2.1 and are on the load side of a residual current device, an RCD having an immunity to surge currents of at least 3 kA 8/20, shall be used.**

NOTE 1: S-type RCDs satisfy this requirement.

NOTE 2: In the case of surge currents higher than 3 kA 8/20, the RCD may trip causing interruption of the power supply.

If the SPD is installed downstream of the RCD, the RCD should be of the time delayed type with an immunity to surge currents of at least 3kA 8/20.

Section 534.2.2 of BS 7671 details the minimum SPD connection requirements (based on the SPD modes of protection) at the origin of the installation (typically a Type 1 SPD). An SPD configuration based on Connection Type 1 (CT1) is for TN-C-S/TN-S earthing arrangements as well the TT earthing arrangement where the SPD is fitted downstream of the RCD.

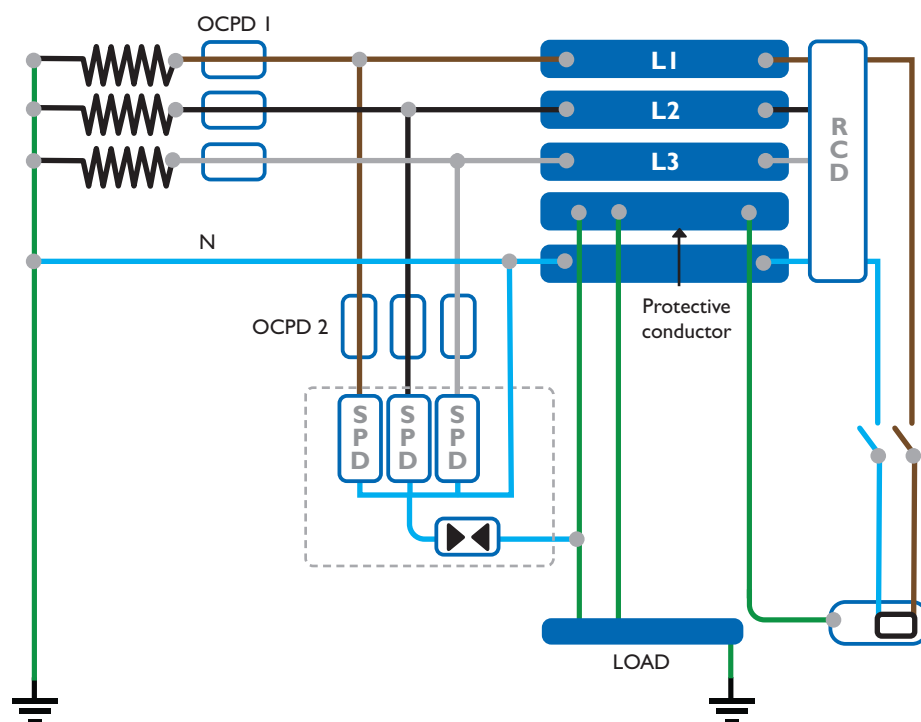


**Figure 38:**  
SPDs installed  
on load side  
of RCD

In general, TT systems require special attention because they normally have higher earth impedances which reduces earth fault currents and increases the disconnection times of OCPDs. Therefore in order to meet the requirements for safe disconnection times, RCDs are used for earth fault protection.

An SPD configuration based on Connection Type 2 (CT2) is required on a TT earth arrangement if the SPD is upstream of the RCD. The RCD being downstream of the SPD would not operate should the SPD become defective.

**Figure 39:**  
SPDs installed on  
supply side  
of RCD



The SPD arrangement here is configured such that the SPDs are applied between the live conductors (live to neutral) rather than between live conductors and the protective conductor. Should the SPD become defective it would therefore 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 within the required disconnection time.

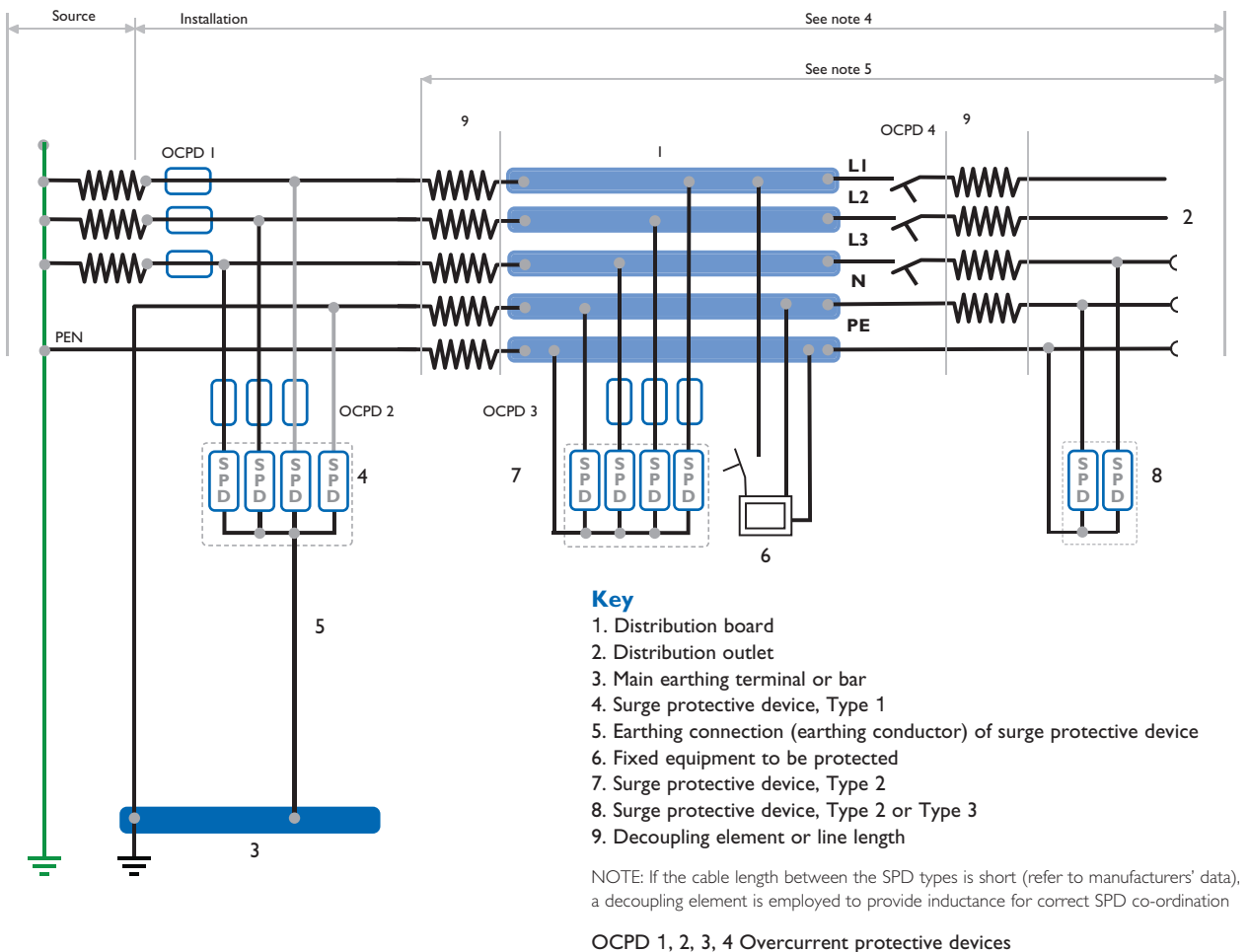
A higher energy SPD is used between neutral and the protective conductor. This higher energy SPD (typically a spark-gap for a Type 1 SPD) is required as lightning currents arise towards the protective conductor and as such this higher energy SPD sees up to 4 times the surge current of the SPDs connected between the live conductors. Clause 534.2.3.4.3 therefore advises that the SPD between neutral and the protective conductor is rated at 4 times the magnitude of the SPD between the live conductors.

Therefore only if the impulse current  $I_{imp}$  cannot be calculated, 534.2.3.4.3 advises that the minimum value  $I_{imp}$  for an SPD between neutral and the protective conductor is 50kA 10/350 for a 3 phase CT2 installation, 4 times 12.5kA 10/350 of the SPDs between the live conductors. The CT2 SPD configuration is often referred the '3+1' arrangement for a 3 phase supply.

#### SPDs and TN-C-S earth configurations

The minimum SPD connection requirements at or near the origin of the installation for a TN-C-S system requires further clarification as Section 534 of BS 7671 illustrates (see Figure 40) a Type 1 SPD being required between the live and PE conductors – the same as required for a TN-S system.

**Figure 40:**  
Installation of Types 1, 2 & 3 SPDs,  
for example in TN-C-S systems



The term 'at or near the origin of the installation' creates ambiguity given the fact that the word 'near' is not defined. From a technical point of view, if SPDs are applied within a 0.5m distance of the PEN split to separate N and PE, there is no need to have an SPD protection mode between N and PE as shown in the figure.

If BS 7671 would allow the application of SPDs to the TN-C side (utility side) of the TN-C-S system (observed in some parts of Europe), then it may be possible to install SPDs within 0.5m of the PEN split to N and PE and omit the N to PE SPD protection mode.

However as SPDs can only be applied the TN-S side (consumer side) of the TN-C-S system, and given SPDs are typically installed at the main distribution board, the distance between the SPD installation point and the PEN split will almost always be greater than 0.5m so there is a need to have an SPD between N and PE as required for a TN-S system.

As Type 1 SPDs are specifically installed to prevent the risk of loss of human life (to BS EN62305) through dangerous sparking which could present a fire hazard for example, in the interests of safety alone, the engineering judgement is that an SPD should be fitted between N and PE for a TN-C-S system as it would in a TN-S system.

In summary, as far as Section 534 is concerned, TN-C-S systems are treated the same as TN-S systems for the selection and installation of SPDs.

## 9 Installation of Surge Protection Devices

Where installed at the main intake switch panel or a distribution board the Surge Protection Device (SPD) should have a separate overcurrent protection device (OCPD), depending on the maximum prospective fault current at the point of installation.

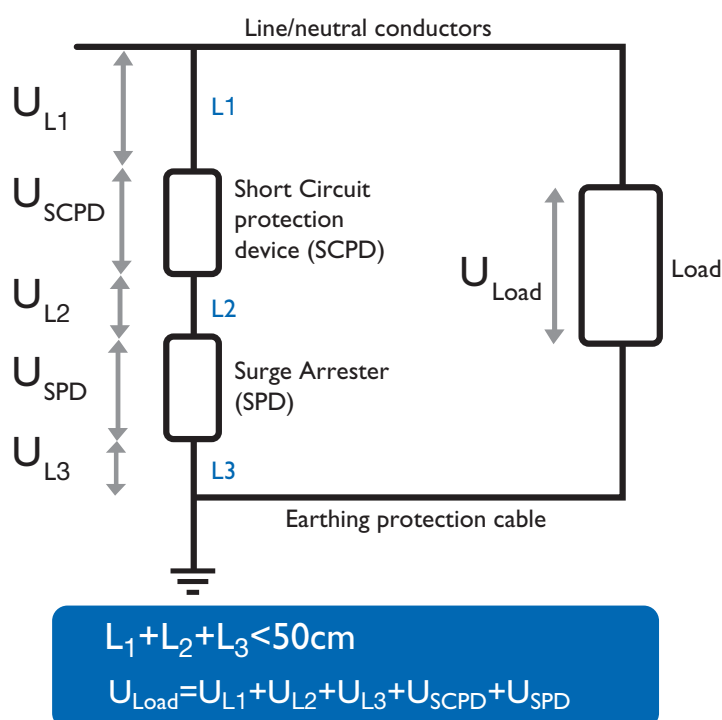
It is recommended that provision should be made for readily disconnecting the neutral conductors for testing purposes this should be achieved by 2-pole or 4-pole means of isolation.

### 9.1 Connections

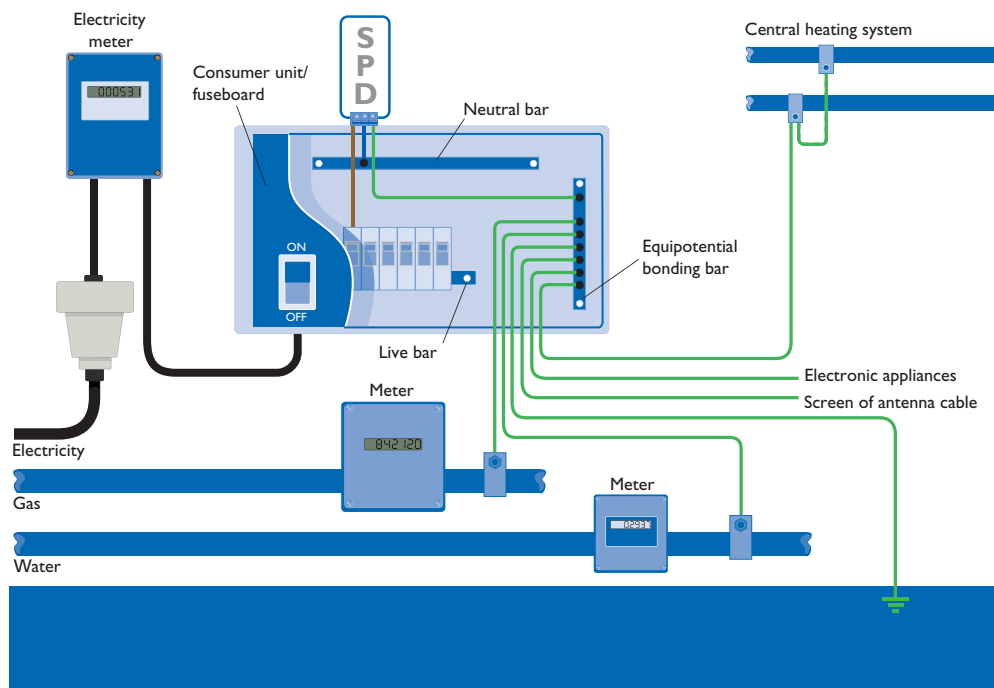
The SPD connections should be as short as possible in order to reduce the value of the voltage protection level (installed  $U_p$ ) on the terminals of the protected equipment.

The total length ( $L = L_1 + L_2 + L_3$ ) of SPD connections to the network and the earth terminal block should not exceed 50 cm (see below).

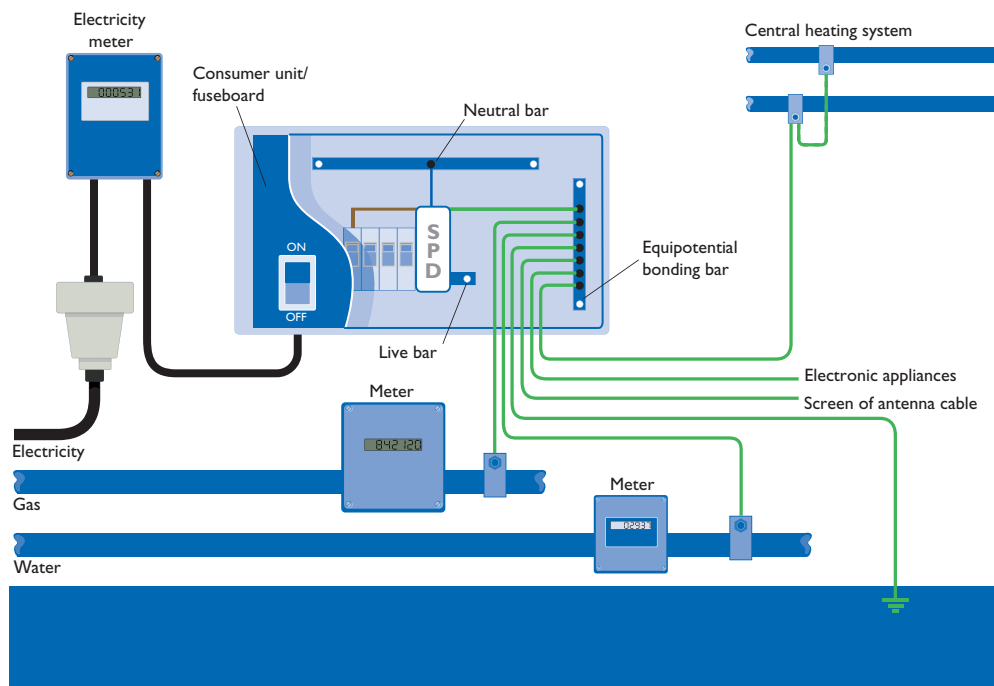
**Figure 41:**  
Breaking the  
50 centimetre rule



### 9.1.1 Examples of installations

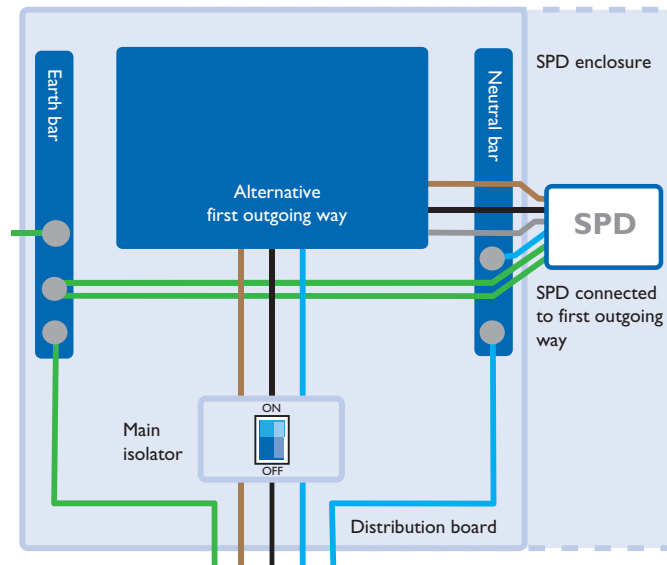


**Figure 42:**  
Installed adjacent  
to a consumer unit  
(retrofit)

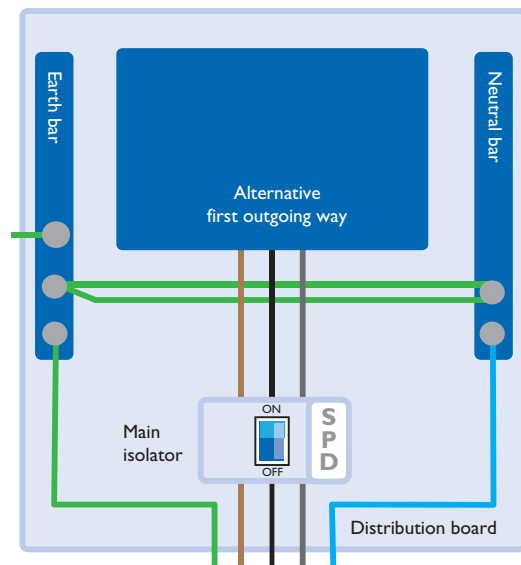


**Figure 43:**  
Installed inside a  
consumer unit

**Figure 44:**  
Installed adjacent  
to a distribution  
board



**Figure 45:**  
Installed within  
distribution board



## 9.2 Notice

Where SPDs are installed a durable notice should be fixed adjacent to the distribution board(s) and equipment complying with the requirements of BS 7671.

# 10. Inspection & Testing Electrical Installations Fitted with SPDs

## 10.1 Initial Verification

### Insulation Resistance Testing

BS 7671 Part 6 details insulation resistance testing with consideration of SPDs fitted within the installation.

Although SPDs should not be affected by insulation resistance testing at 500V, since they require a connection to earth for functional purposes, if required by manufacturer's instructions to avoid influencing the test result and give a false reading, they should be disconnected.

Where it is not practical to disconnect the SPD (e.g. a fixed surge protected socket outlet), a 250V test should be applied between live conductors and Earth in accordance with BS 7671 Regulation 612.3.2.

## 10.2 Periodic Inspection & Testing

When carrying out a periodic inspection and test of an existing installation it is important prior to applying any insulation resistance tests, to establish if the installation has any SPDs installed. Where SPDs are installed the following procedure should be applied.

**WARNING :** – SPDs should be isolated during insulation resistance testing, as the SPD could operate, by treating the test voltage applied to the system as a transient overvoltage, thus defeating the object of the test.

1. Check that the OCPD has not operated and that the SPD is still in a servicable condition. (SPDs have fault indicators that will show when the device has been damaged or destroyed by a surge).
2. With the OCPD in the open position apply a 500V insulation resistance test between live conductors and earth. The resistance value should be  $>1\text{M}\Omega$  see BS 7671 Table 61.
3. Where fixed surge protected socket outlets are installed, a 250V insulation resistance test should be applied between live conductors and earth in accordance with BS 7671 Regulation 612.3.2.

Following the above tests ensure that SPDs are re-connected.



## II. Inspection and maintenance of an SPM

The object of the inspection is to verify the following:

- The SPM complies with its intended design
- The SPM is capable of performing its design function
- Additional protection measures are correctly integrated into the complete SPM

The procedure should comprise visual inspections, test measurements, checking and maintaining the technical documentation. Visual inspections are very important, and should verify, for example, if bonding conductors and cable shields are intact and appropriate cable 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. For example, a power supply line to external CCTV cameras or car park lighting may have been added as this line is likely to cross an LPZ. Suitable protection measures (e.g. SPD) should be employed to ensure the integrity of the complete SPM is not compromised.

Care should be taken to ensure that SPDs are re-connected following insulation resistance testing during routine electrical maintenance (see Inspection & Testing Installations Fitted with SPDs) .

Inspections should be carried out:

- During the installation of the SPM
- After the installation of the SPM
- Periodically thereafter

## 12. Frequently Asked Questions

### What are transient overvoltages?

The power disturbance known as a 'transient' is a very brief but extreme burst of extra energy. They can occur on a.c. power lines, signal, telephone or data lines. A transient can also be referred to as a 'spike' or a 'surge'.

### Is there any difference between a 'surge' and a 'transient' or 'transient overvoltage'?

The terms 'surge', 'transient voltage' and 'lightning transient' are used by many industry standards and documents to describe the very short duration increases in voltage caused by lightning. In this context 'surge' means the same as 'transient overvoltage', or in its shortened form 'transient'. However 'surge' is a vague term also used to describe overvoltages of up to a few seconds ('swells') in duration. It is for this reason that the terms 'transient overvoltage' and 'transient' have been used throughout this handbook.

### Are transients a new problem?

No. Transients are a natural result of any electrical activity and have existed ever since Edison ran the first power line. They are generated every time wires, motors or electrical elements are energized or de-energized.

### How are transients caused and where do transients come from?

Transient overvoltages can be generated by lightning, (through resistive, inductive or capacitive coupling) or by electrical switching events. About 35% of all transients come from outside the facility from such sources as lightning, utility grid switching, switching large capacitor banks on the utility lines, electrical accidents or heavy motors or loads from nearby industry. The remaining 65% are generated inside our homes and facilities and come from such unsuspected sources as microwave ovens, laser printers and copiers, air conditioner motors and even lights being turned on or off.

### What are the modes transient overvoltages occur in?

'Modes' refers to the combinations of conductors which transient overvoltages occur in, and can be measured between. Lightning transients generally start as disturbances with respect to earth, whilst switching transients start as disturbances between line/phase and neutral. During propagation, mode conversion can occur (e.g. as a result of flashover). Hence transients can exist between any pair of conductors, in any polarity, simultaneously.

### Why should I be concerned about transients?

Each generation of microcircuit chips becomes faster, smaller and more densely populated. This technological progress comes with tremendous risks as these new designs are less tolerant of small electrical disruptions and are more susceptible to damage and disruption. Added concern comes from broad use of microprocessor technology. Every new automated function makes us that much more dependent on computer technology and that much more vulnerable to inconvenience when these devices fail. These disruptions can have devastating effects, with life and death consequences when interrupting communications, traffic control or medical functions. At the very least, these disruptions can cause inconvenience and frustration.

### How do transient overvoltages degrade and damage electronic equipment?

Degradation and damage differ in their degree of severity – both are caused by flashover and heating.

## How do transient overvoltages cause flashover?

Consider a transformer winding and an earthed lamination. If a small transient voltage is present between the winding and earth, no current flows and no heating occurs. However, if a larger transient voltage is present, flashover or insulation breakdown occurs, and a transient current flows through the transformer, causing heating, burning and arcing. In a minor case the transformer would be able to continue operation after the event. The next transient would find it much easier to flashover the now degraded insulation. The process could then continue until a catastrophic short circuit failure occurs. Similar degradation can occur to the silicon dioxide insulation in integrated circuits (or microchips). In severe cases the first transient will be terminal!

## How do transients cause energy damage?

Energy damage is the result of overheating. Many components, such as resistors and forward biased semiconductors, normally have a current flowing through them. The current flowing through the component will be increased by a transient overvoltage, causing overheating. If sufficient heat is generated, material in the component will melt, changing its characteristics. Once this occurs a component may fail short circuit or open circuit. If the transient overvoltage is still present, then secondary failures may occur, e.g. a component that has already failed open circuit may then suffer flashover. Fuses, resistors and printed circuit board tracks are all damaged in this way.

## Is component damage always visible?

Most cases of damage are not obvious. It is common to find circuit boards that look as good as new, but with every semiconductor internally damaged. Only in most severe cases do we see ruptured cases, charring and fire. In fact much of this more spectacular damage is caused by power follow-on and not by the transient.

## What is power follow-on?

When a transient overvoltage causes a short circuit failure, this can create a path for the power supply. Consider a component connected to live and neutral on a mains power supply, failing short circuit as a result of a transient. At this point no outward signs of damage exist. Mains current flows into the short circuit and continues until a fuse blows or the component spectacularly blows itself apart. This also explains why it is often difficult to tell how big a transient overvoltage was by looking at the damage it caused.

## How can I protect against transients?

The only sure ways to avoid these problems are to (1) not use microelectronics or (2) disconnect them! However, the only reasonable way to enjoy the use of these modern conveniences with minimal frustration is to assure that the electrical supply is kept within micro-circuitry tolerances through the use of Surge Protection Devices SPDs.

## I have circuit breakers/fuses why would I need Surge Protective Devices (SPDs)?

The two technologies provide separate functions. The OCPD is designed to protect your home, business, equipment, and possibly even your life from an event such as a short circuit. Fortunately electrical short circuits are not an everyday occurrence at a given site. Short circuits being quickly defined as an accidental low resistance path in a circuit causing abnormally high current flow. It is this abnormally high current flow that could cause damage if it were not for the OCPD which senses this high current and opens the circuit.

The SPD is specifically designed to protect your equipment from events such as extremely short duration high electrical spikes. These electrical spikes or transients are an everyday occurrence, and can be caused by everything from turning a lamp on to a lightning storm. However most spikes are of low energy. Some spikes inside facilities however can reach up to 6000V which could possibly cause irreparable damage to equipment if SPDs were not installed to redirect the harmful voltage away from the equipment.

## Is it just computers that need protection?

No. Any microprocessor device is vulnerable to damage or disruption and should be protected. Home electronics, appliances, electronic instruments, communications and telemetry equipment, medical instrumentation, factory automation and PLC's, electronic ballasts, traffic controllers, finance, data centres, theme parks, EPOS systems, fuel pumps, etc.

## How do I protect these with SPDs?

Any device that plugs into a socket outlet can be easily protected with a quality industry tested plug-in SPD – simple installation that is ideal for protection against transients in the home. Larger devices such as appliances, 'direct wired' equipment, process automation, specialist equipment and full facilities can be protected by hard-wiring SPDs to electrical distribution panels. While this sounds complicated and costly, it is actually quite simple and surprisingly inexpensive in light of the protection provided. By eliminating the bulk of the transient at the service entrance panel, the coordinated downstream SPDs at the sub-distribution socket outlet are able to limit the transients to safe levels for equipment protection.

## How do transient overvoltage protectors work?

Transient overvoltages can be eliminated in two ways. Protectors can behave like an open circuit during a transient overvoltage, keeping the transient voltage on the other side of the protector and stopping the flow of transient current. Opto-isolators in common mode, transformers by open circuit in common mode and, to an extent, in-line inductors all behave in this manner.

Alternatively, protectors can behave like a short circuit during a transient overvoltage, shorting out the transient voltage and allowing the transient current to flow through it. Many transient overvoltage protectors with MOV technology follow this principle. Many transient overvoltage protectors with (MOV) technology follow this principle.

Although many protectors are based on the 'short circuit' principle, in reality they do not cause a short circuit.. The oscilloscope trace in how a protector suppresses a transient overvoltage on a mains power supply, without disrupting the power supply. The 'short circuit' is only created for the microsecond's duration of the transient. The lower the transient overvoltage is clipped, the better the equipment is protected. This is known as the protector's protection level or let-through voltage.

## Do transient overvoltages on power cables only happen on mains power supplies or can they also occur on other power supplies?

Although transient overvoltages are associated with mains supplies they can also occur on generator supplies, battery supplies and UPS outputs. If the generator, battery or UPS is located in a separate building then the supply can be susceptible; to resistive, inductive and capacitive transients in just the same way as a mains power supply. Also generator, battery and UPS supplies have a lower current capability than the mains and hence a higher source impedance. This means that it is easier for switching events to cause transients.

## Is transient overvoltage protection really needed on a power supply that incorporates a tap-switching line conditioner or other form of voltage regulator?

Yes. Dr Standler, a leading American authority in transient protection, has applied transient overvoltages of up to 6kV to the input side of tap-switching line conditioners from two well-known manufacturers. Their electronic control circuits were destroyed and one of the line conditioners had an output RMS voltage 20% higher than it should be. This sort of sustained increase in RMS voltage is capable of destroying many pieces of electronic equipment. The installation of effective transient overvoltage protection, before the conditioner, will prevent its damage and hence protect the equipment it supplies.

## **My power supply is already protected by a filter.....isn't it?**

Filters, although providing excellent protection against radio frequency interference, can actually make transient overvoltages worse! They don't provide protection against transient overvoltages, hence an SPD is therefore required.

## **I've been told that 11kV to 415V distribution transformers provide transient overvoltage protection – is this true?**

The short answer is, yes and no! Whilst distribution transformers certainly provide a degree of protection they also contain 'sneak paths', which allow transients through to the LV power distribution system. High voltage to low voltage transformer action theoretically eliminates transient overvoltages with respect to earth (i.e. live to earth and neutral to earth). However stray capacitance between the primary and secondary windings of the transformer can still provide transients with a high frequency path through the transformer.

Where line to line transients exist, transformers are of little protective value. Line to line refers to transients which exist live to live and neutral to live. When high voltage power lines are struck by lightning they flashover to earth. One line will flashover to earth before the others, converting a transient between lines and earth to one between line(s) and line. These will pass easily through transformers. During line to line transient tests, transient overvoltages pass straight through the transformer. Indeed, as a result of resonant ringing the transients were larger on the output than on the input side!

Live to earth transient tests showed surprisingly large transient overvoltages let-through the transformer. Transients recorded on the output side were as much as half of those input, as a result of inter-winding capacitance. So whilst transformers have some protective benefit, they can hardly be called effective transient overvoltage protection.

Additionally, where transformers at one earth reference feed power distribution boards in another building, or site lighting etc at another earth reference, resistively coupled transients can occur.

## **Do SPDs save data?**

SPDs on a mains power supply can save data by SPDs avoiding a crash or power problem during which corruption could occur. SPDs on data communication signal and telephone lines cannot save data, only the system. This is because the protection level or let-through voltage can appear as an invalid signal, distorting a sequence of data. However, since the protector has prevented damage, the system's error checking facility will request retransmission of the data sequence.

## **Why are specialised SPDs required for network systems, such as Ethernet?**

SPDs for data communication signal and telephone lines ('Lightning Barriers') are fitted into the line (i.e. in series). This introduces a small impedance into the line and a capacitance across the line. For twisted pair signalling below 1MHz, this generally causes no problems. However, at higher frequencies this impedance and capacitance would cause problems. SPDs for these systems need to be specially designed to have lower line capacitance and impedance. For impedance matched systems (e.g. coaxially wired computer networks such as Ethernet) it is essential that the SPD is impedance matched, in order to avoid reflections.

## **Will an SPD also protect against overvoltages of few seconds ('swells')?**

Transients of microseconds duration and overvoltages or swells of up to a minute in duration are two different disturbances that require two different technologies for protection. The overvoltage/swell causing gradual overheating of equipment is protected by the OCPD. The transient causing damage to more sensitive electronics or continually breaking down such items as motor windings is protected against by SPDs. There is a common myth that SPD protects against overvoltages/swells but it does not. Transient overvoltage protection is a whole separate industry from overcurrent protection and it involves technologies such as Metal Oxide Varistors, Silicon Avalanche Diodes and Gas Discharge Tubes.

# Appendix A




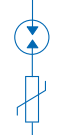

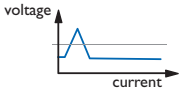
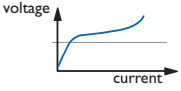
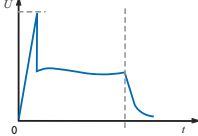
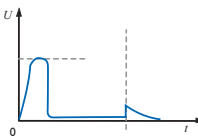
## Designs of SPD

Several technologies are available for the protection element. They each have advantages and disadvantages:

- Zener diodes;
- The gas discharge tube (controlled or not controlled);
- The varistor (zinc oxide varistor).

The table below shows the characteristics and the arrangements of three commonly used technologies.

**Figure 46:**  
Types of SPD

Component	Gas Discharge Tube (GDT)	Encapsulated spark gap	Zinc oxide varistor	GDT and varistor in series	Encapsulated spark gap and varistor in parallel
Characteristics – Component symbols					
Operating mode	Voltage switching	Voltage switching	Voltage limiting	Voltage switching and limiting in series	Voltage switching and limiting in parallel
Operating curves					
Application	<ul style="list-style-type: none"> <li>• Telecom network</li> <li>• LV network (associated with varistor)</li> </ul>	LV network	LV network	LV network	LV network
SPD Type	Type 2	Type I	Type I or Type 2	Type I+Type 2	Type I+Type 2

# Appendix B

## Comparison between BS EN 62305-4 and BS 7671:2008 Incorporating Amendment No 1:2011- Section 443 – Protection against overvoltages of atmospheric origin or due to switching.

### 1 Introduction

Although BS EN 62305 is referred to throughout Section 443, it is made clear to the reader that Section 443 currently is based on CENELEC HD 60364-4-443:2006 – a Harmonized Document (HD) that is not fully aligned with the more up to date BS EN 62305. This is explained through the following two notes within Section 443.1.1.

“NOTE 1: BS EN 62305 provides a comprehensive risk assessment based system for lightning protection. This includes protection for electrical and electronic systems using a number of methods such as surge protective devices.

NOTE 2: This Section takes into consideration the technical intent of HD 60364-4-443:2006, which was not fully aligned to BS EN 62305. IEC are currently reviewing Section 443 and re-aligning it with IEC 62305.”

It is important for the reader to note that the HD itself was based on outdated documents (namely IEC 61024, IEC 61312 and IEC 61662 all of which are superseded by IEC 62305 series (UK standard BS EN 62305 series). These previous standards (circa 1990's) have been considerably updated, particularly in the area of protection of equipment.

Where there is a difference between a European Norm (EN) and an HD then the former should prevail, especially when in this case the Standard is based on more recent information and itself supersedes the standards on which the HD is based.

Our reliance as a society on electronic equipment has increased dramatically over the last two decades; hence IEC/BS EN 62305 has therefore specifically recognised the protection of such equipment within a normative part BS EN 62305-4. To directly quote BS EN 62305-4

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

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

### 2 Risk assessments

The BS EN 62305 standards base the protection against lightning on a risk assessment and there are many factors that have to be taken into account in making a full risk assessment in accordance with BS EN 62305-2: – the collection area of the structure, its environment, the service cabling (overhead or underground, the presence of a transformer), screening, routing and withstand voltages of cables and equipments in the building, the construction and use of the building (e.g. structures housing explosives). This comprehensive approach considers the damage from all 4 sources (S1 to S4 discussed above) and produces risk values that are compared to defined tolerable values (within BS EN 62305) which correspond to their equivalent types of loss, namely, Risk of loss of human life, Risk of loss of service to the public, Risk of loss of cultural heritage. Protection against lightning is required if the calculated risk is greater than the defined tolerable risk. The use of SPDs helps reduce the risk and hence offers equipment protection as well as provide protection against switching overvoltages that could also be generated within the structure (e.g. from inductive loads).

In comparison Section 443 details a method based on AQ values relating to keraunic levels or “Thunderstorm days” originating from superseded IEC 61024 standard “Protection of structures against lightning.” An interesting observation is the title of this standard which simply considers the structure whereas BS EN 62305 “Protection against lightning” covers complete protection for the structure and electronic systems. The use of Thunderstorm days itself is not in line with BS EN 62305 which considers a measured flash density. Incidentally the formula relating Thunderstorm days to flash density is different between BS EN 62305 and HD 60364. Moreover, the use of Thunderstorm days as the sole criterion of tolerable risk is a significant deviation from BS EN 62305 which uses many factors as listed above.

Within 443, the keraunic level is set to an arbitrary 25 thunderstorm days and the general need for protection is simply based on whether a region is above this value or below. The derivation of the 25 day value is not explained or justified. Within the outdated IEC 61024 standard, a mid table value for thunderstorm days is 25 so one could assume this is why the value was chosen. However the UK as a region is below this 25 day value and therefore under this method protection against overvoltages of atmospheric origin is not required, irrespective on the type of structure (e.g. structures housing explosives) or lines feeding it. Switching overvoltages are not even considered. A note however is included to cover such scenarios by referring back to BS EN 62305

*“Irrespective of the AQ value, protection against overvoltages may be necessary in applications where a higher reliability or higher risks (e.g. fire) are expected. See BS EN 62305.”*

In order to ascertain if an application of “higher reliability” or “higher risk” is necessary a comprehensive risk analysis such as detailed with BS EN 62305 should be undertaken

### 3 Focusing specifically on the actual 443 clauses

443.1.1 "Protection according to this section can be expected if the relevant equipment product standards require at least the values of withstand voltage of Table 44.3 according to the overvoltage category of equipment in the installation".

However, Note 3 states : -“ Transient overvoltages transmitted by the supply distribution system are not significantly attenuated downstream in most installations”.

Therefore this regulation does not mean that protection is inherent if equipment has withstand values according to table 44.3. It means that protection is achieved if the overvoltages presented are below the withstand values of the equipment as stated within the table.

In conclusion, protection will normally require a combination of equipment having the appropriate withstand voltage and correct selection of SPD(s).

443.2.2 Where an installation is supplied by a low voltage network which includes overhead lines or where the installation includes an overhead line and in either case the condition of external influences AQ1 ( $\leq 25$  thunderstorm days per year) exists, no additional protection against overvoltages of atmospheric origin is required if the impulse withstand voltage of equipment is in accordance with Table 44.3.

NOTE: Irrespective of the AQ value, protection against overvoltages may be necessary in applications where a higher reliability or higher risks (e.g. fire) are expected. See BS EN 62305.

This is only valid under following conditions:

- No direct strikes to the line, to the structure and close to the structure are considered due to the scope of 443. If we have to consider any of these sources of damage, then SPDs are required.
- The building is supplied by a completely buried low-voltage system and does not include overhead lines



In practice even when both conditions are fulfilled external SPDs may be necessary, due to the fact that surge currents and partial lightning currents are distributed via the underground cables.

So it is not just a matter of voltage but also a matter of current distribution. So e.g. if a neighbouring building, equipped with an LPS is struck by lightning or even a tree close to a neighbouring building, a substantial partial lightning current or surge current is distributed via the cabling system. Describing the surge environment means to consider BOTH overvoltage and surge currents.

As an alternative to the AQ method, 443 details a simplified risk assessment based on “levels on consequence” could be used (originating from superseded standard IEC 61662). Consequences relating to human life, public services and to commercial or industrial activity all require overvoltage protection, irrespective of the flash density  $N_g$  and therefore the thunderstorm days. For consequences relating to groups of individuals or individuals (essentially domestic residences), the need for protection is based on formula which allows the user to calculate a length of line ( $d$ ) and compare it against a critical length ( $d_c$ ). Again protection against switching transients is not covered.

Given the length of the line  $d$  is limited to 1 km and the UK has a lightning flash density of 1 (flashes or strikes to ground per km<sup>2</sup> per year) or less,  $d$  will never exceed the critical length ( $d_c$ ) and as such no additional protection is required if the withstand voltage of equipment is in accordance with Table 44.3. Again, direct strikes to the structure or overhead line or strikes near the structure are not considered in this simplified risk assessment method (it refers to the use of BS EN 62305 for this), and consideration should be given to data, signal and telecom lines.

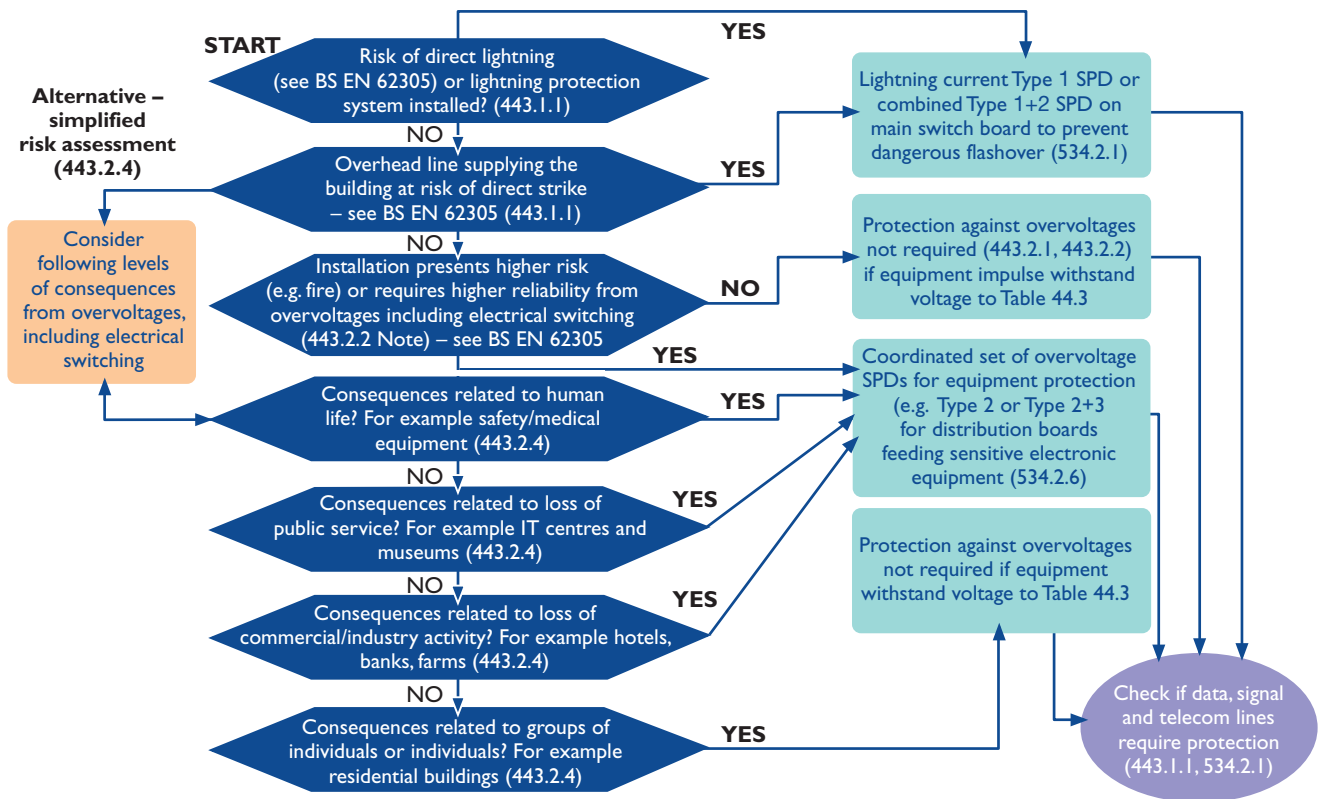
In summary SPDs are to be considered in the following circumstances, where:

- the supply to the installation, at some point, is provided by bare overhead conductors if at risk of direct strike
- the building requires or already has a lightning protection system (LPS) (as direct lightning strikes are a risk – refer to BS EN 62305)
- the risk of loss of any part of the installation or equipment due to damage caused by transient overvoltages is not acceptable (443.2.2 Note, 443.2.4).

Of the two methods, the current simplified risk assessment of 443 is reasonably closer to the BS EN 62305 risk assessment in terms of levels of consequence.

#### 4 Simplified risk assessment

The following flow chart aids the decision making process, based on section 443 (including the simplified risk assessment). Note that Types of SPD are covered later in this guide:



#### 5 Insulation coordination for equipment within low-voltage systems

IEC 60664-1 (Edition 2) 'Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests' is the base document that defines impulse withstand categories as used in Section 443 Table 44.3 and Table 44.4.

## Documents to which reference is made in the guide

BS EN 61643 Series	Low-voltage surge protective devices.
BS EN 61643-11	Low-voltage surge protective devices – Surge protective devices connected to low-voltage power systems. Requirements and test methods.
BS EN 61643-21	Low-voltage surge protective devices – Surge protective devices connected to telecommunications and signalling networks. Performance requirements and testing methods.
BS EN 62305 Series	Protection against lightning.
BS EN 62305-1	Protection against lightning – General principles.
BS EN 62305-2	Protection against lightning – Risk management.
BS EN 62305-3	Protection against lightning – Physical damage to structures and life hazard.
BS EN 62305-4	Protection against lightning – Electrical and electronic systems within structures.
BS 6651	Code of practice for protection of structures against lightning.
BS 7671	Requirements for electrical installations. – IET Wiring Regulations – Seventeenth Edition.
CENELEC HD 60364 Series	Low-voltage electrical installations.
IEC 60364 Series	Low-voltage electrical installation.
IEC 62305 Series	Protection against lightning.
IEC 60664 Series	Insulation coordination.
IEC 60664-1	Insulation coordination for equipment within low-voltage systems – Principles, requirements and tests.



**BEAMA Limited**

Westminster Tower  
3 Albert Embankment  
London  
SE1 7SL

Telephone: +44 (0)20 7793 3000

Fax: +44 (0)20 7793 3003

Email: [info@beama.org.uk](mailto:info@beama.org.uk)

**[www.beama.org.uk](http://www.beama.org.uk)**

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